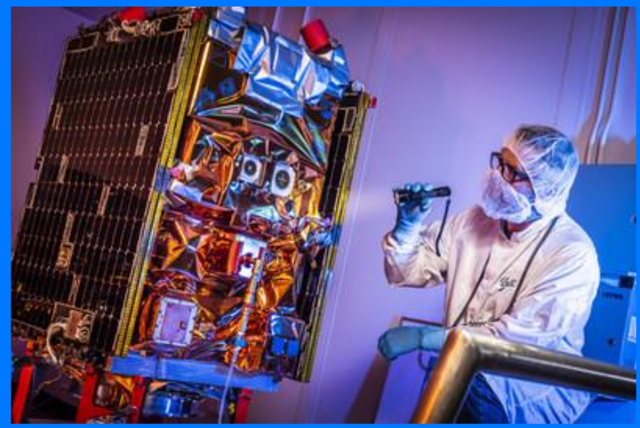

MISSION UTILITY-BASED SMALLSAT DESIGN CONSIDERATIONS

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I. ABSTRACT

SmallSat's offer low-cost solutions to traditionally high cost, high SWaP mission areas including GEOINT, space domain awareness (SDA), and science missions. While initial engineering may offer intriguing cost vs. performance value, it is important to evaluate space vehicle and payload interactions in order to understand their impact on overall on-orbit mission performance. Many space vehicle and payload desires are in direct conflict and require careful allocation, requirement management and performance evaluation to ensure the SmallSat offering lives up to its mission goals. Lessons learned from large satellite design can be directly applied to SmallSats, while allowing flexibility to meet the mission's cost, performance, and risk posture. This paper discusses key design considerations and lessons learned for creating a SmallSat that offers mission utility while maintaining cost competitiveness.

II. BACKGROUND

Many space vehicle and payload desires are in direct conflict and require careful allocation, requirement management and performance evaluation to ensure the SmallSat offering lives up to its mission goals. In this poster we will be describing the following design considerations:

- 1st order metric traps and example (III & IV)
- Pointing Impacts and Considerations (V)
- Mission Data Processing and Communications (VI)
- Mission Assurance Considerations (VII)

III. THE 1ST ORDER SDA METRIC TRAP

- Everyone starts with a 1st order radiometric link budget analysis
- Many designs stop here
- Many higher order effects can have severe radiometric implications
  - Most 2nd and 3rd order effects impact negatively
  - Difficult to model
  - Some require specific detailed knowledge of the system design
    - E.g. Stray Light Effects from Sun/Moon/Earth-shine
  - Some are dependent on host platform characteristics
    - E.g. Jitter
- Don't launch a useless SmallSat!

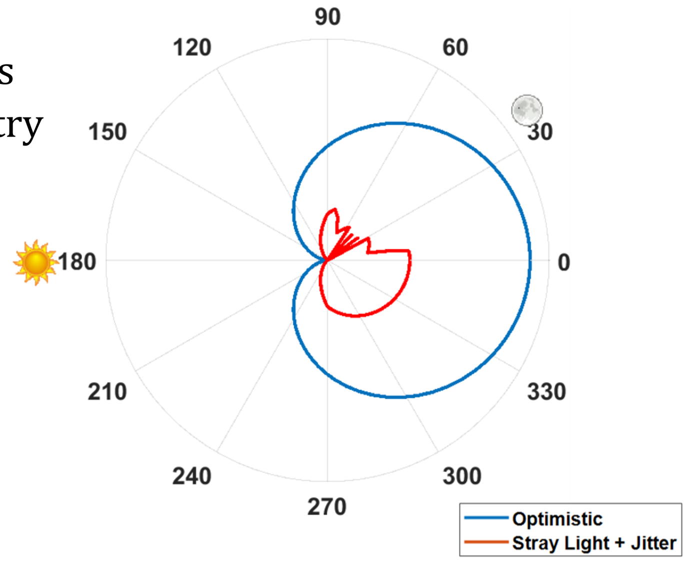
SDA Analysis	Parameter Terms	Impacts
First Order	• RSO Size / Range • Aperture Diameter • Integration Time • Diffuse (Lambertian) Lighting • Signal/Image Processing (Frame Stacking) • Read / Electronic Noise • Shot Noise • Dark Current	• Standard/Basic optical modeling parameters • Relatively easy to simulate and specify
Second Order	• Specular (BRDF) Lighting / RSO Materials • Jitter (Pointing Noise) • Smear (Rate Track Error) • FPA Details (Well Depth / Gain / Quantization) • Quantum Efficiency / Transmittance	• Terms require detailed knowledge of sensor, target vehicle, and/or dynamic geometry • Jitter and smear strongly affect sensitivity especially for narrower IFOV systems
Third Order	• Stray Light • Pixel Ensquared Energy (ABP) • Radiation/Contamination Loss • Mirror Reflectivity / Lens Loss • Celestial/Galactic Background • Image Processing Residuals (Star Subtraction)	• Higher order analysis requires extensive testing to validate and have on-orbit considerations • Stray light affects ability to observe near bright light sources

Higher-order Optical Design Considerations Can Have Dramatic Effects

IV. THE 1ST ORDER METRIC TRAP IN ACTION: CARDIOID COMPARISON

- Omitting complicated terms from the SNR calculations can lead to dramatic results
- For example, a system with a small FOV is highly susceptible to jitter (pointing errors)
  - 1 arc-second iFOV system produces optimistic expectations (blue) without jitter or stray light models
  - Even a small amount of jitter (2 arcsecond s) dramatically reduces the telescope sensitivity (red)
  - Stray light modeling raises the noise floor when observing near bright light sources (Sun/Moon/Earth); reduced sensitivity occurs near such sources (red)
- These SNR terms can be difficult to compute
  - Rely on detailed telescope design/CAD models
  - Change dynamically based on viewing geometry

Higher-order radiometric terms can have surprisingly large and negative consequences



V. ADDITIONAL CONSIDERATIONS: STEERING, POINTING AND JITTER

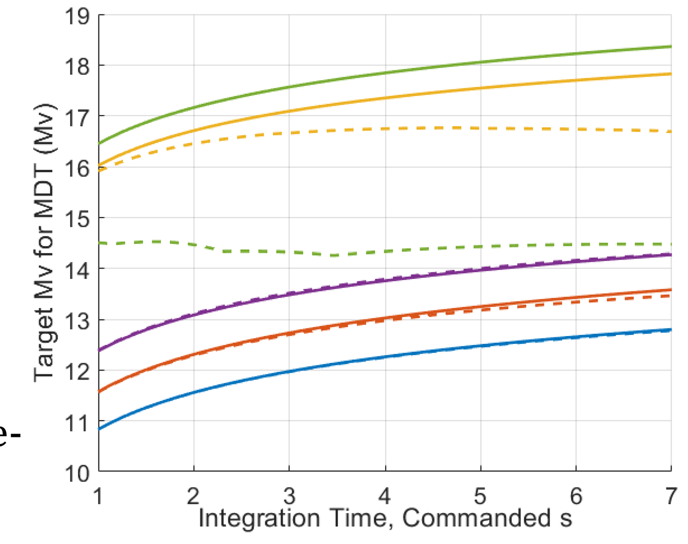
Pointing Options:

- Bus (Fixed) Mount
  - Bus must orient the camera
  - Bus agility and jitter directly influences mission performance
  - RWAs (cheaper/less-agile) vs. CMGs (expensive/more-agile)
- Steering Mirror
  - Significantly more agile than bus pointing
  - Mirror control can reduce bus jitter and rate-track target hypotheses
  - Limited mirror swing range
  - Susceptible to stray light (large solar/lunar exclusion angles)
- Gimballed Telescope
  - More agile than bus pointing, but more expensive than mirror steering
  - Gimbal control can reduce bus jitter and rate-track target hypotheses
  - Greater swing range (limited only by cable wrap and mechanical constraints)
  - Payload baffling can be incorporated

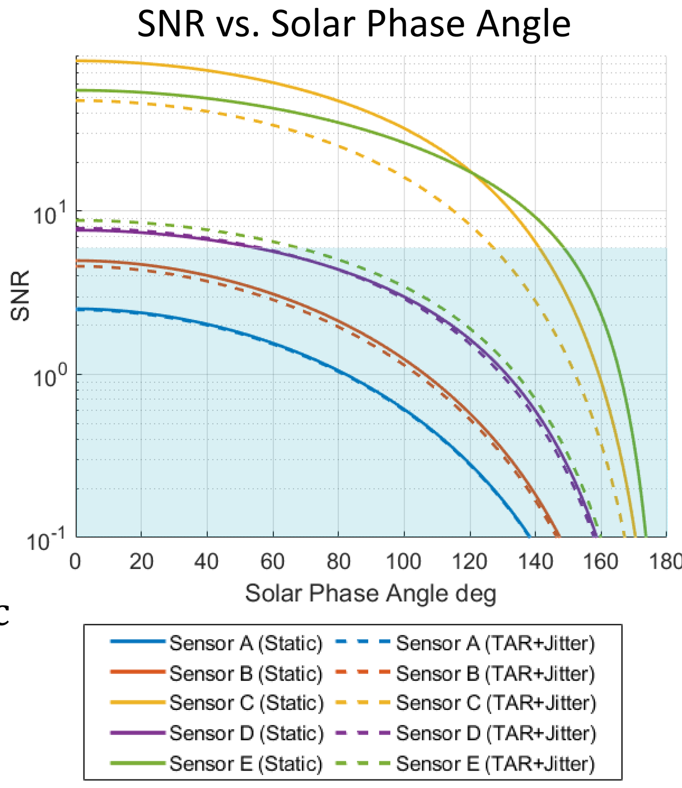
Jitter is the vibration imparted from the host vehicle onto the sensor

- Bus solar-arrays, attitude control, and harmonic flexure are primary contributors
- Low-frequency jitter manifests as random pointing error
- High-frequency jitter blurs the point spread function
- Jitter detrimentally affects sensitivity and angular accuracy as shown in the figures on the right

Target Mv for Minimum Detectable Target vs Integration Time



SNR vs. Solar Phase Angle



In both figures above, jitter (shown by the dotted line) imparted negative impacts to the sensors' sensitivity. Note that, some had larger impacts than others due to the sensor's IFOV.

It is crucial to create system level requirements, decompose, and allocate them to both the sensor and the bus to ensure integrated SmallSat performance

VI. TRADING MISSION DATA PROCESSING (MDP) VS. COMMUNICATION SYSTEMS

- Communication systems can drive SmallSat SWaP needs (larger dish, increased power) to meet downlink bandwidth requirements
- On board MDP provides the ability to reduce bandwidth needs by moving mission processing from the ground to the Space Vehicle, thus only requiring mission relevant data to the ground
- Types of MDP that can be implemented onboard:
  - Image Correction (Non-uniformity correction, bad pixel mapping, distortion correction)
  - Image Characterization (Star registration, co-adding frames, velocity match filtering, target/object detection, object classification, clutter background subtraction)
  - Autonomous operation (Auto-track allowing object custody, self tasking, change detection)
  - Artificial Intelligence/ Machine Learning
- Space Domain Awareness Case Study:
  - 1k x 1k detector, 6 second integration, 16 bits / pixel
  - Bandwidth need without MDP: 3 Mbps
  - Bandwidth need with MDP: <100 kbps

On board mission data processing can provide increased mission capability while also reducing Communication needs

VII. MISSION ASSURANCE CONSIDERATIONS

A major cost driver for SmallSats can be derived from Mission Assurance needs.

- Per Aerospace's ATR 2015-03151 "Mission Risk Posture Assessment Process Description" mission class is used to characterize and document the accepted risk posture of a program
  - Defined at the beginning of program, it provides industry best practices for program class and can be tailored
  - Tailoring of the ATR can effectively and clearly document deviations from industry recommendations and evaluate risk to mission success
- Hardware selection may drive increased testing needs when lower TRL hardware is selected
  - SmallSats provide an essential path to provide heritage of new technologies, but it is important to evaluate risk posture vs. needed space qualifying environmental tests
- Fault Tolerance is also scaled for mission classes and risk acceptance
  - Typically, SmallSats are signal fault tolerant due to their short mission life, limited SWaP, and higher risk postures.
  - Orbits may also require an increased fault tolerance for specific subsystems. For example, GEO SmallSats are required to be single fault tolerance to disposal which increased design complexity

Defining and tailoring mission assurance requirements early ensure Customer risk tolerance can be met with baseline design

Robust mission level Systems Engineering and high order mission modeling can ensure SmallSat meets on orbit mission requirements