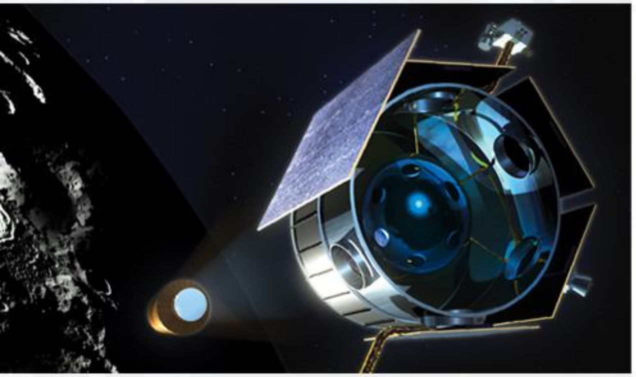
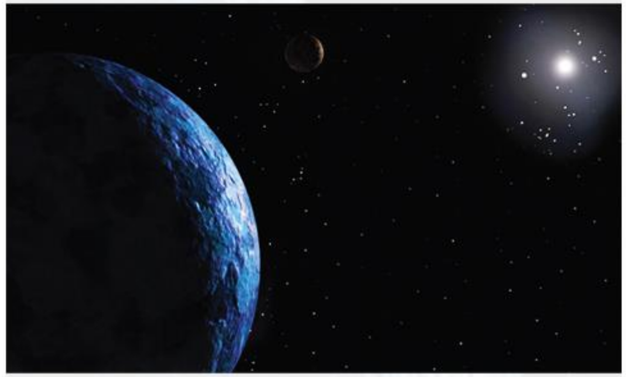




Moog Capabilities for CubeSat Launch and Deployment

14th Annual CubeSat Developer's Workshop

Joe Maly, Marissa Stender, Chris Loghry

27 April 2017

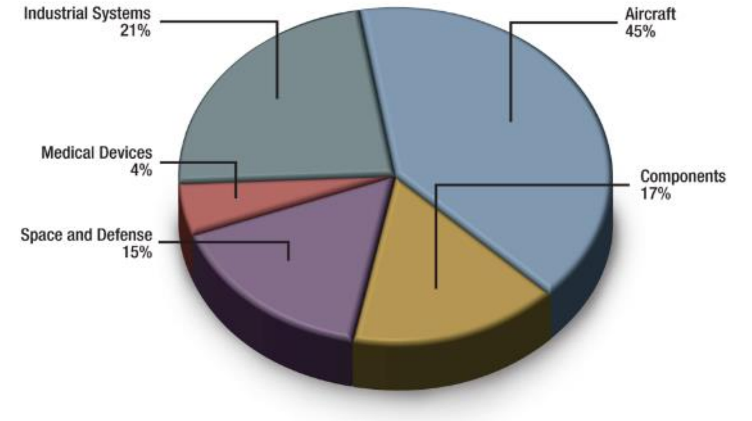
MOOG
SPACE AND DEFENSE GROUP

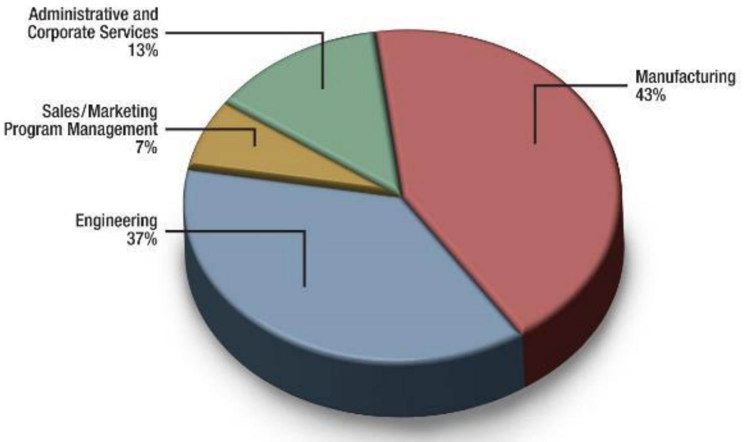
Presentation Overview

- Moog background
  - Moog Space Access and Integrated Systems
- Moog is a flexible partner and can work at any level of a mission
  - Components through launch infrastructure and integration
  - Mission conceptualization through advanced systems
- Moog works in several areas of the CubeSat market
  - Propulsive Multi Payload Carriers (SL-OMV)
  - Multi Payload Carriers (ESPA, ESPA Grande)
    - New ESPA class capability following Delta Qualification test program
  - Launch Environment Mitigation (ShockWave, SoftRide)

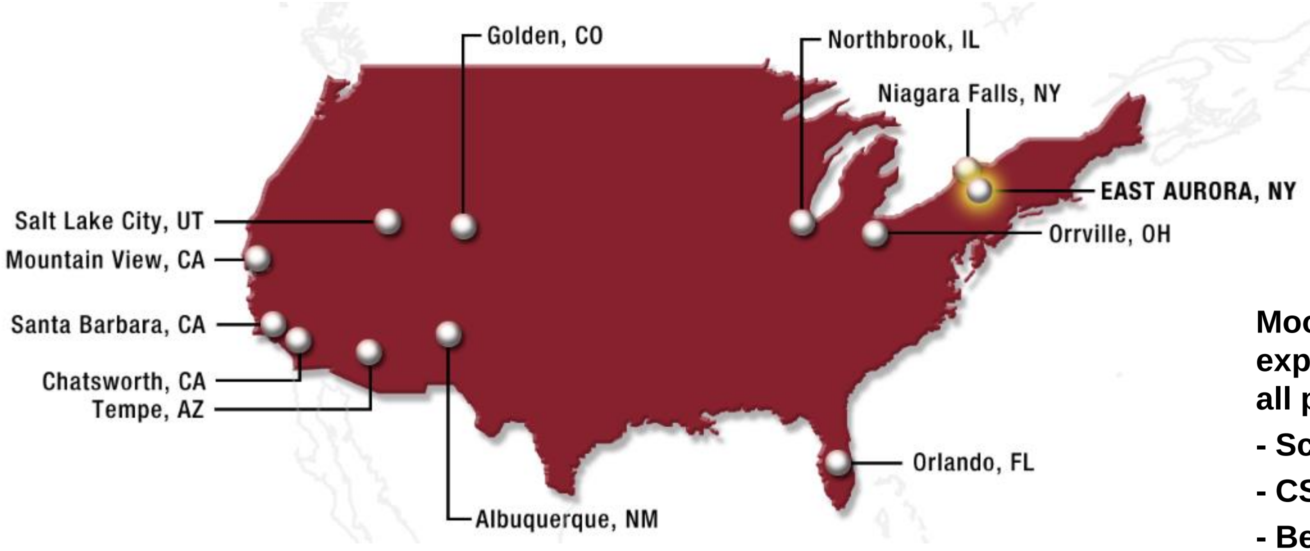
Company Background

- **Founded in 1951 by Bill Moog**
- **Headquarters in East Aurora, NY**
  - Over 300 Acre Facility
- **Global Company**
  - 25 Countries
- **~11,000 Employees Worldwide**
- **$2.41 Billion in Revenue** (FY 2016)
- **Aerospace, Defense, Industrial**
- **Precision Control Systems Solutions and Component Provider**





Moog Space and Defense Group Information



Moog Space leverages the unique experience from acquisitions to include all perspectives in the Space market

- Schaeffer Magnetics

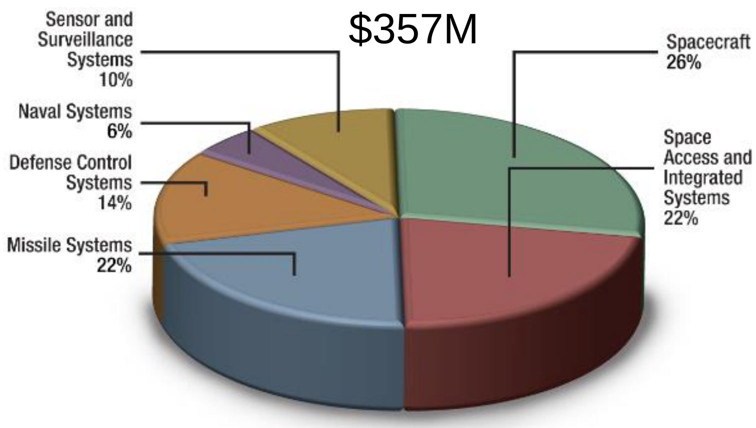
- CSA Engineering

- Bell/ARC/AMPAC In-Space Propulsion

- Broad Reach Engineering

2016 Sales

$357M



MOOG SPACE AND DEFENSE GROUP

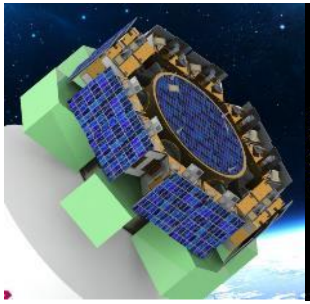
Solutions for Every Stage of a Space Mission

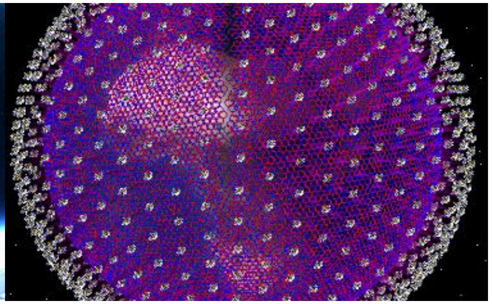
MOOG SPACE AND DEFENSE GROUP

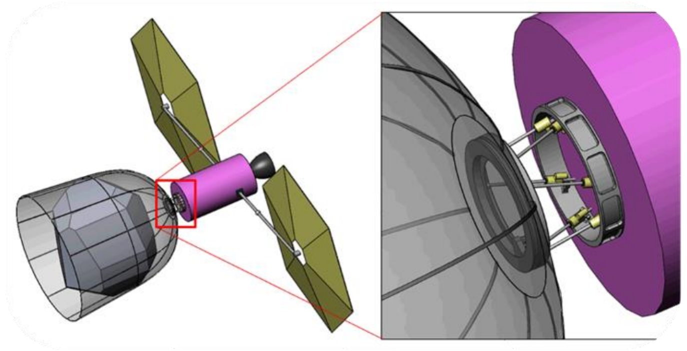
Moog Space Access & Integrated Systems

OMV work is mainly supported by Moog personnel in Golden, CO, Mountain View, CA and Chatsworth, CA

- **Moog Integrated Systems provides a focal point to harness the breadth and depth of Moog capability**
  - Mission architecture/design
  - Launch strategy
  - Spacecraft systems engineering
- **Moog works with customers at the initial stages to identify and optimize technical, cost, risk and programmatic trades**
- **Moog has supported trades and developed concepts for:**
  - Commercial GPS-RO Weather constellation
  - Commercial Broadband Satellite Mega Constellation
  - NASA Asteroid Return Mission
  - Non-traditional Mars Mission
- **Numerous mission concepts based on Orbital Maneuvering Vehicle (OMV)**







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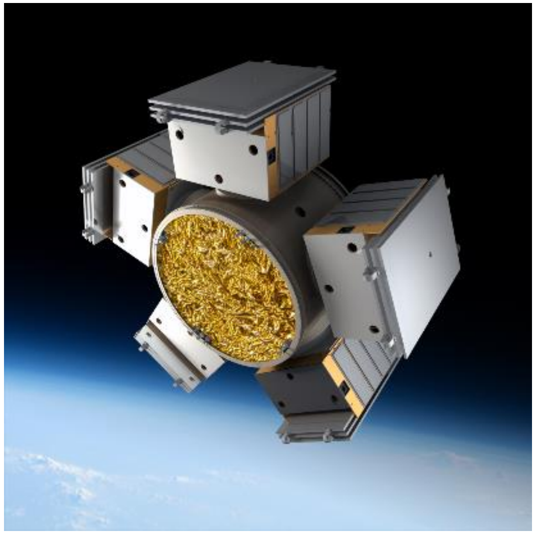
COMET – Commercial ESPA Tug

- An OMV to meet the needs of rideshare passengers and constellations by performing the role of a “tug” to drop-off payloads in their ideal orbits
  - The small, fixed solar array allows the OMV to perform multiple burns, phasing maneuvers, RAAN adjustments and/or delivery to BEO (eg. Lagrange point orbits) with a single configuration
- Key Specifications
  - Vehicle mass 406 kg, Propellant mass 153 kg
  - Monoprop hydrazine
    - 4 x 22N DeltaV thrusters, Isp = 233 s
    - 6 x 5N ACS thrusters
  - 4-, 5-, or 6-port ESPA ring, 42" tall, 62" diameter
  - Up to 1500 kg of Port-mounted Payload
  - Altitude: 350 km to 1200 km
  - Inclination: 45 degrees to Sun-synchronous (varies with altitude: 96.85° to 100.42°)

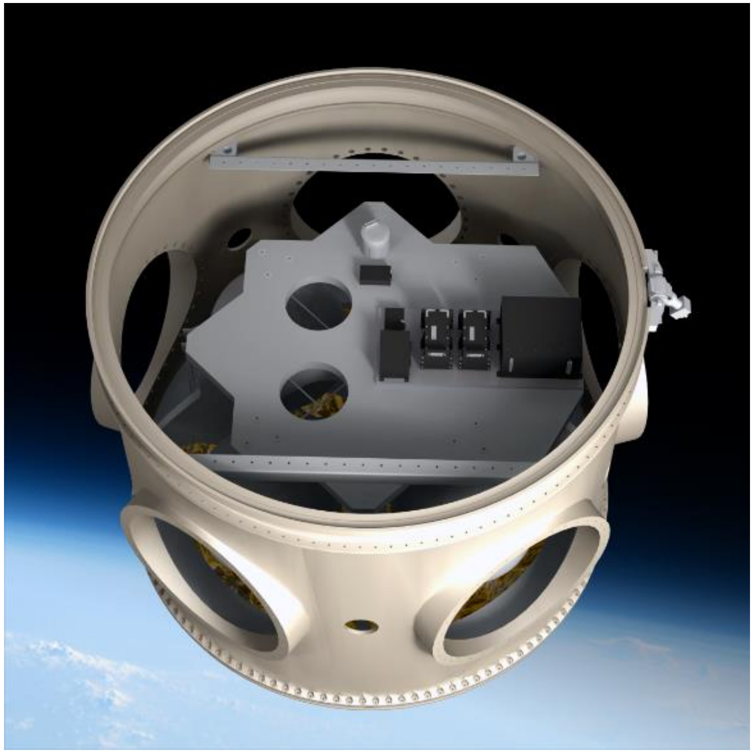


- Baseline Mission Class: Hybrid C/D
- Commercial Variant targeting sub-$10M price point
- Target Beginning of Hardware Procurement: June 2017
- Flight Readiness: Early 2019

COMET – Commercial ESPA Tug

Launch Configuration with 5 x 300 kg Small Spacecraft

Platform Only
(Solar Array Removed)



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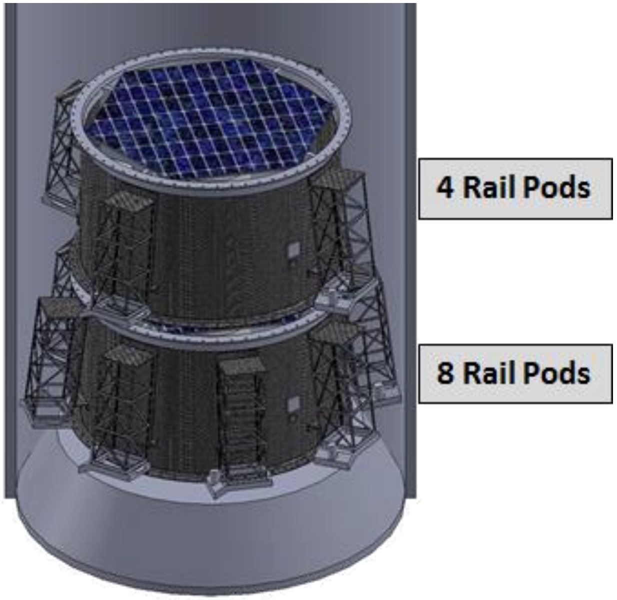
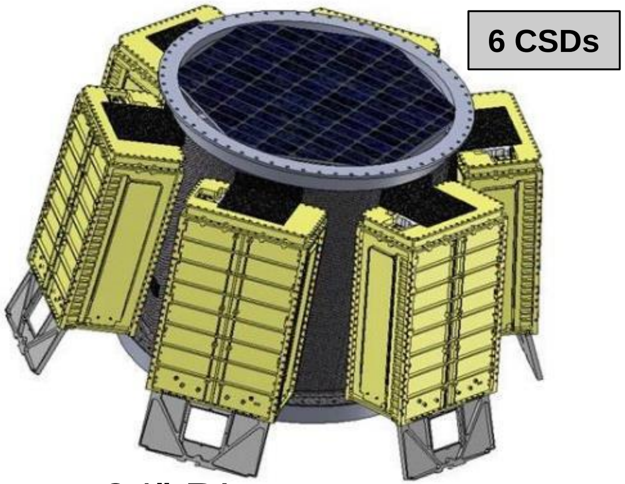
Leveraging Low Cost Launch for Resilient Constellations

Small Launch OMV (SL-OMV)

- Adapter designed for "light" primary payload (<300 kg) and smaller diameter LV fairing
  - 24" to 38.81" Bolt Circle interface, 20" Height
- Minimal mass and maximum payload capacity
  - Composite cylinder adapter
  - Compatible with multiple CubeSat dispensers
    - Tyvak RailPOD (shown)
    - FANTM-RAIL
    - Teton Aerospace dispenser
    - Planetary Systems CSD (shown)
- ΔV >125 m/s fully loaded (e.g. 16 x 3U)
  - Vehicle Wet Mass: ~70 kg
  - With 16 x 3U or 6 x 6U = 150 kg
- Modularity
  - Flexible adapter diameter and height
  - Customizable quantity of dispensers



38.8" Diameter



24" Diameter

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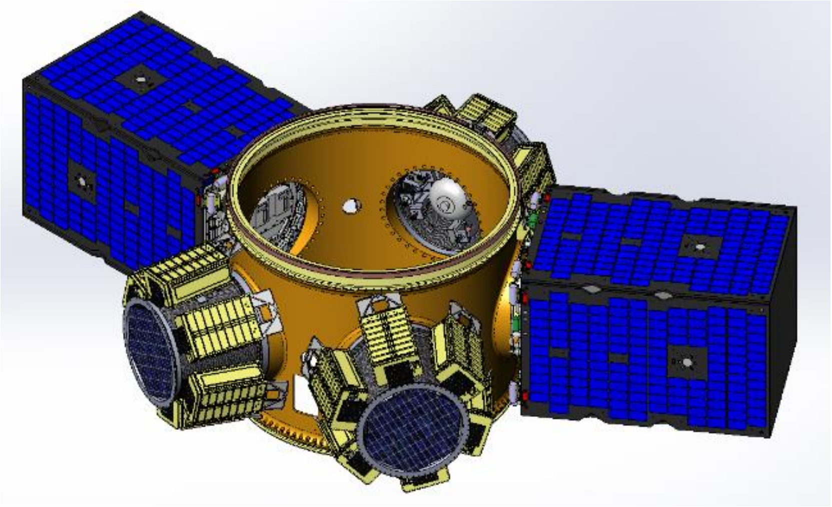
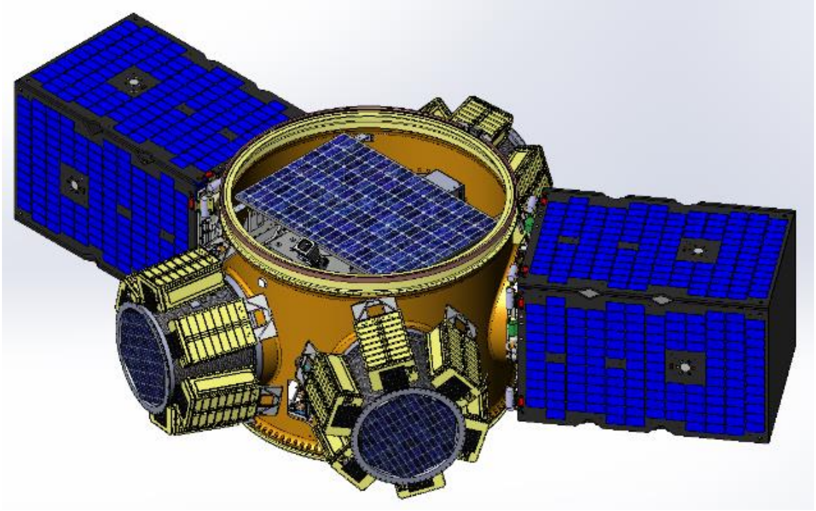
OMV Family Flexibility

- The OMV, SL-OMV, and ESPA can be used in conjunction
- SL-OMV can be a "payload" on an ESPA Grande port
  - Can be used for LEO and potentially direct inject to MEO/GEO launches
  - Can be part of "Freight Train to Space"



- SL-OMV can be a "payload" on an OMV
  - OMV can be used for large transfers
  - SL-OMV can be used to deploy payloads
  - Strong resiliency options using "nested propulsive adapters"



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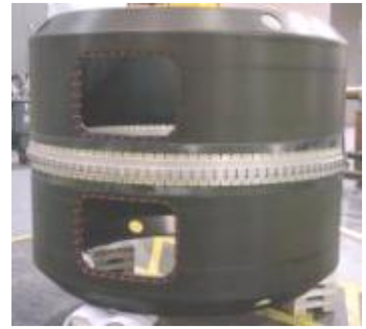
Moog Multi-Payload Carriers

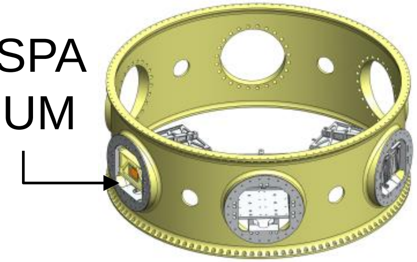
ESPA

Flat Plate Adapters



CASPAR

ESPA SUM

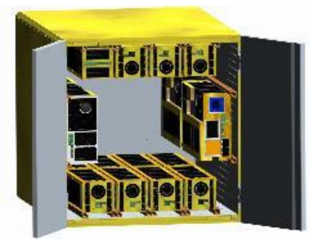


CubeStack Wafer

ESPA 6-15-24 LCROSS

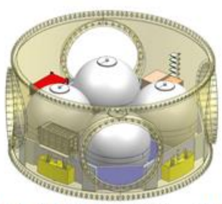
SL ESPA 15

SL ESPA 24

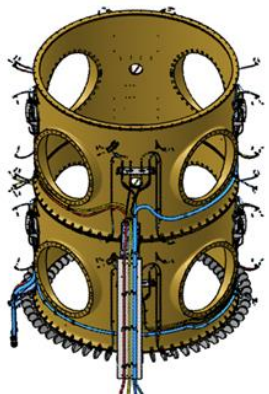


FANTM-RiDE

ESPA 4-15-24 DSX



ESPA 4-24-32 SPECIAL OMEGA



2x ESPA 4-24-42 ORBCOMM

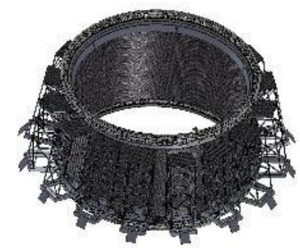
ESPA 2-15-24-4PT EAGLE

ESPA 5-24-42 SHERPA

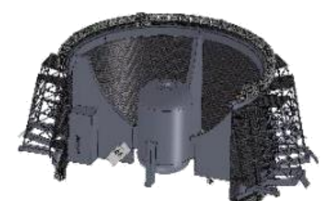
ESPA n-d-h

n=number of ports, d=port diameter (inches), h=ring height (inches)

OMV (Ø62")



Small Launch Adapter and SL-OMV (Ø38")



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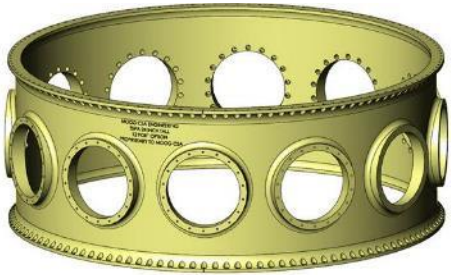
Modular ESPA Options

- ESPA diameter (bolt circle) range Φ31.5” to Φ120”
- ESPA ring heights to 42”
  - Minimum ESPA Grande height 32”
  - Special forgings available for rings up to 60”
  - Small Launch ESPA with 8” ports is 15” high
- Port configuration
  - Standard port diameters are Φ15”, Φ24”
  - Custom diameters driven by customer needs
  - 3- or 4-point mounts for discrete separation systems and hosted payloads
  - Mixed port designs are feasible
- Number of ports selected by customer
  - Maximum number limited by ring diameter
- Special features
  - Internal flanges
  - Mounting bosses
  - Custom access and mounting holes



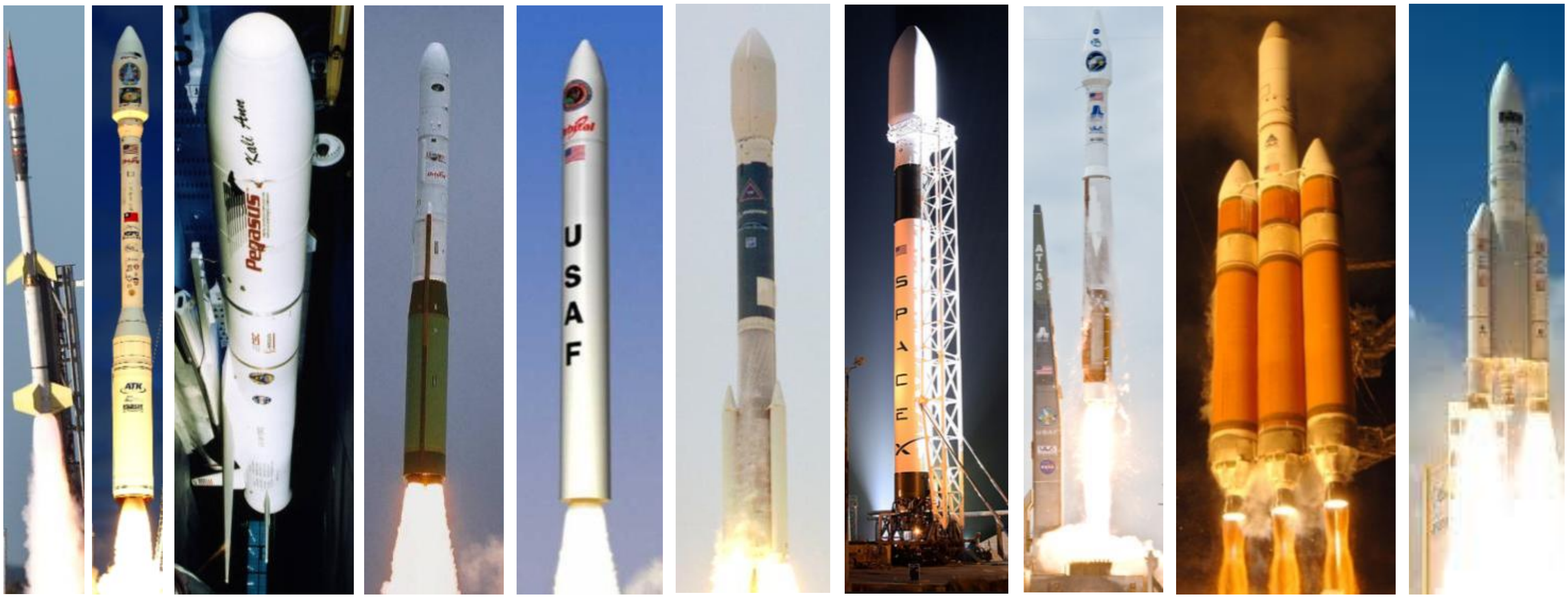
Re-Defining ESPA Class

- ESPA payload capability was established with qualification testing in 2002 using 10g/10g design load factors
  - Defined 400lb at 20” (181kg at 51cm) as “ESPA-Class” payload
- Following STP-1 lessons learned, ESPA port design was modified to facilitate integration
  - “Boss” port substantially increased strength and stiffness
    - Effectively built in a “no-test” factor of safety in ESPA structure
  - 5/16” fastener option further enhances capability
- Delta Qualification Program at AFRL September 2016 quantified ESPA port capacity with 8.5g/8.5g load factors
  - Delta-Qual ESPA test article had both 5/16” and 1/4” port fasteners
  - Satellite design, separation systems, isolation hardware capability are impacted by heavier cantilevered payloads

Delta Qualification Results

- Testing performed in September 2016
  - All load cases were executed with no evidence of yielding or other damage
  - Model correlation was demonstrated by comparing measured and predicted strains in high-stress regions near ports
- ESPA capability demonstrated for Heavy Payloads with 5/16” fasteners and Light Payloads with ¼” fasteners
  - Heavy APL 710 lb (320 kg) with CG at 20” (51 cm) from ESPA port
  - Light APL 485 lb (218 kg) with CG at 20” (51 cm)
  - PPL 17,000 lb (7711 kg) with CG at 120” (305 cm) above standard interface
- Similar testing will be performed on ESPA Grande in 2017

SoftRide Launch Vehicle Heritage



Terrier Imp. Orion	Taurus	Pegasus	Minotaur I, IV, V		Delta II	Falcon 1, 9, Heavy	Atlas V	Delta IV, IV Heavy	Ariane 5 ECA
2	6	6	7	2	4	5 (2)	2	5	1

SoftRide has flown 39 times on 13 launch vehicles

Extensive heritage for the world's only system that provides Whole Spacecraft Isolation

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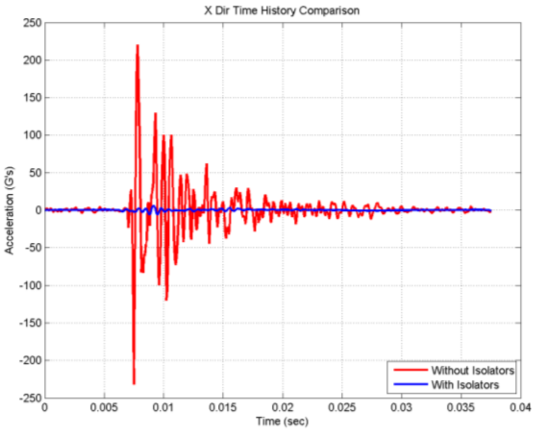
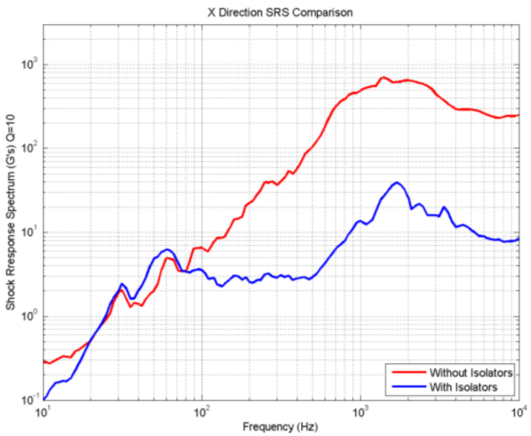
Vibration/Shock Isolation for CubeSat Launch

- Cyclic loading contributes significantly to CubeSat failures*
  - Random vibration and shock
  - Thermal loading
  - Pressure, vacuum, humidity cycling
  - Assembly cycles
- Vibration isolation (low-pass mechanical filter) greatly reduces payload accelerations
  - Moog CSA SoftRide has flown on 39 launches since 1998
- ShockWave (patent pending) for CubeSats introduced at Workshop 2016

** Methods to predict fatigue in CubeSat structures and mechanisms,* W. Holemans, Planetary Systems Corp., 12th Annual Summer CubeSat Developers' Workshop, August 2015

Acceleration responses with and without ShockWave in time and frequency domains





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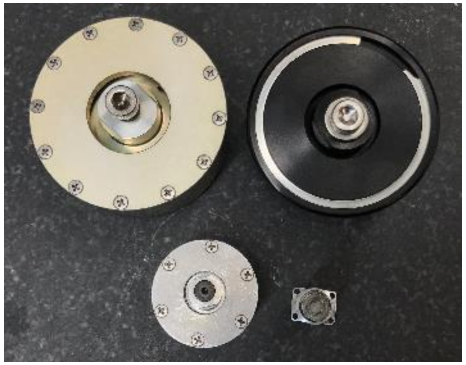
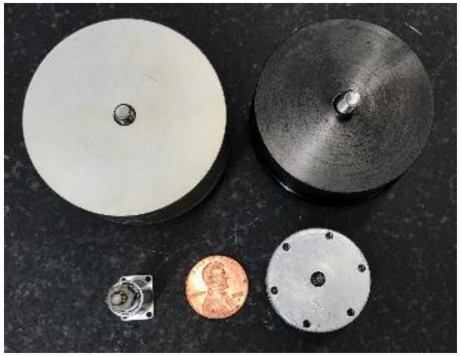
ShockWave Product Line

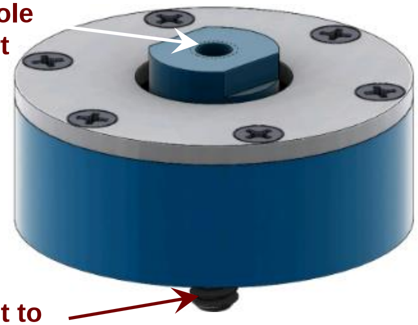
- First product in ShockWave family introduced 2016
- Features
  - Low-cost
  - Short lead times
  - Modularity
  - Easy integration
- Can be used for launch shock and/or on-orbit isolation
  - CubeSat dispensers
  - CubeSat payloads
    - Component isolation for jitter-sensitive applications, i.e., lasercom
  - Non-space industrial applications

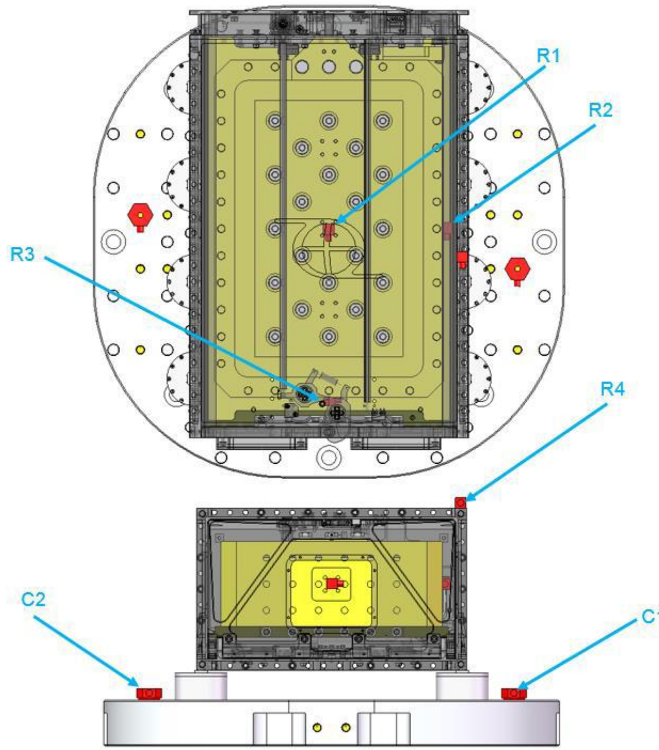


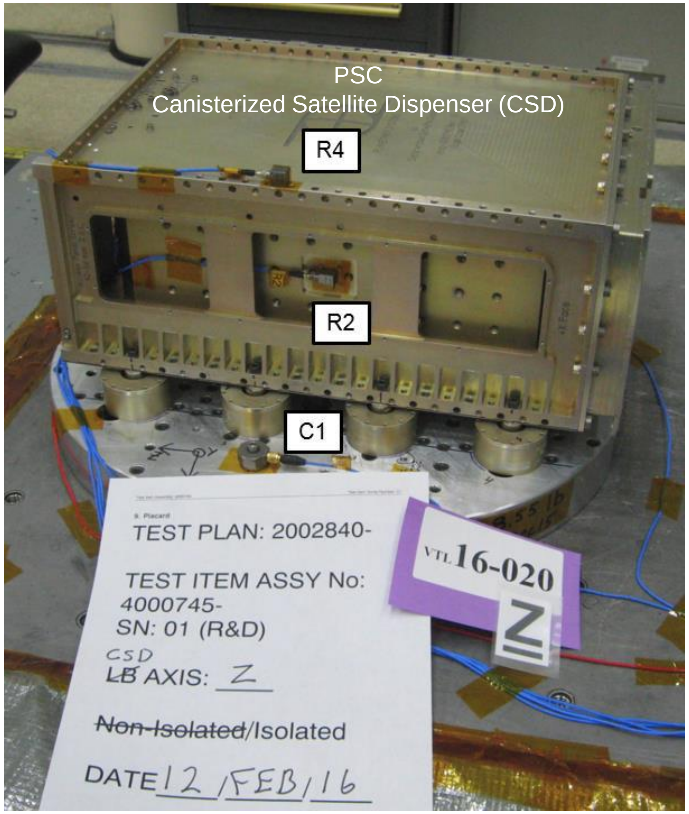


ShockWave Testing at Planetary Systems

- Testing performed during 6U CSD qualification program at PSC
- Dispenser mounted to vibration table with eight ShockWave isolators







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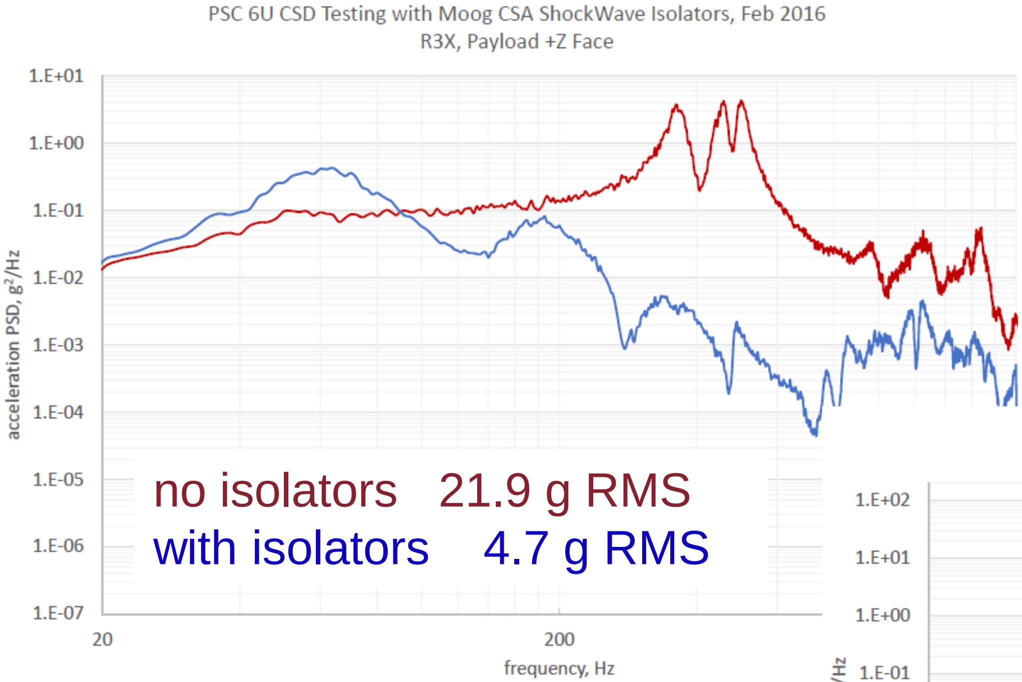
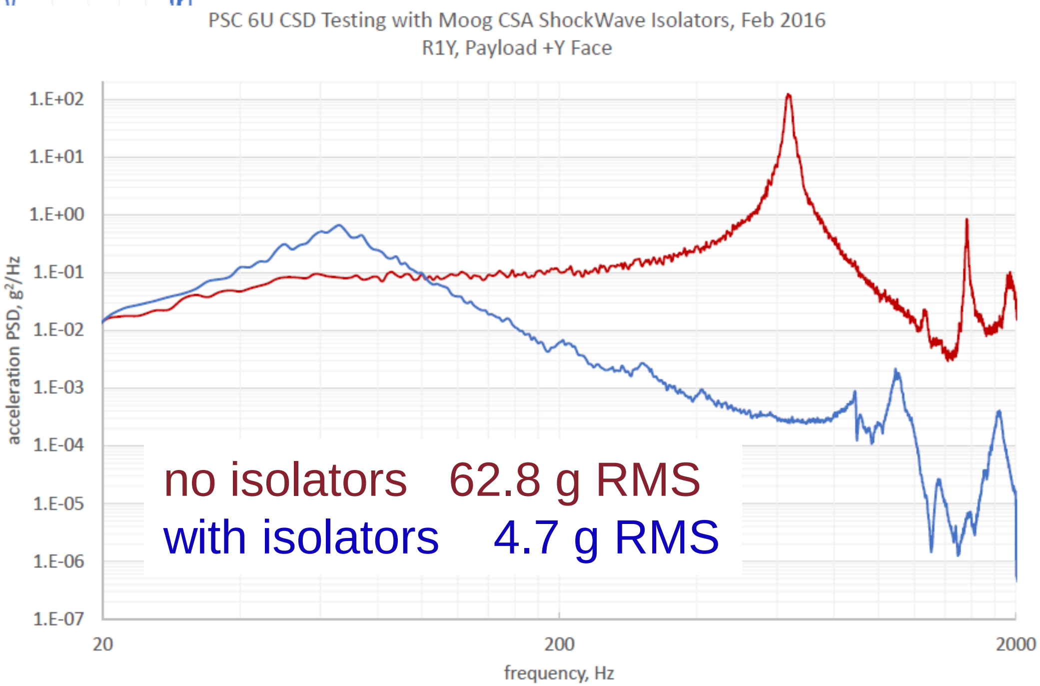
Measurements at PSC with/without ShockWave

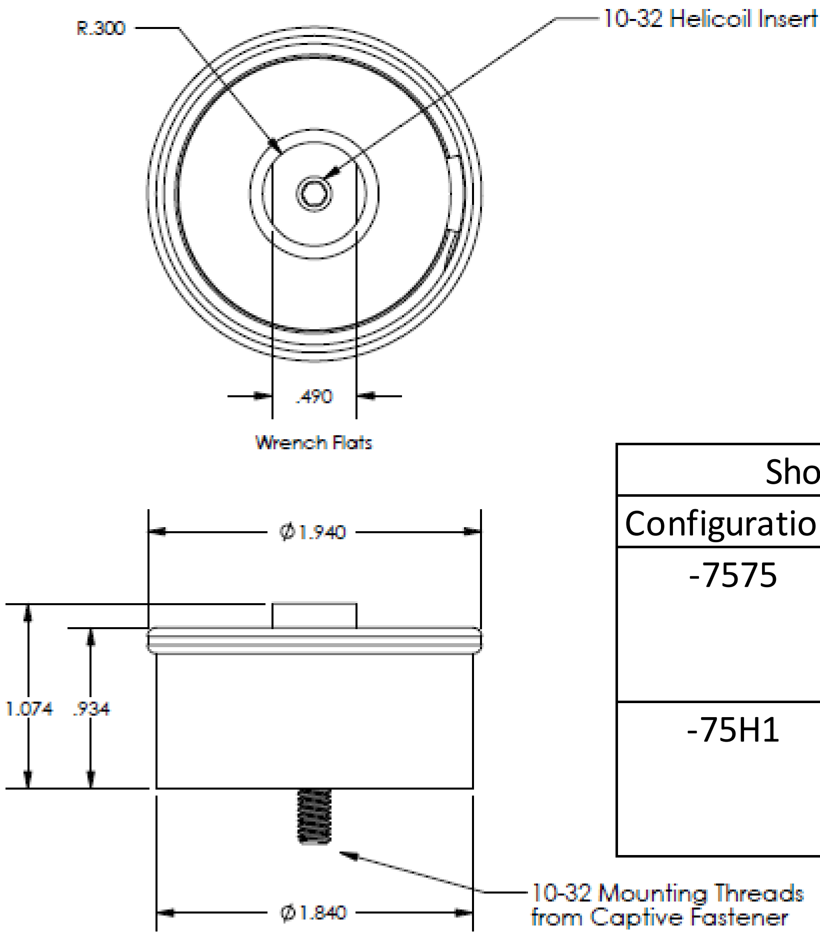




Isolators are cheap insurance against mission failure

ShockWave SW-150-1000-190 Specifications

ICDs available on request



1. ASSEMBLY MASS: 80 GRAMS
2. TYPICAL MOUNTING TORQUE: 38 IN-LBS
3. SURVIVAL TEMPERATURES: -60°C TO 80°C
4. MECHANICAL STROKE LIMITS:
    1. AXIAL: 0.10 in
    2. RADIAL: 0.08 in
5. MAXIMUM OPERATING LOADS:
    1. AXIAL: 200 lbs
    2. RADIAL: 200 lbs

ShockWave SW-150-1000-190 Nominal Stiffness				
Configuration		20 Hz	50 Hz	100 Hz
-7575	Axial (lbf/in)	10000	12500	15000
	Lateral (lbf/in)	6000	7500	9500
	Loss (% structural)	>30	>40	>40
-75H1	Axial (lbf/in)	2300	2700	3200
	Lateral (lbf/in)	4400	5800	7900
	Loss (% structural)	>40	>40	>40

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Summary

- Family of Propulsive Multi Payload Carriers (OMV)
  - Commercial ESPA Tug – COMET
  - Small Launch OMV – SLO-MV
- Multi Payload Carriers
  - ESPA increased payload capacity based on test
  - ESPA Grande (24-inch port) test in coming year
- Launch Vibration Isolation
  - SoftRide and ShockWave

Contact Info

Please contact us with any questions or potential applications you would like to discuss

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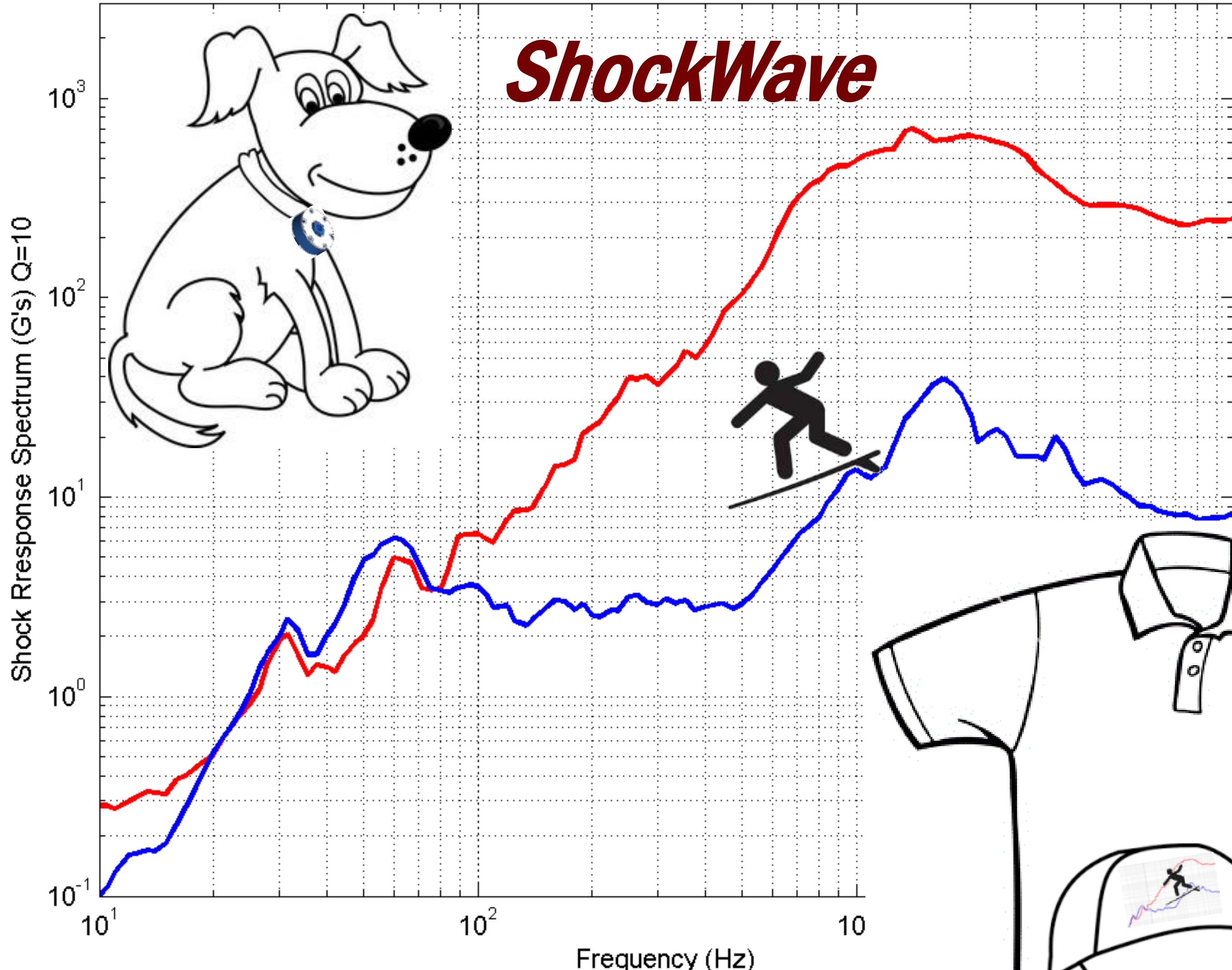
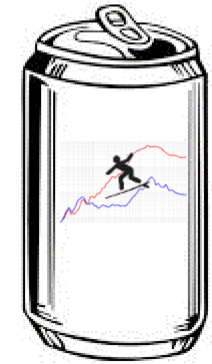
- Marissa Stender
  - mstender@moog.com
  - 720-557-3872
- Chris Loghry
  - cloghry@moog.com
  - 818-734-3445





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