



## LOW DISTURBANCE TECHNOLOGY

## SATELLITE IMAGING SOLUTIONS

Moog has been an industry-leader in designing and manufacturing satellite control solutions to meet the demanding requirements of the space environment for more than 60 years. Successful Earth imaging requires minimal jitter during the image taking process, yet any subsystem on-board these satellites can cause vibrations that result in sub-optimal performance. Moog's portfolio of low jitter mechanisms, damping and isolation solutions, and advanced spacecraft avionics ensure mission success.

Moog's space technology portfolio includes but is not limited to:

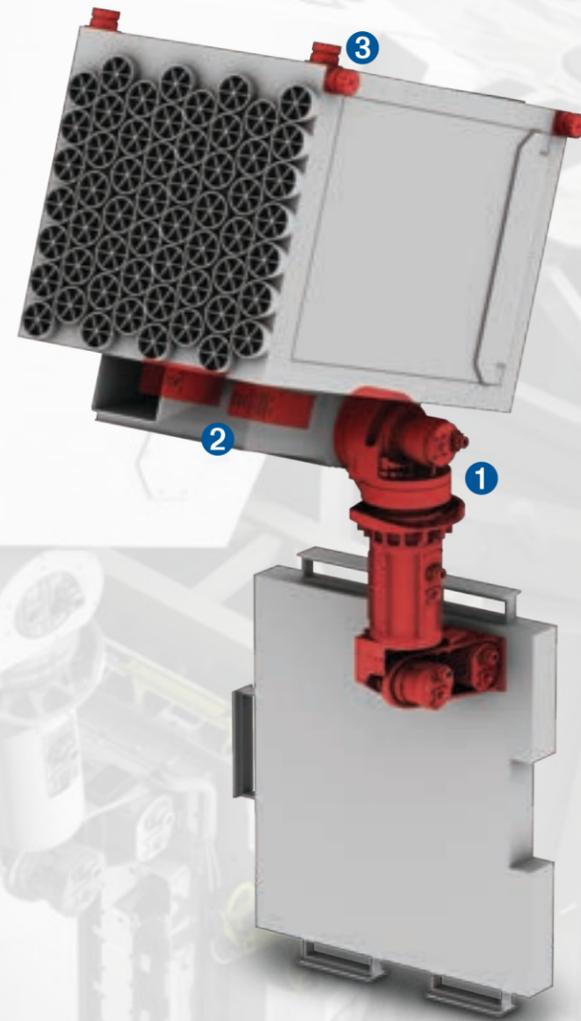
- Actuation
- Avionics
- Power
- Propulsion
- Shock and Vibration Isolation
- Spacecraft Mechanisms
- Structures
- Fluid Controls
- Environmental Control
- Life Support Systems

Moog Space facilities:

- Gilbert, Arizona
- Chatsworth, California
- Mountain View, California
- Arvada and Golden, Colorado
- Huntsville, Alabama
- East Aurora and Niagara Falls, New York
- Reading, United Kingdom
- Nieuw-Vennep, The Netherlands
- Hiratsuka, Japan

## MOOG LOW JITTER SOLUTION FOR NASA'S NICER

The Neutron star Interior Composition Explorer (NICER) mission on-board the International Space Station (ISS) provides high-precision measurements of neutron stars – objects containing ultra-dense matter at the threshold of collapse into black holes. This mission represents the first test of innovative in-space technology that relies on pulsars as navigation beacons, a technique that will eventually facilitate human exploration to the outer reaches of our solar system and the unexplored space beyond.



### 1 MECHANISMS

Moog designed and manufactured a customized stepper motor, which is the primary movement mechanism of the NICER deployment and positioning system's rotary actuators. The low inertia and low cogging motor within these mechanisms allow for significant jitter reduction.

### 2 AVIONICS

The actuators are driven by Moog micro-stepping drive electronics on the International Space Station (ISS). Employing smooth driver electronic techniques, such as micro-stepping and servo control decreases unwanted disturbances and jitter.

### 3 STRUCTURES, SHOCK AND VIBRATION CONTROL

Moog technologies are critical for jitter mitigation. By designing smart structures, adding damping, and/or isolation solutions, Moog is able to support mission critical imaging/observation objectives. Implementing active or passive vibration control solutions, such as dampers and isolators, is a low impact (mass and size) augmentation to spacecraft architectures.



## PORTFOLIO OF LOW JITTER MECHANISMS

Moog mechanisms for spacecraft motion control have a pedigree of design and flight heritage spanning more than 5 decades. With origins in historic programs such as Apollo and Pioneer and extending to present-day satellite programs, Moog is a leading provider of heritage-based solutions to spacecraft mechanisms technology. The spacecraft mechanisms facility in Chatsworth, CA offers fully-integrated engineering, design, manufacturing and test capabilities. Moog spacecraft products are adaptable and designed for flexibility to meet our customers' requirements on a wide array of applications ranging from commercial to government flight programs.

### OPTICAL BEAM CONTROL FAST STEERING MIRROR

The future of telecommunications is largely dependent upon the development of free-space inter-satellite laser communication. The expansion of this technology hinges on the development of a reliable method of directing a laser beam from one satellite to another, which requires extremely high pointing accuracy, low power, and sufficient bandwidth to counteract satellite disturbances. Moog's fine pointing mechanism is a miniature electromagnetic tip/tilt mechanism that is more efficient and reliable than voice-coil actuated devices. It is capable of greater travel than piezoelectric-actuated devices.



### ORBITAL POINTING SERVO

The Orbital Pointing Servo (OPS) is a miniature pan/tilt mechanism designed to point a small payload/sensor anywhere within a +/-45 degree range in any direction. Unlike other pan/tilt designs which use the principle of motion-on-motion to achieve two degrees of freedom, the OPS has only one moving part mounted on a true gimbal and driven by a single two-dimensional motor. This results in a smaller and lighter device that exhibits low jitter performance in a highly efficient package.



### LOW INERTIA HIGH DAMPING STEPPER DRIVEN IN CARDINAL STEPPING

Moog designed and manufactured a small inertia stepper motor as the prime driver of the rotary actuator. This actuator uses a tandem high gear transmission ratio and high damping system resulting in low-noise operation and fine resolution and was initially developed as the coarse pointing device on the LADEE Instrument for laser communication between lunar orbit and Earth. This Actuator has since become a standard product for applications requiring smooth operation (low jitter) and fine resolution pointing.



### LOW COGGING STEPPER DRIVEN IN MICRO-STEPPING

This unique stepper motor with a very low cogging (detent) torque is a perfect fit for micro-stepping applications requiring low jitter operations. It has flight heritage going back to the early 2000s. The actuators built around this unique motor topology are in production for JPSS-2, to be driven by micro-stepping drive electronics, as well as for use in another classified Earth imaging payload application.



### DIRECT DRIVE LOW COGGING BRUSHLESS MOTORS

Moog has also designed and manufactured direct drive brushless DC motors for imaging payload systems. It is currently in use on the LASP TSIS instrument pointing system on the ISS.



### IRONLESS ZERO-COGGING BRUSHLESS MOTORS

Moog has a portfolio of products that includes direct drive ironless brushless DC motors for optical payload systems complete with servo-control electronics. The flight heritage of these units include the ILAS, SOFIS and TES programs.



## PORTFOLIO OF DAMPING AND ISOLATION SOLUTIONS

All active mechanisms within a spacecraft produce vibration excitation. The two greatest sources of jitter are momentum wheels and cryocoolers. Moog is an industry-leader in designing, manufacturing, and integrating isolation and damping mechanisms into spacecraft and launch vehicles. Moog's first jitter mitigation device was installed during STS-109 on the Hubble Space Telescope (HST). The new rigid solar arrays on board the HST required damping at the interface to the spacecraft. Those products are still performing as well today and the first day they were installed.

Since then, Moog has provided reaction wheel isolators, root dampers, cryocooler isolators, payload isolators, and other jitter reduction technologies on dozens of missions. Moog also offers ground-based 6-DOF jitter simulators and testing to replicate operational environments. Moog designs, assembles, and validates all isolation and damper systems internally.

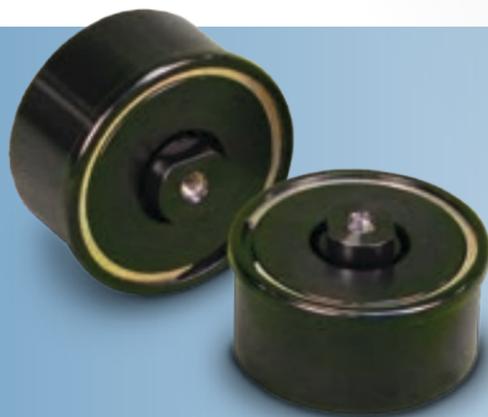
### REACTION WHEEL ISOLATORS

The greatest source of jitter in any imaging spacecraft comes from the momentum wheels and reaction wheels. Typically, isolating at the jitter source is ideal. Moog offers a range of momentum wheel isolators that cater to the breadth of wheel designs in the industry. Most missions are unique and have unique dynamically-coupled responses. Moog specializes in developing custom solutions for unique missions. Momentum wheel isolators can be designed to survive launch loads without the use of launch locks. Or, if mission critical, simplified launch locks can be integrated into a vibration isolation package.



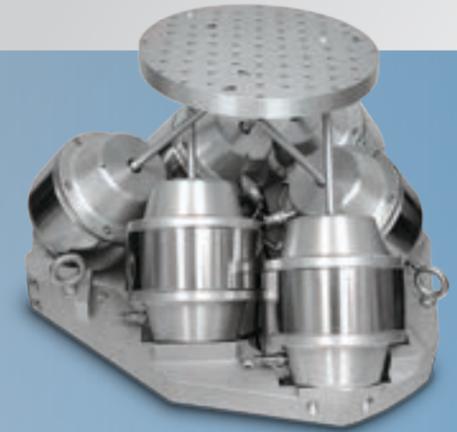
### TUNED MASS DAMPERS (TMD)

When the imaging platform response is tonal in nature (single frequency), integrating a TMD into the system is the most mass efficient way to reduce unwanted response dynamics. TMDs dissipate vibration energy by adding to the structure a damped mode that couples with the target structure resonance. An idealized TMD with a moving mass of 1% of the modal mass can add 5% critical damping to the target mode. TMDs can be designed for both low disturbance energy (jitter) or high energy (launch).



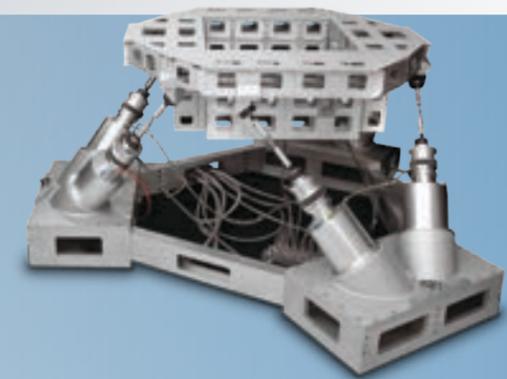
### ACTIVE DAMPING AND CANCELLATION

Moog provides active damping and/or cancellation technologies. Coupling a control loop to a voice coil actuator and amplifier can deliver broadband damping for a given system. This targets multiple response modes. The actuator can be placed at the disturbance source, thus cancelling out the unwanted excitation. Active control of Reaction Mass Actuators (RMAs) increases performance compared to traditional passive solutions.



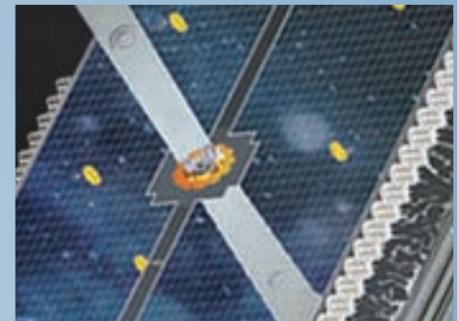
### JITTER SIMULATORS

Test-as-you-fly is critical to most spacecraft. Installing and operating your jitter source earlier in validation testing of the payload may not be programmatically efficient. Moog offers a variety of jitter simulators that deliver arbitrary six DOF disturbances that can replicate momentum wheels and cryocoolers. The jitter simulators enable validation of jitter compensators, such as fast steering mirrors and offer real world simulation for optical tracking algorithms.



### SOLAR ARRAY DRIVE ASSEMBLIES (SADA) / GIMBAL DAMPERS

Slewing of deployed mechanisms, such as solar arrays and high gain antennas, produces jitter. In the case of the Hubble telescope, the transition between sun exposure and earth shadow causes snap in the solar arrays resulting in jitter during long exposure windows. Placing a root damper between the array and spacecraft absorbs the energy from the thermal snap and eliminates jitter during long exposure.



### TEST SERVICES

Ground-based verification of microvibration environments for components susceptible to jitter is critical to mission success. Moog's microvibration test facility that mechanically, acoustically, and thermally isolates the test article from surrounding environments. Moog offers a series of single DOF and multi DOF gravity offloading devices for true inertial space measurements.



## PORTFOLIO OF AVIONIC SOLUTIONS

Moog is a proven-provider of high-performance and reliable space-rated avionics hardware and software. Core products include solutions for control and data handling, payload interface cards and mass memory, GPS receivers, motor and actuation drivers and controllers, and on-board computing. Moog offers both off the shelf and custom avionics software solutions to meet the needs of its customer. Many designs are radiation-hardened for extreme environments.

### GIMBAL CONTROL ELECTRONICS (GCE)

The Moog GCE is a block redundant system that contains different board types. The controller board is responsible for host communication, the motor driver board drives the motors, and the DCDC board regulates the internal power bus supplies. These motor drive outputs control and drive small, three-phase Wye, six state, and permanent magnet actuators. Each motor drive circuit is equipped with a current sense resistor and circuit to provide current control on each of the motor drives allowing the user to select from 16 different torque current levels. The GCE communicates with the spacecraft using MIL-STD-1553 data bus or RS422. Moog offers multiple configurations of the GCE with successful flight heritage. All can be uniquely customized for specific mission needs.



### NINE CHANNEL SERVO MOTOR DRIVER ASSEMBLY

Configurable servo motor driver provides control for 2 or 3-phase servo motors up to a 10A maximum servo drive. The control algorithm is performed within the FPGA using a BRE SNAP micro-controller with programmable control algorithm parameters.



# MOOG

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