**Introduction**


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 as 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.

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**

Powered Descent Initiation (PDI)  
\[ t_p = 6 \text{ min } 36 \text{ s} \]  
Altitude 15 km  
Range 163 km  

Begin Vertical Descent  
\[ t_v = 21 \text{ s} \]  
Altitude 97 m  
Range 0 km  

Vertical (Terminal Descent) phase  

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.

**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.

**Linear Covariance**

**REFERENCES AND FURTHER INFORMATION**