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Automating an Orbiter Approach to Space Station Freedom to Minimize Plume Impingement

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Technical

Space shuttle orbiter Reaction Control System (RCS) plume impingement during proximity operations with Space Station Freedom (SSF) is a structural design driver for the SSF solar panels and radiators. A study underway at the Johnson Space Center (JSC) is investigating whether the use of an automated approach controller could result in the reduction of plume impingement induced loads during orbiter approach to SSF. Ongoing real time man-in-the-loop (MIL) simulations of an orbiter approaching SSF show that orbiter trajectory control can vary significantly from one pilot to the next. This variation is a cause for concern since current analyses predict that plume impingement loads resulting from MIL orbiter approaches may exceed the solar panel and radiator load limits. The use of an automated approach controller is expected to reduce peak loads by both minimizing orbiter translational jet firings in certain directions and controlling the frequency at which they occur during various phases of the approach.

An automated glideslope approach controller was implemented into the orbiter's Guidance Navigation and Control (GN&C) system in Lockheed's multi-vehicle Proximity Operations Simulator (POS) to control a +Vbar approach of the orbiter to the SSF. Orbiter approaches are also being flown by astronaut and engineering pilots in the real time MIL Systems Engineering Simulator (SES) at JSC. Both the MIL and automated approach simulations are initiated with dispersions in orbiter position and velocity two minutes prior to +Vbar arrival in the manual trajectory control phase of the rendezvous. In this phase, the orbiter approaches from below and in front of SSF with a nominal +Vbar intercept target point range of 400 feet. RCS jet firing histories from the MIL SES runs and automated POS runs are recorded and used to drive high fidelity plume impingement and structural models of SSF so that a structural load comparison can be made.

The current groundrules for a nominal orbiter +Vbar approach to SSF require that the orbiter's attitude is tail to earth, payload bay towards the SSF. The Digital Autopilot (DAP) will be in NORMZ or LOWZ mode. NORMZ mode does not restrict any of the orbiter's 38 primary RCS jets (870 lbf each) from firing during attitude or translational control. LOWZ mode inhibits all jets firing towards SSF, thus reducing plume impingement on SSF. However, it provides very inefficient braking and much more fuel is consumed than when in NORMZ. At a range of 75 feet the DAP transitions from LOWZ to NORMZ.

Proximity operations piloting techniques use a combination of rendezvous radar for range and range rate information; payload bay Closed Circuit Television (CCTV) camera angle triangulation or CCTV monitor overlays for range estimation (range rate by back differencing); and the Crew Optical Alignment Sight (COAS) for bearing information. The rendezvous radar is quite noisy and has a minimum range limit of 80 feet for tracking small targets. Performance when tracking a structure as large as SSF may be degraded, but analysis is not yet complete. An orbiter-based laser ranging device would provide the best information and is required for an automated orbiter approach. The addition of a laser is currently being debated.

The glideslope approach controller works by periodically calculating the delta-v required to maintain the orbiter on a trajectory with a constant glideslope angle. The equations for the controller are derived from the Clohessy-Wiltshire (C-W) equations. The glideslope controller requires accurate navigation and therefore we assume that an orbiter-based laser sensor provides the navigation with measurements of range, range rate, and bearing angles.

Preliminary results are promising. The controller can reduce the amount of fuel consumed in proximity operations, and it can reduce peak plume impingement loads on SSF.

Historical

The glideslope controller was first developed by T. Quan Le in 1986. The POS is a high fidelity multi-vehicle integrated GN&C simulation which currently contains an orbiter and a space station vehicle. The SES has been used as an engineering, astronaut training, and orbiter procedures development tool for many years.

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