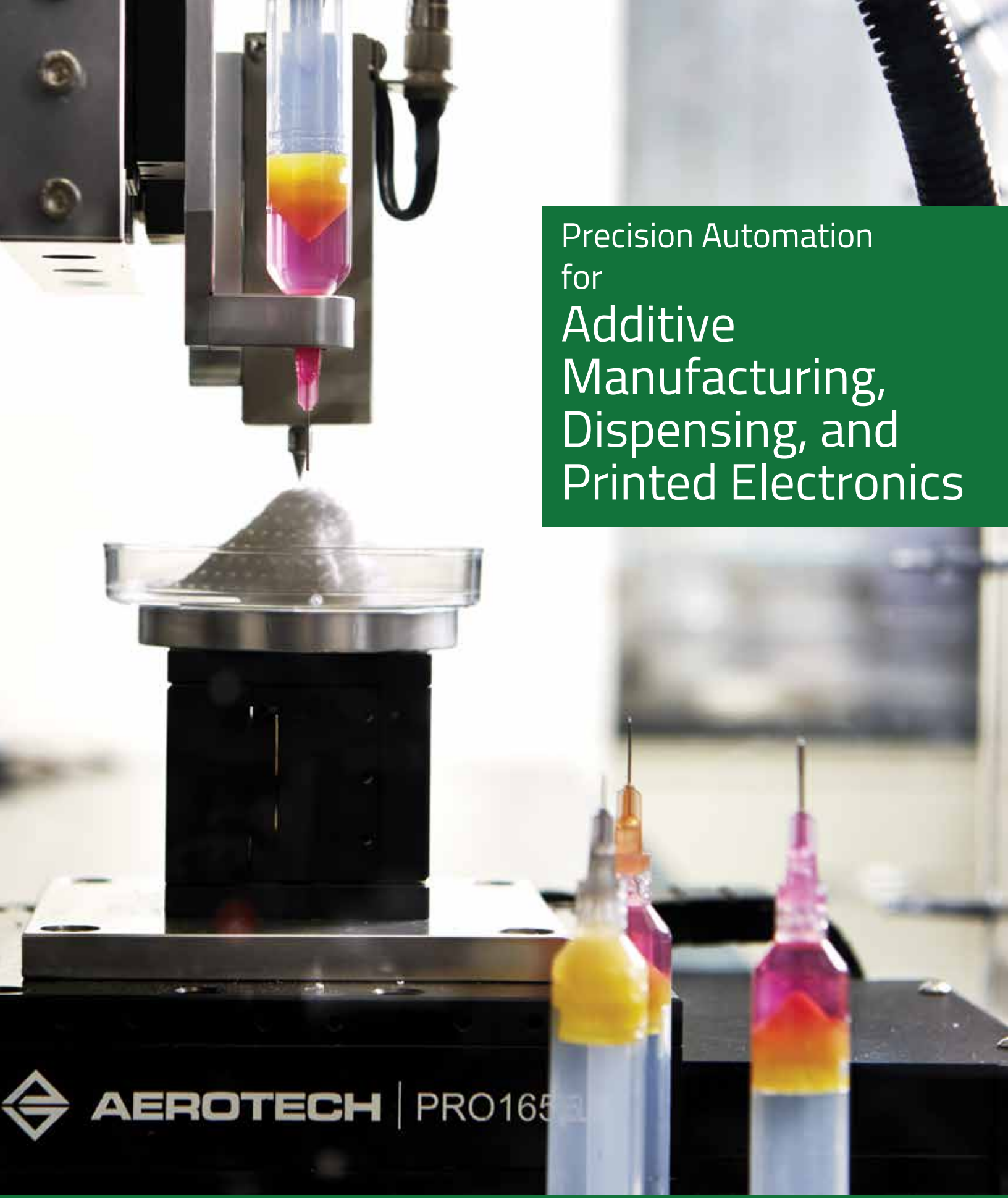


Precision Automation
for
Additive Manufacturing, Dispensing, and Printed Electronics

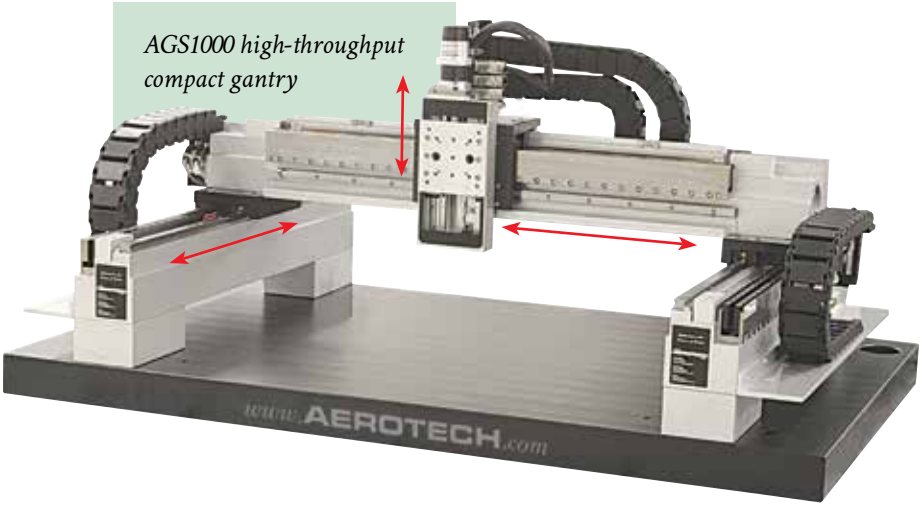
Aerotech Overview

Aerotech provides the precision motion necessary for the advancement of additive manufacturing processes, and we've been at the forefront of high-precision motion control for over 40 years. Material extrusion processes are optimized by using Aerotech's high-throughput gantries and component-level solutions, while printed electronics and dispensing applications benefit from advanced multi-degree of freedom control and mechanics. Powder bed fusion and laser sintering applications benefit from Aerotech's high-accuracy galvanometers and motion controllers, which are coupled in a way to give the end-user more feedback than any other solution on the market. Whatever motion control your additive manufacturing application requires, Aerotech is the partner that can make your project a success.

Additive Manufacturing Applications

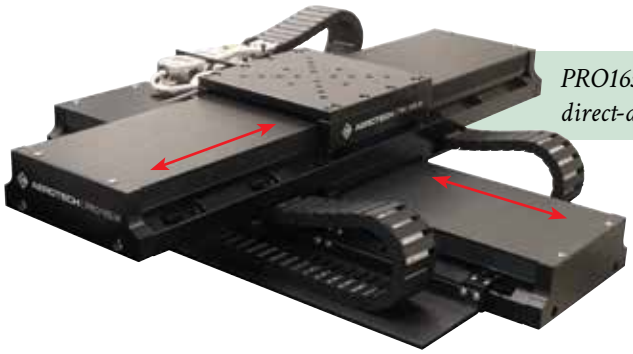
Material Extrusion/ Deposition

- Gantry configurations allow for overhead tool operation and fixed-part placement
- Zero backlash linear motors for smooth velocity control, higher accuracies, and higher throughput
- Nanometer resolutions and micron-level accuracies and repeatabilities for consistent depositions
- Aerotech controls simplify gantry set-up and operations



AGS1000 high-throughput compact gantry

Direct drive tip/tilt rotary assembly



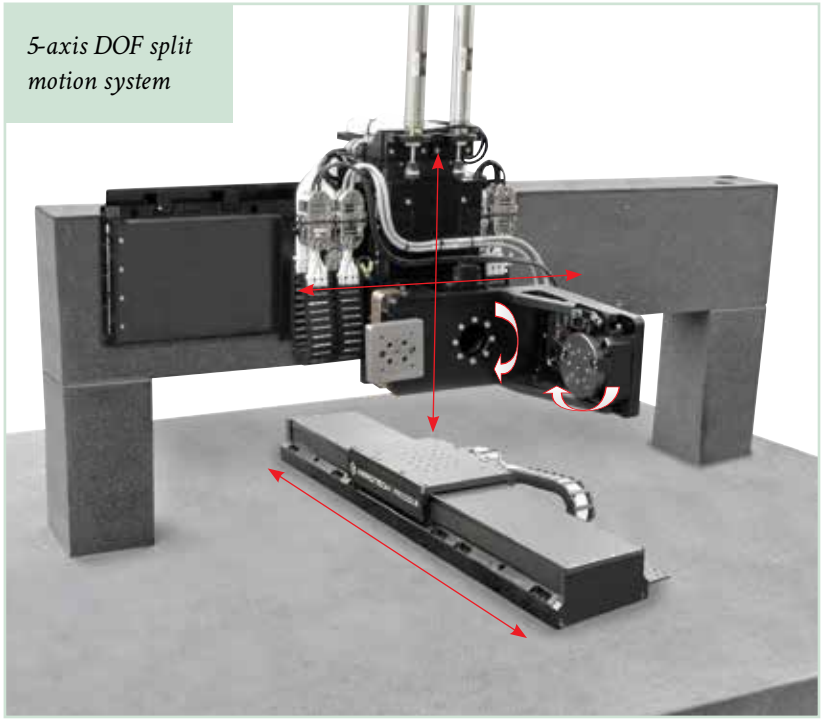
PRO165LM-XY direct-drive linear stages

- Standard and application-specific custom linear and rotary motion components or subsystems to fit any application
- Integrated cable management options simplify routing of customer cable and hoses
- Linear motor and ball-screw options open up wide range of performance and cost-effective solutions

Visit aerotech.com for a full list of linear and rotary stages to fit your application.

Dispensing/ Printed Electronics

- Multi-axis assemblies tailored for printing/dispensing along complex contours
- Precision alignments and work-point calibrations reduces 3D stack-up errors at the work point
- Aerotech's Position Synchronized Output (PSO) allows for encoder feedback to be coupled directly to the dispensing head to achieve consistent deposition and high part quality



5-axis DOF split motion system

High Throughput Dispensing

- Custom configuration including multiple motion arms for multiple dispense heads that increase the throughput of the process
- Aerotech controllers provide coordinated motion between work points
- Systems offered in both "T-style" and "H-style" Cartesian gantries

Quad-head "H-style" Cartesian dispensing system

Aerotech Controller Features Improve Our Systems' Dispensing Performance.

See Page 8 for More Controller Key Features.

Precision Mechanics + Advanced Controls = Innovative Motion Control

Analog Power Control:

Adjust the setting of an analog output in relationship to the real-time vector speed of two axes to enable automatic regulation of material dispensing.

Autofocus:

Automatically adjust the focus for consistent spacing between tool and part directly from an external sensor output.

Kinematics:

Execute complex inverse kinematic equations within the flow of the trajectory generation.

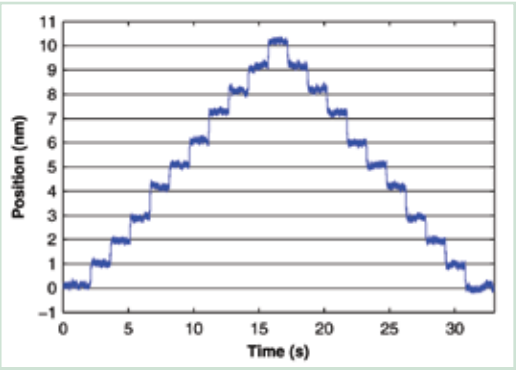
Micro- and Nano-Level Dispensing

Multi-Axis Applications

- Reduced feature sizes possible due to submicron accuracies and repeatabilities
- Compact, direct-drive axes exhibit excellent in-position stability with no hysteresis or backlash
- Anti-creep crossed-roller bearings allow smooth velocity regulation and consistent deposition
- Available in linear and rotary configurations for a wide variety of motion needs
- Nanometer and sub-arc-sec step sizes possible when coupled with Aerotech's powerful controls
- Proven results tested using advanced metrology methods

3-axis counterbalanced nanopositioning system

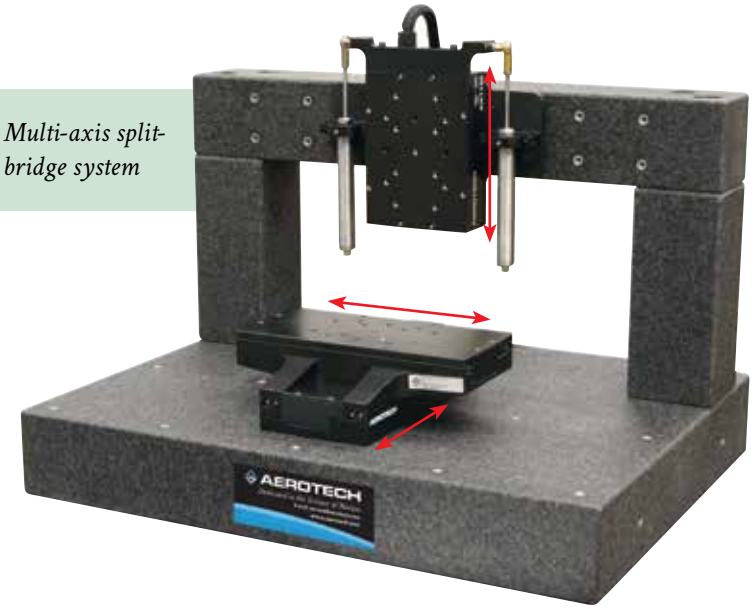
6-axis nanopositioning system



ANT95-50-L-PLUS 1 nm step plot tested using advanced metrology methods

Custom Solutions

- Custom engineered solutions designed to meet your application needs
- Counterbalanced linear motor vertical axes allow for high dynamics and small step sizes
- Extensive mechanical configuration options specifically designed for an application

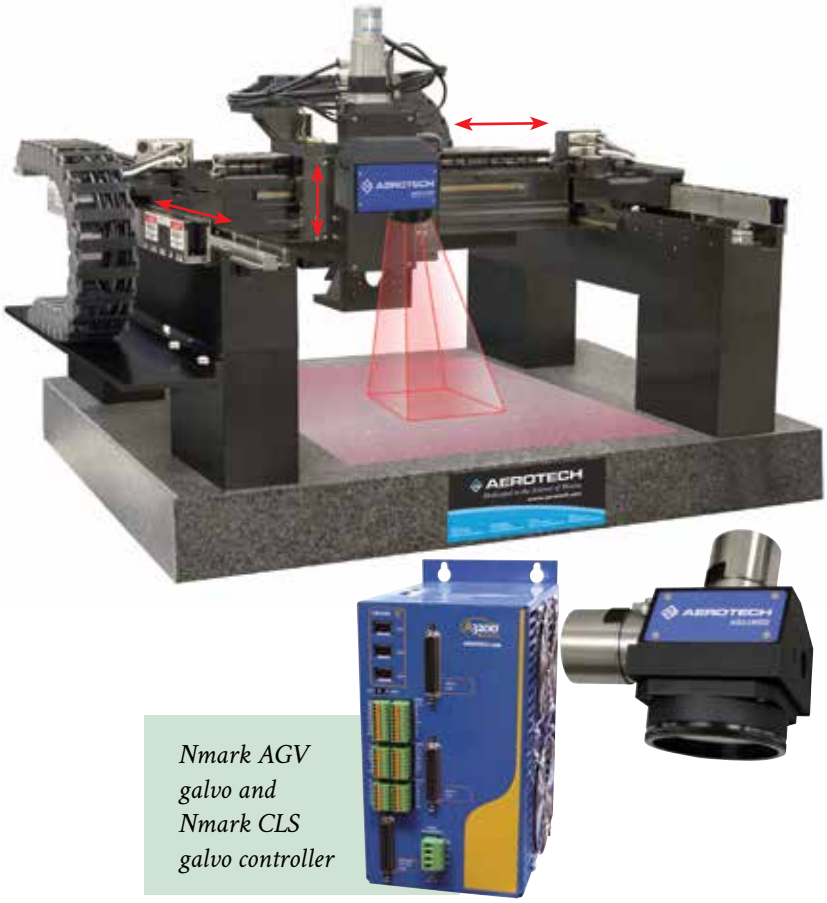


Multi-axis split-bridge system

Powder Bed Fusion (Laser Sintering) and Stereolithography

Galvanometer Scanner and Controls

- Micron-level field of view accuracy achieved by thermally stable feedback sensors
- Direct access is granted to the position sensors of the galvanometer to close the control loop and virtually eliminate lag and tracking errors typically associated with scanners
- The controls and galvanometer can be seamlessly integrated with linear servo stages to create an Infinite Field of View (IFoV) that eliminates stitching errors that are often present with other scanner systems

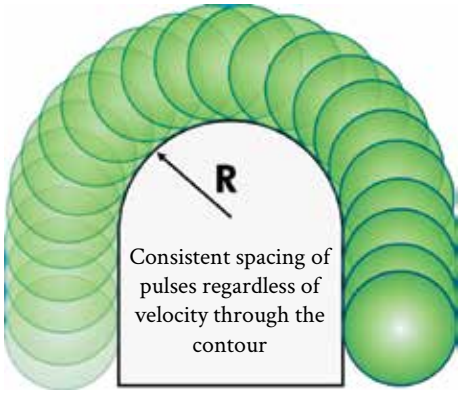


Nmark AGV galvo and Nmark CLS galvo controller

Aerotech also offers drive electronics and controls to run 3rd party galvo scanners

Position Synchronized Output

- Patented Aerotech control feature
- Fire your tool based on actual calibrated encoder counts for higher accuracy and increased throughput
- Up to 3 axes of PSO to trigger:
  - Lasers
  - Dispense/print heads
  - Cameras
  - Data acquisition
  - And more
- Trigger based on specified arrays, windows, or distances

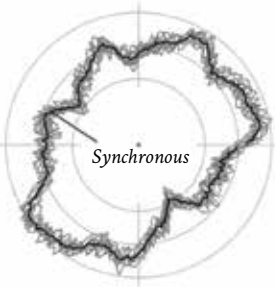


Laser pulsing based on a fixed distance

Advanced Metrology for Dispensing/Additive Manufacturing

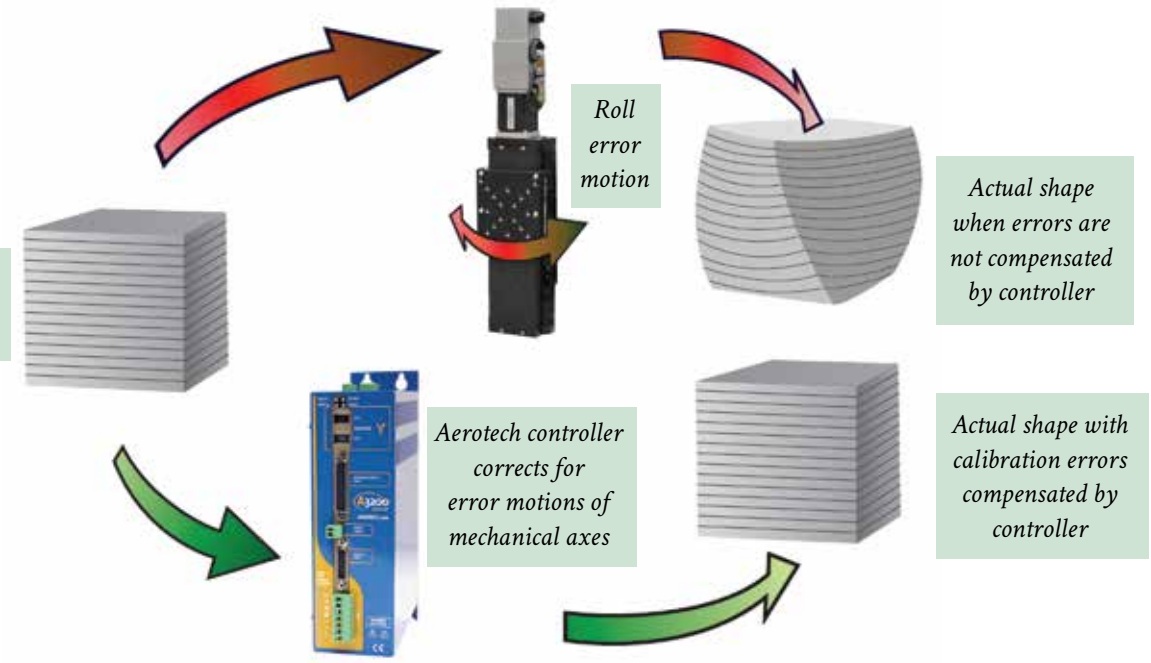
Understanding Motion Specific Problems: Inherent Mechanical Errors

- Both linear and rotary stages have imperfections that create error
- Errors from each axis contribute differently in all six degrees of freedom
- Up to 36 error contributions in a six-axis system with six error contributions each
- Multi-axis misalignments and work-point offsets increase the effects of angular errors



Rotary stages exhibit axial, radial, and tilt errors. Runout is also a common undesirable effect.

What the problems amount to:

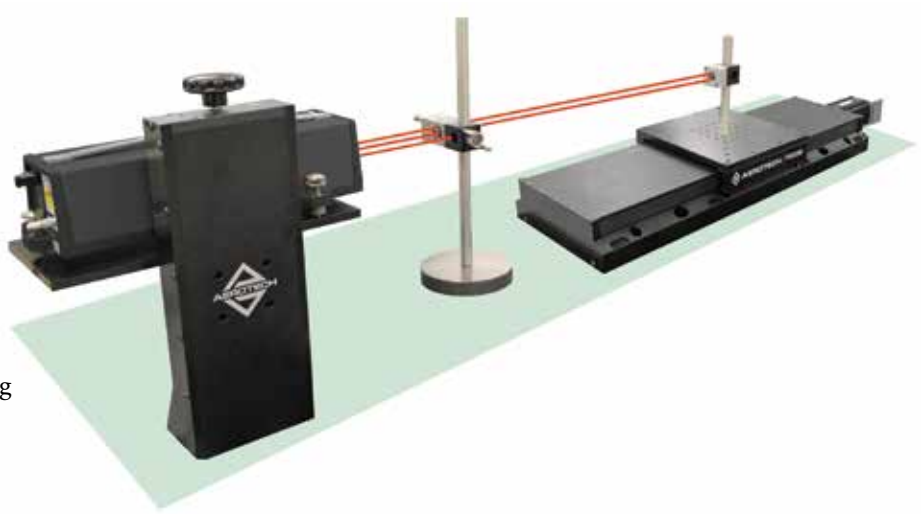


This is just one example of one error affecting the final product.

Aerotech Metrology

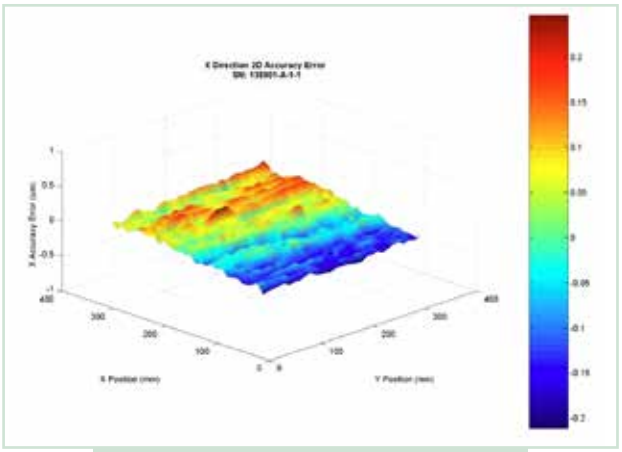
Metrology Measurement

- Aerotech has extensive metrology capabilities that allow for precision measurements:
  - Interferometry for linear errors
  - Collimation for angular errors
  - Capacitance setups for rotary errors
  - Dynamic tests for motion process testing



Error Mapping and Calibration

- The controller compensates for errors of the motion system by making a lookup table of the measured error motions, and then the trajectory generation is modified by the controller to eliminate the measured errors
- Calibration is performed at the work point to minimize errors at the process point for best results
- Offered in both 1D and 2D
- Available for both linear and rotary motion errors



Errors shown on a 2D calibration map

Precision Alignments

- Capabilities include multi-axis alignments of linear and rotary stage assemblies:
  - Perpendicularity between axes
  - Axes of intersection for rotaries
- Performed using precision granite surfaces and telescoping techniques

Drive Electronics and Controls

Advanced System Controls and Software

Aerotech motion controllers, drives, and software are used in our own positioning systems and in motion control and positioning systems around the world. Our Windows®-based motion controllers offer powerful, user-friendly software and are easily configured for brushless, brush, and stepper motors. Our PWM and linear drives offer up to 200 A peak output current. Aerotech controls provide a state-of-the-art integrated development environment to create your motion program, with a diagnostics toolkit that is second to none and easy to use calculators and autotune routines.

Automation 3200 Controller

- PC-based
- 1 to 32 axes of coordinated motion
- Up to 32 tasks
- RS-274 G-code, .NET, LabVIEW®, AeroBasic™
- Advanced features for demanding applications
- PLC and integrated motion controller
- Coordinated galvo scanner and servo control

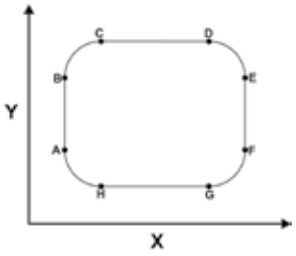
Ensemble Controller

- Stand-alone 1 to 10-axis controller
- GPIB, Ethernet, USB
- Up to 4 tasks
- .NET, C++, LabVIEW®, AeroBasic™

Interfaces

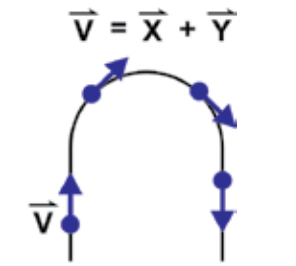
- Ethernet/IP™
- Modbus®/TCP
- DeviceNET
- Ethernet TCP/IP
- USB
- RS-232
- GPIB

Controller Features



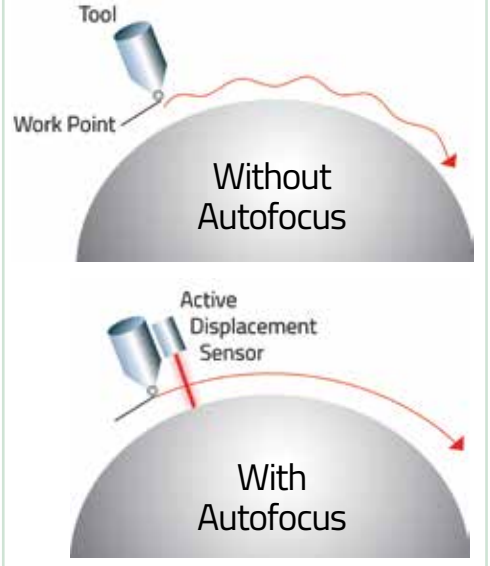
Coordinated Motion

Linear and circular motions are supported in all languages.



Velocity Profiling

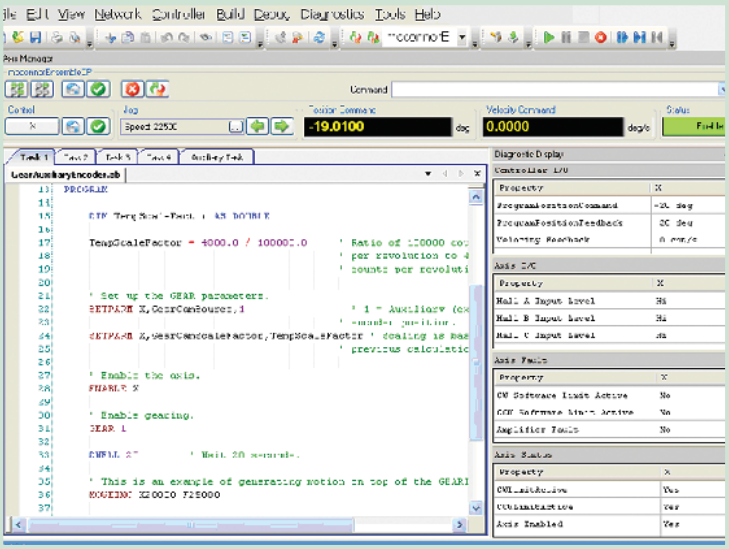
Maintains a constant vector velocity along the programmed path.



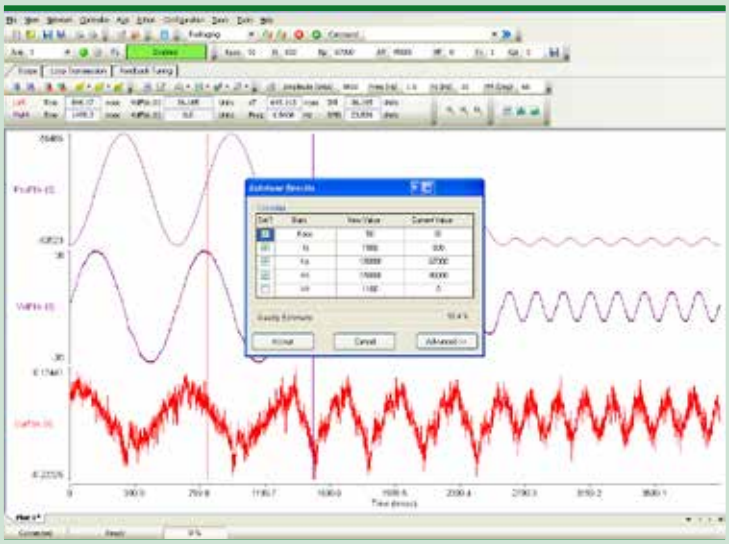
Autofocus

Autofocus capabilities allow for constant offsets to be held between the tool and part surface. This allows for complex contouring over 3D shapes while maintaining constant deposition.

Standard Software Interfaces Included with all Controllers

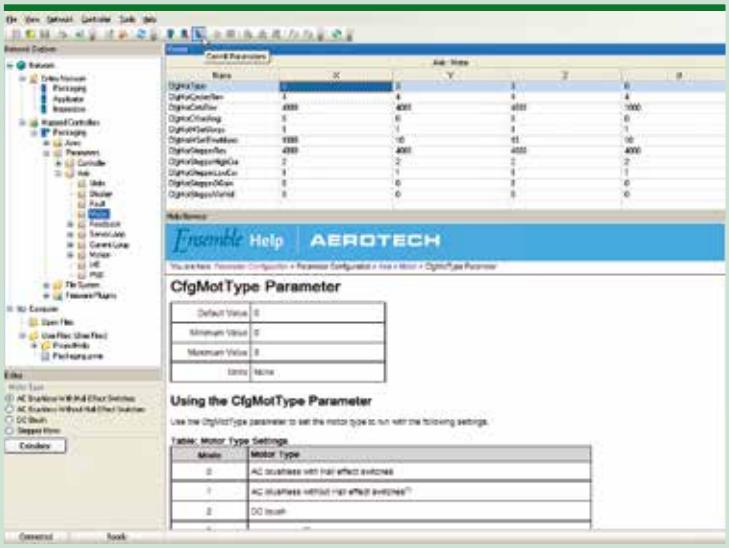


Programming Interface

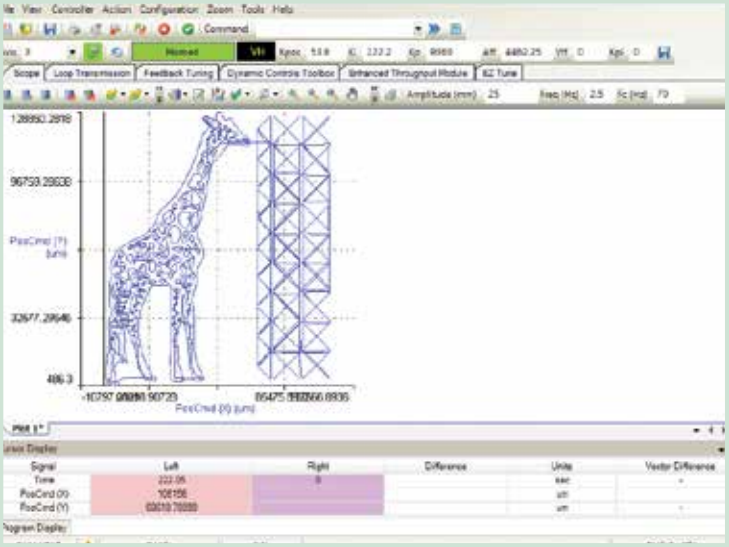


Autotune

CNC OI



Parameter Editor



Digital Scope

MotionPAC

Capabilities in Other Markets

Electronics Manufacturing and Assembly

Speed, accuracy, and reliability are the key requirements for pick-and-place machines, stencil cutting machines, printed circuit board assembly, and other electronic manufacturing and assembly equipment. Since 1970 Aerotech has exceeded the most stringent criteria used to judge electronic manufacturing and assembly equipment, and we continue to raise the standard with our advanced motion technologies by addressing industry-specific challenges in pick-and-place machines, stencil cutting machines, and printed circuit board assembly systems.

Visit **aerotech.com** to download a pdf of our brochure *Motion and Automation for Test, Measurement and Inspection*, or to order a hard copy.

Medical Device Manufacturing and Life Sciences

Aerotech manufactures high-performance motion systems and components for medical and life sciences applications including stent cutting, medical laser welding systems for cardiac pacemakers and catheters, IOL and contact lens manufacturing, DNA sequencing, blood sequencing, haptic mills and drills, x-ray machines, magnetic resonance scanners, and CAT scanners. We can customize a medical laser welding system for any need.

Visit **aerotech.com** to download a pdf of our brochure *Automation Solutions for Medical Device Manufacturing and Life Sciences*, or to order a hard copy.

Control Systems

Aerotech motion controllers, motors, and drives are utilized in our own positioning systems and by end users and OEMs worldwide. From our Automation 3200 software-based motion controller that can control up to 32 axes, to the Soloist single-axis servo controller, to the Ensemble multi-axis stand-alone motion controller, we provide a variety of options to suit your application.

Visit **aerotech.com** to download a pdf of our brochure *Integrated Automation Solutions*, or to order a hard copy.

Laser Processing

Aerotech has extensive experience in providing motion components and subsystems for laser processes such as cutting, welding, marking, etching, and micromachining. These processes are the key to advancing technology in markets such as photovoltaic manufacturing, aerospace, and medical device manufacturing.

Visit **aerotech.com** to download a pdf of our brochure *Capabilities in Laser Processing and Micromachining*, or to order a hard copy.

Defense and Aerospace

Aerotech has manufactured thousands of high-accuracy systems including many for high vacuum (10^{-6} Torr) and cleanroom environments. Our equipment is used for testing electro-optic systems, high-performance laser processing, materials testing and manufacturing, target tracking, satellite sensor calibration and verification, inertial guidance testing, scanning, optical pointing, and repeatability and life-cycle testing for quality control. Custom systems are available with minimal development time.

Visit **aerotech.com** to download a pdf of our brochure ***Advanced Motion Systems for Defense, Aerospace, and National Security***, or to order a hard copy.

Government and Education Research and Development

The breadth of Aerotech's product line offers solutions for the wide-ranging requirements of academic and government R&D. Our nanopositioners provide the accuracy required not only for photonics experiments, but also for micro- and nanomachining workstations. Aerotech's multi-axis rotary positioners and gimbals offer the high precision needed for defense, satellite, and space science research. Unique applications call for unique solutions, and Aerotech can provide custom-engineered systems to meet your needs.

Visit **aerotech.com** to download a pdf of our brochure ***nano Motion Technology***, or to order a hard copy.

Precision Manufacturing

Aerotech's industrial manufacturing components and subsystems are used in applications encompassing drilling, EDM, grinding, turning, boring, broaching, gear cutting, tapping/threading, turning centers, lathes, machining centers, and station-type machines. Furthermore, Aerotech products can also accomplish other multidimensional processes such as routing, water-jet cutting, knife cutting, CNC machining, and electrochemical machining.

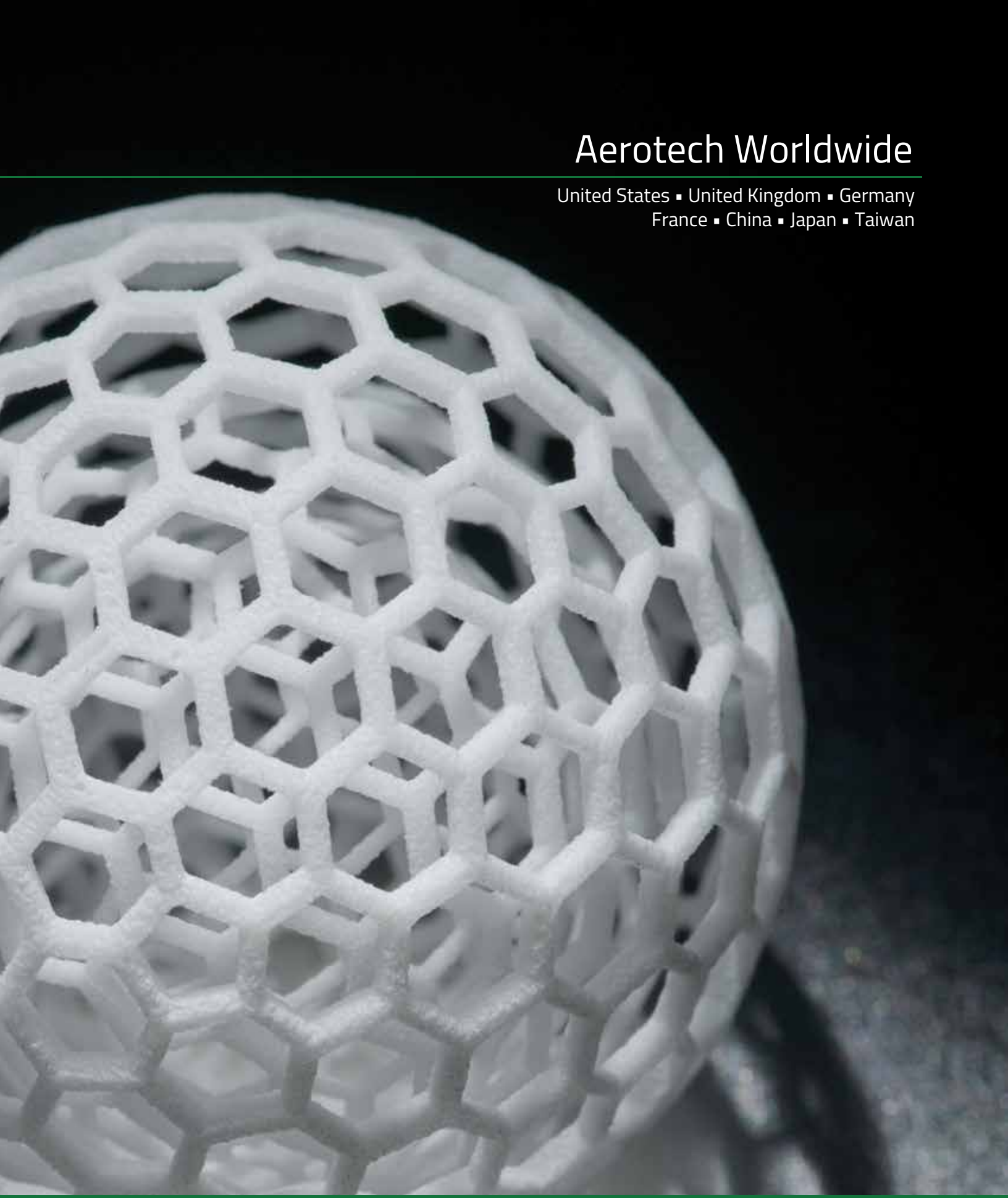
Visit **aerotech.com** to download a pdf of our brochure ***Motion Control for Precision Manufacturing***, or to order a hard copy.

General Automation

Aerotech has manufactured top-quality automation products since 1970. The breadth of our product line, including automated nanopositioners, planar air-bearing systems, high-speed gantries, linear and rotary and lift stages, brushless linear and rotary servomotors and drives, single- and multi-axis motion controllers, goniometers, and gimbals/optical mounts, makes Aerotech unique among motion control manufacturers. Aerotech is *Dedicated to the Science of Motion.*

Aerotech Worldwide

United States ▪ United Kingdom ▪ Germany
France ▪ China ▪ Japan ▪ Taiwan



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