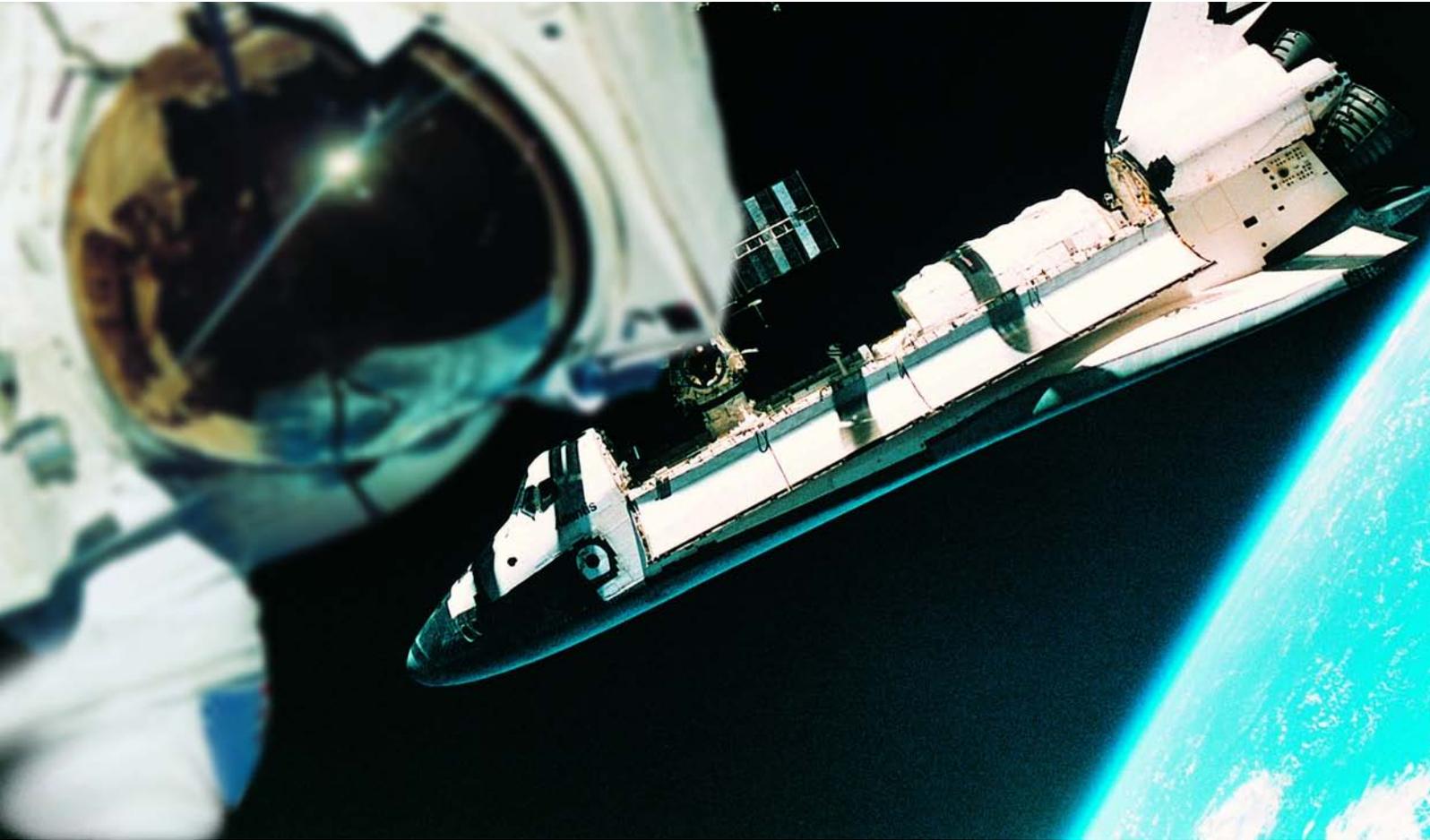


Case Study

NASA Perfects Orbital Docking Right Here on Earth



■ For most of those not directly involved, space exploration and research conjure up triumphant images of weightlessness and exotic technologies straight out of a science-fiction novel. However, most of the painstaking engineering efforts that go into reaching orbit take place on the ground. Due to the exorbitant, prohibitively high cost of leaving anything to chance and the inherent dangers involved, exhaustive tests and simulations of all systems and system interactions are performed here on Earth.

■ By Dennis Warren and Neven Jeremic

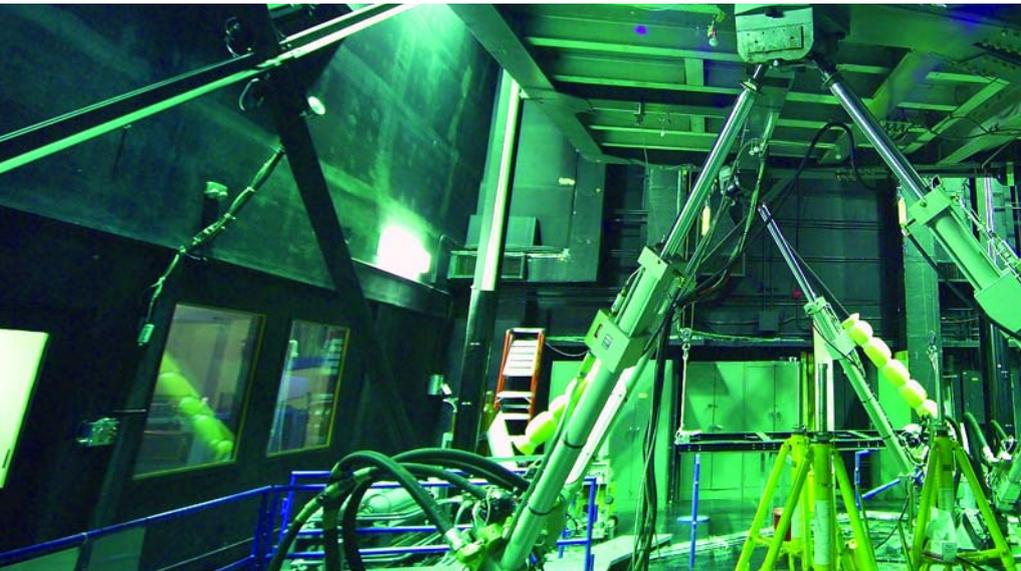
NASA has used robots for many years to simulate different aspects of docking and space maneuvering. In the past, these robots were checked with static measurements, and NASA was looking for a way to check the robots' dynamic response. Due to a myriad of special considerations and limitations being placed on any metrology system being implemented (such as the vastness of the testbed, the tightness of available space and the need for tremendous freedom of movement of the system being inspected), NASA contacted Leica Geosystems with the request for an off-the-shelf solution that would require few, if any, modifications to complete the complex measurement task remotely, with no personnel present inside the facility.

The NASA Marshall Space Flight Center (MSFC) wanted the robots in the Flight Robotics Laboratory (FRL) and the Contact Dynamics Simulation Lab (CDSL), which make up the MSFC integrated testbed, to be verified using dynamic measurements with six degrees of freedom (6DoF) to determine how accurately the robots respond to commanded moves.



- when it has to be **right**

Leica
Geosystems



Motion system driven by six hydraulic legs (left); payload section of the Flight Robotics Laboratory (FRL) with the Leica T-Probe mounted and Leica LTD800 Laser Tracker in the foreground (above)

Off-the-Shelf Portable CMM Ready for Take-Off

Verifying robot accuracy

A typical berthing or docking mechanism is composed of two mating components, one for each vehicle. In the CDSL, one component of a docking mechanism is attached to a motion-base, while the other component is mounted to a force and torque sensor fixed in the support structure above the motion-base. The motion system is driven by 6 hydraulic legs controlled by a 12 processor Silicon Graphics Inc., Challenge computer operating on a IRIX platform. The facility is capable of full 6DoF motion over a large operating space with 20,000-pound (9,800kg) payload capability.

The Flight Robotics Laboratory is centered around a 44-foot by 86-foot (13.5m x 26m) precision air bearing floor, the largest of its kind in the world. A mobility base called the Air Bearing Spacecraft Simulator (ABSS) is used on the air-bearing floor and is capable of 3DoF of actual motion and 3DoF of simulated motion, and holds a 400-pound (180kg) payload. An 8DoF overhead gantry, called the Dynamic Overhead Target Simulator (DOTS), provides a 1,000-pound (454kg) payload capability for simulating relative motion with respect to a fixed target on the facility floor. A computer system provides inverse kinematics and allows the gantry to act as a target or as the 6DoF rendezvous vehicle. The target reaction dynamics are simulated through force/torque feedback from sensors mounted at the payload interface.

Leica Laser Tracker

A top-of-the-line Leica LTD800 Laser Tracker with a Leica T-Cam and a Leica T-Probe were used for the measurements without any special modifications. This arrangement provided the measurement capability for XYZ coordinates along with rotation angles for full six degrees of freedom information for the position of the Leica T-Probe, which was used without a stylus.

The Leica T-Probe was mounted on the adaptor plate that was bolted onto an especially fabricated bracket on the CDSL. This bracket was bolted onto a frame extension of the platform. The resulting arrangement positioned the T-Probe on the edge of the platform pointed down at the LTD800 tracker. This position allowed the platform to make a full range of movement in all six degrees of freedom. Leica T-Probe's freedom-to-rotate acceptance angle of a full 360° in roll, and ±45° in pitch and yaw has meant that there was always an acceptable angle between the T-Probe and the T-Cam, placing few limitations on the movement of the robot itself.

Easy data collection

Leica Axyz, a well-established and easy-to-use menu-driven measurement and analysis package, was used to create the initial coordinate system for the two robots and to establish reference values on both the payload section targets and the floor monuments. Axyz was selected since it was well populated with geometry and alignment routines that gave the flexibility to

analyze the geometry of the robots and establish the coordinates for the new monuments and reference targets.

The emScon Base User Interface (BUI) is an intuitive, user-friendly Internet Explorer-based user interface that is set up as a web-based application. The emScon BUI performed system checks, set environment parameters and set up the T-Probe conditions. This reduced the complexity of the other programs and thus significantly reduced their development time. Most of the laser tracker functions can be accessed by the emScon BUI.

The rich set of emScon commands allowed special programs to be generated very quickly to handle a wide variety of diverse applications. Two applications that used emScon functions were quickly developed to accomplish the required tasks, illustrating the ease and simplicity of emScon programming.

The transformation program was a straightforward Visual Basic for Applications (VBA) program located in a spreadsheet. The spreadsheet held the reference data, measurements, transformed data, residuals and transformation parameters. The VBA program inside the spreadsheet communicated with emScon and used the Excel spreadsheet to hold the data. The VBA program established communications with emScon, read the reflector list, selected the units, cleared the previous transformation, sent a measure command, got the resulting measurements,

sent data to emScon for the transformation, stored the transformation results and finally set the transformation active in emScon. The actual calculations for the transformation were done in emScon and the results returned to the Excel spreadsheet for the operator to evaluate.

The data collection program was a Visual Basic application that simply turned on the triggered measurement mode of measurement and stored the measurements in a file. The emScon interface did most of the work.

Easy does it

There was no limit on the operation of the CDSL since the maximum movements of this robot did not exceed any capability of the Leica T-Probe to measure nor the Leica Laser Tracker to follow. The Leica T-Probe is the only system whose operational range is large enough for this application. Due to the enormous size of the FRL robot, the set of measurements was split into two parts. Despite the vastness of the robot, the entire set of measurements was done with just one repositioning of the Leica Laser Tracker, which in itself is a one-person operation.

The room where the CDSL robot is located has a very limited area to establish a reference coordinate system. The robot fills most of the space in the room and a high percentage of the floor was covered with lift-off access panels. Over the course of 5 days, 150 measurement files were created, containing anywhere from a few hundred measurements to over 200,000 points. For safety reasons, all of the measurements were performed remotely, with no personnel in the room with the robot.

When everything else is second best

The Leica LTD800 laser tracker with a T-Cam and a T-Probe provided the unique capability to measure a trajectory with 6DoF synchronized with a trigger pulse. This allowed NASA to synchronize the expected position of the payload section of the robots with the measured location with a full six degrees of freedom. The complete system provided by Leica Geosystems was the only such system available on the market that corresponded to the need for a highly flexible wireless, portable CMM system that imposed few limitations of its own on the NASA MSFC facility and delivered highly precise measurement data within the shortest time frame possible.



"We purchased the Leica LTD800 Laser Tracker with Leica T-Probe to improve our Flight Robotics Laboratory and Contact Dynamics Simulation Laboratory. We wanted a 6DoF sensor with the largest measurement volume to improve all our motion facilities, and the Leica system ideally matched our requirements. It gave us the capability to accurately measure 6DoF relative position while keeping our tight schedule."

Marlin Williamson, NASA Aerospace Engineer

About the Marshall Center

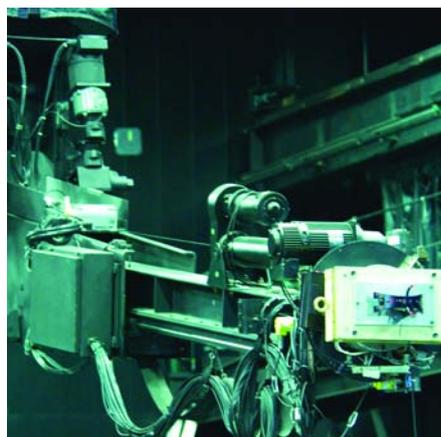
The Marshall Space Flight Center in Huntsville, Ala., is one of NASA's largest and most diversified installations. The Marshall Center has been a key contributor to numerous significant NASA programs during the Agency's 45-plus-year history – from the 1961 flight of the first U.S. astronaut into space, to the Apollo missions exploring the Moon, to development and operation of America's Space Shuttle fleet, and construction of and scientific discovery aboard the International Space Station.

Engineers and scientists at the Marshall Center use state-of-the-art equipment and facilities to accomplish NASA's mission. Marshall manages the key propulsion hardware and technologies of the Space Shuttle, develops the next generation of space transportation and propulsion systems, oversees science and hardware development for the International Space Station, and handles a variety of associated scientific endeavors to benefit space exploration and improve life here on Earth.

The Marshall Space Flight Center currently uses one Leica LTD800 Laser Tracker plus a Leica T-Cam and a Leica T-Probe.



Leica T-Probe, mounted on the edge of the CDSL platform, lets NASA verify the robots in the MSFC integrated testbed.



Close-up of the FRL payload section of the robot with the T-Probe mounted.

Whether building the fastest car, the biggest plane, or the most precise tooling, you need exact measurements to improve quality and productivity. So when it has to be right, professionals trust Leica Geosystems Metrology to help collect, analyze and present 3-dimensional (3D) data for industrial measurement.

Leica Metrology is best known for its broad array of control and industrial measurement products including laser trackers, Local Positioning Technology (LPT) based systems, 3D software and high-precision total stations that capture data accurately, model quickly, analyze easily and present 3D information. Those who use Leica Metrology products every day trust them for their dependability, the value they deliver, and the world-class service & support that's second to none.

Precision, reliability and service from Leica Geosystems Metrology.

When it has to be right.

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