AIAA 93-4753

AUTONOMOUS RENDEZVOUS AND DOCKING SCENARIOS FOR THE DEVELOPMENT OF GUIDELINES AND STANDARDS

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AIAA Space Programs and Technologies Conference and Exhibit

September 21-23, 1993 / Huntsville, AL

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ABSTRACT

The scenarios presented in this paper were selected by the AIAA Space Automation and Robotics Committee on Standards to expose key technical issues which must be addressed in order to establish engineering guidelines and standards for space automation and robotics. The committee has decided to emphasize missions involving international cooperation and trans-orbital missions in its work. Three scenarios are briefly described: the fully automatic rendezvous and docking of two unmanned spacecraft in low Earth orbit, the rendezvous and docking of a Space Station assembly stage and the Space Shuttle, and rendezvous and docking for a Mars mission. The committee will maintain technical data concerning each scenario and will from time to time update the scenario descriptions as required.

INTRODUCTION

The American Institute of Aeronautics and Astronautics (AIAA) Space Automation and Robotics Committee on Standards (SAR/COS) was established in 1990 with a charter to develop, recommend, modify, and adopt standards, practices, and guidelines relating to automation and robotics utilized in space missions. The committee's responsibilities include addressing the need for national and international standards in space automation and robotics (SAR) technology for Earth orbit, Lunar, Mars, and other trans-orbital missions. The committee decided, during its January 27-28, 1993 meeting, that it needed a set of autonomous rendezvous and docking (ARD)‡ scenarios to help its six technical working groups (Avionics / Electronics / Computers, Human Factors, Mechanical / Mechanisms, Mission Factors, Safety / Reliability, and Software) focus and coordinate their activities. The SAR/COS is currently engaged in a project to develop a set of engineering design guidelines for space missions which require autonomous rendezvous and docking. This paper presents three initial working draft scenarios (two Earth orbit scenarios and a trans-orbital mission scenario) to help each of the Working Groups (WGs) identify generic issues, requirements, and terminology that are common to spacecraft and systems which must perform autonomous rendezvous and docking as part of their overall mission.

The United States has routinely performed rendezvous and docking with men in the loop as early as the Gemini program. The first rendezvous by the United States was performed in 1965 with the Gemini 7-6 mission. Two manned Gemini spacecraft rendezvoused and orbited the Earth at only 0.15 m (six inches) apart.[1] In March of 1966, Gemini VIII performed a manual docking with an unmanned Gemini Agena Target Vehicle. The Soviets demonstrated automatic rendezvous and docking with two unmanned Kosmos (Soyuz-class) spacecraft in October of 1967[2]. Since then, the Soviets have gone on to perform countless automated dockings of their Progress resupply vehicle to the manned Mir space station (with some ground support capability).

Autonomous rendezvous and docking (ARD) provides a valuable method for replenishment of consumables and payload exchange. Many current and future missions would benefit from an ARD capability. Examples include propellant resupply for satellites, fluid/gas resupply for orbiting laboratories, and payload exchange for experiments or servicing missions.

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‡ We are using the acronym "ARD" to emphasize, "***autonomous*** rendezvous and docking," rather than the more commonly used acronym "RVD" for "rendezvous and docking" in general.

SCENARIO 1: AUTONOMOUS RENDEZVOUS AND DOCKING IN LOW EARTH ORBIT

A low Earth orbit (LEO) scenario for autonomous rendezvous and docking (ARD) is described in this section. This scenario represents a near-term option for validating many of the technologies and concepts that can be applied toward other ARD missions, including trans-orbital ARD missions. Using the real constraints imposed by this LEO scenario, guidelines and eventually standards can be addressed in a realistic fashion.

On a short-term basis, many elements of an ARD system can be verified by performing an autonomous rendezvous and docking in low Earth orbit, using two unmanned spacecraft launched by expendable launch vehicles. The application of ARD to this type of scenario will be discussed. The design and operational issues for an on-orbit ARD demonstration that will involve two COMmercial Experiment Transport (COMET) spacecraft are then presented.

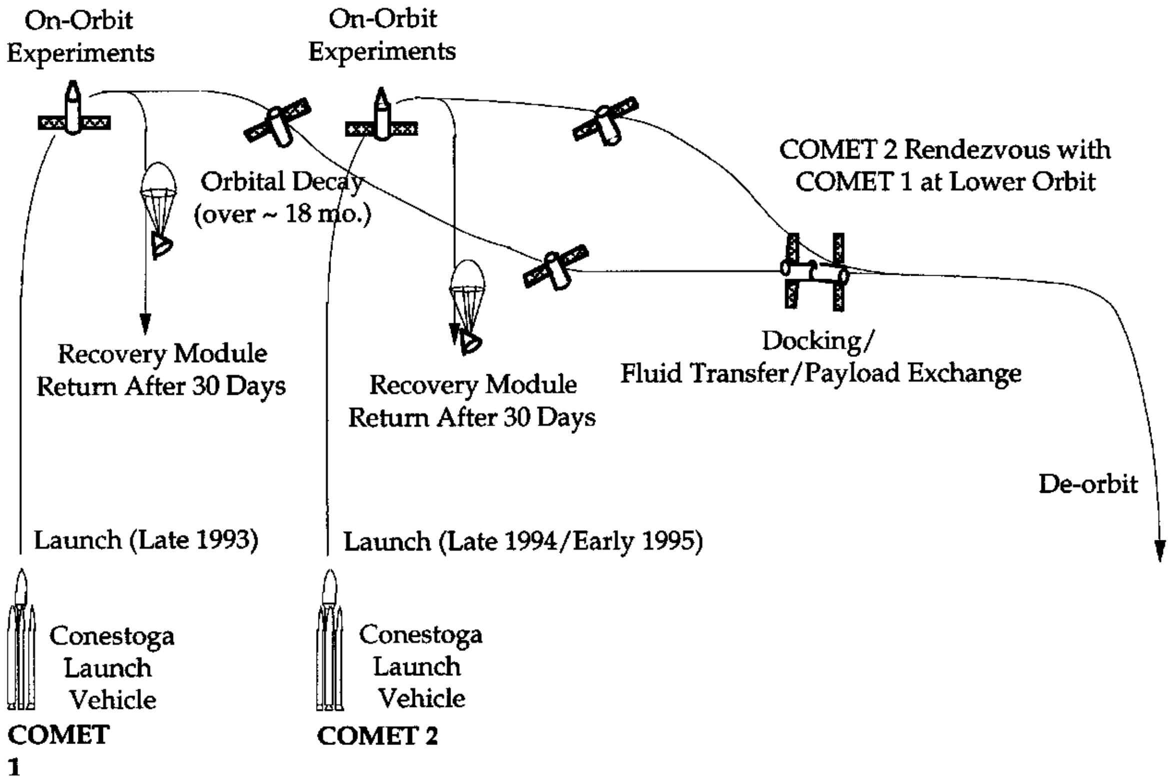

Figure 1.1 SpARC Low Earth Orbit ARD Mission Scenario

The Space Automation and Robotics Center (SpARC), a NASA Center for the Commercial Development of Space (CCDS), in conjunction with its industrial affiliates, initiated a flight demonstration of ARD technology to take place in the 1994 to 1995 time frame. This initial demonstration will make use of two Commercial Experiment Transporter (COMET) Service Modules that will be launched by expendable launch vehicles as illustrated in Figure 1.1. This demonstration will provide a significant step in the validation of enabling technologies for autonomous rendezvous and docking.

This COMET-based ARD demonstration will be performed autonomously (i.e., without any human intervention) to demonstrate a cost-effective resupply capability. By reducing the scope of the experiment to docking with a stable, cooperative[*] target spacecraft, and taking advantage of the Global Positioning System (GPS), the complexity and cost of validating ARD technology is considerably reduced. One of the most important assets for Earth orbit ARD today is the availability of GPS for navigation during rendezvous and proximity operations. GPS reduces some of the demands on sensors that must determine position and velocity to prepare the two spacecraft for docking.

The Commercial Experiment Transporter (COMET) Mission

COMET is the first system to provide commercially available transportation and recovery services to the space experiment community. On behalf of the 17 CCDSs, the NASA Office of Commercial Programs has procured payload space on COMET. At this time, four payloads,

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[*] Cooperative Target - a target vehicle having specially designed active or passive target patterns or devices to aid in tracking or position/attitude determination; Non-cooperative Target - a target vehicle that has not been augmented with any type of pattern, marking, or device to specifically aid (or inhibit) the vehicle's detection.

including ARD, are ready for transport in the COMET 1 Service Module. Eight other experiments will be placed in the Recovery Module section of COMET, to be returned to Earth after 30 days on-orbit. The Service Module will remain on-orbit in anticipation of docking with COMET 2. Although not specifically designed for an ARD capability, the COMET Service Module will be made into a suitable platform by retro-fitting with the SpARC ARD payload.

The COMET spacecraft will be inserted into low Earth orbit from a launch facility on Wallops Island, Virginia. The mission parameters are listed in Table 1.1[3]. Table 1.2 contains the payload accommodation parameters for the Service Module[4], where the ARD payload will be carried.

Autonomous Rendezvous and Docking Demonstration

Unlike most COMET payloads, ARD will involve two COMET Service Modules. By maintaining the COMET 1 Service Module (launch date: late 1993) in orbit for approximately 18 months, a rendezvous and docking can be performed with a second COMET Service Module that is scheduled for launch in late 1994 to early 1995 (see Figure 1.1).

The first COMET Service Module will act as a passive target. It will be three-axis stabilized, but no orbit change capability will exist. COMET 2 will contain the orbital adjust and maneuvering systems to enable rendezvous and docking of the two spacecraft.

SpARC evaluated several types of consumable resupply mechanisms[5,6,7,8], sensors[9,10,11], and docking mechanisms for use in this demonstration. The major subsystems of the baselined ARD demonstration include:

- Global Positioning System (GPS) receivers on both spacecraft for relative position and velocity information during rendezvous and close proximity operations.
- Video-based and laser-based, closed-loop sensing and the associated processing for position, attitude and rate information during close proximity/docking operations.
- A single-point, probe/cone docking mechanism with sufficient compliance for autonomous docking.
- A resupply connector interface mechanism to allow efficient transfer of fluid/gas resources.
- A payload exchange (i.e., harvest) capability using a small, robot-accessible replacement unit.

For this initial demonstration, a MOOG resupply interface system will be used in a gas exchange (N_2) experiment. For rendezvous, both spacecraft will be equipped with GPS receivers and there will be a

Table 1.1 COMET Mission Parameters

Parameter	Requirement
Mission Duration	Recovery Module/Service Module Exps: 30/100 days ARD Experiment (Service Module): 2 yrs +
Nominal Orbit	555 km (300 nmi), 40.6° inclination
Microgravity Level	$< 10^{-5}$ Gs continuous
Attitude Pointing	Solar Inertial ± 5° Earth Pointing ± 1° (limited periods)
Attitude Control	3 Axis Active Control

Table 1.2 COMET Service Module Payload Accommodation Parameters

Parameter	Capability
Total Payload Weight	68 kg (150 lbs) minimum
Total Payload Volume	Approx. 0.425 cubic m (15 cubic feet)
Power Available	
- continuous	350 W
- peak	400 W for 200 hrs.
- voltage	28 ± 4 VDC
Heat Rejection	Approx. 570 W
Internal Environment	
- pressure	Vacuum
- temperature	22.2° ± 2.8° C (72° ± 5° F) at baseplate
Communications (half duplex)	
- command uplink	9.6 kb/s
- data downlink	250 kb/s
- video downlink	Merged with data downlink
- frequency of transmissions	Average: 5 pass/day, 40 min/day

dedicated radio link between the two Service Modules. The receivers will provide relative position location of the spacecraft to within approximately 100m (or less) and relative velocities to within approximately 0.01 m/s. For proximity and docking operations, both a laser-based sensor and a video-based sensor will be used to provide position, range, orientation, and the associated rates.

Scenario 1 Summary

Autonomous rendezvous and docking is a critical element in the retrieval of experiment payloads (i.e., containerized harvest and resupply) and resupply of consumables (e.g., fuels, gases, water, and others). At this time, only limited autonomous capability has been demonstrated, even though many future missions would benefit greatly from this capability. The motivation behind this experiment is to demonstrate a cost-effective method of rendezvous and docking using available technology. The COMET system provides a fast (1994 to 1995 time frame), economical method of performing the ARD demonstration. COMET has the necessary operational platform characteristics, access to potential ARD payload users, and a timely launch schedule to meet the requirements of an ARD technology demonstration.

The low Earth orbit scenario for rendezvous and docking as described here presents a near-term opportunity for demonstrating several enabling technologies. This scenario also provides a convenient opportunity to develop guidelines and eventually standards with verification using actual flight data.

SCENARIO 2: RENDEZVOUS AND DOCKING OF THE SPACE SHUTTLE WITH A SPACE STATION ASSEMBLY STAGE

The Space Station is envisioned to be assembled in stages, using multiple Space Shuttle missions. A complete description of the assembly sequence can be found in[12]. The partially assembled stages are referred to as mission-build stages. In this scenario we will assume that multiple missions of the Space Shuttle will deliver components into orbit which will be added to each successive mission-build stage. The Space Shuttle, with its manifest, must rendezvous with the orbiting, mission-build stage. Close proximity maneuvers will then be mutually conducted to maneuver the Shuttle relative to the stage and into a position where docking can be accomplished. After docking, operations are conducted to build the next stage. NASA has considered several techniques of conducting these close proximity maneuvers. One method, the primary, is to fly the Space Shuttle into docking position using the Space Shuttle Reaction Control System with the mission-build stage inert. In another backup method, the Space Shuttle Remote Manipulator System grapples the stage and places it into docking position. In all cases the rendezvous and docking is to be accomplished manually with little, if any, automation involved. The purpose of this scenario is to afford the technical community the opportunity to study automation of this near term space operation. The stage selected for the scenario is mission-build stage 5, and the Space Shuttle mission is referred to as MB 6. This stage was selected since it involves non-coaxial docking of large spacecraft, each having complete attitude control capability. After docking, on-orbit assembly operations then take place to build stage 6. After the stage 6 build, the Space Shuttle and the stage separate.

Geometric and Mass Characteristics for MB 6

Figure 2.1 is a drawing illustrating some of the major components of stage 5. The subsystems illustrated are: the starboard Photovoltaic System arrays (PV), the starboard Thermal Control System (TCS), the Space Station Remote Manipulator System (SSRMS), and Node 2. Major elements not identified on the figure (for clarity) are: the Solar Array Alpha Joint (SARJ), the Propulsion Module platforms and tanks, the Control Moment Gyroscopes (CMGs), the Mobile Transporter, Copula 1 (installed on the port side of Node 2), and the Pressurized Mating Adapter (PMA1). Also shown on the figure is the stage reference coordinate system. The coordinate system is consistent with that used in the Space Station program[13]. Table 2.1 contains pertinent geometry and mass characteristics of the stage 5 configuration with respect to the coordinate system shown. It also contains the required information for the combined spacecraft after initial docking (combined beginning), for the combined spacecraft just prior to separation, and for the assembled stage 6.

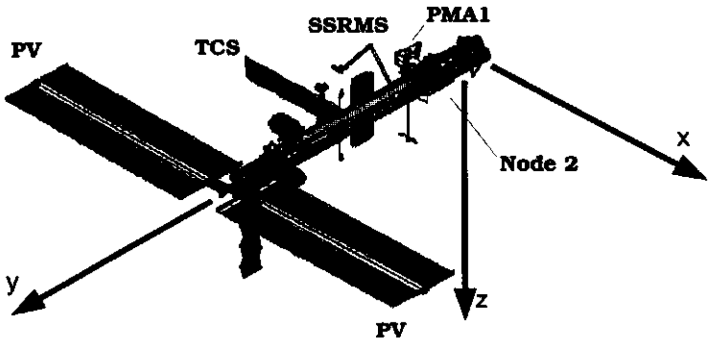

Figure 2.1 - Major elements of stage 5 showing its reference coordinate system.

Table 2.1 - Geometric and mass characteristics for MB 6 in stage 5 coordinates.

Stage 5:		
Mass:		
70,703 kg		
Center of Gravity:		
X: -1.1948 m	Y: 13.7587 m	Z: 1.1765 m
Moments of Inertia:		
I_{xx}: $1.7499(10)^7$ kg-m^2	I_{yy}: $.2327(10)^7$ kg-m^2	I_{zz}: $1.8583(10)^7$ kg-m^2
I_{xy}: $-.1248(10)^7$ kg-m^2	I_{yz}: $-.0281(10)^7$ kg-m^2	I_{zx}: $-.1024(10)^7$ kg-m^2
Combined Beginning:		
Mass:		
$1.8362\ (10)^5$ kg		
Center of Gravity:		
X: 5.8704 m	Y: 2.7097 m	Z: 3.3589 m
Moments of Inertia:		
I_{xx}: $6.2541(10)^7$ kg-m^2	I_{yy}: $9.3906(10)^6$ kg-m^2	I_{zz}: $6.7678(10)^7$ kg-m^2
I_{xy}: $1.2073(10)^7$ kg-m^2	I_{yz}: $-1.555(10)^6$ kg-m^2	I_{zx}: $-5.397(10)^6$ kg-m^2
Stage 6:		
Mass:		
87,452 kg		
Center of Gravity:		
X: -0.5669 m	Y: 10.7564 m	Z: 1.7617 m
Moments of Inertia:		
I_{xx}: $2.1199(10)^7$ kg-m^2	I_{yy}: $2.9373(10)^6$ kg-m^2	I_{zz}: $2.2501(10)^7$ kg-m^2
I_{xy}: $5.0979(10)^6$ kg-m^2	I_{yz}: $-1.398(10)^5$ kg-m^2	I_{zx}: $-1.807(10)^6$ kg-m^2

Altitude and Attitude Strategy

The altitude strategy is, following separation, to have the orbiting stage boosted to an altitude from which expected decay will result in a 220 nautical mile altitude at the time of the next mission-build flight. The following subsections deal with details of the attitude and approach strategies.

Rendezvous: Prior to the MB-6 rendezvous, stage 5 is in a Local-Vertical, Local-Horizontal-Torque Equilibrium Attitude (LVLH-TEA) and must maneuver from this attitude to a -X gravity gradient (GG) attitude for Space Shuttle approach. The LVLH-TEA attitude is the Torque Equilibrium Attitude (TEA) that orients the vehicle so that its X, Y, and Z coordinate axes are nearest to the Local-Vertical, Local-Horizontal (LVLH) axis system (see figure 2.2). A TEA is the attitude for which average secular disturbances are minimized over a single orbit; and, the LVLH axis system is an axis system with its Z-axis pointed to the center of the Earth, its X-axis along the orbital velocity (assuming a circular orbit), and its Y-axis normal to the orbit plane. This approach is illustrated in figure 2.3. The -X GG attitude is one where the stage X-axis points to the negative orbital velocity direction and the Y-axis is pointed away from the center of the Earth (as opposed to the Z-axis). This attitude is selected so that the Orbiter can rendezvous with the Node 2 grapple fixture using an approach along the orbital velocity vector. The PV arrays are oriented so as to minimize Orbiter plume impingement and contamination and the TCS is oriented so as to minimize plume induced loads during proximity operations.

Combined Beginning, End, and Separation: After rendezvous the Orbiter mates with stage 5 via the Pressurized Mating Adapter. The combined vehicles are maneuvered using the stage 5 CMGs to a -X GG-TEA

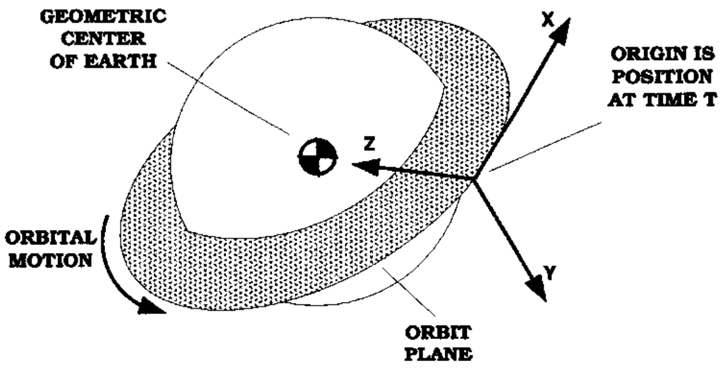

Figure 2.2 - LVLH coordinate system.

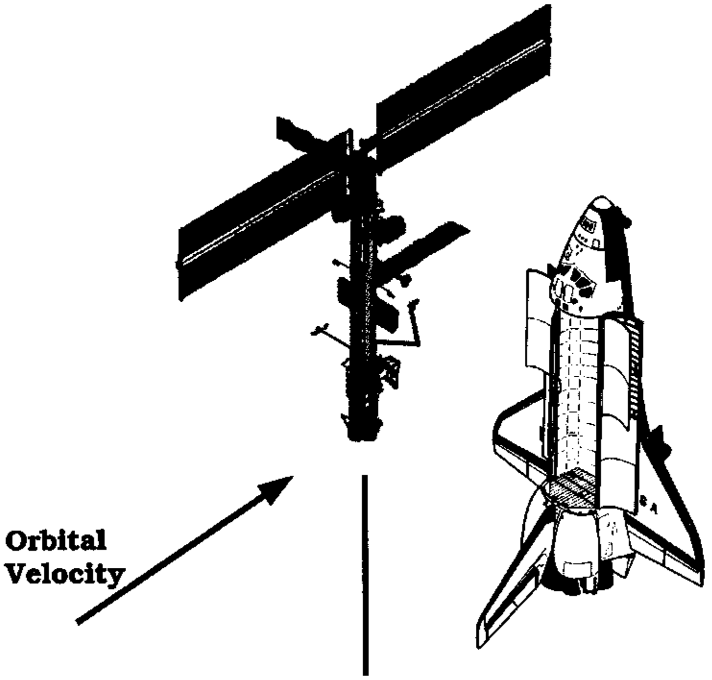

Figure 2.3 - Altitude and Attitude Strategy

with the underside of the Orbiter forward and normal to the orbital velocity. This attitude has been selected to minimize the need for attitude adjustments while the Orbiter is mated to the stage. During mating, attitude control is provided with the stage 5 CMGs. Once the -X GG-TEA is achieved, the PV arrays are commanded to a Sun track mode while the TCS is in an anti-Sun tracking mode to maximize radiation cooling.

On-orbit operations are conducted during mating to build stage 6. After the stage 6 build, the Orbiter separates from stage 6. During separation stage 6 must hold attitude to a +/- 1 degree deadband while the Orbiter fires its jets to back away. This attitude must be maintained until the Orbiter is at least 305 m (1000 ft.) away from stage 6. During separation the PV arrays are oriented so as to minimize Orbiter plume impingement and contamination.

SCENARIO 3: TRANS-ORBITAL MISSIONS (EARTH TO MARS)

The generic autonomous rendezvous and docking (ARD) spacecraft we envision is unmanned and it receives its mission orders from Earth ground control. Its mission is to ferry consumables to a cooperative rendezvous target. We will assume that ground control consists of a network of cooperating international ground stations and satellites. For example, we could assume that the spacecraft and its launch systems are built using components supplied by international vendors and assembled by a U.S. integration firm, it is owned and operated by a European firm, and it is capable of docking with and resupplying any spacecraft with compatible docking and consumables transfer systems (e.g., U.S., Russian, European, Japanese, etc.).

Spacecraft Systems

The spacecraft is designed to automatically maintain a communications link with Earth ground control except for brief periods when certain maneuvers may cause a temporary misalignment of the communications antenna or when environmental or trajectory disturbances (e.g., moon eclipse) cause the spacecraft or the Earth ground control to loose the communications link. The spacecraft is designed to continuously attempt to regain the Earth ground control communications link whenever it is lost. Maintaining the communications link is a primary mission task. Earth ground control has the capability to periodically update the spacecraft's knowledge of its own location and motion parameters as well as those of its ARD target. Earth ground control also maintains a similar communications link with the ARD target system.

The spacecraft is equipped with a single main propulsion thruster fixed to the rear of the craft. It provides translation motion in one degree of freedom along the positive Y axis of the spacecraft (international standards for coordinate frames of reference, axis naming conventions and polarities, and angular measurement direction would be very useful). The craft is equipped with twelve fixed maneuvering thrusters to provide fine positioning and steering in six degrees of freedom for motion control (translation at very slow to slow speed along the X, Y, and Z axis plus roll, pitch, and yaw), with four thrusters on each axis. The spacecraft is also equipped with sensors such as an inertial navigation system (INS) containing gyros and accelerometers, an astrotracker capable of optically tracking celestial objects (e.g., Sun, Earth, Moon, Polaris, the planets, etc.), a microwave beacon tracking system capable of locking onto and tracking an actively transmitting beacon on a cooperating target, radar, a laser ranging device, stereo video/infrared cameras, and a lighting system for docking. The spacecraft's antennas and optical systems are all capable of pan and tilt. The craft is equipped with a docking probe fixed to the front of the spacecraft. This docking device is capable of extension and retraction over short distances and is equipped with grasping/latching mechanisms, contact sensors, and various mating interfaces (e.g., electrical power, communications, fuel, fluids, gases, etc.).

ARD Target Spacecraft Systems

The generic rendezvous and docking target craft is assumed to be cooperative and capable of actively participating in the autonomous rendezvous and docking operation. It may or may not be manned. The target craft could be another spacecraft, a satellite, a space station, or some other orbiting space system. The target craft may be owned, operated, designed, and built by a number of international space technology concerns. The target craft incorporates many of the systems and capabilities described above for a generic ARD spacecraft. It is equipped with a system for maintaining communication with earth ground control, a position and attitude sensor suite (INS and astrotracker), at least a three degree-of-freedom maneuvering system (roll, pitch, and yaw), a beacon system, a docking port, spacecraft compatible grasping, latching, and interface mechanisms, docking lights, and it may have tracking sensors to detect and localize a docking spacecraft. The target craft might also be capable of establishing a two-way link and communicating its identification and status to the docking spacecraft during the rendezvous and docking operation.

Earth to Mars ARD Mission

The Earth to Mars mission scenario we envision involves an autonomous unmanned spacecraft beginning its mission from Earth orbit. The spacecraft is in communication with Earth based ground control using a radio frequency (RF) link. Ground control gives the spacecraft its mission orders. The spacecraft is ordered to rendezvous and dock with a space station in orbit around Mars. The rendezvous is to take place in 200 Earth days. The spacecraft is given updates on its own current position and orbit relative to Earth as well as the pertinent information needed for the spacecraft to compute a transit trajectory (i.e., a solar orbit path) to intercept the Mars space station in 200 Earth days.

The minimum Earth to Mars transit velocity is approximately 30.42 km/s (18.9 miles/s). Earth's closest approach to Mars is 78,390,000 km (48,700,000 miles). The maximum distance between Earth and Mars is 399,000,000 km (248,000,000 miles) with a mean distance of 288,000,000 km (141,100,000 miles). Mars is approximately 13 light minutes from Earth, in mean distance, which gives a gross approximation of the expected communications latency between Earth ground control and Mars.

After computing its intercept trajectory and propulsion requirements the spacecraft uses its maneuvering thrusters to assume the proper attitude for a main propulsion thruster burn. The burn time is calculated to achieve the desired transit velocity. During the transit the spacecraft monitors tolerance thresholds on its trajectory. This is done using updates from ground control and continuous feedback from the INS and the astrotracker system. Whenever a threshold is exceeded a new trajectory and steering parameters are computed, the maneuvering thrusters are activated, and a mid-course correction burn of the main thruster is executed. The transit phase of the mission is completed when the spacecraft arrives within orbit distance of Mars (within Mars' sphere of influence). At this point the spacecraft executes a braking maneuver. Generally this involves using the maneuvering thrusters to orient the craft approximately 180 degrees about and firing the main thruster. Once orbit around Mars is achieved, an orbiting intercept trajectory is computed and executed to come into rendezvous distance of the Mars space station.

Rendezvous distance is achieved when the spacecraft and the space station are separated by a distance less than the maximum range of the spacecraft's primary distance/direction measurement sensor (normally either the microwave beacon or the radar system). Once rendezvous distance is achieved a sensor search is conducted until contact is made with the cooperating target. At this point the sensors are locked onto the target and they begin tracking it, thereby providing continuous feedback on the distance and direction to the target. Next the target is identified to confirm that rendezvous has been achieved. This can be accomplished using communications and/or sensor readings of known patterns on the target.

Gross positioning maneuvers begin after target identification is confirmed using only the maneuvering thrusters. During this phase the spacecraft must achieve a pre-docking position and orientation relative to the docking port on the Mars space station. Earth ground control orders the Mars space station to null out any rotational motions it might be experiencing (e.g., roll, pitch, or yaw velocities), in preparation for docking, at this point in the mission. The pre-docking position and orientation brings the spacecraft into synchronous orbital motion with the docking port, with the docking device aligned for docking, and with the close proximity sensors (stereo video/infrared cameras) locked and tracking the docking port. The spacecraft also nulls all of its rotational motions during the pre-docking alignment procedure.

The next phase is docking. At this point a final check of safe docking conditions is made (e.g., verification of safe docking port conditions using sensor inspection of the port or alternatively a final communication with the space station to confirm readiness for docking). The final docking maneuver is then executed, perhaps including extension of the docking probe until the contact sensors indicate contact. When contact is achieved the latching/grasping device is engaged. The last step is to confirm proper spacecraft to space station latching and interface system connections using interface sensors and spacecraft to space station communication over the docking probe. This completes the ARD mission.

The ARD mission described above can be summarized in the following steps:

Transit Phase (starts outside of sensor range, ends inside primary sensor range)

1. Transit to the rendezvous location.
2. Initiate Rendezvous Phase

Rendezvous Phase (starts inside primary sensor range, ends inside pre-docking range)

1. Search for target until detection, begin tracking (inside primary sensor range).
2. Identify the target (using sensors and/or communications).
3. Approach the target (gross positioning) until pre-docking distance is achieved.
4. Spacecraft and target null rotations and achieve close-aboard synchronous orbit

5. Initiate Docking phase.

Docking Phase (may have two-way communications, must be in sensor contact, and within pre-docking range)

1. Detect docking port.
2. Identify docking port and verify safe conditions.
3. Approach the port (fine positioning using sensors).
4. Capture and mate with docking port.
5. End of Rendezvous and Docking, initiate next mission phase.

Technical Issues and Requirements

By analyzing this Earth to Mars mission scenario a number of generic issues and requirements can be highlighted. A few of them are discussed here. The assumption that this space venture is an international effort requires that ***the major spacecraft components and the target craft docking systems be built according to international standards***. The components must comply with form and fit, interface, and interoperability standards. They must also perform a certain minimum set of standard functions. These interchangeable components will include mechanical, electrical, electronic, computer, and software components. *International standards for mission terminology and measurement conventions* (e.g., coordinate system definitions) are also obviously needed.

In this scenario an important requirement is the need for maintaining a ***continuous communication link with Earth-based ground control***. This link is used for high-level command and control of the spacecraft and to exchange relevant mission data. This requirement leads to a host of other sub-requirements and issues such as the need for ***international standards for communications*** protocols, syntax, and semantics of command, control, and information messages, the communications medium to be used, the channel bandwidth required, communications relay mechanisms required, etc. Since the link must be maintained throughout the mission this implies that communications will likely account for a substantial amount of the power used aboard the spacecraft over the entire mission.

Two significant communications issues are the ***communications window*** and ***communications latency***. The communications window comes into play whenever the communications link must be broken during some mission phases. This means that the spacecraft must be able to safely function during communications blackout times. This may require a moderate amount of autonomy to insure safety during blackout periods.

The communications latency issue can have a larger impact on the need for autonomy and automation, especially for unmanned spacecraft. The communications latency problem becomes more acute as the spacecraft's distance from Earth increases. As can be seen in the Earth to Mars mission above, we can reasonably expect two-way communications to have a mean latency on the order of 26 minutes. This magnitude of latency makes it impractical to control the details of rendezvous and docking from an Earth-based ground control station. As a consequence of communications latency we must rely on a greater degree of autonomous operation for unmanned spacecraft, especially in trans-orbital missions.

Another basic mission parameter which drives other requirements is ***mission duration***. As the mission duration increases, the quantity, storage space, and mass of consumables (e.g., fuel and gases) must be increased. This in turn dictates spacecraft size, mass, and propulsion requirements. Mission duration will also dictate the degree of reliability required and the number of backup systems required.

Manned spacecraft require human environmental systems and safety systems which are not required for unmanned spacecraft. As a result, manned spacecraft will generally be larger and more massive than unmanned spacecraft. Human safety requirements will also drive the specifications for systems reliability. On the other hand, manned systems provide a higher degree of flexibility in mission operations and allow more complex maintenance to be performed.

CONCLUSIONS

Three scenarios have been presented in this paper which were selected to cover both near term and long range needs of automation and robotics technology for space. These have been selected by the AIAA Space Automation and Robotics Committee on Standards to expose key technical issues which must be addressed in order to establish engineering guidelines and standards for space automation and robotics. This paper has briefly described the scenarios in light of novel problems that each possesses. The fully automatic rendezvous and docking of two unmanned spacecraft in low Earth orbit emphasized consumables resupply and docking mechanisms for small spacecraft in low Earth orbit whereas the rendezvous and docking of a Space Station assembly stage and the Space Shuttle emphasizes large spacecraft with man-rating reliability requirements. Finally, the rendezvous and docking for a Mars mission deals with the need for full automation with little possibility of teleoperator interaction. It is the intent of the SARCOS to maintain a technical data base concerning each scenario and will from time to time update the scenario descriptions as required and publish more detailed descriptions of the scenarios as they mature.

ACKNOWLEDGMENTS

The COMET-based ARD program (Scenario 1) is sponsored by the Space Automation and Robotics Center (SpARC), a NASA Center for the Commercial Development of Space, through NASA Contract NAGW1198, and by SpARC's ARD program industrial and field center affiliates. Special recognition is due to M. E. Dobbs, D. J. Apley, Jr., D. J. Conrad, and M. P. Frazer of the Environmental Research Institute of Michigan (ERIM), Space Automation Robotics Center (SpARC), Ann Arbor, Michigan , and D. K. Slayton, EER Systems Corporation, Space Services Division, Seabrook, Maryland, for their assistance in preparing the Scenario 1 section of this paper.

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