TRACK AND CAPTURE OF THE ORBITER WITH THE SPACE STATION REMOTE MANIPULATOR SYSTEM

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SUMMARY

Results of the first study using the real-time, man-in-the-loop Systems Engineering Simulator (SES) for track and capture of the Space Shuttle Orbiter with the Space Station manipulator are presented. Objectives of this study include evaluation of the operational coordination required between the Orbiter pilot and the Space Station manipulator operator, evaluation of the locations and required number of closed-circuit television cameras, and evaluation of the Orbiter grapple fixture clearance geometry. The SES is a premium quality real-time facility with full fidelity Orbiter and Space Station crew workstations and cockpits.

INTRODUCTION

Fundamental to the combined operations of the Space Shuttle and the Space Station is the method of physically linking the two spacecraft while on orbit. The traditional technique for this operation is to dock an active vehicle with a passive target and has been used successfully for the Gemini, Apollo, Apollo/ Soyuz, and Skylab programs. To set up a docking maneuver, the active vehicle is put on an intercept course with the attitude-stabilized target and then the relative closure rate is reduced by a series of thrusts from the active vehicle's Reaction Control System (RCS) jets. The intercept is assured by maintaining a near-zero inertial line of sight rate between the spacecraft. Contact or "docking" typically occurs at a rate of .1 to .2 ft/sec. While this is a proven technique, it does tend to contaminate the target vehicle with the exhaust gases of the jets and also requires the physical contact mechanisms to be rather robust in order to dissipate the contact energy. With the flight experience that has been accumulated with the Space Shuttle Remote Manipulator System in the track, capture, and berthing of satellites such as SPAS, Solar Max, and others, consideration can be given to the use of a remote manipulator for the track, capture, and berthing of the Orbiter to the Space Station. The much larger masses of the Orbiter and Space Station relative to previous experience as well as crew safety considerations indicate that future extensive efforts are required in the analysis and design of safety factors and fault tolerant systems before this technique can be deemed feasible. The effort reported herein is only the first step.

SYSTEMS ENGINEERING SIMULATOR

The Systems Engineering Simulator (SES) has been used for the design, development, procedures verification, and flight support of manned spacecraft systems since 1963 (reference 1). Presently, the SES (figure 1) includes the following facilities:

- Five SEL 32/8780 supermini digital computers
- Seven SEL 32/75 supermini digital computers
- Three vector graphics systems (to simulate the Orbiter CRT's)
- Two electronic scene generators
- One Cyber 840 digital computer
- One LMI symbolics processor
- Orbiter forward station
- Orbiter aft station
- Space Station crew command module
- Manned maneuvering unit station

The real-time simulation can be exercised for as many as six orbiting bodies, each with its own unique dynamics. Any combination of these six bodies can be linked or separated with full dynamic fidelity. A flexible Remote Manipulator System (RMS) is included that has 14 modes which are reduced to 5 operating modes with cutoff of all modes above 10 hz. The manipulator currently proposed for the Space Station is made up of seven revolute joints while the Shuttle RMS consists of six. Derivation and coding of a generic manipulator model that can accommodate both kinds of manipulators in the SES is underway but was not available to support this analysis. Instead, the six-joint Shuttle RMS model was attached to the Space Station dual keel model (reference 2). Thus, these results should be considered preliminary in nature.

Previous analysis on the SES (reference 3) addressed the track and capture of the Space Station using the Shuttle RMS (figure 2, reference 4). This effort demonstrated the procedural feasibility of using a manipulator to null the relative motion of the two spacecraft. An effort has begun to determine specific upgrades to the Shuttle RMS required to support Space Station assembly and operations. In general, retrofit upgrades of operational flight systems are very expensive to implement. Since the Space Station and its manipulator (figure 3, reference 5) are in their initial design phases, an overall cost advantage may be identified--if the track, capture, and berthing can be accomplished solely by the Station manipulator.

TRACK AND CAPTURE STUDY OBJECTIVES

The primary objective of this study was to determine if the Space Station manipulator could be used to track and capture the Orbiter on an intercept trajectory (a slow collision course). This includes an assessment of the procedures and problems of operating two separate crew work stations--the Orbiter aft station and the Space Station manipulator workstation. Also, determination of Closed-Circuit TeleVision (CCTV) camera locations and viewing requirements were to be evaluated as were grapple fixture clearance geometries and the Orbiter/Space Station closure speeds.

CREW STATION CONFIGURATIONS

The Orbiter aft cockpit was used with the pilot observing the station through the overhead windows. Displays used by the Orbiter pilot included the Orbiter payload bay CCTV and the Universal Pointing display page on the Cathode Ray Tube (CRT) from the Orbiter General Purpose Computers. The pilot also used a Laser Ranging display page that was developed to provide the crew with precise range, range rate, azimuth and elevation angles and rates. The laser model was considered to be on the Orbiter with reflectors on the Space Station. Controls used by the pilot included the translation hand controller, Digital Auto-Pilot (DAP) selection switches and the Orbiter CCTV controls.

The Space Station crew control station (figure 4) was configured prior to phase B in 1984, based on the best available information at that time. The configuration used included RMS-type three-degrees-of-freedom hand controllers, two Space Station CCTV monitors, and four 13 inch color CRT's equipped with a touch input that interface with the Space Station data management system. The display pages in the Space Station provide display and controls (soft switches) for the attitude control system, RMS transporter system, CCTV, RMS data and moding, RMS error detection, and end effector controls. The RMS CRT display and control parameters used in the Space Station are essentially the same as used on the Orbiter RMS dedicated and CRT display and controls.

TEST CASE EXECUTION

Two sessions of 3 1/2 hrs each were scheduled per week for 11 weeks on the SES. Four test runs were typically executed during each session. Initial conditions used in the study were based on a nominal or a +/- 1 sigma state vector to provide the pilot and RMS operator some variety. The test case was terminated at the time of the Orbiter capture. Test case run times varied between 15 and 20 min with 15 being typical.

APPROACH TRAJECTORIES

For track and capture or docking studies, the intial conditions of the relative motion between the Shuttle and Space Station can be assumed to be those achieved by standard rendezvous operations. Typically, the spacecraft are separated by a few hundred feet and have a zero relative motion. From these stable initial conditions, the Shuttle is put on a slow intercept course with the berthing and docking port and is kept on this trajectory while maintaining constant attitude and braking by the RCS jets. Among the many conditions and variables that must be considered in planning these operations are the contamination and torques imparted on the Space Station by the Shuttle jets. Other sensitive parameters include mechanical clearances, fuel usage, and abort trajectory planning. Three trajectories under consideration for Shuttle approach to the Space Station are approach along the orbit velocity vector (V-bar), approach along the line connecting the center of earth and the station (R-bar), and approach along a minimum thrust curve defined by orbital mechanics (guided V-bar). These three trajectories are shown in a ralative motion plot using local vertical target centered coordinates (figure 5). Each trajectory offers advantages and disadvantages and the performance of all are sensitive to the Space Station geometric configuration. At the time of this track and capture study, the R-bar approach exhibited clearance problems with the dual keel configuration and the guided V-bar approach required non-standard operational rules. Thus, for this study, the V-bar approach trajectory was used.

ORBITER PROCEDURES

Study runs were begun with the Orbiter about 100 ft relative range in front of the Space Station with a 0 closure rate, to represent the final phase of a V-bar approach. The Orbiter pilot turned on the laser and selected the CRT displays to begin the final approach. The Orbiter began with the vernier RCS jets selected and the Orbiter DAP in the Local Vertical Local Horizontal (LVLH) attitude hold mode. The vernier jets produce 24 lbf and were selected to minimize the plume impingement effects when holding attitude. The pilot set up the desired Orbiter DAP configuration of LVLH with translation in pulse mode, switched to the primary RCS jets and initiated a closing rate to move toward the station. The Orbiter DAP commands specified RCS pulses for precise translation control in the pulse rate mode. The primary jets produce 870 lbf of thrust and are used for controlling the closing rate and vehicle path during the approach. The pilot switched back to the vernier jets and repeated this process as necessary to control the closing rate and reboost the Orbiter when it dropped below the desired approach. The Orbiter pilot flew the vehicle toward the station until the grapple fixture could be reached by the station RMS and the desired closure rate at capture of either 0.1 or 0.05 ft/sec was set up. Just prior to initiating capture the DAP was switched to free drift.

SPACE STATION PROCEDURES

The Space Station DAP was in the LVLH hold mode at the start of the run. The operator set up the CCTV system to monitor the Orbiter approach. The operator selected the RMS Space Station mode to maneuver the RMS into position for the capture. This RMS mode provided the RMS hand controllers with Space

Station body axis system commands. When the range reached about 25 ft, the Space Station DAP was put in free drift. The operator then selected the RMS end effector mode to perform the capture and the runs were terminated. The end effector mode provided hand controller commands relative to the end effector. The range at capture was generally about 20 ft. The operator generally used a single joint command mode that was available, only when it was necessary to move out of a joint limit, RMS reach limit, or singularity. The activity timeline is shown in table 1 for both the Orbiter and the Space Station.

Orbiter RCS jet firing data showed from 15 to 26 firings in the Orbiter X-direction and about 1 to 3 firings in the Z-direction. The Z-direction is toward the Space Station and the X-direction is in the radial direction. The X-jet firings reflect the adjustment in orbit due to orbit mechanics necessary to primarily control the closure rate and reboost.

GRAPPLE FIXTURE LOCATIONS

Three locations (figures 6, 7, and 8) of the grapple fixture were studied: Location 1 -- aft in cargo bay along the centerline facing the port side; Location 2 - forward in cargo bay attached to a longeron facing starboard side; and Location 3 - forward in the cargo bay attached to the docking post support facing the port side and inclined 45 degrees.

Location 1 was chosen to require lower torques at capture due to smaller center of gravity offset from that of the Orbiter. This location also offered good clearance for collision avoidance. However, the manipulator reach was found to be insufficient, and the berthing was found to be impossible after the capture due to insufficient length of the arm.

Location 2 was found to be reachable with the Space Station manipulator in all runs made. Furthermore, the manipulator did not exhibit being near any reach limits during the track and capture procedures. However, collisions with the base plate and docking port were encountered during capture. Higher torques were required at capture due to the larger c.g. offset of 36 ft. vs. 13 ft. of Location 1.

Location 3 at the time of this writing has been proposed for evaluation but has not been the subject of a substantive number of runs. Its configuration is expected to relieve some of the collision problems between the manipulator and the docking port tunnel.

CRT DISPLAYS FOR CONTROL INPUTS

An early result of this study found a conflict between the need of the operator to look at the CCTV monitor activity and the necessity of his/her having to look at the CRT's in order to locate a "soft switch" on a CRT. This redirection of attention away from the CCTV monitor and the subsequent reorientation time when the operator again looked at the monitor was found to have a negative effect on the performance of the track and capture procedure. While dedicated switches are admittedly expensive, they do allow tactile orientation through the operator's hand that can be done without necessarily requiring the operator to look at the switch.

CCTV LOCATIONS

Tantamount to a safe execution of the track and capture of one orbiting spacecraft by another, is providing a clear view of the workspace to the operator of the telemanipulator. Such a view can be provided only through multiple CCTV locations that 1) provide an unobstructed view of the Orbiter and Space Station modules without interference from the truss structure, and 2) provide a view of the Orbiter cargo bay and grapple fixture. Continuity of this set of views over the entire track and capture process required that the CCTV cameras be panned and tilted periodically during the trajectory. Minimization of this CCTV camera movement was factored into the selection of the baseline set of camera location (figure 9). These locations have been used in all runs executed to date. Camera D provides the best cues for relative distance between the Orbiter and the RMS and camera A gave the best view of the grapple fixture just prior to the start of the track and capture.

CONCLUDING REMARKS

The first man-in-the-loop, real-time simulation of track and capture of the Space Shuttle Orbiter using the manipulator of the Space Station has completed its first phase. Results indicate that the procedure is feasible operationally, but that the grapple fixture location has an effect on the functionality of the manipulator reach geometry and the loading placed on the manipulator after capture. CCTV camera locations should be carefully selected in order to provide favorable operator viewing of the manipulator and contacting surfaces.

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SYSTEMS ENGINEERING SIMULATOR SES ARCHITECTURE

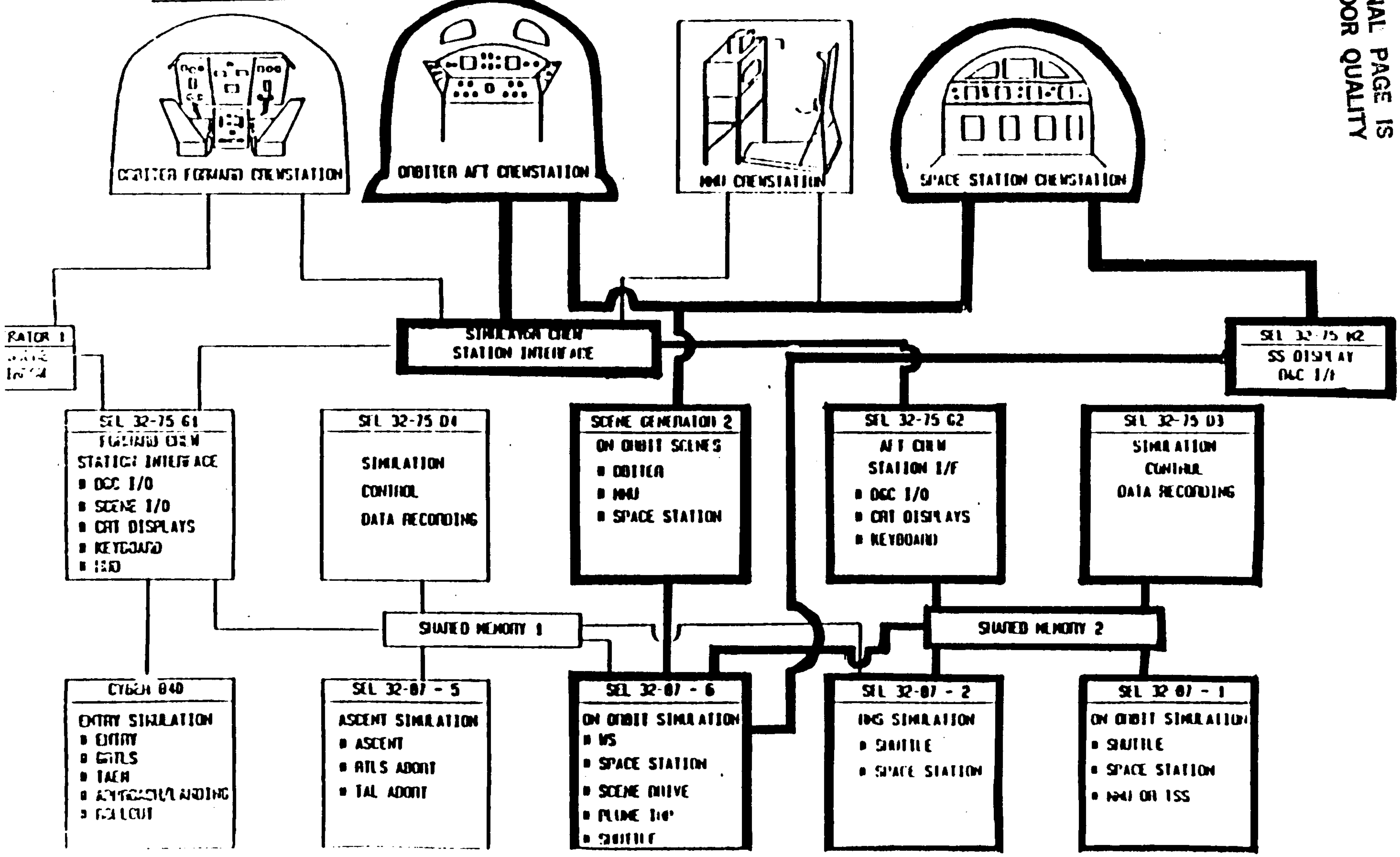
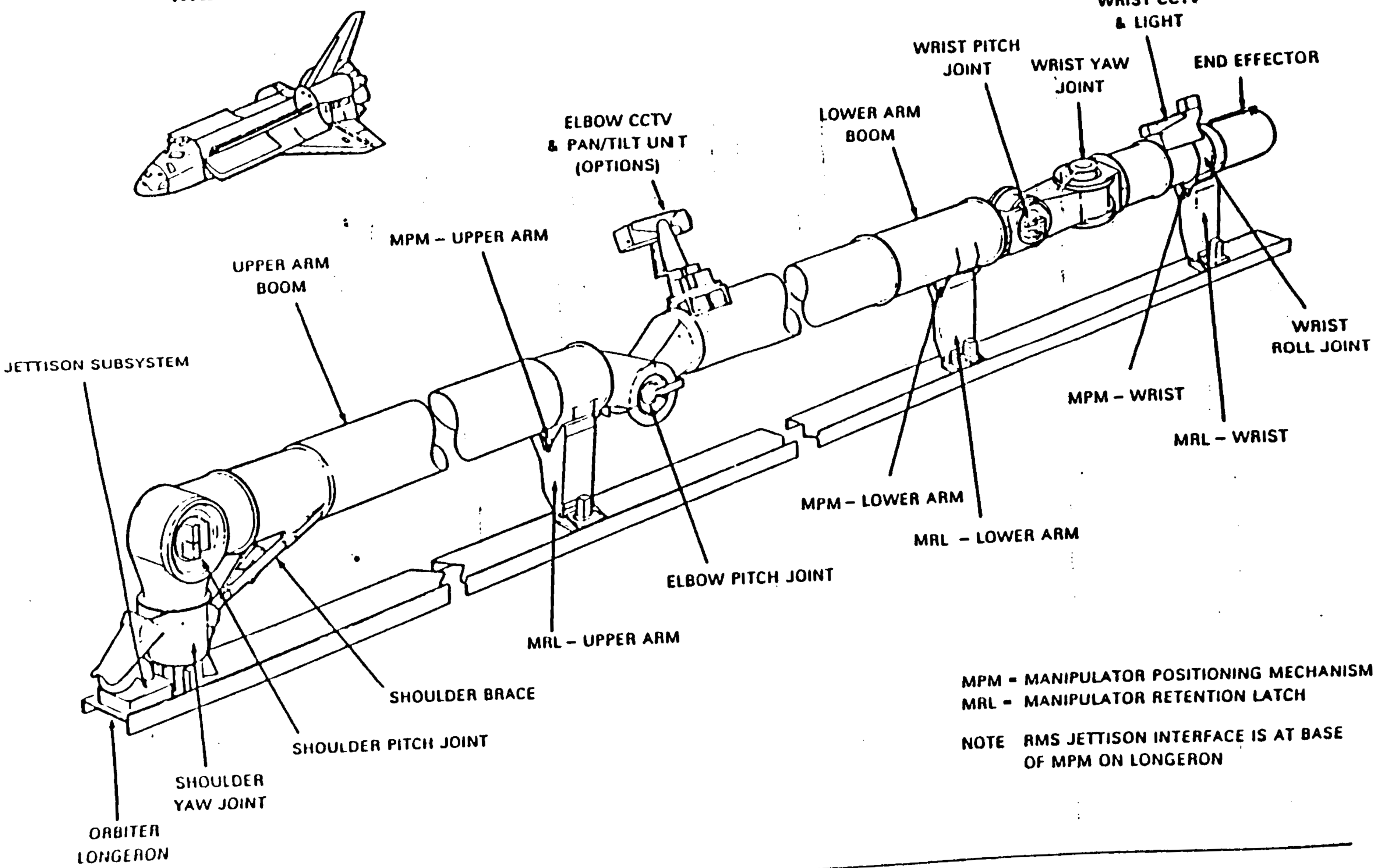


FIGURE 1

SHUTTLE REMOTE MANIPULATOR SYSTEM

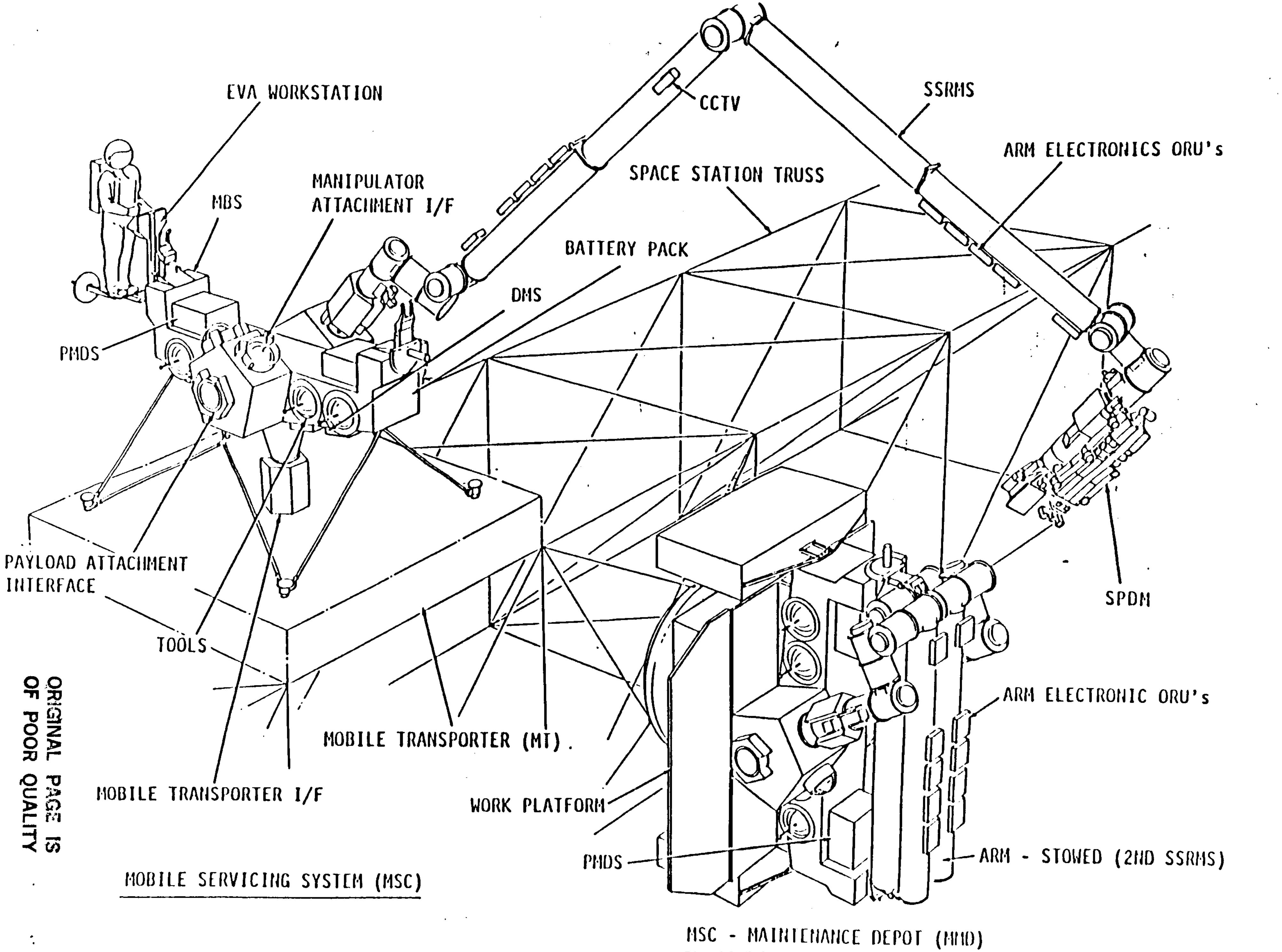
MECHANICAL ARM - STOWED POSITION & GENERAL ARRANGEMENT



MPM = MANIPULATOR POSITIONING MECHANISM
MRL = MANIPULATOR RETENTION LATCH

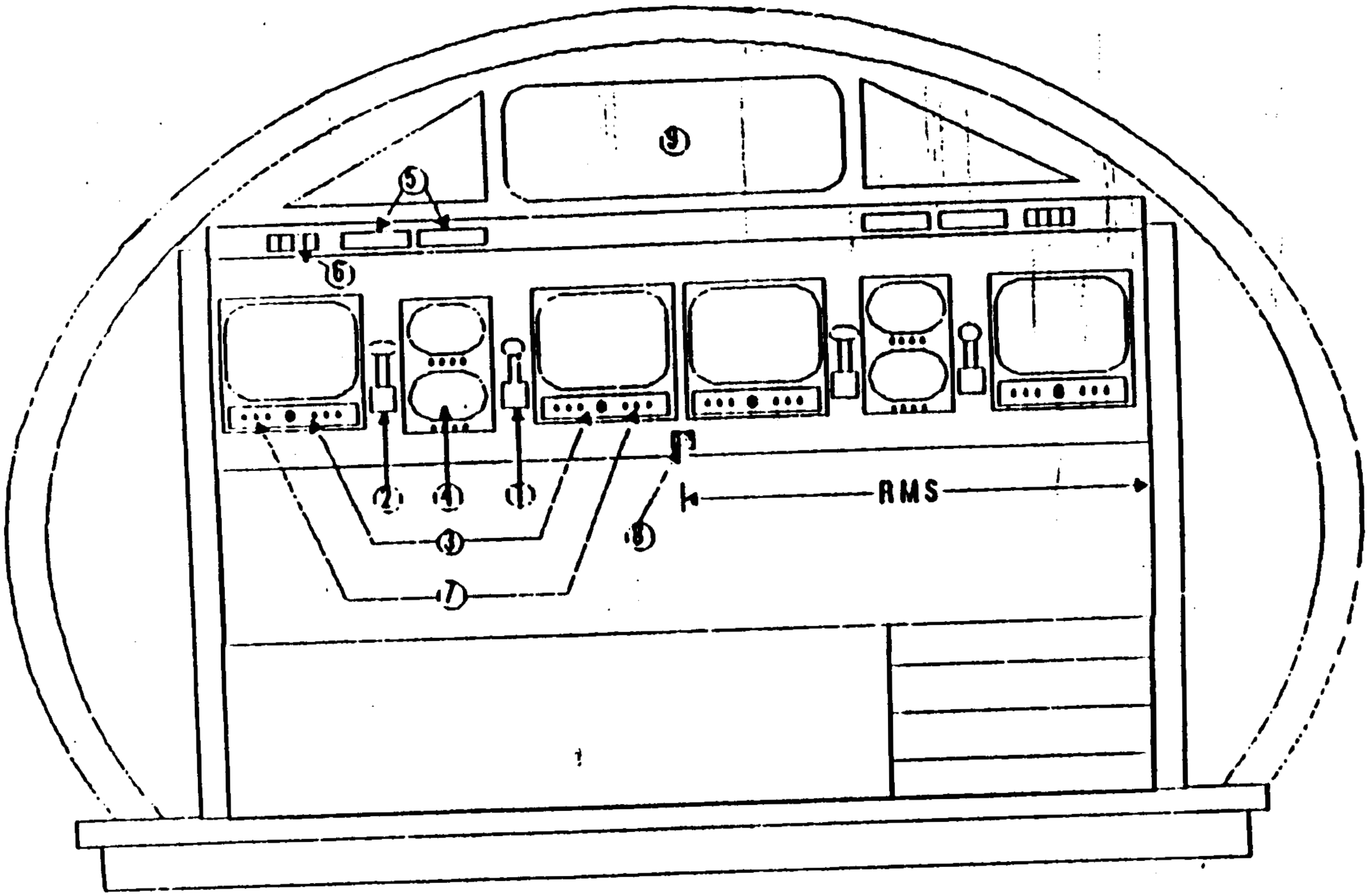
NOTE RMS JETTISON INTERFACE IS AT BASE OF MPM ON LONGERON

FIGURE 2



MSC & MMD ON THE SPACE STATION

FIGURE 3



1) Translational hand controller
2) Rotational hand controller
3) 19" Aydin color CRT (two)
4) 9" black and white CCTV monitors (two)
5) 2"x7" Electroluminescence displays (two)
6) Programmable Display Pushbuttons (PDP)
7) 19" Carrol Technology infared scan touch panels (two)
8) Interstate Voice unit (one for both work stations)
9) Out-the-window scene

Current Space Station Crew Control Mockup

FIGURE 4

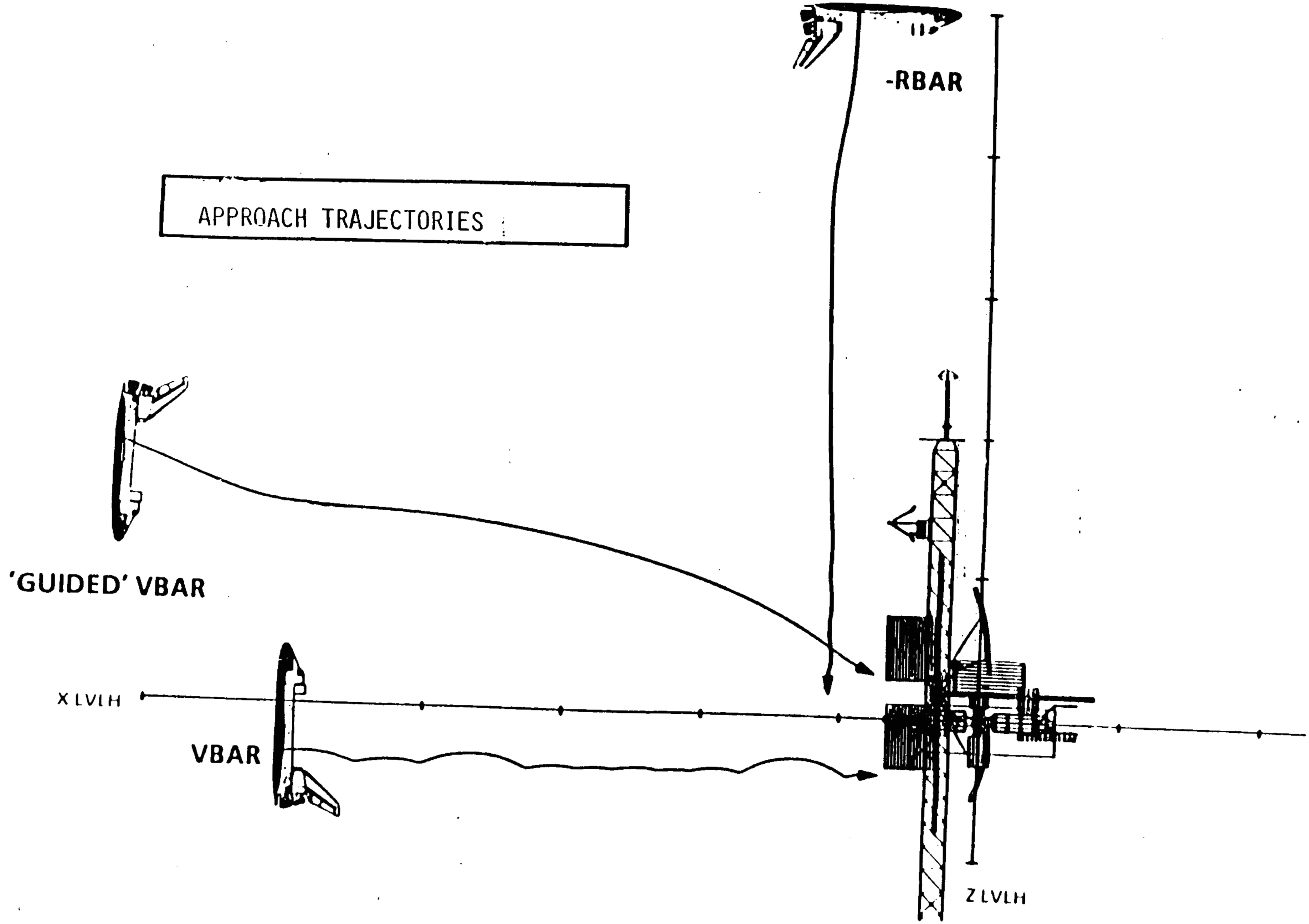
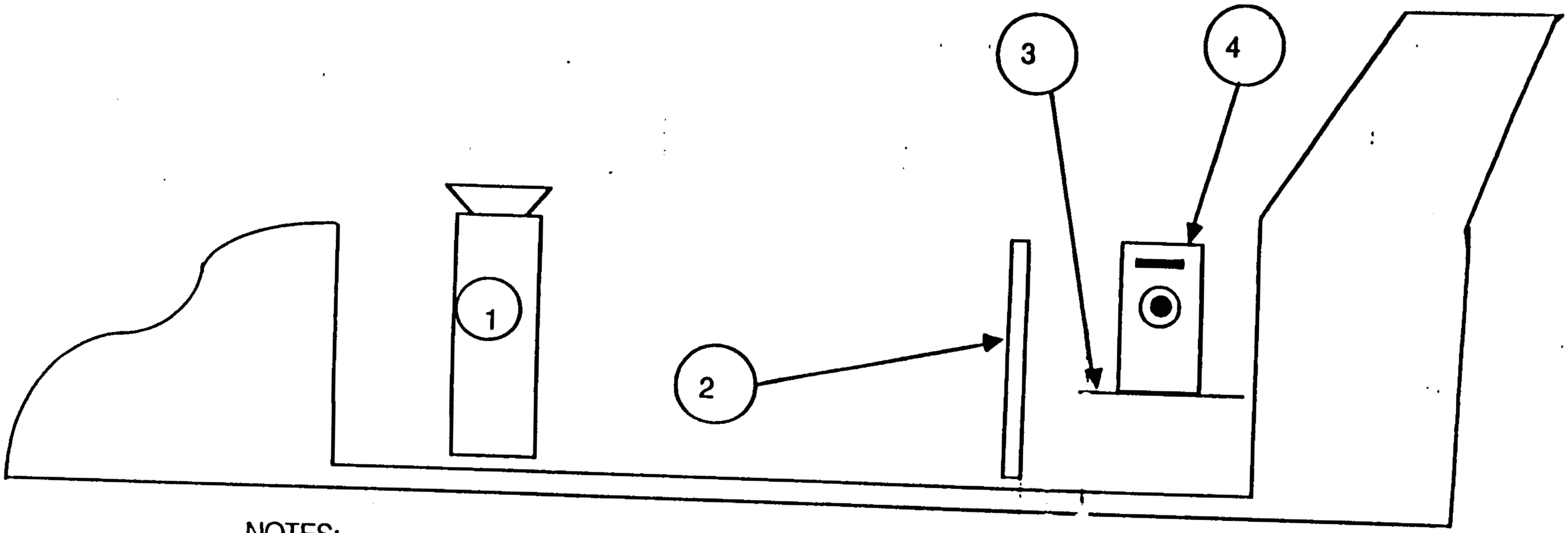


FIGURE 5

GRAPPLE FIXTURE LOCATION 1



NOTES:

1 ORBITER DOCKING PORT AS MODELED IN OSDS SIM.

2 CIRCULAR PLANE 14.5' IN DIAMETER, CENTERED AT Y=0, Z=33.33'
PLANE IS AT X = 101.17'.

3 RETANGULAR PLANE AT Z=34.5'
FRONT EDGE AT 103.17', BACK EDGE AT 105.17'
PORT EDGE AT -7.25', STARBOARD EDGE AT +7.25'.

4 VERTICAL PLANE UNDER GRAPPLE AT Y=0
BOTTOM EDGE AT 34.5' AND TOP EDGE AT 39.5'.
BACK EDGE AT 105.17' AND FRONT EDGE AT 103.17'.

FIGURE 6

GRAPPLE FIXTURE LOCATION 2

GRAPPLE FIXTURE 2

A STANDARD RMS GRAPPLE FIXTURE IS IN THE FORWARD END OF THE BAY, ATTACHED TO THE PORT CARGO BAY WALL, WITH THE ALIGNMENT AID UP, FACING THE STARBOARD AND A 45° TILT UP IN Z DIRECTION.

X= 690.0"
Y= -78.88"
Z= 407.62"

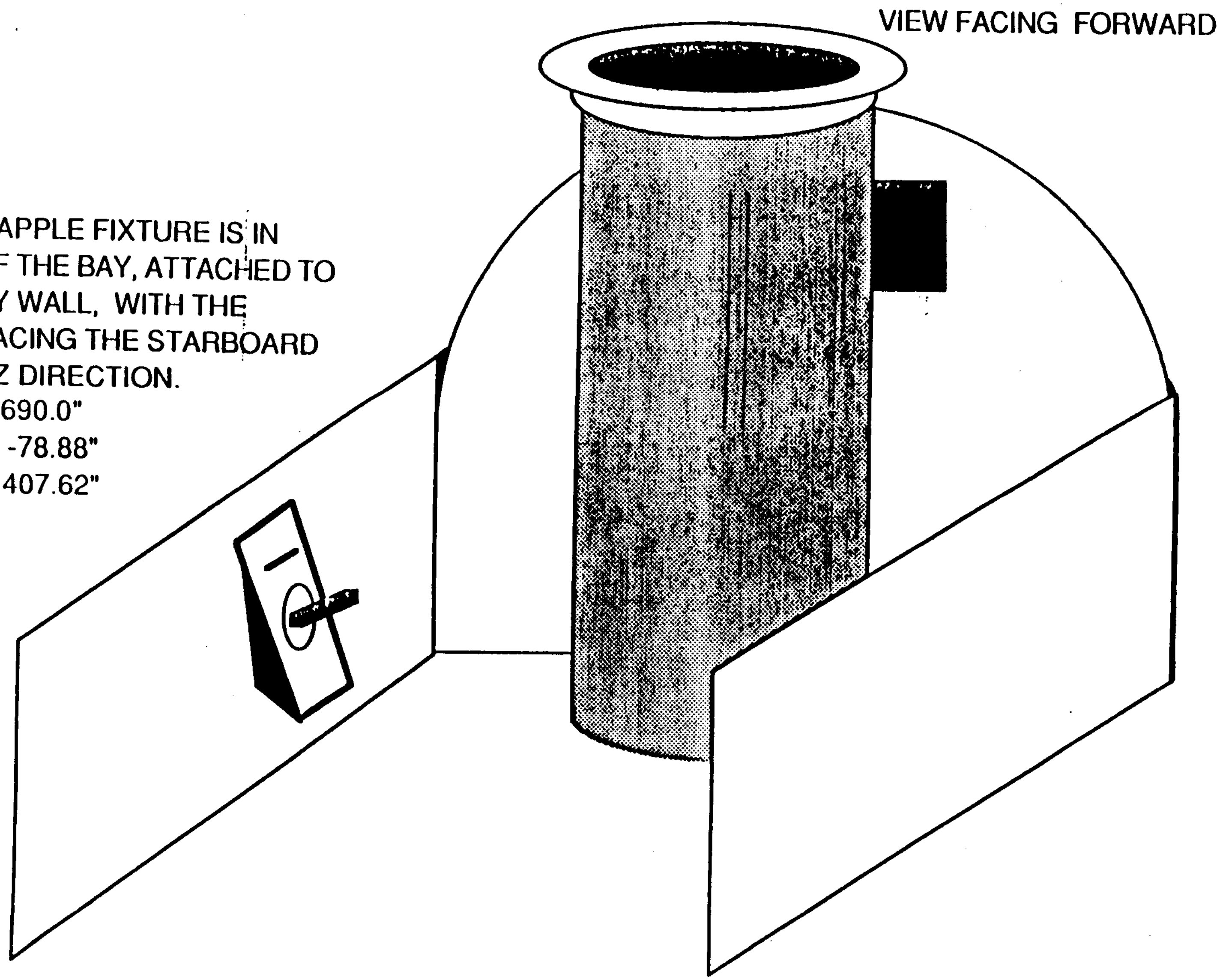
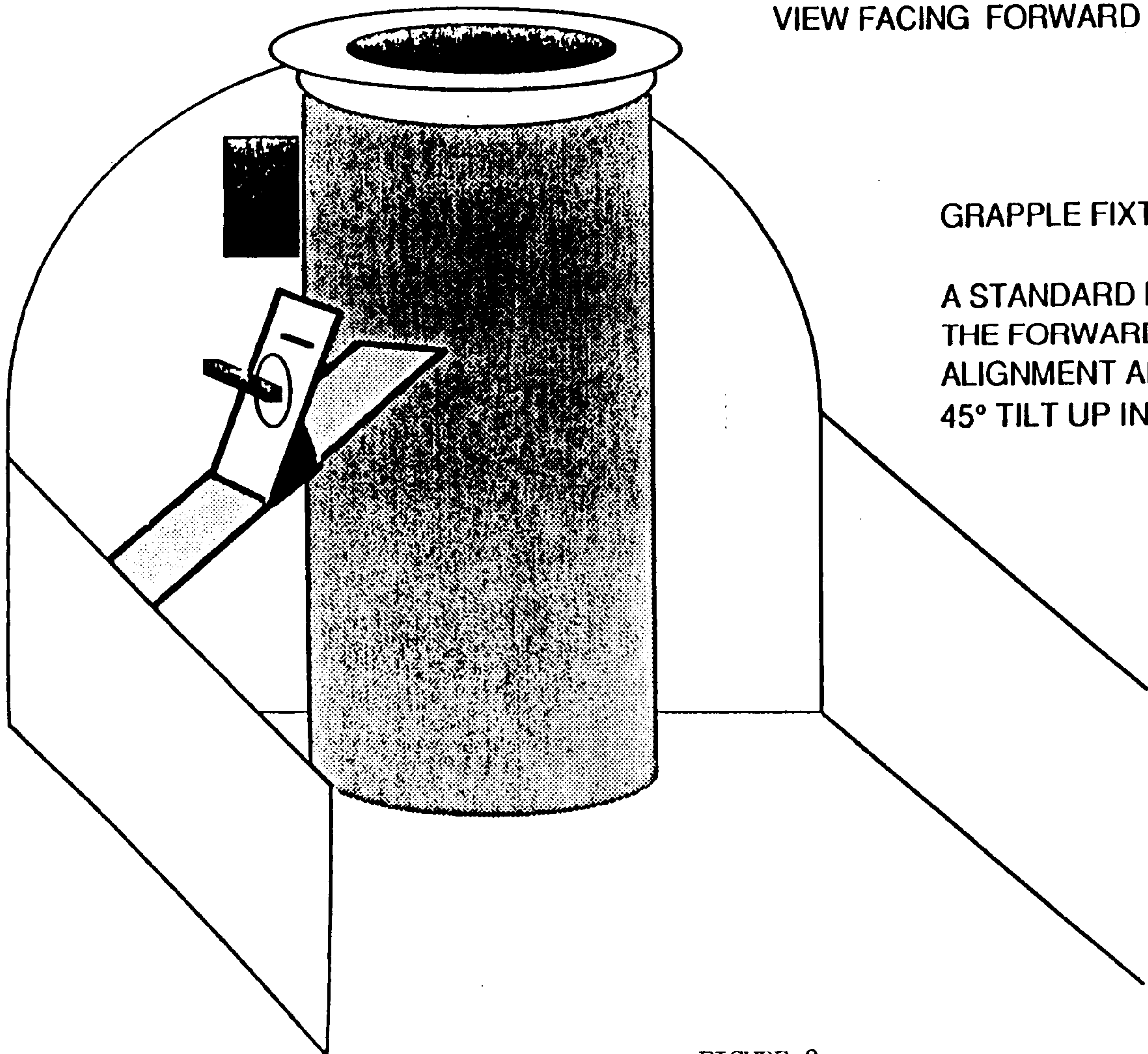


FIGURE 7

GRAPPLE FIXTURE LOCATION 3

VIEW FACING FORWARD



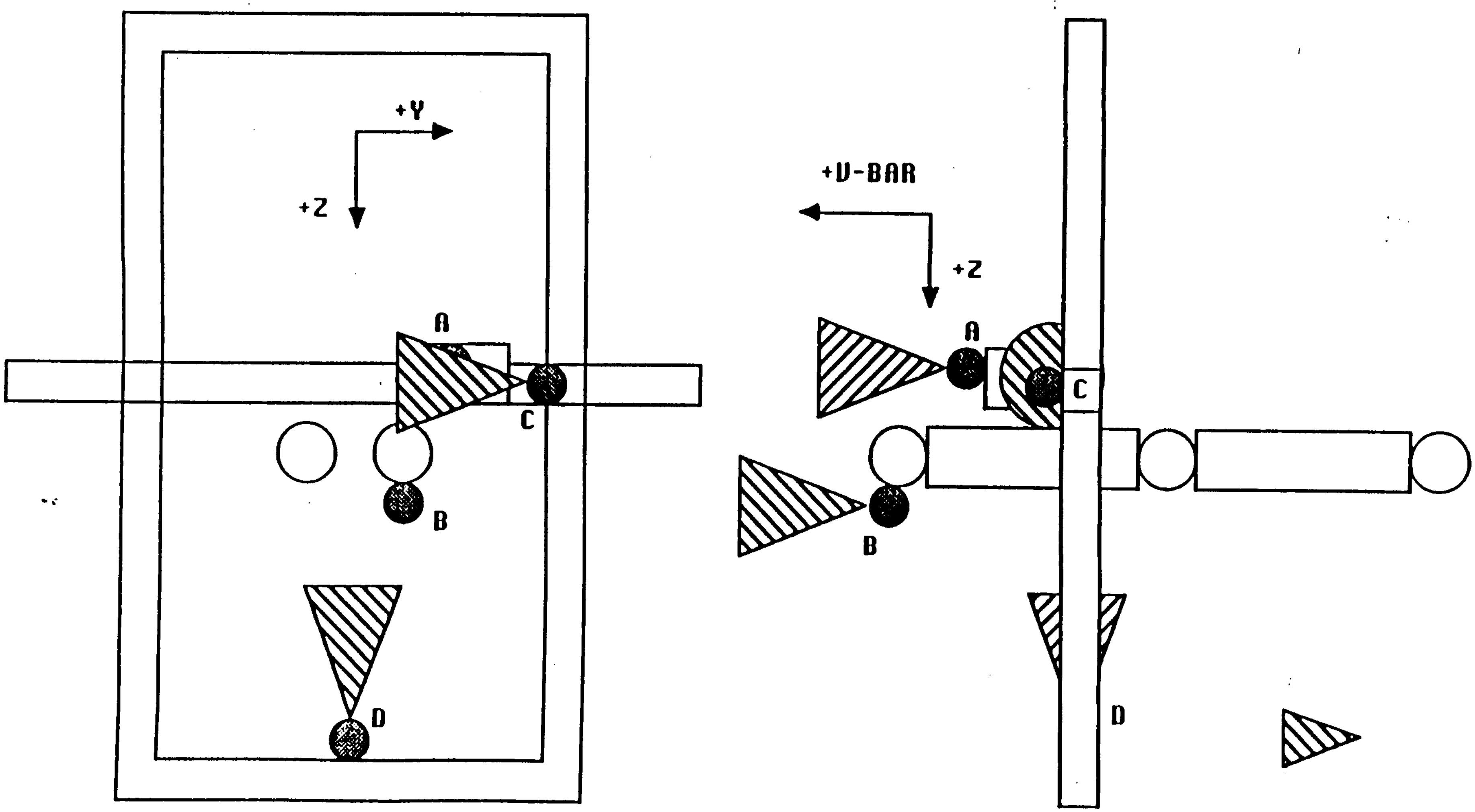
GRAPPLE FIXTURE 3

A STANDARD RMS GRAPPLE FIXTURE IS IN THE FORWARD END OF THE BAY, WITH ALIGNMENT AID UP, FACING PORT AND 45° TILT UP IN Z DIRECTION.

X= 618.0"
Y= -93.6"
Z= 441.6"

FIGURE 8

CAMERA LOCATIONS



SPACE STATION

• NOTE: EACH CAMERA HAS 40° FIELD OF VIEW.
• NOT TO SCALE DRAWING

FIGURE 9

TABLE 1

ACTIVITY TIMELINE

TIME/EVENT	ORBITER PILOT	SPACE STATION RMS OPR.
0 MIN. RANGE = 100FT	DAP IN LVLH WITH VERNIER JETS	DAP IN LVLH SET UP CCTV TO MONITOR FOR COLLISIONS
	TURN LASER ON	POSITION RMS WITH SPACE STATION MODE
	SET UP DAP IN PULSE MODE WITH PRIMARY JETS FOR CONTROL OF APPROACH	
	SWITCH BACK TO VERNIER FOR LVLH ATTITUDE HOLD	
	REPEAT AS NECESSARY	
11 MIN. RANGE = 25FT	DAP TO FREE DRIFT	DAP TO FREE DRIFT
15 MIN. RANGE = 20FT		PERFORM CAPTURE WITH RMS IN END EFFECTOR MODE