In summary, any vehicle that is designed to perform rendezvous and proximity operations must consider at least the following conditions in the design of the vehicle: plume impingement and contamination, sensors, visual cues, data transmission times, data presentation to the pilot, flying qualities from jet placement, and grapple operations.

Autonomous Rendezvous and Docking - A Commercial Approach to On-Orbit Technology Validation

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SpARC, in conjunction with its corporate affiliates, is planning an on-orbit validation of autonomous rendezvous and docking (ARD) technology. The emphasis in this program is to utilize existing technology and commercially available components wherever possible. The primary subsystems to be validated by this demonstration include GPS receivers for navigation, a video-based sensor for proximity operations, a fluid connector mechanism to demonstrate fluid resupply capability, and a compliant, single-point docking mechanism.

The focus for this initial experiment will be ELV based and will make use of two residual Commercial Experiment Transporter (COMET) service modules. The first COMET spacecraft will be launched in late 1992 and will serve as the target vehicle. After the second COMET spacecraft has been launched In late 1994, the ARD demonstration will take place. The service module from the second COMET will serve as the chase vehicle.

The ARD mission begins with the validation state, in which the ARD payload is powered up and the payload controller (a 286 running VRTX and the Spacecraft Command Language) starts executing tasks. GPS almanac data is uploaded from the ground station and loaded into the GPS receivers on COMETs 1 and 2, allowing GPS data collection to begin.

In the ready state, COMET 1 is maneuvered into velocity vector mode in preparation for ARD, via commands from the ground station. At this point the RF link is activated and time stamped GPS and ACS data is transmitted through the link. COMET 2 begins monitoring the RF link for COMET 1 transmissions.

In the rendezvous state, ephemeris data for COMETs 1 and 2 (based on ground tracking and on-orbit GPS data) are used to compute the targeting commands required for COMET 2 to rendezvous with COMET 1. The resulting command sequence is then uploaded into COMET 2 from the ground station. The COMET 2 Orbital Adjust System (OAS) begins executing the commands to reach a station keeping state near COMET 1. While still several kilometers away from COMET 1, COMET 2 will be able to receive data through the RF link.

Relative position and velocity can then be used to keep COMET 2 in a station keeping state approximately 1 km from COMET 1.

Upon successful validation of system operations by the ground station, COMETs 1 and 2 are set into the proximity operations state. Using a combination of relative GPS information, a video tracker, and video-based proximity sensor, the Translation Maneuvering System (TMS) on COMET 2 executes commands to place COMET 2 within approximately 1 m from COMET 1.

At this point, the two spacecraft enter the docking state. COMET 2 instructs COMET 1 to shut down its ACS, allowing docking to take place with a stable, yet passive, spacecraft. The docking

is essentially a two-step process, consisting of a latched, but loose, coupling between the spacecraft followed very quickly by a braking procedure, hard docking and rigidization.

In the alignment state, the two spacecraft are rotated relative to one another to ensure they will be lined up close enough for the fluid connector halves to mate. Once the two spacecraft are aligned, the fluid connector mechanism draws the two connector halves together in preparation for the fluid exchange experiment. The two spacecraft will undock and dock several times to fully test the system.

The three primary technology areas to be validated by this demonstration are navigation sensors, docking mechanism, and fluid exchange system. The major subsystems of the baselined ARD demonstration include: GPS receivers on both spacecraft for relative position and velocity information during rendezvous and close proximity operations, video-based, closed-loop sensing and processing for position, attitude, and rate information during close proximity/docking operations, a single-point, probe-type docking mechanism with enough compliance for autonomous docking, and a fluid connector interface mechanism to allow efficient transfer of fluid resources.

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Experimental Validation of Docking and Capture Using Space Robotics Testbeds
by John Spofford, Martin Marietta

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Docking concepts include capture, berthing, and docking. Definitions of these terms, consistent with AIAA, are: Capture (Grasping) - the use of a manipulator to make initial contact and attachment between transfer vehicle and a platform. Berthing - positioning of a transfer vehicle or payload into platform restraints using a manipulator. Docking - propulsive mechanical connection between vehicle and platform. The combination of the capture and berthing operations is effectively the same as docking; i.e., Capture(Grasping) + Berthing = Docking.

Accurate estimation of target vehicle position and attitude is critical to successful autonomous rendezvous and capture. Computer vision is a sensing technique that can provide accurate position data at close ranges. With appropriate targets, the required computing power for target feature extraction is minimized. An advantage of using computer vision-type sensors is that human operators also can use the direct video image.

Martin Marietta has a 20 x 30 foot epoxy air bearing floor. Three testbeds, a Free Flying Vehicle, a Large Space Manipulator and a Dexterous Manipulator, provide a three DOF environment that closely approximates zero gravity. The testbed vehicle has three maneuvering DOF: two translational and one rotational. The vehicle has mounting points for additional test mechanisms and interfaces.

There are a few technical challenges to address. First, an integrated simulation of the complete capture and berthing operation, incorporating vehicle, platform and manipulators, should be implemented on a hardware testbed. Second, the control of a manipulator from a free flying vehicle is still an R&D activity. Finally, flight validation of the autonomous capture and berthing method will have to occur before user confidence is complete.

Questions / concerns addressed following the presenting: How does one determine the range, using the video system? With a five point non-planer target of known geometry and based on the viewed image, the range is calculated as well as out of plane parameters. How is the gap between rendezvous and capture bridged? Some other system, perhaps laser based, is needed for range of one kilometer and out.