Navigation and Guidance Linear Covariance Analysis for Lunar Powered Descent

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Outline

- Introduction
  - ALHAT / LSAM
  - Lunar Powered Descent
- Guidance
- Linear Covariance Analysis
- Sample Results
- Research Objectives, Future Work

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Introduction

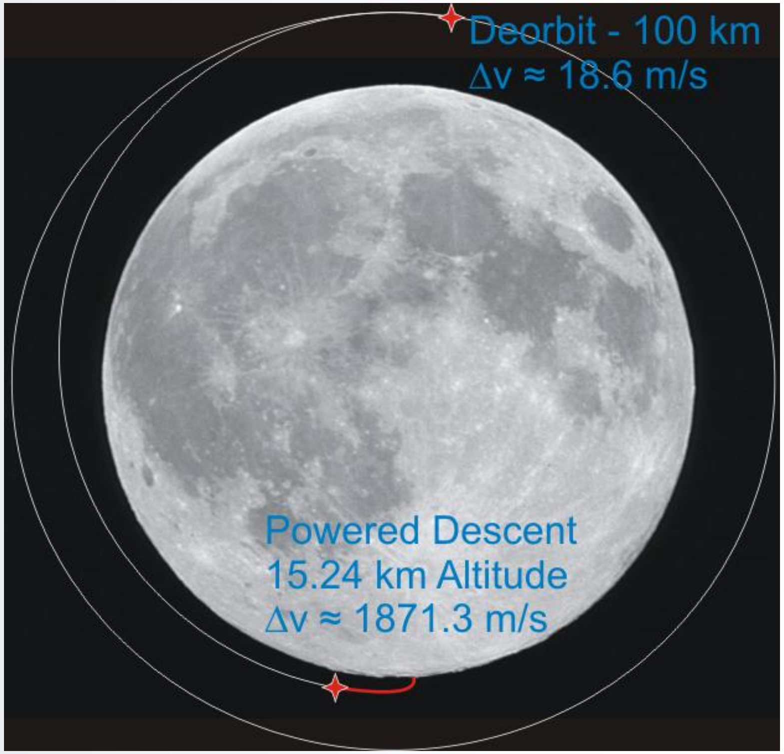
- NASA's *Vision for Space Exploration*
  - Return to the moon by 2020
  - New vehicles already in development (CEV/Orion, Ares, LSAM)
- Some technologies incorporating Apollo and Shuttle designs
- Simulation/analysis in preliminary design

ALHAT

- LSAM to incorporate Autonomous Landing and Hazard Avoidance Technology
  - Terrain Relative Navigation (TRN)
  - Hazard Detection and Avoidance (HDA)
- Advanced sensors
  - LIDAR
  - Hi-res map comparison

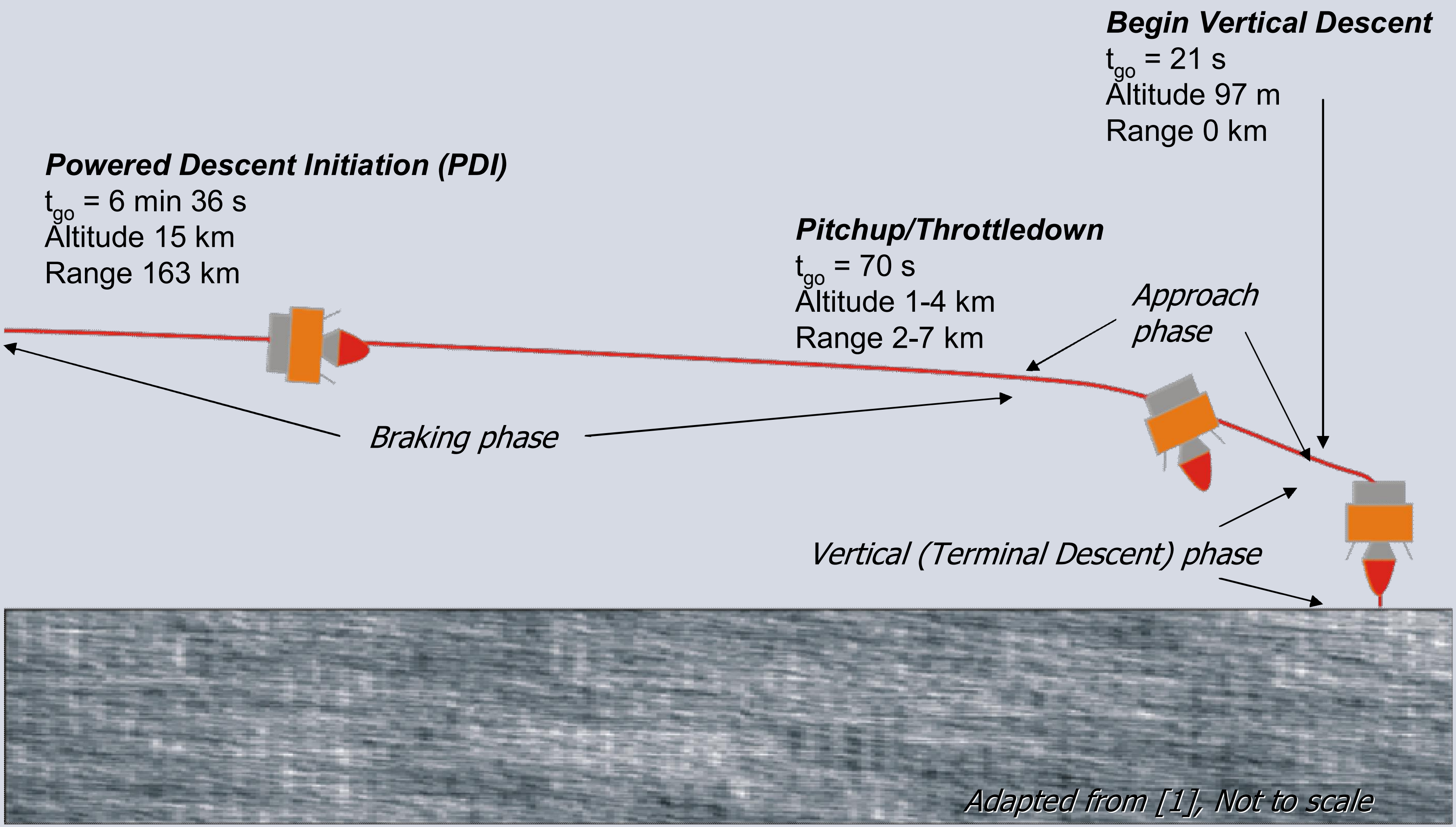
LSAM Descent Profile

- 100×100 km LLO
- Deorbit burn to lower perilune to ≈15 km
- Powered Descent
  - Braking Phase
  - Approach Phase
  - Vertical Phase



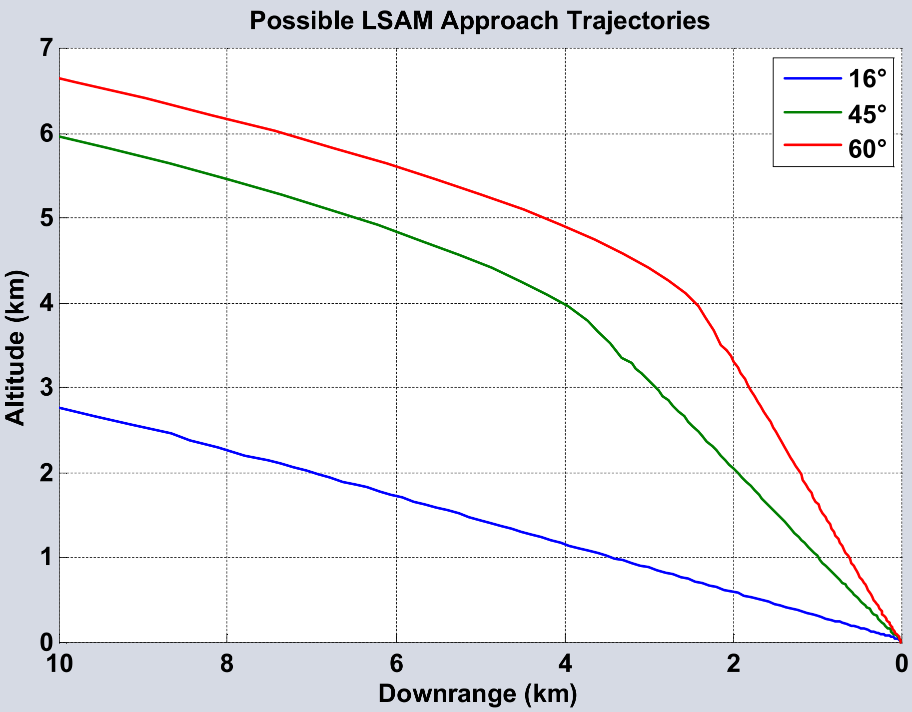
(Illustrative, not to scale)

Powered Descent Trajectory



Powered Descent Trajectory

- Glide slope of approach phase
  - Shallow 16° glide path (Apollo-like)
  - Moderate 45° glide path
  - Steep 60° glide path (max - viewing constraint)



Steeper approach facilitates better sensor data near target site, and more flexibility in HDA.

Shallower approach offers better crew view of landing target, and is more fuel-efficient.

Powered Descent Guidance

- Braking Phase
  - Linear acceleration profile
- Approach Phase
  - Quadratic acceleration profile
- Descent Phase
  - Quadratic acceleration profile
- Coefficients calculated from time-to-go (t_{go}) and target position & velocity (and acceleration)

$$a(t) = c_0 + c_1 t$$

$$a(t) = c_0 + c_1 t + c_2 t^2$$

$$\begin{bmatrix} c_0 \\ c_1 \end{bmatrix} = -\frac{12}{t_{go}^4} \begin{bmatrix} \frac{1}{6}t_{go}^3 & -\frac{1}{2}t_{go}^2 \\ -\frac{1}{2}t_{go}^2 & t_{go} \end{bmatrix} \begin{bmatrix} v_T - v_0 \\ r_T - r_0 - v_0 t_{go} \end{bmatrix}$$

Refer to [1]

Other Guidance Schemes

- Time-to-go varying, including
- Optimal Guidance (see [4])
  - Bilinear tangent steering law
    $$\tan\theta = \frac{c_0 + c_1 t}{c_2 + c_3 t}$$
  - Linear tangent steering law (Shuttle PEG)
    $$\tan\theta = c_0 + c_1 t$$
- t_{go} may be calculated
  - Ahead of time and fixed
  - On-the-fly (Shuttle)
  - Recalculated if target changed (Apollo, see [3])

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Linear Covariance Analysis

- Monte Carlo-like results
- Fraction of the computation time
- Equations include propagation and update of Covariance Matrix, like as is done in an extended Kalman Filter.
  - Equations linearized about nominal trajectory.
  - Propagates statistics (covariance matrix).
- Unlike Kalman Filter, *dispersions* from the nominal propagated, rather than an actual state.

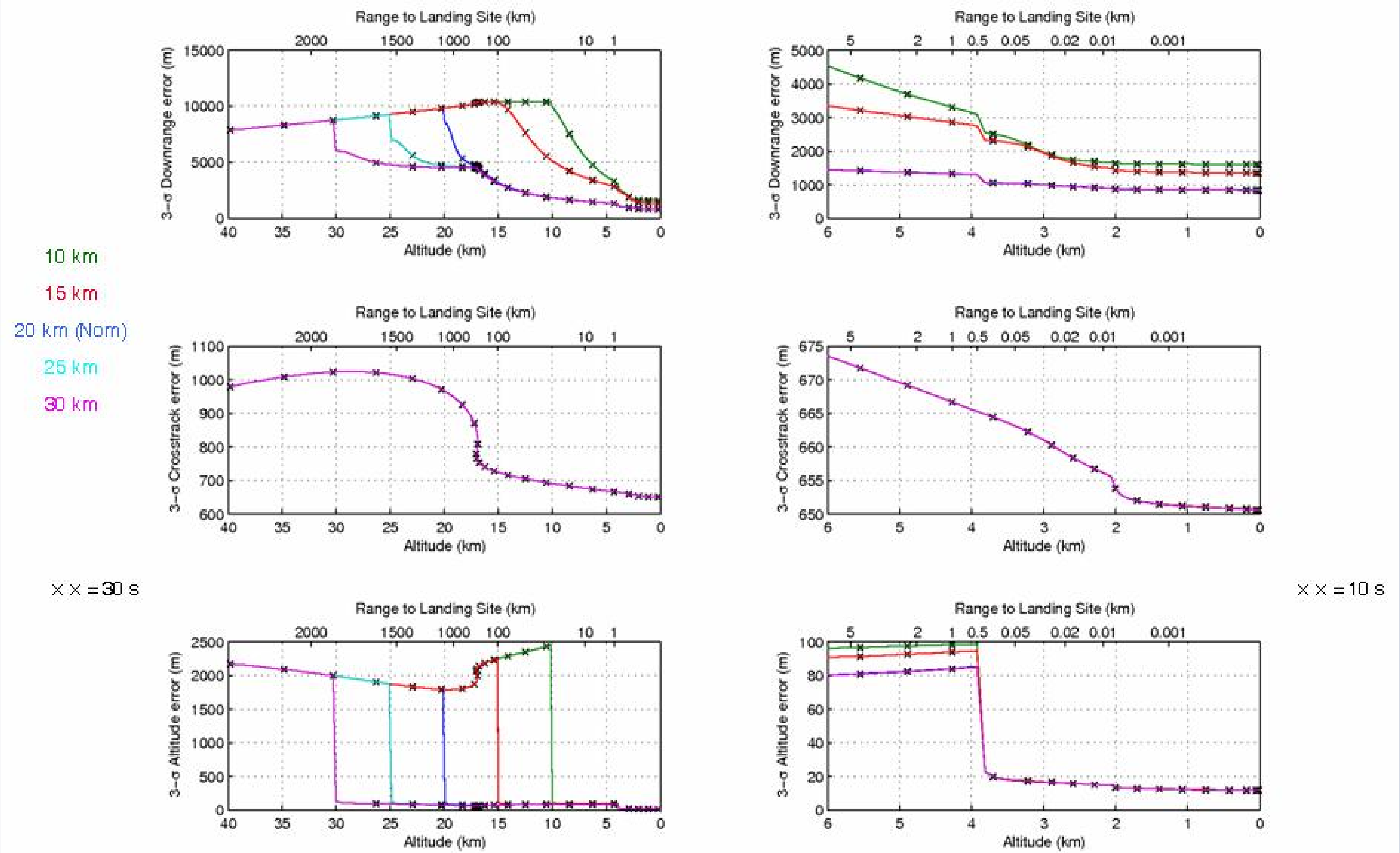
Linear Covariance Analysis

- Quantify individual sources of error
- Vary scenario parameters and get new results after only one run
- Quickly sweep through a range of values to find an optimum
- LinCov tool adapted from Geller [2]

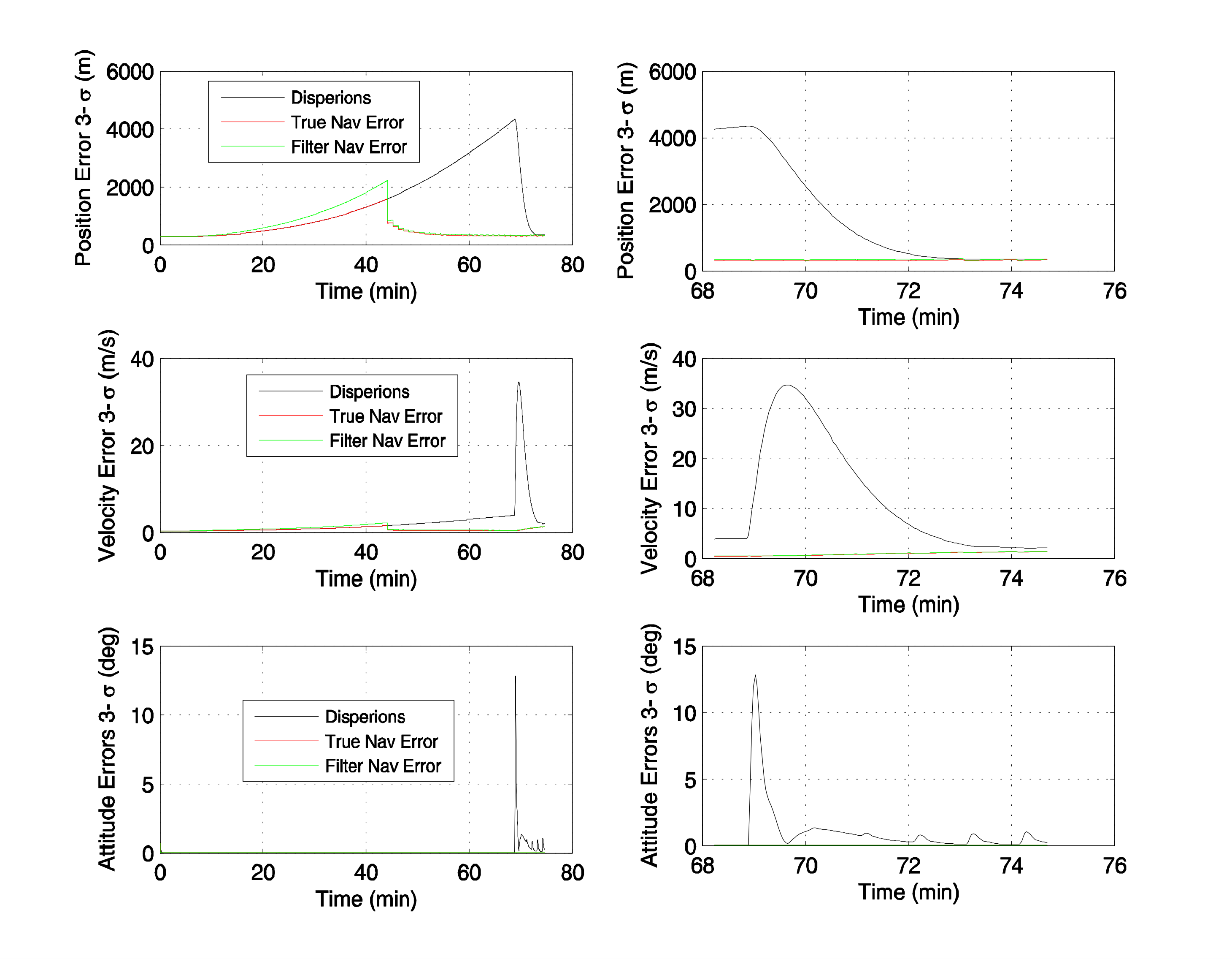
LinCov Navigation States

True States (84), Filter States (84)
Landing site states: inertial pos/vel (6)
Lander states: inertial pos/vel, attitude, attitude-rate (12)
Gravity error states (3)
Gyro error states (9)
Accelerometer error states (9)
Star-camera error states (3)
Altimeter error states (3)
Velocimeter error states (9)
Camera (SFT) error states (3)
Lidar error states (9)
Thruster/rotational error states (9)
Thruster/translational error states (9)

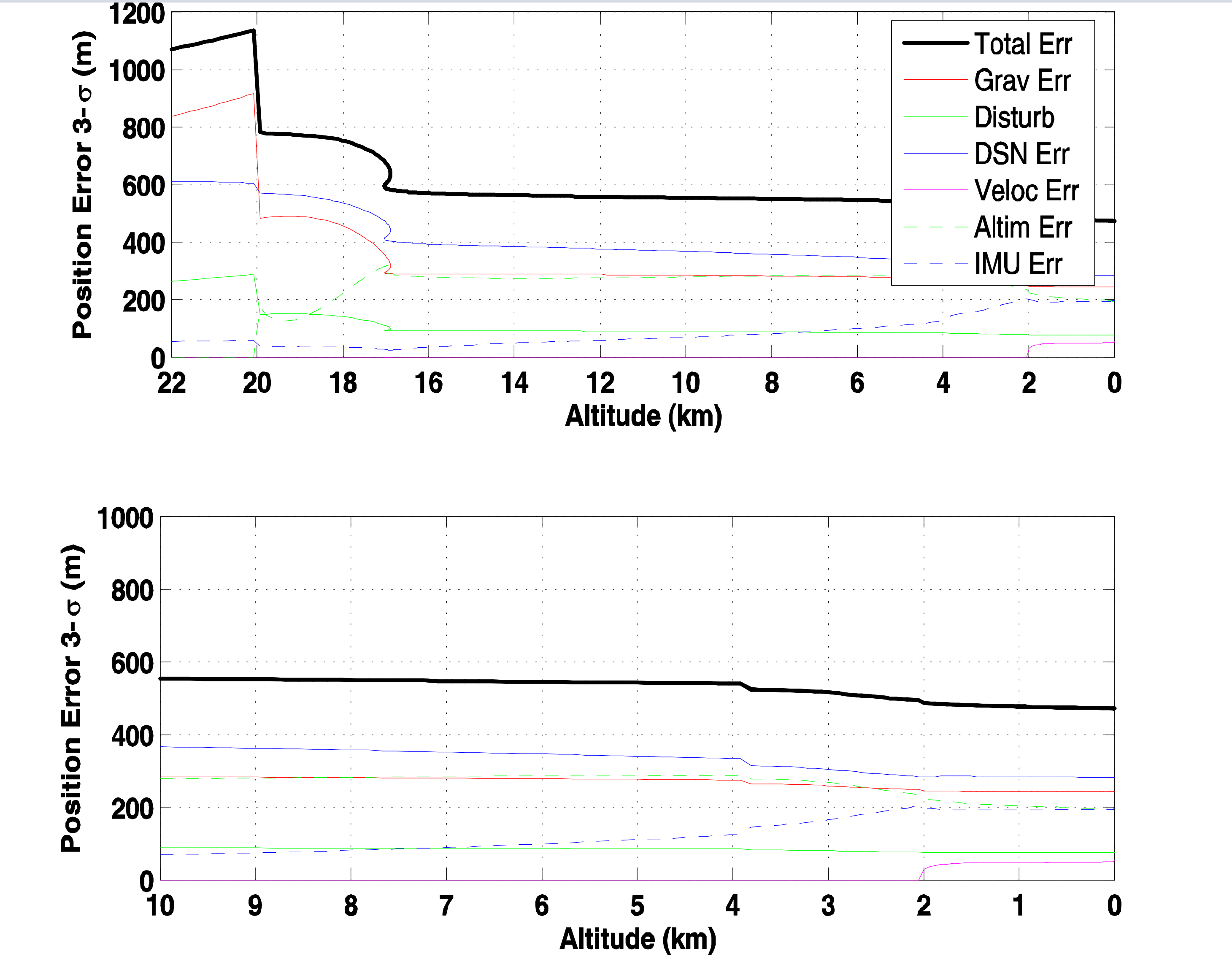
Inertial-only Navigation Errors, Altimeter Operation



PD-Controller Guidance Sample True/Nav Errors and Dispersions



Navigation Errors – Sensitivity Analysis



Research Direction

- Formulate LinCov equations for various guidance schemes
- Incorporate fixed- and variable-time maneuvers into LinCov analysis
- Study how timing of PDI (trigger) affects dispersions and navigation errors
- Study Δv and Fuel dispersions

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References

- [1] Sostaric, R.R. & Rea, J.R.
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- [2] Geller, D.K.
  "Linear Covariance Techniques for Orbital Rendezvous Analysis and Autonomous Onboard Mission Planning," *Journal of Guidance, Control, and Dynamics,* 2006, vol. 29, 1404-1414.
- [3] Klumpp, A.H.
  "Apollo Lunar Descent Guidance," *Automatica,* 1974, vol. 10, 133-146.
- [4] Bryson, A.E. & Ho, Y.-C.
  Applied Optimal Control, Hemisphere Pub. Corp., 1975.