# DEVELOPMENT OF A LIGHTWEIGHT, ENERGY ABSORBING SOFT-LANDING SYSTEM FOR ROBOTIC PROBES

Scott Cooper, Gordon Maahs, Deva Ponnusamy
Johns Hopkins University Applied Physics Laboratory

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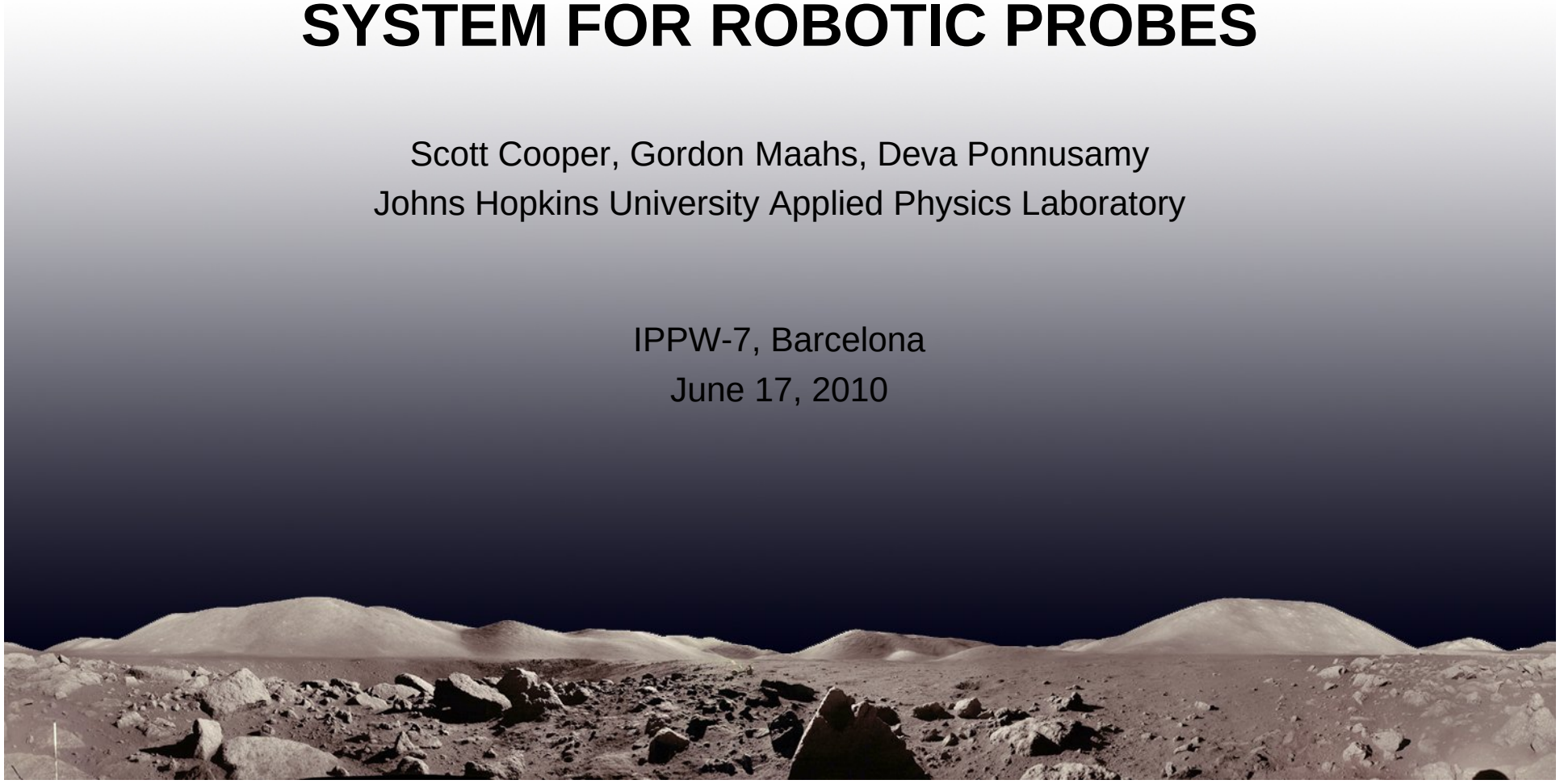
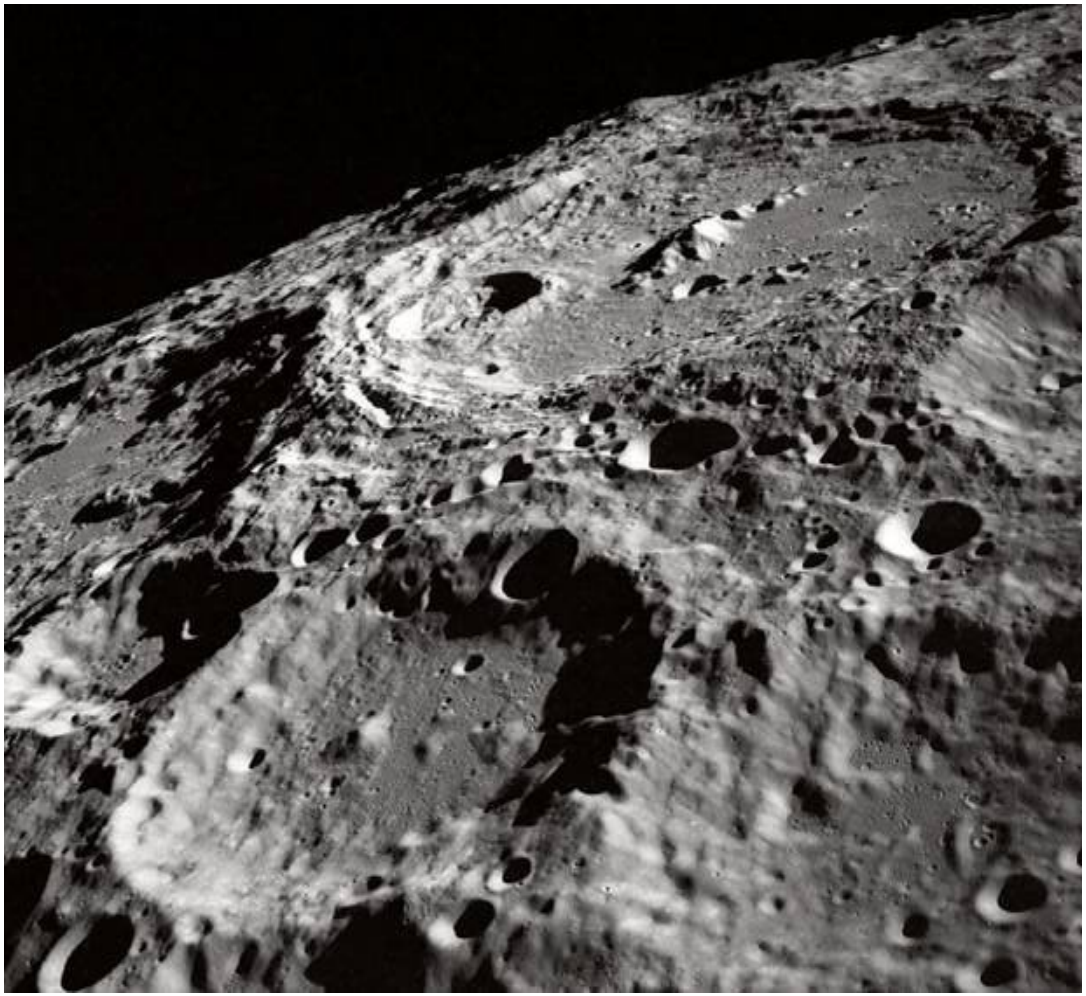


# Overview

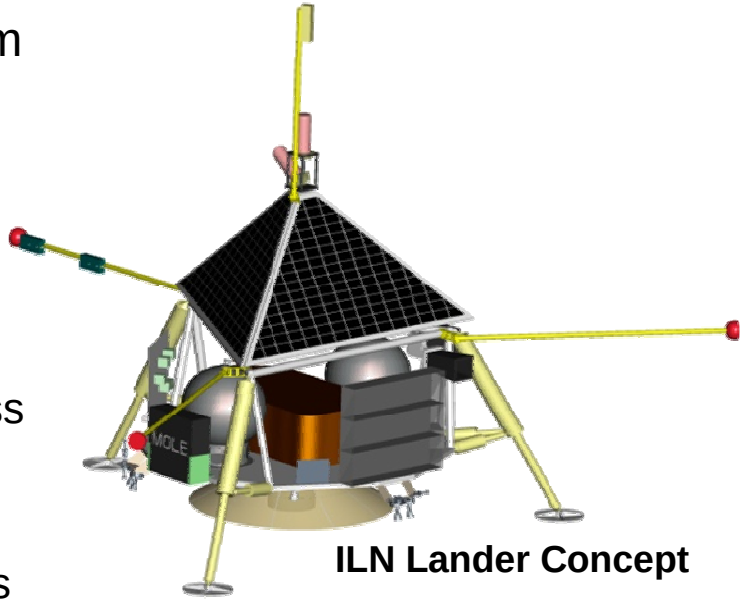
- Goal: Develop parametric landing system design and analysis capability

- Robotic Lunar Lander Project
- Baseline Landing System
  - Requirements
  - Trades
  - Design Description
- Leg Testing
  - Quasi-static honeycomb testing
  - Dynamic honeycomb testing
  - Drop testing
- Landing Simulation & Analysis
  - Dynamic Modeling
  - Component Stress
- Future Work

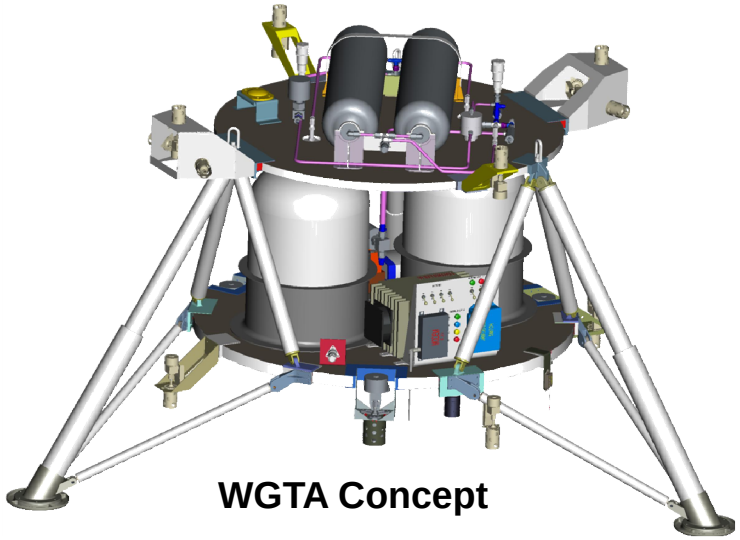


# Robotic Lunar Lander Development Project

- Robotic Lunar Lander Development Project Team
  - Began concept studies in 2005
  - Core team members - NASA/MSFC and JHU/APL
- Variety of mission parameters
  - Both Exploration Systems and Science Mission Directorate missions
    - Supporting NASA studies of small-medium class lunar landers
  - Recent mission concepts studied
    - International Lunar Network (ILN) anchor nodes
    - Lunar Polar Rim
    - Lunar Polar Volatiles
  - Variety of payloads
- Risk reduction tasks
  - Warm Gas Test Article (WGTA)
    - Earth-based GNC testbed
    - Targets terminal descent phase of landing



**ILN Lander Concept**



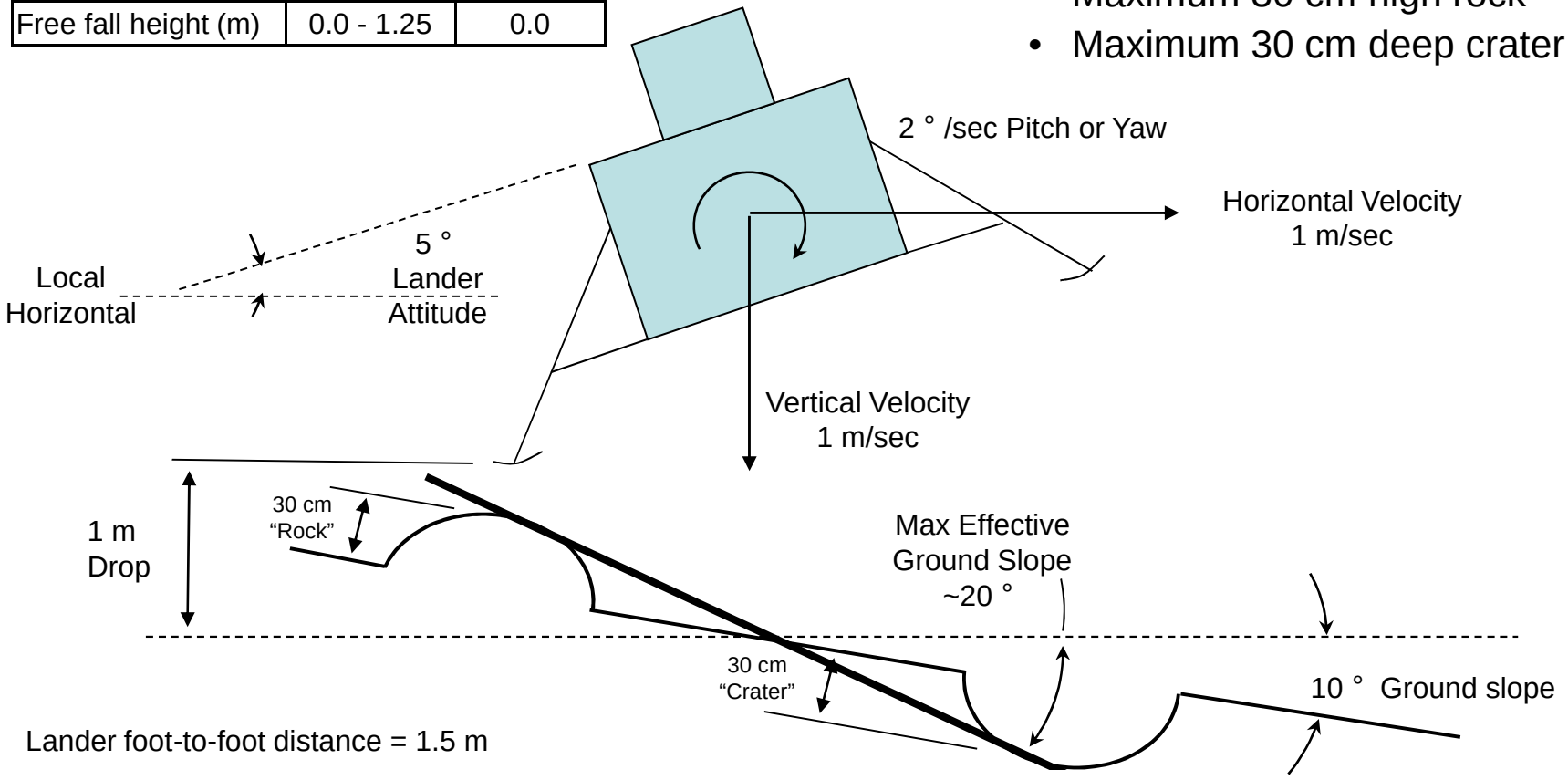
**WGTA Concept**

# Baseline Landing System Design Assumptions

- Descent Assumptions

| Parameter | RLL | WGTA |
|---|---|---|
| Vertical rate (m/sec) | 0.0 - 1.25 | 0.0 - 4.0 |
| Lateral rate (m/sec) | 0.0 - 1.25 | 0.0 - 1.5 |
| Lander angle (deg) | 0.0 - 10.0 | 0.0 - 10.0 |
| Angular rate (deg/s) | 0.0 - 5.0 | 0.0 - 10.0 |
| Free fall height (m) | 0.0 - 1.25 | 0.0 |

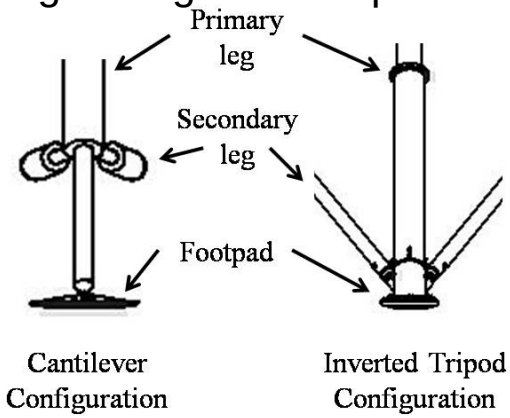
- Landing Site Lunar Surface Assumptions
  - Maximum 20 ° effective landing surface angle
    - Maximum 10 ° slope
    - Maximum 30 cm high rock
    - Maximum 30 cm deep crater



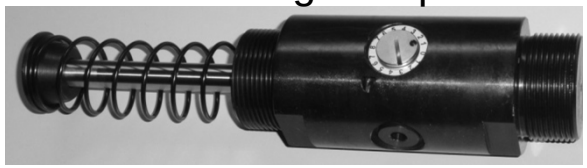
# Baseline Landing System Trades

- Leg Configuration
  - 3 fixed legs, eliminate moment in primary leg
- Energy Absorption
  - Honeycomb Block for RLL design (5 G design load)
  - Hydraulic damper for WGTA reuse (10 G design load)
- Landing Stability
  - Kinematic equations for 2-and-over case

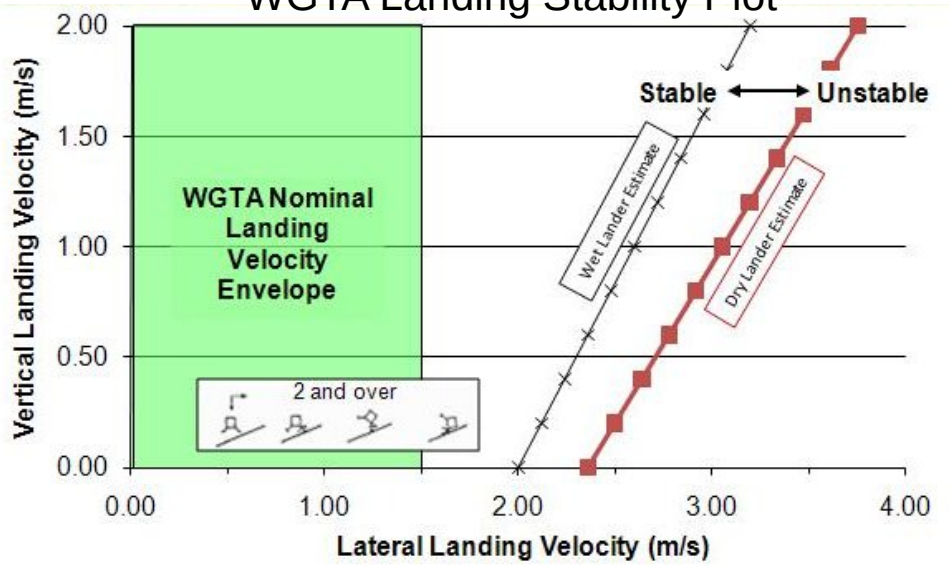
Leg Configuration Options




WGTA Leg Damper

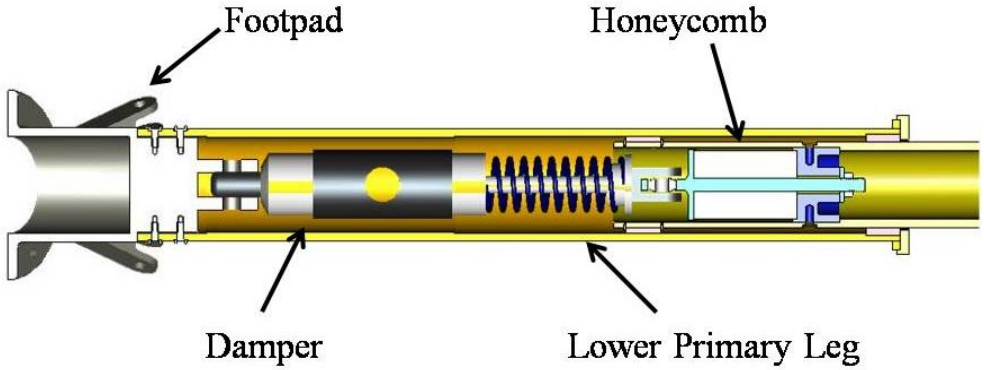



WGTA Landing Stability Plot



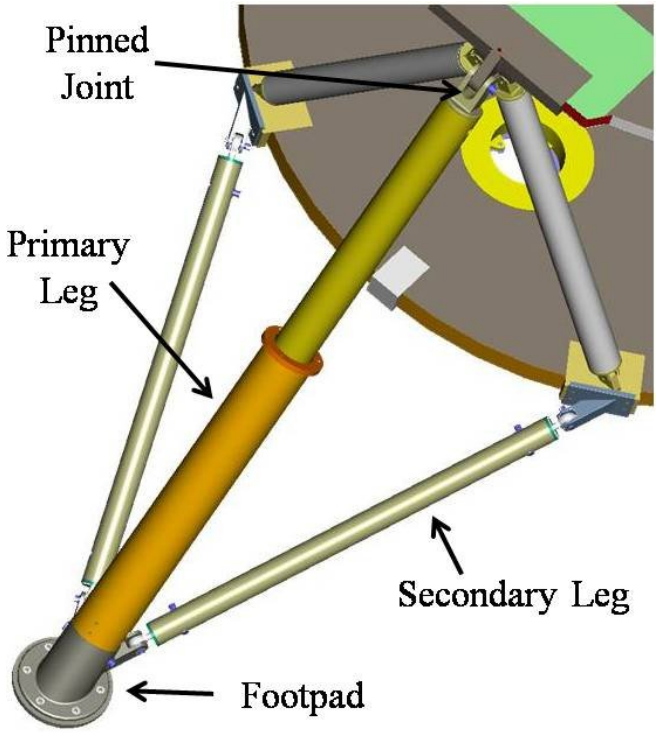
# Baseline Landing System Design

- Primary leg
  - Pinned joint at vehicle attachment
  - Telescopic design accommodates energy absorption stroke
  - WGTA has honeycomb and damper in series
- Secondary leg
  - Axial strut
  - Spherical end fittings
- Footpad
  - Adjusted for desired landing area and shape




WGTA Primary Leg Cross-section

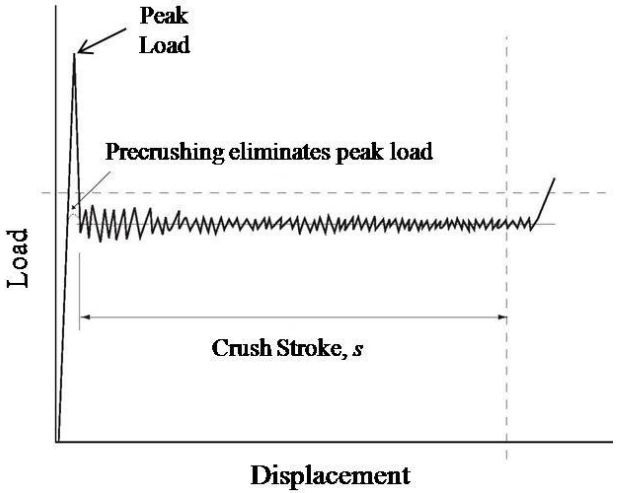
WGTA Landing Leg Assembly



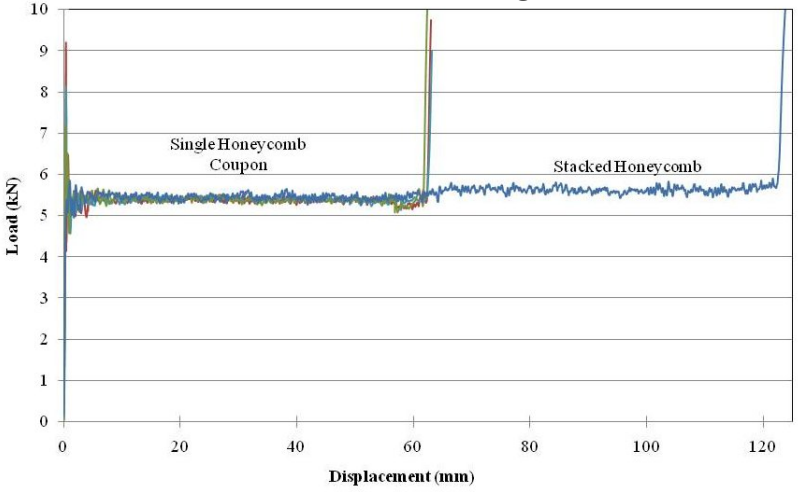
# Quasi-static Honeycomb Testing

- Initial honeycomb sizing
  - Crush stroke determined by vehicle acceleration limit
  - Crush force determined by impact velocity and honeycomb area
  - Initial selection is Hexcel CRIII 1/8-5052-3.1, 7.6 cm thick
    - 900 kPa crush strength
    - Cut into 7.6 cm square test coupons
- Quasi-static loading in Instron at 0.25, 1.3 and 25 mm/min
- Test data linear, consistent and matches calculated values
  - Crush force highly dependent on coupon dimensions

Generic Hexcel Plot



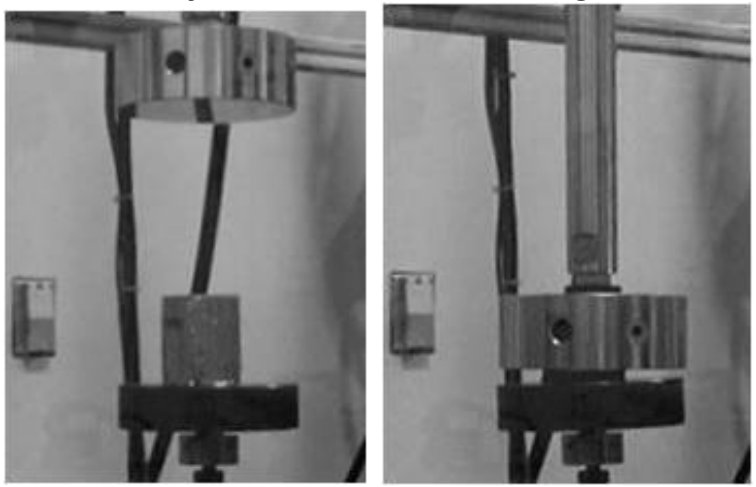

Quasi-static Testing Results



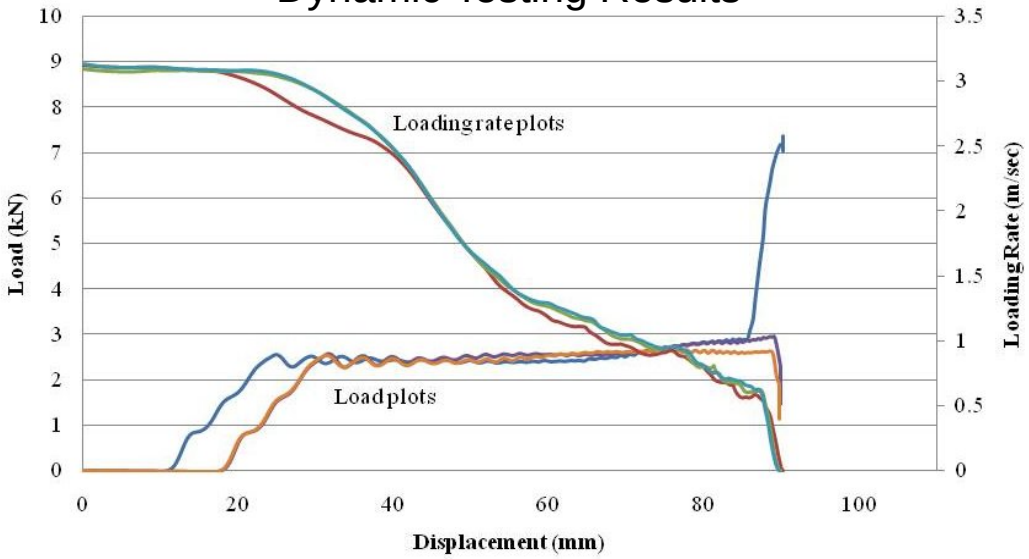
# Dynamic Honeycomb Testing

- Higher loading rates more representative of landing scenarios
- Instron 8821S system used to crush at 2.0, 2.5 and 3.0 m/sec
  - Rolling point average used to filter data
- Coupon size reduced to a 5 cm square
- Test data linear, consistent and matches calculated values
  - Slight increase in dynamic crush strength
- Instron unable to maintain loading rates

Dynamic Crush Testing



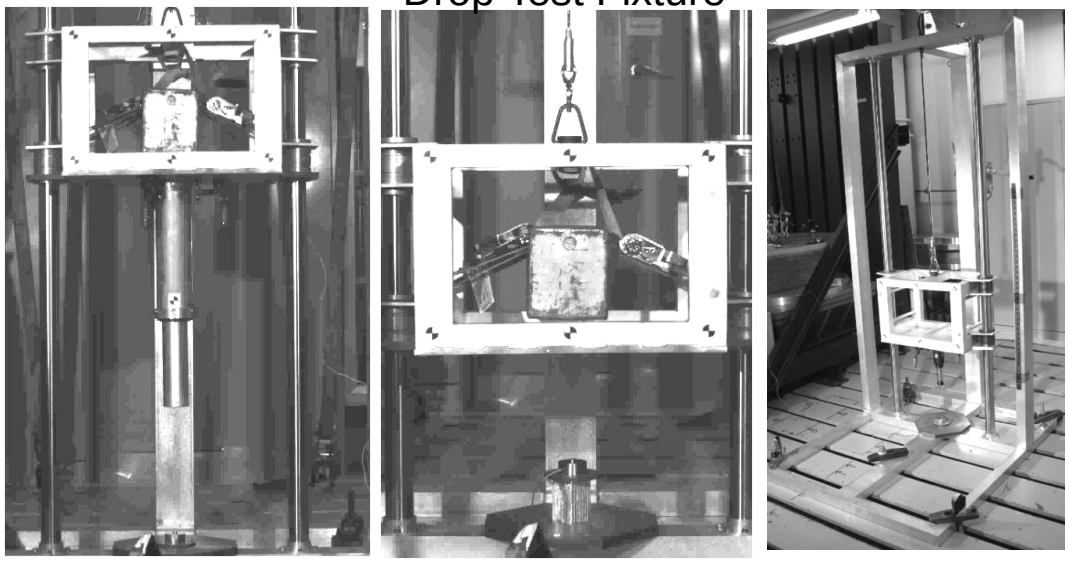
Dynamic Testing Results



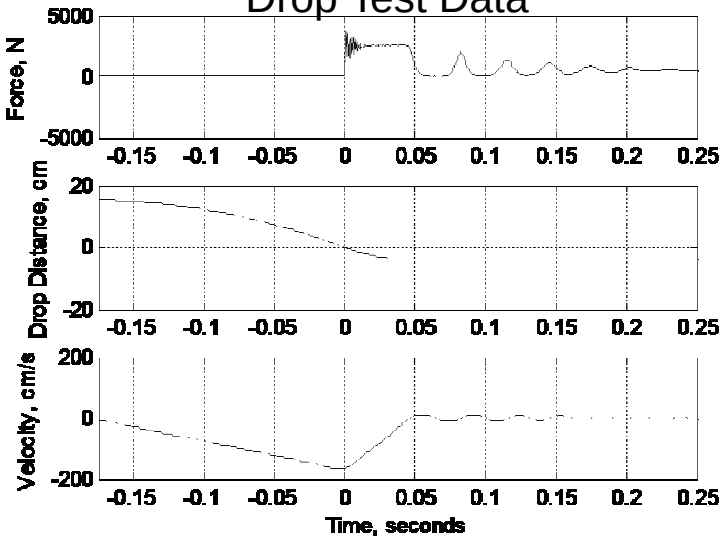
# Leg Component Drop Testing

- Construct test fixture for drop testing
  - Adjust drop mass and drop height
  - Measure force and acceleration
  - Record video and post-process
    - Position and velocity determination
- First crush honeycomb coupons
- Construct primary leg simulator and crush honeycomb inside
- Test WGTA damper performance

Drop Test Fixture



Drop Test Data



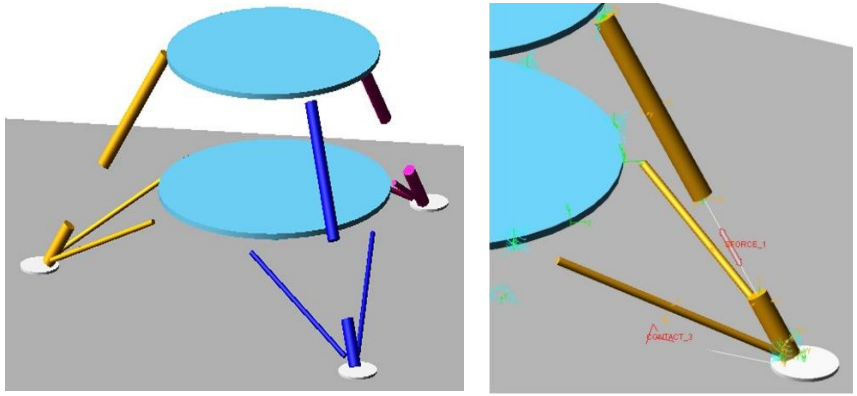

Honeycomb Drop Test Results Summary

| | **Predicted** | **Measured** |
|---|---|---|
| Impact Velocity (m/sec) | 1.74 | 1.67 |
| Crush force (kN) | 2.3 | 2.6 |
| Stopping distance (cm) | 4.12 | 3.88 |

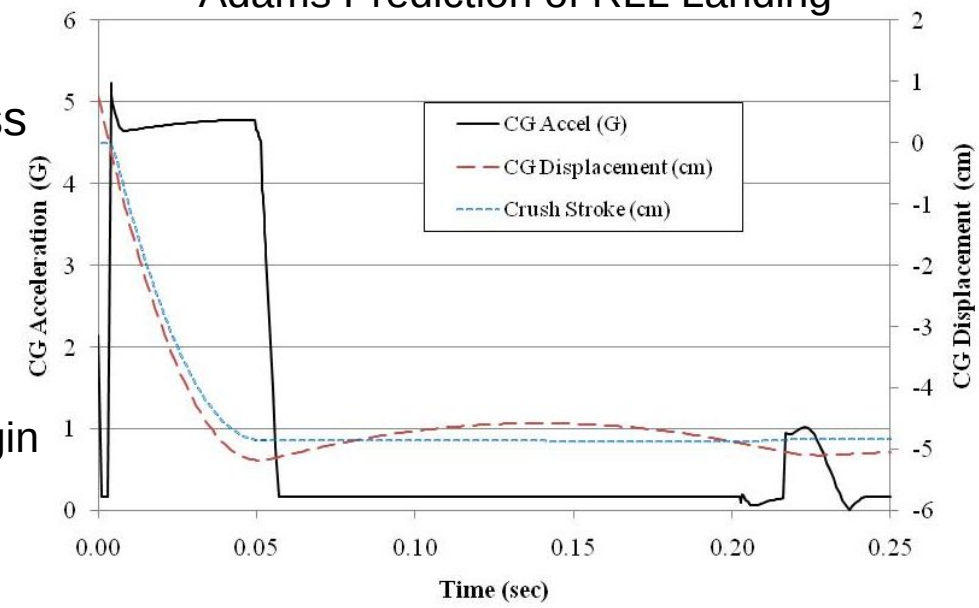
# Dynamic Modeling and Simulation

- Model RLL and WGTA landers in Adams
  - Rigid decks with lander mass located at CM
  - Rigid bars with appropriate end conditions
  - Contact function controls interaction of each footpad with surface
  - Force velocity function inserted along primary leg to simulate energy absorption
    - Based on drop test data
- Extract leg loads for component stress analysis
- Expand landing analysis to include landing stability
  - Size landing footprint for stability margin

Adams RLL Model



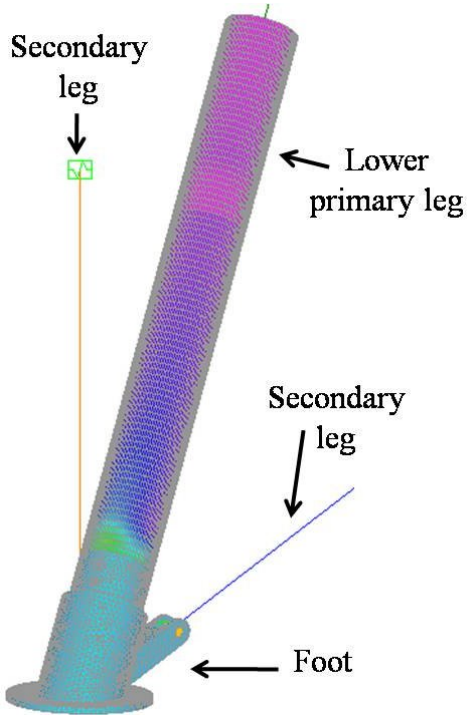
Adams Prediction of RLL Landing



# Leg Stress Analysis

- Extract leg forces from Adams model
- Perform detailed component stress analysis
  - Nastran & FEMAP FEM
  - Analyze members, joints, and attachment loads
- Target components with high margins for mass reduction

Leg Assembly FEM




RLL Leg Component Load Table

| Case # | Landing angle (deg) | Rotation about | Ground impact load (kN) | Primary joint (kN) | Secondary strut #1 (kN) | Secondary strut #2 (kN) | Beam moment (N-m) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | — | 11.9 | 22.4 | 7.5 | 7.5 | 4 |
| 2 | 10 | +Y, Side | 12.3 | 22.4 | 10.1 | 4.6 | 4 |
| 3 | 10 | -X, Out | 13.5 | 22.3 | 5.7 | 6.4 | 4 |
| 4 | 10 each | X & Y | 11.3 | 22.4 | 11.3 | 5.8 | 3 |
| Max-Max | | | 13.5 | 22.4 | 11.3 | 7.5 | 4 |

Foot FEM

# Future Work

- Test leg assembly and correlate analysis models
  - Fabricate EM leg assembly
  - Modify drop test fixture for leg testing
- Fabricate WGTA leg assemblies
  - Improve mass efficiency
- Improve analysis models
  - Combine kinematic and FE models
  - Improve ground contact representation
- Continue to refine leg designs for current and future RLL concepts
- Apply leg designs to other mission concepts

Leg Assembly Drop Test Fixture