Distributed Spacecraft Missions Design: Goddard’s Trade-space Analysis Tool for Constellations (TAT-C)

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Distributed Spacecraft Missions (DSM)

What is a Distributed Spacecraft Mission (DSM)?
A Distributed Spacecraft Mission (DSM) is a mission that involves multiple spacecraft to achieve one or more common goals.

What is a Constellation?
A space mission that, *beginning with its inception*, is composed of two or more spacecraft that are placed into specific orbit(s) for the purpose of serving a common objective.

What is a SmallSat?

<table>
<thead>
<tr>
<th>Satellite Class</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Femtosatellite</td>
<td>0.001-0.01 kg (or 1-10 g)</td>
</tr>
<tr>
<td>Picosatellite</td>
<td>0.01-1 kg</td>
</tr>
<tr>
<td>Nanosatellite</td>
<td>1-10 kg</td>
</tr>
<tr>
<td>Microsatellite</td>
<td>10-100 kg</td>
</tr>
<tr>
<td>Minisatellite</td>
<td>100-180 kg</td>
</tr>
</tbody>
</table>

*SmallSat Classification from NASA Space Technology Mission Directorate (STMD), SmallSat Technology Partnerships, 2013 NASA Cooperative Agreement Notice NNA13ZUA001C*
What is a Distributed Spacecraft Mission (DSM)?

A DSM is a mission that involves multiple spacecraft to achieve one or more common goals.

Drivers

- Enable new science measurements
- Improve existing science measurements
- Reduce the cost, risk and implementation schedule of all future NASA missions
- Investigate the minimum requirements and capabilities to cost effectively manage future multiple platform missions and to cost effectively develop and deploy such missions
TAT-C Objectives

• Provide a framework to perform pre-Phase A mission analysis of Distributed Spacecraft Missions (DSM)
  - Handle multiple spacecraft sharing mission objective
  - Include sets of smallsats up through flagships
  - Explore trade space of variables for pre-defined science, cost and risk goals, and metrics
  - Optimize cost and performance across multiple instruments and platforms vs. one at a time

• Create an open access toolset which handles specific science objectives and architectures
  - Increase the variability of orbit characteristics, constellation configurations, and architecture types
  - Improve performance and enable parallelization
TAT-C Architecture

Tradespace Search Request (TSR)

Validation

Repeated or improper search

DSM Knowledge Base

Proceed with tradespace analysis

Results

Reduction and Metrics

Orbit & Coverage Module

Cost & Risk Module

Model Inputs
## Science Requirements – Inputs

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start Epoch</td>
<td>UTC time</td>
<td>Date when the satellites will initialize. Default is current time.</td>
</tr>
<tr>
<td>Area of Interest</td>
<td>exact Earth locations</td>
<td>Lat/lon/Alt list or Lat/lon bounds. Global is default.</td>
</tr>
<tr>
<td>Ground Stn options</td>
<td>Select and/or file</td>
<td>If the user has existing satellites to complement. Row=GS num, columns=GS lat, lon, alt, band. Default is NEN.</td>
</tr>
<tr>
<td>Launch preferences</td>
<td>Select and/or file</td>
<td>If the user has existing satellites to complement. Row=LV num, columns=LV specs. Default is all.</td>
</tr>
<tr>
<td>Propagation fidelity</td>
<td>low, med, high</td>
<td>Three levels of propagators to be selected against (time and description provided). Default is low.</td>
</tr>
<tr>
<td>Output options</td>
<td>Select</td>
<td>Which of the output variables is the user interested in. Default is all but angles.</td>
</tr>
<tr>
<td>Output bounds</td>
<td>min, max</td>
<td>Min and Max for any of the variables in the Outputs sheet. Default is in the output sheet.</td>
</tr>
</tbody>
</table>

### Satellite Specs

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing Sat options</td>
<td>Select and/or file</td>
<td>User has a sat/constellation in mind. Options: Name, KB file, csv (Row=sat num, columns=initial Kepl. Elems). Default is none.</td>
</tr>
<tr>
<td>Number of new Sats</td>
<td>min, max</td>
<td>Number of new sat allowed in the DSM in addition to existing. One and ten is default respectively.</td>
</tr>
<tr>
<td>Number of satellite types</td>
<td>exact</td>
<td>Enter 1 if const. is homogeneous or number, if heterogeneous. If hetero, all subsequent specs to be provided for each instance.</td>
</tr>
<tr>
<td>Altitude Range of Interest</td>
<td>min, max</td>
<td>Ranges of altitudes the user is interested in. LEO (300-1000 km) is default.</td>
</tr>
<tr>
<td>Inclination Range of Interest</td>
<td>min, max</td>
<td>Ranges of inclinations the user is interested in. 50-90 deg is default.</td>
</tr>
<tr>
<td>Special Orbits only</td>
<td>Select</td>
<td>Select between only SSO with LT option, frozen, critically inclined, ISS</td>
</tr>
<tr>
<td>Angular Rate</td>
<td>min, max</td>
<td>Rotation matrix of the satellite in LVLH. Payload is assumed fixed and rotates at the same rate.</td>
</tr>
<tr>
<td>Maximum pointing</td>
<td>exact</td>
<td>Maximum nadir pointing that a sat is capable of, to determine field of regard or FOR. Default is up to Earth Limb.</td>
</tr>
<tr>
<td>Comm band</td>
<td>exact bands</td>
<td>For downlinking data to ground stations. Default is Ka-band.</td>
</tr>
</tbody>
</table>

### Payload Specs (unnecessary for Stereo)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of payloads/sat</td>
<td>Exact</td>
<td>For multi-instrument sat. Default is one. If more than one, all subsequent specs to be provided for each instance.</td>
</tr>
<tr>
<td>Occumolation or Imaging or Pairs</td>
<td>Select</td>
<td>Determines payload’s measurement cones. Imaging is default.</td>
</tr>
<tr>
<td>Payload Mass</td>
<td>Approximate</td>
<td>Default is 40 kg. Payload will be 40% of satellite mass, by default [Tentative]</td>
</tr>
<tr>
<td>Payload Volume</td>
<td>Approximate</td>
<td>Default is 150 W. Payload will be 60% of satellite power, by default [Tentative]</td>
</tr>
<tr>
<td>Payload Power</td>
<td>Approximate</td>
<td>Default is 0.03 m^3. Payload will be 50% of satellite volume, by default [Tentative]</td>
</tr>
<tr>
<td>Radiometric resolution</td>
<td>min</td>
<td>Number of bits per pixel. 12 bits is default.</td>
</tr>
<tr>
<td>Occultation or Pairs coupling</td>
<td>Exact</td>
<td>Mark observer or occluder/pair, for every occulting or pairs mission.</td>
</tr>
<tr>
<td>Nadir swath or FOV</td>
<td>min, max OR exact</td>
<td>Conical or rectangular dimensions of the full spot size. Default is 15 deg in AT and CT.</td>
</tr>
<tr>
<td>Nadir GSD or IFOV</td>
<td>min, max OR exact</td>
<td>Conical or rectangular dimensions of a single pixel. Default is 30 m in AT and CT.</td>
</tr>
<tr>
<td>Object/s of interest</td>
<td>Select then specify</td>
<td>Select between celestial body or ‘satellite’ if an occultation mission. Fill row 35 if latter. Default is Sun.</td>
</tr>
<tr>
<td>Occultation Altitude</td>
<td>max, min</td>
<td>Tangent altitudes between which occultation measurements will be made. Default is 10-50 km.</td>
</tr>
<tr>
<td>Measurement time</td>
<td>min, max</td>
<td>Sum of exposure and integration time per image or measurement. Default is half-pixel travel time.</td>
</tr>
<tr>
<td>Solar conditions</td>
<td>Select</td>
<td>Determines if the sat is sunlit or eclipsed or agnostic when measuring. Default is agnostic.</td>
</tr>
<tr>
<td>Sun Glint preference</td>
<td>Select</td>
<td>Select if sun glint (&lt;5 deg relative AZ) to be included, avoided or no preference. Default is no preference.</td>
</tr>
<tr>
<td>Spectral or other Channels</td>
<td>Exact wavelengths</td>
<td>Central wavelength for multi-spectral imaging. 300:100:1000 nm is default.</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>exact binwidths</td>
<td>Band or bin width of each central wavelength in the spectral range. 50 nm is default.</td>
</tr>
</tbody>
</table>
## Science Requirements – Output Constraints

All the listed outputs except * will be available per architecture, per ground spot, per unit time. The characteristics just indicate bounds that the user can set as inputs.

Output tabs will include panels for attributes vs. cost, spatial bins and time series. Maybe distributions?

### Spatial Metrics

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Spatial Resolution</td>
<td>min, max, average</td>
<td>Ground pixel size. Default is 30m, 100m, none.</td>
</tr>
<tr>
<td>Effective Swath</td>
<td>min, max, average</td>
<td>Cross and along track extent of one full image. Default is 100 km, 500 km.</td>
</tr>
<tr>
<td>Percentage image overlap</td>
<td>min, max, average</td>
<td>% of every image that overlaps with another. 100% for complete 2-fold and 0% for none. Default is none.</td>
</tr>
<tr>
<td>Covered positions (w/ FOV)</td>
<td>lat, lon</td>
<td>Spatial positions where imaging measurements are made per sat per arch within I/P &quot;Area of Interest&quot;. Default is none.</td>
</tr>
<tr>
<td>Occultation positions</td>
<td>lat, lon</td>
<td>Spatial positions where occultation measurements are made per sat per arch within I/P &quot;Area of Interest&quot;. Default is none.</td>
</tr>
<tr>
<td>Inter-Sat Range and Rate</td>
<td>min, max, average</td>
<td>Distances and Rate (AT,CT,R,euclid) between each satellite in the virtual group (stereo)</td>
</tr>
<tr>
<td>Possible positions (w/ FOR)</td>
<td>lat, lon</td>
<td>Spatial positions where imaging measurements CAN BE made per sat per arch within I/P &quot;Area of Interest&quot;. Default is none.</td>
</tr>
</tbody>
</table>

### Temporal Metrics

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occultation time*</td>
<td>min, max, average</td>
<td>If an occult mission, time which each occultation lasts for</td>
</tr>
<tr>
<td>% period time in Sun*</td>
<td>min, max, average</td>
<td>Fraction of the orbit that the sat spends in the Sun (vs. eclipsed)</td>
</tr>
<tr>
<td>Time to Coverage*</td>
<td>min, max, average</td>
<td>Time to cover the &quot;Area of Interest&quot; entirely once</td>
</tr>
<tr>
<td>Access Time*</td>
<td>min, max, average</td>
<td>Time that any ground spot has access to a satellite (within FOR)</td>
</tr>
<tr>
<td>Latency to downlink*</td>
<td>min, max, average</td>
<td>Time between observation and downlink to the next ground station</td>
</tr>
<tr>
<td>Repeat Time*</td>
<td>min, max, average</td>
<td>Time between repeats (within 1 deg of view angle) of every point in the &quot;Area of Interest&quot;. Calc. for virtual and real sat for Stereo/Comm missions</td>
</tr>
<tr>
<td>Revisit Time*</td>
<td>min, max, average</td>
<td>Time between revisits of every point in the &quot;Area of Interest&quot;</td>
</tr>
</tbody>
</table>

### Angular Metrics

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>View Zenith Angle</td>
<td>min, max</td>
<td>Between the payload-target vector and zenith, if imaging mission. Default is none for all angles.</td>
</tr>
<tr>
<td>View Azimuth Angle</td>
<td>min, max</td>
<td>Between the payload-target vector projection on target normal plane and true north projection on the same plane, , if imaging mission</td>
</tr>
<tr>
<td>Solar Zenith Angle</td>
<td>min, max</td>
<td>Between the sun-target vector and zenith for day measurements, if imaging mission</td>
</tr>
<tr>
<td>Solar Azimuth Angle</td>
<td>min, max</td>
<td>Between the sun-target vector projection on target normal plane and true north projection on the same plane, if imaging mission</td>
</tr>
<tr>
<td>Lunar phase</td>
<td>min, max, average</td>
<td>For night measurements.</td>
</tr>
</tbody>
</table>

### Radiometric Metrics

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Characteristics</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal to Noise Ratio</td>
<td>min, average</td>
<td>Expected signal and noise (SNR) of each arch's satellites with respect on a selected one. Default is 10.</td>
</tr>
</tbody>
</table>

Green highlighted rows correspond to variables needed only for pairs missions, including occultations with satellite pair option.

Blue highlighted rows correspond to variables needed only for occultation missions. Yellow highlighted rows correspond to variables needed only for imaging missions.
**TradeSpace Search Iterator**

**GUI Inputs**
- **Iterator Inputs**
  - Mission Concept (e.g., Area of Interest, Mission Duration, Launch Options)
  - Satellite Specs (e.g., Existing Sats, Alt/Inc ranges, Special Orbits like SSO, comm bands)
  - Payload Specs (e.g., conops # - imaging, occultation, stereo, mass, power, volume, FOV, measurement time, spectral bands)
  - Any constraints on the range of output values

**Iterator Outputs**
- Metrics per architecture (e.g., average, spatial and temporal distributions)
- Spatial (e.g., Spatial res, Swath overlap %, Occultation positions, coverage)
- Temporal (e.g., revisit, access, repeat)
- Angular (e.g., view zenith, solar illumination)
- Radiometric (Signal to noise fall-off)

- TSI reads user inputs given to the GUI to create iterator inputs (JSON files). Uses default values from Landsat 8 (w/ ETM+ payload) if no inputs
- TSI generates DSM architectures for a combination of variable values that satisfy iterator inputs
- A DSM architecture is a unique combination variable values (altitude, inclination, FOV, number of satellites, etc.)
- For each arch, TSI creates files and send commands to module ‘Reduction & Metrics’ to compute architecture performance and to module ‘Cost and Risk’ to compute architecture cost
- **Reduction & Metrics** is responsible for calling module ‘Orbits & Coverage’ to propagate the orbit of every sat and compute coverage given payload specs. ‘Reduction & Metrics’ integrates coverage and computes all performance metrics.
Constellation Types (Currently):
- Uniform Walker Constellations – all satellites in the same altitude, inclination and equal number of satellites per plane
- Ad-Hoc Constellations – all satellites assumed to be located at one of the 48 current Planet Labs slots (available online)
- Non-Uniform Walker constellations – combinations of uniform Walker constellations over different altitudes, inclinations, number of satellites per plane
- Precessing constellations where satellites are dropped off by a single Launch Vehicle at different altitudes, inclinations and disperse over time to give Right Ascension of the Ascending Node (RAAN) coverage

Constellation Types (In Development):
- Ad-Hoc Constellations where satellites are launched as per the next available launch option from a launch database
Orbit-Coverage Module

• **Purpose of Module**
  o Model orbits balancing accuracy and performance
  o Compute coverage metrics for constellation/sensor set
  o Compute ancillary orbit data for performance, cost, risk

• **Concept:**
  o TSI Manages mission architecture configuration
  o TSI Calls O&C to compute coverage and ancillary data
  o O&C returns that information to TSI/R&M for further analysis and reduction

• **Capabilities:**
  o Evenly spaced and custom grid points
  o Conical and Custom sensor
  o J2 Dynamics (fast)
  o Multiple spacecraft
  o State/ephemeris export
  o Analysis of drag needs
Orbit-Coverage Module (cont.)

Complex sensor coverage allows to test if an entire region is in field of view (i.e., can an entire storm be seen from a single sensor?)

O&C computes coverage and ancillary data and returns that information to TSI/R&M for further analysis and reduction.
Cost and Risk Module

- Given a satellite constellation architecture, the C&R module provides estimates of:
  - **Cost**, life cycle cost (RDT&E, manufacturing, launch, operations)
  - **Risk**, profile of the system technical and cost risk

- Cost Module Motivation
  - Motivation
    - Previous work has highlighted the limitations of existing models with respect to constellation missions:
      - Limitations of traditional cost models for high performance small satellites, motivating the SSCM
      - Small satellite learning curve parameters, COTS components, technological complexity as they pertain to DSM
    - No comprehensive cost model for satellite constellation architectures has been developed
Cost Module Implementation

• Aggregate model consisting of Cost Estimating Relationships (CERs) from:
  o Widely accepted, publically available models & references:
    ▪ Unmanned Space Vehicle Cost Model (USCM), Version 10
    ▪ Small Satellite Cost Model (SSCM), 2014 Release
    ▪ NASA Instrument Cost Model (NICM), Version 7
    ▪ QuickCost, Version 6.0
    ▪ Programmatic Estimating Tool (PET)
  o Well-known references:
    ▪ Space Mission Analysis and Design (SMAD), 3rd Edition

• Contextual assessment of the DSM architecture:
  o Function of number and distribution of satellites & number of unique spacecraft within the architecture.
  o This information, in conjunction with satellite mass, is used to select appropriate learning curve factors and spacecraft bus cost reliability factors

• Output: probability density function showing most likely cost for total mission lifecycle and selected mission components, including recurring, nonrecurring, spacecraft bus, and payload
Knowledge Base

• Centralized store of structured data

• Support TAT-C tasks:
  1. Analysis: compose new mission concepts from existing models
  2. Exploration: discover new mission concepts by querying previous results
Knowledge Base Prototype

- Layered architecture with loose coupling between client and server components achieved via a Representational State Transfer (REST) web service.
- Clients access KB functions via a simple HTTP request-response interface (JSON requests).
- Current prototype KB application uses a custom web server built on a Node.js/Express/Mongoose technology stack with a MongoDB database.
- Similar applications in healthcare information systems and to manage data in model sensitivity analyses.
- Local implementation does not require intra- or inter-network resources and associated security implications.
- Will include gathering publicly-available information on existing and proposed Earth science missions to support TAT-C validation and enable rapid generation of new concepts.
Currently Planned TAT-C User Interface includes GUIs, CLIs, and APIs.

- **GUIs (Graphical User Interfaces)** will be portable to any typical graphical computing environment, and will be designed to function like familiar “Software Wizards”, walking users systematically through DSM tradespace choices, and their consequences
  - GUIs will be designed to isolate basic, required, non-expert choices from more expert options typically accessed by more advanced users.
  - GUIs will intuitively blend interactive choosing with visual browsing of analysis output characterizing the results of choices.

- **CLIs (Command Line Interfaces)** will be portable to typical command-line environments, and will be designed to enable scripting of interactions equivalent to those possible via GUIs, especially once users establish (and want to automate) their preferred workflows.

- **APIs (Application Programmer Interfaces)** will expose internal software interfaces to skilled programmers with the expert ability to develop software applications in the “TAT-C Ecosystem”
<table>
<thead>
<tr>
<th>TAT-C (Distributed Spacecraft Mission Architectures) Inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mission Name</strong></td>
</tr>
<tr>
<td><strong>Point of Contact Information</strong></td>
</tr>
</tbody>
</table>

1. When would the proposed mission begin?  
2. How long would it last (active operations)?  
3. What set or range of Earth target (optionally, features at what alt) do you wish to observe?  
4. Other than Earth, what is your observation target (Sun, Moon, artificial satellite, etc)?  
5. What ground stations do you wish to use? What features (comm, bands, etc) should they have?  
6. Access to Space:  
   a. What Launch Vehicles do you wish to use?  
   b. How many?  
   c. What features (mass, volume, etc) should they have?  
7. What are your needs wrt being one of multiple LV payloads? Could you accept a lower priority?  
8. What type of organization will direct the mission (Government, Military, Commercial, Academic, etc)?  
9. How many (or in what number range of) satellites do you wish to launch for this mission?  
10. What existing satellites, if any, do you wish to coordinate with? What are their orbits?  
11. Regarding the flights of the candidate satellites, what are the desired (approx/range/etc) values for:  
   a. altitude, inclination, RAAN, etc  
   b. propagation fidelity (very coarse, more detailed, extremely realistic, etc, simulation)?  
12. Are there any special requirements for the orbits (SSO, Frozen, Critically Inclined, ISS, etc)?  
13. Regarding a candidate observatory, what are desired (approx/range/etc) values for:  
   a. Mass  
   b. Volume  
   c. Power  
   d. Along / Cross-Track Cone & Slewing Angles  
   e. angular scan rate, starting phase (constant or distributed over constellation)  
   f. Communication band(s)  
14. What is/are the desired instrument type(s) and con-ops?  
15. Regarding a candidate instrument, what are desired values for:  
   a. Mass  
   b. Volume  
16. Do you have any min-max constraints you wish to apply, like to:  
   a. coverage, access, revisit, or repeat time, downlink latency, etc  
   b. along/cross-track overlap percentages, number of passes/time, etc  
   c. spatial resolution of observations, along/cross-track swath width, etc  
   d. solar illumination, lunar phase and/or observation geometry during observations  
   e. observatory positioning relative to Earth and/or other objects of interest?
TAT-C User Inputs
JSON File

```json
{
    "MissionConcepts": {
        "StartEpoch": 1455213665,
        "MissionDuration": "0:2592000",
        "AreaOfInterest": "-90:90",
        "ObjectsOfInterest": "",
        "GroundStationOptions": "DSN",
        "LaunchPreferences": "LaunchVehicleList.txt",
        "MissionDirector": "Government"
    },
    "SatelliteOrbits": {
        "ExistingSatelliteOptions": "",
        "NumberOfNewSatellites": "1:3",
        "AltitudeRangesOfInterest": "710:710",
        "InclinationRangesOfInterest": "78.2:78.2",
        "SpecialOrbits": "",
        "PropagationFidelity": 0
    },
    "ObservatorySpecifications": "ObservatorySpecifications.txt",
    "InstrumentSpecifications": "InstrumentSpecifications.txt",
    "OutputBounds": {
        "TimeToCoverage": "",
        "AccessTime": "",
        "RevisitTime": "",
        "CrossOverlap": "",
        "AlongOverlap": "",
        "SignalNoiseRatio": "",
        "LunarPhase": "",
        "ObsZenith": "",
        "ObsAzimuth": "",
        "SunZenith": "",
        "DownlinkLatency": "",
        "SunAzimuth": "",
        "SpatialResolution": "",
        "CrossSwath": "",
        "AlongSwath": "",
        "ObsLatitude": "",
        "ObsLongitude": "",
        "ObsAltitude": "",
        "ObjZenith": "",
        "ObjAzimuth": "",
        "ObjRange": ""
    }
}
```
TAT-C GUI Input Parameters

Both interfaces perform the same function:
- Take user inputs to generate Tradespace Search Request (TSR) JSON file
- **Simple** attempts to simplify process
- **Advanced** provides access to all params.
Starting Run…

While Running, user can:
- Review Inputs, and
- Browse Results from previous runs
Once user’s Run is complete, user can:
• Look at Tradespace-level **Overviews**:
  • Various “Performance vs Cost” trades over any DSM Tradespace variables
• Manage **Storage** for current/previous runs
TAT-C GUI Results: Subspace Charts

For each Subspace of current Tradespace:
- User can browse visualizations of:
  - **Revisit Time** (over Points-of-Interest)
  - **Risk Chart** (Likelihood vs Consequence)
  - **Cost Distribution** (over DSM breakdown)
  - Any other Architecture-level details
Current TAT-C Outputs

- Global Coverage Time as a function of Lifecycle Cost
- Revisit Time as a function of Lat/Long
- Max/Min Revisit Time as a function of Number of Satellites
- Costing Details Visualization
- Average Revisit of a Ground Station as a function of Number of Satellites
- Various distributions for a selected architecture
- Plots for different types of constellations
Current TAT-C Validation

- **Use cases:** Sustainable Land Imaging (SLI) and from a few Earth observation missions (ESTO- and SMD-Funded)

<table>
<thead>
<tr>
<th>Mission Parameters</th>
<th>Deployment</th>
<th>Data Products</th>
<th>Data Collection</th>
<th>Ground System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Satellites</td>
<td>Launch Vehicle</td>
<td>Level 1 Data Products</td>
<td>Time Over Each Ground Station</td>
<td>Mission Operations Center (MOC)</td>
</tr>
<tr>
<td>Number of Planes</td>
<td>Launch Date</td>
<td>Level 2 Data Products</td>
<td>Passes per Day</td>
<td>Location(s)</td>
</tr>
<tr>
<td>Orbit Type</td>
<td>Deployment Module (DM)</td>
<td></td>
<td>Storage Capacity per Satellite</td>
<td>Science Operations Center (SOC)</td>
</tr>
<tr>
<td>Altitude</td>
<td>DM Tiers</td>
<td></td>
<td></td>
<td>Location(s)</td>
</tr>
<tr>
<td>Inclination</td>
<td></td>
<td></td>
<td></td>
<td>Ground Data Network (GDN)</td>
</tr>
<tr>
<td>Revisit Time (Mean)</td>
<td></td>
<td></td>
<td></td>
<td>Location(s)</td>
</tr>
</tbody>
</table>

**Mission Parameters**
- **Satellite Specs**
  - Dimensions
  - Mass of each Satellite
  - Power Available Lifetime
- **Instruments/Payload**
  - Payload mass
  - Payload power
- **Spacecraft Bus**
  - ADCS
  - Electrical Power Subsystem
  - RF Communications
  - Max Data Rate

**Deployment**
- Launch Vehicle
- Launch Date
- Deployment Module (DM)
- DM Tiers

**Data Products**
- Level 1 Data Products
- Level 2 Data Products

**Data Collection**
- Time Over Each Ground Station
- Passes per Day
- Storage Capacity per Satellite

**Ground System**
- Mission Operations Center (MOC)
- Location(s)
- Science Operations Center (SOC)
- Location(s)
- Ground Data Network (GDN)
- Location(s)
Conclusion and Future Plans

- TAT-C: Pre-phase tool for investigating multiple trades of future constellation missions
- Beta-version will be completed in August 2017 and validated on a few Earth Science missions
- Beta-version executable will be made available publicly on a cloud (through ESTO)
- Future version will include:
  - Instrument Module
  - Launch Module
  - Fully populated Knowledge Base
  - Machine Learning and Evolutionary Algorithms to Speed Up Trade-space Search
  - Improved cost and risk
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