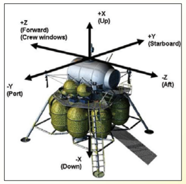
Navigation & Guidance Linear Covariance Analysis for Lunar Powered Descent

Introduction

The NASA "Vision for Space Exploration," announced in January 2004, calls for extended **human expeditions** to the **Moon** no later than 2020. NASA and commercial contractors are developing technologies and vehicles to enable human and robotic lunar landings.

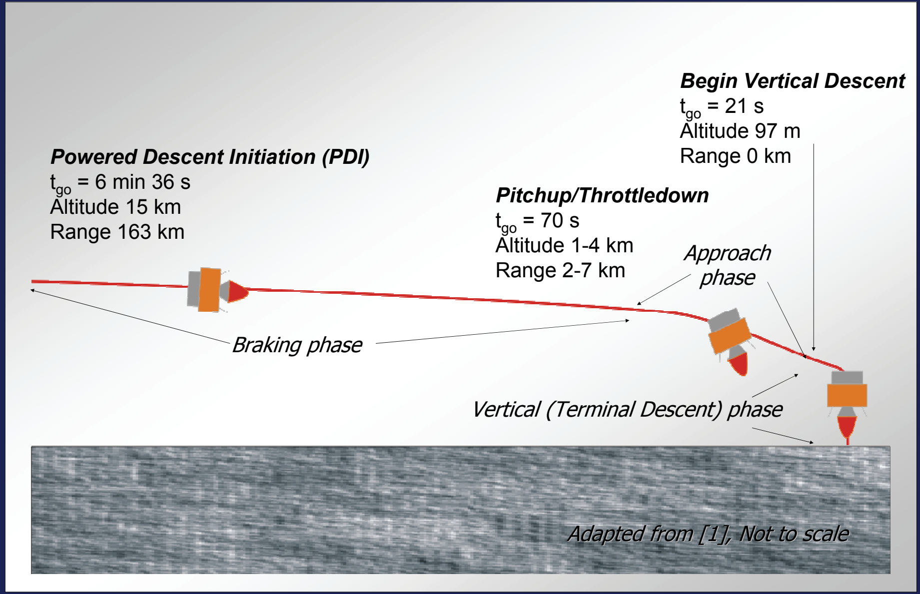
One exciting technology for the Lunar Surface Access Module (**LSAM**) is Autonomous Landing and Hazard Avoidance Technology or **ALHAT**, which operates during the vehicle's powered descent to the lunar surface. ALHAT uses its own set of sensors, including radar and **LIDAR imaging**, to **autonomously** detect potential landing hazards, referred to **Hazard Detection and Avoidance** (HDA). ALHAT also incorporates **Terrain Relative Navigation** (TRN) using high-resolution maps of the target landing area to ensure an accurate landing while avoiding pre-placed surface assets, such as habitats and existing equipment.



The LSAM and a body-fixed coordinate system.

Linear covariance analysis may be used to gauge the **performance** of ALHAT by validating its ability to meet mission constraints, and to **quickly** make **trade studies** and exploring "**what-if**" scenarios.

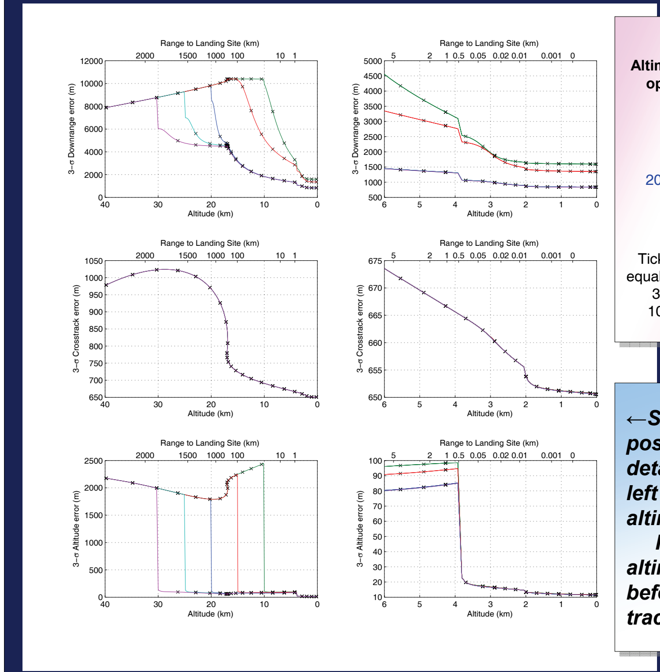
Descent Profile



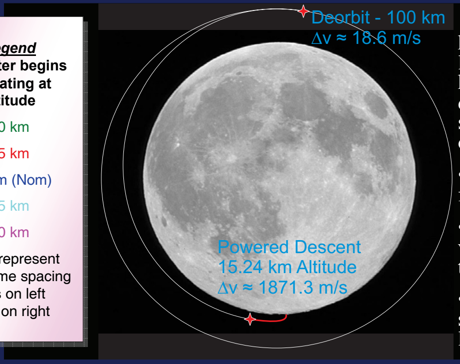
Linear Covariance

Linear covariance (LinCov) analysis is a method of gaining statistical insight into a dynamic problem without the hundreds or thousands of runs necessary with **Monte Carlo** analysis techniques. Rather than simulating the actual states of a dynamic system, a LinCov tool only **propagates the covariance** of the state. The covariance equations are formulated much like an **extended Kalman filter**. Also, true- and navigation-state **dispersions** about a nominal trajectory are propagated using linearized equations of motion. Like an extended Kalman filter, the covariance of the state is propagated using **linearized dynamics** and updated using measurement partial derivatives.

Linear covariance is similar to Monte Carlo analysis in that the quality of the results depends on the **quality and detail of the models**. Linear covariance analysis can provide statistical data of similar quality to that of Monte Carlo analysis, but at a **fraction of the computation time**. However, extra care is required in formulating the equations required for LinCov analysis. Also, the validity of LinCov breaks down as the state dispersions become large enough that the **linearized models** are no longer sufficiently accurate.



Legend
Altimeter begins operating at altitude
10 km
15 km
20 km (Nom)
25 km
30 km
Ticks represent equal-time spacing
30 s on left
10 s on right



Landing begins with the LSAM in a 100 km circular orbit. A retrograde burn lowers perilune, and the lander coasts for half an orbit. Near perilune, powered descent begins, bringing the LSAM to a soft surface landing. Powered descent occurs in three phases:

- **Braking phase** reduces most of the forward momentum.
- **Approach phase** pitches the vehicle so visual and instrumental observations of the landing site can be made.
- **Vertical phase** guides the LSAM to the surface from a point directly above the landing site.

←Study of how the operation altitude of the LSAM altimeter affects the navigation position errors, using only inertial (non-TRN) instruments. The plots on the right are detail plots of those on the left. Spacing between tick marks represents 30 s on the left and 10 s on the right. Each line represents one landing scenario where the altimeter is activated at differing altitudes.

Results indicate that waiting until after PDI (17.5 km altitude) to turn on the altimeter produces larger navigation errors. Also, operating the altimeter significantly before PDI is unnecessary. Note that the altimeter produces no improvement in cross-track navigation knowledge.

LSAM Guidance

Future LinCov studies of the LSAM landing will incorporate **guidance schemes** planned for implementation in ALHAT technology. These guidance schemes include fixed-end-time **linear acceleration profiles** and **quadratic acceleration profiles** in each direction of the Moon-Centered Inertial coordinate system. If possible, the LinCov tool may also be expanded to include optimal guidance schemes such as the **bilinear tangent law** and the **linear tangent law.** Other **free-end-time** guidance laws may be adapted for use in Linear Covariance Analysis as well.

The ALHAT GN&C team consists of individuals representing many of the great aerospace research and development firms and schools including NASA's **Johnson Spaceflight Center**, **Langley Research Center**, **Jet Propulsion Laboratory**, the **Charles Stark Draper Laboratory,** the **University of Texas**, and **Utah State University.**

REFERENCES AND FURTHER INFORMATION

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