Proximity Operations Considerations Affecting Spacecraft Design

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Abstract

Background

Experience from several recent spacecraft development programs, such as Space Station Freedom (SSF) and the Orbital Maneuvering Vehicle (OMV) has shown the need for factoring proximity operations considerations into the vehicle design process. Proximity operations, those orbital maneuvers and procedures which involve operation of two or more spacecraft at ranges of less than one nautical mile, are essential to the construction, servicing and operation of complex spacecraft.

Typical proximity operations considerations which drive spacecraft design may be broken into two broad categories; flight profile characteristics and concerns, and use of various spacecraft systems during proximity operations. Proximity operations flight profile concerns include:

- relative approach/separation line
- relative orientation of the vehicles
- relative translational and rotational rates
- vehicle interaction, in the form of thruster plume impingement, mating or demating operations, or uncontrolled contact/collision
- active vehicle piloting

Spacecraft systems used during proximity operations include:

- Sensors, such as radar, laser ranging devices or optical ranging systems
- effector hardware, such as thrusters
- flight control software
- mating hardware, needed for docking or berthing operations

A discussion of how these factors affect vehicle design follows, addressing both active and passive/cooperative vehicles.

Active Vehicle Design Considerations

For proximity operations purposes, an active vehicle may be defined as one which performs translational maneuvers to approach, stationkeep with or depart from another spacecraft. An active vehicle, then, must either be flown by an astronaut onboard, flown by a remotely located pilot, or controlled by an automatic or autonomous flight control system.

Sensors are a critical part of an active vehicle. The ability of a spacecraft to perform proximity operations successfully is dependent on the accuracy of the sensors. With the NSTS Orbiter, for example, accurate range and range-rate information is needed by the

pilot to control the trajectory and exercise control options to minimize plume impingement on the spacecraft being approached or departed from. The rendezvous radar currently provides this information: however, the need for a more precise sensor has led to the study of laser ranging systems and optical ranging devices, which are also applicable to unmanned or autonomous spacecraft. Additionally, sensors must be located on the spacecraft such that an adequate field of view is provided; i.e., no other structure blocks the sensor field of view, and the sensor is oriented in the proper direction.

Flight control hardware and software must also accommodate proximity operations requirements. It is highly desirable for the vehicle to hold its attitude within small tolerances and be able to make fine adjustments to relative translational rates. Fine translational rate adjustment capability is required to ensure that rates compatible with mating hardware specifications are achievable. The size and location of reaction control system thrusters is critical to the vehicle's ability to make fine corrections in velocity, attitude and attitude rate. For example, simulations of the early STS-C unmanned cargo vehicle design showed a need for thrusters at both ends of the vehicle for effective translational control of the vehicle, as full six degree of freedom control was deemed necessary for a vehicle approaching the SSF. A vehicle's flight control software must provide the necessary operating modes for its mission, and should be flexible enough to accommodate I-load changes and further upgrades as needed. Additionally, for automated or autonomous vehicles, the flight software must protect for contingency scenarios, allowing vehicle safing or emergency bail-out procedures as required.

Passive/Cooperative Vehicle Design Considerations

For proximity operations purposes, a passive vehicle may be defined as one which does not perform translational maneuvers, but can (and frequently does) have an attitude control system. The design considerations which apply to passive vehicles mainly involve compatibility with the appropriate active vehicle.

The control system in a passive vehicle, if it has one, must have sufficient control authority to maintain attitude while an active vehicle approaches or departs from it. The passive vehicle will experience disturbances from active vehicle plume impingement and, during mating and demating operations, forces from contact with the active vehicle.

In some cases, control of the passive vehicle by the active vehicle may be necessary to ensure mission success. The capability for the Orbiter to deactivate the SSF control system just prior to manipulator grapple operations is an example: Orbiter manipulator constraints require that spacecraft being grappled may not have their control systems active at that time.

The passive vehicle structure must also be designed for proximity operations. Mating hardware must be compatible, and must be located such that mating and demating can be achieved without other contact between the vehicles. In addition, equipment to be serviced or replaced must be accessible either by remote manipulator or by an astronaut.

History of Spacecraft Performance Assessment

Our early experience with shuttle proximity operations flight design, beginning in the late 1970's, led to the development of our orbital simulation programs for analysis of proximity operations, starting with two-vehicle (orbiter and payload) batch-mode simulations on a desktop calculator. By adding real-time, man-in-loop capability to these tools, the basis for our current analysis capability was established. These simulation tools were used to design proximity operations techniques and procedures, starting with STS-7, the first dedicated Orbiter proximity operations flight, and are in use currently to assess trajectories, docking and berthing feasibility, spacecraft plume impingement and surface contamination, visual and sensor requirements, and to do preliminary development of flight techniques. Our simulation tools have been modified and used to simulate and analyze various other spacecraft, including the OMV, STS-C, the Assured Crew Return Vehicle (ACRV), the Man-Tended Free-Flyer (MTFF), the Tethered Satellite System (TSS) and the Simplified Aid For EVA Rescue (SAFER). Current work on the Space Station Freedom program includes analysis of Orbiter/SSF interaction during docking and berthing operations, assessment of Orbiter plume-induced loads on the SSF solar arrays, and the establishment of a requirement for a direct Orbiter-to-SSF radio-frequency (RF) command and telemetry link for Orbiter control of unmanned SSF assembly stages.

Summary

Spacecraft which must interact with other space vehicles must incorporate capabilities and features in their design to address the unique requirements of on-orbit proximity operations. Our experience in analyzing proximity operations and vehicle performance for a variety of manned and unmanned spacecraft over the past 14 years has shown that the suitability of a vehicle for proximity operations is linked to how well the vehicle design reflects the sensor accuracies and controllability it will require during actual operations.