AUTONOMOUS PRECISION LANDING WITH HAZARD AVOIDANCE

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CAPABILITIES

- Autonomous real-time navigation technology for safe precision landings on any solid solar body under any lighting conditions

![Moon](image1.png)
- Moon
- Dark Poles
- Craters w/ Ice

![Mars](image2.png)
- Mars
- Rocky terrain
- Canyons

![Enceladus](image3.png)
- Enceladus
- Geysers

![Europa](image4.png)
- Europa
- Ice sheets

![Asteroids](image5.png)
- Asteroids
CAPABILITIES

• Terrain Relative Navigation within 30 m (1σ) of a pre-defined landing target
  – Requires orbital reconnaissance information
  – ALHAT field-tested two methods for TRN
    • Passive optical camera given adequate ambient surface illumination; ~1 kg, very low power and small footprint
    • Active lidar systems under any ambient lighting conditions - sensor choice can vary depending on single or multiuse sensors
CAPABILITIES

• Autonomous Hazard Detection and Avoidance (HDA)
  – Utilizes an active 3-D lidar sensing system to identify safe landing areas in real time during the approach trajectory
  – Detects small local surface slope and roughness hazards (1° / 30 cm)
  – Both flash lidar and scanning lidar sensors are viable options
  – Lidar Sensor ROM: 6 to 7 kg, 50 to 100W, 4400 cm³

• Precision velocimetry & ranging
  – Doppler Lidar
    • Three-beam CW sensor with an operational range of ~2.5 km provides surface-relative vector velocity accurate to < 1 cm/s and LOS ranges accurate to 17 cm. ROM: 13 kg, 70W
  – Laser Altimeter
    • Pulse sensor with an operational range of 50+ km provides range accuracy 30cm and precision <8 cm. ROM: 6 kg, 50W
**ALHAT**
Autonomous Precision Landing and Hazard Avoidance Technology

TRN = Terrain Relative Navigation
HDA = Hazard Detection and Avoidance
HRN = Hazard Relative Navigation

**LRO 1m Mosaic of Shackleton Rim**

- **Rocks < 2m**
- Safe landing site (20m diameter) selected with HDA, navigated to with HRN
- **Small Craters**

**Hazard Map Area (200x200m)**

- **Landing Ellipse without ALHAT** (700m diameter)
- **Landing Ellipse with TRN** (<200m diameter)
- **1km Slopes**
- **10m slopes**

- Vertical Descent
- Powered Descent Initiation
- Braking maneuver
- Roll and Pitch-up

- **HDA/HRN Phase**
- **TRN Phase**

- **300 km**
- **15 km**
- **30 m**

**30 m slant range**

- **Hazard Map Area**

**A. Johnson/JPL**
IMPLEMENTATION

- A lander can choose to use the entire ALHAT System or only individual capabilities with supporting sensors and software.
- Requirements levied on the host spacecraft include regulated power, thermal control, command/data management, and mechanical integration.
- All sensors must have a clear view of the surface during approach and landing.
- Approach and landing attitude profile will impact sensor location and pointing.
IMPLEMENTATION

- ALHAT sensors provide ground-relative navigation measurements – a Kalman navigation filter has been developed to process the ALHAT sensor data.

- ALHAT HDA data processing approach for crewed lunar landings leverages a separate Compute Element with multicore CPU and FPGA for high speed, parallel processing in real time. Embedded processing is used for the Doppler lidar and laser altimeter sensors.

- Data processing architecture for robotic landers can be tailored for specific missions with the potential for sharing on-board computing resources.
TECHNOLOGY READINESS LEVEL

• Prototype ALHAT system has been tested in relevant terrestrial environments using helicopters, winged aircraft, and the rocket-powered Morpheus vertical take-off and landing vehicle

• The ALHAT Team considers all techniques at TRL 6 and ready for spaceflight infusion

• Space-qualified passive optical cameras are readily available

• ALHAT lidar sensors require additional refinement for spaceflight applications
SCHEDULE

The utilization and implementation of ALHAT systems is dependent on the landing destination, mission profile, lander design, etc.

In order to develop GFE systems for spaceflight, the ALHAT Team will require a significant influx of funding from HEOMD, STMD, and/or SMD starting in FY15.

Any of these ALHAT landing system capabilities can be ready for integration in a spacecraft within three years.

Expertise is available to develop/refine sensor and software ICDs starting in the fourth quarter of FY14.
Information is highly dependent on the mission utilization of ALHAT technologies.

Please use POCs for desired information.
INTEGRATION COSTS

Integration costs are dependent on mission requirements and associated sensors and software.

Integration costs must include:

- Physical integration such as mounting, power connectivity, data connectivity, precision alignment, etc.
- Software integration and testing to ensure needed functionality.

Experience has shown that considerable integration testing will be required before systems are space-ready.
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