N71-17808

NASA CR-111847

MAN-MACHINE SHUTTLE SUPPORT PROGRAM

BY HARRY L. LOATS, JR. AND G. SAMUEL MATTINGLY

PREPARED UNDER CONTRACT NO. NAS1-8975-3 BY
ENVIRONMENTAL RESEARCH ASSOCIATES
ESSEX, MARYLAND

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NASA CR-111847
ERA 71-1

MAN-MACHINE SHUTTLE SUPPORT PROGRAM

BY HARRY L. LOATS, JR. AND G. SAMUEL MATTINGLY

PREPARED UNDER CONTRACT NO. NAS1-8975-3 BY
ENVIRONMENTAL RESEARCH ASSOCIATES
ESSEX, MARYLAND

FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER

ABSTRACT

A PLANNING STUDY WAS ACCOMPLISHED TO DETERMINE HUMAN FACTORS SUPPORT REQUIREMENTS FOR THE SPACE SHUTTLE PROGRAM. THE HUMAN FACTORS EFFORT EMPHASIZED MANNED-SIMULATION TECHNIQUES AND SPECIFICALLY ADDRESSED CARGO AND CREW TRANSFER, RENDEZVOUS AND DOCKING, EXTRAVEHICULAR ACTIVITY, AND ABORT.

CURRENT SHUTTLE CONTRACT INFORMATION WAS USED AS A BASIS TO DETERMINE COMPOSITE VEHICLE AND MISSION MODELS. PROGRAM PLANS WERE SPECIFIED FOR THREE MAIN AREAS--CARGO TRANSFER, CREW TRANSFER, AND RENDEZVOUS AND DOCKING. THE INDIVIDUAL PLANS WERE DIVIDED INTO THREE AREAS--STUDY REQUIREMENTS, MOCK-UP AND EXPERIMENT HARDWARE REQUIREMENTS, AND EXPERIMENT PERFORMANCE SEQUENCE. A COMBINED PROGRAM PLAN INCLUDING THE THREE AREAS WAS PRODUCED COVERING THE 1971 PERIOD.

A METHODOLOGY WAS DEVELOPED TO HANDLE OTHER AREAS AND FUTURE EVOLUTION OF THE THREE AREAS SPECIFICALLY IDENTIFIED.

TABLE OF CONTENTS

TABLES

FIGURES

SUMMARY

THE REUSABLE SPACE SHUTTLE WAS CONCEIVED BY NASA TO PROVIDE A LOW COST POST-APOLLO CAPABILITY. THE NASA PHASE A STUDIES DETERMINED THAT A REUSABLE MANNED BOOSTER AND A REUSABLE MANNED ORBITAL VEHICLE WAS THE MOST DESIRABLE CONFIGURATION. IN SUPPORT OF THE NASA PHASE A STUDIES, CONTRACTS WERE NEGOTIATED WITH NORTH AMERICAN ROCKWELL, MCDONNELL-DOUGLAS, LOCKHEED AIRCRAFT CORP., AND GENERAL DYNAMICS. IN ADDITION, THE MARTIN MARIETTA CORP. CONDUCTED A STUDY ON AN UNFUNDED BASIS. AT THE CONCLUSION OF THE PHASE A SHUTTLE STUDIES, TWO CONTRACTORS, NORTH AMERICAN ROCKWELL AND MCDONNELL-DOUGLAS, WERE SELECTED TO CONTINUE WITH ADDITIONAL STUDIES IN PHASE B. MCDONNELL-DOUGLAS SELECTED MARTIN MARIETTA AS A MAJOR SUBCONTRACTOR AND NORTH AMERICAN ROCKWELL SELECTED GENERAL DYNAMICS AS A MAJOR SUBCONTRACTOR.

THE SIMULATION AND HUMAN FACTORS BRANCH OF THE FLIGHT DYNAMICS AND CONTROL DIVISION INITIATED THIS CONTRACT TO IDENTIFY MAN-MACHINE CONSIDERATIONS OF THE SHUTTLE MISSIONS. PART I OF THIS STUDY EFFORT IS A REVIEW AND EVALUATION OF THE CONTRACTOR REPORTS AND A DETERMINATION OF THE STATE-OF-THE-ART FOR CREW AND CARGO TRANSFER AND DOCKING OPERATIONS. PART II, THE MAJOR RESULT OF THE CONTRACT, IS THE DEVELOPMENT OF A COMPREHENSIVE PLAN FOR ANALYTICAL STUDY AND SIMULATION EXPERIMENTS OF CREW, PASSENGER, AND CARGO TRANSFER PROBLEMS.

THE INFORMATION MADE AVAILABLE BY NASA LANGLEY RESEARCH CENTER AND NASA HEADQUARTERS INCLUDED THE PHASE A SHUTTLE CONTRACTOR REPORTS, THE PHASE B WINNING PROPOSALS, THE PHASE B SPACE STATION CONTRACTOR REPORTS, AND EXCERPTS FROM THE NASA 11 YEAR PLAN COMPILED BY BELLCOMM, INC. IN ADDITION, LITERATURE SURVEYS WERE CONDUCTED IN THE FOLLOWING AREAS:

1. SPACE STATIONS
2. CARGO HANDLING IN WEIGHTLESSNESS
3. RENDEZVOUS-DOCKING
4. TELEOPERATOR AND REMOTE HANDLING

THE ENVIRONMENTAL RESEARCH ASSOCIATES INTERNAL LIBRARY CONTRIBUTED ADDITIONAL STUDIES IN EACH OF THESE CATEGORIES. THE LITERATURE SURVEYS WERE NOT INCLUDED, BUT GIVEN SEPARATELY.

THIS REPORT COVERS THE EFFORT PERFORMED UNDER CONTRACT NAS1-8975, TASK ORDER 3, AND REPRESENTS APPROXIMATELY 12 MAN-MONTHS EFFORT.

I. HUMAN FACTORS RESEARCH REQUIREMENTS ANALYSIS FOR A COMPOSITE SHUTTLE

INTRODUCTION

CURRENT NASA PLANNING HAS DEFINED THE SPACE SHUTTLE TO BE A REUSABLE CREW/CARGO FERRY OPERATING IN EARTH AND CISLUNAR ORBIT. AFTER AN INITIAL IN-HOUSE PLANNING PHASE, THE NASA AWARDED SEVERAL PHASE A STUDIES TO DETERMINE POTENTIAL CONFIGURATIONS OF THE SHUTTLE. DURING THE PHASE A EFFORT, THE NASA REORIENTED THE STUDY REQUIREMENTS TO CONSTRAIN THE PRELIMINARY DESIGN PHASE TOWARD THE DEVELOPMENT OF REUSABLE SYSTEMS HAVING A LOW EARTH ORBIT PAYLOAD OF 50,000 LB WITH A CARGO CONTAINMENT VOLUME COMPRISING A CYLINDRICAL SECTION 15 FT IN DIAMETER BY 60 FT IN LENGTH. AS A RESULT OF THIS PHASE A EFFORT, TWO MAJOR PHASE B CONTRACTOR TEAMS WERE SELECTED ON THE BASIS OF PRELIMINARY DESIGN.

WHEN THIS STUDY WAS INITIALLY CONCEIVED, THE PART I EFFORT WAS DESIGNED TO DEVELOP A REPRESENTATIVE SHUTTLE MISSION ON WHICH IT WOULD BE POSSIBLE TO OVERLAY AN ANALYTICAL AND SIMULATION STUDY PROGRAM. CAREFUL STUDY HAS SHOWN THAT IT IS MORE REALISTIC TO DEVELOP SEVERAL MISSIONS IN ORDER TO COVER THE PROPOSED RANGE OF SHUTTLE MISSIONS. THOSE MISSION PROFILES WERE THEN ANALYZED BY COMMONALITY AND PRIORITY TECHNIQUES.

SHUTTLE MISSIONS TRAFFIC MODEL

AN UNDERSTANDING OF THE SHUTTLE MISSION REQUIREMENTS CAN BEST BE ACCOMPLISHED IN CONJUNCTION WITH THE NOMINAL SPACE SHUTTLE TRAFFIC MODEL[1] DETERMINED BY THE NASA SPACE SHUTTLE TASK GROUP. THIS MODEL UTILIZES AN AVERAGE LAUNCH RATE OF 51 FLIGHTS PER YEAR, AND FORMS ONE OF THE DESIGN POINTS IN THE PHASE A EFFORT. THE MODEL COVERS AN 11-YEAR PERIOD. THE INITIAL PERIOD INCLUDED THE TIME SPAN FROM CALENDAR 1975 THROUGH CALENDAR 1985. HOWEVER, BUDGETARY AND PLANNING CONSIDERATIONS HAVE ALTERED THIS INITIAL SCHEDULING.

[1]NASA SPACE SHUTTLE TASK GROUP REPORT, VOL. I, 12 JUNE 1969.

THE CHARACTER OF THE TRAFFIC MODEL IS SUCH THAT THE MODEL CAN BE USED TO DETERMINE THE RELATIVE PRIORITY OF THE MISSIONS AND ALSO TO PROVIDE A SLIDING BASELINE TIME SCHEDULE. THE TWO MAJOR MISSIONS IDENTIFIED ARE PROPELLANT TRANSFER AND SPACE STATION/BASE LOGISTIC SUPPORT. THESE TWO MISSIONS ACCOUNT FOR 83 PERCENT OF THE TOTAL FLIGHTS.

FOR THE PURPOSE OF DEVELOPING A COMPREHENSIVE PROGRAM PLAN, FIVE BASIC SHUTTLE MISSIONS ARE USED. WHILE IT IS RECOGNIZED THAT FUTURE PLANNING CAN DRASTICALLY ALTER THE PLANNED FLIGHT PROFILES, IT IS SUFFICIENT FOR THIS PLAN TO UTILIZE THE NOMINAL TRAJECTORY AND ORBITAL ELEMENTS SPECIFIED IN THE PHASE A AND PHASE B REPORTS. CERTAIN IMPLICIT ELEMENTS OF THE MISSIONS HAVE NOT, HOWEVER, BEEN IDENTIFIED TO THIS DATE. WHERE REQUIRED, ENVIRONMENTAL RESEARCH ASSOCIATES PROVIDED THE EXTRAPOLATED ELEMENTS IN ORDER TO INSURE THE COMPREHENSIVENESS OF THE PLAN. A SUMMARY OF THE TRAFFIC MODEL AND THE MISSION CHARACTERISTICS RELEVANT TO THE TRAFFIC MODEL ARE GIVEN IN TABLES I AND II.

PHASE B--SUMMARY

PHASE B OF THE SPACE SHUTTLE SYSTEMS PROGRAM IS CURRENTLY BEING CONDUCTED AND, AS SUCH, HAS NO FINAL RESULTS AVAILABLE. HOWEVER, SPECIFIC INFORMATION IDENTIFIED BY NASA IN THE WORK STATEMENT FOR THE PHASE B STUDIES IS OF IMPORTANCE TO THIS CONTRACT, AND HAS BEEN USED AS SUPPORTING INFORMATION FOR THE DEVELOPMENT OF THE VARIOUS SIMULATION PROGRAM PLANS. THE PHASE B WORK STATEMENT[2], EMPHASIZING PARTICULAR ITEMS OF INTEREST TO THIS CONTRACT, IS ABSTRACTED IN THE FOLLOWING PARAGRAPHS.

THE SPACE SHUTTLE SYSTEM IS A SYSTEM THAT CAN TRANSPORT PERSONS AND CARGO TO LOW EARTH ORBIT AND RETURN THE CREW, PASSENGERS, AND CARGO SAFELY TO EARTH AT GREATLY REDUCED COSTS OVER PRESENT SYSTEMS.

---

[2] SPACE SHUTTLE SYSTEM PROGRAM DEFINITION (PHASE B) STATEMENT OF WORK. ENCLOSURE NO. 4 TO RFP NO. 10-8423, OFFICE OF MANNED SPACE FLIGHT, NASA, FEBRUARY 1970.

THE FOLLOWING CHARACTERISTICS HAVE BEEN IDENTIFIED IN ORDER TO ACHIEVE THE GOAL OF A LOW COST SPACE TRANSPORTATION SYSTEM.

1. AN OPERATIONAL MODE WHICH WILL REDUCE COST AN ORDER OF MAGNITUDE BELOW PRESENT COSTS.
2. A FLEXIBLE CAPABILITY TO SUPPORT A VARIETY OF PAYLOADS AND MISSIONS.
3. AN AIRLINE-TYPE OPERATION FOR PASSENGERS AND CARGO TRANSPORT.
4. A REUSABLE SYSTEM WITH A HIGH LAUNCH RATE CAPABILITY AND SHORT TURNAROUND AND REACTION TIMES COMPATIBLE WITH THE RESCUE MISSION.

TABLE I
11 YEAR SHUTTLE TRAFFIC MODEL

SHUTTLE MISSIONS / YEAR	1	2	3	4	5	6	7	8	9	10	11	TOTALS
PROPELLANT DELIVERY SUBTOTAL				42	42	28	28	28	28	28	28	252
LH_2				36	36	24	24	24	24	24	24	
LO_2				6	6	4	4	4	4	4	4	
LOGISTIC SUPPORT SUBTOTAL	7	7	7	13	13	29	29	29	29	29	29	221
SPACE STATION RESUPPLY/EQUIPMENT	4/3	4/3	4/3	4/3	4/3							
SPACE BASE RESUPPLY/EQUIPMENT						20/3	20/3	20/3	20/3	20/3	20/3	
LUNAR MISSION RESUPPLY				6	6	6	6	6	6	6	6	
STAGES	7	1	8	3	4	6	5	2	7	5	3	51
SATELLITE SUPPORT	2	2	2	2	2	2	2	2	2	2	2	22
SHORT ORBIT	2	2	2	2	2	2	2	2	2	2	2	22
TOTALS	18	12	19	62	63	67	66	63	68	66	64	568

TABLE II

SHUTTLE MISSION CHARACTERISTICS (NASA)

MISSION	DURATION (DAYS)	ALTITUDE (N.M.)	INCLINATION (DEGS.)	MANEUVER ΔV (ALLOWANCE-KFPS)
PROPELLANT DELIVERY	7	200-300	28.5-55	1-2
LOGISTIC SUPPORT	7	200-300	28.5-90	1-2
PROPULSIVE STAGE & PAYLOAD DELIVERY	7	100-200	28.5-55	1-1.5
SATELLITE SUPPORT	7-15	100-800	28.5 (SUN SYN.)	1-5
SHORT DURATION ORBIT	7-30	100-300	28.5-90	1-2
RESCUE	7	270	55	2-5
MINIMUM	7	100	28.5	1
MAXIMUM	30	800	90	5

THE SHUTTLE AND THE ORBITER WERE OPTIMIZED FOR TWO CONDITIONS--HIGH AIR DYNAMIC CROSS RANGE-1500 N.M. AND LOW DYNAMIC CROSS RANGE-200 N.M. CONTROL SYSTEM DESIGN AND HANDLING QUALITIES FROM INITIAL ENTRIES TO LANDINGS SHALL BE EVALUATED BY FIXED BASE SIX-DEGREE-OF-FREEDOM PILOTED SIMULATION STUDIES.

PAYLOAD INTEGRATION.--ANALYSIS SHALL BE CONDUCTED BY THE CONTRACTOR TO DETERMINE THE INTERFACES BETWEEN THE SPACE SHUTTLE, THE SPACE STATION, THE SCIENCE APPLICATION EXPERIMENT MODULES, THE UNMANNED SATELLITE PROJECTS, AND GROUND FACILITIES SERVICES. A STANDARD INTERFACE BETWEEN THE SPACE SHUTTLE UNPRESSURIZED PAYLOAD BAY AND REPRESENTATIVE PAYLOAD CONTAINER MODULES SHALL BE DEFINED. THE INTERFACE SHALL INCLUDE PROVISIONS FOR INSTALLATION, DEPLOYMENT, AND RETRIEVAL OF PAYLOADS. PROVISIONS SHALL BE MADE FOR PROVIDING SPACE ORIENTATION DATA UPDATING TO THE PAYLOAD SATELLITES OR EXPERIMENT MODULES.

ABORTS.--THE CONTRACTOR SHALL INVESTIGATE INTACT ABORT FOR THE SPACE SHUTTLE IN ORDER TO PROVIDE FOR CREW RECOVERY AND CRITICAL CARGO RETRIEVAL. INTACT ABORT IMPLIES THE CAPABILITY OF THE BOOSTER AND ORBITER TO SEPARATE AND CONTINUE FLIGHT TO A SAFE LANDING: THE ORBITER TO LAND WITH THE FULL PAYLOAD.

DOCKING SYSTEMS.--THE CONTRACTOR SHALL PERFORM ANALYSIS OF AN AUTOMATIC APPROACH AND DOCKING CAPABILITY. THE ANALYSIS WILL ASSESS THE OPERATIONAL ASPECTS, INCLUDING SAFETY OF VARIENT DOCKING OPTIONS; I.E., SHUTTLE DOCK WITH THE SPACE STATION, SPACE BASE, OR OTHER ORBITING VEHICLES; DEPLOYED PAYLOAD MODULES DOCKED WITH SPACE STATIONS, SPACE BASE, OR OTHER ORBITING VEHICLES; ETC. THE NUMBER OF PILOT TASKS NECESSARY DURING THE DOCKING MANEUVER SHOULD NOT REQUIRE MORE THAN ONE CREWMAN. ONCE PHYSICAL CONTACT HAS OCCURRED BETWEEN THE SHUTTLE OR ITS PAYLOAD MODULE AND ANOTHER ORBITING VEHICLE, THE DOCKING SYSTEM MUST BE CAPABLE OF LIMITING THE RELATIVE MOTION OF THE TWO VEHICLES. REMOVAL OF THE DOCKING HARDWARE IN WHOLE OR IN PART SHOULD NOT BE REQUIRED IN ORDER TO FACILITATE TRANSFER TO THE DOCKING PORT. THE DOCKING SYSTEM MUST BE REUSABLE. TRADE-OFF STUDIES SHALL BE MADE TO DETERMINE TO WHAT

EXTENT STABILIZATION OF THE DOCKED SHUTTLE/SPACE STATION OR OTHER ORBITING VEHICLES WILL BE A SHARED OR COMPLIMENTARY FUNCTION, AND HOW THIS AFFECTS DOCKING MECHANIZATION. THESE STUDIES SHALL CONSIDER THE POSSIBLE NEED FOR SOFT OR FLEXIBLE DOCKING, POSSIBLY TO ALLEVIATE STRUCTURAL LOADS ON BOTH THE SHUTTLE AND SPACE STATION.

HABITABILITY.--THE DESIGN APPROACH SHALL BE ONE WHICH ACHIEVES MAXIMUM WORK EFFICIENCY, MINIMUM FATIGUE, ADEQUATE REST AND DIVERSION DURING NONDUTY PERIODS, AND MAXIMUM SAFETY DURING ALL MISSION PHASES. LAYOUTS OF THE CREW COMPARTMENT AND INSTRUMENT PANEL SHALL BE PREPARED. ANALYSES SHALL INCLUDE TRADE-OFF STUDIES OF OPTIMUM WAYS OF ACCOMMODATING 12 PASSENGERS, INCLUDING PERMANENT SEATING IN A CABIN VS. PALLETIZED ACCOMMODATION IN THE CREW COMPARTMENT. SINCE MOST MISSIONS REQUIRE TWO PASSENGERS FOR HANDLING CARGO, CONSIDERATION WILL BE GIVEN TO PROVIDING PERMANENT ACCOMMODATION FOR A MINIMUM OF TWO PASSENGERS. AN OPTIMUM TUNNEL CONFIGURATION SHALL BE PROVIDED FOR ACCESS BETWEEN THE CREW AND PASSENGER/CARGO COMPARTMENT.

PROGRAM CHARACTERISTICS.--BASELINE IS THE SECOND HALF OF 1977. LAUNCH RATES WILL VARY FROM A MINIMUM OF 25 TO A MAXIMUM OF 75 PER YEAR. TABLE III SHOWS THE GENERAL MISSION CHARACTERISTICS CONSIDERED AS INPUTS TO THE PHASE B EFFORT.

VEHICLE CHARACTERISTICS.--PROVISIONS SHALL BE MADE FOR DEPLOYMENT AND BOARDING OF A CYLINDRICAL PAYLOAD OF 15 FT DIAMETER BY 60 FT LENGTH. THE CREW ENVIRONMENT SHALL BE SHIRT SLEEVE. THE SPACE SHUTTLE SHALL HAVE AN INTERNAL SEALABLE TUNNEL WITH A STANDARD INTERFACE BETWEEN THE CREW COMPARTMENT AND THE UNPRESSURIZED PAYLOAD BAY. THE SPACE SHUTTLE CREW/PASSENGER COMPARTMENT ATMOSPHERE AND TOTAL PRESSURE SHALL BE COMPATIBLE WITH THE SPACE STATION AND SPACE BASE.

THE SPACE SHUTTLE SYSTEM SHALL PROVIDE FOR SAFE MISSION TERMINATION IN THE EVENT OF MAJOR MALFUNCTIONS OCCURRING DURING PRELAUNCH PREPARATION AND SUBSEQUENT TO LIFTOFF. THE DESIRED SAFE MISSION

TABLE III

MISSION PROFILE SUMMARY

	S/S BASE LOGISTICS SUPPORT	PLACEMENT AND RETRIEVAL OF SATELLITES	DELIVERY OF PROPULSIVE STAGES AND PAYLOAD	DELIVERY OF PROPELLANTS	SATELLITE SERVICE & MAINTENANCE	SHORT ORB. MISSION
ALTITUDE (N. MI.)	200-300	100-800	100-200	200-300	100-800	100-300
INCLINATION (DEG.)	28.5-90	28.5- SUN SYN	28.5-55	28.5-55	28.5- SUN SYN	28.5-90
ON-ORBIT ΔV (1000 FPS)	1-2	1-5	1-1.5	1-2	1-5	1-2
ON-ORBIT STAY TIME (DAYS)	7	7	7	7	7-15	7-30
CREW	2	2	2	2	2	2
PASSENGERS (MIN.)	ROTATE 50 MEN / QTR	2	2	2	4	12
DISCRETIONARY PAYLOAD						
WEIGHT (1000 LBS.)	* 70 / QTR					
VOLUME ($1000\ FT^3$)		5-10	10	10	10-15	4-6
CRITICAL DIMEN DIA. (FT)	5-10	15	15	15	15	15

* INCLUDE PASSENGERS

TERMINATION CAPABILITIES SHOULD ALLOW FOR CREW AND PASSENGER EGRESS PRIOR TO LIFTOFF, AND FOR IMPACT SEPARATION OF ORBITER FROM BOOSTER FOLLOWING LIFTOFF. CARGO ELEMENTS CONTAINING HAZARDOUS MATERIALS SHALL HAVE SELF-CONTAINED PROTECTIVE DEVICES OR PROVISIONS AGAINST ALL HAZARDS.

A VARIETY OF SELF-CONTAINING PAYLOAD TYPES SHALL BE INCLUDED IN THE PAYLOAD INTEGRATION. PRELAUNCH PAYLOAD INTEGRATION PROCEDURES SIMILAR TO CURRENT AIR CARGO CARRIER OPERATIONS ARE DESIRED. IN GENERAL, PAYLOADS SHOULD BE LOADED PRIOR TO MOVING TO THE LAUNCH PAD. LIMITED TRANSFER OF CARGO SHALL BE POSSIBLE THROUGH THE PERSONNEL TRANSFER HATCH. THE VEHICLE SHALL BE DOCKED TO THE SPACE STATION OR SPACE BASE, AND DOCKING TO ACCOMMODATE PERSONNEL AND CARGO TRANSFER SHALL NOMINALLY BE ACCOMPLISHED IN A SINGLE OPERATION. PERSONNEL AND CARGO TRANSFER SHALL NOMINALLY BE AN INTRAVEHICULAR ACTIVITY. PERSONNEL AND CARGO TRANSFER FOR LOGISTICS MISSIONS WILL BE BY INTRAVEHICULAR ACTIVITY.

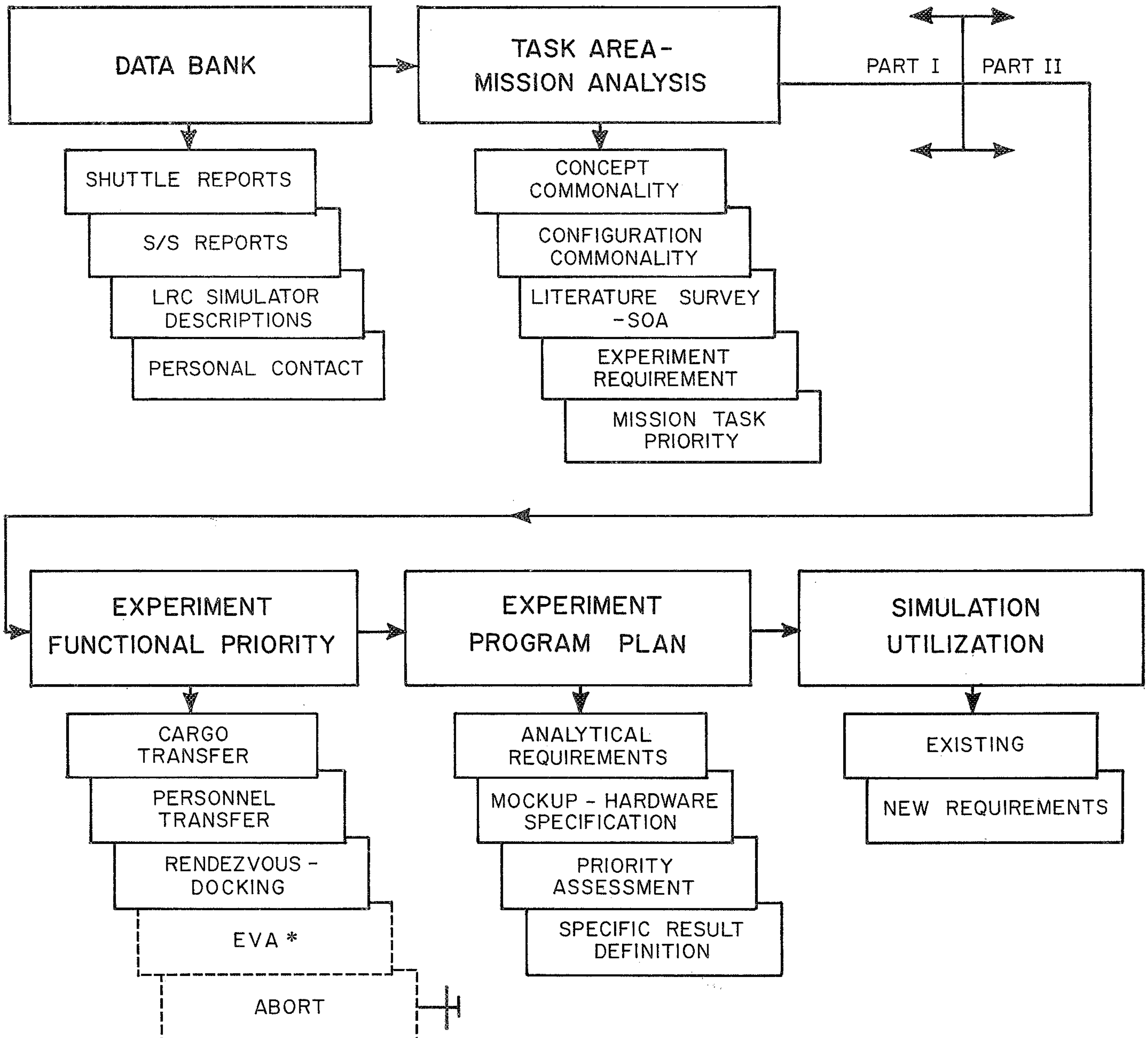
EVA CAPABILITIES SHOULD BE PROVIDED AT THE EXPENSE OF THE ALLOCATED PAYLOAD WEIGHT. THE DESIGN OF THE VEHICLE SHOULD NOT PRECLUDE EVA CAPABILITY. BY USING GROUND FACILITIES AND OTHER AIDS, WHEN APPROPRIATE, THE SPACE SHUTTLE SHALL BE CAPABLE OF ACCOMPLISHING RENDEZVOUS WITH A PASSIVE TARGET. THE SPACE SHUTTLE SHALL BE CAPABLE OF OPERATING WITHIN THE CARGO RANGE OF ZERO TO MAXIMUM CAPABILITY.

METHODOLOGY

THE SPECIFIC METHODOLOGY ADOPTED FOR THE DEVELOPMENT OF A HUMAN FACTORS EXPERIMENT-ANALYSIS SUPPORT PLAN FOR THE ORBITER VEHICLE PORTION OF THE SPACE SHUTTLE IS ILLUSTRATED IN FIGURE 1. THE TASKS WERE SEPARATED INTO TWO PARTS WHICH ARE IDENTIFIED CONTRACTUALLY AS PARTS A AND B. FOR THE PURPOSES OF AVOIDING AMBIGUITY WITH SHUTTLE PHASES A AND B, PART A IS IDENTIFIED AS PART I AND PART B AS PART II IN THIS REPORT.

THE DATA BANK, DESCRIBED PREVIOUSLY, WAS SUPPLEMENTED BY EXTENSIVE PERSONAL CONTACT, PRIMARILY WITH NASA SHUTTLE PERSONNEL, AND MUCH

METHODOLOGY FLOW CHART



* APPLIED ACROSS 3 TASK AREAS

FIGURE 1

VALUABLE DATA WAS ADDED FOR SUBSEQUENT ANALYSIS. THE MISSIONS AND TASK AREA PRIORITY CRITERIA WAS USED TO LOGICALLY ARRANGE THE DATA BANK INFORMATION.

NASA MISSION PRIORITY WAS ESTABLISHED, BASED ON ALLOCATED FREQUENCY AND THE CONTRACTING OFFICER'S REPRESENTATIVE (COR)-DEVELOPED SPECIFIC TASK PRIORITY. A TWO-DIMENSIONAL RANKING TECHNIQUE WAS UTILIZED WHICH INVOLVED IDENTIFYING TASK AREA UTILIZATION FOR EACH NASA-IDENTIFIED MISSION, MULTIPLYING THE TWO PRIORITY RANKS FOR EACH NONZERO ELEMENT, SUMMING OVERALL ELEMENTS, AND NORMALIZING.

THE MULTIPLE RANKING TECHNIQUE SUBSTANTIALLY PRESERVES THE COR RANKING FOR THE MISSIONS SINCE THE TWO MOST FREQUENT MISSIONS WERE GREATLY SEPARATED FROM THE FOUR LESS FREQUENT MISSIONS. THE IMPORTANCE PLACED ON THE RENDEZVOUS-DOCKING AREA BY THE COR ACCOUNTS FOR THE SHIFT IN THE RANKING OF THE PROPELLANT TRANSFER AND SPACE STATION LOGISTIC MISSIONS. THE FINAL PRIORITY RANKINGS ESTABLISHED ARE SHOWN IN TABLE IV.

THE CREW/CARGO TRANSFER AREA WAS SEPARATED INTO TWO ELEMENTS IN ORDER TO PRESERVE THE DICHOTOMY OF THE ENTRIES. THE FINAL RANKINGS, BOTH FOR MISSIONS AND AREAS, THEN REPRESENT THE PRIORITY RANKING USED DURING THE PROGRAM PLANNING PORTION OF THE STUDY. THIS PRIORITY RANKING, IN CONJUNCTION WITH RELATIVE SCHEDULING DERIVED FROM THE TRAFFIC MODEL, PROVIDES A SLIDING TIME REFERENCE FOR THE DEVELOPMENT PROGRAM. A SLIDING BASELINE WAS NECESSARY BECAUSE OF THE FLUID NATURE OF FLIGHT SCHEDULING AND PLANNING. IT IS ANTICIPATED THAT THE PROGRAM DERVIED IN THIS MANNER WILL CONTAIN SUFFICIENT FLEXIBILITY TO PERMIT UPDATING WITH MINIMUM REWORK.

THE METHODOLOGY REQUIRED THAT THE INFORMATION FROM THE DATA BANK BE COLLATED BY MEANS OF TASK AREA-MISSION ANALYSIS. THE TASK AREA-MISSION ANALYSIS INCLUDED DERIVING CONTRACTOR-GENERATED CONCEPT AND CONFIGURATION COMMONALITIES AND DEVELOPING A SHUTTLE TASK AREA AND CONFIGURATION COMPOSITE. THIS COMPOSITE INCLUDED THE RANGE OF

IDENTIFIED INFORMATION AND, WHERE POSSIBLE, IDENTIFIED PREFERRED CONCEPTS. THE CONCEPT COMPOSITE SERVED TO DETERMINE THE CATEGORIES OF TASKS NECESSARY TO BUILD A COMPREHENSIVE PROGRAM.

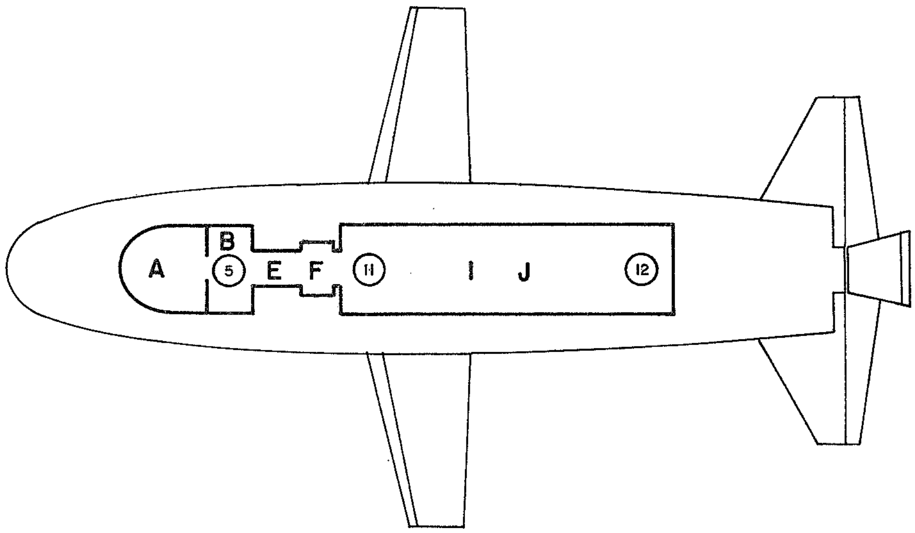
TABLE IV.--MISSION/TASK IMPACT

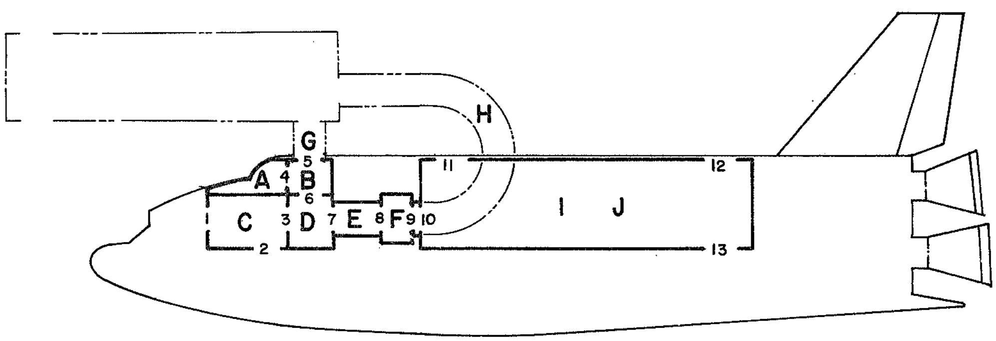
TASK AREA AND RESEARCH EFFORT ALLOCATION (INITIAL)	MISSIONS (11-YEAR PLAN)						
	PROPELLANT DELIVERY	SPACE STATION/BASE LOGISTIC SUPPORT	PROPULSIVE STAGE DELIVERY & CHECKOUT	SATELLITE PLACEMENT & RETRIEVAL	SATELLITE SERVICE & MAINTENANCE	SHORT DURATION ORBITAL	RESEARCH EFFORT ALLOCATION (FINAL)
RENDEZVOUS-DOCKING 0.40	X	X	X	X	--	--	0.50
CARGO TRANSFER 0.20	X	X	X	X	X	--	0.25
ABORT 0.10	X	X	X	X	X	X	0.13
CREW TRANSFER 0.20	--	X	--	--	--	--	0.10
EVA 0.10	--	--	--	X	X	X	0.02
	0.41	0.47	0.08	0.02	0.01	0.01	1.00
11-YEAR MISSION FREQUENCY (%)	44	39	9	2	2	4	

FIGURE 2 SUMMARIZES THE CONFIGURATION COMPOSITE ADOPTED. THE CONFIGURATION COMPOSITE QUANTITATIVELY DESCRIBES THE PHYSICAL FEATURES OF THE SHUTTLE WHICH AFFECTED THE SPECIFIC MOCK-UP AND EXPERIMENT HARDWARE DESIGNS. LITERATURE SURVEYS WERE ALSO RUN IN PARALLEL

SHUTTLE CONFIGURATION COMPOSITE

A CREW COMPARTMENT	F IVA TUNNEL/AIR LOCK
B CABIN OPERATIONS/PASSENGER COMPARTMENT	G CABIN EGRESS TUNNEL/AIR LOCK
C EQUIPMENT BAY	H FLEXIBLE CREW TRANSFER TUNNEL
D CABIN OPERATIONS/PASSENGER COMPARTMENT	I CARGO/PASSENGER MODULE
E IVA TUNNEL	J CARGO BAY





FUNCTION		DESCRIPTION	DIMENSIONS (APPROX.)		
			MIN	MAX	(FT)
1	HATCH	ESCAPE	2.5	5	DIAMETER
2	HATCH	ESCAPE	2	6	DIAMETER
3	HATCH	CABIN	3	6	DIAMETER
4	HATCH	CABIN	5	6	DIAMETER
5	HATCH	CABIN-PAYLOAD EGRESS	3	6	DIAMETER
6	HATCH	CABIN	3	6	DIAMETER
7	HATCH	IVA TUNNEL	2.5	5.5	DIAMETER
8	HATCH	AIR LOCK	2.5	5.5	DIAMETER
9	HATCH	CREW-PAYLOAD TUNNEL	2.5	5.5	DIAMETER
10	HATCH	PAYLOAD	3	6	DIAMETER
11	HATCH	CABIN-PAYLOAD EGRESS	3	6	DIAMETER
12	HATCH	PAYLOAD EGRESS	5	6	DIAMETER
13	HATCH	PAYLOAD-S/S	3	6	DIAMETER
E	TUNNEL	IVA	8 2.5	70 7	LENGTH DIAMETER
H	TUNNEL	CREW-PAYLOAD	7 2.5	14 7	LENGTH DIAMETER
I	MODULE	CARGO-CREW	15 9	60 22	LENGTH DIAMETER

FIGURE 2

WITH THE DEVELOPMENT OF THE TASK AREA-MISSION ANALYSIS TO LIMIT THE RANGE OF EXPERIMENTS WHERE SUFFICIENT INFORMATION EXISTS.

AT THIS STAGE IN THE OVERALL SHUTTLE PROGRAM, SOME AREAS HAVE NOT BEEN SUFFICIENTLY DEVELOPED TO PROVIDE THE BACKGROUND INFORMATION NECESSARY FOR A SIMULATION PROGRAM PLAN. IN PARTICULAR, THE AREA OF ABORT, WHILE OBVIOUSLY OF CRITICAL IMPORTANCE TO THE OVERALL SHUTTLE PROGRAM, HAS NOT BEEN SUFFICIENTLY DEVELOPED IN THE DOCUMENTS PROVIDED FOR THIS STUDY. THE ABORT AREA, THEREFORE, WAS NOT CARRIED BEYOND PART I OF THIS CONTRACT.

ALTHOUGH EXTRAVEHICULAR ACTIVITY IS BY DEFINITION NOT REQUIRED IN ANY OF THE SHUTTLE MISSIONS, IT IS ALSO NOT RULED OUT. SINCE SEVERAL OF THE SHUTTLE MISSIONS IMPLY FUNCTIONS EXTERIOR TO THE SPACECRAFT, THE USE OF EXTRAVEHICULAR ACTIVITY CANNOT BE DISCOUNTED. HOWEVER, EVA IS A MODE RATHER THAN A FUNCTION (SUCH AS CARGO TRANSFER) AND, AS SUCH, REQUIRES A DIFFERENT TYPE OF ANALYTICAL TREATMENT. THE RESULTS OF THE EVA ANALYSIS APPEAR AS AN OVERLAY ON THE FUNCTIONS OF CARGO TRANSFER, CREW TRANSFER, ETC., ON THE COMBINED 1971 PROGRAM PLAN.

THE RESULTS OF THE TASK AREA-MISSION ANALYSIS PROVIDED AN EFFECTIVE FRAMEWORK FOR THE PART II EFFORT OF ESTABLISHING AN ANALYTIC-EXPERIMENT PROGRAM PLAN. UTILIZING THESE ANALYSES, AN EXPERIMENT FUNCTIONAL PRIORITY WAS ESTABLISHED FOR THE THREE PRIMARY TASK AREAS: CARGO TRANSFER, PERSONNEL TRANSFER, AND RENDEZVOUS-DOCKING. THIS FUNCTIONAL PRIORITY ASSESSMENT DERIVED THE CATEGORIES OF EXPERIMENTS NECESSARY TO ESTABLISH A RATIONAL EXPERIMENT PROGRAM BY DETERMINING THE SEQUENCE IN WHICH THE SCIENTIFIC INFORMATION WAS REQUIRED; E.G., DEFINES THE INTERDEPENDENCE AND INTERACTION OF THE SEPARATE EXPERIMENT CATEGORIES.

THE RESULTS OF THE EXPERIMENT FUNCTIONAL PRIORITY ANALYSIS WERE COMBINED WITH THE EXISTING SHUTTLE SCHEDULE TO DEVELOP THREE TASK-ORIENTED EXPERIMENT PROGRAM PLANS. THE INDIVIDUAL EXPERIMENT PROGRAM PLANS WERE DEVELOPED BY DEFINING A SEQUENTIAL AND LOGICALLY

INTERCONNECTED ORDERING OF FOUR SEPARATE ELEMENTS: STUDIES, MOCK-UP AND EXPERIMENT HARDWARE, EXPERIMENT SEQUENCE, AND RESULTS. THE TIME FRAME OF REFERENCE CONSIDERED WAS 70-73 SINCE EXTENSION BEYOND THIS TIME PERIOD WAS IMPRACTICAL BECAUSE OF THE DEPENDENCE OF THE ELEMENTS OF THE 70-73 PLAN ON THE FLUID SHUTTLE DEVELOPMENT SCHEDULE.

A DETAILED ANALYSIS OF THE PROGRAM PLAN RESULTED IN THE FINAL ELEMENT OF THE METHODOLOGY. THIS ELEMENT, SIMULATION UTILIZATION, SHOWED THE RELATIONSHIP BETWEEN THE EXPERIMENTS, THE MOCK-UP HARDWARE IDENTIFIED IN THE EXPERIMENT PROGRAM PLAN, AND THE EXISTING SIMULATORS AT LRC. WHERE REQUIRED, NEW COMBINATIONS AND CLOSELY RELATED EXTENSIONS TO THE EXISTING LRC SIMULATION COMPLEX WERE ADDED TO ACCOMMODATE CRITICAL EXPERIMENT AREAS.

II. EXPERIMENT PROGRAM DEVELOPMENT

INTRODUCTION

PART II OF THIS TASK ORDER IS THE DEVELOPMENT OF A PROGRAM PLAN WHICH ADDRESSES THE ANALYSIS AND SIMULATION REQUIREMENTS IN THE SELECTED AREAS OF CARGO TRANSFER, PERSONNEL TRANSFER, AND RENDEZVOUS-DOCKING. THE SIMULATION PHILOSOPHY ADOPTED ADDRESSES EACH EXPERIMENT AREA BY A THREE-STAGE EXPERIMENT PROCESS.

1. FAMILIARIZATION TESTS: WHICH PREPARE THE TEST SUBJECTS FOR THE GENERAL TASK PERFORMANCE AND, IN EFFECT, PROVIDE A LEARNING PERIOD. (EVALUATES SIMULATION TECHNIQUES AND ARTIFACTS.)
2. PARAMETRIC TESTS: WHICH DETERMINE MAN-MACHINE INTEGRATION.
3. MISSION SIMULATIONS: GO-NO GO TYPE TESTS THAT PROVIDE SPECIFIC TIME LINES OF TASK PERFORMANCE. TESTS OF THIS NATURE PROVIDE TARGETS OF OPPORTUNITY SUCH AS INTERFERENCE BETWEEN FUNCTIONAL ELEMENTS THAT ARE NOT APPARENT IN OTHER PRESTRUCTURED TESTING.

THIS PROGRAM PLAN, WHILE IDENTIFIED WITHIN THE SPACE SHUTTLE TIME FRAME, IS A BASIC RESEARCH PROGRAM, AND DOES NOT IMPACT OTHER EXISTING MAN-MACHINE INTEGRATION STUDY PROGRAMS FOR THE SHUTTLE AT MSC AND MSFC. SPECIFICALLY, THE WORK BEING PERFORMED AT MANNED SPACECRAFT CENTER GENERALLY DEALS WITH ASTRONAUT TRAINING AND TASK EVALUATION FOR ASTRONAUT PARTICIPATION. THE WORK PERFORMED AT THE MARSHALL SPACE FLIGHT CENTER IS GENERALLY OVERALL MISSION SIMULATION WHICH IS A STAGE BEYOND THE MISSION SIMULATIONS IDENTIFIED WITHIN THE RESEARCH PROGRAM PLAN, AND INCLUDES EVALUATIONS OF SYSTEMS OPERATED BY MAN. THERE WILL BE SOME DUPLICATION OR OVERLAPPING OF EFFORTS BETWEEN THE CENTERS, BUT THERE APPEARS TO BE A CLEAR DISTINCTION OF THE CHARTERS UNDER WHICH THE DIFFERENT CENTERS OPERATE.

COMPLETE PERFORMANCE OF ALL THE EXPERIMENT ELEMENTS IDENTIFIED IN THE PROGRAM PLANS RECOMMENDED IN THIS STUDY CONSTITUTES A LARGER HUMAN FACTORS RESEARCH EFFORT THAN HAS BEEN PREVIOUSLY PERFORMED AT THE LANGLEY RESEARCH CENTER. THIS LARGER EFFORT IS JUSTIFIED SINCE THE VALUE OF THE RESULTING RESEARCH IS MUCH GREATER THAN ITS COST. THE VALUE OF HUMAN FACTORS RESEARCH IS DIFFICULT TO ASCERTAIN. HOWEVER, EXAMPLES FROM PREVIOUS EFFORTS CAN BE CITED IN SUPPORT OF SUCH PROGRAMS. ACTIVATION OF THE ASTRONAUT MANEUVERING UNIT WHICH WAS ABORTED IN GEMINI IX, AND TOTALLY SCRUBBED FROM GEMINI XII, WAS THE CULMINATION OF A MULTIMILLION DOLLAR PROGRAM. THE WATER IMMERSION SIMULATION PROGRAM WHICH IDENTIFIED THE PROBLEMS OF ACTIVATION AND PROVIDED SOLUTIONS WAS ACCOMPLISHED IN LESS THAN TWO WEEKS, AND RESULTED IN A TIMELY AND NECESSARY RESTRUCTURING OF THE EVA TASK. ANOTHER EXAMPLE IS THE SIMULATION OF THE REMOVAL OF THE DOME COVER ON THE ORIGINAL DESIGN OF THE SKYLAB VEHICLE. THIS SIMULATION DEMONSTRATED THE DIFFICULTIES WHICH WERE EVENTUALLY RESOLVED BY A REDESIGN OF THE DOME COVER. ALTHOUGH THE REDESIGN COST ADDITIONAL MONIES, IT WAS CONTRACTED EARLY ENOUGH IN THE PROGRAM TO AVOID A MUCH GREATER COST AT A LATER DATE, OR POSSIBLE FAILURE OF THE MISSION.

OPTIMUM UTILIZATION OF MAN WITHIN THE CARGO/PERSONNEL TRANSFER AREAS OF THE SHUTTLE PROGRAM IS THE GOAL OF THE RESEARCH IDENTIFIED IN THIS STUDY. ADDITIONALLY, A CONTRIBUTORY PROGRAM IN THE RENDEZVOUS-DOCKING AREA WAS ACCOMPLISHED.

CARGO TRANSFER

GENERAL.--SIMULATIONS CONDUCTED IN THE ZERO GRAVITY AIRCRAFT HAVE CONCLUDED THAT THE MAXIMUM MASS RECOMMENDED FOR HUMAN HANDLING IN WEIGHTLESSNESS SHOULD BE LESS THAN 5 SLUGS. OTHER STUDIES HAVE CONCLUDED THAT THIS MAXIMUM SHOULD BE LESS THAN 3 SLUGS. GENERALLY, THESE EXPERIMENTS-STUDIES HAVE NOT IDENTIFIED THE LIMITED VALIDITY OF THE ZERO GRAVITY AIRCRAFT SIMULATION IN ADDRESSING THE PROBLEM OF MASS HANDLING IN WEIGHTLESSNESS. ALTHOUGH THE PACKAGE FLOATING IN THE AIRCRAFT IS WEIGHTLESS, THE AIRCRAFT ITSELF RANGES

APPROXIMATELY ± 0.05 GRAVITIES DURING A ZERO GRAVITY MANEUVER. THE INTERACTION BETWEEN THE AIRCRAFT AND THE PACKAGE CAN PRODUCE APPARENT ACCELERATIONS OR FORCE LEVELS HIGHER THAN THOSE REQUIRED TO MOVE THE PACKAGE. THIS "BACKGROUND NOISE LEVEL" PRODUCES MISLEADING RESULTS AND CONTRIBUTES TO THE IMPRECISE AND SOMETIMES INVALID LIMITS BEING PLACED ON HUMAN PERFORMANCE. SIMILAR EXPERIMENTS, UTILIZING WATER IMMERSION OR AIR-BEARING PLATFORMS, ARE ALSO CONSTRAINED BY INHERENT SIMULATION DEGRADATIONS. IN WATER IMMERSION SIMULATIONS, FOR EXAMPLE, DRAG AND HYDRODYNAMIC "INERTIA" OF LARGE OBJECTS MASK THE DATA FROM TESTING INVOLVING MOVEMENT OF MASSES THROUGH THE WATER.

THE CONSENSUS OF CURRENT HUMAN FACTORS EXPERIMENTS AND STUDIES IS THAT MAN IS SEVERELY LIMITED IN WEIGHTLESSNESS AS REGARDS MANUAL CARGO TRANSFER. INFORMATION FROM ACTUAL SPACE MISSIONS VERIFIES THE CAPABILITY OF MAN TO MOVE AROUND INSIDE A SPACE VEHICLE AND TO TRANSFER SMALL PACKAGES. THIS WAS DEMONSTRATED IN THE APOLLO XIII MISSION DURING THE ON-BOARD ENGINEERING OF THE LIFE SUPPORT SYSTEM. AS PACKAGES GET LARGER AND HEAVIER, OBVIOUSLY MAN'S ABILITY TO CONTROL AND TRANSFER WILL BECOME MARGINAL. THE MAJOR QUESTIONS TO BE ANSWERED IN SUPPORT OF THE CARGO TRANSFER PORTION OF THE SHUTTLE PROGRAM ARE "WHAT ARE THE LIMITS OF MANUAL CARGO TRANSFER?" AND "BY WHAT METHOD IS THIS DETERMINATION TO BE MADE?" THE CARGO TRANSFER PROGRAM PLAN DEVELOPED IN THIS STUDY FOR THE SHUTTLE PROGRAM WILL DEVELOP A QUANTITATIVE UNDERSTANDING OF HOW MAN CAN BEST BE USED WITHIN CONSTRAINTS OF THE OVERALL SHUTTLE MISSION.

PACKAGES OR MODULES OF A MASS OR VOLUME BEYOND MAN'S CAPABILITY TO HANDLE WILL BE TRANSFERRED BY A POWERED TRANSFER DEVICE SUCH AS A TELEOPERATOR. HOWEVER, A TELEOPERATOR DESIGNED TO OPTIMALLY HANDLE A 10,000 LB SATELLITE WOULD NOT NECESSARILY BE THE PROPER DEVICE FOR TRANSFER OF A 500 LB PALLET. THE NEED FOR MAXIMUM UTILIZATION OF AVAILABLE RESOURCES DICTATES AN OPTIMIZATION OF CARGO TRANSFER TECHNIQUE BY THE PROPER BLEND OF MAN AND MACHINE.

EXPERIMENT FUNCTIONAL PRIORITY.--IN PART I, THE SHUTTLE CONTRACTORS' CONCEPTS WERE ANALYZED. TABLE V, CARGO TRANSFER AREA COMPOSITE, LISTS THE IDENTIFIED COMPOSITE CHARACTERISTICS IN THE CARGO TRANSFER AREA. THE CARGO TRANSFER AREA COMPOSITE WAS DERIVED BY PERFORMING A CONCEPT COMMONALITY ANALYSIS ACROSS THE FIVE PHASE A CONTRIBUTORS, AND ALSO INCLUDES INFORMATION FROM THE PHASE B PROPOSALS OF MCDONNELL-DOUGLAS AND NORTH AMERICAN ROCKWELL. THE COMPOSITE SPECIFIES THE TOTAL RANGE OF CONCEPTS PRESENTED, AND DOES NOT IMPLY THE SELECTION OF ANY ONE OPTIMAL CONFIGURATION. CERTAIN IMPORTANT CONCLUSIONS CAN BE DRAWN FROM TABLE V. PERHAPS THE MOST SIGNIFICANT, FROM THE HUMAN FACTORS VIEWPOINT, IS THE ESTABLISHMENT OF BROAD CARGO CLASSES. THESE CLASSES (IDENTIFIED AS SUCH BY ENVIRONMENTAL RESEARCH ASSOCIATES) REPRESENT THE STRUCTURAL FRAMEWORK BY WHICH THE OPTIMIZATION OF MAN-MACHINE CARGO TRANSFER CAN BE EXPERIMENTALLY DETERMINED AND QUANTIFIED.

THE EFFECT OF THESE CLASSES CAN BE SEEN IN FIGURE 3, HUMAN PERFORMANCE--PACKAGE DENSITY INTERFACE, WHICH IDENTIFIES THE VOLUME AND WEIGHT OF A REPRESENTATIVE COMPOSITE SPACE STATION CARGO COMPLEMENT. THE COMPOSITE WAS DERIVED BY DETERMINING THE FREQUENCY OF OCCURRENCE OF RESUPPLY CARGO IN EACH OF THE VOLUME AND WEIGHT CLASSES SHOWN. THE COMPOSITE NATURE OF THE DETERMINATION DOES NOT IMPLY THAT ANY SINGLE CARGO RESUPPLY MISSION WOULD INCLUDE ALL OF THE PACKAGES SHOWN OR INDEED WOULD BE LIMITED TO FREQUENCIES SHOWN.

THE AREA IN WHITE, LESS THAN 100 LB AND LESS THAN 5 CU FT VOLUME, IDENTIFIES THE PACKAGES WHICH ARE, BY CONSENSUS, NOW ASSIGNED TO HUMAN HANDLING, TYPE 1, WITHIN THE CURRENT STATE-OF-THE-ART. PACKAGES IN THE SHADED AREA THEN MUST BE HANDLED BY MANUAL-POWER ASSIST DEVICES OR AUTOMATIC TRANSFER SYSTEMS. SIGNIFICANT EXTENTION OF TYPE 1 TO INCLUDE ALL CARGO IN THE LIGHTLY SHADED AREA WOULD RESULT IN MANUAL HANDLING OF ALL INTRAVEHICULAR CARGO TRANSFER. SUCH A DEVELOPMENT WOULD BE OF MAJOR IMPORTANCE TO THE

TABLE V.--CARGO TRANSFER AREA COMPOSITE

MODE
.MANUAL (IVA)--FOR CLASS 1 CARGO .MANUAL-POWER ASSIST (IVA)--FOR CLASS 2 CARGO .MANUAL-POWER ASSIST (CONTROLLER-IVA)--FOR CLASS 2-CLASS 3 CARGO .AUTONOMOUS/TUG--CLASS 3 CARGO SYSTEMS
CONFIGURATION
.UP TO 15 FT DIAMETER BY 60 FT LENGTH CARGO MODULE .CARGO MODULE RIGID-DOCKED TO SPACE STATION .CARGO/PALLETS ATTACHED TO SHELL CARGO MODULE SURFACE AT BULKHEADS OR LONGERONS .VARIOUS POWER ASSIST HARDWARE PROPOSED FOR GREATER THAN CLASS 1 TYPE CARGO .CARGO CLASS CHARACTERISTICS GENERALLY UNDEFINED .IVA CARGO TRANSFER ON USE BASIS .MOTION/STABILITY AIDS INDICATED BUT UNDEFINED
CYCLE DURATION
.RANGES FROM 2.8 HR (MDAC) TO 32.0 HR (LAC)
SPECIFIC DETAILS
.2-MAN CREW SPECIFIED BY NASA .CARGO DEFINITION UNDEFINED EXCEPT BY IMPLICATION OF SPACE STATION STUDIES .CARGO BAY UTILIZATION FOR OTHER MISSIONS REQUIRE SELF-CONTAINED PRESSURIZED ENVIRONMENT-CONDITIONED MODULES .5 FT DIAMETER (CLEAR) HATCHES REQUIRED .SPECIFIED CARGO LIMITS HAVE WIDE DISPERSION .BULK CARGO ONLY CONSIDERED
SIMULATION REQUIREMENTS
.ZERO G AIRCRAFT .WATER IMMERSION .5-6 DOF (COUNTERBALANCE) .MOCK-UPS OF SHUTTLE AND HANDLING EQUIPMENT .MISSION RUN-THROUGHS INDICATED--NO INDICATION OF KINEMATIC/DYNAMIC CAPABILITY INVESTIGATIONS EVEN THOUGH IMPLICITLY REQUIRED

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 3

SHUTTLE PROGRAM, AND THE SAVINGS IN DEVELOPMENT COST AND PAYLOAD WEIGHT WOULD MORE THAN JUSTIFY THE REQUIRED RESEARCH.

THE CARGO EXPERIMENT FUNCTIONAL PRIORITY, AS SHOWN IN FIGURE 4, IDENTIFIES THE MAJOR ELEMENTS OF MANUAL CARGO TRANSFER. THE FUNCTIONS, WHICH APPEAR IN CHRONOLOGICAL ORDER IN THE SECOND COLUMN, HAVE BEEN EVALUATED TO DETERMINE THE VALIDITY OF THE VARIOUS SIMULATIONS. ALL OF THE MAJOR ELEMENTS OF THE FUNCTIONS OF DISCONNECT, INTERFERENCE, AND STOWAGE CAN BE SIMULATED WITH HIGH FIDELITY. THESE FUNCTIONS HAVE ALSO BEEN SUCCESSFULLY DEMONSTRATED IN CONCEPT IN EITHER THE GEMINI OR APOLLO PROGRAMS. THE FUNCTIONS OF STABILIZATION AND TRANSLATION HAVE NOT BEEN ADEQUATELY DEMONSTRATED IN SPACE BEYOND THE ABILITY OF THE ASTRONAUTS TO STABILIZE AND TRANSLATE THEMSELVES. THESE, THEREFORE, ARE THE CRITICAL EXPERIMENTS IN THE CARGO TRANSFER PROGRAM PLAN.

HYBRID SIMULATION TECHNIQUES, CURRENTLY UNDER DEVELOPMENT IN CONTRACT NAS1-8975-2, MAY PROVIDE THE INFORMATION NEEDED FOR AN EVALUATION OF THOSE ELEMENTS AS THEY AFFECT THE REQUIREMENTS OF THE SHUTTLE PROGRAM. IT IS ADDITIONALLY RECOMMENDED THAT AN ORBITAL TEST BE DESIGNED FOR VERIFICATION OF SIMULATION RESULTS AND QUANTIFICATION OF SIMULATOR VALIDITY. THE PROGRAM PLAN INDICATES THAT THIS EXPERIMENT SHOULD BE CONDUCTED DURING THE SKYLAB B FLIGHT. VALUES ESTABLISHED BY THE STUDIES AND TEST OF MOTION WILL PROVIDE INFORMATION FOR THE INTERACTION EXPERIMENTS. THE FUNCTION OF STOWAGE, WHILE GENERALLY A DERIVATIVE OF THE INTERACTION PROBLEM, HAS UNIQUE FEATURES WHICH ARE PRIMARILY MISSION SENSITIVE.

<u>EXPERIMENT PROGRAM PLAN</u>.--THE CARGO TRANSFER PROGRAM PLAN, FIGURE 5, IDENTIFIES THE REQUIRED STUDIES, MOCK-UPS, SIMULATION EXPERIMENTS, AND RESULTS UNDER THE CHRONOLOGY ESTABLISHED BY THE PHASED SHUTTLE PROGRAM TO SUPPORT THE EXPERIMENT FUNCTIONAL PRIORITIES ESTABLISHED. THE EARLIEST STUDIES DEAL WITH THE CRITICAL PROBLEMS OF MOTION. SUBSEQUENT STUDIES SERIALLY UTILIZE THE RESULTS OF PRECEDING STUDIES AND TESTS TO DEVELOP OVERALL MISSION

CARGO EXPERIMENT FUNCTIONAL PRIORITY

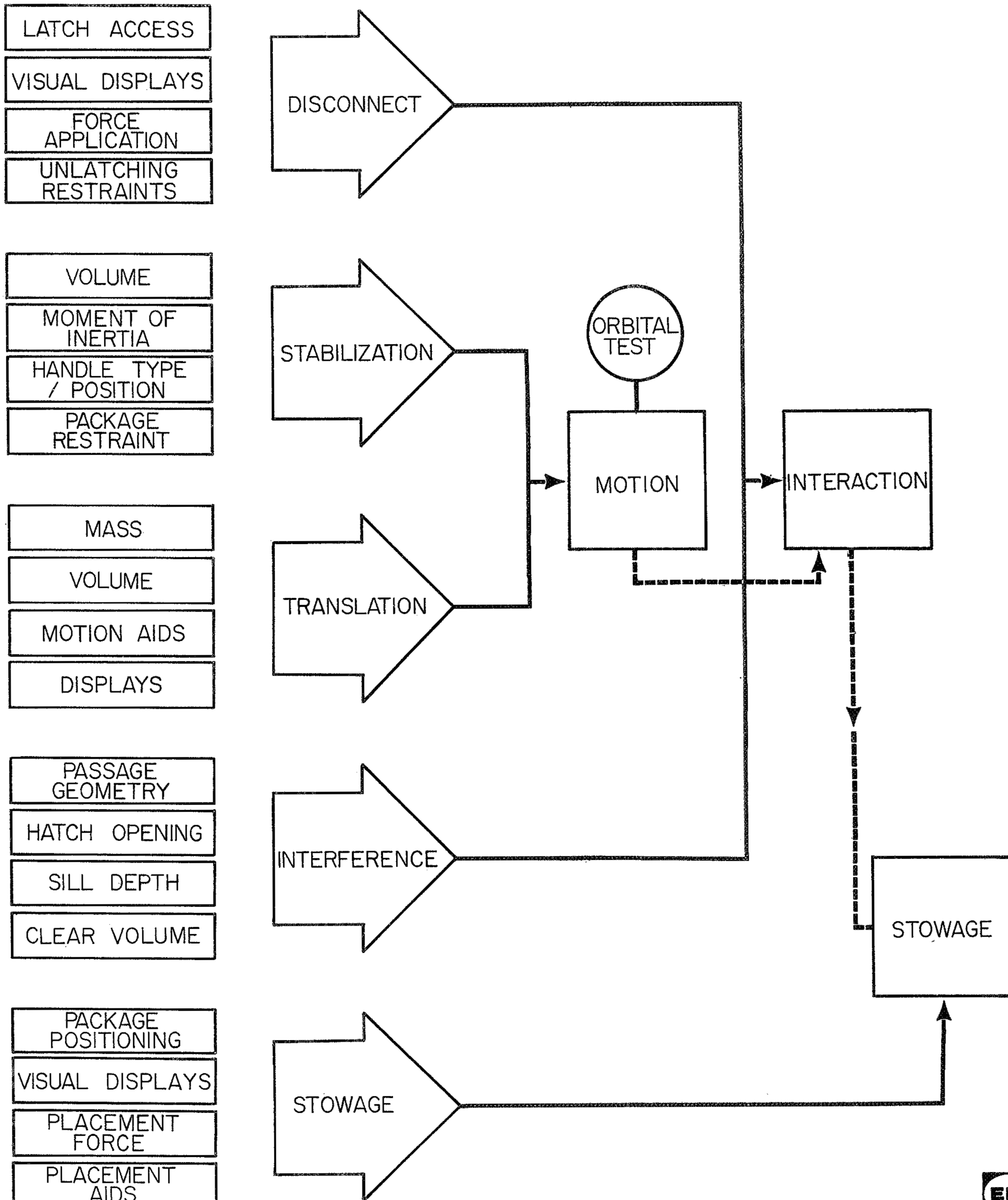


FIGURE 4

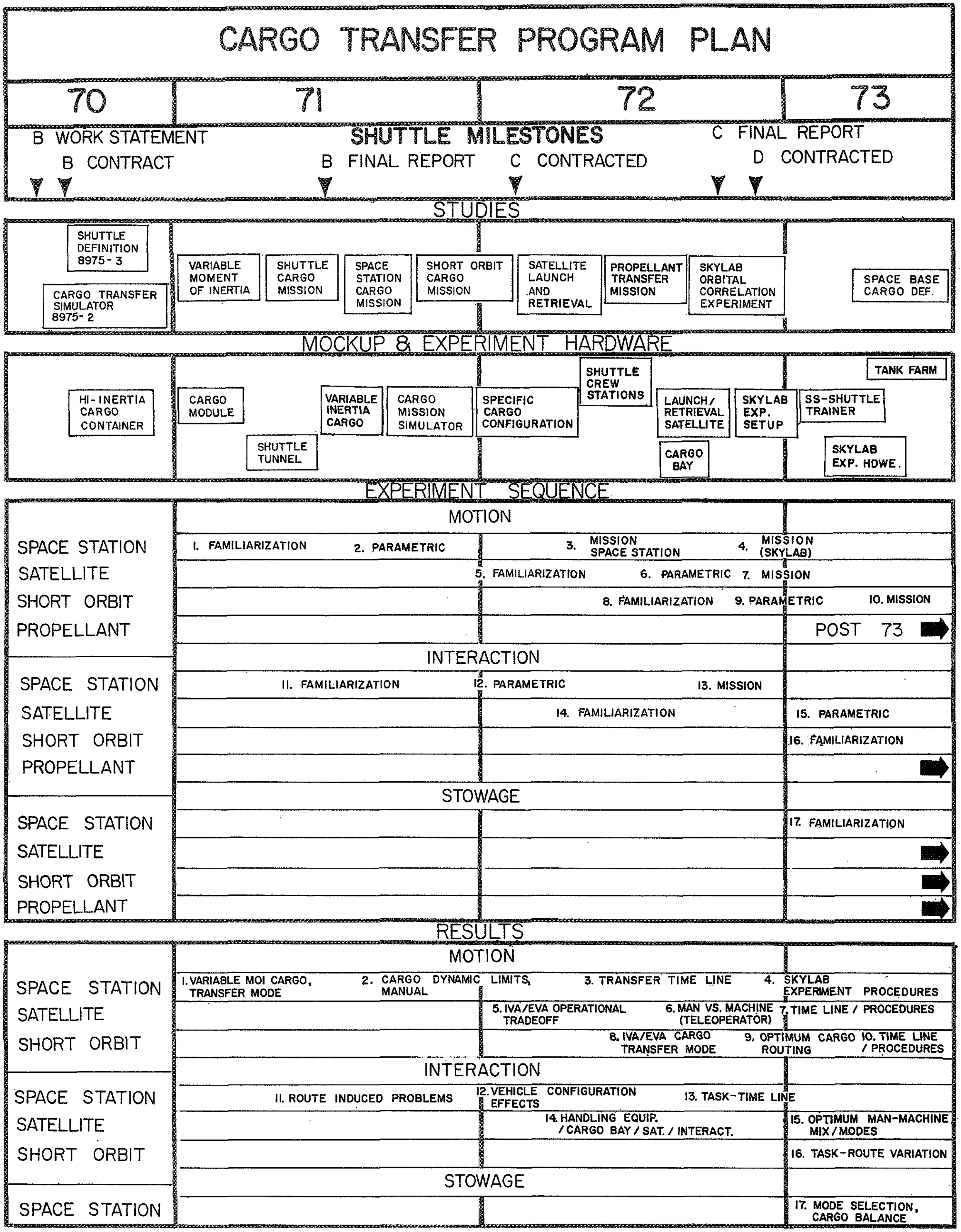

CARGO TRANSFER PROGRAM PLAN
70
71
72
73
B WORK STATEMENT
B CONTRACT
SHUTTLE MILESTONES
B FINAL REPORT
C CONTRACTED
C FINAL REPORT
D CONTRACTED
STUDIES
SHUTTLE DEFINITION 8975-3
CARGO TRANSFER SIMULATOR 8975-2
VARIABLE MOMENT OF INERTIA
SHUTTLE CARGO MISSION
SPACE STATION CARGO MISSION
SHORT ORBIT CARGO MISSION
SATELLITE LAUNCH AND RETRIEVAL
PROPELLANT TRANSFER MISSION
SKYLAB ORBITAL CORRELATION EXPERIMENT
SPACE BASE CARGO DEF.
MOCKUP & EXPERIMENT HARDWARE
HI-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. HDWE.
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 MOI CARGO, TRANSFER MODE
2. CARGO DYNAMIC LIMITS, MANUAL
3. TRANSFER TIME LINE
4. SKYLAB EXPERIMENT PROCEDURES
5. IVA/EVA OPERATIONAL TRADEOFF
6. MAN VS. MACHINE (TELEOPERATOR)
7. TIME LINE / PROCEDURES
8. IVA/EVA CARGO TRANSFER MODE
9. OPTIMUM CARGO ROUTING
10. TIME LINE / PROCEDURES
INTERACTION
SPACE STATION
SATELLITE
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 5

SIMULATIONS. SATELLITE LAUNCH AND RETRIEVAL STUDIES, SCHEDULED EARLY IN 1972, WILL ATTACK THE PROBLEM OF CARGO TRANSFER FROM THE VIEWPOINT OF MANUAL-POWER ASSIST (I.E., TELEOPERATOR). A DESCRIPTION OF EACH STUDY, ITS OBJECTIVES AND ANALYTICAL REQUIREMENTS, AS WELL AS A DESCRIPTION OF THE INDIVIDUAL MOCK-UP AND EXPERIMENT HARDWARE SPECIFIED IN THE CARGO TRANSFER PROGRAM PLAN, IS INCLUDED AT THE END OF THIS SECTION.

THE SEQUENTIAL ORDERING OF THE STUDIES IS BASED ON THE CRITICALITY OF THE INFORMATION BEING DEVELOPED. THE ORDERING OF MOCK-UP AND EXPERIMENT HARDWARE WAS BASED ON THE AVAILABILITY OF INFORMATION WITHIN THE SHUTTLE AND SPACE STATION SCHEDULES, AND IS SUBJECT TO MODIFICATION OR REARRANGEMENT AS THESE SCHEDULES ARE MODIFIED. EXTREME MODIFICATION OF THE SPACE STATION/SHUTTLE SCHEDULES MAY REQUIRE A POSTPONEMENT OF EXPERIMENTS DEALING WITH MISSION SIMULATION, BUT SHOULD NOT ALTER THE FAMILIARIZATION AND PARAMETRIC TEST SEQUENCES.

<u>SIMULATION UTILIZATION</u>.--FIGURE 6, CARGO TRANSFER SIMULATION UTILIZATION, IDENTIFIES THE SIMULATION MODES PROPOSED TO SUPPORT THE VARIOUS REQUIRED EXPERIMENT SEQUENCES. THOSE EXPERIMENT ELEMENTS EXHIBITING THE GREATEST KNOWLEDGE GAP, SPECIFICALLY FAMILIARIZATION AND PARAMETRIC EVALUATIONS OF MOTION, WILL REQUIRE COMPREHENSIVE STUDY AND EXPERIMENT PLANNING EFFORTS IN ORDER TO BRING THE LEVEL OF KNOWLEDGE TO THE SAME COMPETENCE LEVEL WHICH EXISTS IN THE AREAS OF INTERACTION AND STOWAGE.

THE MAIN SIMULATION TECHNIQUE TO BE USED FOR THE MOTION EXPERIMENTS IS THE HYBRID SIMULATOR. AN EXAMPLE OF HYBRID SIMULATION IS FIGURE 7 SHOWING THE CARGO TRANSPORT SIMULATOR (CTS) DEVELOPED UNDER CONTRACT NAS1-8975-2 WHICH UTILIZES WATER IMMERSION SIMULATION TO PROVIDE TRACTIONLESSNESS FOR THE TEST SUBJECT. THE SUBJECT AND PACKAGE ARE NEUTRALLY BUOYANT, AND THE SUBJECT AND CARGO ARE AFFECTED BY COMPUTER-GENERATED MOTION DYNAMICS.

CARGO TRANSFER SIMULATION UTILIZATION

EXPERIMENTS	MOCK-UP HARDWARE	SIMULATORS						
		1 G	WIS	HYBRID	OMPRA	AIR PAD *	TELEOPERATOR *	AIRCRAFT
MOTION	HI INERTIA CARGO		⊗	⊗	⊗	⊗	⊗	⊗
	VARIABLE INERTIA CARGO			⊗		⊗	⊗	⊗
	CARGO BAY						⊗	
	SKYLAB EXPERIMENT			⊗				⊗
	SS/SHUTTLE TRAINER	⊗	⊗					
INTERACTION	CARGO MODULE		⊗					
	TUNNELS		⊗					
	LAUNCH/RETRIEVAL		⊗				⊗	
	SS/SHUTTLE TRAINER	⊗	⊗					
	SKYLAB EXPERIMENT	⊗	⊗					
STOWAGE	MISSION SIMULATOR		⊗					
	CARGO COMPLEMENT		⊗					
	SS/SHUTTLE TRAINER	⊗	⊗					

* COMBINED IN REVAMP OF KINESTHETIC SIMULATOR

FIGURE 6

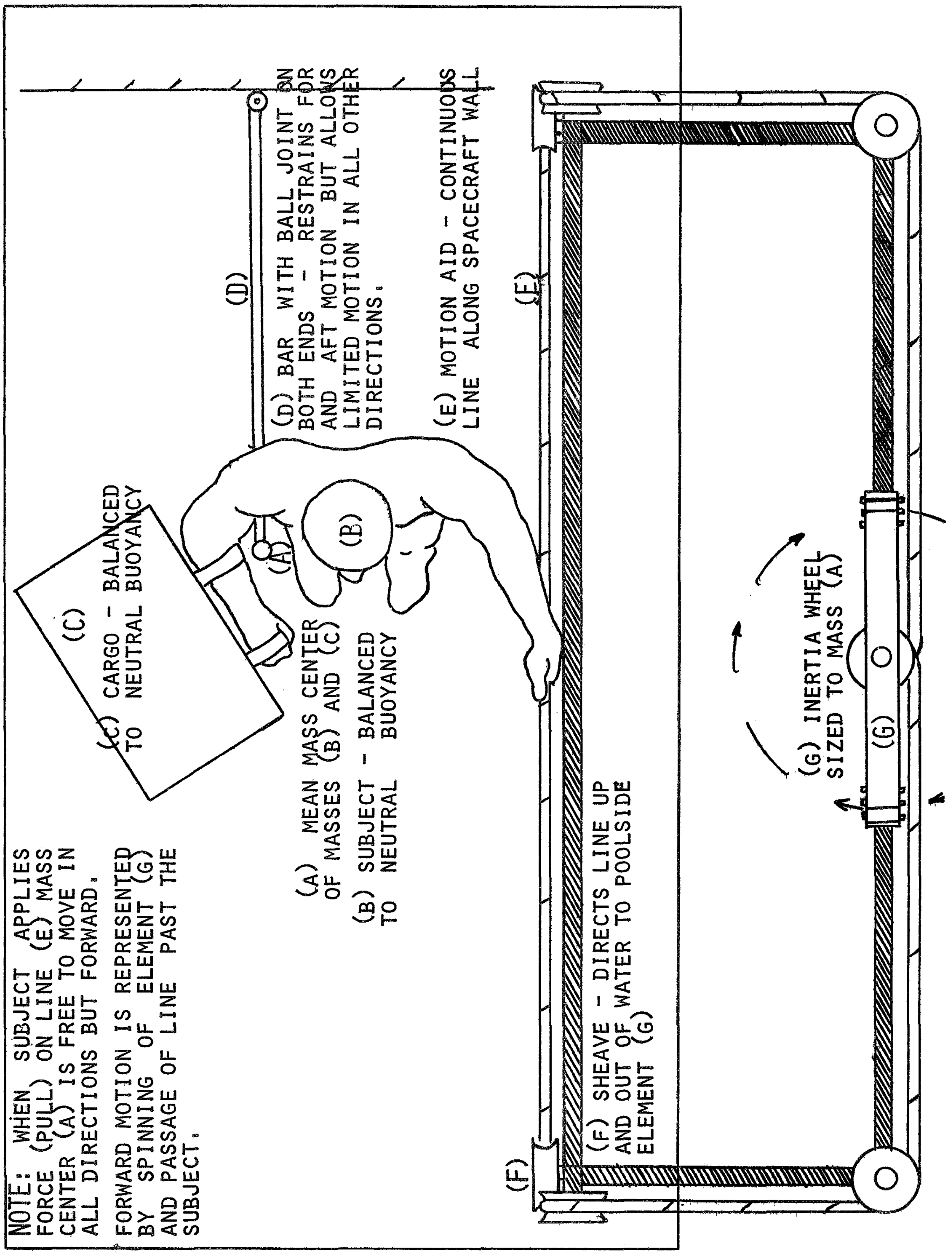


FIGURE 7 - CARGO TRANSPORT SIMULATOR

FIGURE 8, CARGO EXPERIMENT DATA, IS A GRAPHIC REPRESENTATION OF INFORMATION ANTICIPATED FROM A PLANNED TEST USING A HYBRID SIMULATOR IN WHICH A 5-SLUG TEST SUBJECT WITH A 10-SLUG CARGO MASS TRANSLATES ALONG A 40-FOOT STRAIGHT COURSE IN 25 SEC. THE INTEGRATED FORCE PROFILES TOTAL 43 LB-SEC FOR THE ACCELERATION AND DECELERATION PHASES. COMPARISON OF THESE DATA WITH THOSE FROM TESTS WITH GREATER MASSES PROVIDES THE CRITERIA FOR DETERMINING MAN'S LIMITATIONS.

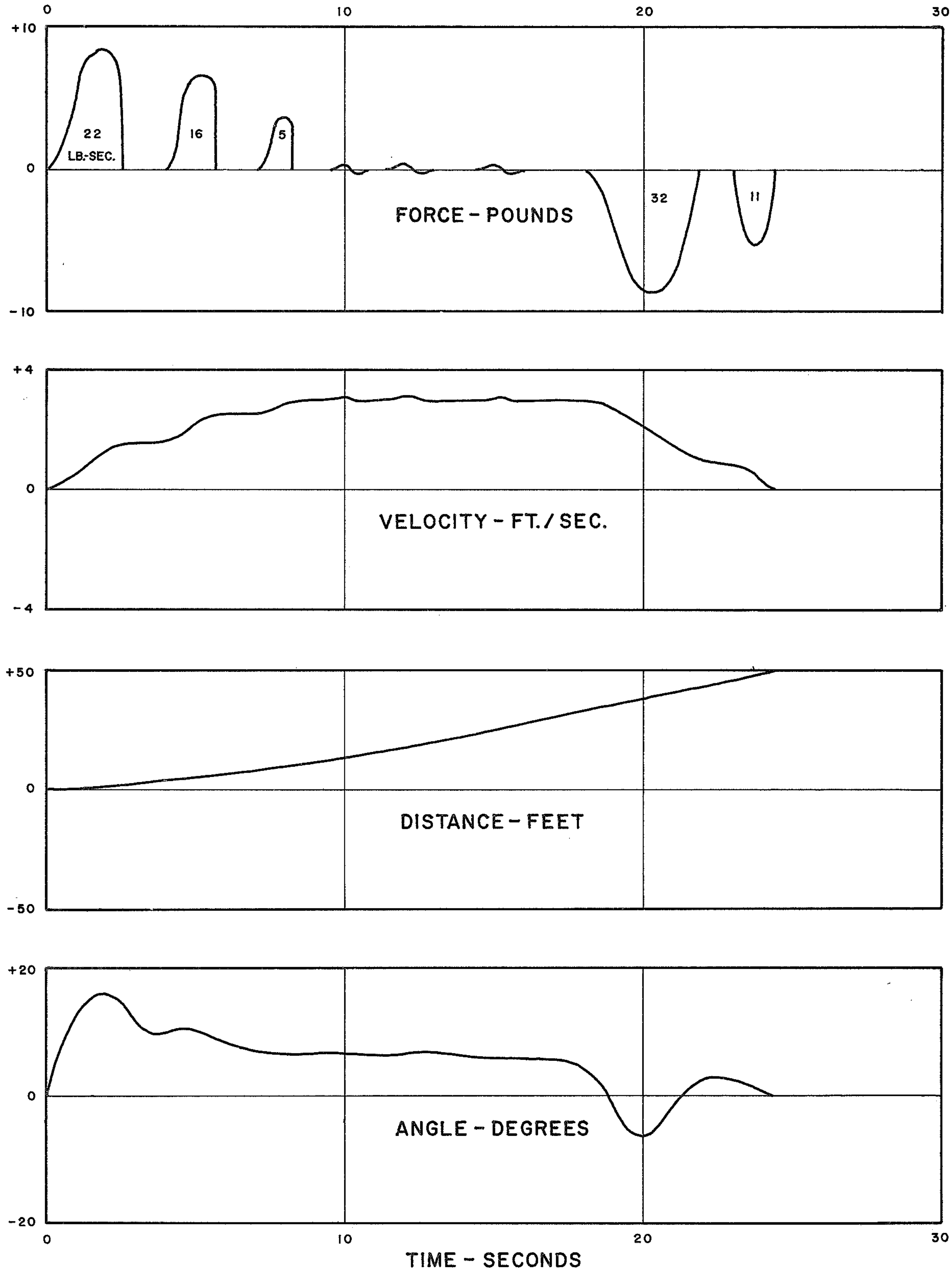
STUDIES AND MOCK-UP HARDWARE.--THE CARGO MISSION PROGRAM PLAN IDENTIFIES A GROUP OF STUDIES AND MOCK-UP HARDWARE REQUIRED FOR SIMULATIONS. THESE STUDIES AND HARDWARE ITEMS ARE EACH BRIEFLY DESCRIBED BELOW.

SHUTTLE DEFINITION (8975-3): OBJECTIVES--A COMPARISON ANALYSIS OF THE CURRENT (UP TO JULY 1970) SHUTTLE DESIGN EMPHASIZING THE CARGO AND CREW TRANSFER AREAS. RENDEZVOUS AND DOCKING, ABORT, AND EVA WILL ALSO BE COVERED. SPECIFIC EMPHASIS WILL BE PLACED ON CONFIGURATION COMMONALITIES. THE RESULTS OF THE STUDY WILL BE A POTENTIAL TIME PHASED EXPERIMENTAL-RESEARCH PROGRAM FOR LRC. THE PROGRAM WILL SPECIFICALLY IDENTIFY SIMULATOR USAGE AND SUPPORTING ANALYTICAL REQUIREMENTS.

ANALYTICAL REQUIREMENTS--COMPARISON ANALYSIS OF MISSION-CARGO, CONFIGURATION COMMONALITIES, PROCEDURAL COMMONALITIES OF THE SEVERAL SHUTTLE DESIGNS. ANALYTICAL VERIFICATION OF CRITICAL DATA AS REGARDS CARGO, FUEL FLOW, AND DOCKING DYNAMICS. TAXONOMIC AND FUNCTIONAL FLOW CHARTING OF THE CREW, CARGO, RENDEZVOUS AND DOCKING AREAS AS REGARDS HUMAN FACTORS SIMULATION REQUIREMENTS.

CARGO TRANSFER SIMULATOR (8975-2): OBJECTIVES--THE DEVELOPMENT OF A FIRST GENERATION HYBRID WATER IMMERSION SIMULATOR TO SPECIFICALLY INVESTIGATE THE DYNAMICS OF MANUAL CARGO TRANSFER RELATED TO SHUTTLE-SPACE STATION RESUPPLY. THIS NEW HYBRID TECHNIQUE WAS REQUIRED TO OPTIMIZE WATER IMMERSION SIMULATION FIDELITY BY ELIMINATING MOTION-INDUCED DRAG-DAMPING EFFECTS.

CARGO EXPERIMENT DATA



MASS 15 SLUGS

FIGURE 8

ANALYTICAL REQUIREMENTS--KINEMATIC AND DYNAMIC ANALYSIS OF MANUAL CARGO TRANSFER IN FREE SPACE. ANALYTICAL EVALUATION OF THE CTS WITH VERIFICATION OF PERFORMANCE CHARACTERISTICS. DESIGN OF AN ANALOG COMPUTER PROGRAM TO PROCESS MAN-GENERATED SIGNALS. ANALYSIS OF VARIOUS TRANSFER MODES TO PREDICT OPTIMIZATIONS AS TO TIME-ENERGY.

VARIABLE MOMENT OF INERTIA: OBJECTIVES--DEVELOP A VARIABLE MOMENT OF INERTIA CARGO CONTAINER FOR USE IN WIS. PACKAGE WILL INCLUDE NEUTRAL BUOYANCY PROVISIONS AND PERMIT MOI VARIATION OVER A WIDE RANGE APPLICABLE TO POTENTIAL MANUALLY HANDLED CARGO RELATED TO THE SHUTTLE.

ANALYTICAL REQUIREMENTS--SIX-DEGREE-OF-FREEDOM ANALYSIS OF CARGO BOTH IN WIS AND IN SPACE AMENABLE TO SUBSEQUENT ORBITAL CORRELATION EXPERIMENTS.

SHUTTLE CARGO MISSION: OBJECTIVES--DEFINE IN DETAIL THE CARGO MISSION FOR THE SHUTTLE INCLUDING GROUND, UPLOAD, AND DOWNLOAD WITH SPECIFIC EMPHASIS TO SIMULATOR AND SIMULATION REQUIREMENTS. DETAILS OF THE TIME PHASED REQUIREMENTS SHOULD BE CORRELATED WITH APPROPRIATE NASA USERS.

ANALYTICAL REQUIREMENTS--CARGO TYPE AND INTERNAL DISTRIBUTION ANALYSIS WITH DETERMINATION OF EFFECTIVE LAUNCH, FLIGHT, AND HANDLING FORCE ENVELOPE.

SPACE STATION CARGO MISSION: OBJECTIVES--SPECIFY AND VALIDATE PROCEDURES AND TECHNIQUES FOR HANDLING IDENTIFIED CARGO RELATED TO SPECIFIC SPACE STATION RESUPPLY MISSIONS. THIS INCLUDES THE GENERALIZED DESIGN AND DESCRIPTION OF ALL SPECIFIC CARGO HANDLING AND STOWAGE EQUIPMENT. POTENTIAL MANUAL AND POWER ASSIST TRANSFER AIDS WILL BE DESCRIBED.

ANALYTICAL REQUIREMENTS--FACTOR-VARIATION DESIGN OF EXPERIMENTS AND SIMULATION TO DEVELOP CRITICAL INFORMATION ITEMS IDENTIFIED.

KINEMATIC AND DYNAMIC ANALYSIS OF THE CARGO TRANSFER AND STOWAGE TASKS, BOTH MAN AND POWER ASSIST, SPECIFICALLY IDENTIFYING THE DATA MODIFICATIONS TO SIMULATION RESULTS NECESSARY TO PREDICT, DESCRIBE, OR DEFINE ACTUAL ORBITAL OPERATIONS.

SHORT ORBIT CARGO MISSION: OBJECTIVES--DEFINE THE SPECIFIC CARGO HANDLING REQUIREMENTS RELATED TO IDENTIFIED SHORT ORBIT MISSIONS. THESE REQUIREMENTS ARE ANALOGOUS AND FORM A SUBSET OF SIMILAR REQUIREMENTS RELATED TO INTERNAL SPACE STATION OPERATIONS. A TIME TASKLINE WILL BE PRESENTED TO IDENTIFY INITIAL TASKS. IVA AND EVA SUPPORT REQUIREMENTS WILL BE SPECIFICALLY IDENTIFIED.

ANALYTICAL REQUIREMENTS--CARGO UTILIZATION ROUTE COMPARISON BY MEANS OF GENERALIZED TIME-ENERGY TECHNIQUES DETERMINED PREVIOUSLY. CLASSIFICATION OF THE MISSION CARGO (MASS VS. INERTIA VS. VOLUME) AS RELATED TO PURE MANUAL, MANUAL-POWER ASSIST, AND AUTOMATIC MODE. ANALYTICAL COMPARISON OF IVA VS. EVA TECHNIQUES.

SATELLITE LAUNCH AND RETRIEVAL: OBJECTIVES--EVALUATE THE SELECTED LAUNCH AND RETRIEVAL SATELLITE MISSION TO DETERMINE MAN'S POTENTIAL ROLE. DESIGN A SET OF PROCEDURES SUFFICIENT TO NUMERICALLY COMPARE MAN VS. MACHINE LAUNCH AND RETRIEVAL TECHNIQUES. SPECIFY TEST AND SIMULATOR CHARACTERISTICS WHICH PERMIT THE ABOVE DETERMINATION.

ANALYTICAL REQUIREMENTS--ANALYZE THE IDENTIFIED SATELLITES TO DETERMINE THE ENVELOPE, GARAGING PROCEDURES, AND FORCES. DEVELOP THE ANALYTICAL SUPPORT NECESSARY TO SIMULATE MANUAL-POWER ASSIST MODE (TELEOPERATOR) AND AUTOMATIC MODE.

PROPELLANT MISSION: OBJECTIVES--TO DETERMINE MAN'S FUNCTION IN SUPPORT OF FLUID TRANSFER PROPELLANT MISSION AND TO CONTRAST THIS WITH A PURELY AUTOMATIC SYSTEM. AS A RESULT OF THIS COMPARISON, IF THERE IS SUFFICIENT VALUE, A CONTINUATION EFFORT TO IDENTIFY CRITICAL TEST REQUIREMENTS WILL BE MADE.

ANALYTICAL REQUIREMENTS--PREDICTION OF THE RANGE OF MISSION DESCRIPTIVE ELEMENTS TO EVALUATE EXACT EVA REQUIREMENTS. CALCULATION OF EXPECTED TRANSFER RATES AND TIMES TO SUPPORT EXACT TIME TASK-LINE DETERMINATION. CALCULATION OF THE FORCE ENVELOPE EXPECTED DURING LINK UP, CONNECTION, AND DE-ERECTION.

SKYLAB ORBITAL CORRELATION EXPERIMENT: OBJECTIVES--PRIMARY, TO RESOLVE BY INFLIGHT EXPERIMENTATION THE CURRENT TECHNOLOGICAL DISAGREEMENT OVER THE LIMITS OF MAN'S CAPABILITY TO TRANSFER MASSES IN THE MANUAL MODE. TO DETERMINE BY FACTOR VARIATION SPECIFIC WORKLOAD EFFECTS DUE TO GRAVITY BALANCE. SECONDARY, TO PROVIDE THE NECESSARY EXPERIMENTAL DATA TO VALIDATE THE RESULTS OF THE HYBRID SIMULATION TO PERMIT THE UTILIZATION OF EXTRAPOLATION FOR CARGO OF GREATER MASS/INERTIA THAN WOULD BE PERMITTED IN ORBITAL EXPERIMENTS. TO QUANTITATIVELY DETERMINE THE SIMULATION FIDELITY OF THE HYBRID SIMULATOR.

ANALYTICAL REQUIREMENTS--ANALYTICAL DESCRIPTION OF THE EXPECTED ORBITAL PERFORMANCE INCLUDING KINEMATIC AND DYNAMIC EFFECTS. FACTOR-VARIATION DESIGN OPTIMIZATION TO PRODUCE THE MOST EFFICIENT NUMBER AND SIZE OF PACKAGE TO BE HANDLED. PRE- AND POSTFLIGHT CORRELATION OF SIMULATOR RESULTS TO PRODUCE MAXIMUM RESULTS. PREDICTION OF THE EFFECTS PRODUCED DUE TO INFLIGHT DISTURBANCES PRODUCED BY THE SPACECRAFT. ANALYTICAL DETERMINATION OF THE SIMULATOR FIDELITY AS A RESULT OF THE ABOVE DATA.

HI-INERTIA CARGO CONTAINER: A MOCK-UP OF A 40 IN. CUBICAL PACKAGE WITH THE MAXIMUM PRACTICAL WEIGHT PLACED SYMMETRICALLY AS FAR FROM THE MASS CENTER AS POSSIBLE. WATER IMMERSION EXPERIMENTATION REQUIRES FLOATATION MATERIALS PLACED AT THE MASS CENTER SO THAT THE PACKAGE WILL HAVE NO PREFERENTIAL ATTITUDE IN THE WATER. IN OTHER SIMULATIONS, SUCH AS AIR BEARING, A UNIVERSAL JOINT PLACED AT THE MASS CENTER OF THE MOCK-UP TO ALLOW A LIMITED ROLL, PITCH, AND YAW WILL BE REQUIRED.

CARGO MODULE: ONE-HALF OF THE PROPOSED CARGO MODULE WOULD BE DESIGNED AND FABRICATED FOR USE PRIMARILY IN THE WATER IMMERSION FACILITY. THIS OVERALL STRUCTURE, 15 FT IN DIAMETER BY 30 FT LONG, WOULD BE BUILT IN A NUMBER OF SUBASSEMBLIES PROVIDING A VARIETY OF TECHNIQUES OF INGRESS/EGRESS, CARGO, AND MOTION AID ATTACHMENT POINTS.

VARIABLE INERTIA CARGO CONTAINER: WOULD BE BASED ON THE RESULTS OF THE EARLIER TESTS USING HI-INERTIA CARGO CONTAINER, BUT WOULD PERMIT ADJUSTABLE POSITIONING OF THE BALLAST WHICH WILL EFFECTIVELY ALTER THE MOMENT OF INERTIA.

CARGO MODULE/SHUTTLE TUNNEL: THE DIMENSIONS OF THE SHUTTLE TUNNEL, AS PROVIDED BY THE SHUTTLE VEHICLE CONTRACTORS, WOULD BE REPRODUCED. IN ADDITION, CRITICAL AREAS, SUCH AS TURNS AND HATCH INTERFACES, WOULD BE REPRODUCED WITH VARIATIONS INCLUDING BOTH LARGER AND SMALLER DIMENSIONS TO PROVIDE FOR PARAMETRIC EVALUATION OF CONFIGURATIONS.

CARGO MISSION SIMULATOR: A COMBINATION OF A PORTION OF THE CARGO MODULE, SELECTED TUNNELS, AND A PORTION OF THE SPACE STATION DOCKING PORT.

SPECIFIC CARGO COMPLEMENT: UTILIZING THE CARGO MISSION SIMULATOR, A NUMBER OF CARGO CONTAINERS REPRESENTATIVE OF A SPECIFIC SPACE STATION CARGO SUPPLY MISSION WOULD PERMIT THE PROPER SPACING AND POSITIONING FOR AN OVERALL MISSION EVALUATION.

CARGO BAY: A CARGO BAY MOCK-UP WOULD BE FABRICATED AND UTILIZED IN SIMULATIONS CONCERNING SATELLITE RETRIEVAL OR STAGE DELIVERY. IT WOULD INCLUDE A SECTION OF THE OPEN DOORS AND ATTACHMENT POINTS FOR LARGE CARGO ITEMS.

LAUNCH/RETRIEVAL SATELLITE: THE SATELLITE SELECTED FOR RETRIEVAL ON THE SHUTTLE PROGRAM WOULD BE DUPLICATED IN A GENERALIZED CONFIGURATION. IT WOULD INCLUDE ITEMS WHICH WOULD BE IDENTIFIED IN THE STUDY CONCERNING ATTACHMENT POINTS, MOVING PARTS, ETC.

SKYLAB EXPERIMENT SETUP: HYBRID SIMULATIONS WILL YIELD VALUES OF MASS AND VOLUME WHICH MUST BE VERIFIED BY SPACE EXPERIMENT. AN EXPERIMENT STUDY WILL CONSIDER WHETHER EQUIPMENT EXISTING ON THE SKYLAB COULD BE UTILIZED IN THE EXPERIMENT OR WHETHER SPECIAL EQUIPMENT MUST BE DESIGNED AND BUILT FOR THIS EXPERIMENT. THE MOCK-UP WILL REPRODUCE THE EQUIPMENT AND THAT PORTION OF THE SKYLAB IN WHICH THE EQUIPMENT WILL BE USED.

SPACE STATION-SHUTTLE COMPREHENSIVE TRAINER: THIS MOCK-UP WOULD INCLUDE PORTIONS OF THE PRECEDING SHUTTLE-DEPENDENT MOCK-UPS, UPDATED AS SIGNIFICANT MODIFICATIONS IN THE SHUTTLE PROGRAM ARE RECEIVED. THE SPACE STATION CONFIGURATION WOULD BE CONCEPTUAL, AND REPRESENT APPROVED DESIGNS EXISTING AT THE TIME OF TRAINER MANUFACTURE.

SKYLAB EXPERIMENT HARDWARE: ACTUAL EXPERIMENTAL HARDWARE TO BE USED ON THE SKYLAB B TEST.

TANK FARM: A MOCK-UP OF A PORTION OF THE VEHICLES IN THE PROPELLANT TRANSFER MISSION, INCLUDING NECESSARY CONNECTORS, VALVES, ETC., TO BE OPERATED UTILIZING ASTRONAUT PARTICIPATION.

PERSONNEL TRANSFER

GENERAL.--PERSONNEL TRANSFER AS IDENTIFIED IN THIS PROGRAM PLAN WAS ORIGINALLY CONSIDERED TO BE CREW TRANSFER AND, PRIMARILY, THE TRANSFER OF THE SPACE STATION OPERATING CREW. AS SUCH, CREW TRANSFER WAS CONSIDERED BY ENVIRONMENTAL RESEARCH ASSOCIATES FROM THE POINT OF VIEW OF THE EXPERIMENTALIST TO BE MANUAL CARGO TRANSFER WITH ZERO MASS CARGO. DURING THE STUDY, HOWEVER, CREW TRANSFER HAS EVOLVED TO INCLUDE ALL SHUTTLE PERSONNEL TRANSFERS (OPERATING CREW AS WELL AS SCIENTIFIC CREW) FOR EACH OF THE MISSIONS. AS AN EXAMPLE, THE USE OF THE CARGO BAY DURING SHORT ORBITAL MISSIONS MAY REQUIRE A NUMBER OF TRANSFERS OF PERSONNEL ENCUMBERED WITH TOOLS OR SCIENTIFIC APPARATUS. POTENTIAL EMERGENCY SITUATIONS FURTHER REQUIRE CONSIDERATION OF PRESSURE-SUITED TRANSIT THROUGH

THE IVA TUNNELS. SINCE THESE TUNNEL CONFIGURATIONS ARE NOT YET IN FINAL DESIGN, IT IS IMPORTANT TO ANALYZE AND CONDUCT A PARAMETRIC SIMULATION EVALUATION OF THE DIMENSIONAL CHARACTERISTICS OF IVA TUNNELS WITH PARTICULAR EMPHASIS ON TURNS AND HATCH INTERFACES. THE DEVELOPMENT OF THE PERSONNEL TRANSFER PROGRAM PLAN FOLLOWS THE FORMAT DESCRIBED IN THE METHODOLOGY AND ILLUSTRATED IN THE CARGO TRANSFER SECTION.

<u>EXPERIMENT FUNCTIONAL PRIORITY</u>.--TABLE VI, PERSONNEL TRANSFER AREA COMPOSITE, LISTS THE IDENTIFIED COMPOSITE CHARACTERISTICS OF PERSONNEL TRANSFER AS DERIVED FROM THE DATA BANK INPUTS. ALTHOUGH THE STATE-OF-THE-ART OF PERSONNEL TRANSFER IS COMPARATIVELY WELL KNOWN DUE TO THE EXPERIENCE OF THE APOLLO PROGRAM, AND THROUGH EXTENSIVE SIMULATION PROGRAMS, THERE ARE SIGNIFICANT CHARACTERISTICS OF THE SHUTTLE PROGRAM WHICH REQUIRE EARLY ATTENTION. THE MOST CRITICAL REQUIREMENT IS AN ADDITIONAL STUDY AND SIMULATION OF THE INTERACTION OF MULTICREW TRANSFERS AS WOULD BE REQUIRED IN THE SPACE STATION SCIENTIFIC CREW CHANGE. SECONDARILY, THE REQUIREMENT FOR A BACKUP EVA CAPABILITY REQUIRES FURTHER DEFINITION OF SUIT AND SUPPORT EQUIPMENT AVAILABILITY. IF A BACKUP EVA MODE IS REQUIRED FOR SCIENTIFIC CREW TRANSFER, THERE MUST BE A DEVELOPMENT OF A TRAINING PROGRAM FOR PRESSURE SUIT OPERATIONS.

FIGURE 9, PERSONNEL TRANSFER FUNCTIONAL PRIORITY, IDENTIFIES TWO FUNCTIONS, STAGING AND TRANSLATION, TO RECEIVE PRIMARY ATTENTION. THESE TWO FUNCTIONS ARE GROUPED INTO THE DYNAMICS OF TRANSFER, AND ARE CLOSELY RELATED TO THE MOTION EXPERIMENT SEQUENCE IN CARGO TRANSFER. SECONDARILY, THE INTERACTION FUNCTION PERMITS QUANTITATIVE DETERMINATION AS TO THE EFFECTS OF SPECIFIC CONFIGURATIONS ON THE DYNAMICS OF TRANSFER.

<u>EXPERIMENT PROGRAM PLAN</u>.--PERSONNEL TRANSFER PROGRAM PLAN, FIGURE 10, UTILIZES MOCK-UPS PREVIOUSLY IDENTIFIED IN THE CARGO TRANSFER PROGRAM PLAN, AND SPECIFIES THOSE ADDITIONAL MOCK-UPS WHICH ARE REQUIRED FOR EVALUATION OF PERSONNEL TRANSFER. THE EXPERIMENTS TO

TABLE VI.--PERSONNEL TRANSFER AREA COMPOSITE

MODE
.PRIMARY--IVA .BACKUP--EVA
CONFIGURATION
.IVA TUNNEL TO PASSENGER/CARGO MODULE .THRU DOCKING PORTS-CARGO MODULE-STATION .GROUND EMERGENCY EGRESS THRU NOSEWELL AREA .MULTIPLE COMPARTMENT CABIN WITH HATCHES .OPERATIONS CREW IN CABIN OR PAYLOAD COMPARTMENT .PASSENGER TRANSFER MODULE (UP TO 50) IN CARGO BAY (INTEGRAL CARGO USE) .TRACK-SLED MOTION AIDS .LADDER, FIXED HANDLE MOTION AIDS .AIR LOCKS AT EITHER END OF IVA TUNNEL .IVA TUNNEL VERSION-FIXED-FLEXIBLE
STUDY/EXPERIMENT REQUIREMENTS
.PERSONNEL TRANSFER MOTION-INTERACTION STUDY-SIMULATION .COMPARTMENT-CREW FUNCTIONAL LAYOUT AND INTERACTION SIMULATION .SHORT DURATION MISSION USED AS TEST BED .MOTION AID DEVELOPMENT AND SIMULATION .SHUTTLE TRANSFER CONFIGURATION-PERSONNEL TRANSFER INTERACTION DEVELOPMENT SIMULATION STUDIES

PERSONNEL TRANSFER FUNCTIONAL PRIORITY

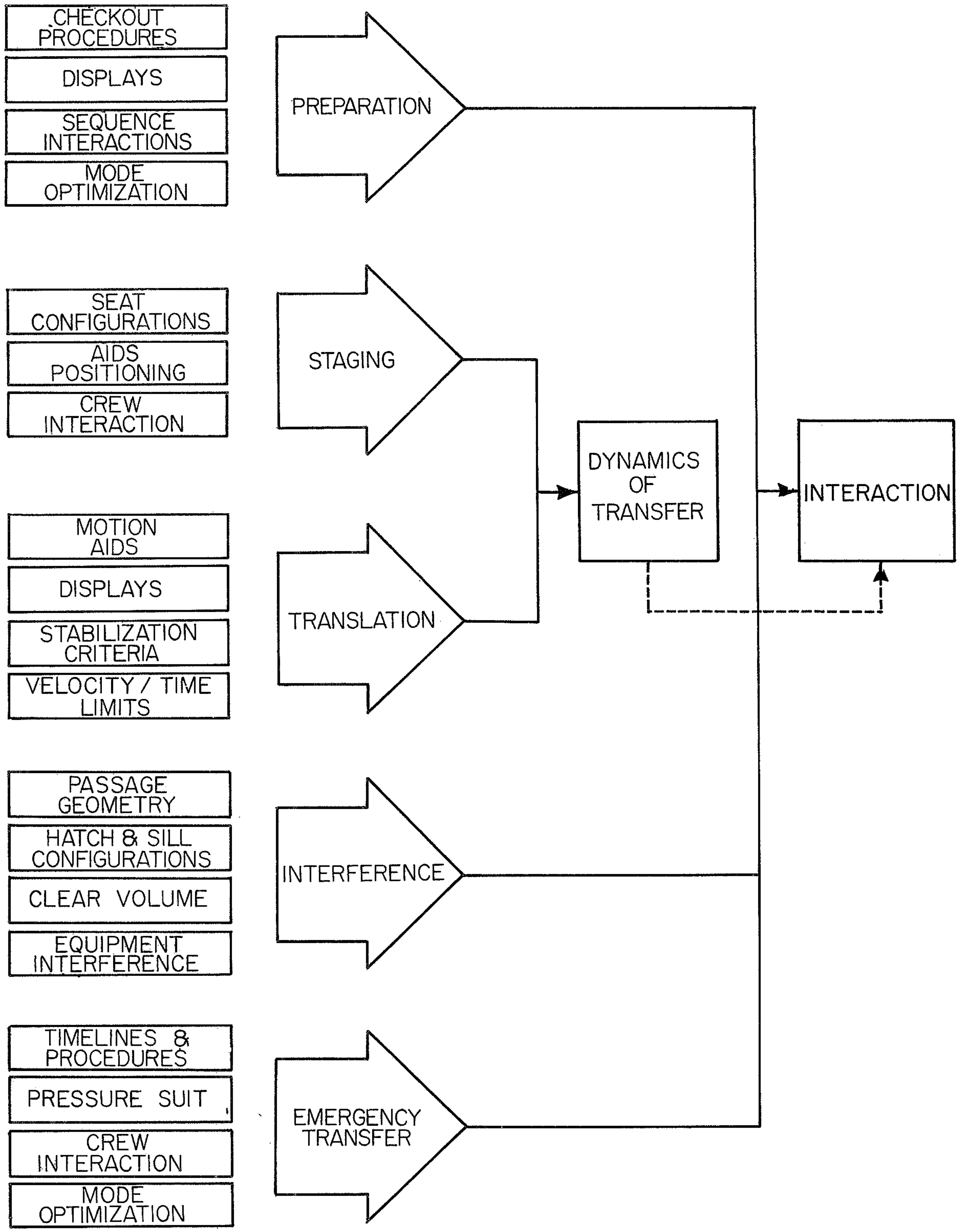


FIGURE 9

PERSONNEL TRANSFER PROGRAM PLAN

	70	71	72	73
SHUTTLE MILESTONES	B WORK STATEMENT; B CONTRACTED	B FINAL REPORT	C CONTRACTED; C FINAL REPORT; D CONTRACTED	
STUDIES	SHUTTLE DEFINITION 8975-3	SHUTTLE PERSONNEL TRANSFER (A); SHUTTLE MISSION EMERGENCY PERSONNEL TRANSFER (B); SHORT ORBIT CARGO MISSION----	SHORT ORBIT CARGO MISSION----; SPACE STATION RESCUE MISSION (C)	SPACE BASE RESCUE MISSION
MOCKUP & EXPERIMENT HARDWARE		CREW COMPARTMENT; PERSONNEL MODULE; SHUTTLE TUNNEL----; CARGO MISSION SIMULATOR----	SPECIFIC CARGO CONFIGURATION----; CARGO BAY----	SS-SHUTTLE TRAINER----

EXPERIMENT SEQUENCE

	71	72	73
	DYNAMICS OF MOTION		
SPACE STATION	1. FAMILIARIZATION (A) 2. FAMILIARIZATION (B)	3. PARAMETRIC (A,B)	4. FAMILIARIZATION (C)
SHORT ORBIT	5. FAMILIARIZATION (CONTINUATION IS UNDER INTERACTION)	5. FAMILIARIZATION (CONTINUATION IS UNDER INTERACTION)	
SATELLITE	COVERED IN SPACE STATION/SHORT ORBIT		
PROPELLANT	COVERED IN SPACE STATION/SHORT ORBIT		
	INTERACTION		
SPACE STATION		6. PARAMETRIC (A,B)	7. MISSION (A,B)
SHORT ORBIT		8. PARAMETRIC	
SATELLITE			POST 73 ➡
PROPELLANT			➡

RESULTS

	71	72	73
	DYNAMICS OF MOTION		
SPACE STATION	1. PERSONNEL MOTION SIMULATION TECHNIQUE 2. MULTI-MAN SIMULATION TECHNIQUE	3. CREW/PASSENGER MOTION AID EVALUATION	4. SIMULATION TECHNIQUES SPACE STATION CREW
SHORT ORBIT	5. IVA CREW MOTION PROCEDURES & TIME LINES	5. IVA CREW MOTION PROCEDURES & TIME LINES	
SATELLITE	COVERED IN SPACE STATION / SHORT ORBIT		
PROPELLANT	COVERED IN SPACE STATION /SHORT ORBIT		
	INTERACTION		
SPACE STATION		6. HATCH/TUNNEL/AIRLOCK/ COMPARTMENT INTERACTIONS	7. OPTIMUM ROUTING, TIME LINES & PROCEDURES
SHORT ORBIT		8. SHORT ORBIT CONFIGURATION INTERACTIONS	8. SHORT ORBIT CONFIGURATION INTERACTIONS
SATELLITE			➡
PROPELLANT			➡

---- INDICATES DEVELOPED UNDER CARGO TRANSFER PROGRAM PLAN

ERA

FIGURE 10

BE PERFORMED UNDER THE HEADING "DYNAMICS OF MOTION" ARE PRIMARILY FAMILIARIZATION EXPERIMENTS IN WHICH THE RESULTS ARE EVALUATION OF THE MERITS OF RELATIVE TECHNIQUES. THERE IS, HOWEVER, ONE AREA OF PARAMETRIC EXPERIMENTATION IDENTIFIED DEALING WITH THE SPACE STATION CREW TRANSFER IN WHICH THE MOCK-UP SIZES ARE VARIED AND DESIGN DATA IS DERIVED.

SIMULATION UTILIZATION.--FIGURE 11, PERSONNEL TRANSFER SIMULATION UTILIZATION, IDENTIFIES THE SIMULATORS TO BE USED FOR THE EXPERIMENT

PERSONNEL TRANSFER SIMULATION UTILIZATION

EXPERIMENTS	MOCK-UP HARDWARE	SIMULATORS			
		1 G	WIS	HYBRID	AIRCRAFT
MOTION DYNAMICS	CREW COMPARTMENT	ⓧ		ⓧ	ⓧ
	SHUTTLE IVA TUNNEL			ⓧ	ⓧ
	PERSONNEL MODULE	ⓧ	ⓧ	ⓧ	ⓧ
INTERACTION	CARGO MISSION	ⓧ	ⓧ		
	SPECIFIC CARGO	ⓧ	ⓧ		
	CARGO BAY	ⓧ	ⓧ		
	SS-SHUTTLE TRAINER	ⓧ	ⓧ		

FIGURE 11

SEQUENCES. AS IN THE CARGO TRANSFER SECTION, MOTION EXPERIMENTS REQUIRE A HYBRID SIMULATION WITH ZERO GRAVITY AIRCRAFT BACKUP. INTERACTION EXPERIMENTS CAN BE SATISFIED BY ONE GRAVITY WALK-THROUGHS PLUS WATER IMMERSION SIMULATION.

RENDEZVOUS-DOCKING

GENERAL.--EARLY SPACE SHUTTLE MISSIONS REQUIRE RENDEZVOUS-DOCKING WITH SPACE STATION FOR PURPOSES OF CREW AND CARGO TRANSFER. THE SPACE SHUTTLE-SPACE STATION INTERFACE REQUIRES THAT A LARGE (15 FT DIAMETER × 60 FT LENGTH × 50,000 LB) CARGO CONTAINER BE TRANSFERRED FROM THE SHUTTLE CRAFT CARGO BAY (HAVING THE SAME APPROXIMATE DIMENSIONS AS THE CARGO CONTAINER) TO THE SPACE STATION DOCKING PORT AND BE HARD-DOCKED TO THE SPACE STATION FOR SUBSEQUENT USE AS AN ADJUNCT CARGO HOLD. THERE ARE FOUR PRIMARY TRANSFER MODES UNDER CONSIDERATION:

1. ARTICULATED CARGO CONTAINER HARD-DOCKED TO THE STATION BY THE SHUTTLE.
2. USE OF AN AUXILIARY CARGO TUG WHICH CAPTURES THE CARGO CONTAINER AT OR NEAR THE SHUTTLE, FERRIES THE CARGO TO THE STATION, AND HARD DOCKS THE CARGO.
3. A SELF-CONTAINED/SELF-PROPELLED CARGO MODULE.
4. AN ISOMORPHIC REMOTE MANIPULATOR LOCATED EITHER ON THE SHUTTLE OR THE STATION WHICH GRASPS THE CARGO CONTAINER WHILE IN THE CARGO HOLD AND MANIPULATES THE CARGO INTO FINAL DOCKING WITH THE STATION.

ALTHOUGH THE SPACE SHUTTLE AND SPACE STATION ARE OF A MUCH GREATER MASS AND VOLUME THAN THE PRESENT SPACE VEHICLE, THE TECHNIQUES OF STUDY AND SIMULATION OF THE PHYSICAL ATTACHMENT BETWEEN ORBITAL VEHICLES ARE WELL KNOWN. THREE OF THE FOUR PRIMARY TRANSFER MODES WILL BE INVESTIGATED IN THIS FASHION. THE ADVANTAGES AND MISSION FLEXIBILITY OF THE FOURTH CONCEPT REQUIRE A DEEPER INVESTIGATION, PARTICULARLY FROM THE STANDPOINT OF AN ENGINEERING-ORIENTED INVESTIGATION OF THE HUMAN FACTORS OF MANUAL CONTROL OF SUCH A MANIPULATOR.

IN GENERAL, A MANIPULATOR CONCEPT REQUIRES THAT THE SPACE SHUTTLE-SPACE STATION INITIALLY FLY A CLOSE QUASI-STABILIZED STATIONKEEPING MANEUVER. THIS MANEUVER WOULD PROBABLY BE REQUIRED FOR A PERIOD OF 15-60 MINUTES TO PERMIT SAFE, CONTROLLED COUPLING OF THE CARGO CONTAINER BY THE GRAPPLING HEAD OF THE MANIPULATOR. THE STATIONKEEPING MANEUVER WOULD REQUIRE SEPARATION DISTANCES ON THE ORDER OF 25-50 FT WITH RELATIVE SEPARATION VELOCITIES $\leq$ 0.5 FT/SEC. THE SENSITIVITY OF THESE PARAMETERS TO MANUAL CONTROL CAPABILITY CAN EASILY BE ASSESSED BY THE COMPUTERIZED SIMULATION. THE GENERALIZED EXPERIMENT CONFIGURATION IS SHOWN IN FIGURE 12.

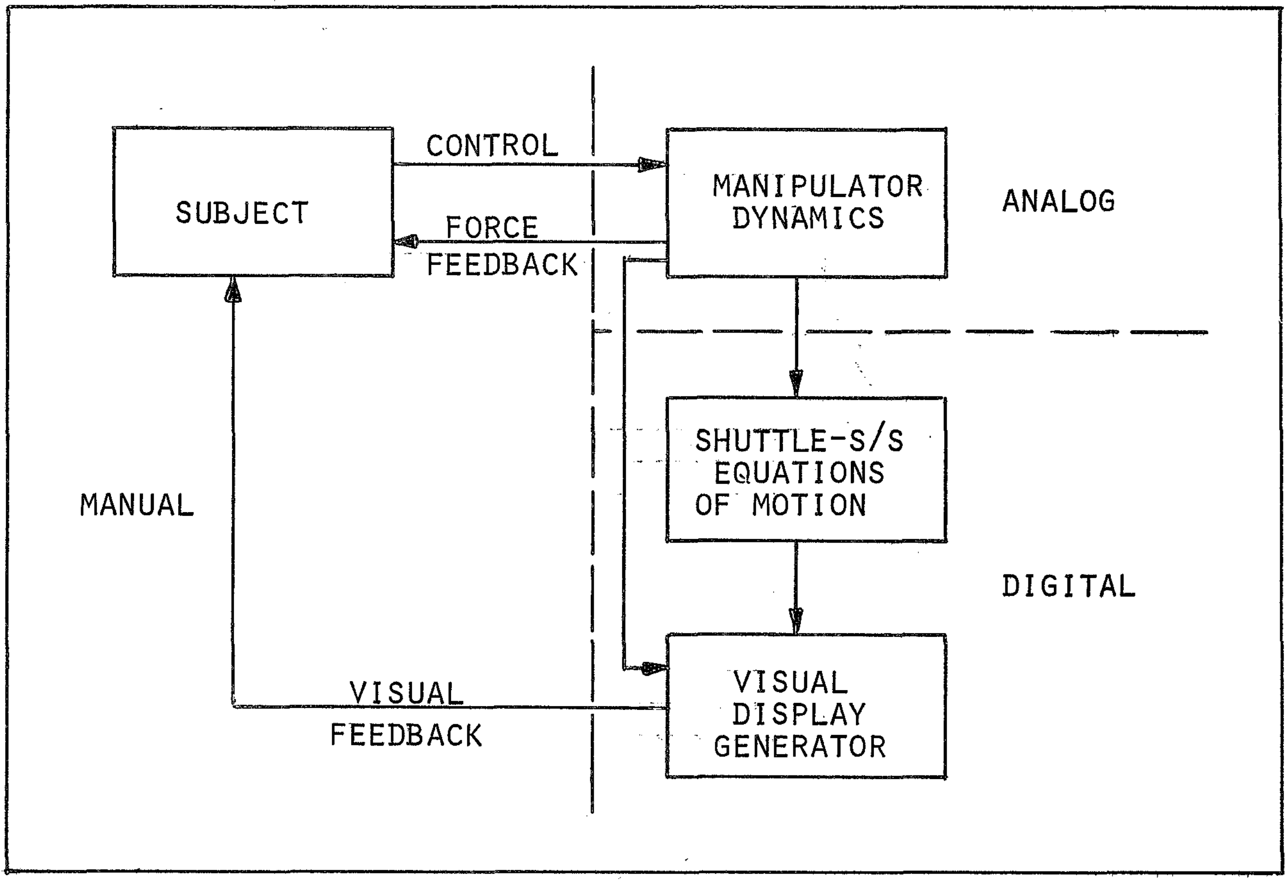


FIGURE 12 - EXPERIMENT CONFIGURATION BLOCK DIAGRAM-GENERAL CONCEPT

THE FIGURE IS DIVIDED INTO THREE SECTIONS:

1. MANUAL: THE MANUAL SECTION INCLUDES THE SUBJECT, THE DISPLAY CONSOLE, THE MANIPULATOR CONTROLS, AND THE DATA RECORDING STATION.

2. ANALOG: THE ANALOG SECTION INCLUDES THE PHYSICAL ANALOG COMPUTER INTERFACE, THE ANALOG COMPUTER SIMULATION OF THE REMOTE MANIPULATOR DYNAMICS, AND THE ANALOG-DIGITAL INTERFACES.
3. DIGITAL: THE DIGITAL SECTION INCLUDES THE SHUTTLE-SPACE STATION EQUATION OF MOTION PROGRAM WHICH ACCOMMODATES THE FORCING FUNCTION INPUTS FROM THE ANALOG PROGRAM, THE DIGITAL-DIGITAL INTERFACE TO THE VISUAL DISPLAY GENERATOR, AND THE DIGITAL-DISPLAY INTERFACE.

TABLE VII, RENDEZVOUS-DOCKING AREA COMPOSITE, LISTS THE COMPOSITE CHARACTERISTICS OF THE SHUTTLE RENDEZVOUS AND DOCKING AREA, AND SUMMARIZES THE VARIOUS VERSIONS PRESENTED IN THE PHASE A AND B REPORTS ANALYZED. THE MOST IMPORTANT FACTORS IDENTIFIED ARE THOSE IN THE STUDY/EXPERIMENTS REQUIREMENTS SECTION. THE SOLUTION TO THESE, HOWEVER, DEPEND LARGELY ON LATER SPECIFICATIONS OF THE SHUTTLE VEHICLE AND TARGETS. IT IS REQUIRED, THEREFORE, TO DEPEND HEAVILY ON PARAMETRIC EVALUATIONS TO OPTIMIZE RENDEZVOUS AND DOCKING PERFORMANCE.

<u>EXPERIMENT FUNCTIONAL PRIORITY</u>.--FIGURE 13 IDENTIFIES THE ELEMENTS USED TO ESTABLISH THE RENDEZVOUS AND DOCKING FUNCTIONAL PRIORITIES. IT IS SEEN THAT THESE PRIORITIES STRONGLY EMPHASIZE PARAMETRIC INVESTIGATIONS OF THE DOCKED CONFIGURATIONS.

<u>EXPERIMENT PROGRAM PLAN</u>.--FIGURE 14 PRESENTS THE PROGRAM PLAN FOR THE RENDEZVOUS AND DOCKING AREA. IT CAN BE SEEN THAT OPTIMUM UTILIZATION OF STUDIES AND MOCK-UPS DEVELOPED IN THE CARGO TRANSFER AREA WAS MADE.

<u>SIMULATION UTILIZATION</u>.--FIGURE 15 PRESENTS THE SIMULATION-MOCK-UP EXPERIMENT MATRIX FOR THE RENDEZVOUS AND DOCKING AREA. IN GENERAL, IT IS PROPOSED THAT THE NEW GENERATION SIMULATORS BE UPDATED, INCLUDING MODIFIED VERSIONS OF THE EXISTING RENDEZVOUS-DOCKING SIMULATORS.

TABLE VII.--RENDEZVOUS-DOCKING AREA COMPOSITE

MODE
.MECHANICAL PRESENTATION OF CARGO MODULE .HARD DOCK THRU CARGO MODULE, CARGO MODULE FORWARD AND ON TOP OF ORBITER .SPACE TUG ACTS AS INTERMEDIATE TRANSFER SYSTEM
RENDEZVOUS
.CATCH-UP TECHNIQUE PRIMARY RENDEZVOUS MODE .OPTICAL-LASER PRIMARY RENDEZVOUS SENSOR .EXTREMELY LOW CLOSURE RATES IN TERMINAL PHASE AND PRE-DOCK PHASE .COOPERATIVE TARGET GENERALLY ASSUMED
DOCKING
.AUTOMATIC HARD DOCKING A REQUIREMENT .MECHANICAL HARD DOCKING SPECIFIED IN CERTAIN CONFIGURATIONS .POTENTIAL INTERFERENCES WHEN SHUTTLE MASS IS GREATER THAN STATION MASS .SHOCK AND MOTION MITIGATION HANDLED BY MECHANICAL CARGO ROTATION SYSTEM .UNIVERSAL DOCKING MECHANISM A DESIGN GOAL (NO APOLLO TYPE)
STUDY/EXPERIMENT REQUIREMENTS
.DOCKING CHARACTERISTIC STUDY-FLEXIBLE VS. HARD DOCK; MANUAL VS. AUTOMATIC .DESIGN STUDY REQUIRED FOR TARGET MODES (COOPERATIVE VS. UNCOOPERATIVE) .6 DOF FIXED-BASE SIMULATOR REQUIRED .MANUAL DOCKING-RENDEZVOUS MODE SIMULATION PARTICULARLY REQUIRED DUE TO VEHICLE SIZE (EYEBALL-DOCKING LINE OFFSETS, ETC.)

RENDEZVOUS-DOCKING FUNCTIONAL PRIORITY

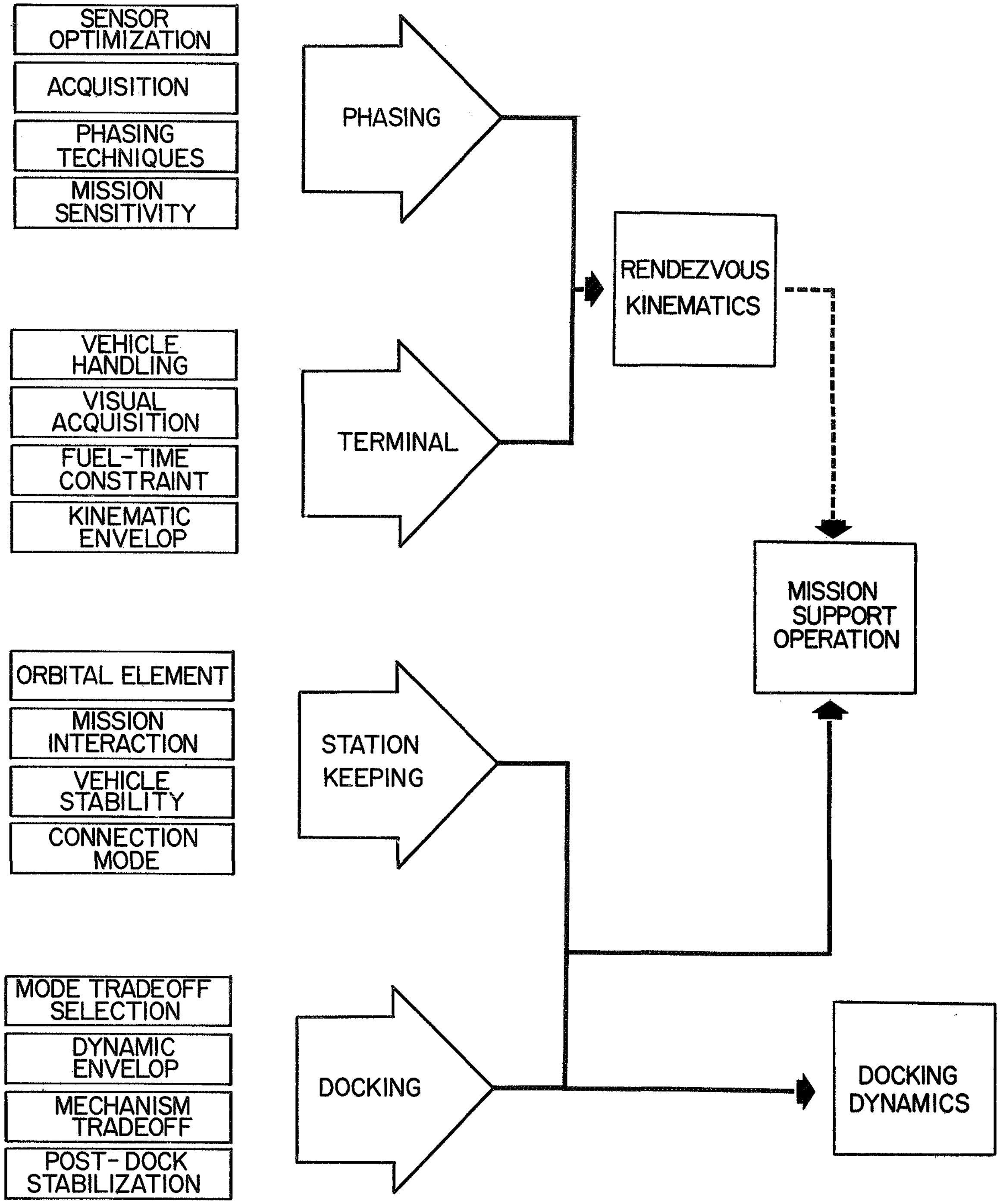
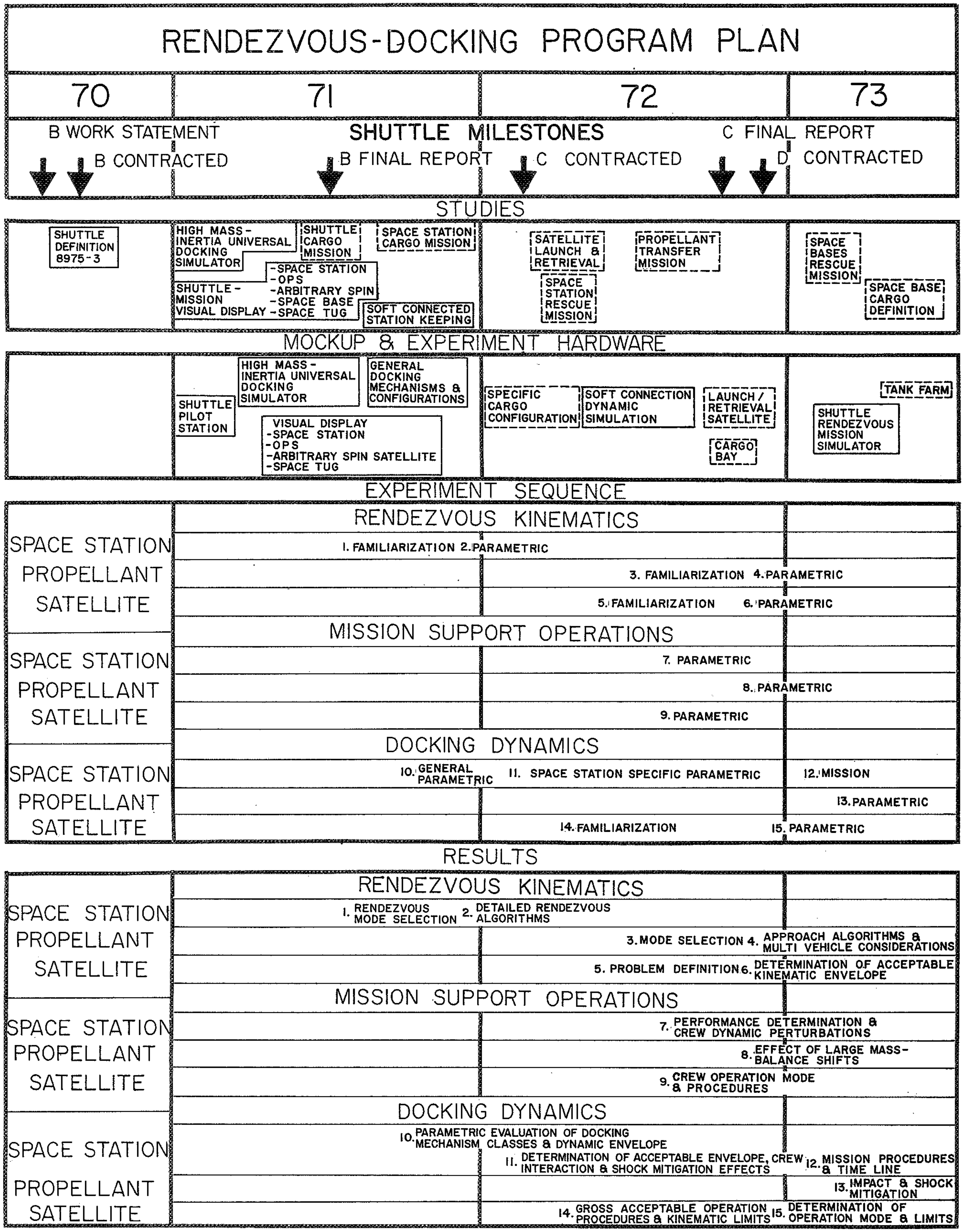


FIGURE 13



----- INDICATES CARRY OVER FROM CARGO/PERSONNEL TRANSFER PROGRAM PLANS

FIGURE 14

RENDEZVOUS-DOCKING SIMULATION UTILIZATION

EXPERIMENTS	MOCK-UP HARDWARE	SIMULATORS: RDS	UNIV. DOCKING DYNAMICS	VISUAL DOCKING	AIRPAD * TELEOPERATOR *
RENDEZVOUS KINEMATICS	PILOT STATION			Ⓧ	
	VISUAL DISPLAYS			Ⓧ	
MISSION SUPPORT OPERATION	PILOT STATION	Ⓧ	Ⓧ		Ⓧ
	VISUAL DISPLAYS	Ⓧ	Ⓧ		Ⓧ
	SOFT CONNECTION DYNAMIC		Ⓧ		Ⓧ
DOCKING DYNAMICS	PILOT STATION	Ⓧ	Ⓧ		
	VISUAL DISPLAYS	Ⓧ	Ⓧ		
	GENERAL DOCKING CONFIGS.	Ⓧ	Ⓧ		Ⓧ
	ARBITRARY SPIN SATELLITE	Ⓧ	Ⓧ		Ⓧ
	CARGO BAY & DETAILS	Ⓧ	Ⓧ		
	TANK FARM	Ⓧ	Ⓧ		

* COMBINED IN REVAMP OF KINEMATIC SIMULATOR

FIGURE 15

EXTRAVEHICULAR ACTIVITY

PERHAPS THE LEAST UNDERSTOOD OF MAN'S CAPABILITIES IN WEIGHTLESSNESS IS THE CAPABILITY TO PERFORM EXTRAVEHICULAR TASKS. MUCH OF THIS LACK OF UNDERSTANDING CAN BE TRACED TO THE GEMINI PROGRAM WHERE THREE OF THE FIVE EXTRAVEHICULAR ACTIVITIES WERE TERMINATED EARLY. EACH OF THESE TERMINATIONS CAN BE TRACED TO A LACK OF ZERO GRAVITY ENGINEERING OR TO A LACK OF PROPER TRAINING FOR THE ASTRONAUT. THE FINAL SUCCESSFUL EXTRAVEHICULAR TASKS PERFORMED IN GEMINI XII PROVED THAT ZERO GRAVITY TASKS CAN BE DESIGNED AND THAT WITH PROPER TRAINING AND SIMULATION A HIGH ORDER OF TASK PERFORMANCE CAN BE EXPECTED. ON THE OTHER HAND, GEMINI XII MADE NO ATTEMPT TO DEFINE THE OVERALL LIMITATIONS AND CAPABILITIES OF EXTRAVEHICULAR HUMAN PERFORMANCE, BUT MERELY DEMONSTRATED TASKS WELL WITHIN THE ASTRONAUT'S CAPABILITY.

ALTHOUGH THERE ARE NOT SPECIFIC EXTRAVEHICULAR TASKS IDENTIFIED IN THE SHUTTLE MISSIONS AT PRESENT, IT HAS BEEN IDENTIFIED IN THE SHUTTLE DOCUMENTS THAT AN EXTRAVEHICULAR CAPABILITY MUST BE AVAILABLE. THEREFORE, EVA HAS BEEN CONSIDERED IN THIS STUDY, BUT NOT WITHIN THE FRAMEWORK OF A PROGRAM PLAN. EVA IS A MODE OF TASK PERFORMANCE RATHER THAN A FUNCTION. IT MUST COMPETE WITH OTHER PERFORMANCE MODES, E.G., TELEOPERATOR OR AUTOMATED DEVICES, FOR TASK ASSIGNMENTS.

THE DEGRADATION OF EXTRAVEHICULAR HUMAN PERFORMANCE IS GENERALLY CAUSED BY THE ENCUMBRANCE OF THE REQUIRED PRESSURE SUIT. TO GAIN AN UNDERSTANDING OF THE MAGNITUDE AND CAUSES OF THIS DEGRADATION, A COMPARISON MUST BE MADE BETWEEN SUITED AND UNSUITED TASK PERFORMANCE. SELECTED HUMAN PERFORMANCE EXPERIMENT SEQUENCES (I.E., FAMILIARIZATION AND PARAMETRIC) IN EACH OF THE PROGRAM PLANS COULD BE PERFORMED BOTH SHIRT SLEEVE AND SUITED-PRESSURIZED. THIS WOULD REQUIRE NO ADDITIONAL MOCK-UPS AND LITTLE ADDITIONAL EXPERIMENT PLANNING. THE EXPERIMENTS WHICH SHOULD BE RUN WITH THIS MULTIMODE TECHNIQUE ARE IDENTIFIED IN THE COMBINED PROGRAM PLAN, FIGURE 16.

ADDITIONAL WORK BEYOND THE SCOPE OF THESE PROGRAM PLANS IS REQUIRED TO UPGRADE EVA KNOWLEDGE. THERE ARE TWO MAJOR REQUIREMENTS FOR SUPPORT OF THE FUTURE DEVELOPMENT OF EVA FOR THE SHUTTLE.

1. A MEANS OF EVALUATING SUBJECT AND SUIT PERFORMANCE.
2. DEVELOPMENT OF A REALISTIC EXTRAVEHICULAR TASK THROUGH WHICH HUMAN PERFORMANCE CAN BE COMPARED TO SEMIAUTOMATED OR AUTOMATED PERFORMANCE.

IT IS RECOMMENDED THAT A STUDY EFFORT BE INITIATED TO THIS END.

THE SHUTTLE MISSION WHICH PROVIDES THE GREATEST POTENTIAL FOR THE DEVELOPMENT OF EVA IS SATELLITE REPAIR/REPLACEMENT. A FURTHER ANALYSIS OF THIS MISSION AND SELECTION OF POTENTIAL SATELLITES AND TASKS WOULD PROVIDE THE FORMAT FOR DETERMINATION OF THE VALUE OF EVA. SHOULD EVA PROVE SUPERIOR TO OTHER MODES OF OPERATION, THE SATELLITE REPAIR/REPLACEMENT MISSION, AS WELL AS THE ENTIRE SHUTTLE PROGRAM, WOULD BE ENHANCED

CONCLUSIONS AND RECOMMENDATIONS

THE SHUTTLE PROGRAM SCHEDULE, AS WELL AS THE VEHICLE CONFIGURATIONS THEMSELVES, IS NOT YET FIRM AND WILL UNDERGO CHANGES PRIOR TO DESIGN FREEZE. MAN-MACHINE INTEGRATION EFFORTS APPEAR TO HAVE A PROFOUND EFFECT ON THE SHUTTLE PROGRAM, AND CAN MATERIALLY AFFECT THE OVERALL COST OF SUCH A PROGRAM. WITHIN THE SPECIFIC AREAS RESEARCHED FOR THIS REPORT, WE HAVE ARRIVED AT THE FOLLOWING CONCLUSIONS:

1. CARGO TRANSFER STUDIES RECOMMENDED IN THIS REPORT MAY HAVE A SIGNIFICANT EFFECT ON THE SHUTTLE PROGRAM.
    - A. DOCKING MODES
    - B. MODULE DESIGN
    - C. MISSION DEFINITION
2. PERSONNEL TRANSFER INVOLVES UNIQUE PROBLEMS NOT INCLUDED IN CARGO TRANSFER, AND REQUIRES ATTENTION AT AN EARLY DATE.
3. RENDEZVOUS-DOCKING STUDIES REQUIRE AN UPDATING OF EXISTING SIMULATORS, AND CAN BENEFIT FROM THE DEVELOPMENT OF NEW SIMULATION TECHNIQUES.
4. EXTRAVEHICULAR ACTIVITY REQUIRES DEFINITION OF TASK REQUIREMENTS BEFORE EVALUATIONS CAN BE MADE.

THE THREE PROGRAM PLANS COVERED IN THIS STUDY HAVE BEEN COMBINED INTO AN OVERALL PROGRAM PLAN, FIGURE 16, COVERING THE CALENDAR YEAR 1971. IT IS RECOMMENDED THAT THIS COMBINED PROGRAM BE IMPLEMENTED.

EACH OF THE THREE AREAS IMMEDIATELY REQUIRE A BALANCED PROGRAM OF STUDY, MOCK-UP AND EXPERIMENT HARDWARE DESIGN AND FABRICATION, AND EXPERIMENTS IN ORDER TO PROVIDE TIMELY DESIGN INPUTS TO THE SHUTTLE PROGRAM. TWO DISTINCT TYPES OF STUDIES ARE REQUIRED--STUDIES ORIENTED TO UPDATING SIMULATOR STATE-OF-THE ART AND DETAILED MISSION-SPECIFIC STUDIES.

COMBINED PROGRAM PLAN - 71

STUDIES

CARGO TRANSFER	VARIABLE MOMENT OF INERTIA	SHUTTLE CARGO MISSION	SPACE STATION CARGO MISSION	SHORT ORBIT CARGO MISSION
PERSONNEL TRANSFER	SHUTTLE PERSONNEL TRANSFER (A)	SHUTTLE EMERGENCY PERSONNEL TRANSFER (B)		
RENDEZVOUS -DOCKING	HIGH MASS-INERTIA UNIVERSAL DOCKING SIMULATOR	SHUTTLE MISSIONS VISUAL DISPLAY REQUIREMENTS		SOFT CONNECTED STATION KEEPING

MOCK-UP & EXPERIMENT HARDWARE

CARGO TRANSFER	CARGO MODULE	SHUTTLE TUNNEL	VARIABLE INERTIA CARGO	CARGO MISSION SIMULATOR
PERSONNEL TRANSFER	CREW COMPARTMENT	PERSONNEL MODULE		
RENDEZVOUS -DOCKING	SHUTTLE PILOT STATION	VISUAL DISPLAYS -SS -OPS -ARBITRARY SPIN SATELLITE -SPACE TUG	HIGH MASS-INERTIA UNIVERSAL DOCKING SIMULATION	GENERALIZED DOCKING MECHANISMS & CONFIGURATIONS

EXPERIMENT SEQUENCE

CARGO TRANSFER	FAMILIARIZATION (SS/MOTION) [FAMILIARIZATION (SS/INTERACTION)]	[PARAMETRIC (SS/MOTION)]	PARAMETRIC (SS/INTERACTION)
PERSONNEL TRANSFER	[FAMILIARIZATION (A/MOTION)]	[FAMILIARIZATION (B/MOTION)]	FAMILIARIZATION (SO/MOTION)
RENDEZVOUS -DOCKING		FAMILIARIZATION (SS/KINEMATICS) GENERAL PARAMETRIC (SS/DOCKING)	PARAMETRIC (SS/KINEMATICS)

[- - -] INDICATES MULTI MODE EXPERIMENTS (COMBINED IVA/EVA)

FIGURE 16

IN THE CARGO TRANSFER PORTION OF THE PROGRAM, THE "VARIABLE MOMENT OF INERTIA" STUDY PROVIDES A MECHANISM WHEREBY CURRENT WATER IMMERSION RESEARCH CAN BE QUANTIFIED AND UPGRADED TO INCLUDE DYNAMICALLY REPRESENTATIVE CARGO. THE LANGLEY RESEARCH CENTER HAS HISTORICALLY BEEN IN THE FOREFRONT OF THE DEVELOPMENT OF SIMULATION TECHNIQUES. THE HYBRID SIMULATOR RECOMMENDED FOR CREW AND CARGO TRANSFER STUDIES IS AN EVOLUTION OF THE WATER IMMERSION TECHNIQUES DEVELOPED BY LANGLEY RESEARCH CENTER DURING THE GEMINI PROGRAM. FURTHER, THIS PORTION OF THE OVERALL PROGRAM PROVIDES CRITICALLY NEEDED INFORMATION TO DETERMINE THE PRACTICAL LIMITS OF MANUAL CARGO HANDLING FOR THE SHUTTLE MISSIONS. WITHOUT THIS DETERMINATION, A SIGNIFICANT PORTION OF THE SPACE SHUTTLE PAYLOAD MUST BE RELEGATED TO NONMANUAL CARGO HANDLING WITH CONCOMITANT EXTENSIVE DEVELOPMENT OF SEMIAUTOMATED HANDLING DEVICES.

THE CARGO TRANSFER AREA IS PARTICULARLY SENSITIVE TO STUDIES AND SIMULATIONS OF MOTION IN WEIGHTLESSNESS, AND IT IS RECOMMENDED THAT AN ORBITAL TEST BE SCHEDULED IN THE SKYLAB PROGRAM FOR VERIFICATION OF SIMULATION DATA.

PARTICULAR EMPHASIS MUST BE PLACED ON MISSION-ORIENTED TASK DEFINITION STUDIES IN THE PERSONNEL TRANSFER AREA BECAUSE OF THE LACK OF SPECIFIC DESIGN CONFIGURATION DETAILS AT PRESENT. THE CARGO TRANSFER AND PERSONNEL TRANSFER PROGRAMS PROVIDE CURRENTLY NEEDED DESIGN INFORMATION DATA ON WHICH TO OPTIMIZE SIZES AND CONFIGURATIONS. EACH OF THE THREE AREAS CAN BE SEEN TO INTERACT IN THE DEVELOPMENT OF INFORMATION. OPTIMIZATION OF CARGO AND PERSONNEL TRANSFER, FROM THE HUMAN FACTORS VIEWPOINT, COULD GREATLY INFLUENCE THE DOCKING TECHNIQUES AND PROCEDURES CHOSEN.

THE RENDEZVOUS-DOCKING AREA WOULD BENEFIT GREATLY BY THE DEVELOPMENT OF THE ANALOG-DIGITAL COMPUTER DISPLAY SIMULATION TECHNIQUES TO PROVIDE NECESSARY TARGET-VEHICLE FLEXIBILITY.

IMPLEMENTATION OF THE PROGRAM PLAN INDICATES THAT THE EXISTING SIMULATORS AT THE LANGLEY RESEARCH CENTER CAN BE FULLY UTILIZED

IN SUPPORT OF THE SHUTTLE PROGRAM. ADDITIONALLY, CONTRACTOR FACILITIES WILL BE REQUIRED IN ORDER TO SUPPORT THE PLANNED SPACE SHUTTLE SCHEDULE.