ORBITER BASED CONSTRUCTION EQUIPMENT

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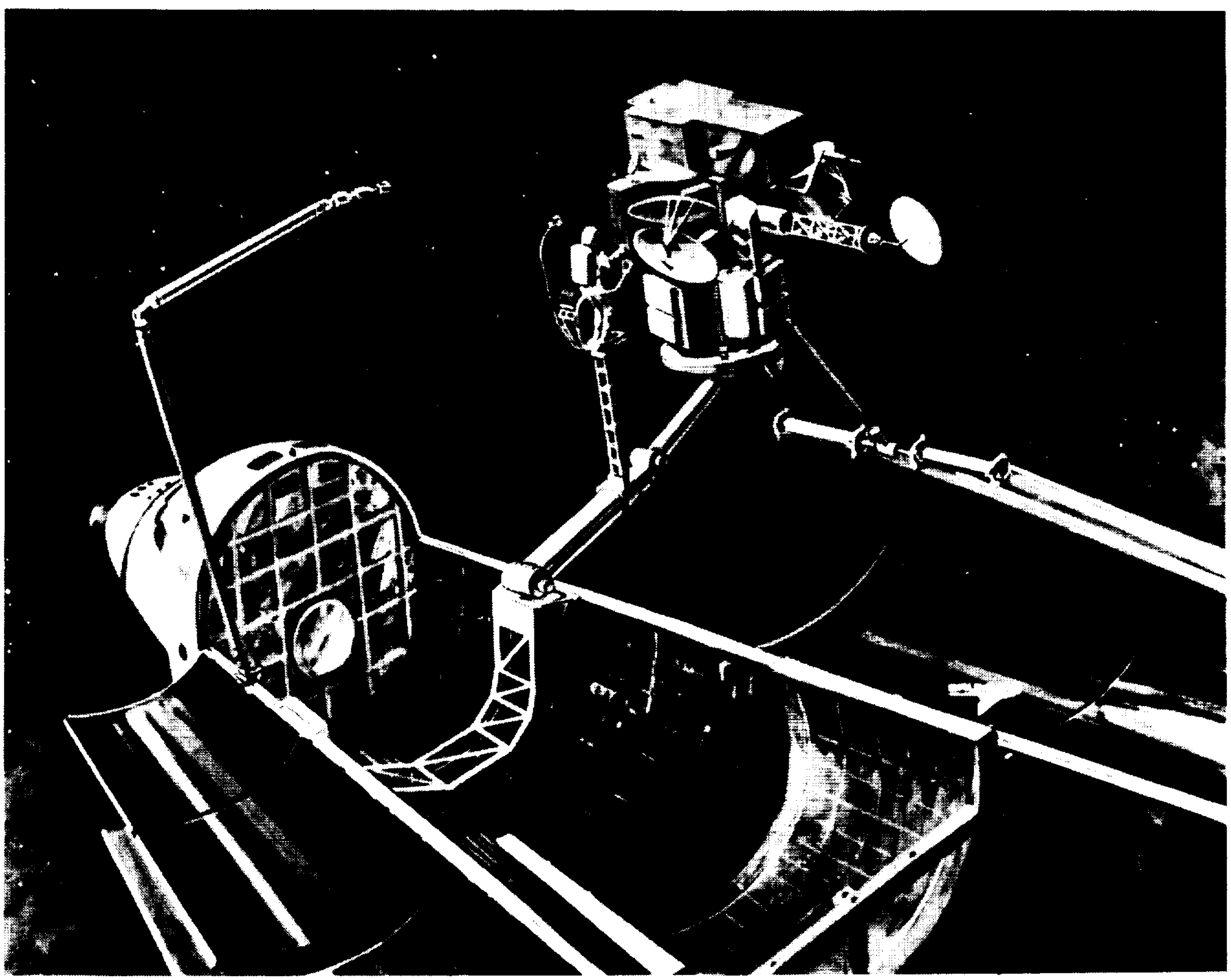
HANDLING AND POSITIONING AID IN USE

Many orbiter based activities need equipment to hold a payload steady while it is being worked on. This work may be construction, updating, repair, services, check-out, or refurling operations in preparation for return to Earth. The Handling and Positioning Aid (HPA) shown here is intended for use as general purpose equipment. It is initially conceived as being simple to operate, relatively stiff, and having the capability of holding the items to be worked on clear of the cargo bay, within the view field of the aft flight deck and within the envelope of the RMS. The basic HPA has a turntable at its tip, which can rotate the work-piece for easy access. It can support an EVA work platform with a large envelope - adjustable both for position along the HPA and for distance from it. The HPA base, which spans the cargo bay from longeron to keel to longeron, which spans ness and strength to support the shoulder. It can be ground adjusted to many stations along the length of the orbiter cargo bay.



HPA REQUIREMENTS SUMMARY - TWO CATEGORIES

From an analysis of ten reference missions, we have determined that two types of HPA mobility are needed: a tilt table, which simply swings out of the cargo bay, pivoting about an athwartships "y" axis, and an articulated arm with the general features of the previous illustration. These two types of HPA differ in their reach, degrees of freedom, location within the bay, stiffness requirements, and the amount of cargo they might be called upon to support during shuttle ascent and descent.

This paper will discuss some of the more detailed requirements, particularly as they apply to the articulated arm version.

MOBILITY	TILT TABLE	ARTICULATED ARM
• REACH	NA	4.5 – 5.5 m
DOF	1 OR 2	3 TO 5
ANGULAR RANGE	90 TO ±180°	130 TO ±180°
• LOCATION VARIES	MID TO AFT BAY	FORWARD TO MID BAY
• ARM STIFFNESS	1.8×10^6 Nm/RAD	@1.15×10^7 $N.m^2$ EFFECTIVE EI
• CARGO SUPPORT	2000/4000 kg	0 TO 10 000 kg
• BERTHING DEVICE	SINGLE STANDARD?	SOME STANDARDIZATION BUT NOT COMPLETE
• SPACECRAFT INTERFACES		
– POWER – DATA	AUTOMATIC CONNECT & DISCONNECT. REQUIRED.	
– FLUID	NA	MANUAL CONNECT & DISCONNECT. FEASIBLE
• WORK ZONE PREFERENCE	• WITHIN THE VIEW PYRAMIDS • INSIDE THE 80% RMS RADIUS	

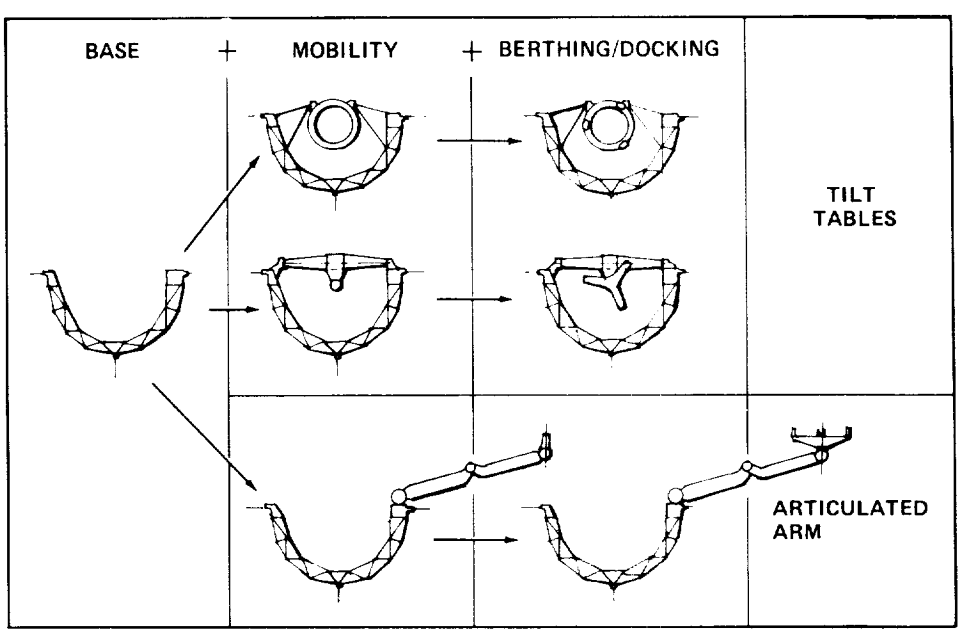
HPA MODULAR CONCEPT

The full HPA concept has tilt table versions and an articulated arm version. Each mounts various end effectors to suit the different missions. To simplify change of configuration on the ground and to minimize costs, a modular approach is used.

A base frame mounts the HPA to the orbiter and supports the active parts of the system. For inboard operations, movement of the berthing fixture from stowed to operational position is achieved by mounting a tilt table to the base frame. In one version, the table is a ring supported off the base frame by auxiliary struts. The berthing capability is, in fact, incorporated in this ring and is positioned for operations when the table/ring is tilted from its stowed position. An alternative version of the tilt table has a fulcrum spanning the base frame. The center of the fulcrum mounts a berthing spider which goes from stowed to operational position by rotating the fulcrum. Either tilt table version can be mounted to the base frame.

For an outboard HPA, a two piece articulating arm is mounted to the same base frame. Although commonality of arm piece length is an objective, each can be varied at ground assembly if a particular mission demands it. The tip of the outboard arm piece accommodates the berthing fixture required for the mission.

The base frame may, on occasion, be used without either tilt table or articulated arm, as a cargo support - spanning around the lower part of the cargo bay. In this way, modular components can be ground assembled to provide the various HPA configurations.



CONTROL COMPLEXITY - ARTICULATED ARM

Routine operation of the articulated arm comprises, typically, unstowing the arm, positioning the tip in a predetermined position, rotating the tip, moving to some other position, etc., and finally, restowing the arm. After each movement, there is usually one fairly long period - (hours, a whole shift) - while work is performed on the payload and the arm remains still. The five degrees of freedom afford access to anywhere in a 5.5 m radius hemisphere. The one-joint-at-a time control mode allows the control system to be kept simple. Even though the control speed is slow, the basic arm movements do not consume many minutes each. To keep arm checkout simple, sufficient power is supplied to allow for ground operations.

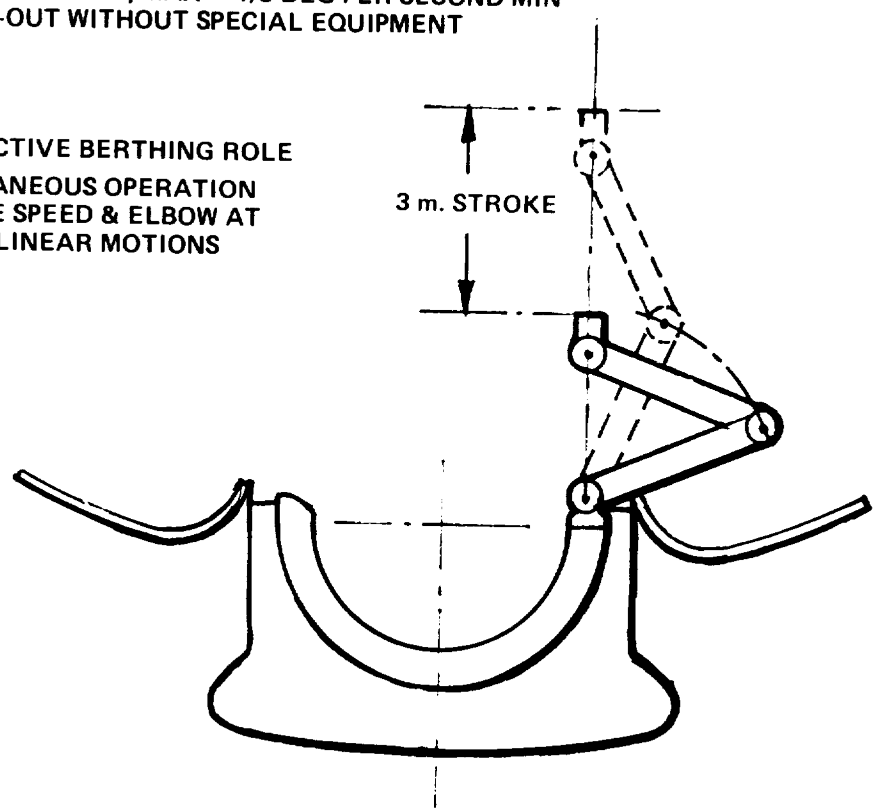
The HPA may be required to play an active role in payload berthing. Present analysis shows that the five degrees of freedom will be adequate for this function, if three of the joints can be coupled in the lunge mode (see sketch). This coordinated linear movement does not require any significant increase in control complexity.

ROUTINE OPERATIONS

- 5 DEGREES OF FREEDOM ~ SHOULDER 2, ELBOW 1, WRIST 2
- CONTROL FROM AFT FLIGHT DECK ~ ONE JOINT AT A TIME
- CONTROL RATES ~ 1 DEG PER SECOND, MAX ~ 1/3 DEG PER SECOND MIN
- POWER FOR GROUND CHECK-OUT WITHOUT SPECIAL EQUIPMENT

ADDITIONAL CAPABILITY FOR ACTIVE BERTHING ROLE

- THE LUNGE MODE SIMULTANEOUS OPERATION OF SHOULDER & WRIST AT ONE SPEED & ELBOW AT TWICE THAT SPEED PROVIDES LINEAR MOTIONS



THE EFFECT OF HPA ARM STIFFNESS ON COUPLED BODY FREQUENCY - SPACECRAFT WEIGHT & SIZE VARIED PARAMETRICALLY

This chart provides some insight into the fundamental frequency of a sizeable payload and an Orbiter coupled together by a medium length arm mounted 12 m (40 ft.) from the Orbiter cg, as shown on the upper right.

Before considering the parametric variables, various frequency boundaries should be noted. The Orbiter Prime Reaction Control Subsystem (PRCS) provides "easy" control down to a frequency of 2 cycles per second; by software modifications, control authority could be extended down to about 0.3 cps. The Vernier Reaction Control Subsystem (VRCS) can currently control down to 0.1 cps and again, by modification, its capability could be extended down to 0.02 cps.

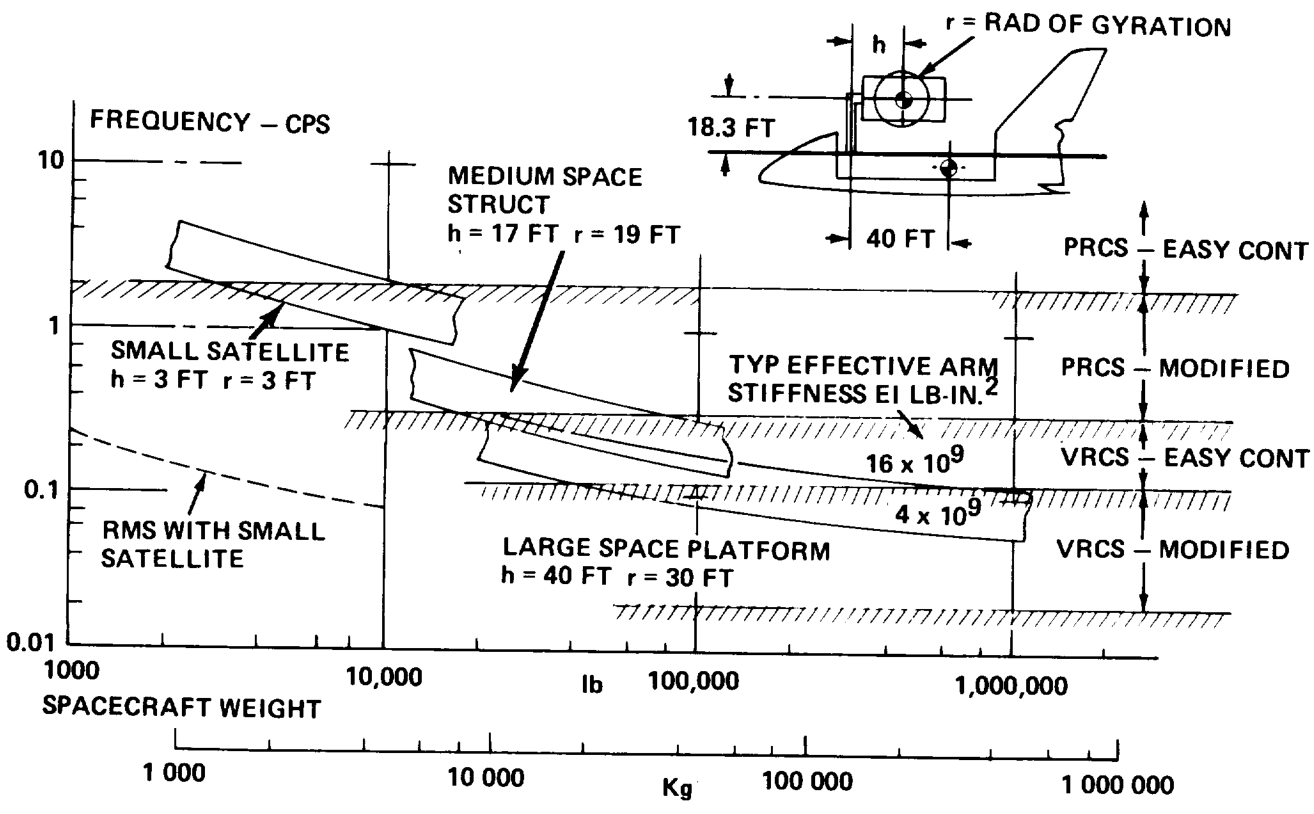
Besides spacecraft weight - the horizontal ordinate - there are two parameters treated in the plot: (1) Effective arm stiffness, with a lower value of EI = 1.2×10^7 N-m^2 (4×10^9 lb-in^2) and a higher value four times as high. The lower value results in a relatively modest structural weight - the higher value borders on the unacceptable. (2) Spacecraft size; expressed in terms of h, the offset between the arm pick-up and the spacecraft cg and r, the spacecraft radius of gyration. These quantities are to some extent interchangeable. Three sets of h and r values have been chosen typical of a small satellite, a medium sized space structure, and a large space platform. The arm length of 5.6 m (18.3 ft) is chosen to suit a spectrum of representative payloads.

The three frequency bands reflecting these spacecraft sizes and arm stiffness values cut across the RCS boundaries as a function of spacecraft weight. Upon study of this plot we have selected the lesser effective arm stiffness for the following reasons.

- It is lighter
- The VRCS is likely to be the system of choice during service and construction activities, which will permit handling a structure of about 50,000 kg without RCS modification.
- Any large space platform to which the Orbiter is attached may have a CMG/Inertia Wheel control which would make the use of the VRCS moot.

As a point of interest, the performance of the RMS supporting a small satellite is shown in the lower left corner of the plot.

THE EFFECT OF HPA ARM STIFFNESS ON COUPLED BODY FREQUENCY – SPACECRAFT WEIGHT & SIZE VARIED PARAMETRICALLY

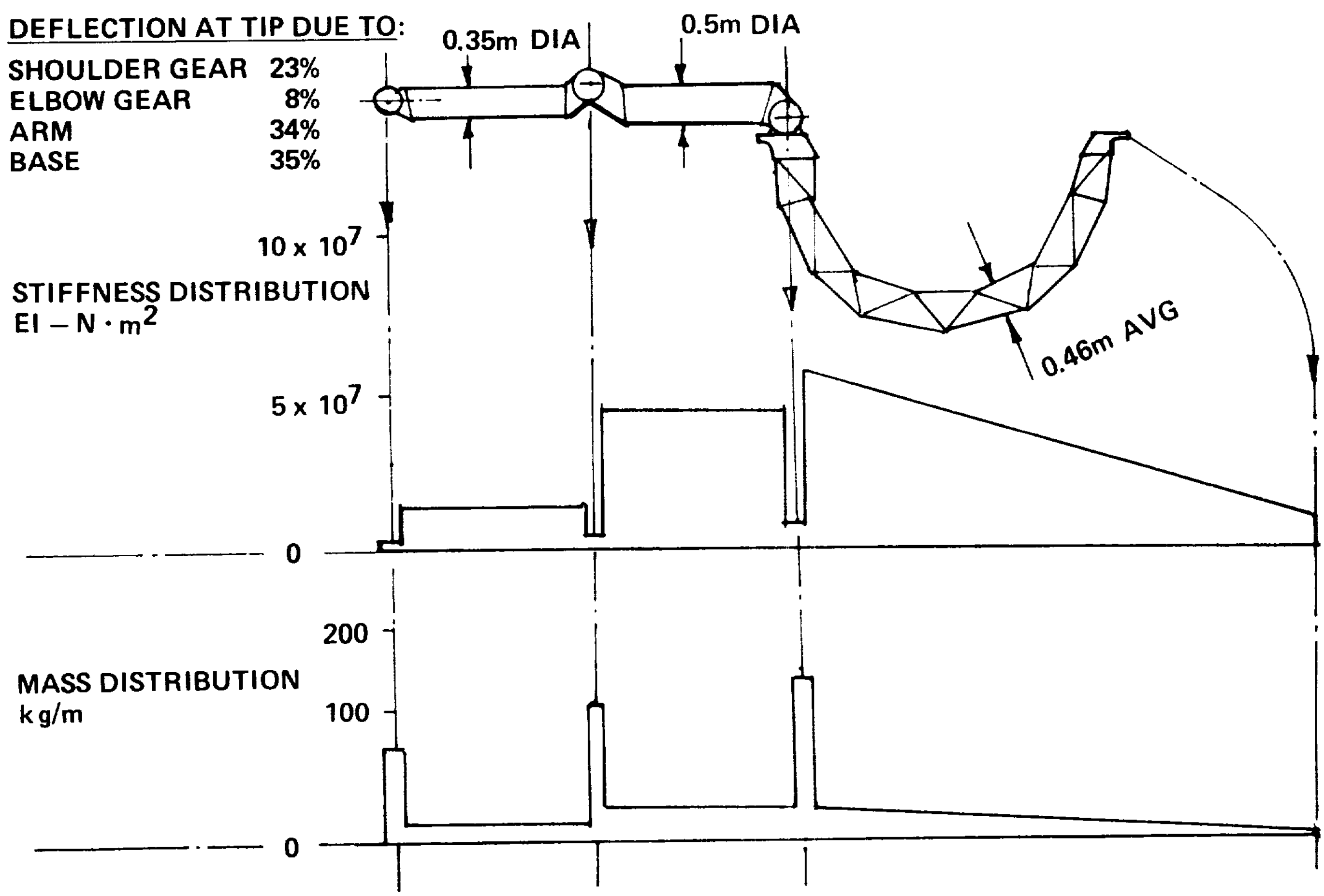


PRELIMINARY OPTIMIZATION OF ARTICULATED ARM
FOR STIFFNESS WITH MINIMUM WEIGHT

This chart shows an arm designed to produce an effective stiffness between its shoulder joint and tip (inclusive) of 1.2 x 10^7 N-m^2 (4 x 10^9 lb-in.^{2}) EI.

As shown by the plot of stiffness distribution, the shoulder and elbow gears are the weak links in providing high stiffness. The gear boxes are very heavy for the stiffness they provide. They represent only 6% of the total structural length, but account for 40% of the weight.

The table at the top left hand corner of the chart shows the contribution of each element to the tip deflection.



BERTHING AND DOCKING FIXTURES - FIRST APPRAISAL

The chart illustrates three berthing fixtures that could be used with a tilt table and four berthing/docking fixtures to be used with an articulated arm. Also shown is our first appraisal of which reference mission will use which fixture.

Considering first the five tilt table users, four are initially listed as employing the open center version, which is borrowed from the MMS/FSS hardware. The fifth, the Geostationary Platform, requires a tilt table with latches spaced to pick up on an Orbit Transfer Vehicle of nearly 4.6 m (15-ft.) diameter. This is mission dedicated equipment and does not suit any other reference mission.

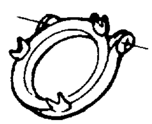
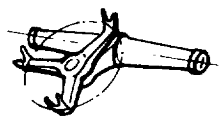
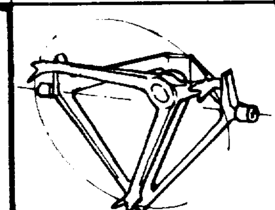
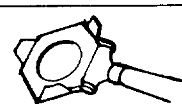
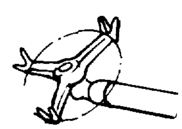
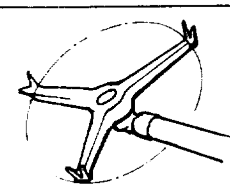
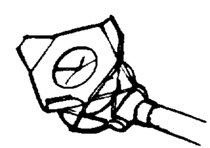
Three missions employing an articulated arm use a center bearing spider fixture, possibly having more than one size. The SOC mission is shown twice. In one case the reference mission is assumed to involve docking, and, in another case, berthing. In both cases the fixture includes a center hole for the passage of shirtsleeved astronauts. It should be noted that the SOC (berthing) mission fixture will quite possibly be mounted not on an HPA but on the so-called Orbiter Docking Tunnel. In this event it should not, properly speaking, appear on this chart.

In endeavoring to reduce the number of fixtures it was noted that the four tilt table missions initially shown as using the open-center turntable do not make significant use of the hole in the middle. They could therefore interface with a spider turntable of the same latch pitch circle diameter (1.8m). Further examination of the Large Space Structure (LSS) mission shows that its interface device can also be adjusted to use the 1.8-m diameter size spider.

Seven of the nine reference missions shown would then use an essentially common spider structure, some in a tilt table version, some on an articulated arm.

The two logical exceptions to this standardization initiative are the large diameter interface for an OTV and the "hole-in-the center" astronaut interface for the SOC whether berthing or docking.

BERTHING AND DOCKING FIXTURES — STANDARDIZATION?

	BERTHING			DOCKING
	OPEN CENTER	SPIDER	SPIDER	OPEN CENTER
TILT TABLE • LATCH PITCH CIRCLE DIA • REP MISSIONS	 1.8 m ST → UARS → INTELSAT → OAO →	 1 – 1.8 m • • • •	 4.2 m GEO PLATFORM (MISSION PECULIAR OTV INTERFACE)	
ARTICULATED ARM • LATCH PITCH CIRCLE DIA • REP MISSIONS	 1.3 m SOC BERTH (MAY ATTACH TO DOCKING TUNNEL NOT. HPA)	 1 – 1.8 m • ORB SERV RTFM • 25 kw PWR MOD • ←	 3.3 m LSSD	 1.5 m SOC (DOCK)

SUPPORT EQUIPMENT

Items of support equipment identified during analysis of the reference missions are listed. Certain items are shown to be required repeatedly, even in this limited sample of future missions. The items indicated in the final column will have measureable impact on the use of the cargo bay volume; therefore, stowage provisions and locations should be selected carefully. It may be possible to provide stowage for many of the commonly used pieces of equipment within the framework of the HPA base structure.

EQUIPMENT	REFERENCE PAYLOADS										
	GEO PLATFORM	DEPLOY PLATFORM	LSSD	SOC	ST	UARS	INACT OAO	INTELSAT	25 kw PM	PEP	CARGO BAY STOWAGE IMPACT
HPA	√	√	√	√	√	√	√	√	√	√	•
RMS	√	√	√	√	√	√	√	√	√	√	
UMBILICAL – FLUID									√		
– DATA			√		√				√	√	
– POWER			√		√				√	√	
BERTHING/DOCKING DEVICE	√		√	√		√	√		√	√	•
SPECIAL TOOLS	√	√	√	√		√	√		√	√	
PROXIMITY OPS MODULE		√					√				•
CARGO BAY STORAGE		√	√		√	√	√				•
SPECIAL END EFFECTOR			√	√			√				
OCP/MFR		√	√			√			√		•
MODULE REPLACEMENT AIDS					√					√	
STARBOARD RMS			√								
WORK PLATFORM		√	√		√	√	√				

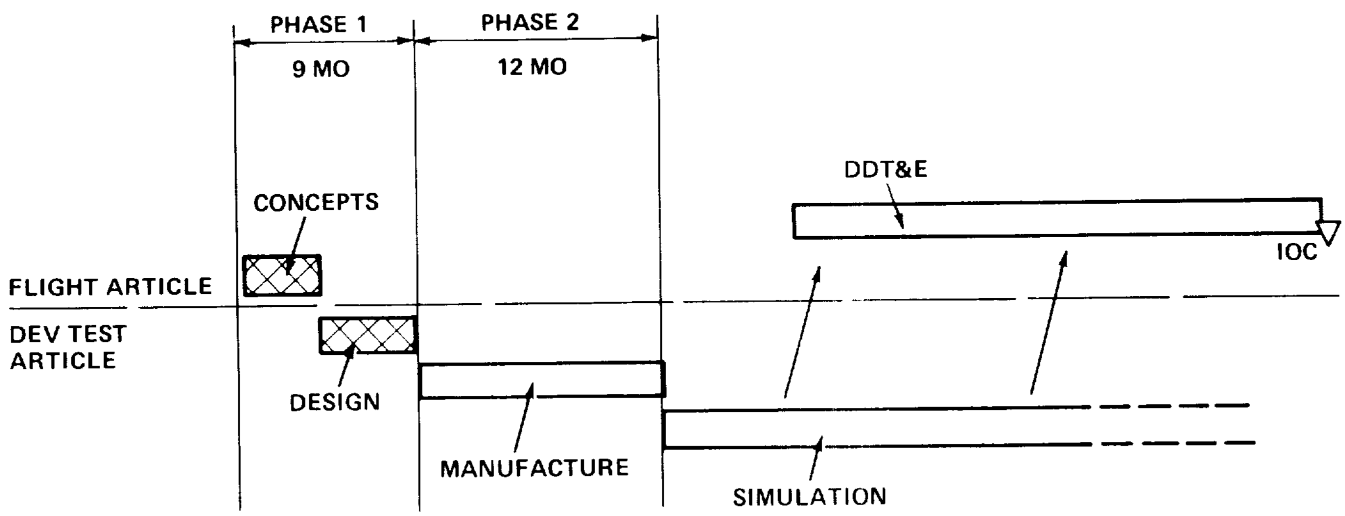
STANDARDIZATION & INTEGRATED STOWAGE

OVERALL PROGRAM STATUS

To place the HPA in its proper time context, the overall program and its status are shown.

There are two types of hardware: the flight article and a ground development test article. In phase 1, which is just drawing to a close, an initial look at flight article concepts has been followed by design of the ground test article. Phase 2 will see this test article manufactured, after which simulation at Bethpage and at NASA JSC will commence.

If all goes according to plan, flight article activity will resume when simulation results start to accumulate.



PHASE 1 OBJECTIVES:

FOR ORBITER BASED CONSTRUCTION & SERVICE SUPPORT EQUIPMENT:

- DEFINE TECHNOLOGY ADVANCEMENTS NEEDED
- DEVELOP HANDLING & POSITIONING AID CONCEPTS
- PREPARE PRELIMINARY DESIGN OF DEVELOPMENT TEST ARTICLE

PHASE 2 OBJECTIVE:

- BUILD DEV TEST ARTICLE ON TIME AND WITHIN BUDGET

HPA CHARACTERISTICS

In summary, the HPA provides a wide choice of work station positions, both immediately above the orbiter cargo bay and beyond. It can act in a primary docking role and, if required, can assist actively in the berthing process.

The HPA is intended to be stiff; it can, therefore, be robust. In addition, its control philosophy is simple. For these reasons we believe it can be made inherently reliable.

Finally, it is modular to provide several configurations to serve many missions.

ACTIVITIES

- WORK STATION
  - INBOARD
  - OUTBOARD
- ASSIST WITH BERTHING?
- PRIMARY DOCKING DEVICE

FEATURES

- STIFF/ROBUST
- SIMPLE
- RELIABLE
- MODULAR