Lunar Penetrator Technology for Ice Detection

Paul Hayne, Norbert Schorghofer, Gerald Sanders, Leon Alkalai, Paul Lucey, Matthew Siegler, Barbara Cohen, William Feldman, and David Lawrence

Keck Institute of Space Studies, California Institute of Technology, Pasadena – November 2013
What are kinetic penetrators?

- Instrumented projectiles
- Survive high speed impact ~ 300 m/s
- Penetrate surface ~ few metres
- A complementary alternative to soft landing
- Lower cost and low mass => multi-site deployment
Typical Penetrator Design

Lunar-A penetrator

Figure 2-1a Baseline Penetrator Design

Fig. 12. Original, detailed design of the CRAF penetrator, from a 1986 Martin Marietta NASA study (Adams et al., 1986).
Architecture

- **Spacecraft Support**
  - attachment, power, comms

- **Penetrator Delivery System**
  - structure
  - thruster
  - ACS
  - Camera

- **Penetrator**
  - platform
    (structure, power, comms, data handling)
  - instruments

- Detachable Propulsion Stage
- Point of Separation
- PDS (Penetrator Delivery System)
Justification

• A single penetrator with neutron detectors and mass spectrometer could measure the abundance (with depth), phase, and isotopic ratios of H-bearing species

• Multiple penetrator probes could do this for diverse (thermal) environments

• Without a sampling system and mass spec, could still get abundance and distribution of H-bearing species
History

• First detailed planetary penetrator discussion is probably a Mars Penetrator design in 1974 at Sandia National Labs based on military technology

• Targets for studied, proposed, or flown missions include: Mars, Moon, Mercury, Vesta, icy satellites, comets, and Earth

(From Lorenz, 2011. “S” indicates a study or proposal, “D” indicates development or flight)
Payload Accommodation

• ~0.5-1.0 m in length, ~10 cm diameter?
• Neutron spectrometer
• Mass spectrometer + sampling system
• Sampling systems:
  – Passive port
  – Drill + inlet
• Seismometers
• Heat flow + soil conductivity
• Many other possibilities: magnetometer, x-ray spectrometer, alpha proton spectrometer, etc.
Navigation for Airless Bodies

- Need spacecraft to get to low lunar orbit
- Decelerate to near zero velocity ("stop and drop")
- Spin rapidly to stabilize orientation

Fig. 21. The Lunar-A delivery concept. The free-fall phase after the motor burn lasts only a few tens of seconds, during which time the vehicle must be precessed around to the vertical. Note that the whole vehicle penetrates the surface (no aftbody), and communicates through the lunar regolith.
Impact Velocity and Mechanical Loads

Military weapons technology has proven instrument survival with > 50,000 g and penetration depths of 30 m earth, or 6 m of concrete.
PN 1 GAS GUN TEST

PN 1 Test Parameters
Test Date: 2/20/03
Velocity = 425 ft/sec
AOI = 90°
AOA = 0°
Gun Pressure = 605 psi
Launch Weight = 77.03# 
Penetrator Weight = 75.03#

1/3 Scale BLU109

49.625" to back of Penetrator
52.5"
18ft
90°

4x4x4' Stack of 3/4" Plywood
4ft
4ft
31.67"
1" Pusher Plate

Mass Spectrometer
Neutron Detector & High Voltage Compartment

Down Range
PN 2 GAS GUN TEST

PN 2 Test Parameters
Test Date: 2/20/03
Velocity = 425 ft/sec
AOI = 90°
AOA = 0°
Gun Pressure = 615 psi
Launch Weight = 77.03#
Penetrator Weight = 75.03#

1/3 Scale BLU109
Communications/Telemetry

- Many penetrators use two-body approach, where antenna is left behind at surface
- Mars penetrators used ~1 W power to transmit ~7 kbps to relay orbiter
- How much power is needed to transmit a minimal amount of data direct to Earth? To relay orbiter e.g. LRO?

Fig. 1 Two body penetrator (DS2) [25]
Power and Lifetime

• Typically batteries, sometimes charged by RTG
• 12-hr lifetime without RTG (Polar Night penetrators)
• Lifetime many days with RTG
Cost

• DS-2: ~$30M (hitched a ride on Mars Polar Lander)
• Lunar-A: $132M (not completed)
• Polar Night: ?

• What drives cost? Probably spacecraft system to slow down the penetrator. Inexpensive instruments (e.g. neutron detector) exist