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KINEMATIC STUDY OF FLIGHT TELEROBOTIC SERVICER CONFIGURATION ISSUES

R.H. Lewis, R.D. Scott and W.S. Howard
RCA Astro Space Division
Princeton, NJ 08543-0800

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Abstract

Several factors, such as body size and shape, and the number of arms and their placement, will influence how well the Flight Telerobotic Servicer (FTS) is suited to its potential duties for the Space Station Program. In order to examine the implications of these configuration options, eight specific 2, 3, and 4 armed FTS configurations were simulated and used to perform a Space Station Orbital Replacement Unit (ORU) exchange. The strengths and weaknesses of each configuration were evaluated. Although most of the configurations examined were able to perform the exchange, several of the 3 and 4 arm configurations had operational advantages. The results obtained from these simulations are specific to the assumptions associated with the ORU exchange scenario examined. However, they do illustrate the general interrelationships and sensitivities which need to be understood.

Introduction

The Flight Telerobotic Servicer (FTS) is intended to provide a supplemental EVA capability on the Space Station without the extra risks associated with actual manned EVA. It can be remotely controlled from within the Station's pressurized volume as an IVA activity. A number of tasks are under consideration as candidates for regular FTS assignments. The exchange of Orbital Replacement Units (ORU)s is one such work assigment. ORUs are standardized modules which contain replaceable Station and instrument subsystem elements. These ORUs will be located throughout the Space Station's trusswork on Station Interface Adapter (SIA) pallets. Transportation of the FTS around the Space Station will be provided by the Canadian Mobile Servicing Centre (MSC), which will carry the FTS at the end of one of its remote manipulator arms. The MSC arm also provides coarse positioning for the FTS over its local work area.

Assumptions

Before starting the FTS arm configuration kinematic study it was necessary to make a number of initial assumptions. In all exchanges, one arm is dedicated to providing stabilization by grasping the stability fixtures, located on the MSC and SIA, and the remaining arms move and operate the ORU. The exchange of a Work Package 4 electrical power systwas baselined for all FTS configurations examined. These ORLssumed to be 23"x25"x12". Two versions of these ORUs were modr the two and three armed FTS configurations, the standard attaevice was assumed to incorporate a combined handle and attacechanism. This system, based on RCA designs, requires only one with an appropriate end effector to both hold and operate the connsconnection mechanism. For the four arm FTS confis an alternate version of the ORU was employed. Its attacechanism consisted of two bolts which required one arm equip a special end effector to operate while a second arm equip another end effector was used to hold the ORU handle. Simusing this ORU required a minimum of three arms to compe ORUs were assumed to be mounted in a three by three array with earances between adjacent ORUs. The ORU to be replaced in all theions was the central ORU in the array. This represented the mult exchange in terms of reach and clearance. The SIA was locate of a standard, 16.4 foot (5 meters) on a side, truss cube. A generwith one six degree of freedom, 35.3 foot long manipulator arm wmed. An illustration of this common trade study enviros shown in Figure 1.

ational reach of each FTS configuration is a function of the manipngth, number of manipulators involved, and the size, shape and lahe body used. Rather than model several different manipms, only one design was used and all arms were identical. This puseful redundancy and flexibility during simulations. Speciad effectors were assumed to be available, but their actual designot modeled in the simulations. A generic stub, 14 inches long, n after the wrist joint represented this class of device. The separaance between the shoulders of the FTS was an important study fer. Given identical arms, a greater shoulder separation distanq allow the FTS a greater reach.

Derivecements

Thrs influence the size and shape of the FTS in a direct way. The recnt that the FTS must be IVA servicable implies that the entire Fst have overall dimensions which are compatible with the Space hatches and passageways. The other factor is the

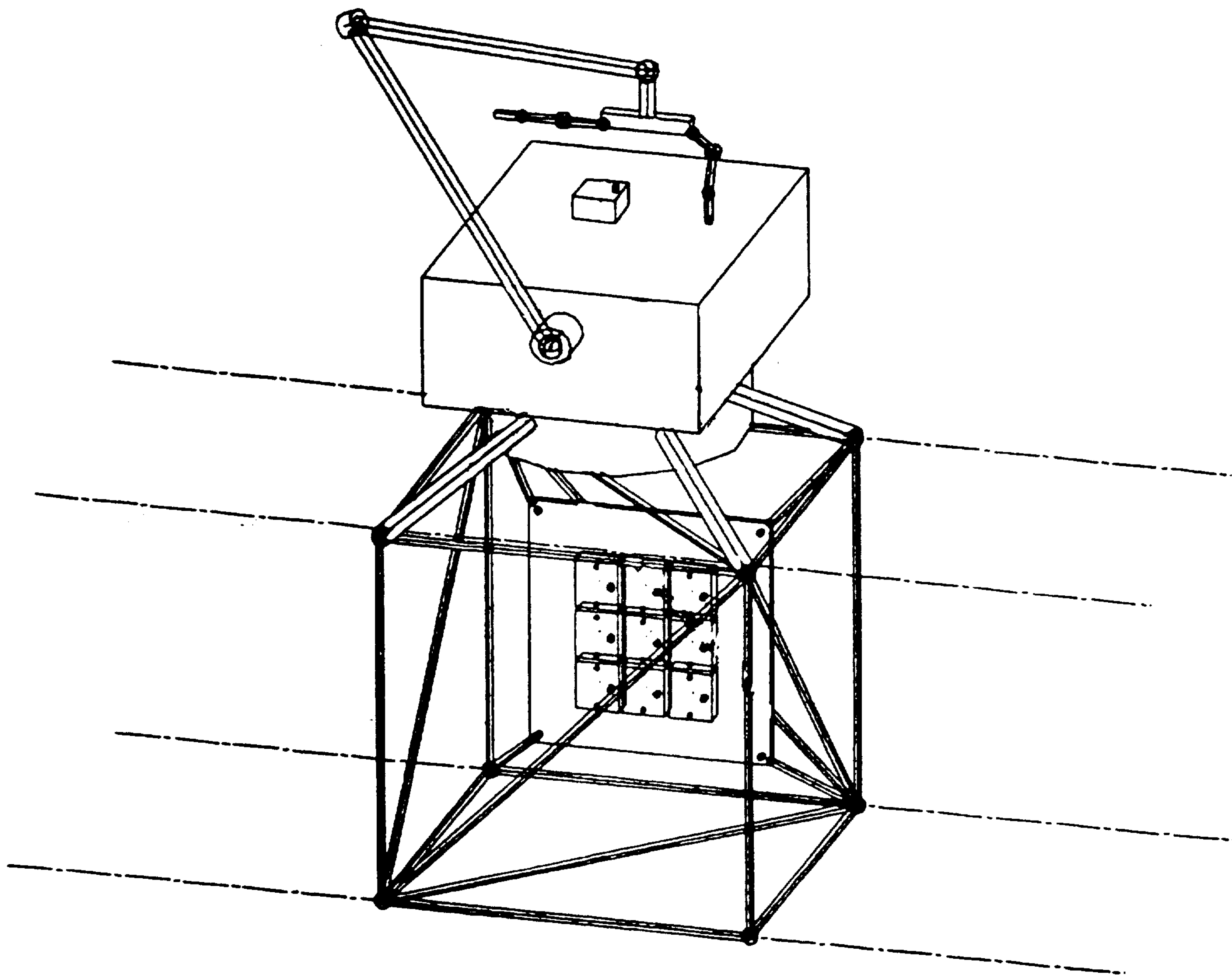


Figure 1. Common Trade Study Work Environment

requirement that the FTS is not responsible for its own transport. Because the MSC transport system positions the FTS in its proper work space, the FTS need not be capable of simultaneously reaching the five meter distance from one truss node to the next. (Physical contact with the truss members under normal conditions is not allowed). Elimination of the need for a five meter reach promotes compatibility with the hatch size requirement. All of the FTS configurations examined will fit through a Space Station hatch as it is currently known.

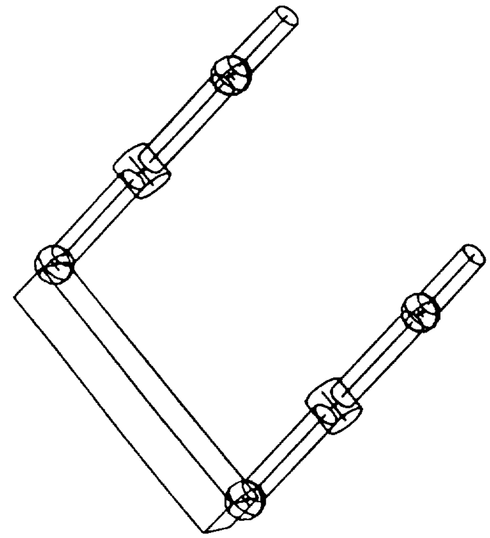
Arm Configuration Descriptions

Every FTS configuration examined used identical six degree of freedom manipulator arms as a common component. When necessary a seventh degree of freedom could be added. Although the arms were less agile than a human arm, they were of anthropomorphic design. The shoulder provided pitch and yaw, the elbow provided pitch, and the wrist provided pitch, roll, and yaw. The shoulder and elbow position the wrist, and the wrist orients the end effector relative to the work area. The arm is made up of a 22 inch upper arm and a 22 inch forearm.

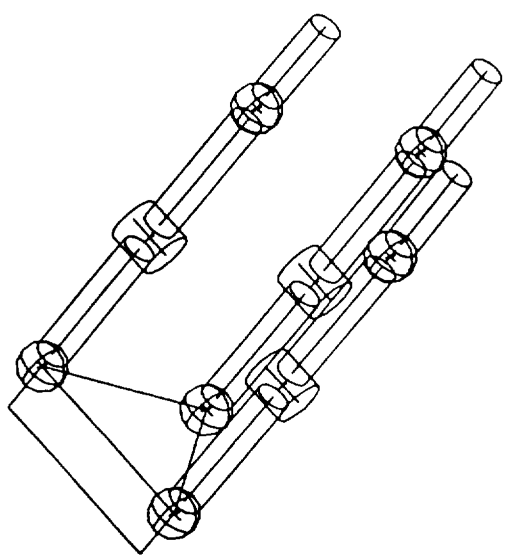
The bodies of the simulated FTS configurations fell into three basic categories based on the number of arms used. Two, three, and four arm FTS configurations were modeled. Within each of these three categories the major variable was the separation distance between adjacent shoulders. The following eight configurations were modeled:

- A two arm bar shaped robot with a 48 inch shoulder separation
- A three arm equilateral triangle shaped robot with 24 inch shoulders
- A three arm equilateral triangle shaped robot with 48 inch shoulders
- A four arm square shaped robot with 24 inch shoulders
- A four arm square shaped robot with 36 inch shoulders
- A four arm square shaped robot with 48 inch shoulders
- A four arm rectangular shaped robot with both 24 and 48 inch shoulders
- A four arm kite shaped robot with both 24 and 48 inch shoulders

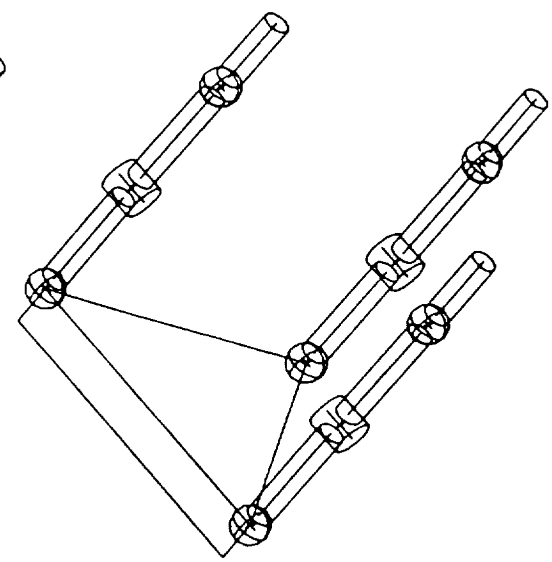
These configurations are illustrated in Figures 2 and 3.



48 Inch Two Arm FTS

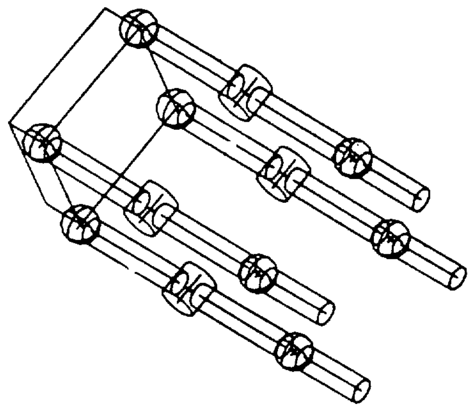


24 Inch Three Arm FTS

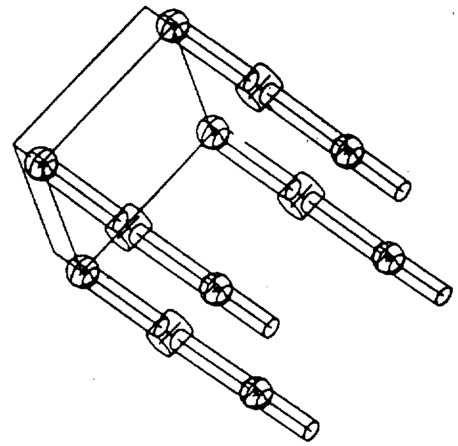


48 Inch Three Arm FTS

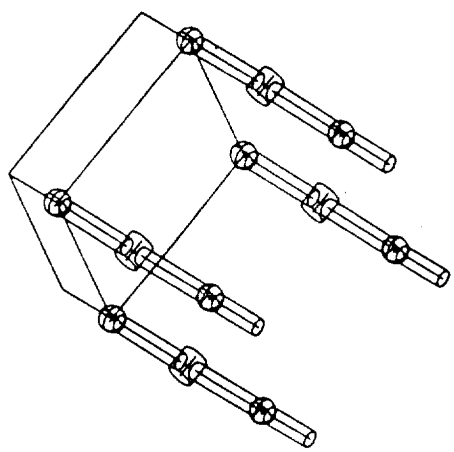
Figure 2. Two and Three Arm FTS Simulation Configurations



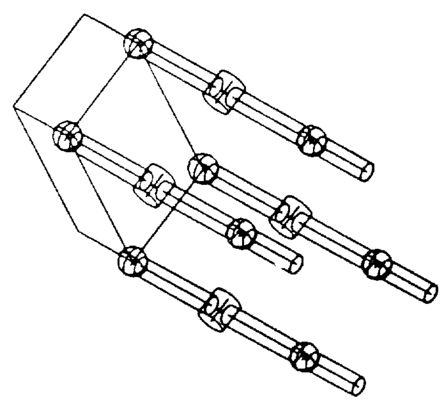
24 Inch Four Arm FTS



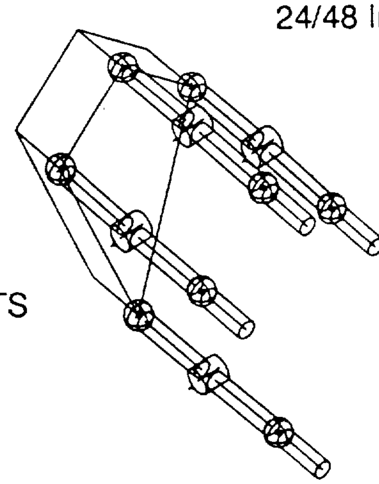
36 Inch Four Arm FTS



48 Inch Four Arm FTS



24/48 Inch Four Arm FTS



Kite Four Arm FTS

Figure 3. Four Arm FTS Simulation Configurations

Configurational Trades, Two Arm FTS ORU Exchange Simulation

A two arm FTS with a shoulder separation of 48 inches was used in this simulation. The ORU exchange simulation started with the FTS being moved inside the truss structure by the MSC arm. In order to pass through the trusswork the FTS orients its arms to minimize its chance of collision. Once inside the trusswork the MSC arm positions the FTS in front of the SIA containing the ORUs. The FTS then grasps a support point on the SIA with one of its arms to stabilize itself relative to the work site. The other arm is used to remove the ORU identified for replacement. Once the ORU has been removed and is clear of the SIA, the FTS releases the support point on the SIA and assumes a posture which minimizes its chance of collision. The MSC arm then transports the FTS and ORU back to the base of the MSC. Once positioned properly, the FTS grasps a support point on the MSC base with its free arm, attaches the ORU to the MSC, and picks up the new replacement ORU. The MSC then transports the FTS and replacement ORU back inside the truss structure. The FTS grasps a support point on the SIA, and places the new ORU in the spot previously occupied by the removed ORU. The FTS is then transported back to the MSC base.

The grasping of the support points on both the SIA and MSC by the FTS is a crucial step in the ORU exchange. In a real exchange, the support point permits the FTS to identify its relative position. The FTS calculates its position in space precisely, since the arm joint angles, location of the work site, and the support point position are known. Automated routines can then be inititated. The support point also allows the FTS to carry the loads associated with connecting and disconnecting the ORU against itself rather than the MSC arm. In the simulation, the locations of the support points were examined to verify their usefulness. Figure 4 shows the two arm FTS removing an ORU. The MSC and other details have been removed for clarity.

The results of this simulation demonstrate that it is possible to exchange an ORU with a two arm FTS. However, two arms are the absolute minimum number necessary to complete the exchange. The dimensions of this particular FTS configuration were compatible with those of the work site. It would be advantageous to have a third arm on the FTS to carry the replacement ORU along when the MSC arm positions the FTS within the truss structure. This would eliminate the need for an extra trip through

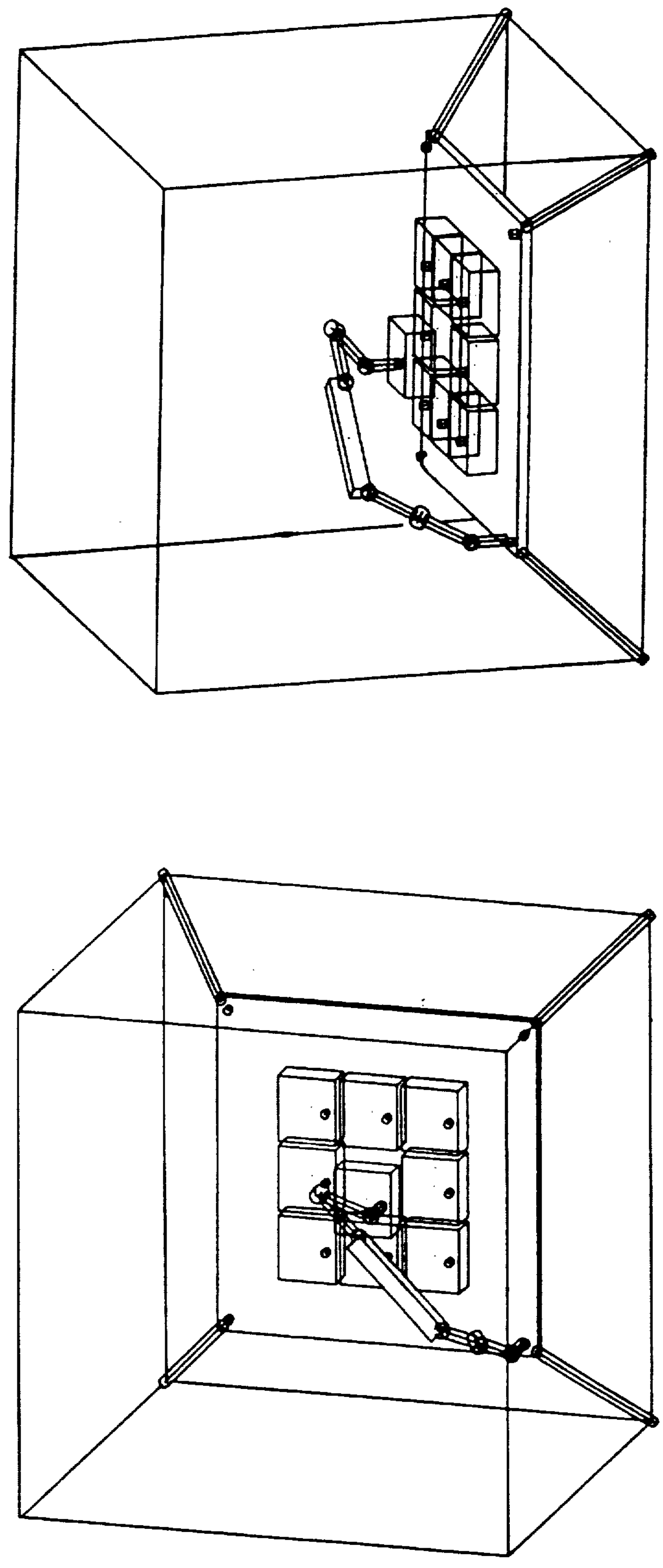


Figure 4. Orthogonal Views of a Two Arm FTS Removing an ORU

the trusswork. The simulation also demonstrated the need for close coordination between the MSC operator and the FTS operator. There were many instances where a lack of coordination between the two operators could result in damage. The movement through the truss and the approach to the SIA and MSC base are of particular concern.

Configuration Trades, Three Arm FTS ORU Exchange Simulation

Two versions of a three arm FTS were simulated. Both versions had equilateral triangle bodies which differed only in size. One used 24 inch shoulder separations, and the other used 48 inch separations.The ORU exchange scenario used for these two simulations was similar to that used previously in the two arm case. Once again, the scenario begins with the MSC arm transporting the FTS. The first stop this time is the MSC base. The FTS uses one arm to grasp a support point and then uses another arm to attach to the replacement ORU. The ORU is disconnected from the MSC and lifted away, the other arm then releases the support point. The MSC arm then transports the FTS and ORU into the truss structure to a location in front of the SIA. In order to do this, both FTS configurations had to assume postures which reduced their collision cross section. This posture is shown in Figure 5. The FTS then uses one arm to grasp the support point on the SIA. While keeping the replacement ORU safely out of the way, the FTS uses its third arm to remove the target ORU. Please refer to Figure 6. The target ORU is moved out of the way and the replacement ORU is moved and attached to the SIA. The FTS releases the SIA support point and the MSC arm transports it back through the trusswork to the MSC base. The FTS grasps a support point and connects the target ORU to the MSC base. The exchange is then complete.

The three arm FTS configurations both have distinct operational advantages over the two arm FTS. An exchange requires significantly less use of the MSC arm and is therefore safer and faster. The 24 and 48 inch shoulders were both capable of performing the ORU exchange. However, the 24 inch shoulder represents the smallest feasible size given the work site dimensions and the length of the FTS arm. With this smaller shoulder separation, the FTS had to stretch its arms to full length to accomplish the exchange. The 48 inch shoulder separation allowed the FTS improved reach under less constrained conditions. The three arm FTS could also emulate the two arm FTS, if necessary. The three arm FTS is capable of

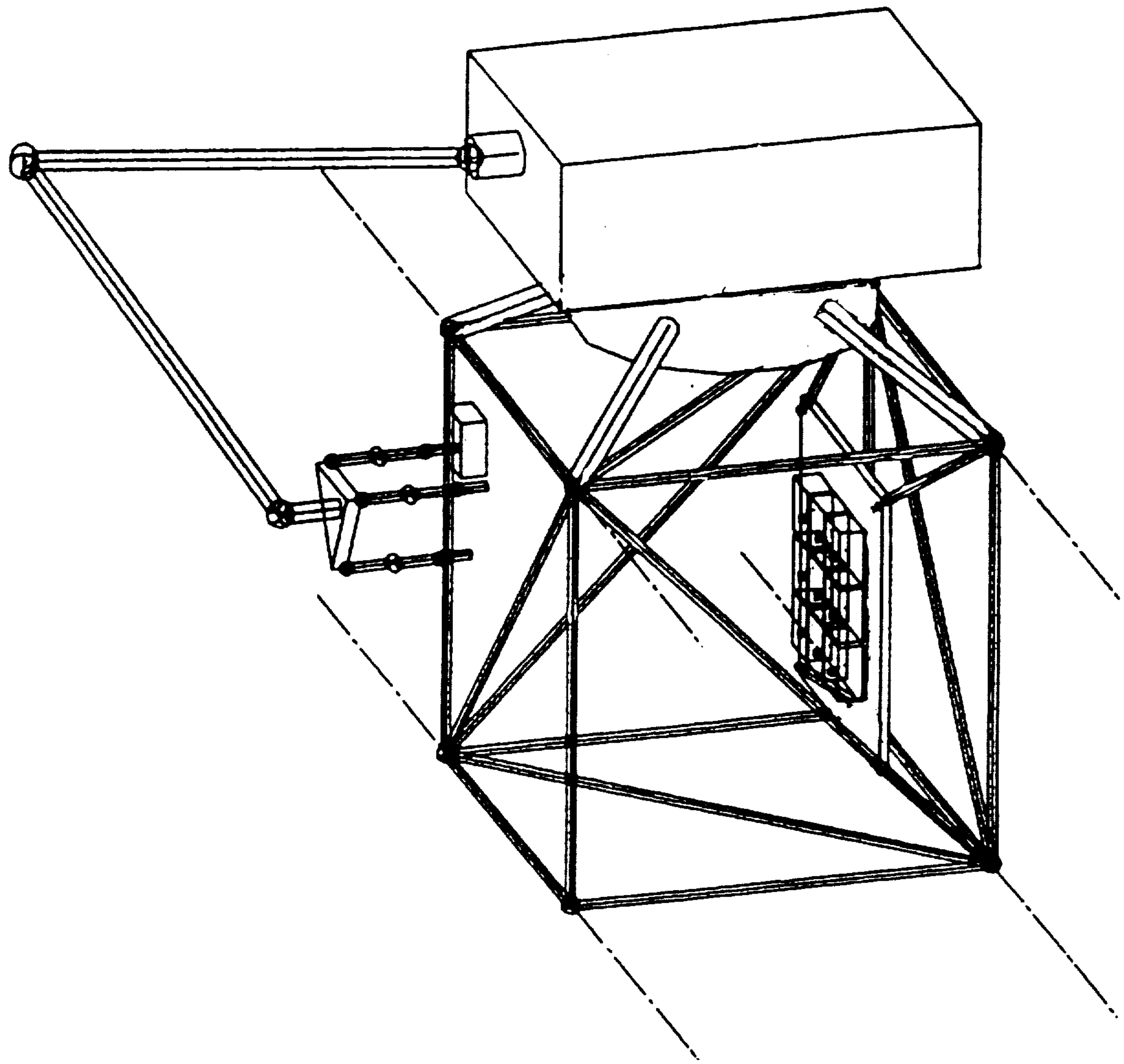


Figure 5. Three Arm, 48 Inch Shoulder, FTS Prior to Insertion into the Truss Cube.

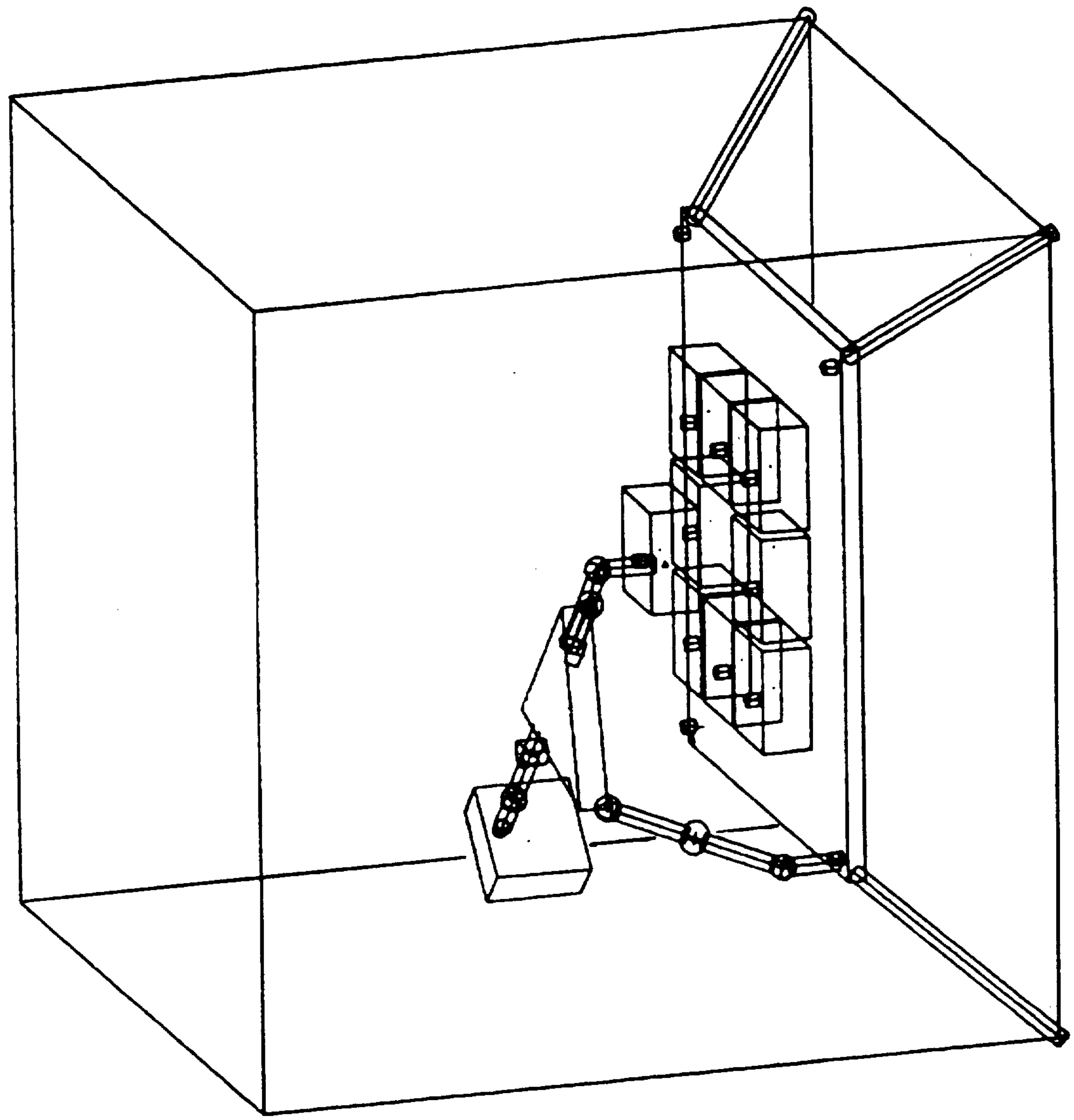


Figure 6. A Three Arm FTS, with a 48 Inch Shoulder Separation, Exchanging an ORU

holding and connecting or disconnecting an ORU which required two arms to operate. This use was not investigated for the three arm configurations, but was baselined for the four arm simulations.

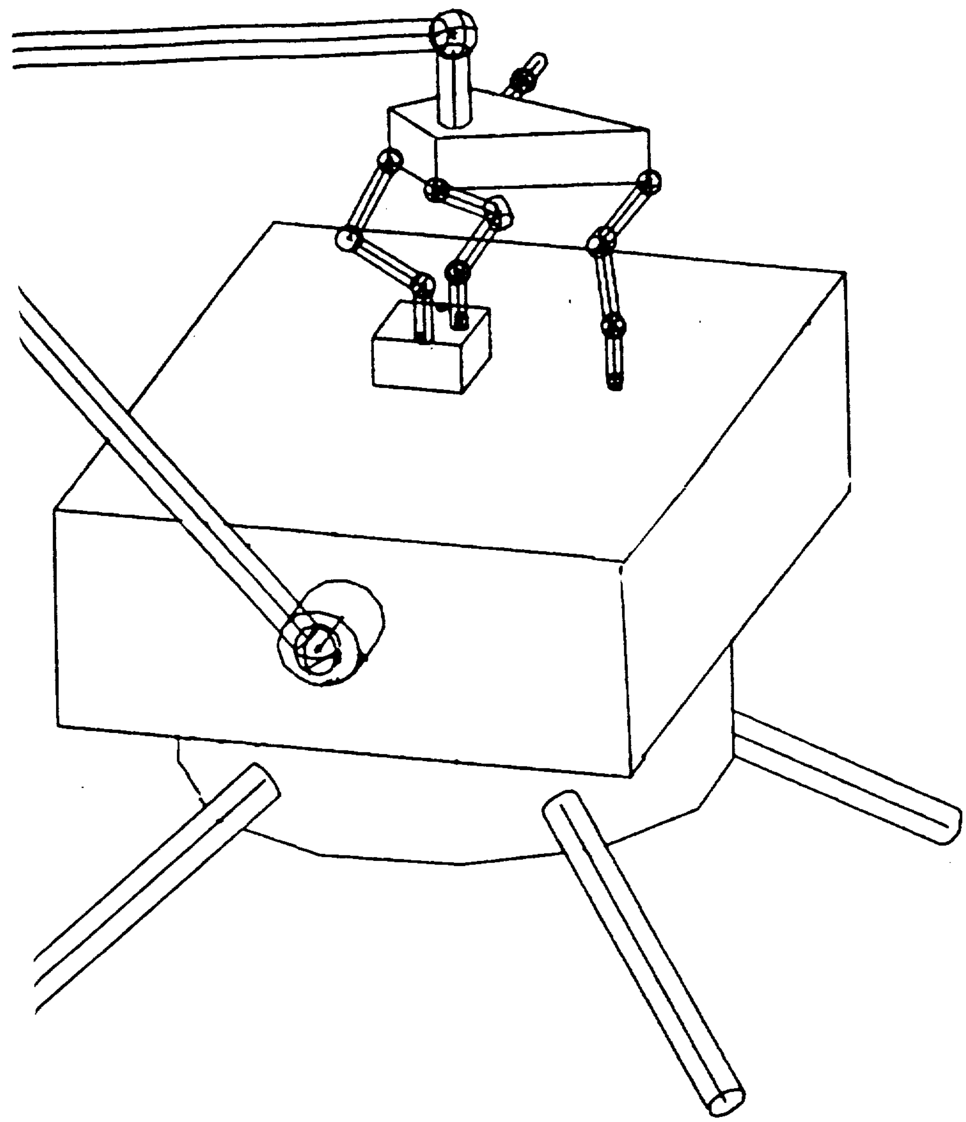
Configuration Trades. Four Arm FTS ORU Exchange Simulation

Five variations of a four arm FTS were simulated, including three square FTS configurations with 24, 36, and 48 inch shoulder separations. A rectangular FTS with two 24 inch and two 48 inch shoulders, and a kite shaped FTS with two adjacent 24 inch shoulders and two adjacent 48 inch shoulders were also investigated.

The ORU exchange scenario simulated for the four arm configurations used ORUs which require two separate arms. One FTS arm holds the ORU and a second operates the connection and disconnection mechanism. Instead of having a specially designed single handle which can be used to both grasp and release/attach the ORU, the new ORU has a handle used only to hold the ORU, and two tie down bolts used to release or attach the ORU. The size of the ORU remains the same.

The scenario used for the simulation started with the MSC arm transporting the FTS to a point near the MSC base. The FTS then uses one arm to grasp a support point, and another to grasp the ORU handle. Using the remaining two arms, the FTS disengages the ORU from the MSC base. These arms are then moved out of the way and the third arm releases the MSC support point. The MSC arm then transports the FTS and ORU to the SIA inside the truss structure. The FTS uses one arm to grasp the SIA support point, and uses the other two arms to grasp the ORU handle and disengage the target ORU. The target ORU is then moved to a point out of the way by one arm. The replacement ORU is then moved into position and the free arm is used to connect it to the SIA. The FTS then releases its hold on the SIA support point and is transported by the MSC arm to the base of the MSC. Once there, the FTS grasps the MSC support point and one arm moves the ORU into place, where the other two arms connect it to the MSC. Figures 7 and 8 illustrate two steps in this scenario for the kite shaped FTS and the 24 inch square FTS.

The tasks simulated in this scenario were considerably more challenging than those used in the previous simulations. The ability of each of the five configurations to reach both the SIA support point with one arm and the proper ORU on the SIA with the remaining three arms was



\ Kite Shaped Four Arm FTS Removing an ORU from the
: MSC

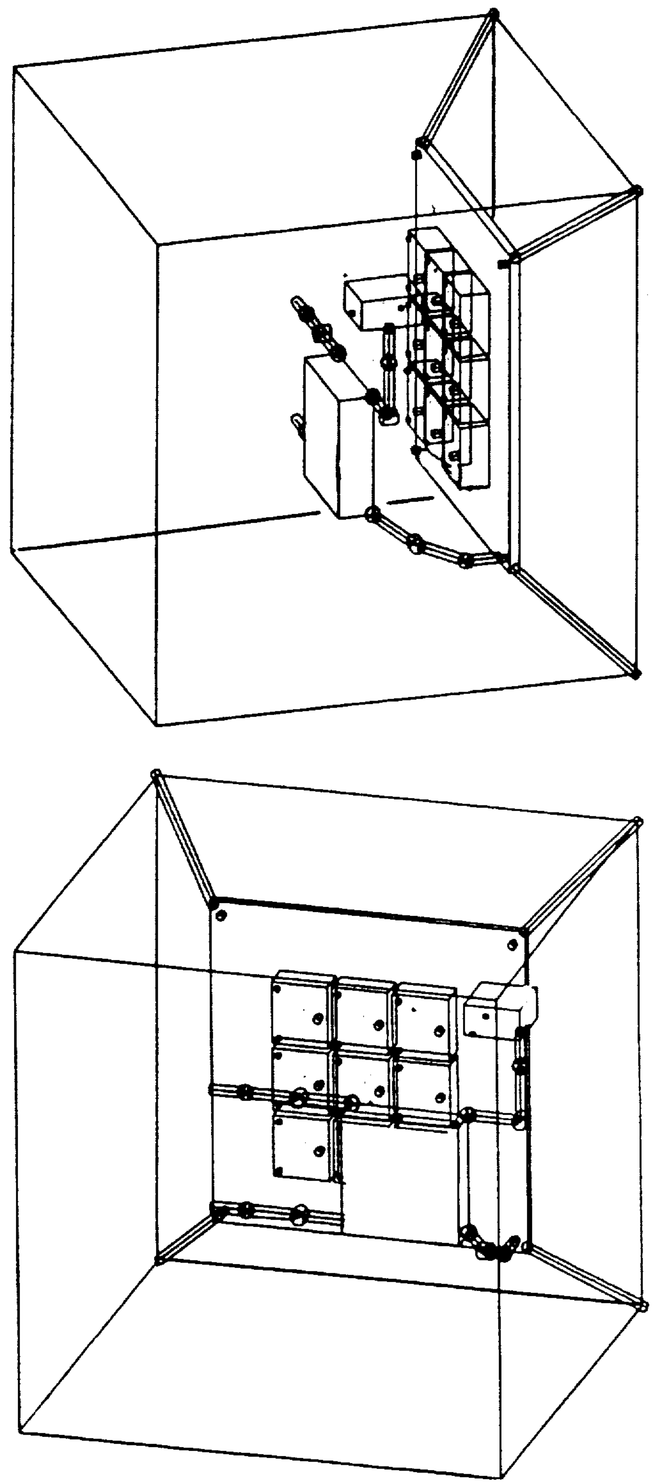


Figure 8. A 48 Inch Square Four Arm FTS Attempting to Exchange an ORU on the SIA

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All FTS configurations examined used one arm for stabilization at the local work site. Thus, two arms are the minimum number necessary for the baseline ORU exchange using the RCA ORU design. The two and three arm FTS configurations used the RCA ORU design with the combined handle and attachment mechanism. This was the only type of ORU that the two arm FTS could use. A generic ORU with separate handle and attachment mechanism, which requires at least two arms to hold and work, was also simulated. This design was used in all of the four arm FTS configuration simulations. The two arm FTS configuration with 48 inch shoulder separation was compatible with the exchange scenario and the local work sites' dimensions and layouts.

A third arm produces an operational advantage over the two arm FTS in that it can be used to carry the replacement ORU during the first passage through the Station truss and thereby eliminate an extra trip back to the MSC base. A four arm configuration also has this operational advantage. The use of an extra TV camera at the end of a free arm would also provide a remote operator with a useful alternate viewpoint when the work space becomes visually congested.

Both the 24 and 48 inch shoulder separation, equilateral triangle, 3 arm FTS configurations were compatible with the exchange scenario and local work environments. However, the 48 inch shoulder separation had better reach characteristics than the 24 inch design.

The 24 inch shoulder square, 48 inch shoulder square, and rectangular (24 and 48 inch shoulders) FTS designs were not compatible with the baseline work environment and could not accomplish the ORU exchange. The 36 inch shoulder square and 24/48 inch shoulder kite FTS configurations were compatible with the baseline work environment and were able to perform the ORU exchange. Of these two, the 24/48 kite FTS represented the most appropriate design for the baseline generic ORU exchange scenario.

This simulation exercise illustrates how the tasks and work environment associated with one specific ORU exchange scenario influenced the success of each FTS configuration examined. The actual FTS will be expected to be able to accomplish a minimum number of tasks in a minimum number of work environments. Simulations of each of these situations and scenarios will be needed before a serious FTS design can be produced. The final FTS design will, in all probability, be the best compromise achieved between the task optimized designs used in these simulations. The ability of the FTS to perform future tasks, which are currently unrecognized, will depend on how well these new tasks and work environments can be understood and modeled and on how much they differ from those used in designing the FTS originally.

Acknowledgements

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