N90-22090

THE RESUPPLY INTERFACE MECHANISM RMS COMPATIBILITY TEST

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ABSTRACT

Spacecraft on-orbit servicing consists of exchanging components such as payloads, orbital replacement units (ORUs), and consumables. To accomplish the exchange of consumables, the receiving vehicle must mate to the supplier vehicle. Mating can be accomplished by a variety of docking procedures. However, these docking schemes are mission dependent and can vary from shuttle bay berthing to autonomous rendezvous and docking. Satisfying the many docking conditions will require use of an innovative docking device. The device must provide fluid, electrical, pneumatic and data transfer between vehicles. Also, the proper stiffness must be obtained and sustained between the vehicles. Fairchild Space Company has developed a device to accomplish this, the resupply interface mechanism (RIM). The RIM is a unique device because it grasps the mating vehicle, draws the two vehicles together, simultaneously mates all connectors, and rigidizes the mating devices.

Johnson Space Center (JSC) Manipulator Development Facility (MDF) was used to study how compatible the RIM is to on orbit docking/berthing. The MDF contains a shuttle cargo bay mockup with a remote manipulator system (RMS). This RMS is used to prepare crew members for shuttle missions involving spacecraft berthing operations. The MDF proved to be an excellent system for testing the RIM/RMS compatibility. The elements examined during the RIM JSC test were:

- RIM gross and fine alignment
- Berthing method sequence
- Visual cuing aids
- Utility connections
- RIM overall performance

The results showed that the RIM is a good device for spacecraft berthing operation. Mating was accomplished during every test run and all test operators (crew members) felt that the RIM is an effective device.

This paper will discuss the purpose of the JSC RIM test and its results.

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INTRODUCTION

The recovery of LDEF in late January 1990 has once again demonstrated that on-orbit retrieval of spacecraft is a routine operation for the shuttle. Perfecting the process of spacecraft retrieval would lead to the enhancement of on-orbit spacecraft servicing. To facilitate on-orbit servicing a spacecraft must be designed for maintainability. Maintainable spacecraft provide easy access for exchange of various components using Extra Vehicular Activity (EVA) or a robotic manipulator such as the RMS. The various components are ORUs, payloads, and consumables. Consumables maintain the spacecraft functional integrity. These consumables consist of propellant, coolant, water, waste, etc. With replenishing capability, the spacecraft operational life can be extended. Replenishing can be accomplished using two scenarios. The first would involve rendezvous and docking of a spacecraft and refueling tanker. The second would require retrieval of a spacecraft using the RMS, and then berthing it to a refueling tanker in the shuttle cargo bay. The interface used to mate the two vehicles has to provide transfer of utilities across the separation plane. The type of utilities requiring transfer are electrical, pneumatic, and fluid. Additionally, the mating interfaces must be brought together to their specified rigidization. The Fairchild Space Company (FSC) realizes the important role that the interface must play in spacecraft servicing. Therefore, FSC initiated an Internal Research and Development (IR&D) program to define, design, build, and test an interface system for generalized spacecraft. The RIM illustrated in figure 1 is the result of this program. The RIM functions are:

1. To provide mating guidance during the docking/berthing process.
2. To capture and draw the two vehicles together.
3. To connect simultaneously all utility connectors.
4. To rigidize the interface.

The unique aspect of the RIM is that it accomplishes the above docking tasks in a single action.

The RIM was tested at JSC MDF to determine its compatibility to the RMS.

RIM DESIGN DESCRIPTION

The RIM illustrated in figure 2 consists of two parts: an active half and a passive half. The cylindrical shape of the RIM is designed such that the passive half fits internally into the

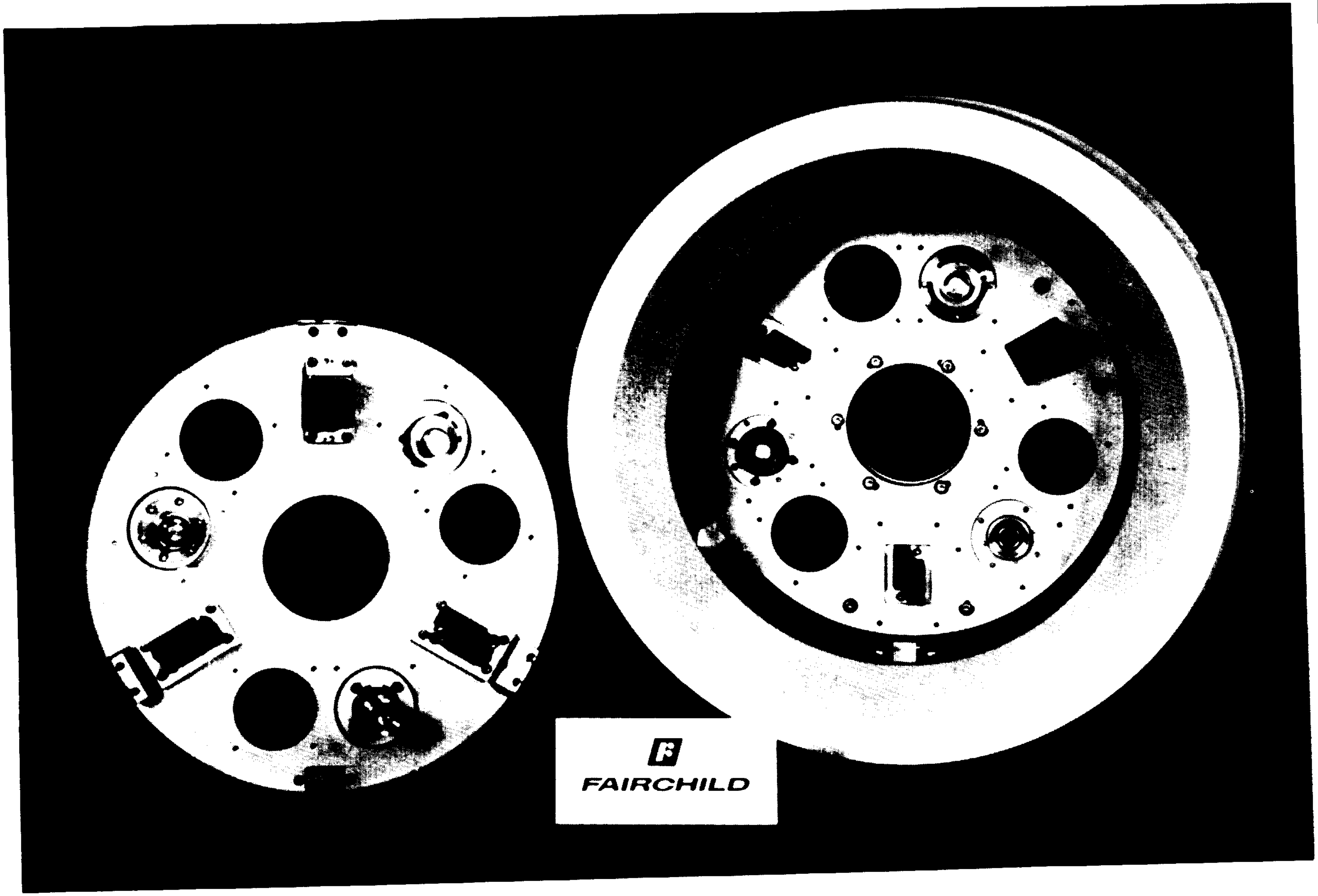

FIGURE 1: THE RIM

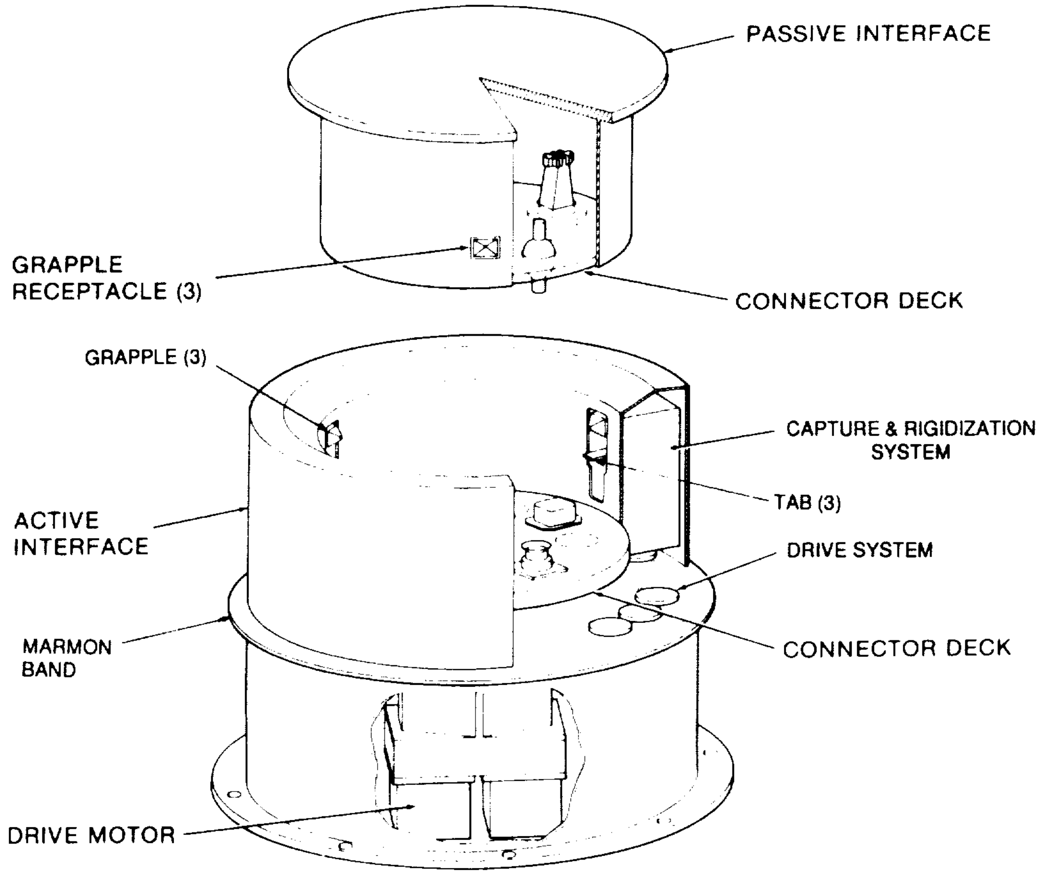

Figure 2: RIM, EXPLODED VIEW

active half. The active half is normally mounted to the refueling tanker. It contains the proprietary capture/rigidization mechanisms, sensors, a controller system, a safety system and the female halves of the electrical connectors and fluid couples. Also, the active half has an opening with a conical rim. The conical rim accepts gross positioning and alignment tolerance of $\pm$ 2.0 inches and $\pm$ 10°. This opening is gradually tapered at a 45° angle providing for a passive RIM final alignment of $\pm$ .200 inches. Fine alignment and positioning of the passive half is provided by the active half inner wall and capture/rigidization system. A radial keyway on the active RIM inner wall corrects for rotational alignment. This keyway is designed to accept a passive RIM final positioning alignment within the connectors' and fluid couplings' mating tolerance. The proprietary capture/rigidization system (see illustration in figure 2) consists of three grapples and tab devices. The grapples and tabs are located two inches below the conical section and 120° apart. These grapples are actuated simultaneously via a chain drive system that is driven by one motor. The grapples travel radially toward the RIM center. The grapples protrude a maximum of one inch beyond the active half inner wall before driving downward. The grapples are used to grasp the RIM passive half and drive the two halves together. The grapples maintained coupler and connector mating during servicing operations and provided the required rigidization.

The passive half is normally mounted to the servicing vehicle. The RIM passive half contains the receptacles for the grapple system and the male half of the electrical connectors and fluid couplings.

All connectors and fluid couplings are mounted on the RIM connector decks (illustrated in Figure 2) that are utilized in each half of the RIM. One deck is located inside of the RIM active half. The connectors on this deck are mounted on floating interface plates which provide 6 degrees of freedom for each connector and coupling. Also, the active RIM connector deck contains load bearing pads. The loads that are produced from berthing and rigidization are transferred by the load-bearing pads, into the RIM structure. The other connector deck forms the interface surface of the passive half. Each connector on the passive connector deck is rigidly mounted.

The RIM is also equipped with an emergency release system. This system consists of three jettison spring assemblies mounted on the periphery of the active half of the RIM at 120° apart. A marmon clamp (illustrated in Figure 2) with explosive bolts is used to secure the two halves of the active RIM system. Firing the bolts releases the marmon clamp, enabling the outer portion of the active half of the mechanism to be jettisoned, demating the connectors in their normal fashion.

The fluid couplings used in this test were supplied by Fairchild Control System Company (FCSC), Moog, and Futurecraft. Electrical connectors have been supplied by both G&H Technologies and AMP.

RIM TWO-PART TESTING

A two-part proof-of-concept RIM test was performed. The first test was conducted in-house to verify mechanism operation and berthing alignment range. The second test verified the compatibility of the RIM mating scenarios with the RMS controls. The RMS test was performed as part of the JSC satellite resupply demonstration/test held in the MDF. In addition to the RIM test JSC also demonstrated the capability of their Magnetic End-Effector (MEE), Force Torque Sensor (FTS) and Tracking and Reflecting Alignment Concept (TRAC). The results of testing these systems will not be presented in this paper.

sighting the cuing marks made it necessary to add two vertical cuing marks on the active RIM. The cuing marks on the active RIM were collimated with the one vertical cuing mark on the passive RIM. When viewed from either camera, the cuing marks were aligned as illustrated in figure 4b. The front of the RIM (the part facing the orbiter aft deck window) had one cuing mark on the passive and one on the active RIM, as illustrated in figure 5a. These cuing marks were arranged to be collimated viewed from the aft flight deck window as illustrated in figure 5b.

To obtain a successful berth, the RIM front and aft cuing marks must be simultaneously aligned before driving the passive and active RIM together.

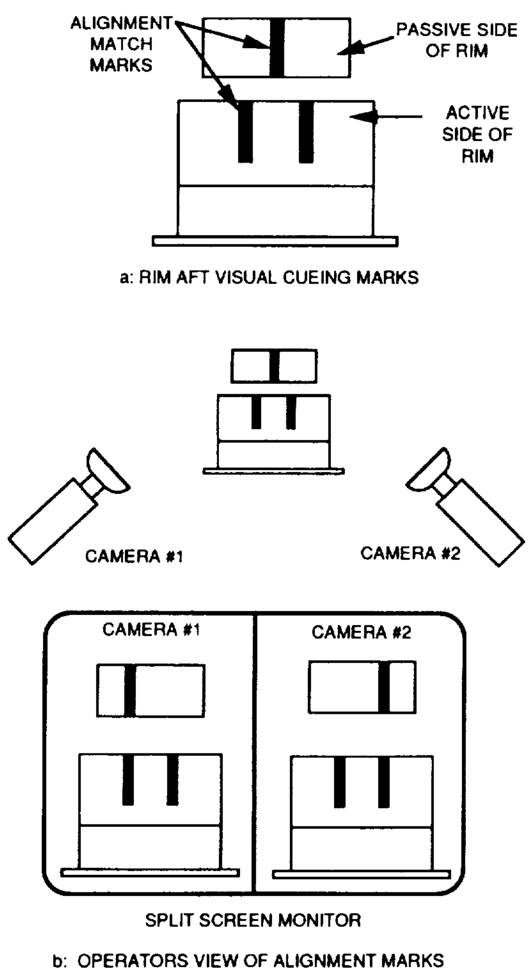

FIGURE 4: AFT RIM CUEING MARKS

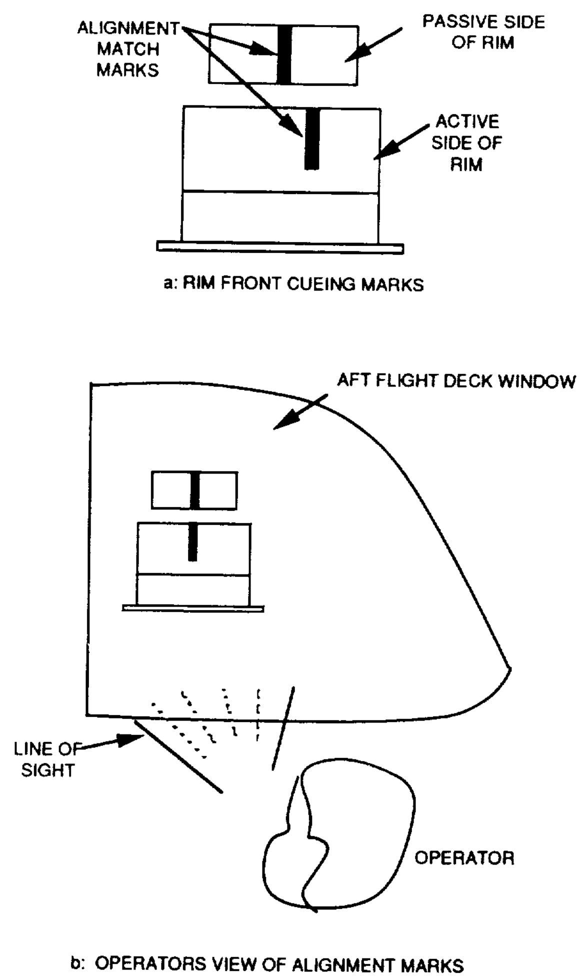

FIGURE 5: RIM FRONT CUEING MARKS

TESTING PLAN

After completing the test setup procedures, the test plan required that the manipulator with the MEE attached grasp spacecraft mock-up. The spacecraft is then maneuvering to a position approximately five to six feet above the active RIM on the tanker. From this hovering position the spacecraft was skewed and placed out of the TRAC camera line of site. This procedure was performed at the beginning of each test run by a different manipulator operator than the one performing the test. The test operator had no prior knowledge of the spacecraft mock-up position at the berthing sequence initiation. Using the FTS, TRAC, and various visual aids, the operator aligned the RIMs and maneuvered them together. When the passive RIM engaged the active RIM, the capture/rigidization mechanism pulled the RIMs together and simultaneously mated all connectors and couplings. For the berthing schemes, we used five different test conditions:

1. Normal mode with FTS and TRAC
2. Normal mode with TRAC
3. Visual mode with cargo bay cameras
4. Visual mode and FTS
5. TRAC and FTS mode

The above test conditions were accomplished by reducing the number of berthing aids available to the operator for each mode. Varying the berthing modes created testing conditions that provided data on the RIM functional operation. The five test conditions are described below.

Normal mode with FTS and TRAC

For the normal mode, the operator had five berthing aids available to assist in the berthing process. These aids are:

1. Visual inspection out of the aft flight deck window.
2. Camera view of the cuing marks on the RIM from the four cargo bay cameras.
3. RMS control coordinate display. This is a digital display that describes the location of the active RIM center point by cartesian (X,Y,Z) and attitude control (P,Y,R) coordinates. This coordinate system is not orbit defined but it is spacecraft (shuttle) fixed, as illustrated in figure 6.
4. FTS
5. TRAC

These berthing aids were used at the operator's discretion.

Normal mode with TRAC

This mode is the same as the normal mode with FTS and TRAC,

Normal mode with TRAC

Normal mode with TRAC did not create any additional challenges for the test operators. The fly-in portion of the berthing process does not require the FTS. In this case, the FTS is only used during the RIM insertion. However, the crew members had no adversities in successfully completing a smooth berth without the FTS. What was interesting was that all the crew members used sighting out of the aft flight deck window to adjust the flying spacecraft attitude and translation coordinate. Then approximately 6 inches above the tanker, they switched to the TRAC for the fly-in and mate.

Visual mode with cargo bay cameras

The visual mode with cargo bay cameras presented several challenges for the crew members. It was difficult to determine the spacecraft depth perception (x position along the shuttle velocity axis). Also, pitch adjustment within 1.5 degrees was hard to obtain. The pitch degree of 1.5 was required to ensure a smooth insertion of the passive RIM into the active RIM during the second alignment stage. Furthermore, the pitch adjustment reduces the probability of binding by preventing any sliding wall act. Some wall sliding is permissible during mating, but, if a perfect engagement is to be obtained, the walls of the RIMs should not touch. These difficulties were solved by first sighting the RIM's visual cuing marks from the aft flight deck window and aft cargo bay cameras, and then adjusting attitude and translational coordinates. Using the split screen mode of the monitor allowed viewing both images of the aft cameras on the same screen, which facilitated adjustments. Pitch was adjusted by using the manipulator digital coordinate display. The digital display was programed to give coordinate location of the passive RIM during fly-in. After making the adjustments, the operators had to only fly the spacecraft into the tanker RIM within the tolerance of the first alignment stage (+/- 2 inches and +/- 10 degrees). The flying RIM was permitted to slide down the RIM conical section and position itself to be grasped by the proprietary capture/rigidizing mechanism. Most of the berths achieved were jerky but doable.

Visual mode and FTS

Without the cargo bay cameras, the aft vertical cuing lines on the RIM could not be used. It became extremely difficult to determine depth perception. Several times the operators had to back the passive RIM out of the active RIM to avoid binding. All the crew members decided to use the digital display and follow similar steps as in the visual mode with cargo bay cameras. Berthing was achieved successfully.

TRAC and FTS mode

Although this mode is unrealistic for RMS berthing operation, it did give us an opportunity to study the RIM compliance to the TRAC and FTS. The TRAC and FTS case require that the aft flight deck window be blocked and the operator have no knowledge about the position of the spacecraft. The crew members' first step was to locate the spacecraft. This was accomplished by raising the spacecraft high enough for it to be observed through the TRAC camera. The spacecraft was then brought close enough (about 4 feet) to the tanker RIM to see the target mirror for attitude adjustment. Translational adjustments were performed continuously during the fly-in. All runs in this case were smoother than the previous mode.

Optional

The optional runs were similar to the test mode, except for one case. One crew member decided to use visual mode only. This involved berthing the spacecraft by viewing the RIM cuing marks from the aft flight deck window. Berthing was successful without using any other cuing aid.

TEST CONCLUSION

The test successfully validated the RIM design and demonstrated the compatibility of the hardware with the RMS. The RIM gross alignment tolerance worked well. The crew members were able to successfully berth the RIM during visual mode with cargo bay cameras scenario by sliding the passive RIM down the conical wall of the active RIM. This action proved that the RIM gross positioning alignment tolerance was adequate even though some jerky motion occurred. The jerky motions produced in some runs can be alleviated by increasing the active RIM inner diameter and rounding the edge where the conical ring meets the inner RIM wall. This would provide smooth transition along the surfaces. Furthermore, adding horizontal hash lines on the passive RIM can give the arm operator insertion depth information when the TRAC and FTS are not available. It was shown when using the TRAC that high mating tolerance accuracy can be accomplished, whereas the visual mode only permits low tolerance. Therefore, the test expressed the importance of determining the proper visual cues for the docking task. We found that the better the visual cues, the tighter the berthing tolerance could be. The type of visual cues to use is a function of the docking vehicle geometry, visibility, lighting, line of sight, viewing equipment, and operator's experience. This test was conducted with one vehicle in the cargo bay. If a second spacecraft was present, the cuing aid scheme would change. It is important to evaluate the condition in which the berthing is going to be performed. This scrutiny will lead to choosing the best cuing aid for the berthing configuration.

ACKNOWLEDGEMENT

The authors wish to thank NASA Johnson Space Center for extending an invitation to Fairchild Space Company to participate in their satellite resupply demonstration. We would like to give special thanks to JSC Propulsion and Power Division, the New Initiatives Office, and the Manipulator Development Facility.

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