Integrated Docking Simulation with Six-degree-of-freedom Dynamic Test System

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The general purpose of the Six-DOF [degree-of-freedom] Dynamic Test System (SDTS) is to demonstrate and verify on-orbit tasks using berthing and docking/undocking such as assembly of space structures. The SDTS is a closed-loop dynamic testing system that combines high-fidelity test articles and software models to produce an integrated simulation of two-body berthing and docking in free space. Common uses of the SDTS include engineering evaluation of mechanical device operation, verification of in-space assembly procedures, development of crew training and operational procedures, and demonstration of advanced robotics technologies.

The SDTS provides a six-DOF motion base platform, a superstructure for mounting test articles and test sensors, an intercom network for voice communications, and a high-speed data acquisition system. It also provides multiple control bay workstations as well as three different dynamic and kinematic simulations to control the motion platform: a two-free-body docking simulation, a Space Shuttle Remote Manipulator System berthing simulation, and a Space Station Remote Manipulator System berthing simulation that includes Orbital Boom Sensor System dynamics. Truth data for the SDTS trajectories are obtained through an independent tracking system.

A task of the Sensor Technology Project (STP) was to develop a simulation and testing infrastructure in which to integrate and test relative navigation sensors at docking and undocking using the SDTS. This required integrating the Orion software simulation, also known as ANTARES, with the SDTS computer system for real-time, closed-loop testing with relative navigation sensors in the loop during docking and undocking scenarios.

ANTARES 7.2.0 is used to provide control inputs to the SDTS. It simulates the environmental and control forces exerted on the Orion spacecraft and the International Space Station (ISS). Low-, medium-, and high-fidelity guidance, navigation, and control (GN&C) functions, contained within the GN&C software, run independently on a PowerPC that is similar to the Orion vehicle management computer. ANTARES and the GN&C software together provide an array of docking capabilities for testing purposes. As the SDTS interface is also Trick-based, a module was integrated into ANTARES to transmit control parameters to the SDTS. Additional interfaces were developed between the GN&C software on the PowerPC and ANTARES and the relative navigation sensors. This multi-interface module enables data acquisition from the various sensors strapped to the platform and the test stand. This adds the capability to compare sensor data to truth data measured from the simulation. Sensor measurements from the platform are fed into the guidance and navigation software, which drives the test stand to the point of docking (figure 1).

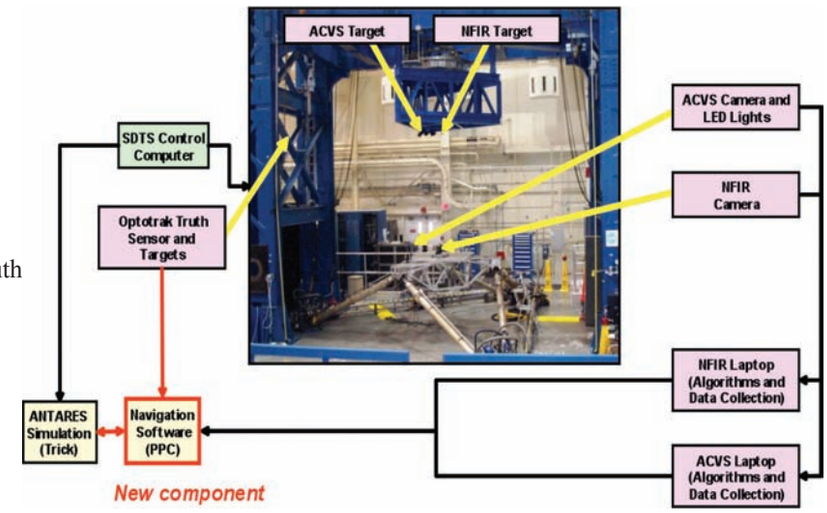

Fig. 1. *Six-DOF test stand equipment configuration.*

Currently, two test articles are available for testing at the SDTS: the AutoTRAC Computer Vision System (ACVS) and Natural Feature Image Recognition (NFIR). ACVS technology employs the "spot pose" technique, in which a sensor uses a cluster of retroreflectors in a known pattern to extract the six-DOF state, or "pose," of the sensor relative to the target vehicle. NFIR uses camera video to match image locations of the target vehicle features with a known

three-dimensional model to extract a pose. Math models for ACVS, NFIR, and a Flash LIDAR [light intensification detection and ranging] that is similar to the Orion visual navigation sensor (VNS) are also available for testing.

SDTS testing occurs at close range (from 3.04 me to contact distance) to mimic docking and undocking; therefore, the test stand is configured with docking targets. Due to the close range, NFIR uses only the docking target with a standoff cross rather than a full docking adapter mock-up. The docking target is nearly identical to the one that is used by shuttle when it docks to the ISS. The ACVS uses a target with a set of five retroreflectors (one of which is out of plane) with a mirror in the center.

Various trajectories have been developed for sensor testing. The trajectories that were selected are used to calibrate the sensors or mimic possible Orion docking trajectories. Three of the trajectories are calibration trajectories that are intended to ensure the sensors are performing consistently from day to day. The three check runs are as follows:

Radial Trajectory – Maneuvers the motion base from 0.914 to 0 m along the boresite of the docking cross. There is no lateral motion of the motion base and no relative rotation of the motion base with respect to the fixed test stand. The test objective is to ensure that the boresite of the sensor is in alignment.

Diamond Trajectory – Applies lateral motion to the motion base at a 0.457-m stand-off distance. The lateral motion is a ±0.305-m off-axis that forms a diamond in the X-Y axes. This trajectory tests the off-axis capabilities of the sensors.

Decaying Error Trajectory – Varies all translational and rotational components of the motion base relative to the fixed test stand. The lateral variations, which go up to a maximum of 0.914 m, vary sinusoidally to 0 m at docking. Likewise, the relative roll, pitch, and yaw offsets are a maximum of 5, 2, and 3 deg at the start of the trajectory and vary sinusoidally to 0 deg at docking. This trajectory is designed to provide distinctive signatures in all axes for sensor calibration and testing.

Four Orion docking trajectories are also on hand; these are designed to demonstrate the approach of the Orion to the ISS. The four test trajectories are as follows:

A nominal approach trajectory that has as its initial condition the Orion docking port, which is located 0.914 m along the boresite of the docking cross from the ISS docking adapter

A positional offset approach trajectory that has as its initial conditions the Orion 0.152-m offset in both lateral axes

A yaw offset approach trajectory that has as its initial conditions the Orion, which is located 0.914 m along the boresite of the docking cross from the ISS at a yaw angle of 5 deg

A retreat trajectory that begins the same as the positional offset approach trajectory and is commanded to a dock abort before it retreats back to a holding position

For the Orion guidance and navigation team, testing of the Orion guidance and navigation prototype software on a real-time processor with dynamic relative navigation sensors in the loop evaluates the accuracies and usefulness of the SDTS as an integrated testing capability. Test plans, procedures, scripts, processes, docking targets, and trajectories can be used as is or can be easily modified for future tests. The vehicles of the Constellation Program and all space flight vehicles require ground-test capabilities for testing, which encompass a broad scope of hardware and software-in-the-loop simulation and testing on real-time avionics. These elements have been combined at the SDTS, resulting in a six-DOF laboratory testing capability.

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