CSA Engineering
Vibration Suppression – Precision Motion Control
A Moog Company

CSA’s Product Line for Simulating Zero-Gravity in Ground Testing of Space Structures

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The zero-g simulation problem

Accurate zero-g simulation for dynamic testing requires a suspension system that can support a test article in 1-g without significantly changing its free-free vibration modes.

Figures of merit for suspension devices:

1. Range of payload weights
2. Vertical stiffness
3. Static sag
4. Added moving mass
5. Friction
6. Added vibration modes

Minimizing characteristics 2-6 and Maximizing characteristic 1 is essential.

CSA’s suspension devices excel in all of these areas.
CSA’s product families for support-from-above zero-g suspension

<table>
<thead>
<tr>
<th>Family</th>
<th>Defining features</th>
</tr>
</thead>
</table>
| Dash-Zero | - Basic, cost-effective design  
- All pneumatic, no electronics                                                                                                                                                                                     |
| Dash-X  | - Integrated magnetic actuator  
- Integrated sensors  
- Added capabilities beyond zero-g suspension                                                                                                                                                                   |
| Dash-VC | - Vacuum compatible  
- Operable in thermal-vac chamber                                                                                                                                                                                   |
| WAGM    | - Large range of motion  
- For ground test of deployable structures                                                                                                                                                                     |

- Numerous sizes and variants have been built within each family  
- Features shown are not mutually exclusive, can be combined  
- Requests for custom designs are welcome
Operating principle

- All devices use regulated air spring based on frictionless piston (blue)
- Dash-X systems add parallel electromagnetic actuator and integrated sensors (red)
- Passive pneumatic system carries nominal payload weight
- Active electromagnetic system used for fine-trim of uplift and other advanced capabilities
- All systems use vertical carriage moving on frictionless air bearings
- Vacuum-compatible versions add a “bell jar” over the mechanism to recapture exhaust air
- Long-travel (WAGM) versions mount the suspension device on an X-Y carriage to follow the payload

Payload is supported from above, horizontal isolation is provided by simple pendulum action (WAGM excepted)
Features common to all families

All devices use a proprietary frictionless air piston spring

Dash-Zero cutaway shown

Typical vertical disp/force frequency response

- 0.04 Hz to 1 Hz
- 10 inches/lbf to 0.01 inches/lbf

20-lb payload
- Frequency response over a range of payloads

350-lb payload
- Frequency response over a range of payloads

Demonstrates very low suspension frequency necessary for zero-g simulation

Typical step-load friction test

- Payload = 67,700 grams
- Active stiffness = 1.5 lbf/inch
- Piston area = 6.15 in²
- External tank = 30 gal.

0.0025 inches
- Carriage displacement during friction test

1.1 gram weight removed here
- Demonstrates friction less than 0.002% of payload

Time - Seconds
0.0 4.0 8.0 12.0 16.0 20.0 24.0

Carriage displacement - inches
(Positive indicates downward carriage motion)
Examples of CSA zero-g suspension devices

Dash-X for very light loads, fully instrumented

Dash-Zero for 10 to 600-lb loads

Dash-Zero for 40 to 1200-lb loads

CSA has built about 120 such devices of at least 10 distinct designs over 20+ years, in most cases to customer specifications for particular applications.
Dash-X device details
(350-lb capacity, 6.0-inch stroke)

- Integral non-contact electromagnetic actuator and sensors (force, disp., acceleration, pressure)
- Controlled disturbance injection, fine-trim force control, cancelling of 80% of device moving mass
Hybrid system example

System of 14 mounts (8 Dash-XVC, 6 Dash-ZeroVC) for testing of 35,000-lb aerospace payload in vacuum

Dash-XVC
2500-lb capacity
(vacuum housings removed from units in foreground)

Dash-ZeroVC
5000-lb capacity

Suspension frequency and payload vs. piston pressure (Dash-X)
WAGM (Walking Anti-Gravity Machine) example

- Cable-pulley displacement multiplier and long-stroke Dash-Zero device give 72-inch vertical range
- Sensors on load cable detect payload horizontal motion through cable deviation from vertical
- X-Y stage supporting suspension device is slaved to cable angle sensors; Tracks the payload motion
- 50 x 76-inch horizontal range of motion, can be extended
- Mounted on mobile, telescoping stand for efficient setup

System in use for ground testing of spacecraft robotic arm

CAD model

Long-stroke Dash-Zero
### Primary specifications (per device)

<table>
<thead>
<tr>
<th></th>
<th>Dash-Zero</th>
<th>Dash-X</th>
<th>Dash-VC</th>
<th>WAGM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum payload, lbs</td>
<td>5800.</td>
<td>2900.</td>
<td>5000.</td>
<td>80.</td>
</tr>
<tr>
<td>Minimum payload, lbs</td>
<td>5.</td>
<td>5.</td>
<td>5.</td>
<td>3.</td>
</tr>
<tr>
<td>Minimum vertical stiffness, lbf/in</td>
<td>0.1 lbf/in per 100 lb of payload</td>
<td>0.1 lbf/in per 100 lb of payload</td>
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<td>0.1 lbf/in per 100 lb of payload</td>
</tr>
<tr>
<td>Minimum vertical frequency, Hz</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
</tr>
<tr>
<td>Minimum horizontal frequency, Hz</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Max. vertical range of motion, in.</td>
<td>18.0</td>
<td>6.0</td>
<td>2.0</td>
<td>72.</td>
</tr>
<tr>
<td>Horizontal range of motion, in.</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>72 x 50</td>
</tr>
<tr>
<td>Vertical friction, % of payload weight</td>
<td>&lt; 0.005</td>
<td>&lt; 0.005</td>
<td>&lt; 0.005</td>
<td>&lt; 0.005</td>
</tr>
<tr>
<td>Added moving mass, % of capacity</td>
<td>1.-3.</td>
<td>1.</td>
<td>1.</td>
<td>1.</td>
</tr>
</tbody>
</table>

These specifications are from existing examples. Requests for custom variants are welcome. Specifications in a column may apply to different members of a family.
Derivative support-from-below system for zero-g simulation of 7200-lb payload

- 3-device system built for AFRL
- Supports payload from below
- Used with space-based laser testbed
- 10” range of motion in 3 directions

Cutaway of suspension device
Derivative support-from-below systems

- Six telescoping struts use Dash-X technology
- Very low stiffness, frictionless air springs support payload, isolate from ambient vibration
- Integrated electromagnetic actuators provide 6-dof motion control
- Operates in vacuum
- Ideal for closed-loop beam control applications