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RECENT RESULTS FROM ZERO 'G' CARGO HANDLING STUDIES

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INTRODUCTION

In the past several years a number of studies have been made of zero 'g' cargo transfer problems. These studies have generally been exploratory or mission-oriented in nature and have provided limited and sometimes conflicting results. Recently cargo handling and transfer has become of greater importance due to the large amounts of cargo planned for delivery by the Space Shuttle. Because of these shuttle requirements it is of considerable importance to determine what means of transfer will be used. That is, can man perform the transfer tasks adequately or are automated or semi-automated systems required.

These questions and others are being investigated as part of LRC's shuttle man/machine integration research effort. This paper will discuss the LRC program and indicate some of the results presently being obtained in the area of cargo handling.

LRC SHUTTLE MAN/MACHINE STUDY PROGRAM

Figure 1 shows the overall LRC shuttle man/machine study effort. As shown, this effort includes: a contract study to define man/machine areas requiring detail investigation; studies of cargo transfer and stowage from both a parametric and a shuttle configuration standpoint;

a cooperative effort to evaluate a laser radar for docking being developed for MSFC on LRC Real-time Dynamic Simulator; studies of personnel transfer and astronaut rescue related to all proposed shuttle missions; a study contract leading to the evaluation of a multiuse, cargo transfer aid; and general review, analysis, and simulations, as required, of shuttle docking, abort, and EVA tasks. The major effort to date has been addressed to the first two tasks shown and these will be discussed in some detail.

SHUTTLE PROBLEM-DEFINITION STUDY CONTRACT

The initial shuttle man/machine integration study conducted at LRC consisted of a problem-definition study contract with Environmental Research Associates (ERA). This study was conducted under Contract NAS1-8975-3 and is reported in NASA CR-111,847. The scope of the study (figure 2) under this contract was as follows: (1) the contractor was to review and evaluate all available shuttle documents including Phase A final reports, Phase B proposals and progress reports, etc. From this review, information on shuttle configurations, and docking, cargo transfer, EVA and abort requirements were compiled and commonality, mission constraints, etc., were determined. (2) Following this review the contractor was asked to determine the state-of-art in personnel and cargo transfer and to a lesser degree in docking and shuttle-related EVA. From this determination deficient areas were determined. (3) Concurrent to the state-of-art review the contractor was to analyze transfer

LANGLEY RESEARCH CENTER SHUTTLE MAN/MACHINE INTEGRATION STUDIES

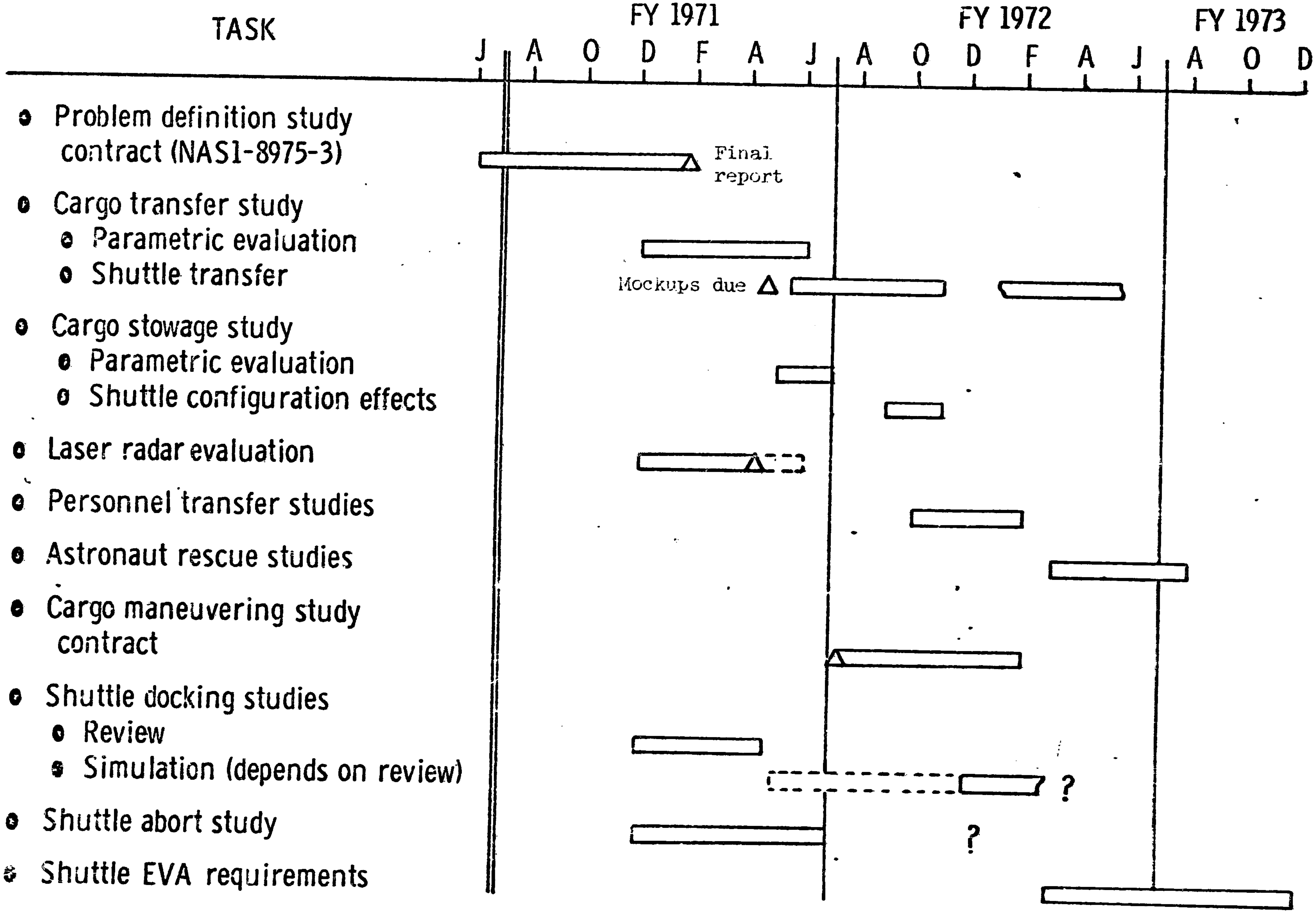


FIGURE 1.

PROBLEM DEFINITION STUDY CONTRACT

CONDUCTED BY ENVIRONMENTAL RESEARCH ASSOCIATES

REPORTED IN NASA CR-111847

SCOPE OF STUDY

- REVIEW AND EVALUATION OF SHUTTLE REPORTS
- DETERMINE STATE OF ART IN PERSONNEL AND CARGO TRANSFER TECHNIQUES AND AIDS
- ANALYSIS OF TRANSFER OPERATIONS FOR TYPICAL MISSIONS
- DEVELOP EXPERIMENTAL PLAN TO STUDY DEFICIENT AREAS

FIGURE 2.

operations, docking and EVA for representative shuttle missions. (4) Finally, taking into account all of the reviews and analyses conducted, the contractor was to develop an experiment plan to study, through analysis and simulation, the deficient areas found in passenger and cargo transfer, docking and EVA.

Figure 3 is a representative sample of the task analysis conducted by ERA. This particular figure is for cargo transfer and shows the various components of the task and the relative priority necessary to study the task. As can be seen the studies of problems related to package stabilization and translation were necessary first, followed by tests to evaluate these problems as they interacted with disconnect and shuttle configuration considerations. Similar flow diagrams were developed for docking and personnel transfer.

Figure 4 illustrates the format for suggested experimental programs. It is for cargo transfer and similar ones were developed for docking and personnel transfer. These program plans indicated studies that should be conducted to supply necessary information in a timely fashion, the mockups and experiment required to support the studies, the experimental sequence of the studies for the different type missions and the type of results to be obtained.

One additional sample of the cargo transfer work reported in the study contract is illustrated in figure 5. This figure illustrates a

CARGO EXPERIMENT FUNCTIONAL PRIORITY

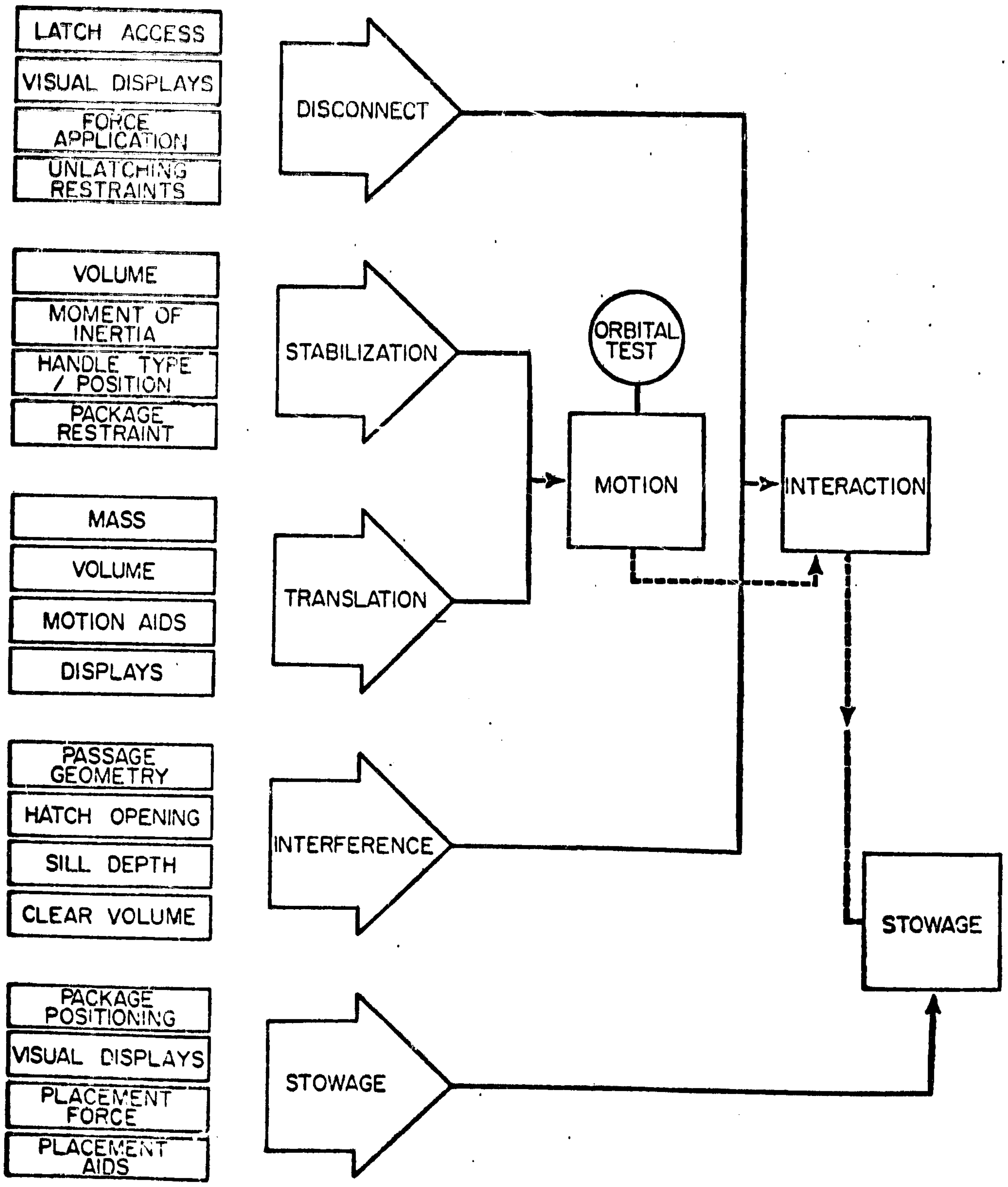
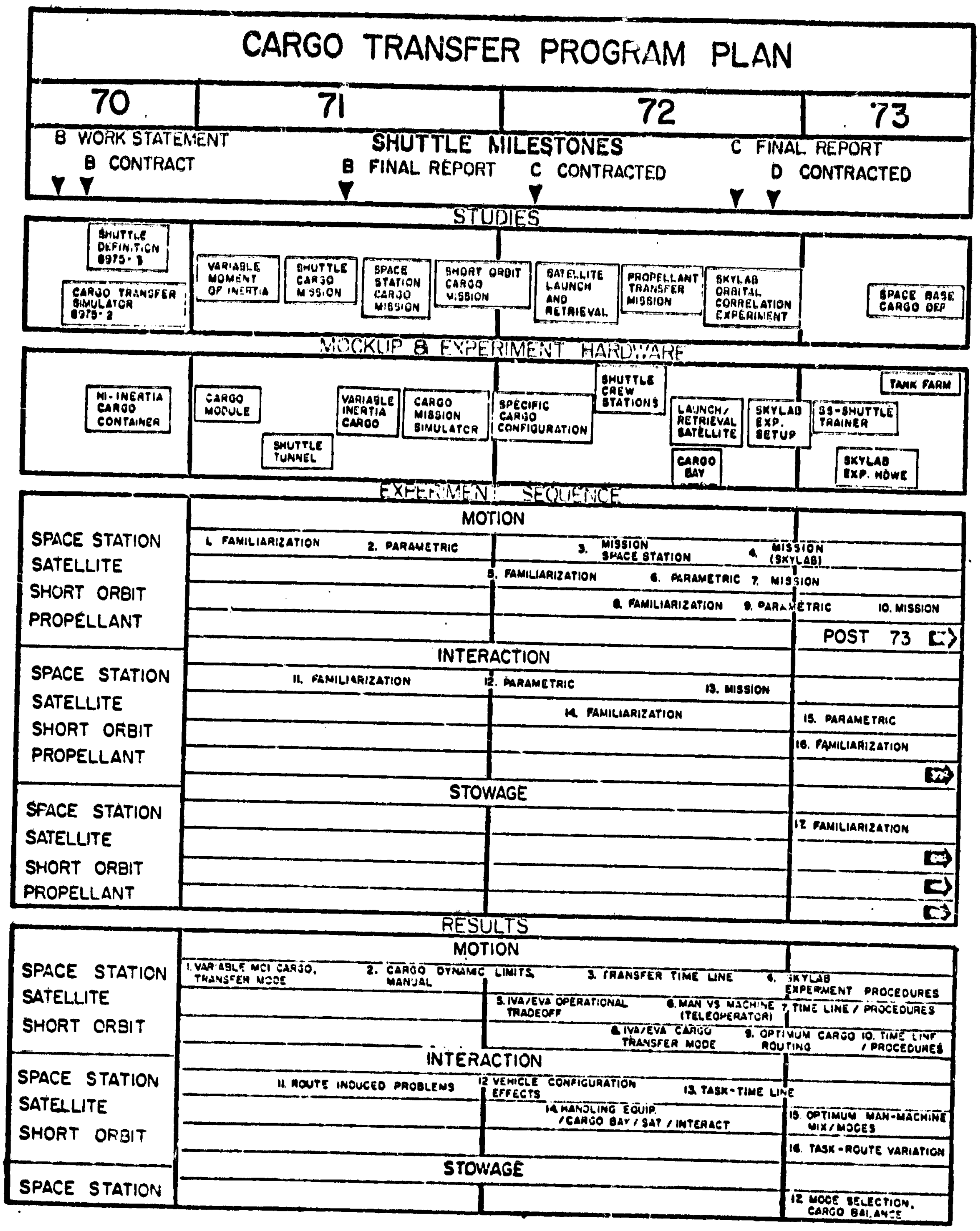


FIGURE 3.



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C CONTRACTED
C FINAL REPORT
D CONTRACTED
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CARGO TRANSFER SIMULATOR 8975-2
VARIABLE MOMENT OF INERTIA
SHUTTLE CARGO MISSION
SPACE STATION CARGO MISSION
SHORT ORBIT CARGO MISSION
SATELLITE LAUNCH AND RETRIEVAL
PROPELLANT TRANSFER MISSION
SKYLAB ORBITAL CORRELATION EXPERIMENT
SPACE BASE CARGO DEF
MOCKUP & EXPERIMENT HARDWARE
MI-INERTIA CARGO CONTAINER
CARGO MODULE
SHUTTLE TUNNEL
VARIABLE INERTIA CARGO
CARGO MISSION SIMULATOR
SPECIFIC CARGO CONFIGURATION
SHUTTLE CREW STATIONS
LAUNCH/RETRIEVAL SATELLITE
CARGO BAY
SKYLAB EXP. SETUP
SS-SHUTTLE TRAINER
TANK FARM
SKYLAB EXP. HOWE
EXPERIMENT SEQUENCE
MOTION
SPACE STATION
SATELLITE
SHORT ORBIT
PROPELLANT
1. FAMILIARIZATION
2. PARAMETRIC
3. MISSION SPACE STATION
4. MISSION (SKYLAB)
5. FAMILIARIZATION
6. PARAMETRIC
7. MISSION
8. FAMILIARIZATION
9. PARAMETRIC
10. MISSION
POST 73
INTERACTION
SPACE STATION
SATELLITE
SHORT ORBIT
PROPELLANT
11. FAMILIARIZATION
12. PARAMETRIC
13. MISSION
14. FAMILIARIZATION
15. PARAMETRIC
16. FAMILIARIZATION
STOWAGE
SPACE STATION
SATELLITE
SHORT ORBIT
PROPELLANT
17. FAMILIARIZATION
RESULTS
MOTION
SPACE STATION
SATELLITE
SHORT ORBIT
1. VARIABLE MCI CARGO, TRANSFER MODE
2. CARGO DYNAMIC LIMITS, MANUAL
3. TRANSFER TIME LINE
4. SKYLAB EXPERMENT PROCEDURES
5. IVA/EVA OPERATIONAL TRADEOFF
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7. TIME LINE / PROCEDURES
8. IVA/EVA CARGO TRANSFER MODE
9. OPTIMUM CARGO ROUTING
10. TIME LINE / PROCEDURES
INTERACTION
SPACE STATION
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SHORT ORBIT
11. ROUTE INDUCED PROBLEMS
12 VEHICLE CONFIGURATION EFFECTS
13. TASK-TIME LINE
14. HANDLING EQUIP. /CARGO BAY / SAT / INTERACT
15. OPTIMUM MAN-MACHINE MIX / MODES
16. TASK-ROUTE VARIATION
STOWAGE
SPACE STATION
17. MODE SELECTION, CARGO BALANCE

FIGURE 4.

HUMAN PERFORMANCE - PACKAGE DENSITY INTERFACE

VOLUME / CUBIC FEET

WEIGHT / POUNDS	<1	1-5	6-10	11-50	51-100	101-500	
<1	1						1
1-10	54	4	1				59
11-50	10	49					59
51-100		18	2		1		21
101-500		8	5	6	2		21
501-1000			2	4			6
1001-5000				2	1	1	4
>5000				1	1	1	3
	65	79	10	13	5	2	

COMBINED SPACE STATION CARGO COMPLEMENT

FIGURE 5.

typical shuttle logistics cargo complement. On the figure the cargo is divided into classes according to weight and volume and the number of packages falling into each class is shown. Superimposed on this cargo matrix, the rows of which are package weight and the columns package volume, are indications of currently accepted manual cargo transfer capability. For example, the white area represents the package volumes and masses generally accepted as being within the handling capability of a man. Most packages expected fall within this category. The dotted area represents areas where there is significant current disagreement as to man's potential. The cross-hatched area is generally conceded to be outside the range of practical manual cargo handling. It can be seen that extension of man's capability into the dotted area would significantly affect considerations of man's role in cargo transfer and the need for automated systems. This area of interest can be considered as a point of departure for LRC studies.

LRC CARGO TRANSFER PARAMETRIC STUDY

LRC in-house simulation studies are directed toward resolving the cargo transfer questions raised in figure 5, by determining through a parametric study the limits of manual cargo handling. The study is being conducted using water immersion simulation techniques and considering the parameters shown in figure 6. As shown, the study is considering package masses from 3 to 50 slugs, volume of 1.5 to 142 cubic feet, moments of inertia up to 900 slug ft^2 and various other aspects such as maneuvering aid, pressure-suit effects and one-man versus two-man transfers.

Many different mockups of cargo were used in the study. Figure 7 illustrates a typical package. The package mockups were constructed using a central sphere to provide buoyancy, lead to provide mass and thin pipes to represent volumetric limitations. Also shown on this figure is the course used in the tests. It consisted of two 1.25" handrails separated by about 18 inches and layed out in a 20-foot-by-10-foot rectangle, thus permitting evaluation of straight line transfers as well as turns.

The prime method of evaluating the cargo handling tasks was through a subject rating scale as shown in figure 8. The ratings range from 1-10 and varied according to compensation (concentration and/or physical strength) required to handle package. The prime subjects used to date include an astronaut with zero 'g' flight experience, an LRC test pilot, two research engineers and an Air Force Flight Surgeon.

CARGO TRANSFER PARAMETRIC STUDY
(STUDY PARAMETERS)

- MASS - (3 TO 50 SLUGS)
- VOLUME - (1.5 TO 142 CUBIC FEET)
- CONFIGURATION - (SPHERICAL, RECTANGULAR)
- MOMENT OF INERTIA - (3.5 TO 900 SLUG FT^2)
- MANEUVERING AID - (ONE OR TWO HANDRAILS)
- PRESSURE SUIT OR SHIRTSLEEVE
- ONE- OR TWO-MAN TRANSFER

FIGURE 6.

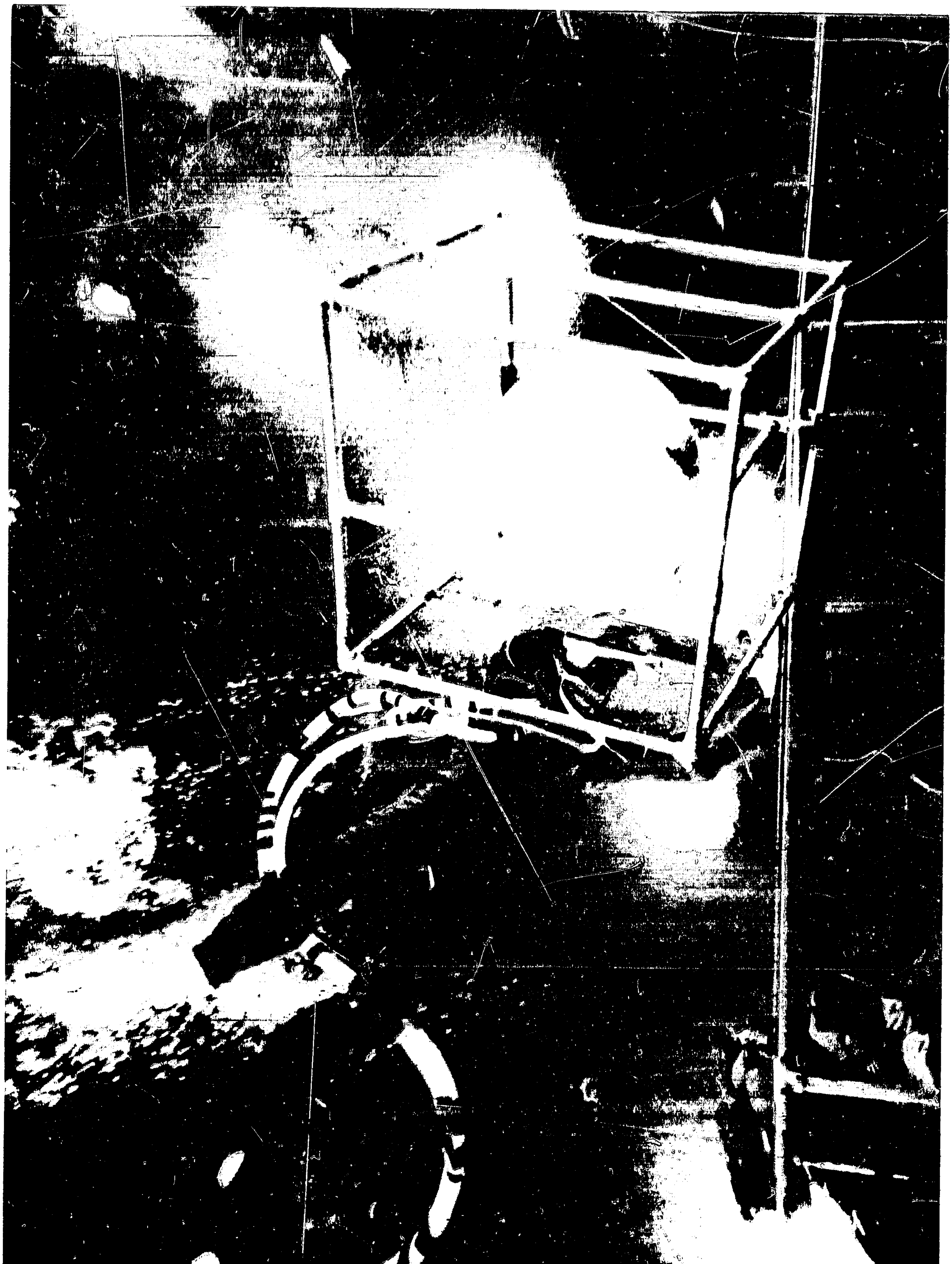
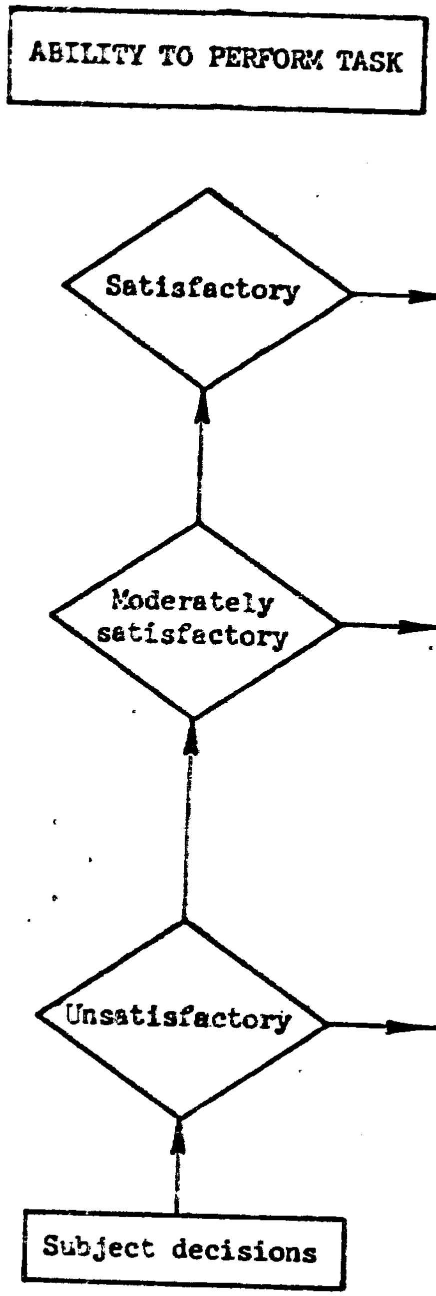


FIGURE 7.

SUBJECT RATING SCALE



PACKAGE CHARACTERISTICS	DEMANDS ON THE SUBJECT FOR SELECTED TASK	SUBJECT RATING
Excellent Highly desirable	Subject compensation* not a factor for desired performance	1
Good Negligible deficiencies	Subject compensation not a factor for desired performance	2
Fair - Some mildly unpleasant deficiencies	Minimal subject compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance required moderate subject compensation	4
Moderately objectionable deficiencies	Adequate performance requires considerable subject compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive subject compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable subject compensation Controllability not in question	7
Major deficiencies	Considerable subject compensation is required for control	8
Major deficiencies	Intense subject compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

*Compensation is defined as concentration and/or physical strength.

FIGURE 8.

The initial phases of the parametric study have been completed and some preliminary results have been determined and are shown in figure 9. These results are as follows: (1) The effects of mass and moment of inertia on cargo transfer are minimal for the range of packages studied (3-50 slugs). Practical considerations such as spacecraft volumetric restrictions, cargo transfer time constraints, etc., would determine actual cargo limits. (2) All transfers were accomplished using either one or two handrails. However, the use of two handrails was found to be more desirable because it provided three points of contact to be used in the control of the packages. For example, the hand used for translation and the two feet (or knees) used for braking, package positioning, and stabilization. The larger the packages the more desirable the two-rail system became. (3) All transfers were accomplished satisfactorily by a single subject but use of a two-subject team reduced the level of effort considerably. Subjects' comments indicated that the reduction in effort was significantly greater than the factor of two which could be expected. Team tests were conducted only on packages of more than 30 slugs and thus the advantages or perhaps disadvantages of team efforts on smaller packages is not known. (4) All transfers were accomplished at average velocities less than 0.7 fps. The average velocities ranged from 0.7 fps for the smallest package to about 0.3 fps for the 50-slug package. This is reported only as a point of interest. Since speed of transfer was not a study parameter and, in fact, subjects were requested to move at a

PRELIMINARY RESULTS

- EFFECT OF MASS AND MOMENT OF INERTIA ON TRANSFER MINIMAL. PRACTICAL CONSIDERATIONS (VOLUMETRIC RESTRICTIONS, TIME, ETC.) WILL DETERMINE CARGO LIMITS
- ALL TRANSFERS COULD BE ACCOMPLISHED USING A SINGLE HANDRAIL BUT A DOUBLE HANDRAIL WAS FOUND MORE DESIRABLE
- ALL TRANSFERS COULD BE ACCOMPLISHED SATISFACTORILY WITH ONE SUBJECT BUT USE OF TWO SUBJECTS AS A TEAM REDUCED LEVEL OF EFFORT CONSIDERABLY (TESTED ON PACKAGES OVER 30 SLUGS ONLY)
- ALL TRANSFERS WERE MADE WITH AVERAGE VELOCITIES LESS THAN 0.7 FPS

FIGURE 9.

speed that felt comfortable and which insured complete control of the package. The low speeds do indicate, however, that drag effects encountered should be minimal.

CONCLUDING REMARKS

Preliminary results obtained in LRC cargo handling studies indicate that manual cargo transfer, in an IVA mode, can be easily accomplished for packages of 50 slugs or more. This appears to preclude the requirement for automated systems for cargo transfer. However, considerations of practical limitations related to the shuttle configuration and time constraints are necessary before final decision is made.

LRC's studies to determine the effect of practical considerations are planned and will in the next few months provide answers to assist in the decision on automated systems. In addition, they will show the problems and limits associated with cargo transfer in a pressure suit and evaluate cargo stowage and attachment problems.