Large Area Lunar Dust Flux Measurement Instrument

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NLSI Lunar Science Forum 2009

July 21-23, 2009

Objective

- **Objective:**
  - Develop an instrument to improve our understanding of the lunar Micrometeoroid (MM) environment.
  - Emphasis on measurement of the potentially dangerous particle population greater than 50 μm.

    MM impacts in this size range are relatively infrequent, requiring a very large target area.

- **Benefits:**
  - Lunar science:

    A good MM environment definition is key to understanding lunar cratering processes and the development, growth, and transport of lunar regolith
  - Operations:

    Data guiding cost-effective impact shielding designs for future exploration activities (large lunar habitats, EVA, etc.*)*

Instrument Approach

- **Constraints:**
  - Must have a very large aperture area (preferably tens of m^2)
  - Although very large, it must still be low-mass, low-cost, low-power, easily transported and deployed on the lunar surface

Mean time between impacts for a 100 m^2 aperture area

Diameter	Flux estimate Per m^2 per year	Time Interval (100 m^2 array)
0.5 mm	~ .0072	~ 1.4 years
100 μm	~ 1.2	~ 3 days
10 μm	~ 100	~ 1 hr

Key Instrument Components

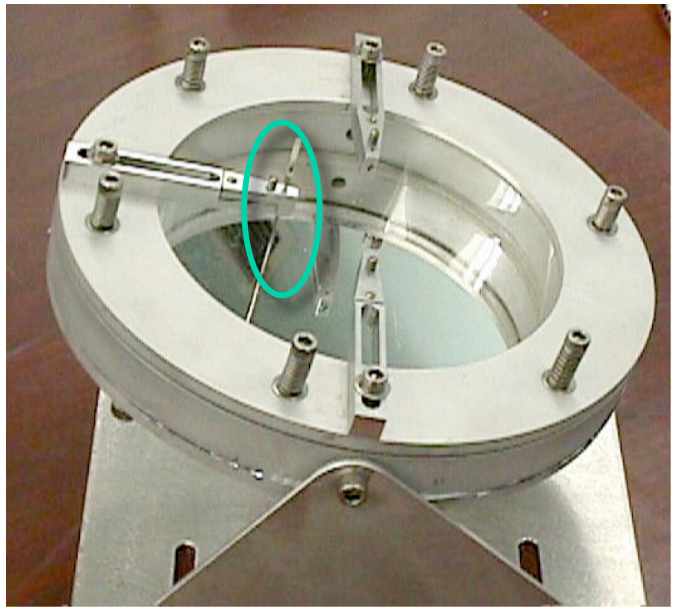
1. Diaphragm impact aperture (Drum-head):

- A large-area thin film (i.e. mylar film) under tension.
- A particle impact generates large (modal) surface motions.
- These vibratory motions persist for some time and are easily detected.

2. Fiber Optic Displacement (FOD) sensor:

- Measures surface motion of film with high sensitivity
- Non-contact, wide dynamic range (1 mm to 1 Angstrom), low-cost, reliable and environmentally suitable.

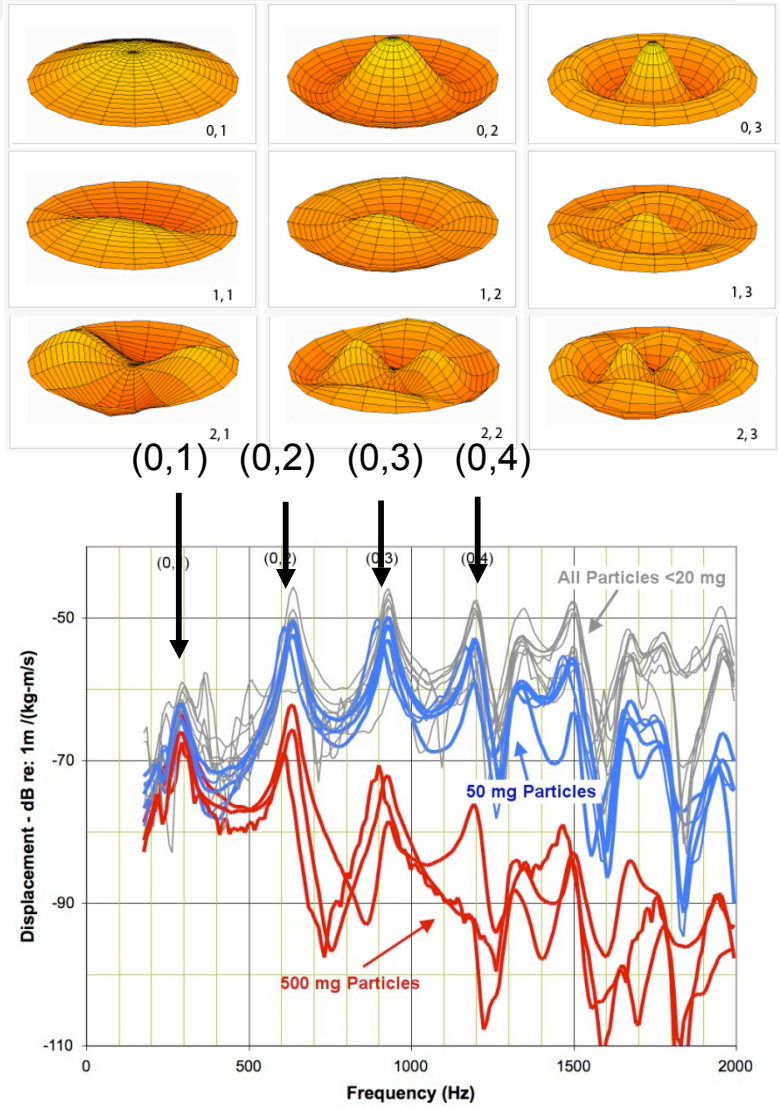
Front Side of Test Unit



Rear Side with 3 FOD Sensors

Component 1. Diaphragm

- **In Acoustics, a diaphragm is a thin membrane that vibrates when excited.**
  - Damping is typically very low. Hence resonant modes develop.
  - These modes are spatially well defined, depending only on the geometry of the boundaries.
  - The modes occur at well defined frequencies, depending only on the film tension and mass per unit area.
- **Hence the response to an impact produces out-of-plane motions that are:**
  - Large in magnitude
  - Persistent over many cycles
  - Predictable

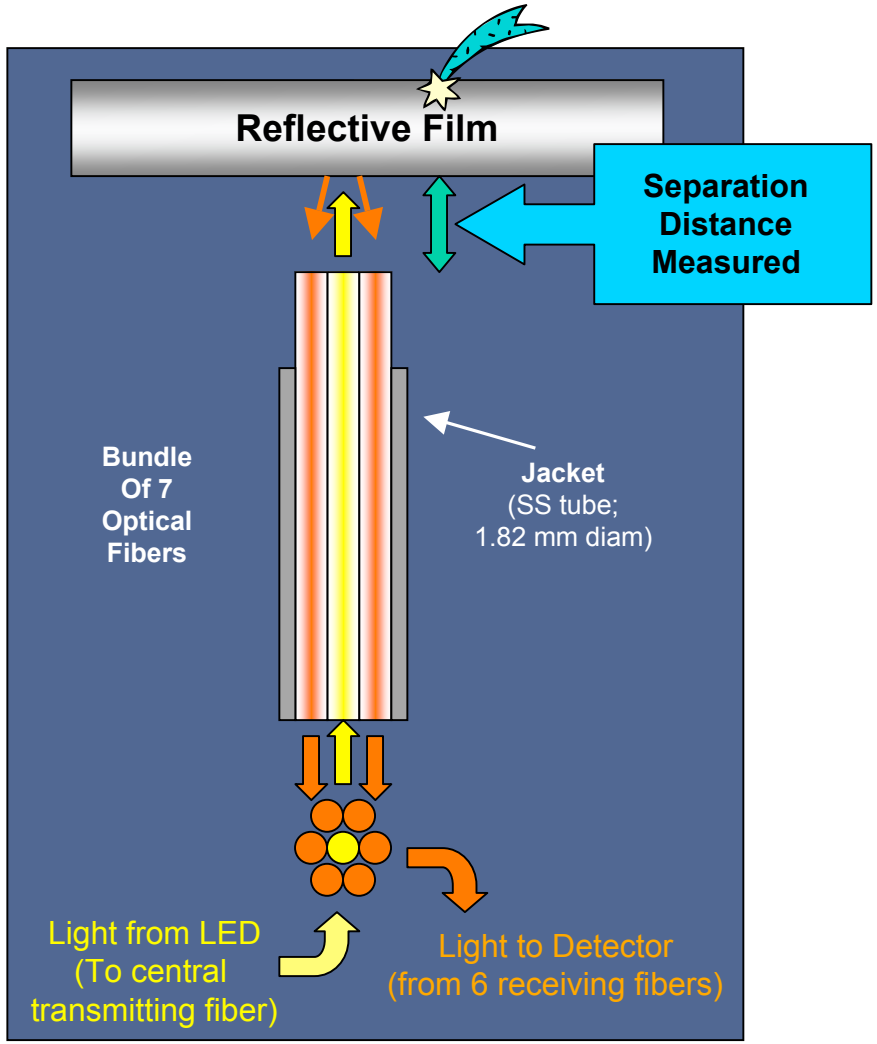


Some modes excited on the Test unit.

Component 2. Fiber Optic Displacement (FOD) Sensor

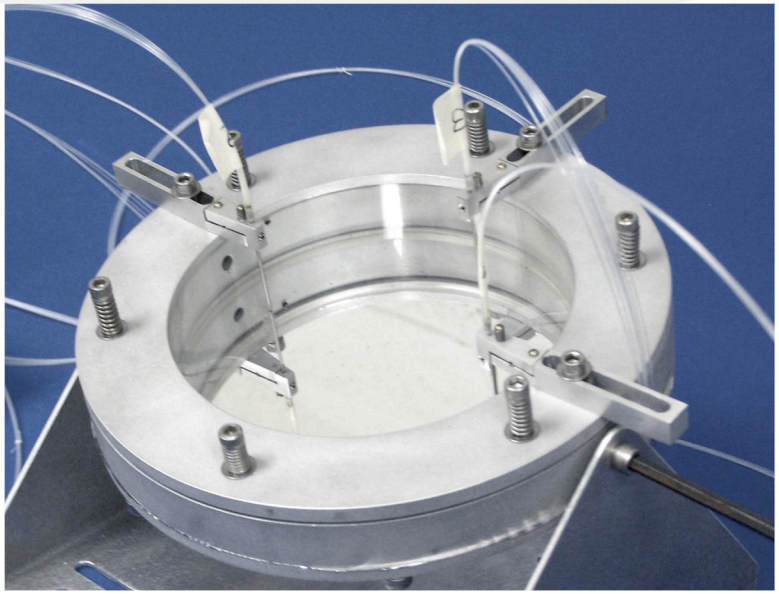
- An optical fiber bundle is positioned below a thin film (under tension)
- An LED sends light up the central fiber (the light transmitter)
- Surrounding fibers receive reflected light, and pass it back to a photodiode
- The intensity of reflected light is directly proportional to separation distance (over usable range).
- Variation in intensity → Vibration of the film

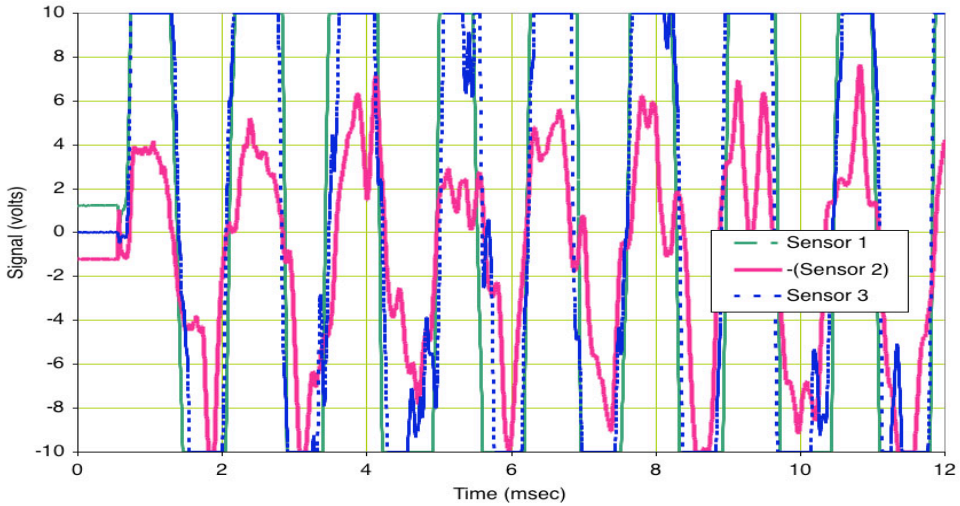
- **Key Features**
  - **Simple, rugged, low mass/cost/power**
  - **Extremely sensitive to motion with angstrom-level resolution**
  - **Wide measurement range (to 1 mm)**
  - **Sensor (glass) is inherently compatible with environment (temperature, radiation, *etc.)***

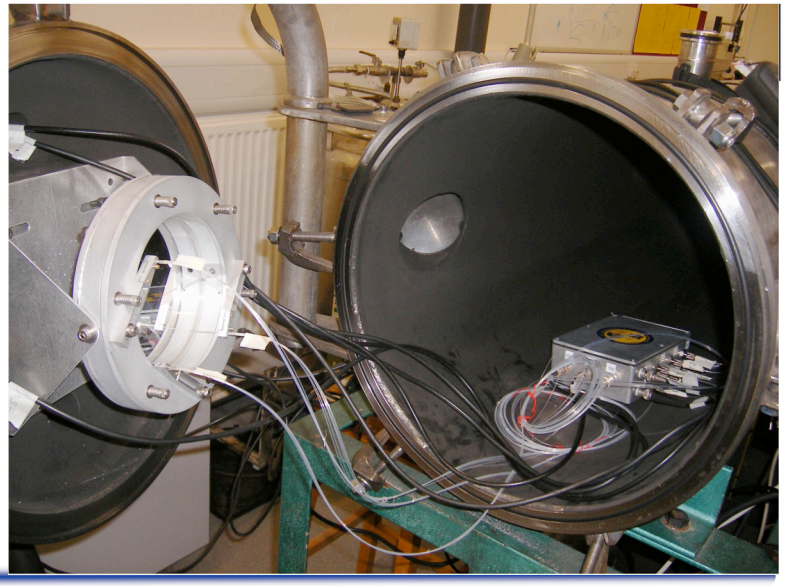


Concept validation

- **Initial tests performed at U. of Kent (UK)**
  - Test unit with 3 FOD-sensors installed
  - Impacted with 800 μm diam. @ 4.8 km/sec
  - Results and observations:
    - *Measured 38 micron motion near rim.*
    - *Very large (~ 5V) signals on all sensors*
    - *Primarily excited modal frequencies.*
    - *Setup and Operation was simple*







Device Development Efforts

Having demonstrated the feasibility,

device development is proceeding in three areas:

1. **Impact tests**

   (penetrating and non-penetrating) to reveal the underlying relationships and inherent device capabilities / limitations.

2. **Larger Arrays**

   mechanical design and testing of deployable array configurations.

3. **Numerical modeling**

   to determine optimum sensor configuration (number and locations) for more accurate measurement of particle size.

1. Low-Speed Impact Tests

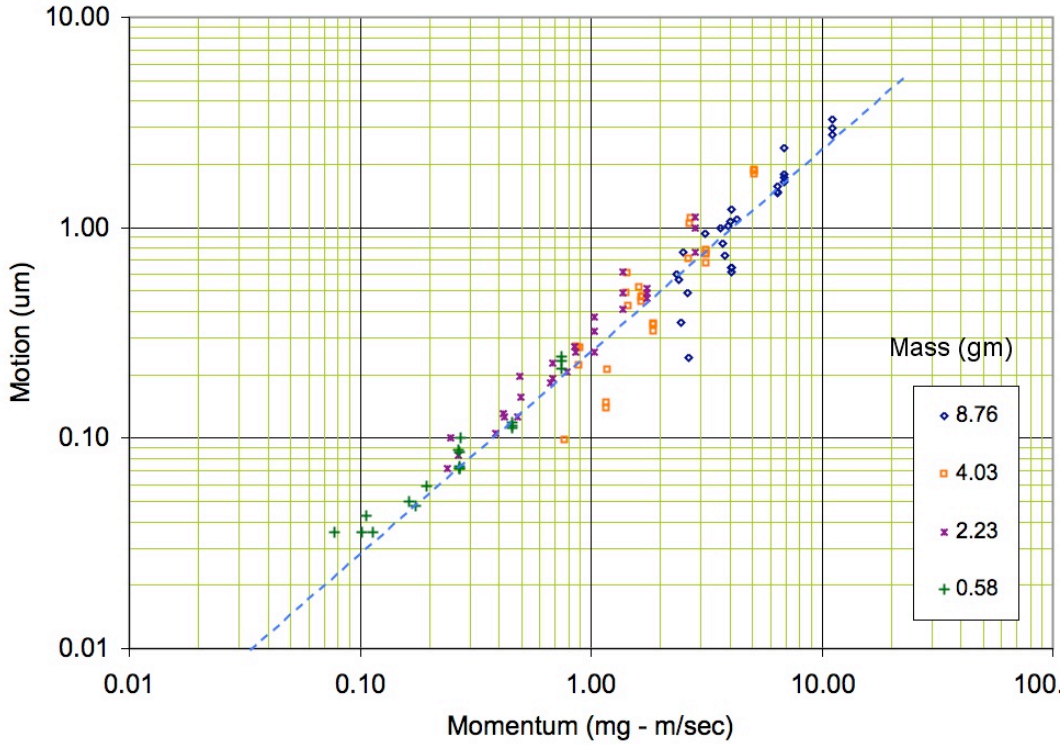
Explored system dynamics / capabilities in laboratory tests using very low speed (non-penetrating) particle impact tests

- Examining system dynamics, which is not a function of impact type.
- Used particles in size range ~0.3 to 3 mm and speeds of 0.5 to 5 m/s.
- Found signal amplitude is proportional to particle momentum (non-penetrating).

The relationship for penetrating hypervelocity particles has not yet been established.

This work also enables an estimate of the **particle detection threshold** (*for an optimally designed system*)

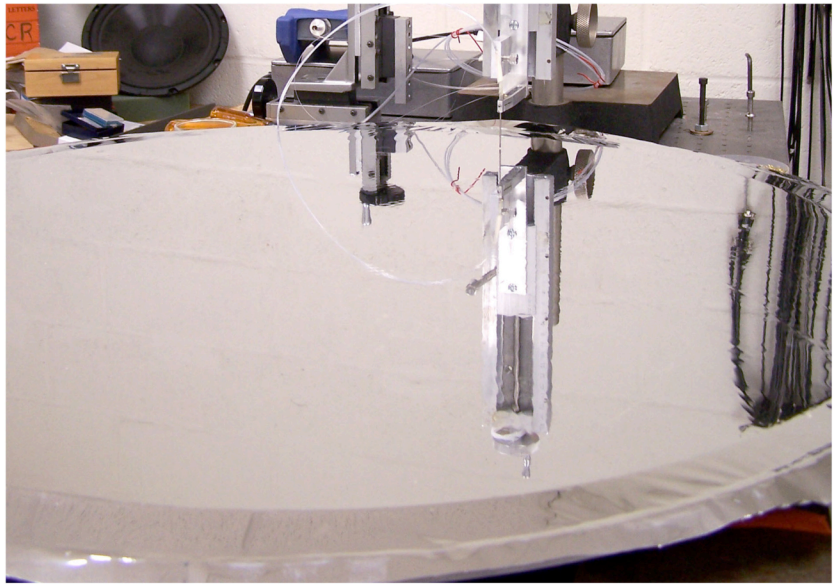
- 0.4 μm diameter for hypervelocity particle (~10 km/sec)
- 1.6 μm diameter for low-velocity particle (~100 m/sec)

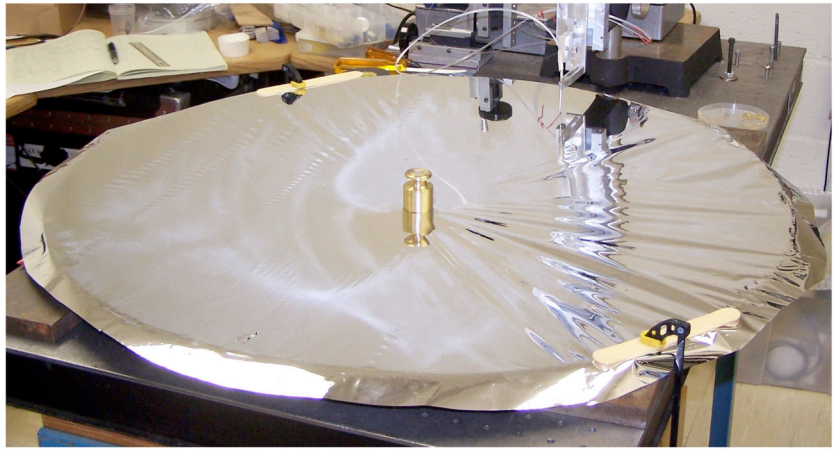


2. Larger Area Device Studies

Larger Area devices fabricated and tested using low-speed impacts.

- Exploring approaches for maintaining constant tension in a large-area, **low-mass** system.
- We have measured good performance for all devices tested to date (to 0.75 m diameter).





3. Numerical Modeling and Signal Processing

- **Particle size can be estimated from direct measurements of signal strength**
  - Estimated uncertainty in particle diameter is ±45% using a **single** sensor at an **arbitrary** location.

    The corresponding uncertainty in particle mass is about a factor of three.
- **More accurate size determinations involve removing complications of the system dynamics**
  - Modal spectrum excited is a function of the ***impact location***.
  - Sensor sensitivity to each mode is a function of the ***sensor location***.
- **Vibration modeling can greatly improve this accuracy.**
  - We have developed a numerical model (from our theoretical analysis) that maps the mechanical transfer function as a function of impact and sensor locations.
  - ***Relatively simple device modifications*** have reduced the uncertainty by half, and much greater improvements are anticipated.

3. Numerical Modeling

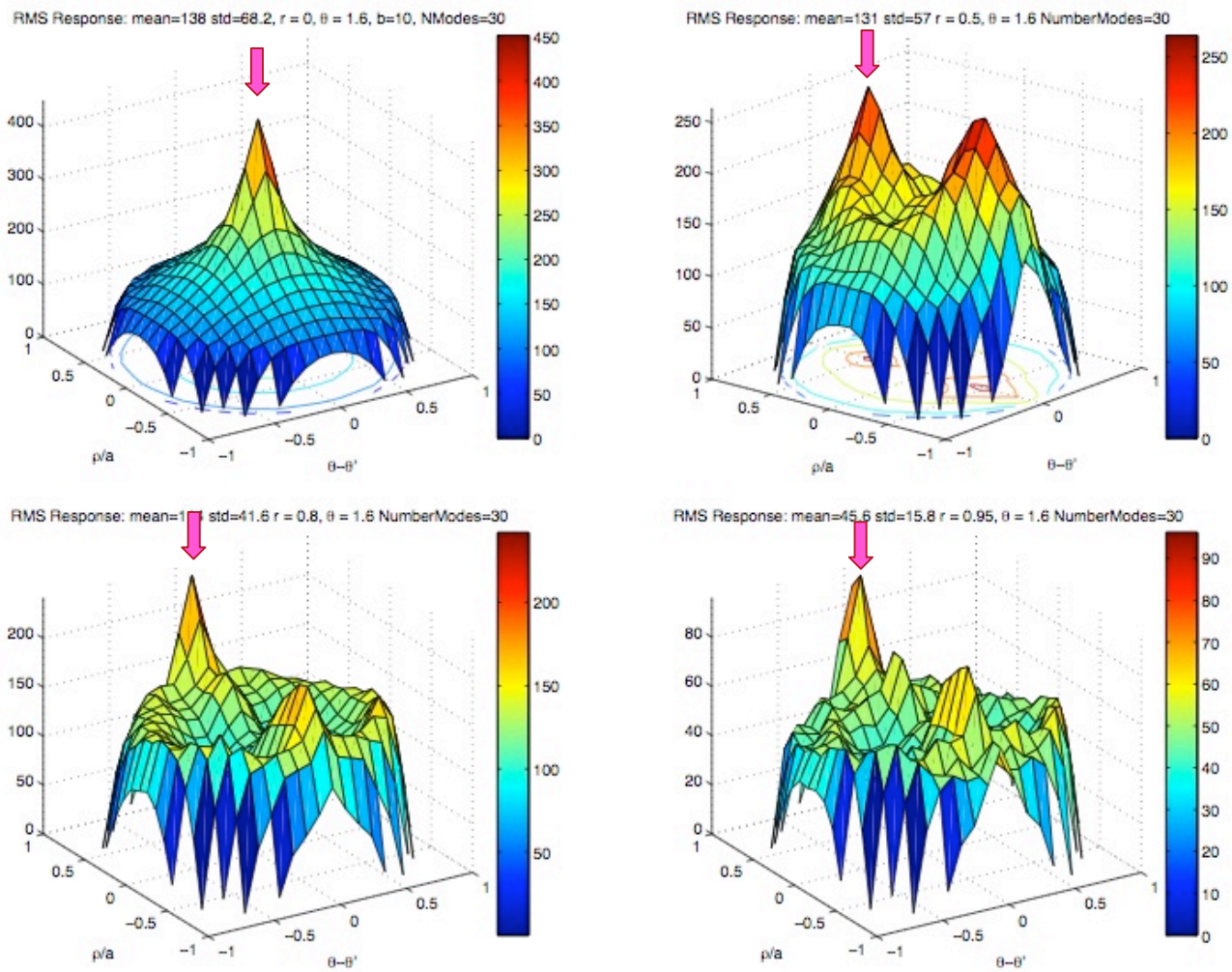
Examples of numerical model results for impacts at four different locations.

Each figure shows a map of the resulting probe response as a function of its location on the surface.

Two obvious approaches for improving system accuracy:

1. Shield small area around probe
2. Use two (or more) carefully-located sensors.

Maps of Total Signal Amplitude for 4 Impact Locations



Summary of FOMIS System Capabilities

- **High sensitivity**
  - FOD can measure ±0.5 mm displacements to better than 1 Angstrom
  - Particle detection threshold estimate far exceeds application requirements.
    - *0.4 μm diameter for hypervelocity particle (~10 km/sec)*
    - *1.6 μm diameter for low-velocity particle (~100 m/sec)*
- **Low resource requirements for large area**
  - Expect to use 2 sensors per square meter area
    - *Power requirement = 100 mW / m^2*
    - *Mass = [50 gm / m^2 for system] + [< 1 kg / m^2 for support framework]*
  - Estimates are for existing units (not yet optimized for application)
- **Other items of note:**
  - Probe is glass - hence inherently compatible with environment (temperature, radiation, etc.)
  - Can be made sensitive to other motions, such as ground tremors
  - Modal frequencies can be used to monitor fabric integrity