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PAYLOAD ACCOMMODATIONS

SATELLITE SERVICING SUPPORT

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INTRODUCTION

On-orbit satellite servicing is expected to be a major focus of future U.S. space activities, with increasing emphasis on the use of unmanned vehicles and the potential for high frequency operations of manned vehicles. Such servicing will require rendezvous and docking/berthing operations by the space transportation system. These operations are currently performed manually by the flight crew in manned space transportation systems or by remote piloting for the first generation of unmanned space transportation systems. Autonomous rendezvous and docking capabilities will increase the effectiveness and availability of space transportation support of these operations.

The NASA Office of Aeronautics and Space Technology is currently funding research in technologies required for autonomous rendezvous and docking, including relative navigation sensors and guidance, navigation and control system algorithms. These technologies and their applicability to satellite servicing will be addressed. The Satellite Servicer System Flight Demonstrations, which will incorporate an autonomous rendezvous and docking capability into the Orbital Maneuvering Vehicle (OMV), are considered to be a near-term target for a subset of these technologies.

This report describes the proposed technology studies discussed at the Space Transportation Avionics Symposium in Williamsburg, VA on 7 - 9 November 1989. The discussions and findings of the Payload Accommodations Subpanel are also summarized.

OBJECTIVES

The major objective of the proposed focused technology development is to develop and demonstrate (ground and flight) autonomous rendezvous, proximity operations, and docking/berthing capabilities to support satellite servicing. It is expected that autonomous rendezvous and docking (AR&D) capabilities will benefit both the users (e.g., satellite developers and operators) and the transportation system developers and operators.

AR&D will provide increased availability of rendezvous and docking services by reducing the operational constraints associated with current capabilities. These constraints include specific lighting conditions, continuous space-to-ground communications, and lengthy ground tracking periods. AR&D will provide increased cost efficiency with the potential for reduced propellant expenditures and workloads (flight and/or ground crews). The AR&D operations will be more consistent allowing more flexibility in the design of the satellite control system and docking/berthing mechanisms.

TECHNOLOGY ISSUES

The major technology issues are the development of relative navigation sensors; development and integration of guidance, navigation and control (GN&C) algorithms and techniques; and integration of sensors, effectors, GN&C algorithms and techniques, and docking/berthing mechanisms into a total system capability. Each of these areas is discuss in more detail below.

Relative Navigation Sensor Considerations

Relative navigation sensors are required to support the operations spanning the rendezvous, proximity operations, and docking/berthing phases and is one of the major technology drivers for development of AR&D capabilities. One immediate issue is whether the technology thrust should be focused on a single sensor which spans all these phases, or a sensor suite, with various components supporting the different phases. Another consideration is the choice of active or passive sensor systems. Active sensor systems include the installation of equipment such as transponders or reflectors on the target vehicle to support the return of RF signals or light waves being transmitted by the chaser vehicle. Passive systems would rely on optical image processing by the chaser vehicle with little, if any, support by the target vehicle. The support might be a specified target form on the target vehicle.

As a result, there are a number of options for relative navigation sensors including radars, lasers, and optical imaging systems. These options are in various states of technology development. The technology studies range from proof-of-concept demonstrations to performance enhancements, where performance includes not only accuracies, but range of operation, size, weight, and power requirements. Indeed, under Project Pathfinder, JSC is performing a sensor survey and trade study to identify candidate sensors and their characteristics.

NASA/JSC is developing a laser docking sensor, a laser radar (LADAR) and LADAR imaging system, and an optical imaging system for the identification and tracking of a target. NASA/MSFC is also developing an optical imaging system for potential application to the OMV. The European Space Agency (ESA) is planning to use the Global Positioning Satellite (GPS) system and optical sensors to support the autonomous rendezvous, proximity operations and berthing of the Man-Tended Free Flyer (MTFF).

Applications of such sensors for exploration missions, particularly Mars missions, will place a premium on ability to withstand long periods of dormancy, light weight, small size and low power demands. Most of these attributes will also benefit their application to satellite servicing support, by reducing the resource requirements to be provided by the chaser vehicle.

Trajectory Design Considerations

Increased availability and high probability of successful rendezvous and docking operations would greatly benefit users. Trajectory designs are a major influence. Trajectory designs to support satellite servicing, using AR&D, will focus on maximizing the launch windows, minimizing operational constraints such as lighting and communications and tracking coverage, adaptability to contingencies, and safety (e.g., passive collision avoidance).

The trajectory designs will be integrated with the relative navigation sensor capabilities to accommodate the sensor field-of-view and required tracking arcs. For some sensors, lighting conditions may impact the trajectory design. Although there will be a focus on reducing the requirement for continuous communications between the orbiting spacecraft and the ground, the trajectory designs will need to address space-to-space communications coverage between the chaser and target vehicles.

The trajectories must also be designed to accommodate manual takeover, either by the flight crew in manned spacecraft or by remote pilots for unmanned vehicles. The manual intervention will at least be required to support aborts and contingencies. The requirement for completion of a failed automatic rendezvous and docking by manual means must be investigated.

Guidance, Navigation, and Control Algorithms

Navigation filters must be designed to estimate relative state (positions and velocities - translational and rotational) using outputs of the selected relative navigation sensors. The adaptability of the navigation algorithm to failed sensors must be addressed. These developments are not expected to be technology drivers, but require a integrated development process.

Guidance and targeting algorithms must be designed such that the targeted maneuvers are within the acquisition range of the relative navigation sensors. They must handle a broad spectrum of dispersions. The guidance routines must be tuned to the performance of the navigation system.

The flight control system design and its impact on proximity operations and docking/berthing are highly dependent on the configurations of the chaser and target vehicles. The configurations and types of control effectors (e.g., hot gas, cold gas, reaction wheels, control moment gyros) will impact proximity operations performance. Therefore, a generic flight control system cannot be developed for all possible spacecrafts.

The development of the flight control system must be iterated with the design of the docking/berthing mechanisms. Preliminary allocations of performance budgets can be established, but it is expected that design studies will dictate the need to modify these allocations based on maturing assessments of capabilities, cost impacts, and technical risks.

A control system moding strategy must be developed to support the docking/berthing operations. Also, the approach to damping the transients resulting from docking/berthing and assured stability of the mated configuration must be developed.

Docking Mechanisms

In general, docking/berthing mechanisms will be customized to specific vehicles and/or services. A NASA standard grapple fixture for the Shuttle Remote Manipulator System (RMS) has already been established. The OMV Program had originally planned to develop a Three-Point Docking Mechanism (TPDM) and a RMS Grapple Docking Mechanism (RGDM) to support satellite servicing by the OMV. Recent funding limits have resulted in the elimination of the development of the TPDM. However, NASA still desires to develop standard docking/berthing mechanisms, which can support satellite servicing.

The international docking study may also establish standard docking/berthing mechanism requirements. These requirements would be reflected in the AR&D development.

Systems Integration

A major effort will be required to integrate the sensor, effector, GN&C, trajectory, and mechanisms "point designs" into a total package which meets the performance requirements and accommodates dispersions and failures. It is expected that tradeoffs and iterations will be required to converge on an effective allocation of the total system performance requirements among the sensors, GN&C, and mechanisms. The evolving designs of these elements will identify cost, schedule and risk impacts, which must be accommodated.

Ground demonstrations are proposed to provide proof-of-concept and proof-of-design before commitment to development of the flight systems. The ground demonstrations will encompass the cost-effective use of engineering simulations, flat-floor simulations, and mechanisms test facilities. The benefits and costs of implementations for these various facilities must be assessed and an integrated plan for their utilization developed.

Flight demonstrations are proposed to provide proof-of-design before commitment to operational use. It is expected that the flight demonstrations will involve the Space Shuttle. A major SE&I task will be development of flight demonstration plans which make maximum use of the Shuttle while accommodating the potentially extensive integration with the NSTS Program. Flight demonstrations must take into account orbiter flight and ground crew monitoring and override capabilities.

TECHNOLOGY DEVELOPMENT APPROACH

It is proposed that a work breakdown structure patterned after the Pathfinder AR&D Project be used to focus the AR&D technology development to support satellite servicing. This WBS is shown in Figure 1.

Also, it is proposed that the AR&D development for satellite servicing be aligned with the proposed Satellite Servicer System Flight Demonstrations. The Orbital Maneuvering Vehicle (OMV) will be used as the chaser vehicle. Sensor options would be evaluated through a series of staged flight demonstrations of AR&D capabilities. The target vehicle will be one of opportunity. The Orbiter will provide the orbital delivery of the OMV and target vehicle and provide the base for flight crew monitoring and supervision of the flight demonstrations.

SYSTEMS INTEGRATION	GN&C DEVELOPMENT	SENSORS & MECHANISMS
- SYSTEM REQUIREMENTS DEFINITION	- RELATIVE GUIDANCE	- RELATIVE NAVIGATION SENSORS
- TRAJECTORY CONTROL RQMTS DEFINITION	- AUTOMATIC PROXIMITY OPERATIONS	- SENSOR TRADES
- SCENARIO ASSESSMENT	- COOPERATIVE CONTROL	- MECHANISMS APPLICATION
- PROGRAM PLANNING	- ARTIFICIAL INTELLIGENCE APPLICATIONS	

Figure 1. AR&D Work Breakdown Structure

MAJOR MILESTONES

A top-level definition of milestones was established for technology development and demonstration of AR&D capabilities to support satellite servicing. These milestones cover the period from CY 1990 through CY 1995.

- Define AR&D system requirements - 1991
- Develop sensor breadboard(s) - 1991
- Develop validated GN&C software - 1992
- Develop preliminary docking mechanism - 1992
- Implement ground demonstration(s) - Late 1992
- Develop plans for flight demonstrations - 1993
- Integrate and implement Satellite Servicer System (SSS) AR&D demonstration flights
  - Demonstration Flight 1 - Late 1993
  - Demonstration Flight 3 - 1995

CANDIDATE PROGRAMS

An assessment was made of programs which might benefit from the development of AR&D capabilities. The near-term focus will be on the Satellite Servicer System Flight Demonstrations.

Lunar and Mars exploration will definitely require AR&D capabilities for unmanned vehicle operations to overcome the signal delays and communications blockages, which preclude effective remote control. Manned Mars missions can benefit from AR&D because flight crew proficiency will be degraded by the long mission durations.

It is expected that future logistics support and orbital operations of the Space Station will involve unmanned transportation vehicles and high frequency operations of manned vehicles. AR&D will allow cost effective operations from the standpoint of resources, man power, and time lines.

The Shuttle Evolution, Assured Shuttle Availability, and Next Manned Transportation System Programs will emphasize user support for orbital operations. AR&D will be a significant enhancing technology for these orbital operations.

MAJOR ACCOMPLISHMENTS

Although there has not been a specific technology program focused on development of AR&D capabilities for satellite servicing, a number of technology studies are under way, which are directly applicable.

NASA/JSC is funding the development of laser docking sensors and optical sensors. One of the laser docking sensors was originally manifested for a flight test on an Orbiter flight, but has recently been reassigned to the Satellite Servicer System Flight Demonstration. An optical sensor is currently under development by NASA/MSFC and is being demonstrated in their ground test facilities.

The AR&D Project under the Pathfinder Program has been under way for nine months. A detailed project plan, mission scenarios, and preliminary system requirements have been developed. GN&C algorithm development, a sensor trade study, trajectory designs, and basic research in mechanisms are under way.

The release of Request for Proposals for the Satellite Servicer System Phase B Study is imminent. The development of the Orbital Maneuvering Vehicle is in progress. A standard NSTS grapple fixture has been established and the Satellite Services System Working Group is sponsoring the development of standard docking and grapple mechanisms. NASA is participating in an International Docking Study to explore the potential for standard docking mechanisms across international space elements.

FACILITIES

The facilities to be used in the development of AR&D capabilities include six and twelve degree-of-freedom engineering simulations, which currently exist at various NASA centers and contractors. No major new simulations are proposed. The significant effort will be the incorporation of pertinent hardware models and applications software into these simulations.

Flat-floor facilities exist at JSC and MSFC which would allow limited ground demonstrations of AR&D capabilities with some true degrees of dynamic motion. No major upgrades to the basic facilities are anticipated. However, installation of the AR&D-unique hardware, hardware emulators, or math models will be required in these facilities.

Thermal/Vacuum facilities exist at JSC and MSFC to provide environmental testing of AR&D components, including sensors and mechanisms. No upgrades are required for these facilities to accommodate the AR&D elements.

Docking mechanism test facilities exist at JSC and MSFC. These hydraulically actuated systems will allow the ground demonstration of docking/berthing mechanisms associated with satellite servicing. No upgrades are expected for these facilities. However, the unique mechanisms must be provided to these labs.

KEY CONTACTS

The following NASA personnel are currently involved with the development of technologies which are applicable to AR&D capabilities.

<u>NASA/JSC:</u>

- o Steve Lamkin, Pathfinder AR&D Project Manager
- o Charles Gott, Trajectory Control Analysis
- o Robert Savely, Artificial Intelligence Development

<u>NASA/MSFC:</u>

- o Tom Bryan, Autonomous Rendezvous and Docking Development
- o Richard Dabney, OMV
- o Ricky Howard, Flight Robotics
- o E. C. Smith

MAJOR FINDINGS/RECOMMENDATIONS FROM STATS PAYLOAD ACCOMMODATION SUBPANEL

Following the briefings to the Subpanel, the participants were requested to identify the technology "holes" in their areas and to correlate the ability of the proposed technologies to meet a set of prescribed "needs." The following provides a compilation of the material provided to the Subpanel chairmen, who condensed these inputs into a composite Subpanel summary for subsequent presentation at the closing plenary session.

Payload Accommodation Technology Holes

o Autonomous Rendezvous and Docking Capabilities

o Systems engineering to develop design and test requirements for AR&D matched to user/mission needs

o Potential commonality in hardware, software, and trajectory requirements

o Low-cost flight demonstrations

o Independent assess of applicable DoD technologies

o Identification of other operations which can use AR&D technologies (e.g., assembly, berthing)

o Assessment of benefits and impacts of AR&D capabilities in ongoing systems (e.g., Orbiter, Orbiter RMS, OMV, Space Station).

Correlation of AR&D Technology to "Needs"

O Increased Reliability

- AR&D provides increased consistency of proximity operations

O Increased Safety

- Provides local control versus remote control
- Use real-time, full-state information

O Decrease Operational Costs

- Will generally decrease operational costs, but the extent will be proportional to the level of trust vested in the autonomous system
- Reduces the current operational constraints (e.g., ground tracking coverage, communications coverage periods, lighting conditions) resulting in increased availability of rendezvous and docking services.
- Reduces resource requirements (e.g., propellant and crew time - flight and ground)

O Lower Hardware Costs

- Reduces mechanisms costs because of lower contact dynamics

O Increased Robustness/Flexibility

- Allows more operational flexibility
- Is adaptable to off-nominal conditions.