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**NASA MSFC Hardware in the Loop Simulations of Automatic Rendezvous and Capture Systems**

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Two complementary hardware-in-the-loop simulation facilities for automatic rendezvous and capture systems at the Marshall Space Flight Center are described. One, the Flight Robotics Laboratory, uses an 8 DOF overhead manipulator with a work volume of 160 by 40 by 23 feet to evaluate automatic rendezvous algorithms and range/rate sensing systems. The other, the Space Station/Space Operations Mechanism Test Bed, uses a 6 DOF hydraulic table to perform docking and berthing dynamics simulations.

The MSFC Flight Robotics Laboratory provides sophisticated real-time simulation capability in the study of human/system interactions of remote systems. The facility consists of a 5800 square foot precision air bearing floor, a teleoperated motion base, an overhead electric manipulator, a remote operator's work station, real time computer system, and various simulation mock-ups. The facility can be used to study the performance of automatic or man-in-the-loop rendezvous systems in a real time environment. Planar hardware demonstrations are performed with the air bearing vehicles, using its pneumatic thrusters for remote control. The overhead manipulator is used for six degree of freedom hardware in the loop simulations. These studies investigate the performance of the automatic rendezvous algorithms, range/rate sensors, and human factor concerns such as light and camera placement, control system sensitivity, and transmission time delays for man in the loop operations. The simulation is best suited for examining the performance of the system up to the point of capture or contact.

The Dynamic Overhead Target Simulator (DOTS) is an 8 DOF, heavy duty electric manipulator capable of traversing over the entire air bearing floor. The system is composed of a precision overhead X-Y crane to which a six degree of freedom robot arm is mounted. A series of micro VAX computers are used in real time to convert arm tip position and orientation commands into crane and arm joint velocity commands. The commands are generated through closed form inverse kinematic relationships and digital control laws housed on the VAX network. An elaborate real-time safety algorithm performs collision avoidance and joint position and rate limiting.

The arm joints, ordered from the X-Y crane, are waist yaw, shoulder pitch, arm extension, wrist pitch, wrist yaw, and wrist roll. The manipulator has a payload capability of 1000 pounds with an 18-inch offset from the roll axis; it has a work volume of approximately 160 by 40 by 23 feet. Each joint on the arm is driven by a rate servo and instrumented with a 12-bit digital encoder and analog tachometer. These sensors are interfaced to the computer and used in real time to generate joint rate commands, monitor arm tip, position for collision avoidance and simulation performance, and limit joint positions and rates.

The micro VAX network currently runs the arm controls and safety software, orbital dynamics simulation, and all input/output data transfer and storage operations in a cycle time less than 50 milliseconds.

The Space Station/Space Operations Mechanism Test Bed consists of a hydraulically driven, computer-controlled 6 DOF force and moment sensor, remote driving stations with computer generated or live TV graphics, and a parallel digital processor that performs calculations to support the real-time simulation.

The function of the mechanism test bed is to test docking and berthing mechanisms for Space Station Freedom and other orbiting space vehicles in a real-time, hardware-in-the-loop simulation environment. Typically, the docking and berthing mechanisms have two mating components, one

for each vehicle. In the facility, one component is attached to the motion system, while the other component is mounted to the force/moment sensor fixed in the support structure above the 6 DOF. The six components of the contact forces/moments acting on the test article and its mating component are measured by the force/moment sensor. The force/moment sensor is interfaced to the real-time Alliant computer system.

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**Space Shuttle Program - Automatic Rendezvous, Proximity Operations,  
and Capture**

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An overview of the current NASA Johnson Space Center capabilities and ongoing activities for the design, development and demonstration of AR&C capabilities was provided. The JSC plans for ground and flight tests/demonstrations of progressive AR&C capabilities, using the Space Shuttle are described. The Space Shuttle could provide an effective "flying test bed" for these demonstrations.

A number of organizations at NASA JSC which responsibilities and capabilities associated with AR&C: the Flight Crew Operations Directorate includes the Astronaut Office, Space Shuttle Support, Office and Space Station Support Office, the Mission Operations Directorate includes the Systems Division provides mission support for Space Shuttle systems, training, operations, flight design and dynamics and Space Shuttle ground systems and the Engineering Directorate which provides engineering support to the Space Shuttle Program. The JSC can provide the following facilities: 6 DOF test facility, GPS test bed, Electro-optics Laboratory, Inertial Systems Laboratory, GN&C Emulator test bed, 6-DOF Docking Dynamic Test System, Robotics and Mechanical Systems Laboratory, Integrated Graphic Operation Analysis Laboratory and Intelligent Systems Laboratory.

The JSC proposes a phased approach to flight demonstrations of AR&C capabilities to minimize impact on the Orbiter and Orbiter operations. The priorities in this phasing are: (1) proximity operations, (2) capture, and (3) rendezvous. Priority is based on a combination of expected return on investment and complexity in integration with the Orbiter.

A four-stage flight demonstration is proposed. The four stages allow for a progressive development, application, integration, and demonstration of AR&C capabilities, that is consistent with the development schedules of the supporting systems and opportunities for Orbiter flight tests. The actual number of sequence of flight demonstrations is still under study and several options are being considered to optimize the costs and complexity of the demonstrations with the benefits. These stages fall into one of three ranges of operations: rendezvous - liftoff to 2 km, proximity operations from 2 km to 15 km; or capture/release - <15 km.

The Stage 1 Flight Demonstration is an open-loop flight test of a laser sensor which provides range, range rate, and bearing information to the Orbiter flight crew via supplemental displays, while the Orbiter is operating in the proximity operations zone of the target (e.g., 2 km to 50 ft). In this region, there is essentially no potential for Orbiter and target vehicle collision, regardless of the performance of the augmented system. Advanced targeting and guidance algorithms would be exercised in a "background," using information from the laser sensor to compute commands as though the loop were closed.

Based on the experience and confidence provided by the Stage 1 Demonstration, the Stage 2 Demonstration would extend the use of the supplemental Orbiter flight crew displays and GN&C algorithms to support manual operations from proximity operations to a capture position. Stage 2 also is an open-loop flight demonstration that moves the Orbiter within the capture range of the