EQUIPMENT INSTALLATION

ON

LARGE AREA SPACE SYSTEMS

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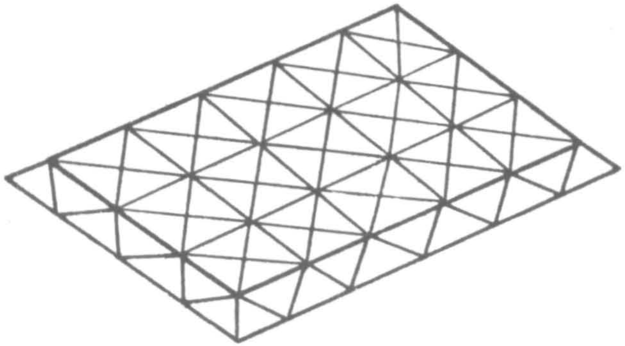
CHART 1 - EQUIPMENT INSTALLATION ON LARGE AREA SPACE SYSTEMS

This paper is concerned with the requirements and concepts for the installation of various types of mission and subsystem equipment on large area space systems. The paper is a synthesis of work performed under company discretionary programs, contractual studies with the Langley Research Center, and current year IR&D plans.

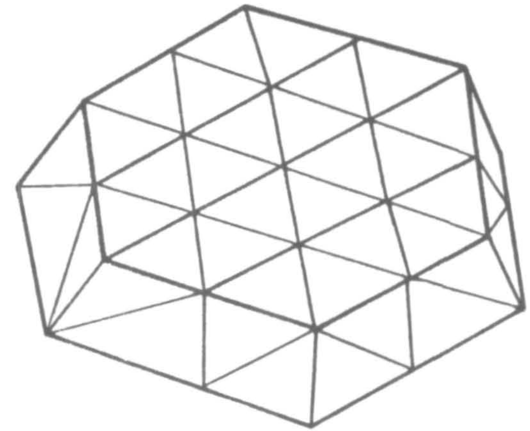
CHART 2 - TYPES OF STRUCTURAL PLATFORMS

Equipment installations will be required on various types of large structural platforms. The major exception to this requirement is the case of fully deployable systems or subassemblies, where the equipment is preinstalled within the packaged system. In most other cases, the equipment will be installed in a series of module placement and interconnect operations. This is because the large area of the platforms will dictate that some, if not most, of the modules and their functions be located at points distant from one another.

DEPLOYABLE PLATFORM



ERECTABLE PLATFORM



FAB-IN-SPACE PLATFORM

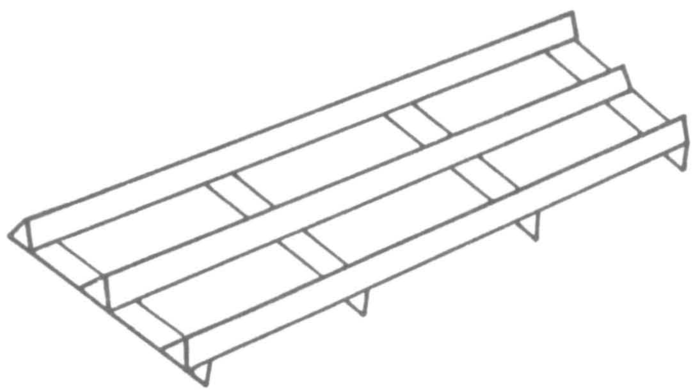


Chart 2

CHART 3 - SCOPE

In the material which follows, two conditions are assumed which scope the applicability of the present conclusions.

First, the concepts are limited to the earliest presumed space constructions; i.e., the mid-80's time period. In this context, it is assumed that the system sizes, designs, construction techniques and equipment, and operations will be somewhat less advanced (although efficient for the jobs at hand) than would be expected for a later time period.

Second, it is assumed that all construction operations in the earliest time period would be performed by the Shuttle system. Previous studies have attested to the validity of this assumption.

- SHUTTLE-BASED ASSEMBLY OPERATIONS
- EARLY SPACE CONSTRUCTIONS

Chart 3

CHART 4 - TYPES OF EQUIPMENT

The purpose of this chart is to illustrate the wide range of weights, sizes, and functions which the installed modules may exhibit. By no means are all the likely types of equipment illustrated--but those shown are a representative sample. It may be noted that several of those illustrated will require unique locations on the platform (e.g., the ion thrusters which could be required for stationkeeping). Although not illustrated, one of the most challenging installations will be the interconnecting power and signal cable sets about which more will be said later.

TYPES OF EQUIPMENT

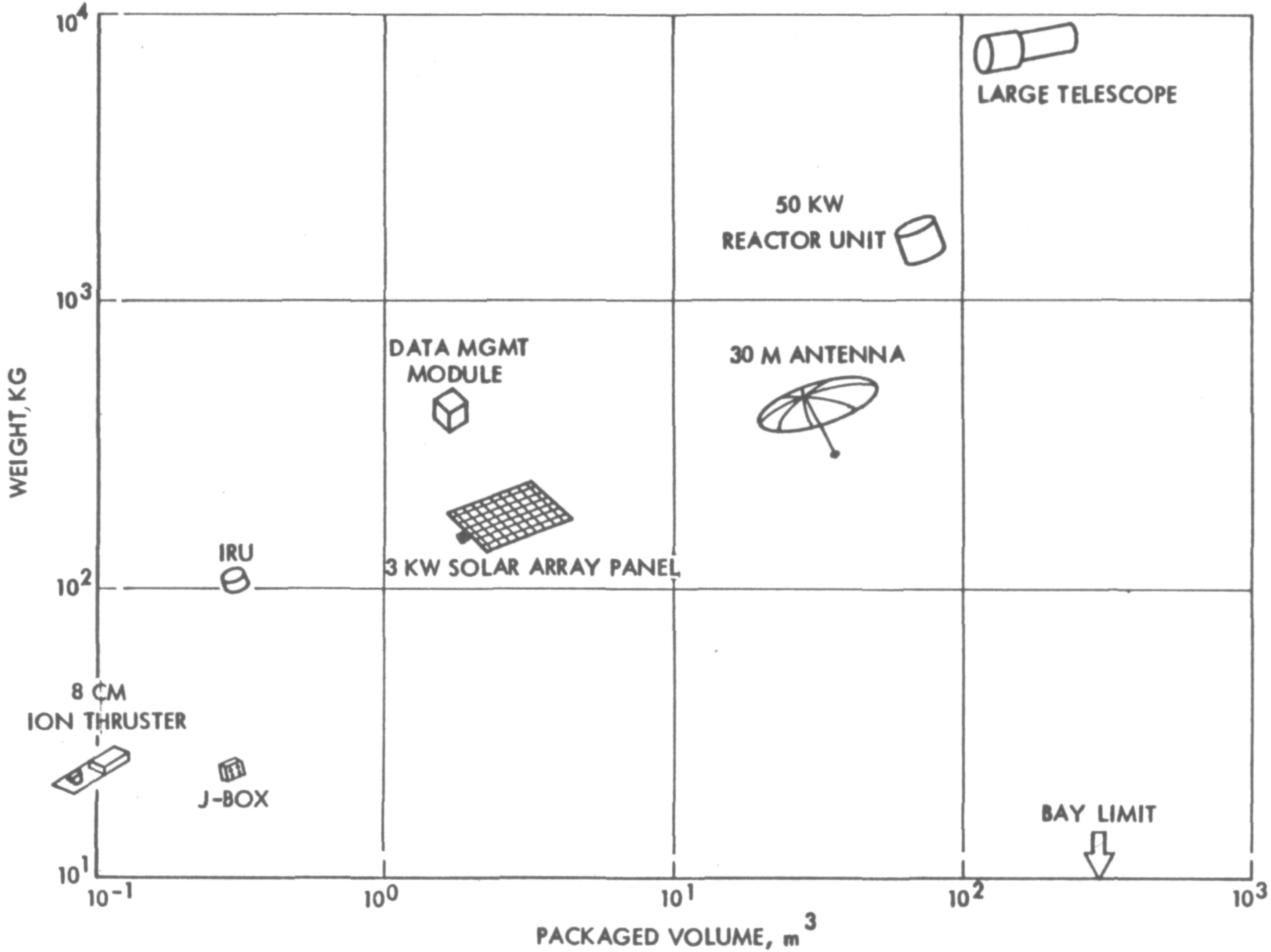


Chart 4

CHART 5 - EQUIPMENT INSTALLATION INTERFACES

The general requirements for the equipment installation are that it be mechanically tied to the structure and electrically interconnected with power and signal sources/receivers. More specifically, those interfaces must be "easy" to make and verify in the orbital environment. The electrical interface is shown to be separate from the mechanical; although integral mechanical-electrical interfaces are possible, they may not be most appropriate for the earliest constructions. The module should generally be installed at a structural node ("hardpoint") where loads can be most effectively distributed. As shown in the following chart, a single node attachment is generally sufficient to accept all but the very largest dynamic modules.

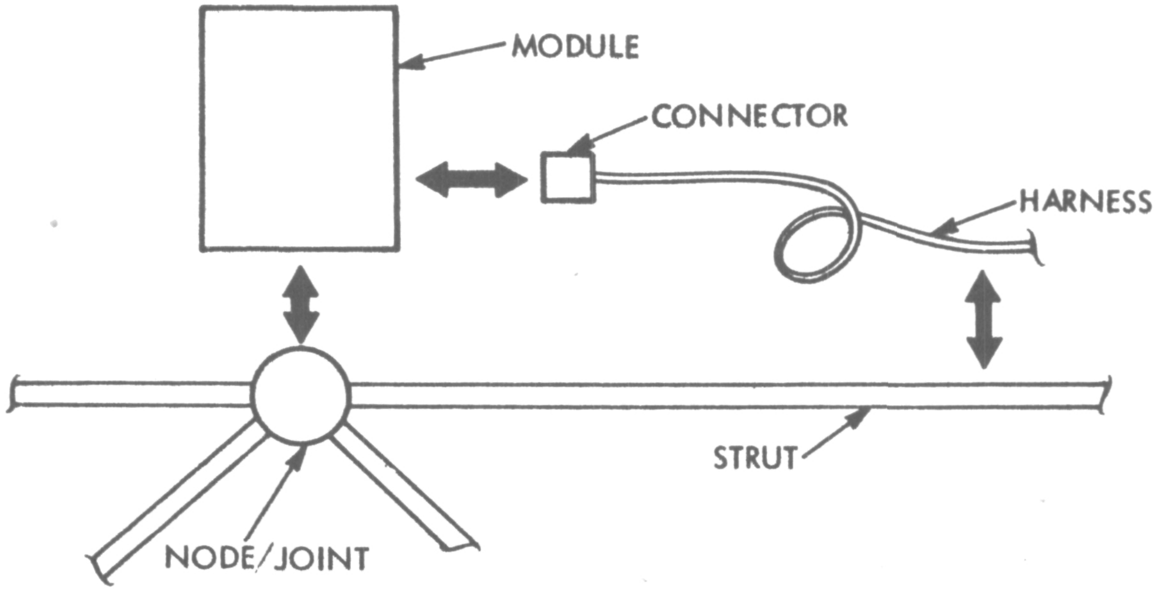


Chart 5

CHART 6 - INTERFACE LOADS

This chart shows the moment expected at the mechanical interface of a "representative" module (≈1 ton, 10-ft height). For this case it is assumed that the module produces no dynamic loads, and that the loads at the interface are those required to react the attitude excursions of the platform system and thrusting during orbit transfer. The graph is plotted as a function of the control frequency to represent the effect of "stiffness" in the control loop. As noted, the interface moment is fairly modest and, at the control frequencies and thrust-weight ratios of interest, is well within the capacity of a lightweight structural node/joint to react. If, of course, the platform were to require fast-slew operations or if--as in the case of a chemical thruster--dynamic loads were to be induced, a multi-node interface could be required.

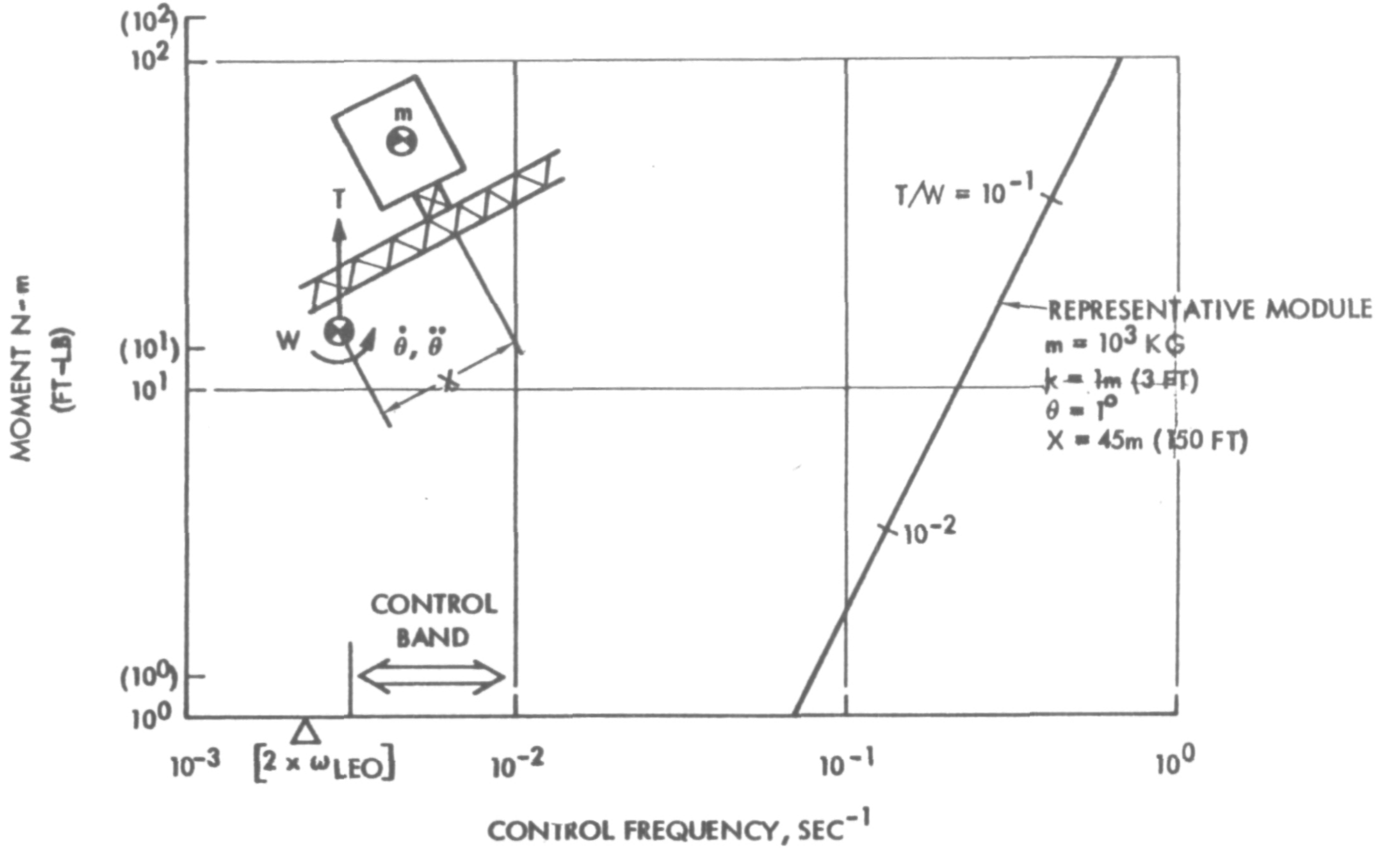

MOMENT N-m
(FT-LB)
(10²)
10²
(10¹)
10¹
(10⁰)
10⁰
m
T
W
θ̇, θ̈
X
T/W = 10⁻¹
10⁻²
REPRESENTATIVE MODULE
m = 10³ KG
k = 1m (3 FT)
θ = 1°
X = 45m (150 FT)
CONTROL
BAND
10⁻³
[2 × ω_LEO]
10⁻²
10⁻¹
10⁰
CONTROL FREQUENCY, SEC⁻¹

Chart 6

CHART 7 - MECHANICAL CONCEPT

A concept of a mechanical interface/adapter is illustrated. This is essentially a probe-drogue type of coupling where the probe is a part of the module. The drogue is incorporated within the multi-strut union as shown in overall view in the upper right-hand diagram. In addition to the interface requirements stated earlier, the coupling must allow an accurate positioning of the module with respect to the node, must react loads and must provide a rigid base for the module. The probe (shown here to be about 0.3-m/1-ft length) is engaged in a two-step latching procedure. As later discussed, the module will be positioned "over" the node and slowly "lowered" into position. In the first step, the ball end of the probe will engage the drogue and its latches. In the second step, the probe's redundant motors will drive the tapered shell of the probe into a "jam" with the walls of the drogue. The motors would be torque-limited and reversible so that disengagement could be effected, if warranted. Power for the motors will be discussed later.

- ACCURACY
- LOADS
- DYNAMICS

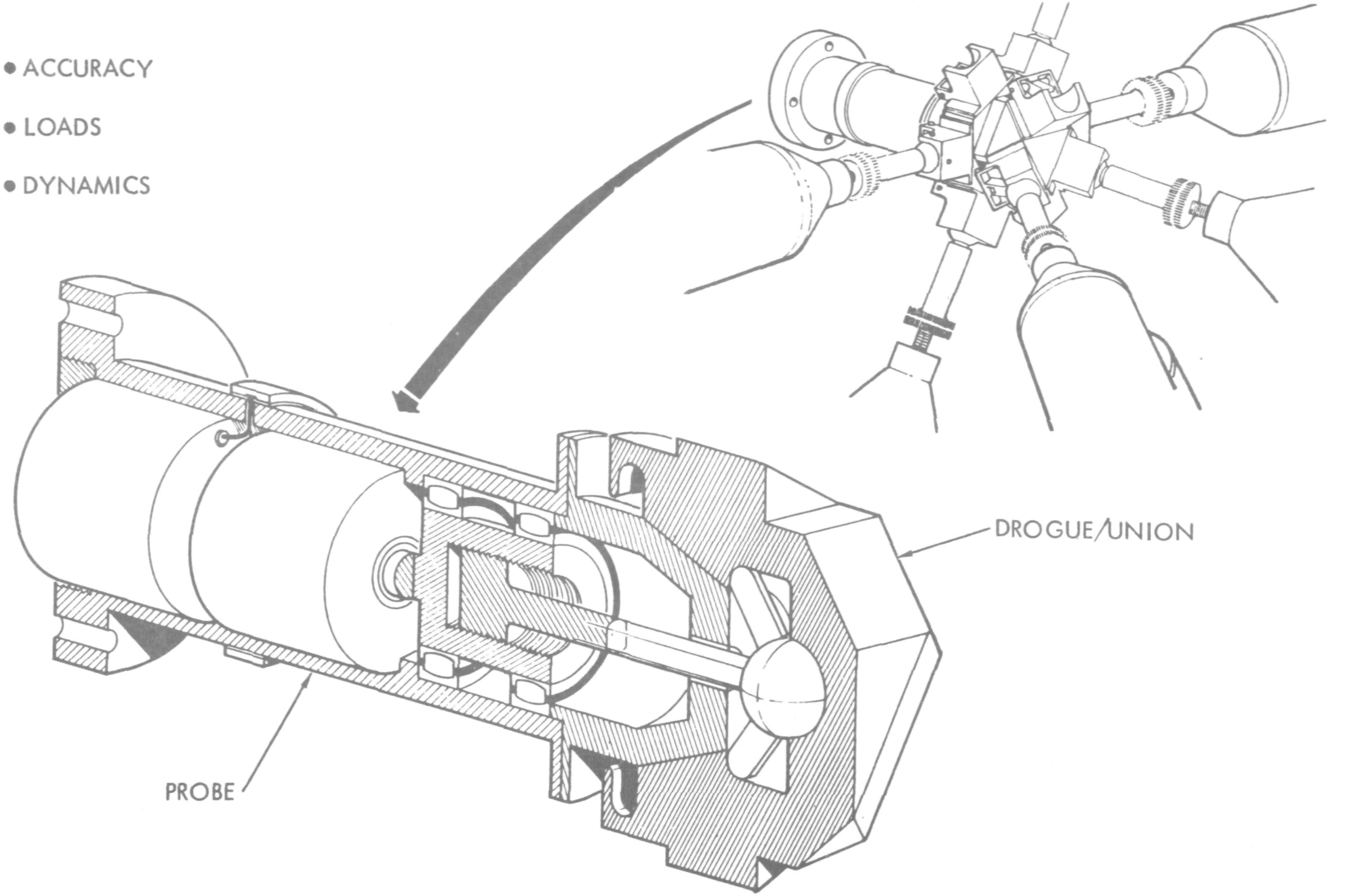


Chart 7

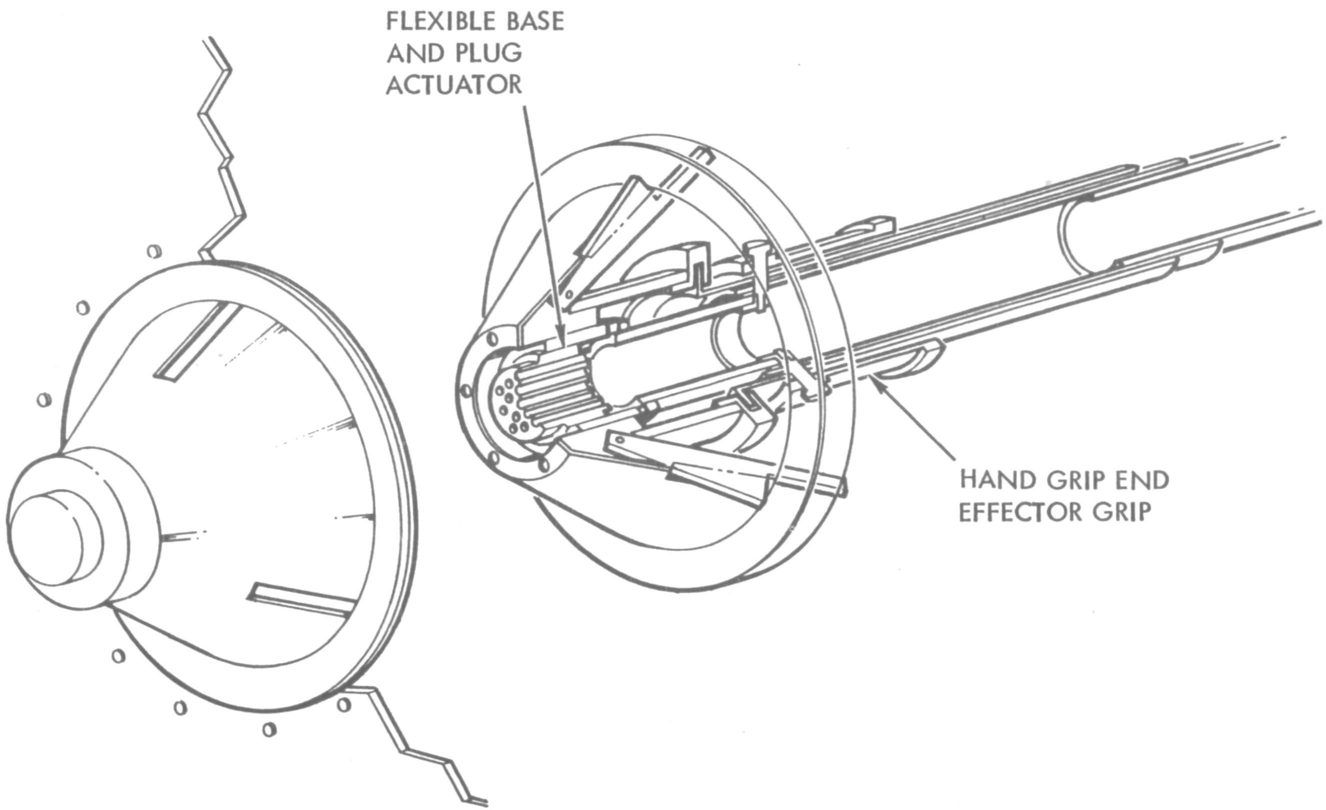
CHART 8 - ELECTRICAL CONNECTOR ASSEMBLY

A concept of an electrical interface/connector is illustrated. As in the previous mechanical device, this is also a probe-drogue type of coupling. The probe is part of the harness assembly and contains the male connector, and the drogue is built into the sidewall of the module. In addition to the earlier stated requirements, particular attention must be given to alignment (to avoid pin-bending) and to the force requirements. Since this concept is envisaged to be compatible with EVA or with manipulator arm operations, these factors are of prime importance. In addition, there should be some way in which the completed connection can be verified and in which the connection could be disengaged, if required.

As in the mechanical concept, this coupling is made in a two-step operation. In the first step the probe is gripped by the astronaut or effector on the outer sleeve and the unit inserted into the drogue. To permit initial misalignments, the probe is designed to have a compliance with respect to the harness/connector. When the probe is fully inserted, its spring-loaded latches will engage the drogue's slotted shell. In the second step, the astronaut/effector will "pull" on the probe's outer sleeve to extend the male connector into a mate with the female in the drogue. The action is designed with a 7:1 mechanical advantage and with key-ways to assure precision pin engagement.

ELECTRICAL CONNECTOR ASSEMBLY

- ALIGNMENT
- CONTINUITY



- FORCE
- DISCONNECT

Chart 8

CHART 9 - INSTALLATION TECHNIQUE

This chart illustrates one possible concept for the installation of modules on the structure. In this case, the Orbiter is shown equipped with two RMS (Remote Manipulator System) arms. The forward arm maintains the Orbiter's location with respect to the structure and also provides TV viewing of the module placement operations. The second arm has grasped the module at the probe end and executes the detailed installation operations. Power to drive the probe motors would be provided through the arm/end-effector to brush pickups on the probe. These operations will, of course, be under the control of the crew at the aft deck control station, and adequate lighting and direct- and TV-viewing will be essential. When the mechanical and electrical connections are completed, the two arms may be used to "walk" the Orbiter to the next installation location--as shown in the following chart. The potential of the RMS arms to perform these operations will be discussed in a later chart.

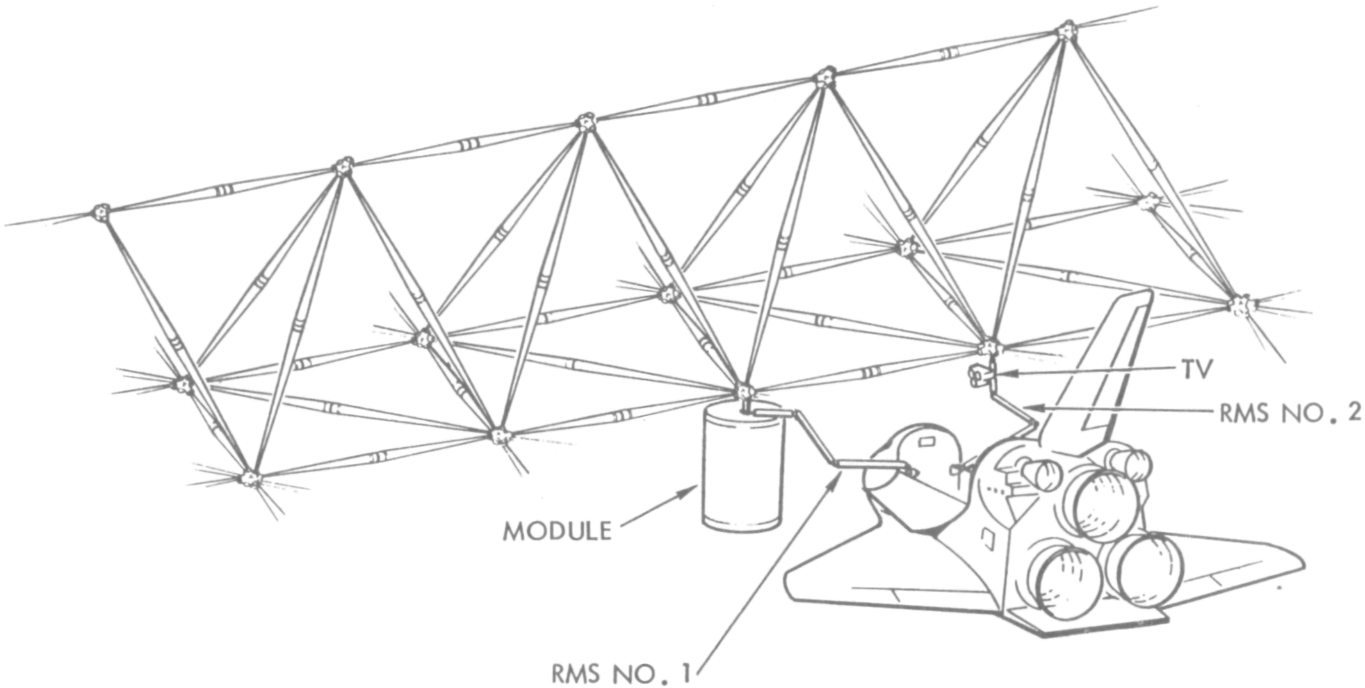
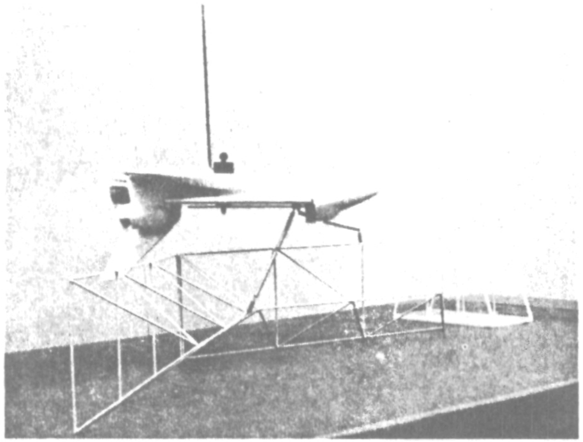


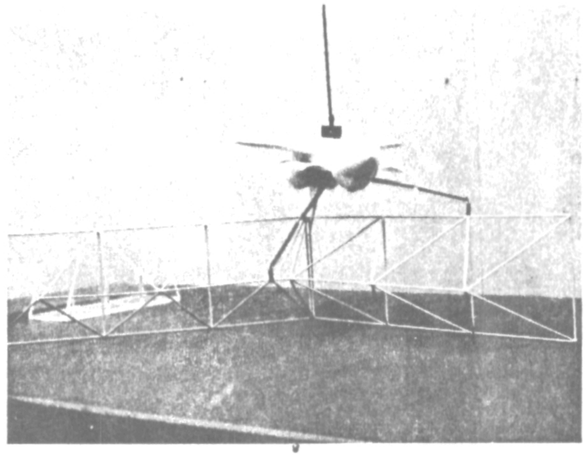
Chart 9

CHART 10 - WALKING TECHNIQUE

This chart illustrates the concept of "walking" the Orbiter--using two RMS arms. The photo insets show two views of a step in the action. For the case illustrated, the structure was a hexagonal frame made up of 14-m (45-ft) length struts; the concept would, however, apply to other structures insofar as the structural nodes would be within the reach of the two arms. In the position shown, the Orbiter has just engaged a forward node with its right-hand arm. The subsequent action would be to disengage the left-hand arm and, using the engaged RMS, maneuver the Orbiter and its free (left-hand) arm to reach the next node. These operations would be, of course, under control of the crew, and the Orbiter's orientation would be such as to assure safe clearance at all times.

The lower graph shows the approximate rate at which the Orbiter could translate with respect to the structure. To achieve this rate, the loads placed on the unions/nodes would be well under 100 N-m/ft-lb. Even at these low rates, the total time required for all walking operations for a 100-m structure could be less than a small fraction of one day's time out of the total mission.





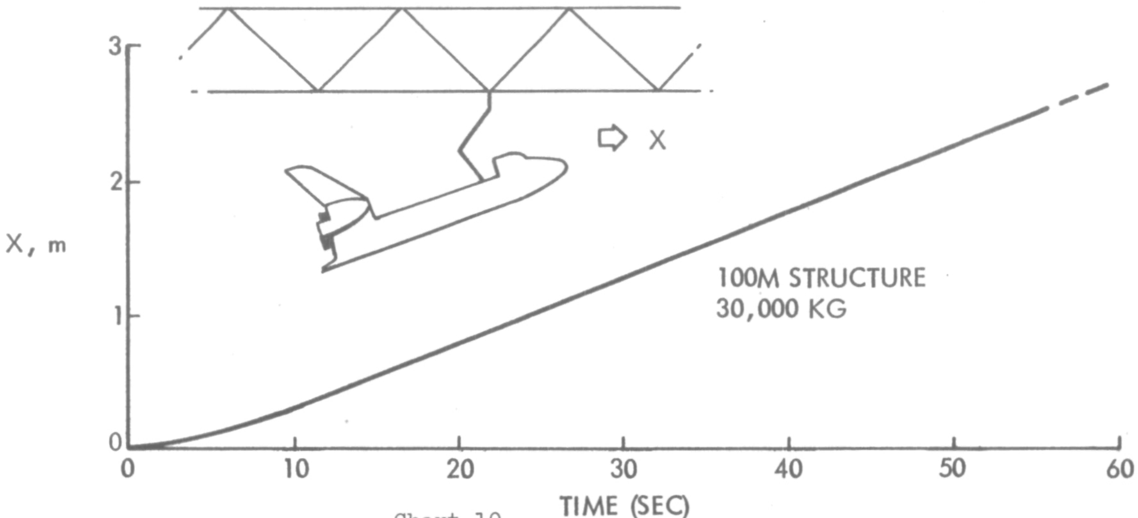


Chart 10

CHART 11 - RMS ISSUES

The previous charts have shown construction operations using the Orbiter's RMS in various ways--but always within its currently specified limits. This chart identifies some of the key issues underlying the feasibility of using the RMS as postulated. The reach of the 15-m (50-ft) long RMS is adequate for most foreseen (early) operations, but additional kinematic investigations are required. The accuracy with which the manually controlled RMS can position an element is still unknown, but on-going simulations at JSC and SPAR are encouraging. The principal question is, perhaps, how much time it will take to make an engagement--not whether an engagement can be made. In some instances, control of two arms may be desirable; more study is required to fully assess the impact upon software and control station provisions. The dynamics of the total Orbiter-platform-RMS system must be evaluated and simulated in detail to guard against undesirable oscillations and dynamic loads. Visibility requirements in terms of field of view, lighting, depth of perception, and other factors must be determined. In addition, the peculiar demands of construction operations will require special end-effector designs and associated tests. The following two charts illustrate planned IR&D experiments which should shed additional light upon some of these questions.

- ☆ REACH
- ☆ ACCURACY - TIME
- ☆ CONTROL
- ☆ DYNAMICS
- ☆ VISIBILITY
- ☆ EFFECTOR

Chart 11

CHART 12 - JOINING EXPERIMENT

This chart shows the concept of an experiment planned for early summer testing in JSC's Manipulator Development Facility (MDF). The test experiment would utilize the existing simulator/arm to evaluate accuracy-time relationships in making a structural joint. The model joint includes a ball-ended strut and a union with latching sockets to accept and retain the strut in place. The test variables would include strut orientation, approach aspect, and initiation distance. Although the test results would be obtained in a 1-g field, electronic simulations at JSC are expected to provide additional understanding of the gravity-dynamics factors.

JOINING EXPERIMENT (MDF)

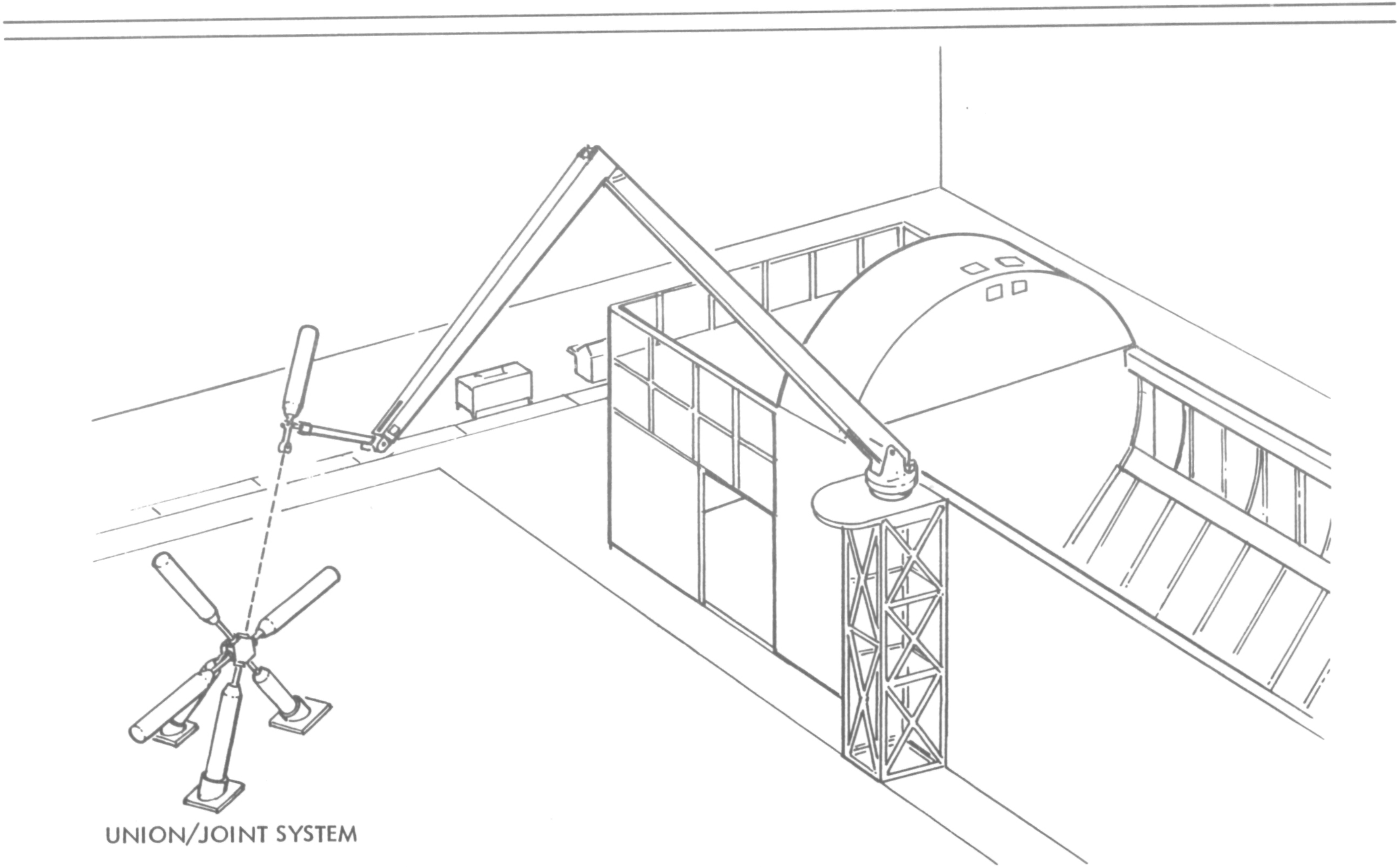


Chart 12

CHART 13 - CONNECTOR EXPERIMENT

A concept for an experiment in MSFC's Neutral Buoyancy Facility (NBF) is shown here. In this experiment, also planned for early summer testing, the capability of an EVA astronaut to make and unmake an electrical connector, similar to that previously described, would be demonstrated. The test model would include both halves of the connector and a harness to provide simulation of handling and bending restraints. The connector would also include a small internal battery circuit to provide visual proof of continuity across all pins.

Upon completion of the NBF/EVA tests, it is planned that a test setup, similar to that of the joining experiment, would be run at the MDF using the simulator arm to demonstrate the RMS mode of making the electrical connection. Although initial discussion on these tests have been held with JSC and MSFC, these experiments have not yet been approved for the MDF and NBF facilities.

CONNECTOR EXPERIMENT (NBF)

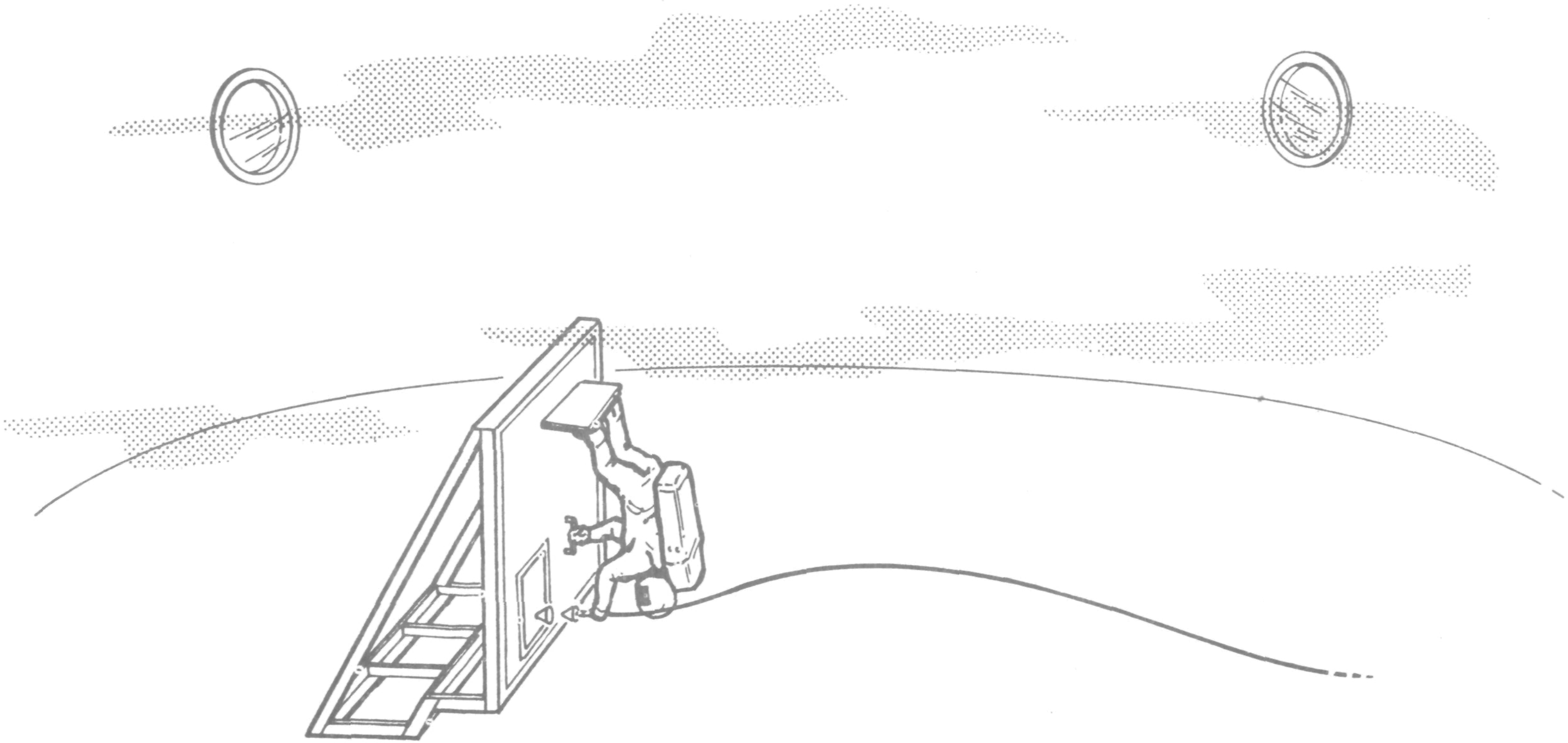


Chart 13

CHART 14 - CONCLUSIONS

The accompanying chart identifies the major points of this paper.

☆ PRELIMINARY CONCEPTS HAVE BEEN IDENTIFIED FOR EQUIPMENT INSTALLATION

- MECHANICAL
- ELECTRICAL
- ORBITER OPERATIONS

☆ STUDIES AND SIMULATIONS ARE REQUIRED FOR PROOF-OF-CONCEPT

☆ FY 1978 IR&D EXPERIMENTS ARE PLANNED TO OBTAIN INITIAL INSIGHTS

Chart 14

COMMENTS OF GENERAL INTEREST FROM QUESTIONS AND ANSWERS

Equipment Installation on Large Space Structures

1. Dynamic Considerations for the Orbiter-Attached-to-Structure During Erection Operations

   The present analyses see no reasons why the erection operations could not proceed with the reaction control system in the Orbiter turned off. A partial structure (no RCS) would move in response to erection operations, but the predicted rates will allow maintaining the relative geometry between the Orbiter and the structure during operations where the Orbiter "walks" along the structure. The force capability of the Manipulator System appears capable of maintaining the "tail down" attitude of the Orbiter.

2. Plans for a Dual Manipulator System

   OFT-3 will be the first flight with any manipulator system. The addition of a second manipulator awaits a subsequent program decision on the part of the NASA and the OMB.