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NASA’s Lunar Impact Monitoring Program

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NASA’s Meteoroid Environment Office has implemented a program to monitor the Moon for meteoroid impacts from the Marshall Space Flight Center. Using off-the-shelf telescopes and video equipment, the moon is monitored for as many as 10 nights per month, depending on weather. Custom software automatically detects flashes which are confirmed by a second telescope, photometrically calibrated using background stars, and published on a website for correlation with other observations. Hypervelocity impact tests at the Ames Vertical Gun Facility have been performed to determine the luminous efficiency and ejecta characteristics. The purpose of this research is to define the impact ejecta environment for use by lunar spacecraft designers of the Constellation (manned lunar) Program. The observational techniques and preliminary results will be discussed.
The NASA Lunar Impact Monitoring Program

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Why are lunar impact monitoring and hypervelocity impact testing necessary?

- Constellation Program needs a spec for lunar impact ejecta
  - Existing spec is for Apollo – circa 1969
  - Astronauts will be exposed to this environment for months as opposed to hours.
- Flux of larger objects is poorly determined
- Production of ejecta particles is very poorly determined.
- We must:
  - Measure the flux and brightness of large impactors - ALAMO
  - Determine the luminous efficiency – fraction of impact kinetic energy which converts to light (which we observe) – Ames Vertical Gun Range
  - That gives the flux versus size of impactors
  - Measure the ejecta properties (mass, speed, direction distributions) and use hydrocode modeling to extend from test regime to lunar regime
  - Use model to fly the particles and estimate flux vs size and velocity at a lunar outpost.
- EV13 houses the Meteoroid Environment Office and the Constellation Environments and Constraints System Integration Group lead – we have the responsibility to do this job
Ejecta particles are 10,000 times as abundant as primaries of same size!
This curve is probably overly conservative.
Automated Lunar and Meteor Observatory

- Telescopes
  - 2 Meade RCX400 14” (355 mm)
  - Meade or Optec 0.33x focal reducer giving ~f2.6

- Recording Devices
  - Astrovid Stellacam EX
  - Sony Digital 8 recorder as digitizer
  - Firewire to PC harddisk
Observing the Moon

• Dark (not sunlit) side only
  • Earthshine illuminates lunar features
  • FOV is approximately 20 arcmin – covering 4.5 to 5 million square km ~ 12% of the lunar surface
  • 12\textsuperscript{th} magnitude background stars are easily visible at video rates

• Crescent and quarter phases – 0.1 to 0.5 solar illumination
  • 5 nights waxing (evening)
  • 5 nights waning (morning)

• Have taken data on about 55\% of the possible nights. > 190 hours in the past year. Cirrus is our enemy.

• Observing procedure
  • Aim scope at Moon
  • Record video from StellaCam EX to hard drive
  • Wait and reposition – working on software to improve tracking of Meade scopes
Probable Leonid Impact
November 17, 2006

Video is slowed by a factor of 7
Impact Candidates

Yellow are sporadic background meteoroids
White is likely Taurid, green Geminids, blue Leonids, red Lyrids
The Usual Suspects

- Noise/cosmic rays
- Boundaries
- Stars
- Satellite glints
- Impacts!
- Establishing 2\textsuperscript{nd} site to discriminate faint glints from orbital debris
Photometric analysis is performed by LunaCon (Swift, poster paper) Currently adding collecting area and "limiting magnitude" determination to LunaCon
Probable Sporadic Impacts
Lunar Viewing and Impact Geometry from 3 Strongest Sporadic Sources

Implies an average of more than 3 kilogram-class impacts per hour somewhere on the moon during non-shower periods.

First Quarter

0.19 sporadic impacts/hour

56.8% of observing time

Antihelion

Full

Observation period

0.07 sporadic impacts/hour

43.2% of observing time

New

Last Quarter

Apex

Helion
Example of a Moderate-Sized Impactor - May 2, 2006

Duration of flash: ~500 ms
Estimated peak magnitude: 6.86
Peak power flux reaching detector: $4.94 \times 10^{-11}$ W/m$^2$
Total energy flux reaching detector: $4.58 \times 10^{-12}$ J/m$^2$
Detected energy generated by impact: $3.394 \times 10^7$ J
Estimated kinetic energy of impactor: $1.6974 \times 10^{10}$ J (4.06 tons of TNT)
Estimated mass of impactor: 17.5 kg
Estimated diameter of impactor: 32 cm ($\rho = 1$ g/cm$^3$)
Estimated crater diameter: 13.5 m
Ames Hypervelocity Impact Testing

- Purposes
  - Determine impact luminous efficiency (in our camera passband) – fraction of kinetic energy converted to light
  - Determine size and velocity distributions of ejecta produced in cratering process
- These parameters are essential in defining the lunar design environment
- Fired ¼ inch pyrex projectiles into pulverized pumice at various speeds and angles (2 – 6 km/sec)
- Preliminary testing completed in October ‘06 – funded exclusively by Meteoroid Environment Office (HQ OSMA sponsored)
  - Recorded impacts with our video cameras and Schultz’s high speed photometer
Ames Vertical Gun Range

Camera ports
Preliminary Results

Luminous Efficiency vs Speed

Leonids (Bellot-Rubio et al.)

Plan to fill in intermediate velocities with Geminids and Lyrids using Bellot-Rubio technique.
Ejecta Flight Model
Very Preliminary Model Test Results
Simple assumed ejecta distribution

Vertical Impact

OBLIQUE VIEWS OF THREE-COMPONENT VECTOR PLOTS
Oblique impact captured at three different times. Vector colors indicate absolute magnitude of velocity

From Schultz et al. (2000)
Summary

- We have a fruitful observing program underway which has significantly increased the number of lunar impacts observed. We plan to continue for the foreseeable future.
  - Improving photometric analysis software
  - Adding 2\textsuperscript{nd} site to discriminate geosynchronous orbital debris
  - Engaging amateur community by porting LunarScan to PC platform
    - Already have one confirmed impact observed by amateur with 8 inch telescope
  - Website
    www.nasa.gov/centers/marshall/news/lunar/index.html
- We have done initial test shots at the Ames Vertical Gun Range – obtained preliminary luminous efficiency values
  - More shots and better diagnostics are needed to determine ejecta velocity distributions
- Development has begun on a model to lash together the primary impactor flux and ejecta distribution models to give the ejecta flux and size/velocity distributions at any landing site
- We are working to have a more accurate ejecta environment definition to support lunar lander, habitat, and EVA design
References


www.nasa.gov/centers/marshall/news/lunar/index.html