CATEGORY 4 - OPERATIONS

Operator-Assisted Planning and Execution of Proximity Operations Subject to Operational Constraints
by Arthur J. Grunwald and Stephen R. Ellis, Ames

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Future multi-vehicle operations will involve multiple scenarios that will require a planning tool for the rapid, interactive creation of fuel-efficient trajectories. The planning process must deal with higher-order, non-linear processes involving dynamics that are often counter-intuitive. The optimization of resulting trajectories can be difficult to envision. An interactive proximity operations planning system is being developed to provide the operator with easily interpreted visual feedback of trajectories and constraints. This system is hosted on an IRIS 4D graphics platform and utilizes the Clohessy-Wiltshire equations. An inverse dynamics algorithm is used to remove non-linearities while the trajectory maneuvers are decoupled and separated in a geometric spreadsheet. The operator has direct control of the position and time of trajectory waypoints to achieve the desired end conditions. Graphics provide the operator with visualization of satisfying operational constraints such as structural clearance, plume impingement, approach velocity limits, and arrival or departure corridors. Primer vector theory is combined with graphical presentation to improve operator understanding of suggested automated system solutions and to allow the operator to review, edit, or provide corrective action to the trajectory plan.

Collision Avoidance for CTV: Requirements and Capabilities
by Thomas Nosek, TRW
Presented by Ken Rourke, TRW

Collision avoidance must be ensured during CTV operations near the space station. The design of the Collision Avoidance Maneuver (CAM) will involve analysis of CTV failure modes during rendezvous and proximity operations as well as analysis of possible problems external to the CTV, but that would require CTV to execute a CAM. In considering the requirements and design of the CAM for the CTV, the CAM design for the Orbital Maneuvering Vehicle (OMV) is a useful reference point from which some lessons can be learned and many CTV design options can be set forth

One design choice, the degree of integration of the CAM with the CTV's primary avionics, will greatly impact the CTV's CAM options. Also, staged CAM options at successive hold distances and times provide options for fault recovery without prematurely terminating the mission.

Questions and issues: Is a dissimilar backup computer required (in spacecraft)? Some people would like to remove the fifth "watchdog" computer unless or until it is shown to be necessary by some requirement or calculation.

MMU Applications for Automated Rendezvous and Capture
by Ed Whitsett, NASA, JSC

The Manned Maneuvering Unit (MMU) is a proven free flying platform that can operate in a piloted or unpiloted mode. The MMU is a possible candidate for an on orbit AR&C demonstration. A pilot can transition the system between manual and automated modes, then monitor the automated system for safety.

There is considerable flight experience with the MMUs. In February 1984, two MMUs were used on Challenger (STS 41-B). Astronauts performed translations of 150 and 300 feet to and from the orbiter. With a Trunnion Pin Attachment Device (TPAD) connected to the MMU control arms, docking exercises were performed on the SESA and SPAS pallets.

Another Challenger mission (STS 41-C) carried two MMUs in April 1984. During EVA, an astronaut attempted to capture a Solar MAX Satellite that was rotating and out of control. Unfortunately, the TPAD could not achieve a hard dock with the trunnion pin.

Discovery (STS 51-A) carried the MMUs up to space again in November 1984. Using the MMU, an astronaut rendezvoused with PALAPA B-2. This time, the TPAD affected a hard dock. The astronaut stabilized the satellite using the MMU's Automatic Attitude Hold (AAH). A WESTAR VI was captured two days later, using the same procedure.

Safe, noncontaminating gaseous nitrogen is the MMU propellant. Recharging can occur on-orbit using the Shuttle's large nitrogen tanks. The MMU can achieve 66 feet per second total change in velocity with a full charge and average sized astronaut. Other system characteristics are:

MMU weight with full charge:	339 pounds
Operation time on one (1) battery:	6 hours
Distance in daylight:	450 feet
Distance at night with running lights:	150 feet
Translation velocity:	0.3 ft/sec
Rotation acceleration:	10 deg/sec/sec
Height:	50 inches
Width:	33 inches
Length:	27 inches (arms folded)

The MMU can fly in either a pilot monitored or unmanned configuration. EVA Retriever programs demonstrated automated systems interfaces using MMU flight hardware.

Primary elements of an MMU based on-orbit AR&C demonstration are the MMU, an avionics package, and the Orbiter Remote Manipulator System (RMS) or Multiple Payload Experiment Structural System (MPESS), for use as a target. An AR&C avionics package can attach to the MMU between the control arms. The avionics container could be based on the IMAX camera design and could be mounted in front of the pilot. The avionics include the docking/capture sensor, GN&C processors, transmitter, additional power, and an optional pilot supervisory display. A docking or berthing mechanism can fit on the exterior of the package. An interface between the avionics package and the MMU would enable the AR&C system to access MMU gyro data and allow control of the MMU propulsion subsystem.

Propulsion system commands can be issued through the handcontroller interface, based on automated control algorithms. Control authority of the CTV can be emulated in a pulsed thruster mode.

Options for the AR&C target are: (1) docking/capture target only; (2) target and docking mechanism; or (3) spacecraft mockup with target and docking mechanism. Either the Orbiter RMS or the MPESS can have a mounted target. The MPESS would be in the Orbiter cargo bay.

A low cost on-orbit demonstration can start in the near term (~1.5 years). Facilities already exist for the design, development, simulation, integration, ground test, and training. The Space Operations Simulation (SOS) Laboratory provides a real-time simulation capability for rapid development, simulation, and system performance evaluation. The JSC Precision Air Bearing

Facility (PABF), using a MMU qualification-unit and EVA Retriever, can support physical integration of the MMU and AR&C systems.

Questions were addressed at the end of the presentation: Can the range of the MMU extend beyond 300 feet? Yes, but at this time a mission rule limits the range to 450 feet. Can an unmanned MMU be considered for an AR&D demonstration flight? Yes, but we want to make sure to provide safety/override capability in the event of an anomaly. What is the astronauts' reaction to the Auto R&D scenario? They do support the effort, but when safety reviews come up, the job of selling the idea gets harder.

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The Realtime Operations of the Space Shuttle Orbiter during Rendezvous and Proximity Operations
by Andrew Dougherty, Goddard Space Flight Center

The Shuttle first demonstrated the capability to perform precision proximity flying in 1983 when the SPAS-01 satellite was deployed and subsequently retrieved. This flight was intended to validate the capability of the Shuttle to perform proximity operations with a co-orbiting vehicle in preparation for the Solar Maximum Repair mission of the next year.

STS-39 was flown in April 1991 and contained the most complex relative trajectory flown by the Shuttle yet. Existing onboard targeting algorithms were used to plan and execute the complex flight profile. New techniques for using the software had to be developed to support the trajectory and they proved to be more accurate than the ground software in executing maneuvers.

Shuttle rendezvous operations have two segments: phasing and "the day of rendezvous." Phasing begins at lift-off and ends when the range to the target is approximately 40 nmi. The "day of rendezvous" phase of operations covers the last 40 nmi to the target. The name comes from the fact that most of the maneuvers executed during that last day are computed onboard, providing a functional difference.

Shuttle proximity operations cover the final phase of the rendezvous. The phase is characterized by crew control of the trajectory based on radar data and out-the-window viewing of the target. It begins immediately after the last rendezvous burn and ends with the successful grapple of the target. A subsection of proximity operations involves the deployment and separations. There are two phases of proximity operations, the standardized transition trajectory and the final approach. As the name implies, transition trajectory is a well known and standard trajectory flown by the crew to transition the Shuttle from an interception trajectory to formation flying with the target some 130 meters in front of it on the velocity vector. The approach, however, is not as standard because it depends on the characteristics of the target. Some targets are Local Vertical/Local Horizontal (LVLH) stabilized and some are inertially stabilized. The Shuttle program prefers the target to be in a LVLH stabilized configuration for grapple and places tight restrictions on the attitude and attitude rates of the target for nominal operations via the PIP.

Many significant lessons can be learned from the Shuttle program that can reduce mission planning costs for future vehicles; for examples: unify flight design and real-time operations software, integrate the flight design and real-time operations personnel, provide a control center and flight vehicle that allows for quick software upgrades, and use new state-of-the-art software development tools to reduce configuration control.

Significant benefits to both the Shuttle and Cargo Transfer Vehicle programs could be realized by co-developing rendezvous and proximity operations software because of the commonality of the algorithms.