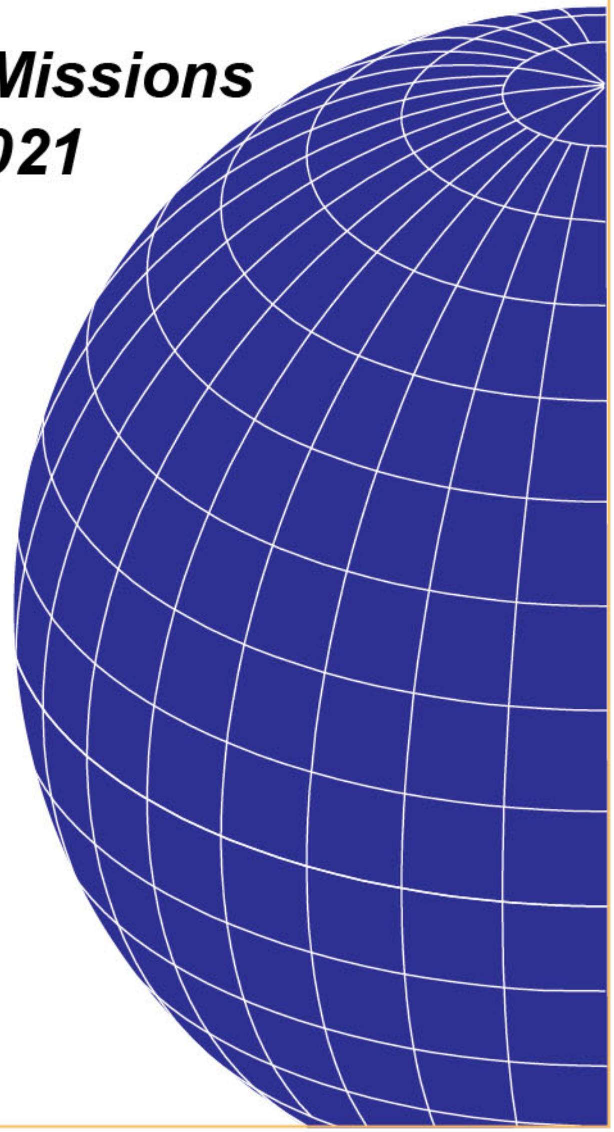
Reinventing Space:
Low-Cost, Responsive Space Missions
USC ASTE 523, Spring 2021



Supplement 5

A. Mapping and Pointing Error Budgets

B. Trading on Error Budgets to Minimize Cost

EXAMPLE: POINTING AND MAPPING ERROR BUDGETS

- ***Pointing*** **= orienting the spacecraft or an instrument toward a target or in a predefined direction**
- ***Mapping*** **= determining the geographic coordinates of an instrument's look point**
- ***Budget*** **= list of all error sources and how much they contribute to the total error**
- **Communications satellites are generally concerned only with pointing; observation satellites need both pointing and mapping**

The system budget should be in terms of <u>what</u> we wish to achieve (mapping and pointing), not <u>how</u> we intend to achieve it (attitude and position control or knowledge).

CONSTRUCTING ERROR BUDGETS

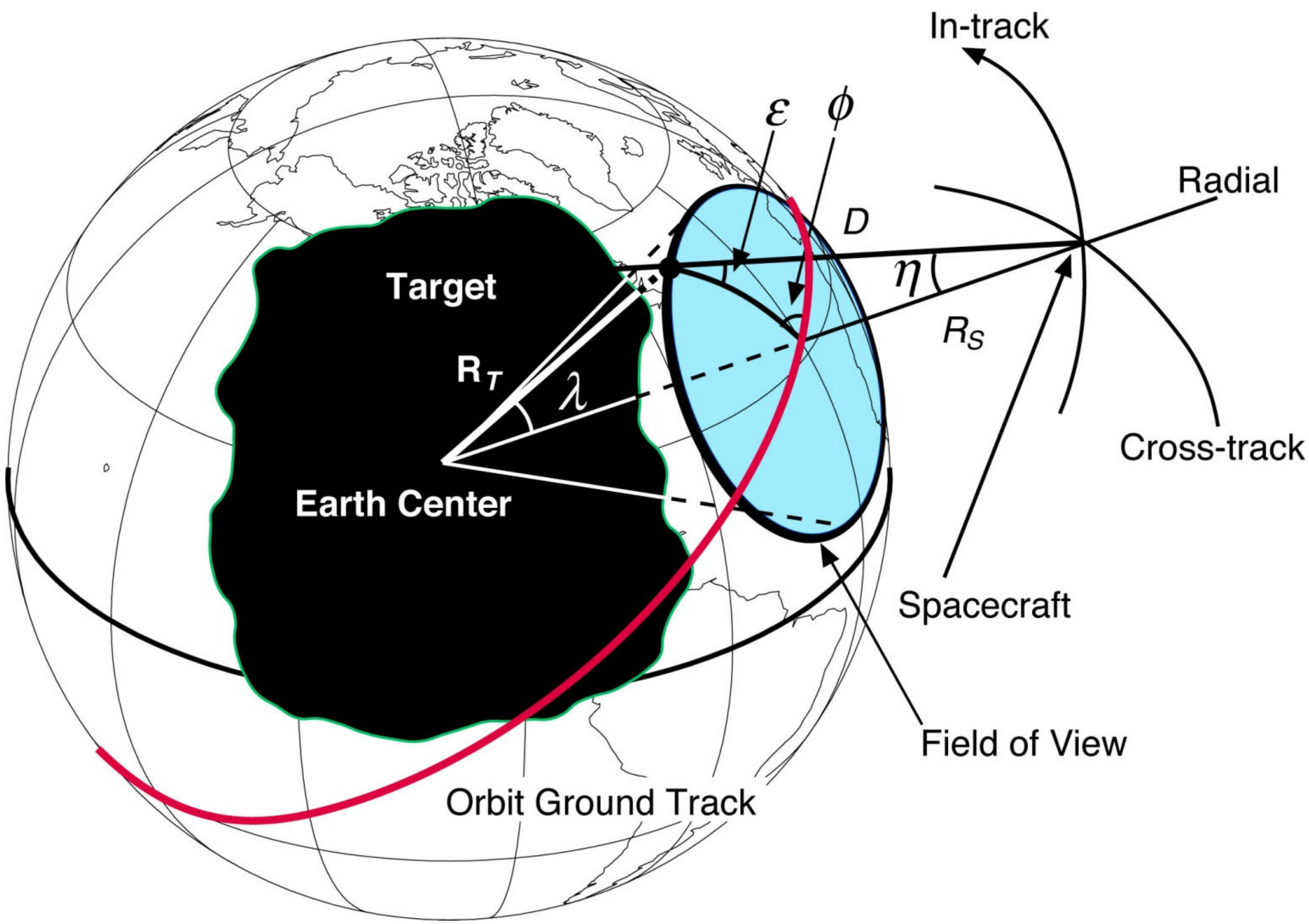
- Many alternative solutions are possible
- In theory, we should adjust each component until the differential cost of improvement ($ per milliradian) is the same for each
  - Doesn't work in practice because performance improvements are not continuously variable

How It Works in Practice

- Spread budget equally among all components
- Divide components into one of three categories
  (A) Those allowing very little adjustment
  (B) Those that easily meet the allocation
  (C) Those allowing increased accuracy at increased cost
- Adjust requirement to meet cost vs. performance trade

The most common mistake in constructing error budgets is to over-constrain the budget and thereby unnecessarily drive up the cost of the mission.

DEFINITION OF POINTING AND MAPPING ERROR COMPONENTS



SOURCES OF POINTING AND MAPPING ERRORS

SPACECRAFT POSITION ERRORS:

ΔI	In- or along-track	Displacement along the spacecraft's velocity vector
ΔC	Cross-track	Displacement normal to the spacecraft's orbit plane
ΔR_S	Radial	Displacement toward the center of the Earth (nadir)

SENSING AXIS ORIENTATION ERRORS (In spherical coordinates about nadir):

$\Delta\eta$	Elevation	Error in angle from nadir to sensing axis
$\Delta\phi$	Azimuth	Error in rotation of the sensing axis about nadir

Sensing axis orientation errors include errors in (1) attitude determination, (2) instrument mounting, and (3) stability for mapping or control for pointing.

OTHER ERRORS:

ΔR_T	Target altitude	Uncertainty in the altitude of the object under observation
ΔT	Clock error	Uncertainty in the real observation time (results in uncertainty in the rotational position of the Earth)

MAPPING AND POINTING ERROR FORMULAS

Error Source	Error Symbol (units)	Magnitude of Mapping Error (km)	Magnitude of Pointing Error (rad.)	Direction of Error
Attitude Errors:[1]				
Azimuth	$\Delta\phi$ (rad)	$\Delta\phi\, D \sin\eta$	$\Delta\phi \sin\eta$	Azimuthal
Nadir Angle	$\Delta\eta$ (rad)	$\Delta\eta\, D / \sin\varepsilon$	$\Delta\eta$	Toward nadir
Position Errors:				
In-Track	ΔI (km)	$\Delta I\,(R_T / R_S)\cos H$ (2)	$(\Delta I / D)\sin Y_I$ (5)	Parallel to ground track
Cross-Track	ΔC (km)	$\Delta C\,(R_T / R_S)\cos G$ (3)	$(\Delta C / D)\sin Y_C$ (6)	Perpendicular to ground track
Radial	ΔR_S (km)	$\Delta R_S \sin\eta / \sin\varepsilon$	$(\Delta R_S / D)\sin\eta$	Toward nadir
Other Errors:				
Target Altitude	ΔR_T (km)	$\Delta R_T / \tan\varepsilon$	———	Toward nadir
S/C Clock	ΔT (s)	$\Delta T\, V_e \cos(lat)$ (4)	$\Delta T\,(V_e / D)\cos(lat)\sin J$ (7)	Parallel to Earth's equator

NOTES:

(1) Includes attitude determination error, instrument mounting error, stability over exposure time (mapping only), and control error (pointing only) The formulas given assume that the attitude is measured with respect to the Earth.

(2) $\sin H = \sin\lambda \sin\phi$.

(3) $\sin G = \sin\lambda \cos\phi$.

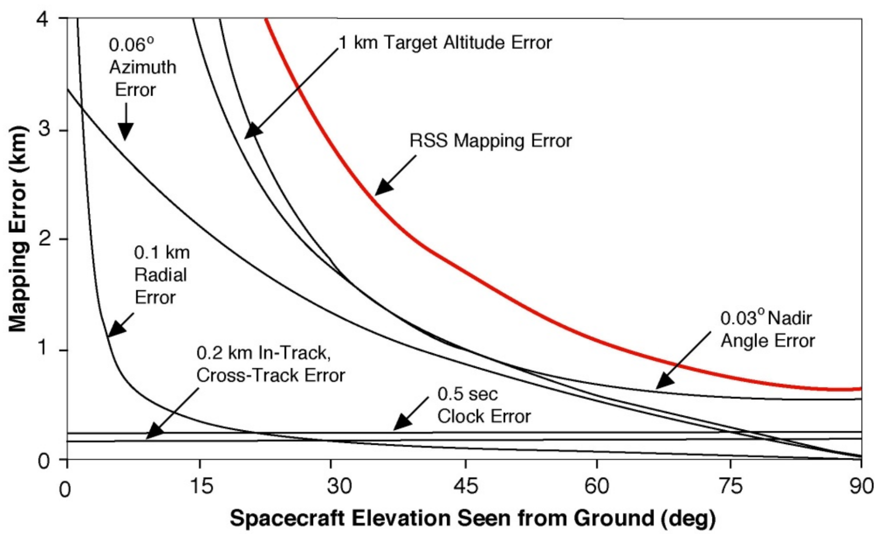
(4) V_e = 464 m/s (Earth rotation velocity at the equator).

(5) $\cos Y_I = \cos\phi \cos\eta$.

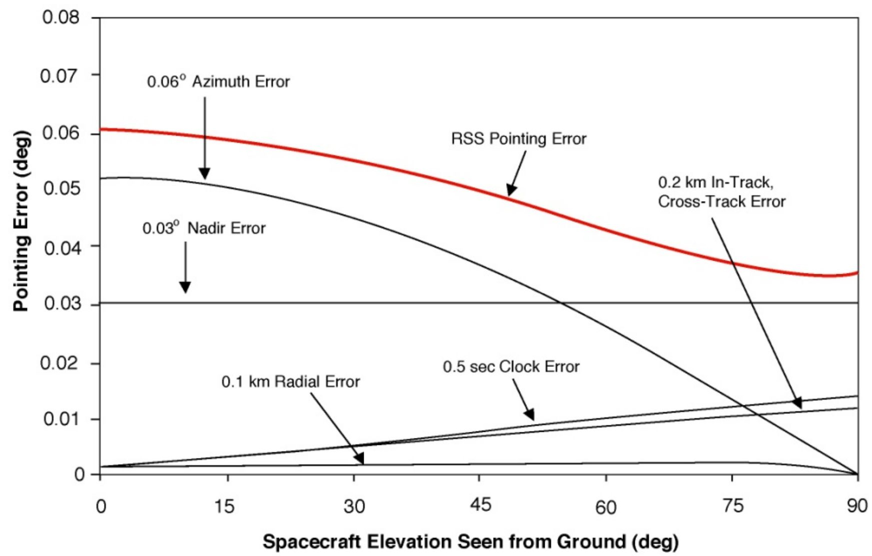
(6) $\cos Y_C = \sin\phi \sin\eta$.

(7) $\cos J = \cos\phi_E \cos\varepsilon$, where ϕ_E = azimuth relative to East.

TYPICAL POINTING AND MAPPING BUDGETS FOR DMSP AT 900 KM



Mapping Error as a Function of Elevation Angle



Pointing Error as a Function of Elevation Angle

Mapping accuracy is critically dependent on how close to the horizon you work (i.e., the elevation angle). Pointing accuracy requirement is nearly independent of elevation angle.