S73-13
ABS. ONLY
N93-22299

6DOF SIMULATION SYSTEM FOR EVALUATING AUTOMATED RENDEZVOUS AND DOCKING SPACECRAFT

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Statement of technical details of the capability being described

Future logistics supply and servicing vehicles such as CTV must have full 6 degree of freedom (6DOF) capability in order to perform requisite rendezvous, proximity operations and capture operations.

The design and performance issues encountered when developing a 6DOF maneuvering spacecraft are very complex with subtle interactions which are not immediately obvious or easily anticipated. In order to deal with these complexities and develop robust maneuvering spacecraft designs, a simulation system and associated family of tools are used at TRW for generating and validating spacecraft performance requirements and guidance algorithms. This presentation provides an overview of the simulator and tools. These are used by TRW for autonomous rendezvous and docking research projects including CTV studies.

The TRW high fidelity 6DOF spacecraft dynamics simulator is called the orbital maneuvering and servicing simulator (OMSS). This simulator is supported by various analysis tools which are used for top level mission and configuration design and initial condition generation. These tools include an interactive targeting trajectory design tool, thruster configuration and evaluation tools, and control loop response and gain selection tools.

The OMSS includes models for all of the key guidance, navigation, control, and propulsion systems for the maneuvering vehicle. Full 6DOF orbital dynamics are simulated for multiple independent vehicles (chaser and multiple targets). The environmental models include J2 gravity, provision for atmosphere and drag models, sun position, and TDRS locations. The OMSS is a high fidelity 6DOF simulator with sufficient accuracy and functionality to have been suitable for deriving orbial maneuvering vehicle (OMV) system and man-in-the-loop technical requirements. All of the autodocking, autonomous proximity operations, and automated rendezvous algorithms developed by TRW Federal Systems Division have been implemented and tested on the OMSS. The OMSS includes a Kalman filter for processing the simulated sensor inputs from the rendezvous sensor, radar, or GPS. An automated mission sequencer has been installed for simulating automated rendezvous with possible midcourse corrections, and the transition to proximity operations. The OMSS has also been interfaced to an actual docking sensor and is used to drive the full-scale motion based simulator at MSFC. The OMSS retains the capability for man in the loop operations.

The primary mission planning support tool which is used to generate initial condition data for the OMSS is the targeting tool called Target. Target is an interactive, graphics based tool which runs on an IBM PC and quickly generates and displays orbital trajectories for rendezvous and phasing. Target includes J2 gravity perturbations and takes J2 biasing into account when performing Lambert transfers. Target allows a user to very quickly see the effects of transfer angles, elevation angles, and downrange displacements on the trajectory shape and delta-V required. Target may be used as a simple initial condition calculator to convert between orbital elements, rectangular ECI, and target relative LVLH coordinates; as a propagation tool for forwards and backwards state vector propagation; and as a mission segment planning tool. By stringing mission segments together, Target allows complicated mission profiles to be developed.

Vehicle thruster configurations are evaluated using two tools - a thruster response spreadsheet, Thrust, and a jet select table evaluation program, Jet_pick. The spreadsheet, Thrust, is especially useful for providing acceleration data when maneuvering heavy payloads with a large center of gravity (CG) displacement from the thruster planes. Thrust allows the rapid selection of thruster sizes and lever arms necessary in order to achieve acceptable control authority. Jet_pick is used to grade the acceleration response from a thruster configuration and jet select table. Any errors within the 728 elements of a jet select table are flagged. This is an important tool since an error in a single maneuver combination might be too small to be detected just by monitoring the simulation results from the OMSS. Jet_pick also allows a quick method for evaluating the effects of thruster output or mounting errors and CG displacements on the resulting vehicle accelerations. Jet_pick uses the same data format as the OMSS for ease of data transfer.

A final set of support tools are the control loop gain selection and evaluation tools. These tools are a spreadsheet, Control1, which allows the user to select the proper gains for either the translational or rotational control loops, and a 2 axis control loop response simulation program, Control2. Control1 allows the user to specify desired deadbands and maneuver rates and computes the control loop gains which correspond to these desired limits. In addition, an indication of control loop stability and limit cycle period is provided based on the estimated control accelerations. The 2 axis control loop simulation, Control2, simulates the cross coupling or a translational axis and a rotational axis (+Z and +Pitch for example). The control loop duty cycle times, effective translational accelerations, stability, and damping are easily observable by examining the output or plotting the data. The response data is presented in two formats, a strip chart which shows position and attitude versus time, and Lotus compatible numeric position, velocity and control loop activity data.

History of the origins and evolution of the capability

These simulations and tools provide a powerful foundation for deriving and validating performance requirements, designing and prototyping algorithms, and evaluating spacecraft performance characteristics. The legacy for these tools dates to the Phase B contract for the OMV and related TRW IRAD projects. Throughout the OMV program the simulation was refined and validated. The OMSS formed the basis for the OMV prototype ground control console which was used to develop flight procedures and human/machine interfaces. The other tools were developed more recently for TRW IRAD projects and the CTV study.

The level of maturity of the capability

All of the tools and simulations mentioned above are mature and fully developed. They continue to evolve with enhancements and added capabilities being incorporated as needed.

Test experience and/or experimental results

TRW has extensive simulations experience. The tools and simulations described here are in current use and are providing data for automated rendezvous and docking requirements development and for CTV configuration and mission evaluation. Figures 1 and 2 show actual OMSS output data for a representative data run. The figures show the approach profile for a heavily loaded CTV with no forward propulsion module. This simulation run begins at the end of a stable orbit rendezvous from 1 nmi to 1000 ft behind the space station. This rendezvous results in a 2 ft/s radial approach velocity to V-bar which the CTV must null out while maintaining LVLH attitude hold.

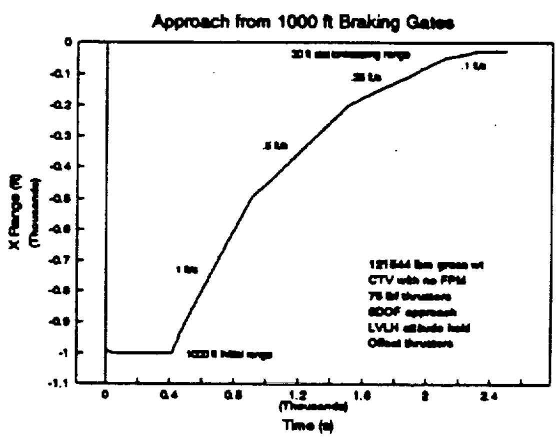

Figure 1.

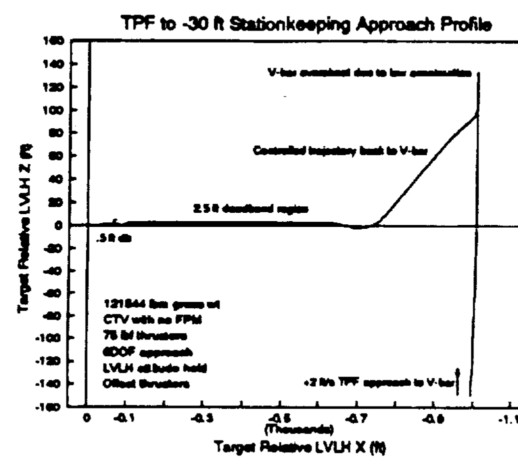

Figure 2.

Source/sponsorship and current funding estimates

The tools described were developed on TRW IRAD funds. During the OMV program, additional capabilities were added to enhance the simulation system. The simulation system is currently being used to support TRW IRAD and the CTV study.