# Development of an On-Orbit Alignment Calibration Methodology for Optical Payloads

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## [1] Problem Statement

Geolocating maritime targets from space is challenging due to the lack of references in the images. To solve this, geolocation is accomplished using on-orbit measured attitude and orbital position data. Attitude data is collected in the form of a star tracker quaternion solution and position data is collected from a GPS receiver.

However, misalignments between actual and expected boresight vectors of the star tracker and payload may exist due to:

- **[1]** Thermal Deformation
- **[2]** Vibrations and Launch Loads
- **[3]** Manufacturing and Assembly Tolerances

## [2] Proposed Solution

Calibrating the offsets that arise from misalignments once on-orbit requires the development of a dedicated methodology. This involves calibrating the imager boresight pointing vector in relation to real star tracker solutions. To accomplish this, a maneuver plan must be developed before the mission commences. As well, companion MATLAB scripts play a crucial role in parsing data, performing geolocation calculations, and determining the magnitude of the offset. Additionally, a look-up table is created to account for thermal deformation during nominal operations.

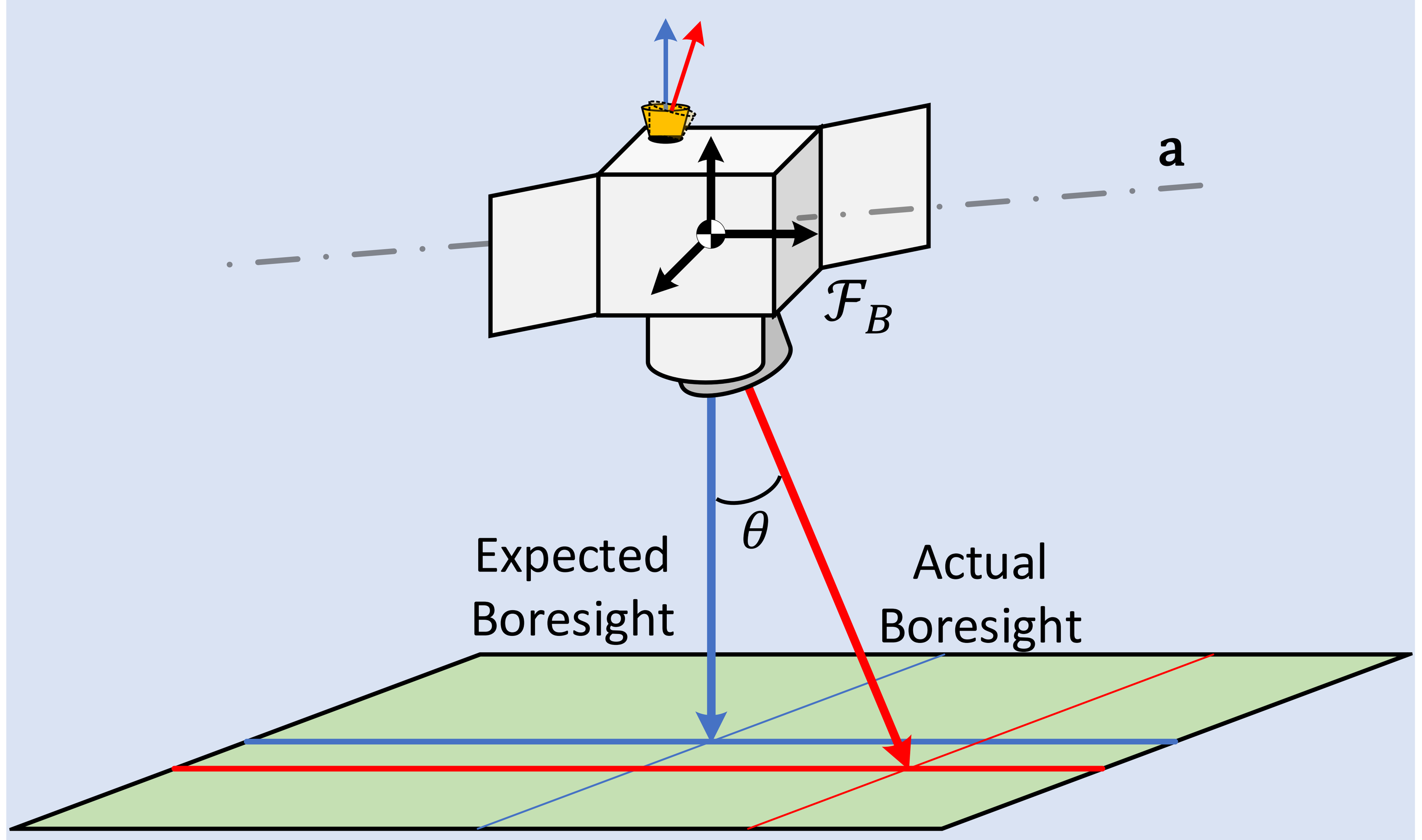


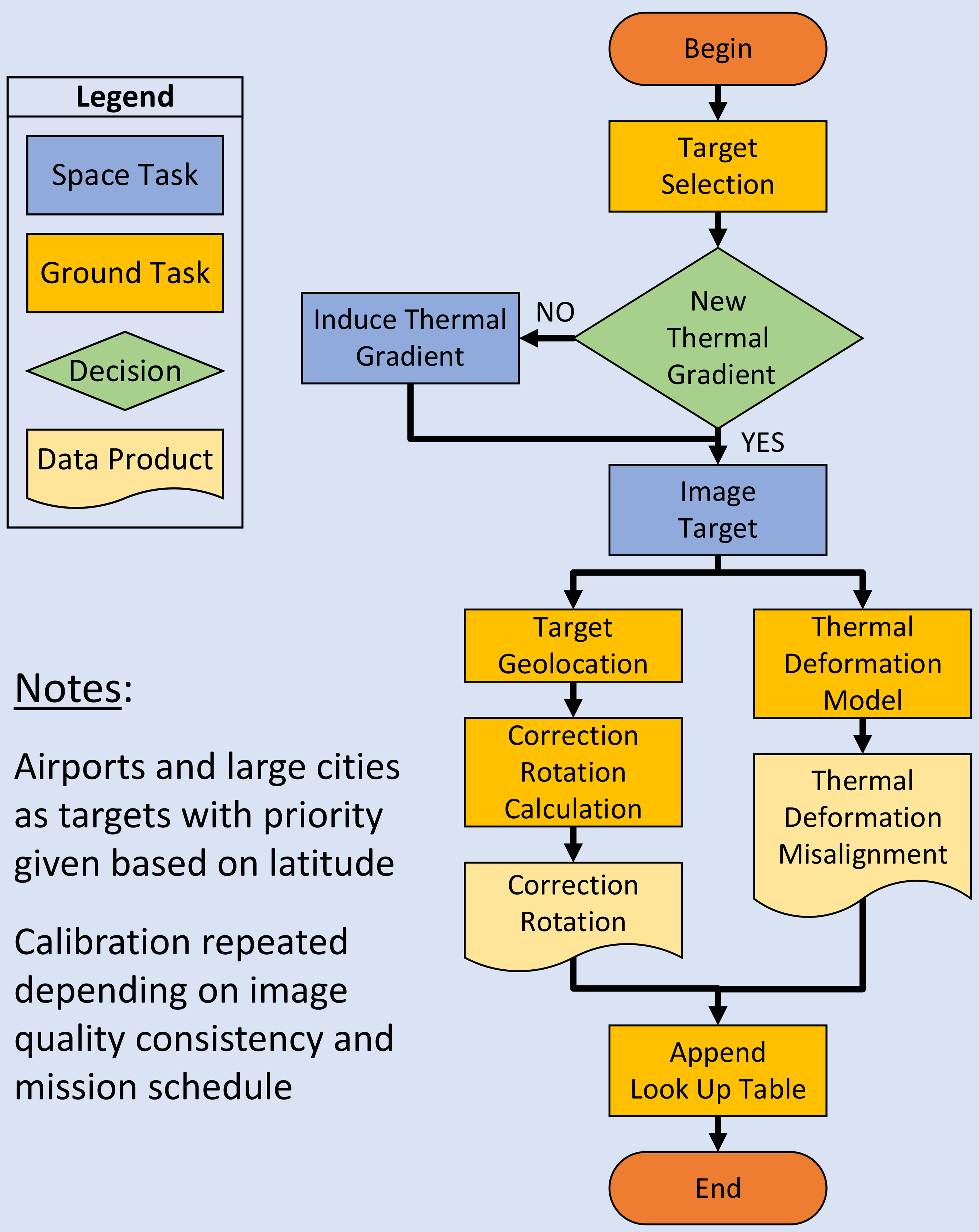

**Figure 1: Example Sensor & Payload Boresight Misalignments**

The look-up table represents the relationship between thermal deformation and geolocation error. This error is modelled in the form of a rotation matrix about the spacecraft body frame, $\mathcal{F}_B$ using Euler's Theorem, where **a** is the *axis of rotation*, and $\theta$ is the *angle of rotation* (Figure 1).

$$\mathbf{C} = \cos\theta\,\mathbf{1} + (1-\cos\theta)\mathbf{a}\mathbf{a}^T - \sin\theta\,\mathbf{a}^\times$$

$$\mathbf{a}^\times = \begin{bmatrix} 0 & -a_3 & a_2 \\ a_3 & 0 & -a_1 \\ -a_2 & a_1 & 0 \end{bmatrix}$$

## [3] On-Orbit Plan




Notes:

Airports and large cities as targets with priority given based on latitude

Calibration repeated depending on image quality consistency and mission schedule

**Figure 2: High-Level On-Orbit Calibration Plan**

## [4] Thermal Deformation Misalignments

Deformation induced by a thermal gradient is of particular interest for the following reasons:

- **[1]** Simulation results showed magnitude is significant
- **[2]** Variation as the thermal environment changes

It is expected to take over one year for the spacecraft to experience the full range of thermal environments (Figure 3). The change in thermal environment is expressed by the beta angle, $\beta$, which represents the percentage of time that a satellite in LEO spends in direct sunlight. As well, orbital insertion uncertainty and orbit drift are considered.

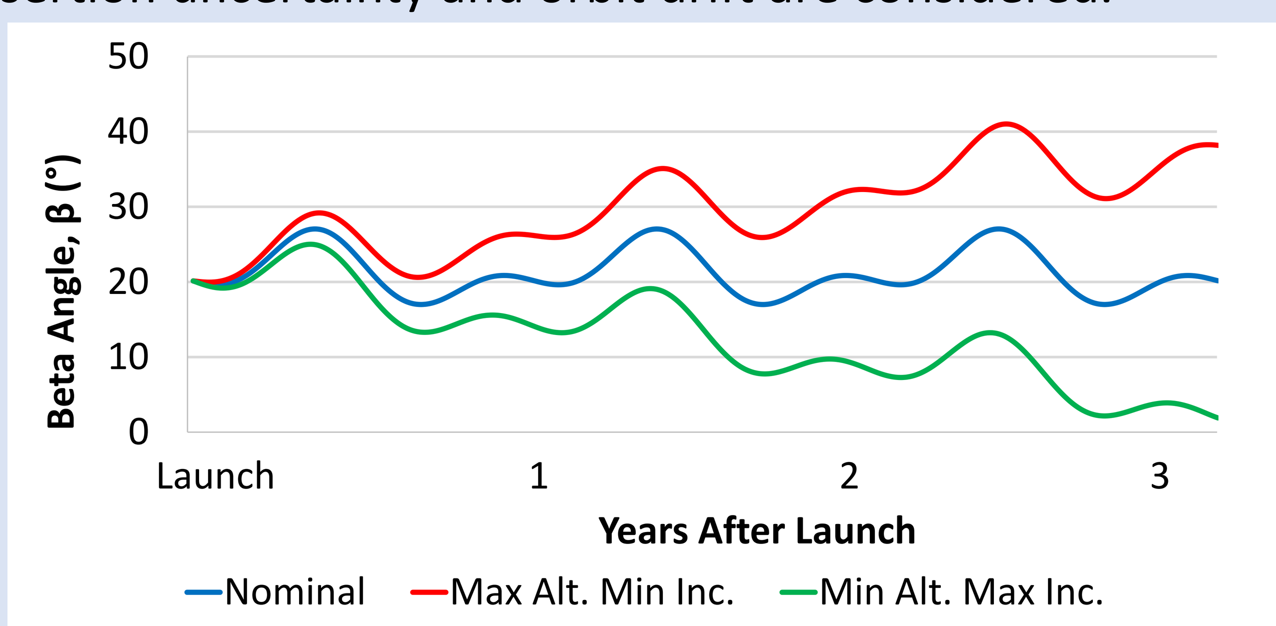



**Figure 3: Beta Angle vs. Time (2σ Altitude & Inclination Uncertainty)**

To save time, thermal gradients can be induced by altering spacecraft attitude preceding calibration opportunities.

## [5] Preliminary Simulations

Thermal Deformation Simulations:

Simulations were performed to quantify the impact of thermal deformation on misalignment. Results indicate that thermal deformation would be the major cause of misalignment. However, on-orbit measurements are necessary due to the uncertainty.

STK and Geolocation Simulations:

Companion MATLAB scripts were validated using data from a heritage SFL mission. The geolocation calculation was performed using this data to determine a set of expected payload boresight intersection point coordinates.

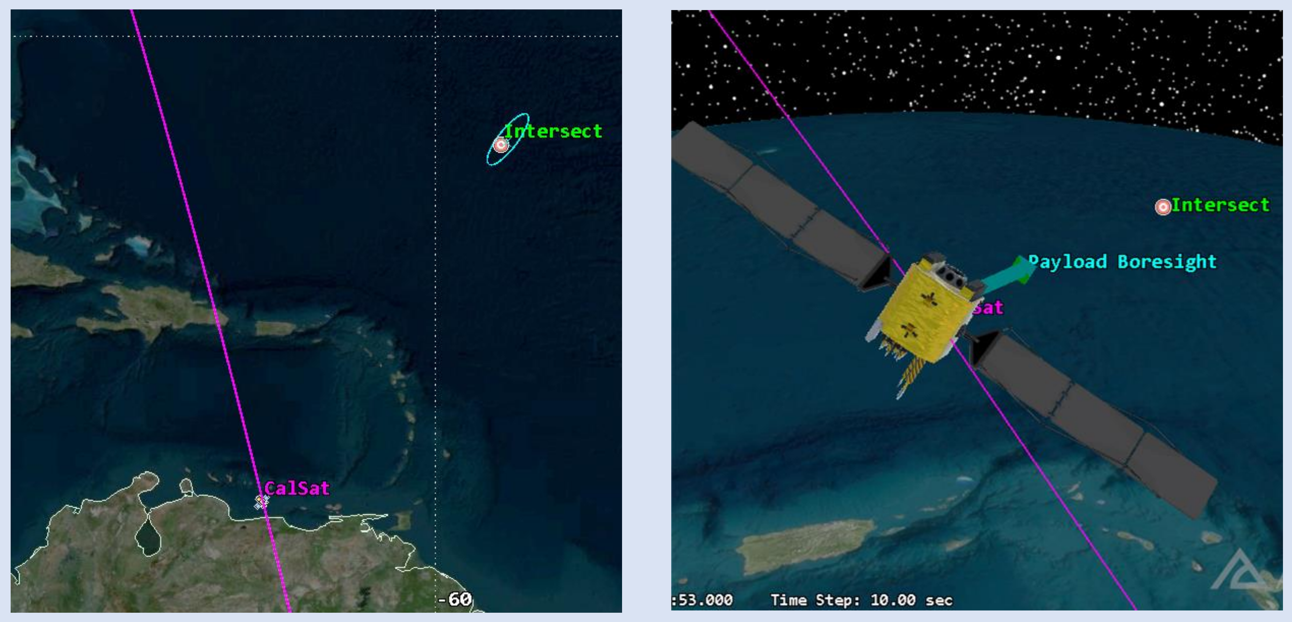



**Figure 4: STK Images of Geolocation Results**

Geolocation results are visualized in STK (Figure 4). The calculated intersection point correlates with the on-orbit position, attitude, and payload boresight vector data.

## [6] Conclusions & Future Work

Conclusions:

- Preliminary thermal simulations showed high uncertainty of thermal deformation misalignments
- A high-level test plan was developed
- MATLAB scripts for geolocation and correction rotation matrix calculations were generated
- STK simulations validated the geolocation MATLAB script

Future Work:

- Implementation of sensor error in geolocation calculation
- Opportunity filtering for integration with SFL's Payload Operations Planning Software (POPS)
- Methodology to be applied on an upcoming mission
- On-orbit data will be used to correlate thermal deformation simulations for future use

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