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VII - Biotechnology

NASA Lewis Research Center
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16. Abstract

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II - Dynamics and Aeroelasticity
(includes dynamic loads and response; aeroelasticity; and flight dynamics and environment)

III - Structures and Materials
(includes structural design technology; thermal protection systems; and materials technology)

IV - Propulsion
(includes main propulsion; auxiliary propulsion; and airbreathing propulsion)

V - Operations, Maintenance, and Safety (Including Cryogenic Systems)
(includes general and cryogenics)

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FOREWORD

The prospect of undertaking a reusable launch vehicle development led the NASA Office of Manned Space Flight (OMSF) to request the Office of Advanced Research and Technology (OART) to organize and direct a program to develop the technology that would aid in selecting the best system alternatives and that would support the ultimate development of an earth-to-orbit shuttle. Such a Space Transportation System Technology Program has been initiated. OART, OMSF, and NASA Flight and Research Centers with the considerable inputs of Department of Defense personnel have generated the program through the efforts of several Technology Working Groups and a Technology Steering Group. Funding and management of the recommended efforts is being accomplished through the normal OART and OMSF line management channels. The work is being done in government laboratories and under contract with industry and universities. Foreign nations have been invited to participate in this work as well. Substantial funding, from both OART and OMSF, was applied during the second half of fiscal year 1970.

The Space Transportation System Technology Symposium held at the NASA Lewis Research Center, Cleveland, Ohio, July 15-17, 1970, was the first public report on that program. The Symposium goals were to consider the technology problems, their status, and the prospective program outlook for the benefit of the industry, government, university, and foreign participants considered to be contributors to the program. In addition, it offered an opportunity to identify the responsible individuals already engaged in the program. The Symposium sessions were intended to confront each presenter with his technical peers as listeners, and this, I believe, was substantially accomplished.

Because of the high interest in the material presented, and also because the people who could edit the output are already deeply involved in other important tasks, we have elected to publish the material essentially as it was presented, utilizing mainly the illustrations used by the presenters along with brief words of explanation. Those who heard the presentations, and those who are technically astute in specialty areas, can probably put this story together again. We hope that more will be gained by compiling the information in this form now than by spending the time and effort to publish a more finished compendium later.

A. O. Tischler
Chairman,
Space Transportation System
Technology Steering Group

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EFFECTS OF "ORBITAL DECONDITIONING" ON CREW/PASSENGER TOLERANCE TO ORBITER REENTRY ACCELERATION

by R. W. Sullivan,* H. C. Vykukal,** K. H. Hyatt,*
R. F. Haines,** and W. R. Vetter*

Abstract

Although previous manned space flight experience has indicated that spacecraft reentry accelerations posed no appreciable physiological or performance problem for the astronauts, the Space Shuttle Orbiter reentries may be of concern, particularly if the Orbiter crew and passengers are seated upright as in conventional aircraft. For this seat orientation, the Orbiter reentry acceleration will result in inertial forces directed from head to foot, rather than the chest-to-back forces typical of previous manned spacecraft reentries. For "orbitally deconditioned" crew and passengers, orbiter reentries may result in impaired cardiovascular system function, even for the relatively low peak accelerations of about 2 to 3 g anticipated during reentry. In this paper, background information on pertinent cardiovascular physiology, results from bedrest studies and from an Ames centrifuge study, and our plans for a more comprehensive study to assess the effects of prolonged bedrest on acceleration tolerance specific to the orbiter reentry are presented and discussed.

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EFFECTS OF "ORBITAL DECONDITIONING" ON CREW/PASSENGER TOLERANCE TO ORBITER REENTRY ACCELERATION

INTRODUCTION

The purpose of this paper will be to examine man's ability to withstand projected Space Shuttle Vehicle "Orbiter" (SSV) reentry acceleration profiles following indefinite periods of habitation in a null gravity environment. This report is confined to the area of cardiovascular tolerance. It will briefly review functional characteristics of the cardiovascular system and its requisites for adequate performance. It will detail the effects of zero G in the production of cardiovascular deconditioning, and review past observations of orthostatic intolerance after true or simulated weightlessness, characterizing anticipated differences in circulatory stresses in the current project design from past manned spacecraft flight. Lastly, we will present an investigational approach to assessing reentry cardiovascular tolerance employing the bed rest analogue of the weightless state and centrifugation. In this endeavor, the results of a pilot study will be presented, as well as a projected detailed study design.

BACKGROUND

The circulatory system may be grossly characterized as a semi-closed conduit reservoir system through which blood is propelled by a reciprocal pump. This reciprocal pump, or the heart, has two control characteristics of a kinetic or centrifugal pump in that volume output is directly related to input pressure, and inversely related to the pressure head against which the pump works. Common with centrifugal pumps the heart can deliver a higher flow as more blood is fed into it. Pump performance is also dependent upon the characteristics of the heart as a muscle, that is, the contractile state of the heart independent of load. In order for the heart to deliver the variable blood flow required by various human needs, an adequate blood volume is needed for "pump priming" or loading. Although this volume is stored throughout the various components of the arterial and venous systems, the bulk of it is stored in the capacitance reservoirs of the venous system. These capacitance reservoirs are capable of great variability in size and must be completely filled at all times in order to maintain adequate return to the input side of the heart. The size of the reservoirs and therefore the volume of their contents is largely dependent upon internal distending pressures. With increased pressures the reservoirs are increased in size and therefore have a higher requirement for fluid to maintain them in a completely filled state. With diminished pressures the reverse is true. Many studies have shown that the volume of fluid contained within the vascular system is dependent upon the mean size of the vascular system. Therefore, factors which tend to increase the size of the vascular system increase the

total blood volume whereas factors which decrease the size of the vascular system decrease the total blood volume.

The vascular system can be simulated as shown in Figure 1 with a distensible mercury-filled bag with a length approximately seven times its width. The internal pressure of the system is maintained by a compressor (the heart). If the pressure exerted by the compressor is maintained constant at all times, then the pressure exerted on the internal wall at any point will be equal to the sum of the filling pressure, the compressor pressure and the pressure exerted by the weight of mercury at that point. The sum of these pressures will be modified by the compliance of the bag. The weight or force exerted by the mercury at any point will be equivalent to the height of mercury over that point. This force is hydrostatic pressure. In the supine or horizontal position, pressure will be equivalent to the width of the column or 12 mm Hg. In the erect or vertical position it will be equivalent to the height of the column or 85 mm Hg. In this situation we are faced with a prime factor which tends to alter the size of this simulated vascular system just as it does the size of the normal vascular system, that is, the effect of gravity. In the vertical position this effect is seven times as great in the horizontal position. In the supine position there is minimal distortion of the bag or of the vascular system. On the other hand, in the erect position or on exposure to a 1 G environment, considerable pressure is exerted on the internal walls of the lower portions of the bag or vascular system. Since the bag as well as the vascular system is quite compliant, this results in great distention. If the volume of mercury in the bag or the volume of blood in the vascular system were to remain constant, the distention of the dependent portion of the bag or the dependent portion of the vascular system would result in underfilling and perhaps collapse of the more superior portion of the bag, that is, the portion toward the compressor end of the bag or toward the heart end of the vascular system. This would result in inadequate filling and inadequate return to the pump or to the heart. Therefore, there would be inadequate output to supply the peripheral needs of the system.

Fortunately, in his adaptation to gravity, man has developed a very finite system of baroreceptors, or pressure sensors, which indicate a need for increased filling of the vascular system. Thus, when increased filling is required, man tends to retain sodium and water; and when the vascular system is over filled, he tends to excrete sodium and water. As noted in the example of the distensible mercury filled bag, when man is placed at bedrest for long periods of time the effect of 1 G along the long axis of the vascular system is reduced to 1/7 of its effect in the upright posture. The vascular compartment is, therefore, smaller and there is relative over filling. This results in excretion of sodium and water with diminished vascular filling, which represents at least one of the factors resulting in

orthostatic intolerance following bedrest. The occurrence of orthostatic intolerance following bedrest has been obvious to physicians for many years. In the past these problems could be avoided by avoiding prolonged bedrest. However, with planned space exploration and long periods of weightlessness which result in effects that are even more profound than bedrest, a renewed interest in the question of orthostatic intolerance was generated. During the past ten years the literature on the effects of weightlessness simulated by bedrest or immersion as well as the effects of true weightlessness induced by bedrest has become extensive. Every study to date has confirmed the occurrence of orthostatic intolerance following either simulated or true weightlessness. Berry[1] has stated "cardiovascular deconditioning as evidenced by diminished orthostatic tolerance has been uniformly reported in the post flight periods of space flights to date." Fortunately, none of the potentially serious complications of orthostatic intolerance have been encountered in either the in-flight or post-flight periods of manned space flight. This has been due primarily to careful advanced planning of reentry following periods of weightlessness. All reentry has been made with EBI or $+G_x$ acceleration. This has avoided any complications during the reentry phase. Following reentry the astronauts have been under continuous medical observation and have not been allowed exposure to unnecessary periods of $+G_z$ acceleration.

Since 1964 the Cardiovascular Research Laboratories at the U.S. Public Health Service Hospital in San Francisco, under the direction of Dr. Kenneth Hyatt,[2-5] have conducted a series of studies aimed at delineating the mechanisms of production of orthostatic intolerance following simulated weightlessness as well as studies aimed at developing methods for preventing these changes. All studies have been conducted under metabolically controlled conditions. The duration of bedrest has varied from ten days to four weeks. Twenty subjects were studied before and after two weeks of bedrest by utilization of cardiac catheterization techniques. Eight subjects were studied before and after two 10 day periods of bedrest during one of which they received 9-alpha-fluorohydrocortisone. An additional 25 subjects have been studied before and after a period of four weeks of bedrest. The latter study was conducted primarily for the purpose of evaluating alterations in the various body fluid compartments during bedrest. The following slides illustrate the results of these studies to date.

RESULTS

Figure 2 shows the problem of greatest concern following weightlessness. This subject tolerated a 20 minute 70° passive tilt prior to bedrest. Following bedrest, syncope occurred in less than 3 minutes with a profound fall in blood pressure and heart rate.

Figure 3 illustrates the hemodynamic changes induced by 70° passive tilt before and after two weeks of bedrest. After bedrest stroke volume fell to a level significantly lower than that seen prior to bedrest. In spite of a significantly higher heart rate, cardiac output could not be maintained at pre-bedrest tilt levels.

Figure 4 shows the hemodynamic response to supine bicycle exercise before and after two weeks of bedrests. Following bedrest there was an inability to augment stroke volume above resting levels, and in spite of a marked increase in heart rate, cardiac output did not reach pre-bedrest levels.

Similar responses to tilt and exercise have been noted after 10 days and after four weeks of bedrest.

Figure 5 shows the alterations in sodium water and aldosterone excretion associated with four weeks of bedrest and re-ambulation. There is a decrease in aldosterone excretion with marked sodium and water diuresis during the initial 48 hours of bedrest. The excretion of sodium and water continue at a lesser but still augmented level throughout bedrest. On re-ambulation a profound reversal of findings is seen in the first 48 hours.

Figure 6 shows the change in body fluid compartments associated with the sodium and water diuresis. Plasma volume and extracellular fluid volume show an early fall and then remain relatively constant. After bedrest volumes are rapidly re-constituted to pre-bedrest levels.

DISCUSSION

Every patient studied to date has shown evidence of orthostatic intolerance following bedrest. In all cases this is manifest by accelerated heart rate following bedrest. In some cases it is manifest by the development of hypotension of a mild to severe degree during post-recumbancy exposure to 1 G_z stress. Although we have attempted to avoid full blown syncope in our studies, pre-syncope or syncope has occurred in 25% of subjects and two cases of brief cardiac standstill have also been noted. The results of our volume studies indicate that the effects of bedrest on volume are of rapid onset and probably reach a near maximal state within 48 hours of assuming the simulated weightlessness condition. Following re-exposure to gravity fluid volume appears to reconstitute itself to pre-bedrest levels within approximately 48 hours. However, plasma volume changes alone may not be the only causes of orthostatic and exercise intolerance seen following periods of weightlessness. In our initial studies after two weeks of bedrest, utilizing cardiac catheterization techniques, it was noted that the subjects were unable to generate an increase in stroke volume during exercise following bedrest. This resulted in cardiac output being maintained only by an accelerated heart rate. Since the exercise was done in a supine position, these changes could not have been on the basis of alteration in venous return to the heart alone. More recent studies

by Saltin[6] have also shown that maximal oxygen uptake is diminished following bedrest. Both of these findings suggest a decrease in myocardial contractility following bedrest. We are currently conducting studies utilizing the apex cardiogram as a measure of ventricular contractility. These studies to date also indicate a decrease in myocardial contractility following bedrest.

Irrespective of the roles of the various factors which may be involved in the phenomenon of cardiovascular deconditioning, it is clear that the occurrence of orthostatic intolerance on exposure to 1 G_z after weightlessness results in a potentially grave risk to the individual. Although these risks have been minimized for the personnel of the Gemini and Apollo projects, the SSV orbiter project would appear to have significantly greater dimensions of risk involved.

Figure 7 depicts space flight operational comparisons between previous manned space flight and current SSV concept design. Firstly, periods of exposure to null gravity environment may be greatly prolonged in this project. Secondly, non-astronauts unfamiliar with high performance aircraft may be passengers. Thirdly, pilot manual control may be required during high G_z reentry maneuvers and during aircraft final approach and touchdown. Last and possibly most important, prior space flight crews have experienced reentry EBI or $+G_x$ acceleration exposure, whereas with SSV reentry a time history of 150-200 seconds of 2.5 G exposure of EBD or $+G_z$ is proposed. Under normal circumstances, pilots conditioned to earth's gravity could withstand these conditions. However, the long duration of weightlessness in orbit coupled with the change from supine seating orientation to proposed upright seating configuration introduces new hemodynamic stresses not previously evaluated.

Miller[7] reported that seven of ten subjects exposed to a modified bedrest regimen showed decreased tolerance to $+G_z$ acceleration. These studies serve to amplify the anticipated hazards regarding tolerance to $+G_z$ or EBD acceleration in space shuttle reentry.

It is imperative to define the magnitude of these potential problems, to determine tolerance of subjects to orbiter reentry acceleration profiles under varying degrees of "orbital deconditioning," and to assess means of maintaining optimum cardiovascular function during SSV reentry.

For this purpose a preliminary study was conducted at the Ames Research Center to obtain some baseline information on human tolerance of orbiter vehicle reentry accelerations. This pilot study had two objectives:

1) To obtain subjective (blackout) tolerance to three levels of $+G_z$ acceleration (2, 3 and 3.5g) under two physiological conditions, normal and hypohydrated (hypohydration appears as one of the effects of prolonged weightlessness).

2) To quantify the peripheral visual detection capability of the human retina and the associated response times for both normal and dehydrated subjects for the two physiological conditions.

Acceleration profiles were chosen to encompass the maximum expected G-time histories of orbiter reentries. Figure 8 shows a typical test sequence and presentation order of the peak accelerations. Each of three male volunteer subjects underwent each of the three G level acceleration runs in a different (random) order. However, each subject was exposed to the same G level in both the normal and the hypohydrated conditions. The Ames' 5 Degree of Freedom Simulator was used to generate the acceleration environments.

The apparatus used to present the peripheral visual detection stimuli is shown in Figure 9. Six, $1/2^{o}$ diameter (35 foot Lamberts luminance) test lights were located 10° arc apart along the horizontal meridian from 40° to 90° arc on each side of the subject's line of sight. The line of sight was held constant by instructing the subject to foveally fixate a small (25 minute arc), diffuse white, luminous cross (11 foot Lamberts luminance). Each peripheral test light was turned on for 0.75 second at random intertrial intervals which ranged from 1.9 to 7.5 seconds (mean = 4 seconds). The presentation order of each test light was also randomized to preclude learning effects.

The subject was told to press a finger button the instant he perceived a peripheral test light. The acceleration run was terminated immediately if the centrally fixated bar pattern disappeared from view (blackout).

This detection task was conducted continuously throughout the day's entire run sequence as shown in Figure 8.

Prior to data runs, each subject was given an indoctrination ride on the centrifuge, being exposed to G series #1, Figure 8. During both the normal, i.e., no body water loss, and hypohydrated runs, the subjects were urged to remain passive, that is, refrain from any muscular activity during the acceleration run.

Hypohydration was achieved by placing the subjects in a heated chamber at 108°F. The subjects were also asked to exercise on an exercycle at about 20 to 25% of maximum output capacity (1/2 hour work followed by 1/2 hour rest period). Water loss was at least 4% of body weight measured prior to entering the chamber. After dehydrating, the subjects were instructed to rest/sleep for two hours prior to the centrifuge run to minimize fatigue and heat effects.

The results of this investigation are summarized in Figure 10. It is apparent that hypohydration reduces one's tolerance to positive acceleration as measured by a foveal blackout criterion. None of the three subjects could continue the task for the full 200 seconds at 3 G and 3.5 G while hypohydrated. Several other conclusions can be drawn from the present data: (1) reaction time tended to lengthen by about 100 milliseconds over each subject's mean reaction time within a period of about 25 seconds prior to blackout; however, subjects differed as to the location within the visual field where this occurred; (2) in every case in which the subject blacked out, he also failed to respond to one or more of the peripherally located test lights presented just prior to blackout; and (3) no statistically significant differences were found between mean reaction times collected under the normal and hypohydrated condition at the majority of the peripheral test light locations.

A more comprehensive study has been proposed by our laboratory and the Ames Research Center to assess the effects of prolonged bedrest on acceleration tolerance. In brief, healthy male volunteers, after thorough medical evaluation and orthostatic testing, will undergo baseline assessment of plasma volume, exercise stress testing with determination of maximum oxygen consumption and external assessment of cardiac contractility by our methods utilizing time from onset of ventricular depolarization to the peak of the first derivative of the apex cardiogram. They will then be centrifuged in the Ames Biosatellite Centrifuge in conformance with proposed SSV orbiter reentry G profiles. Extensive safety systems will be employed during these studies. Subjects will subsequently be placed at complete bedrest for varying periods of time. At completion of bedrest, repeat determinations of the volumes, exercise performance, and contractility will be made. Centrifugation will be repeated and $+G_z$ tolerance will be quantitated in terms of subject's tolerance, electrocardiographic stability, blood pressure, and visual performance. Increasing durations of bedrest will be employed during the study to determine the time required to produce maximal bedrest effects.

In this manner it is hoped that tolerance to $+G_z$ acceleration after progressively prolonged periods of simulated weightlessness can be assessed, and that changes in plasma volume, ventricular performance and exercise capacity may be examined for correlation with acceleration tolerance. Further studies of this nature performed with use of G suits and/or following 48 hours of therapy with 9-alpha-fluorohydrocortisone as a plasma expander are planned.

The impact of these studies on SSV orbiter design is summarized in Figure 11. If bedrest subjects cannot tolerate orbiter reentry acceleration, or if simple management techniques prove ineffective in preserving cardiovascular tolerance, then considerations must include: provisions of articulated seats for crew and/or passengers with attendant penalties in volume weight and crew compartment instrumentation.

*Figures 1 through 6 are presented with the permission of Dr. Kenneth H. Hyatt.

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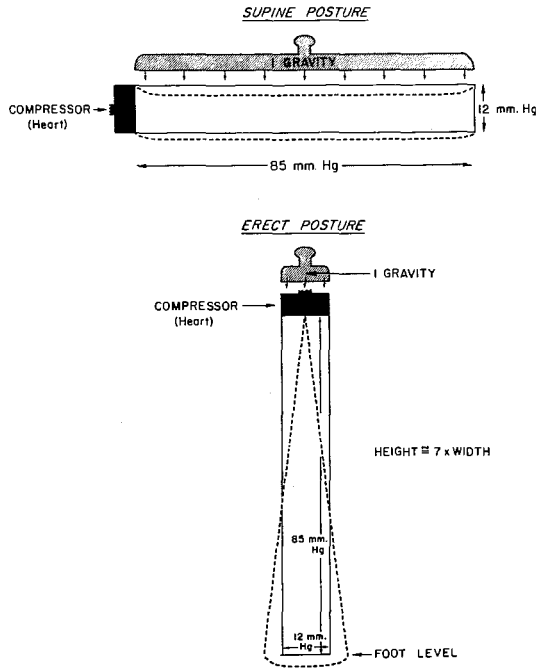

Figure 1. The hydrostatic pressure effect of gravity.*

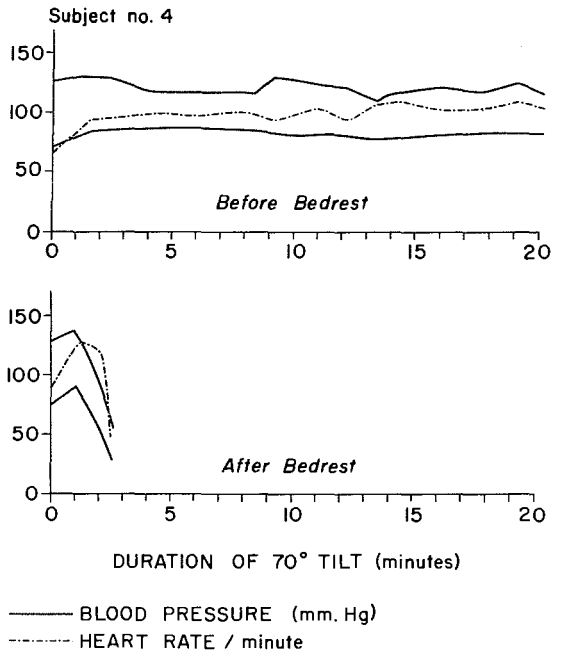

Figure 2. Subject response to 20 minutes of 70° passive foot down tilt before and after two weeks of bedrest.*

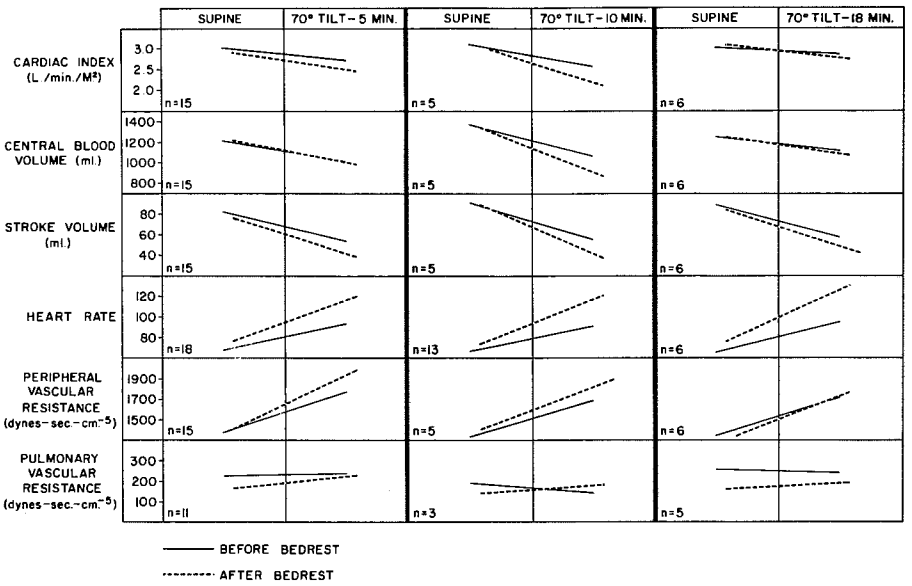

Figure 3. The hemodynamic response to 70° passive foot down tilt before and after two weeks of bedrest.*

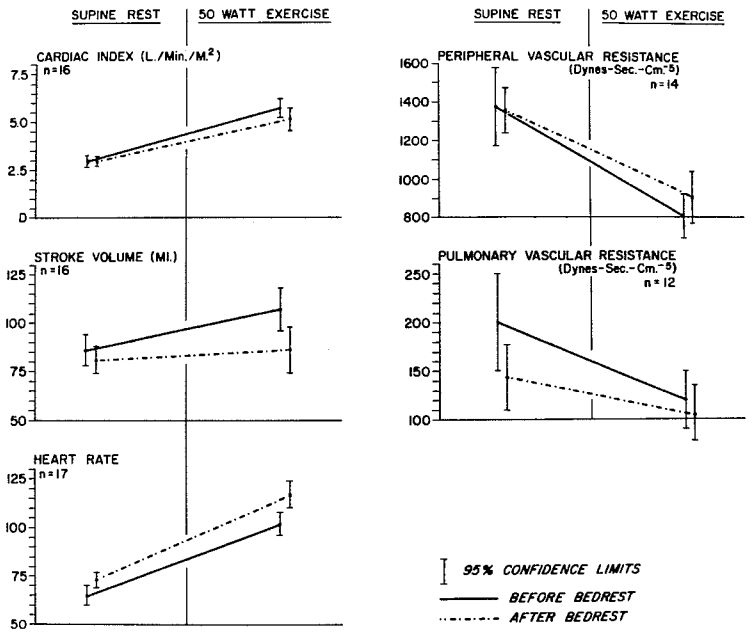

Figure 4. Hemodynamic response to 50 watt supine bicycle exercise before and after bedrest.*

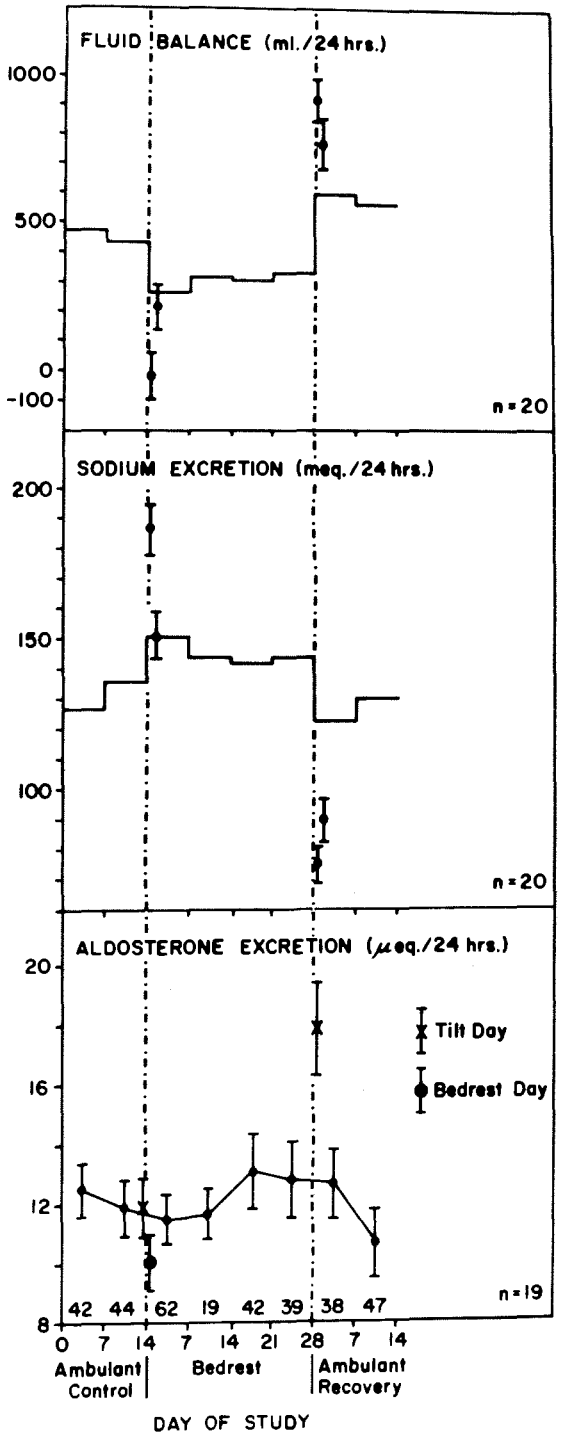

Figure 5. Alterations in sodium water and aldosterone excretion associated with four weeks of bedrest and reambulation.*

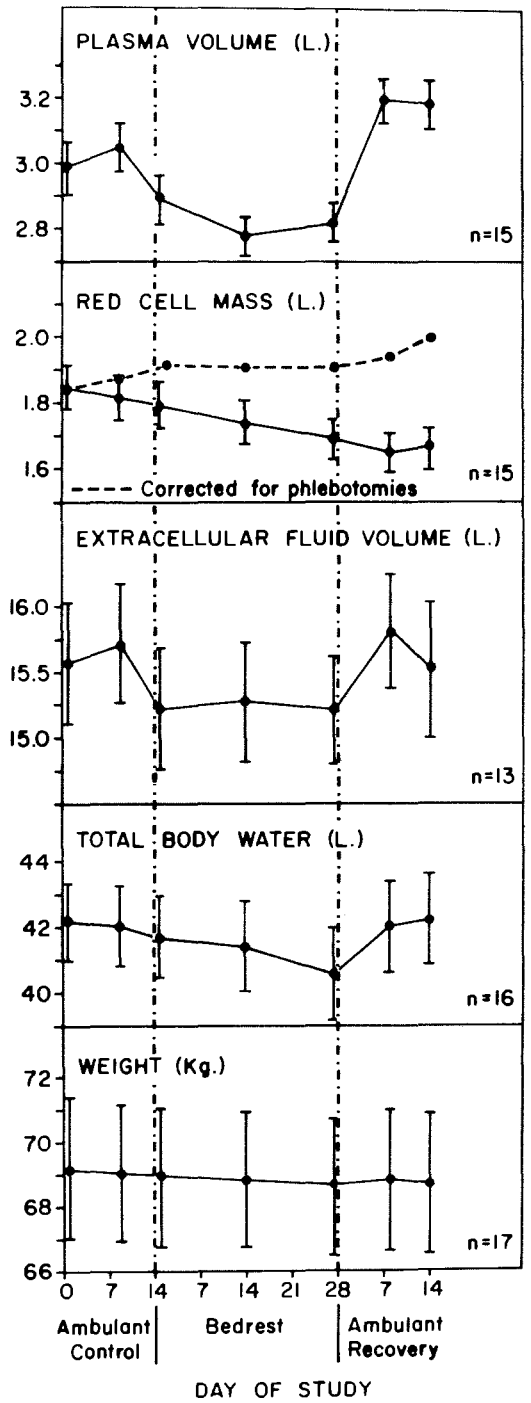

Figure 6. Changes in body fluid compartments associated with sodium and water diuresis.*

	PREVIOUS MANNED SPACEFLIGHT	SSV
SUBJECTS	ASTRONAUTS	ASTRONAUTS & PASSENGERS
TIME IN "0" G	LIMITED	7 MONTHS
REENTRY & LANDING	BALLISTIC/PROGRAMMED	PILOT CONTROLLED
ACCELERATION	$+G_x$ (EBI)	$+G_z$ (EBD)

Figure 7. Space flight operational comparisons between previous manned space flight and SSV in terms of cardiovascular reference.

SERIES NO. 1	2	3	3.5
SERIES NO. 2	3	3.5	2
SERIES NO. 3	3.5	2	3
RATE OF ONSET OF G		I G/15 SEC	

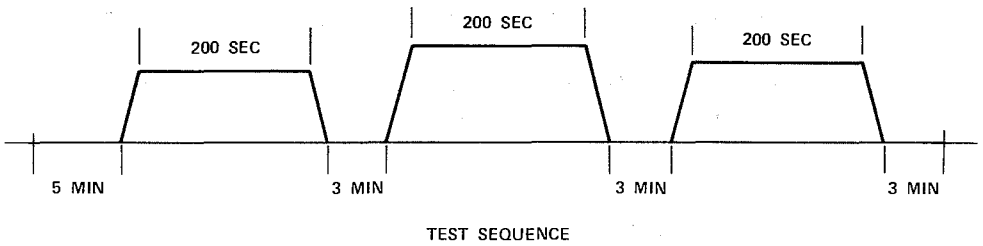

Figure 8. Test sequence and presentation order of G for normal and hypohydrated runs.

Figure 9. Visual test apparatus used in preliminary study.

TIME TO BLACKOUT

	CONDITION					
	NORMAL			HYPOHYDRATION		
	2G	3G	3.5G	2G	3G	3.5G
SUBJECT No. 1	*	*	*	*	153"	1"
SUBJECT No. 2	*	*	197"	*	168"	6"
SUBJECT No. 3	*	142"	134"	*	121"	78"

HYPOHYDRATION—4% + WEIGHT LOSS

*INDICATES COMPLETED 200 sec RUN AT PEAK, NO BLACKOUT

Figure 10. Comparison of time at peak G before blackout for three subjects.

- SHOULD THESE STUDIES INDICATE THAT:
  - "ORBITALLY DECONDITIONED" SUBJECTS CANNOT TOLERATE ORBITER REENTRY ACCELERATIONS.
  - SIMPLE MANAGEMENT MEASURES ARE NOT EFFECTIVE.
- THEN ARTICULATED SEATS WILL HAVE TO BE PROVIDED FOR CREW AND/OR PASSENGERS WITH ATTENDANT PENALITIES IN VOLUME, WEIGHT, AND CREW COMPARTMENT INSTRUMENTATION.

Figure 11. Impact of proposed studies on SSV design.

INTEGRATED LIFE SUPPORT SYSTEMS

FOR THE SPACE SHUTTLE

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INTRODUCTION

The environmental control/life support system (EC/LSS) for the space shuttle poses unique problems because of the multiphased nature of a typical mission; interfaces with space vehicles it will supply, such as a space station; the requirement for rapid turn around refurbishment and reusability; and the variety of cargoes and passengers which must be transported.

An earlier preliminary review of the limited work which had been conducted indicated that while the technology for various components of the EC/LSS was generally at hand, no concentrated or comprehensive design effort apparently had been made to put the components together into a well-designed efficient system. A more detailed survey was therefore made of shuttle EC/LS work accomplished as part of and in conjunction with the ILRV studies and independently by private industry. In addition, some limited design studies were conducted at the Langley Research Center. This paper presents an overview of the results of this activity, discusses various approaches proposed for accomplishing some of the EC/LS functions, and indicates areas of concern.

The paper also presents Langley plans for studies which will examine some of these areas of concern, provide independent assessments of the problems, and provide guidance for solutions which will be implemented with hardware investigations where necessary. Such studies are also

intended to provide guidance to and complement the Shuttle Phase B contractor efforts in areas where increased emphasis may be needed.

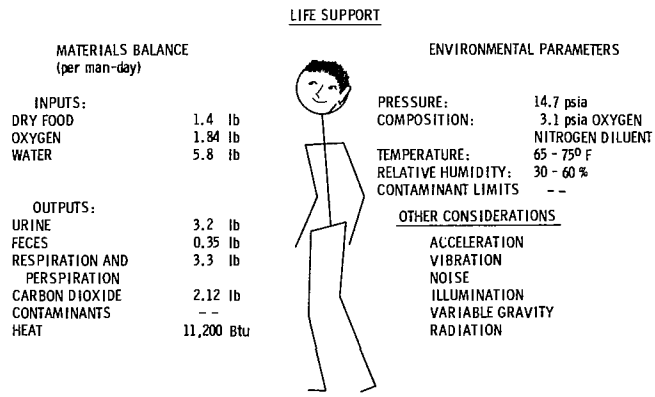
The shuttle flight system consists of a launch vehicle and an orbiting vehicle. The launch vehicle, whether manned or unmanned, will probably have a flight time of less than two hours and remain essentially within the atmosphere. The EC/LSS for this vehicle, therefore, can largely be based on well-developed aircraft technology, and no problems are anticipated. However, commonality of parts, instrumentation, and techniques between launch vehicle and orbiter would be a desirable design goal. On this basis, this paper will consider primarily the environmental control/life support system for the orbiter vehicle.

LIFE SUPPORT (FIG. 1)

For each day of a space mission a person will require the amounts of food, oxygen, and water indicated and in turn will produce the waste products, contaminants, and heat as shown. The EC/LSS must provide these inputs and dispose of the outputs and in addition dispose of heat generated by electronic and mechanical equipment operating at a power level of perhaps 7 or 8 kilowatts.

Many kinds of chemical and biological contaminants will be introduced into the shuttle orbiter by the varied cargo payloads proposed as well as by the crew and passengers, and a very efficient contaminant sensing and control system will be required.

A shirt-sleeve atmosphere having a total pressure of 14.7 psia is assumed in order to be compatible with proposed space station characteristics. While nominal comfort ranges of cabin temperature and relative humidity are shown, it is recognized, for example, that higher temperatures could be tolerated by the passengers and crew for the short reentry period. Radiation will probably be of concern only for very high altitude or inclination orbits.



PERTINENT MISSION CHARACTERISTICS (FIG. 2)

Listed are unique shuttle mission characteristics which impact design of the life support system.

While a reference mission of 7 days has been defined, missions lasting from 3 to 30 days or longer are also under consideration. Mission duration can influence subsystem selection. For example, for 7 days lithium hydroxide would provide the lowest weight carbon dioxide removal technique, while for 30 days or longer a regenerable molecular sieve would be lighter.

Variations in environmental conditions for the various phases of a mission require different approaches to the problem of heat rejection and temperature control.

In addition to astronaut crews, the orbiter may carry men and women passengers who have not had the training or possess the physical capabilities of astronauts. Cargoes may vary from fuels to animals for experiments to food supplies to delicate instruments. All these must be considered in the design of subsystems for waste management, personal hygiene, and contaminant control.

Vehicle reusability implies design for refurbishment, quick turnaround, reliability, fault isolation, and automatic checkout. EC/LSS and personal accommodations will be required for airlocks and access tunnels to allow personnel and cargo transfer to and from a space station, for example.

PERTINENT MISSION CHARACTERISTICS

VARIABLE MISSION DURATION

MULTI-PHASE OPERATION
- ASCENT
- ORBITAL
- REENTRY
- FERRY

VEHICLE REUSABILITY

PAYLOAD VARIABILITY
- CREW
- NON-ASTRONAUT PASSENGERS
- CARGO VARIETY

PERSONNEL-CARGO TRANSFER

TYPICAL EC/LS SUBSYSTEM SELECTIONS (FIG. 3, 4, 5)

A review has been made of the life support portions of the ILRV studies and related independent work pertinent to the shuttle orbiter EC/LSS. In nearly all cases only the crew compartment was considered and the cargo module was largely ignored. The variation in subsystems or techniques selected by the various studies for some of the life support functions is indicated.

Atmosphere Storage and Composition Control - Fig. 3: For atmosphere storage, oxygen as a supercritical cryogen seems to be the unanimous choice for the common supply of metabolic and fuel cell requirements. Diluent nitrogen for the atmosphere was either stored as a supercritical cryogen or as a high pressure gas.

The selected atmosphere and composition control methods can be categorized as being either independent or non-independent. The independent control method supplies oxygen and nitrogen, independent of each other, to maintain respective partial pressures as measured by a mass spectrometer. This is the method presently being used in the NASA-industry 90-Day Manned Test of a regenerative life support system. The non-independent control method supplies oxygen to maintain the desired partial pressure as measured by a polarographic sensor, and then adds nitrogen to maintain the atmosphere total pressure which is measured by either a sensor or regulator. With this latter method, in one instance, it has been proposed that the diluent be supplied mixed with oxygen.

TYPICAL EC/LS SUBSYSTEM SELECTIONS

CARBON DIOXIDE CONTROL:
- LiOH
- MOLECULAR SIEVE

CONTAMINANT CONTROL:
- ACTIVATED CHARCOAL
- ACTIVATED CHARCOAL, CATALYTIC OXIDIZER WITH PRE AND POST SORBENTS

WASTE MANAGEMENT:
- BAG COLLECTION, BACTERICIDE TREATMENT, STORAGE
- BAG COLLECTION, VACUUM DRYING, STORAGE
- BOWL COLLECTION, VACUUM DRYING, STORAGE
- BOWL COLLECTION, ANAL WASH AND VACUUM DRYING, STORAGE

TYPICAL EC/LS SUBSYSTEM SELECTIONS

ORBITAL TEMP. AND R.H. CONTROL:
- CONDENSING Hx
- CONDENSING Hx, NON-CONDENSING Hx
  - COOLANT BYPASS
  - VARIABLE SPEED FAN
  - AIR BYPASS

REENTRY THERMAL CONTROL:
- WATER BOILER
- AMMONIA BOILER
- TURBOJET FUEL

ATMOS. CRUISE THERMAL CONTROL:
- RAM AIR (COOLANT Hx AND CABIN VENTILATION)
- AIR CYCLE REFRIGERATION
- TURBOJET FUEL

Thermal and Humidity Control - Fig. 4: Methods of thermal control proposed for the various mission phases of the shuttle orbiter were as varied as the number of studies examined. In some cases selected methods of one study were rejected by others.

Heat rejection during the orbital phase was recommended to be by a space radiator supplemented by either water sublimation, evaporation, or boiling during periods of peak heat loads. Thermal control of electronic equipment was with cold plates. Crew compartment atmosphere temperature and relative humidity control is accomplished either with a single condensing heat exchanger or with two heat exchangers, one of which is condensing. The relative humidity control method was either unspecified or is with fixed flows in the condensing heat exchanger which results in a variation. A number of cabin atmosphere temperature control methods were selected including coolant bypass, a variable speed fan, and air bypass. Both one and two heat transport fluid systems were also proposed. The concensus seemed to be the two fluid system with water selected as the heat transport fluid within the vehicle and another fluid, possibly Freon or glycol/water, for the radiator.

During the approximately 40-minute reentry phase, heat rejection methods selected were water boiling, ammonia boiling, and the use of the turbojet fuel as a heat sink. Uncertainty was noted, however, regarding the use of the turbojet fuel, and if used, the requirement for precooling prior to launch. It was also recommended that the heat sink capacity of onboard cryogenics such as oxygen, nitrogen, and hydrogen be investigated.

During subsonic cruise flight or during ferry flights, heat rejection was generally accomplished with cooling of the cabin coolant fluid either directly with ram air or indirectly with ram air in an air cycle refrigeration system using jet engine compressor bleed air. With either method cabin ventilation was a possibility. The heat sink capacity of the turbojet fuel was also a candidate.

Carbon Dioxide-Contaminant Control and Waste Management - Fig. 5: The selected method of carbon dioxide control was mission-length dependent with Lithium hydroxide being favored for shorter missions and regenerative molecular sieves for the longer missions. Weight tradeoffs typically show a crossover point at about 15 days although weight alone cannot be the sole judgement criteria for subsystem selection.

The contaminant control technique depends on the assumed mission length, contaminant generation rates (number and kinds of passengers and cargo) vehicle leakage, and permissable contaminant levels. Consequently, the selected methods ranged from minimum provisions of charcoal sorption to maximum provisions of charcoal sorption and catalytic oxidation with pre and post sorption. Vehicle cleanliness and contaminant control design criteria for the shuttle remain to be defined. Factors which must be weighed in these decisions are the desirability of aircraft-like operations, mission and payload variability, and interfaces with space station/bases. Appropriate contaminant sensing equipment must also be developed.

Waste techniques were again as varied as the number of studies examined. Methods involving bag collection of fecal and other solid wastes and either bactericide treatment or vacuum drying with subsequent storage were proposed. With this method the desire to eliminate the manual handling of fecal wastes was indicated. Other selected concepts involved collection, vacuum drying with or without anal wash, and storage all in a single container. In one concept feces and urine were collected together, and transferred to a separate container for vacuum drying and storage. In other concepts, urine and other liquid wastes were collected separately and dumped overboard through a heated vent. The possibility of mixed, non-astronaut like passengers

poses special waste management problems which have yet to be considered.

For the anticipated shuttle missions water recovery will not be required since more than enough potable water will be produced by the fuel cell power system (about 20 pounds per kilowatt-day). Any excess fuel cell water as well as humidity condensate could be used for thermal control purposes. Should water recovery be required a simple recovery process like multi-filtration would be recommended.

This review of EC/LS work accomplished in the various shuttle studies indicates general agreement that EC/LS technology exists, but disagreement in the application of that technology in that life support systems with different components are proposed. These differences are due in part to the varied depth of the analyses which in some cases were mere gross assessments and in others component selection on the basis of incomplete trade-off criteria. EC/LS system weight estimates varied widely and were difficult to assess because of varied or undefined crew and passenger loading, mission duration, power weight penalties, and reliability considerations.

TYPICAL EC/LS SUBSYSTEM SELECTIONS

ATMOSPHERE STORAGE:
- OXYGEN
  - SUPERCRITICAL
- NITROGEN
  - SUPERCRITICAL
  - HIGH PRESSURE

ATMOSPHERE PRESSURE AND COMPOSITION CONTROL:
- INDEPENDENT $O_2 - N_2$ CONTROL
  - pO_2, pN_2 BY MASS SPEC.
- NON-INDEPENDENT $O_2 - N_2$ CONTROL
  pO_2 BY POLAROGRAPHIC SENSOR
  - O_2/N_2 BY P_T SENSOR
  - N_2 BY P_T SENSOR
  - N_2 BY P_T REGULATOR

EC/LS AREAS OF CONCERN (FIG. 6)

A comparison of shuttle mission EC/LS requirements and technology available, and an examination of systems proposed by the ILRV studies and others indicate several areas of concern.

A design philosophy for the orbiter has not been crystallized. EC/LS for the cargo module has been ignored. The design philosophy could vary from using a separate EC/LSS for the orbiter crew compartment and a separate one for each cargo or passenger module, to one which could accommodate the entire vehicle for any mission.

Matching an open cycle shuttle subsystem to a regenerative space station system, controlling atmospheric pressure and handling wastes when the vehicles are coupled, and shutting down and restarting shuttle subsystems are possible shuttle/space station interface problems.

Various combinations of radiators, liquid boiling, liquid fuel heat sinks, ram air, refrigeration, and ground equipment must be coordinated into a thermal management system to cover the mission phases from ascent to reentry and atmospheric cruise back to base.

Contaminant control, waste management, and personal hygiene require emphasis because of passenger and cargo variety and the goal of relaxing current spacecraft cleanliness standards to airline practice.

The requirement for orbit storage and restart of subsystems will necessitate some thought to special equipment, instrumentation, and operating techniques to insure reliability. Again, automatic onboard system checkout will require attention to instrumentation, techniques, and integration with the electronics systems.

Refurbishment, reliability, and maintainability must involve early consideration in the design process of equipment redundancy, packaging, and location as well as new concepts of fault isolation and automatic checkout and operation of EC/LSS components. Equipment commonality between vehicles or cargo modules in the shuttle system as well as between shuttle orbiter and space station would be desirable.

The shuttle system is extremely weight critical, and every subsystem must be designed for weight minimization recognizing tradeoffs with reliability and reusability.

Manned space vehicles to date as well as ground life support system simulator cabins have had objectionably high noise levels. Noise abatement measures such as attention to aerodynamic design of blowers, equipment isolation, and use of acoustical insulation must be considered and weighed against the weight penalties.

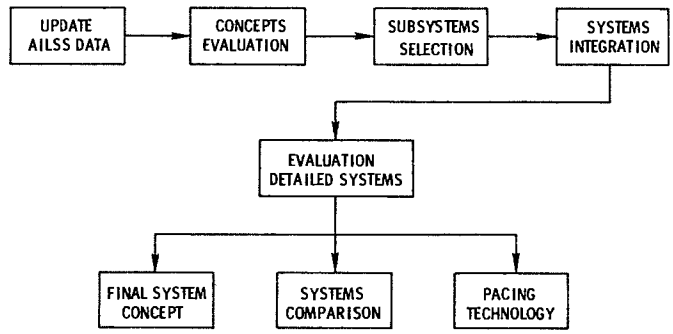
EC/LS AREAS OF CONCERN

- DESIGN PHILOSOPHY FOR MULTI-MISSION USE
- SPACE SHUTTLE/SPACE STATION INTERFACES
- TEMPERATURE CONTROL
- CONTAMINANT DETECTION AND CONTROL
- WASTE MANAGEMENT AND PERSONAL HYGIENE
- ORBIT STORAGE AND RESTART
- AUTOMATIC CHECKOUT, GROUND AND ORBIT
- QUICK TURNAROUND REFURBISHMENT
- RELIABILITY - MAINTAINABILITY
- WEIGHT MINIMIZATION
- NOISE LEVELS

EC/LS SYSTEMS STUDY (FIG. 7)

Attention to the areas of concern early in the shuttle program may keep some of them from becoming real problems later on. The Langley Research Center has therefore initiated a three-element program to assist is certain of these categories.

The EC/LS Systems Study is a contractor effort to evaluate, select, and integrate subsystems into an integrated shuttle orbiter life support system. The study will be independent of but complementary to the Shuttle Phase B studies and will be conducted by a life support system specialist contractor. Full advantage will be taken of the very comprehensive Advanced Integrated Life Support System Study recently completed for Langley by the same contractor.



EC/LS CRITICAL PROBLEMS STUDY (FIG. 8)

A contractor study is planned for a special emphasis analysis and conceptual design effort on four of the more critical areas of concern. This effort will be conducted by an independent life support contractor not associated with the Phase B studies, and should allow a concentration on the problems not otherwise possible.

As with the Systems Study, it is anticipated that results of this effort will provide significant guidance and assistance to the EC/LS portions of the Phase B studies as well as identify pacing technology to assist in guiding R and D activities by NASA and others.

CARGO MODULE CONCEPTS
- ALL-PURPOSE
- CUSTOMIZED
- ADD-ON

SPACE SHUTTLE/SPACE STATION INTERFACES
- ATMOSPHERIC CONTROL
- WASTE MANAGEMENT
- SUBSYSTEM DEACTIVIZATION

THERMAL CONTROL DURING AIRCRAFT OPERATIONS
- ON-BOARD HEAT SINKS
- GROUND EQUIPMENT

REUSABILITY AND QUICK TURNAROUND
- MODULE PACKAGING
- CHECKOUT CONCEPTS

SHUTTLE CONTAMINANT PROGRAM (FIG. 9)

This part of the program is already underway in that contaminant sensing and control systems are being researched and developed for space station application, and the results are also largely applicable to the shuttle orbiter. Included are flight-type mass spectrometers for sensing, and catalytic oxidizers with pre and post sorbers and regenerable charcoal sorbers for control.

Langley is cooperating with MSC and MSFC in developing a flight mass spectrometer for sensing oxygen, nitrogen, carbon dioxide, and water vapor. The ability to sense hydrogen and total organics is now being added to the instrument, and plans are to also add carbon monoxide and methane.

A. ADAPT SPACE STATION CONTAMINANT ANALYSIS AND CONTROL TECHNOLOGY

B. EXTEND MINIATURIZED MASS SPECTROMETER

O_2 N_2 CO_2 H_2O	ADDING	H_2 TOT. ORGAN.	ADD	CO CH_4

NOTE: MSC AND MSFC FLIGHT CONFIGURATION SUPPORTED BY NAS1-9469.

CONCLUDING REMARKS

A survey of environmental control/life support system studies conducted to date relative to the space shuttle indicates the following:

1. Technology exists for the design of components to accomplish life support functions for the shuttle orbiter, but there is no agreement on how to assemble components into an integrated system.

2. Only the crew compartment of the orbiter has been considered. The influence of passengers and the cargo compartment must be factored into EC/LS design.

3. Other major areas of concern appear to be thermal control, problems associated with reusability, and interfaces with the space station.

4. Langley has initiated a program covering an EC/LS Systems Study, a Critical Problems Study, and Contaminant Analysis and Control Hardware which will provide independent assessments of problems and solutions as well as complement the Phase B contractor efforts.

AIRCRAFT FLIGHT DISPLAY/CONTROL INFORMATION RESULTS AND THEIR RELEVANCE TO SHUTTLE APPLICATION

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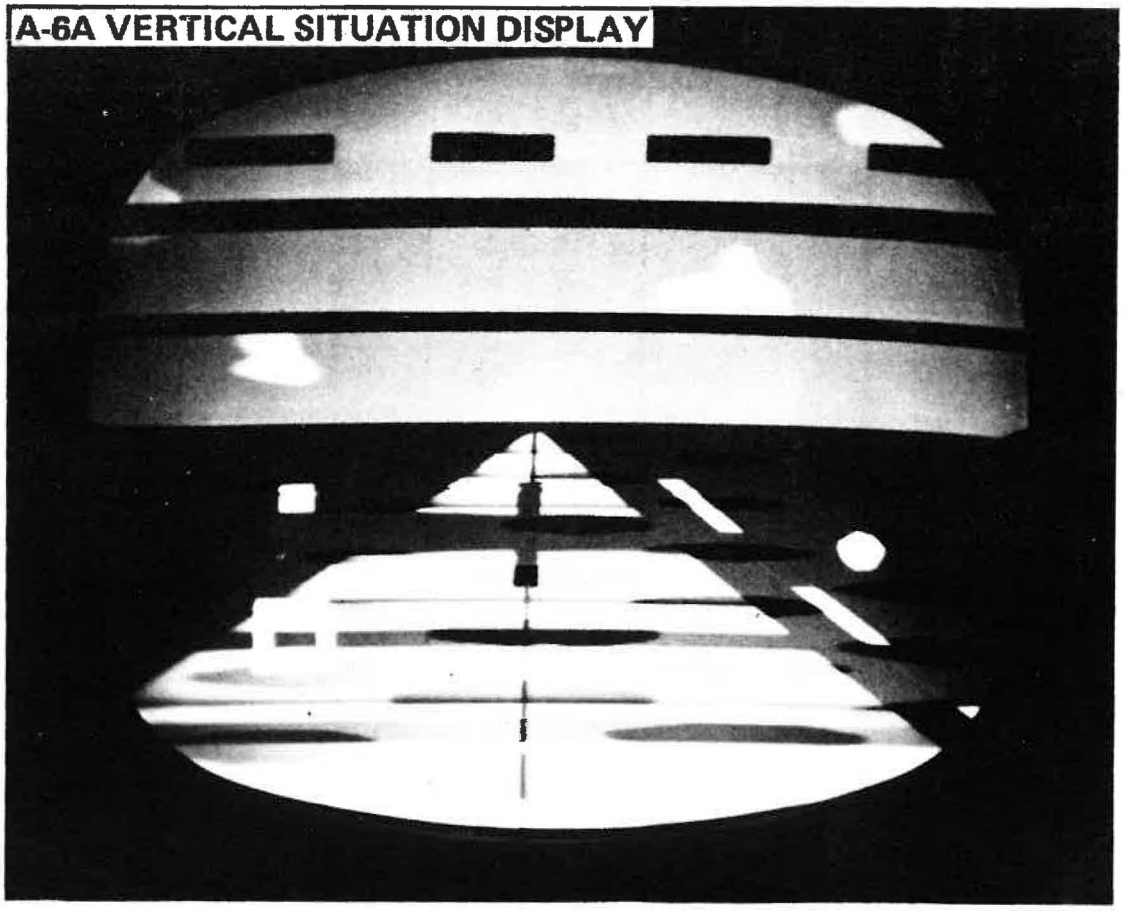
Introduction

The Space Shuttle System Statement of Work asserts that redundant, multipurpose, computer-operated displays be considered for providing both flight path and system status information. It is to this requirement, which is heavily laden with human factors implications, that this paper addresses itself. The objective of this presentation is to briefly summarize some of the more pertinent results derived from more than 12 years of Grumman design and development experience in computer-driven integrated displays, and highlighting those findings which are applicable to shuttle design.

This slide is an actual photograph of the first display unit delivered in 1960 and represents all of the symbology in the test mode.

Pilot comments gathered during A-6 flight tests and early operational use by fleet pilots indicated that the display was overly cluttered with unnecessary pictorial information and that the simultaneous motion of displayed symbology was distracting and served to degrade the piloting task. In addition, they felt the need for more quantitative information to be presented on the display. The valuable experience gained on the A-6 vertical display system led to the refinements and improvements which were incorporated into the development of Grumman's F-111B display concept.

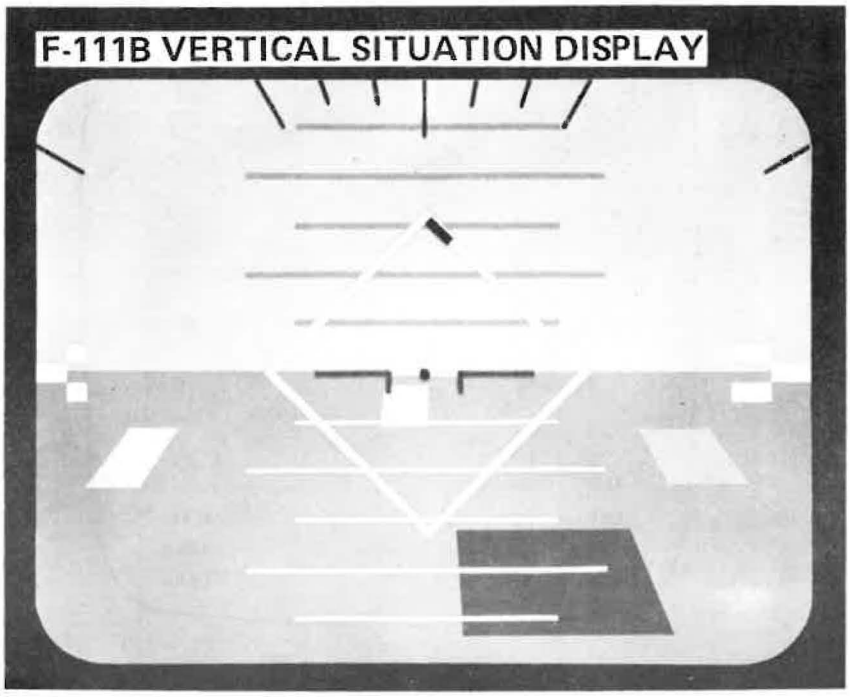


The F-111B vertical situation display retained only those pictorial features which provide the pilot with the information he needs. Pictorial realism was traded off in the interest of creating geometric symbology which convey the real-world situation in quantitative as well as qualitative terms.

The symbols implemented for the F-111B which appear to hold some promise for application to shuttle design are:

- The diamond-shaped time symbol, used for Phoenix missile delivery, which represents a clock with the dark segment acting as a second hand. The indicator ticks off counterclockwise, the time remaining until the aircraft is in target range for weapon delivery. At the 12 o'clock position, t = o. This symbology could be applied to shuttle use for indicating time remaining to rendezvous and docking, or time-to-go to touchdown.

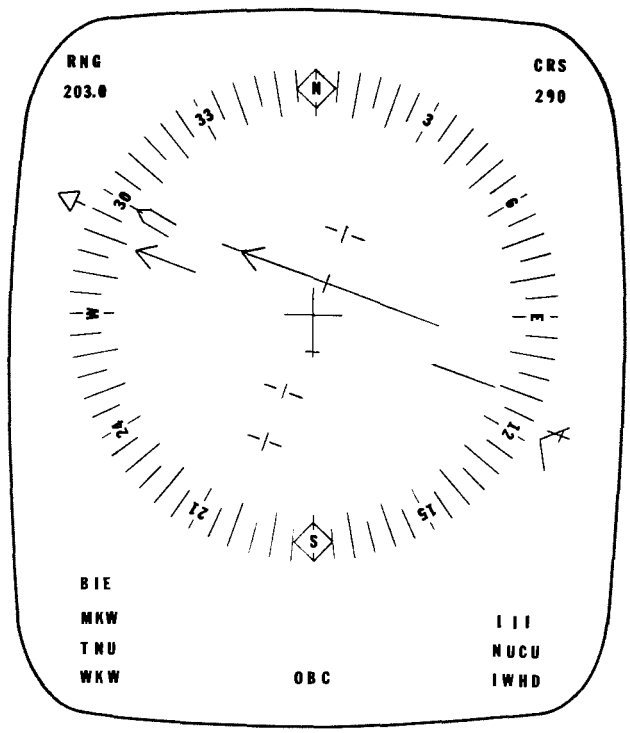
- The breakaway symbol, not shown in this slide, is a cross that flashes at the rate of 2 cycles per second and is used in the F-111 attack mode to signal the completion of all weapon delivery requirements. This same attention-getting indication could be integrated into shuttle display design to signify waveoff during landing, should there be a shuttle go-around capability.



The F-14A horizontal situation display has the following characteristics which are relevant to shuttle application:

- Centrally locates all functions and modes for the crew and enhances redundancy of almost all functions in the case of instrument failure
- Provides increased mission capability through its mutlipurpose presentation with alphanumeric implementation
- Provides a limited onboard checkout capability in that up to three individual failures plus multiple failures can be electronically displayed
- Provides postflight immediate recall and display of failures that occurred inflight, thereby facilitating ground maintenance operations
- Electronically generates a compass rose presentation

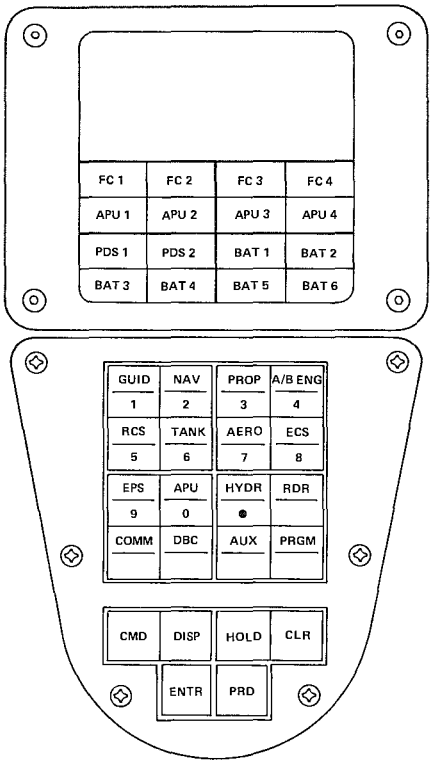
F-14A HORIZONTAL SITUATION DISPLAY



This slide presents an adaptation of Grumman's E-2C auxilliary display unit for potential use in the shuttle for system status monitoring and checkout. Its relevance to shuttle application is as follows:

- A multitude of vehicle parameters (maximum of 4096) are available for display
- Although only a few of these parameters would be displayed to the crew at any given time, the amount of panel space saved by eliminating dedicated instruments is significant
- Does not require the crew to memorize entry codes or use a checklist for data retrieval
- Eliminates the need for elaborate maintenance manuals since the upper portion of the display can be used to generate instructions for handling malfunctions

POTENTIAL DATA ENTRY/DISPLAY KEYBOARD FOR SSV



Conclusions & Recommendations

Grumman's integrated display design for the shuttle will make use of over 12 years of experience in developing multipurpose, computer-operated displays.

Problems encountered by Grumman on past programs which have to be resolved for shuttle application are:

- Information density and display clutter
- Crew task loading in interpreting displayed information
- Pictorial vs geometric vs quantitative means of presentation
- Display size and resolution
- Display brightness and contrast requirements
- Display motion dynamics
- Symbol clarity
- Data entry techniques

PACING CREW SYSTEMS TECHNOLOGY OBJECTIVES FOR SSV DEVELOPMENT

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Space Division
North American Rockwell Corporation

INTRODUCTION

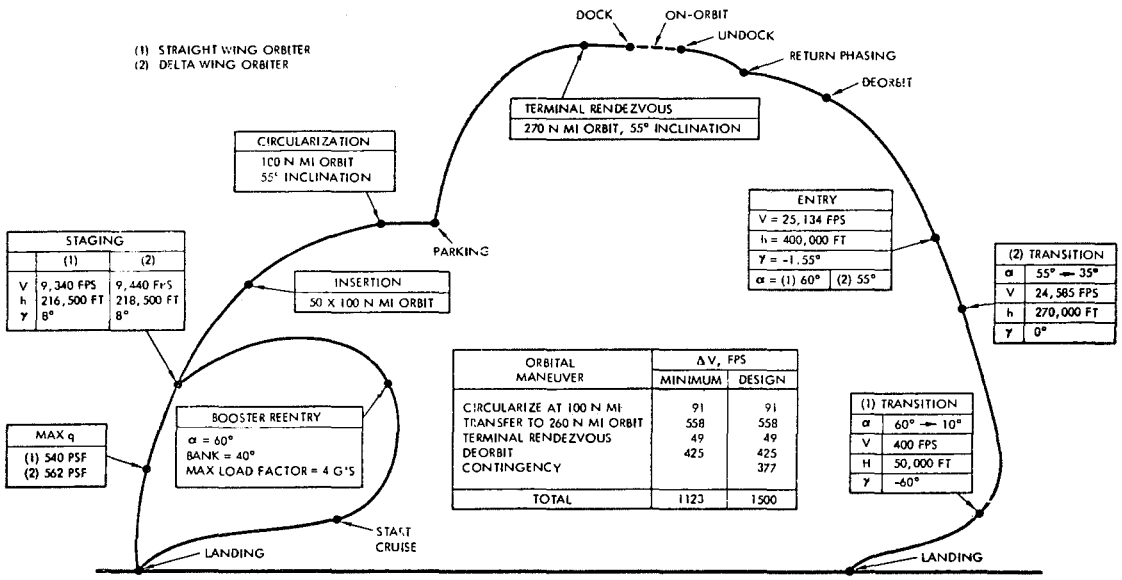
THE OVERALL SPACE SHUTTLE VEHICLE (SSV) MISSION AND SYSTEMS DEVELOPMENT DIRECTS ATTENTION TO CHALLENGING CREW SYSTEMS ENGINEERING PROBLEMS AND DICTATES IDENTIFICATION OF PACING CREW SYSTEMS TECHNOLOGY OBJECTIVES INFLUENCING SSV CONFIGURATION AND SUBSYSTEMS DESIGN. EARLY AND EFFECTIVE ATTAINMENT OF THESE OBJECTIVES WILL INSURE COMPREHENSIVE CREW-SUBSYSTEM INTEGRATION AND ENHANCE CREW OPERATIONS AND MISSION SAFETY. THE SSV FLIGHT CREW SYSTEM IS DEFINED AS THE FLIGHT CONTROL CREW/PASSENGER PAYLOAD AND SUPPORT SYSTEMS REQUIRED FOR ON-BOARD MISSION CONTROL, CREW PERFORMANCE, COMFORT, AND SURVIVAL.

PRIME CONTRACTORS MUST BE AWARE OF IMPLICATIONS WHICH DIRECTLY INFLUENCE CONFIGURATION. THEREFORE, IDENTIFICATIONS AND DESCRIPTIONS OF CREW SYSTEMS TECHNOLOGY AREAS WHICH COULD PACE CONFIGURATION DEFINITION AND SUBSYSTEM ELEMENTS ARE EXAMINED IN THIS PRESENTATION. FOR THE PURPOSES OF THIS PRESENTATION, PACING TECHNOLOGY AREAS ARE DEFINED AS CREW OR PASSENGER NEEDS WHICH REQUIRE ANALYTIC AND/OR EMPIRICAL PROCESSES FOR RESOLUTION CONCOMITANT WITH SSV CONFIGURATION AND SUBSYSTEM STUDIES AND PRELIMINARY DESIGN DEFINITION.

MISSION PROFILE

MISSION HIGHLIGHTS REQUIRING CREW MONITORING AND CONTROL ARE INDICATED. OF SIGNIFICANT IMPORTANCE ARE BOOST AND ENTRY ACCELERATIONS AND CORRESPONDING DIVERSE ANGLES OF ATTACK. A BASIC GROUND RULE WHICH APPEARS TO BE EMERGING FROM CONTINUING ANALYSES IS THE CONSISTENT REQUIREMENT FOR CREW ACTIVE VEHICLE CONTROL THROUGHOUT ALL MISSION PHASES.

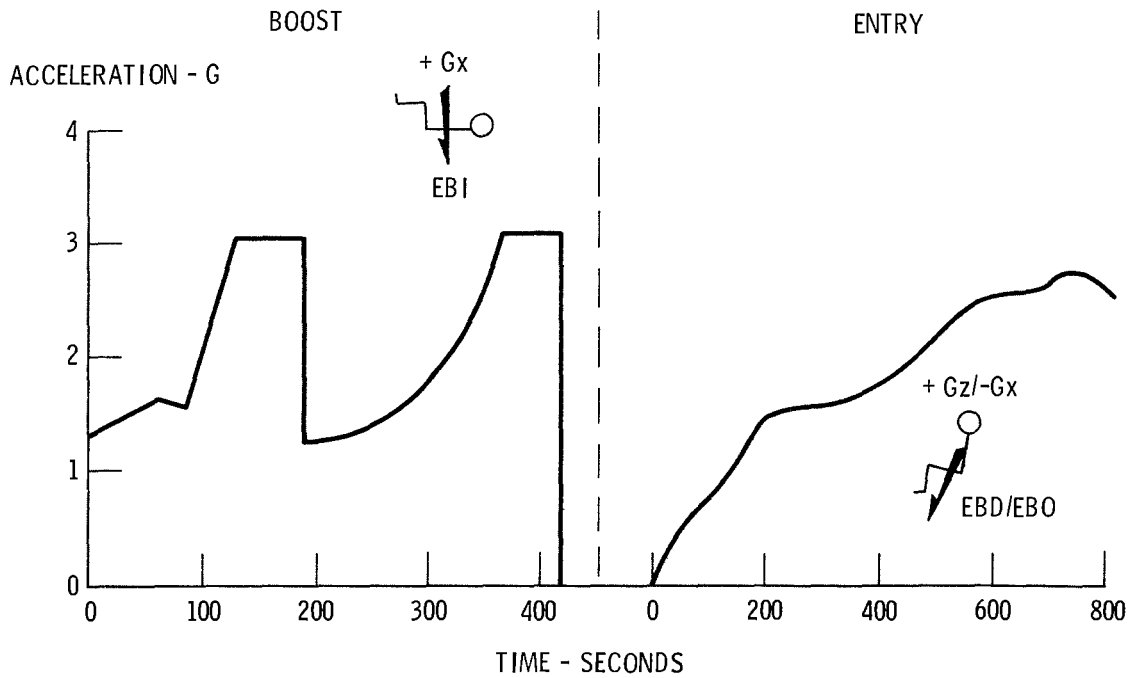
BASELINE REFERENCE MISSION



ORBITAL MANEUVER	ΔV, FPS MINIMUM	ΔV, FPS DESIGN
CIRCULARIZE AT 100 N MI	91	91
TRANSFER TO 260 N MI ORBIT	558	558
TERMINAL RENDEZVOUS	49	49
DEORBIT	425	425
CONTINGENCY		377
TOTAL	1123	1500

A PRELIMINARY SSV ORBITER ACCELERATION PROFILE DEPICTING MAJOR G LOADS OF BOOST AND ENTRY INDICATES PROLONGED DURATIONS -- O/A 7 MINUTES FOR BOOST AND ABOUT 10 MINUTES DURING ENTRY

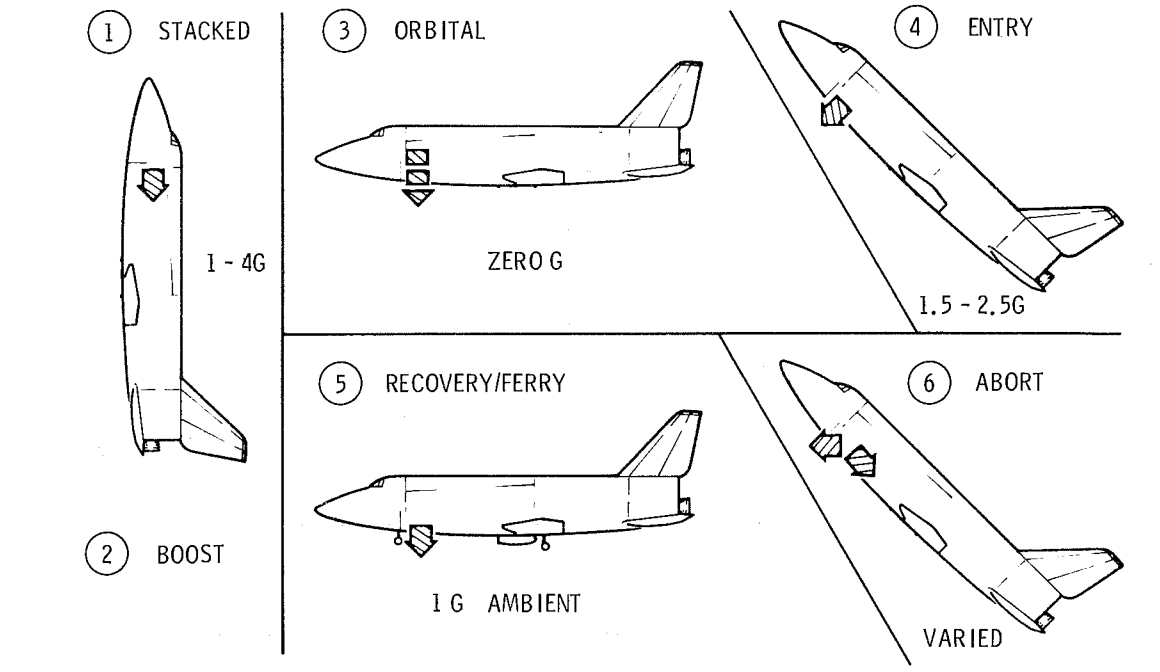
ORBITER MAJOR ACCELERATION PROFILE
CONDITION: LOW CROSS RANGE ORBITER



THE SSV ORBITER ACCELERATION DYNAMICS RESULTS IN A VARIED G VECTOR ORIENTATION FOR THE FLIGHT CREW AND PASSENGERS. WHILE THE ACCELERATIONS ARE NOT GROSS, THE RESULTANT FORCE VECTORS ARE DIVERSE -- FROM THE BOOST $+G_x$ THROUGH ENTRY $+G_z/-G_x$.

ABORT ACCELERATION PROFILES ARE NOT YET DETERMINED AND WILL BE VARIED. THERE IS CONSIDERABLE DIFFERENCE BETWEEN THE SSV MISSION DYNAMICS AND BASIC AIRCRAFT MANEUVERING LOADS, WHICH ARE BASICALLY $+G_z$.

SSV ORBITER DYNAMICS AND CREW ORIENTATION



CREW AND PASSENGER ACCOMMODATIONS

COMPONENTS ARE IDENTIFIED IN CATEGORIES WHICH COLLECTIVELY INDICATE DETERMINANTS RELATING TO VEHICLE/SUBSYSTEM DEVELOPMENT.

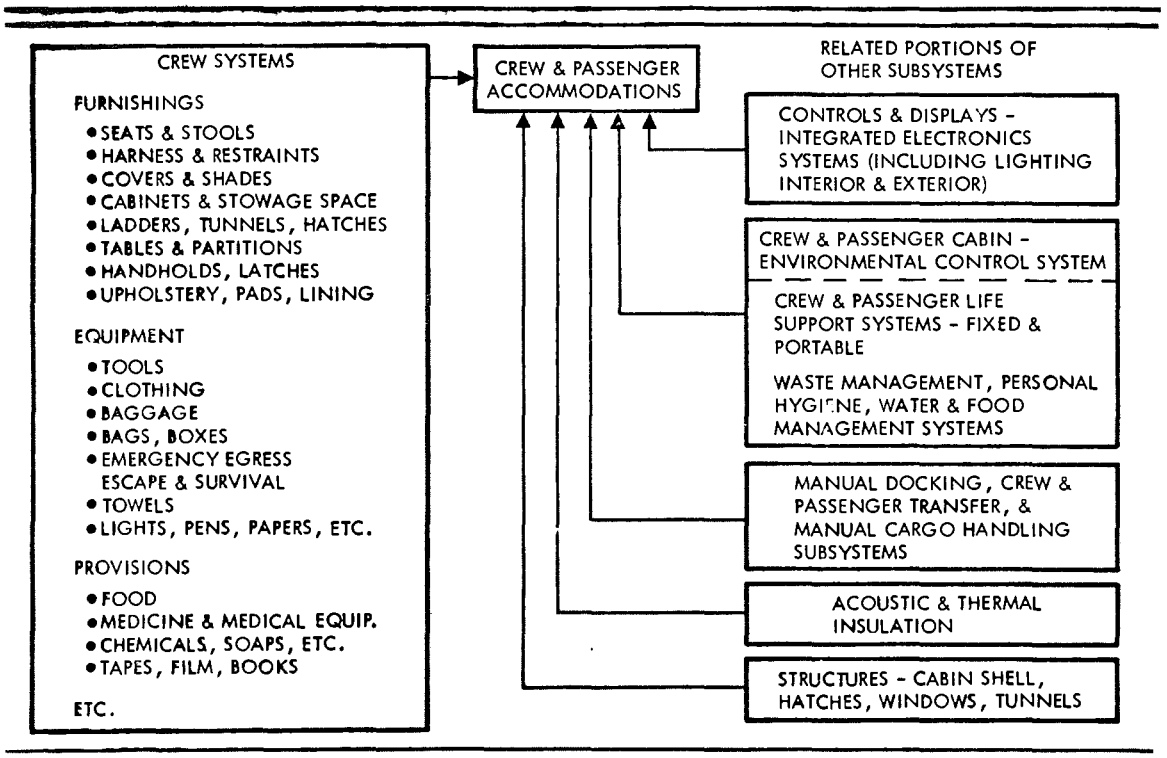
CREW AND PASSENGER ACCOMMODATIONS
BASELINE ORBITER PROVISIONS

KEY ISSUES	CONSIDERATIONS
• OPTIMUM HABITABILITY	• COMFORT LEVEL • ENVIRONMENT • HARDWARE
• KEY SAFETY ITEMS	• FIRE, EXPLOSION, TOXIC GAS • INGRESS, EMERGENCY EGRESS • ABORT • IN-FLIGHT ESCAPE • SPACE RESCUE & SURVIVAL
• OPTIMUM CREW-MACHINE INTERFACE (FLIGHT DECK)	• FLIGHT DECK - BASIC • BOOSTER-ORBITER COMMONALITY
• CREW & PASSENGER VISIBILITY	• FLIGHT DECK WINDOWS • PASSENGER CABIN WINDOWS • EXTERNAL LIGHTING

CREW STATION SUBSYSTEMS AND PASSENGER ACCOMMODATIONS

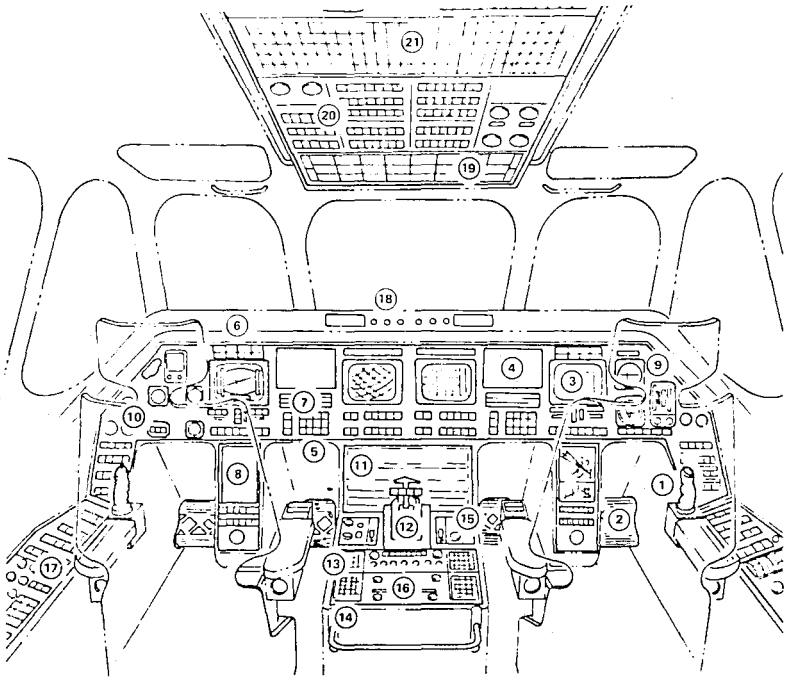
MAJOR ELEMENTS ARE DEPICTED WHICH INFLUENCE INTERNAL ARRANGEMENT, WEIGHTS, AND FRONTAL CONFIGURATION.

CREW AND PASSENGER ACCOMMODATIONS COMPONENTS



FLIGHT CREW STATION DEVELOPMENT IS HISTORICALLY A FOCAL POINT OF ATTENTION. MAJOR TRADE FACTORS INCLUDE COMMANDER POSITION, COUCH/HAND CONTROLLER INTEGRATION, EYE POSITION ENVELOPES, AND INGRESS/EGRESS.

BASELINE ORBITER CREW STATION

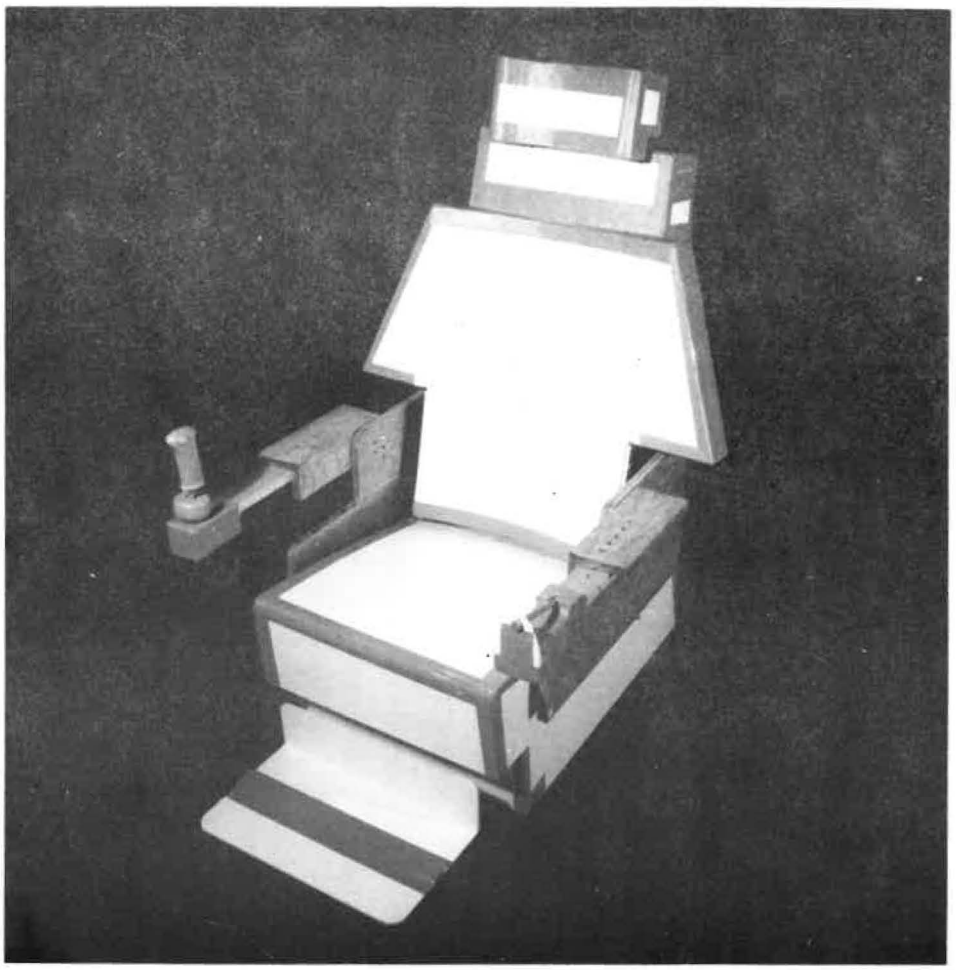


1. ROTATION HAND CONTROLLER
2. RUDDER, NOSE WHEEL STEERING, BRAKES
3. MULTIFORMAT CRT DISPLAY
4. ALPHANUMERIC MESSAGE PANEL
5. COMPUTER ENTRY/CONTROL KEYBOARD
6. TIME READOUT
7. COMPUTER STATUS/ACTIVITY READOUT
8. MICROFILM VIEWER
9. BACKUP FLIGHT INSTRUMENTS
10. BACKUP CONTROLS & INDICATORS
11. PROPULSION & HYDRAULICS CONTROLS, SEQUENCE OVERRIDES
12. THROTTLES & TRANSLATION CONTROLLER
13. FLIGHT CONTROL MODE/FUNCTION SELECTION
14. NAVIGATION MODE SELECTION
15. CREW AUDIO PANEL
16. COMMUNICATIONS CONTROL
17. EPS, EC/LSS CONTROLS
18. MASTER ALARM & EMERGENCY WARNING
19. CAUTION & WARNING STATUS INDICATORS
20. LIGHTING & EMERGENCY POWER
21. POWER DISTRIBUTION CONTROL

FLIGHT CREW STATION LAYOUT ANALYSES ARE INDISPENSABLE IN TRANSLATING PRELIMINARY DESIGNS INTO OPERATIONALLY EFFECTIVE FLIGHT DECK. IN THIS VIEW OF A SOFT MOCKUP STUDY, PRIMARY ELEMENTS SUCH AS CONSOLES, WINDOWS, AND OVERALL INTERIOR STRUCTURE ARE DEPICTED INTEGRATED WITH SECONDARY FEATURES SUCH AS INGRESS/EGRESS HAND HOLDS, OVER-HEAD HATCH ENVELOPES, HEADS UP DISPLAY, ETC.

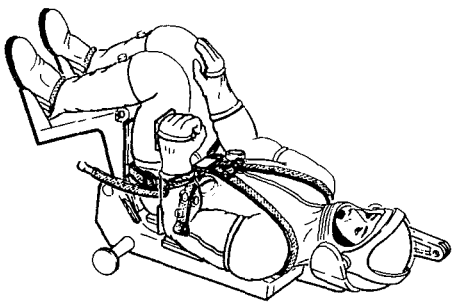
THE FLIGHT CREW COUCH AND RESTRAINT SYSTEM WILL REQUIRE A SIGNIFICANT DEVELOPMENT EFFORT. CONTAINMENT OF THE CREW IN CORRECT ORIENTATIONS DURING FLIGHT ENERGY PROFILES MAY REQUIRE TILTING THE COUCH AND ADOPTION OF AN INTEGRATED RESTRAINT ASSEMBLY. OTHER TRADE FACTORS INCLUDE MANUAL FLIGHT CONTROLLER INTEGRATION, SPECIAL ACCESS ADJUSTMENTS AND VARIABLE EYE POSITIONS FOR SPECIFIC MISSION PHASES. THE SOFT MOCK-UP DEPICTED IS UTILIZED FOR SIZING, INGRESS/EGRESS DETERMINATIONS, CONTROLLER EVALUATIONS, AND OVERALL FORM FACTOR CONCEPTUALIZATION.

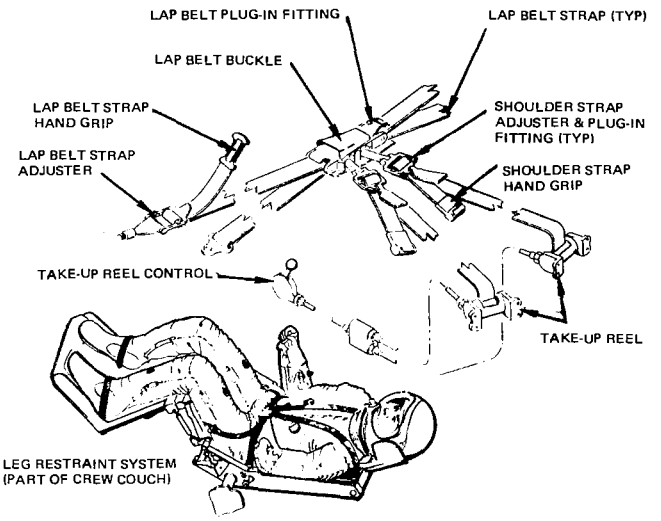
ANOTHER AREA OF ATTENTION WILL BE PASSENGER SEATING AND CONTAINMENT. SPECIAL SUPPORT PROVISIONS MAY BE REQUIRED FOR PASSENGERS.



STATE-OF-THE-ART COUCH RESTRAINTS ARE COMPRISED OF INDIVIDUAL SHOULDER AND LAP BELT STRAPS PLUGGING INTO SINGLE, 3 POINT UNIVERSAL BUCKLE LOCK. CROTCH STRAPS AND FOOT/LEG RESTRAINTS ARE FREQUENT CONSIDERATIONS.

APOLLO CREWMAN RESTRAINT HARNESS ASSEMBLY





DEVELOPMENT OF CREW AND PASSENGER STATION ACCOMMODATIONS REQUIRES SELECTION OF POPULATION SIZE RANGES. WHILE THIS MAY APPEAR AN EVIDENT CONSIDERATION, RECENT ANTHROPOMETRIC DATA ARE INDICATIVE OF INCREASED SIZE PARAMETERS (APPROX. 10 LBS. /1 IN. LARGER = 50%). SELECTION CRITERIA FOR CREW/PASSENGER COMPLEMENT POPULATION IS DRIVING CONSIDERATION.

ANTHROPOMETRIC RANGE
ACCOMMODATION CONSIDERATIONS

FLIGHT CREWS	• CLASSICAL RANGES OF AIRCREWS • UPDATED LARGER RANGE DATA • OTHER
FLIGHT PASSENGERS	• SCIENTIST • ENGINEER • TECHNICIAN
GROUND MAINTENANCE OPERATOR	• SERVICE • ENGINEER • TECHNICIAN • CONTRACTOR PERSONNEL

EXTERNAL VISIBILITY

OVERALL EXTERNAL VISIBILITY FACTORS ARE INDICATED. ANALYSES TO DATE INDICATE THAT MAXIMUM MISSION FLEXIBILITY IS ASSURED BY FULL UTILIZATION OF DIRECT CONTACT VISION BY THE FLIGHT CREW. BASIC MISSION PHASES WHICH REQUIRE EXTERNAL VISION ARE LAUNCH ABORT (BACKUP), DOCKING, ORBITAL INSPECTION, ATMOSPHERIC CRUISE, AND LANDING. THE LATTER TWO REQUIRE THE LARGEST VISUAL ENVELOPE.

CREW AND PASSENGER VISIBILITY

CREW VISIBILITY

- LANDING VISIBILITY - NASA REQUIREMENT
- DIRECT VISION WINDOWS
- SHADES

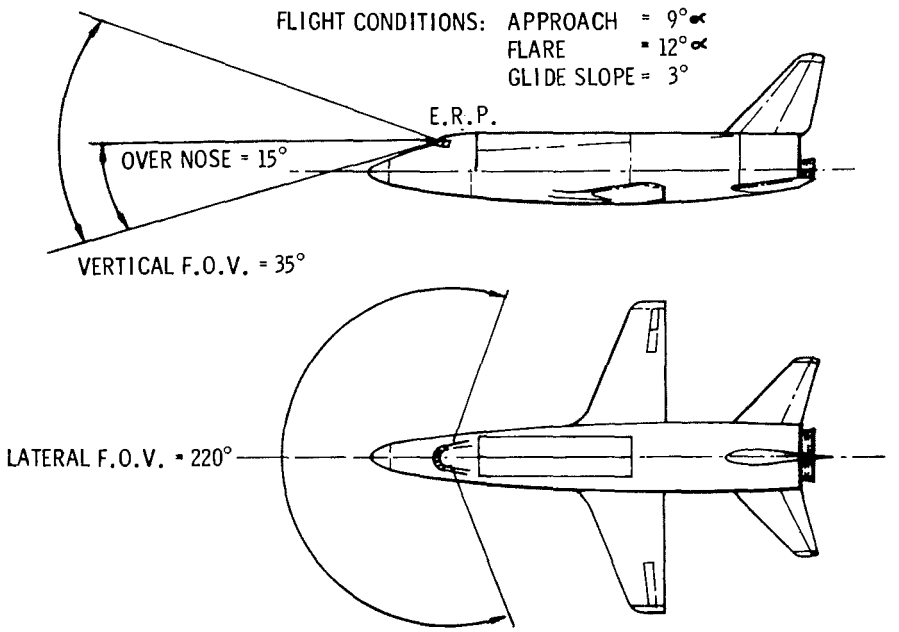
PROBLEMS

- EXTERIOR ANTI-REFLECTIVE COATINGS
- AEROTHERMAL REQUIREMENTS ON MATERIALS, WINDOW CONFIGURATION

PASSENGER VISIBILITY

- WINDOWS - DESIGN GOALS
  - SAFETY
  - EFFICIENCY
  - HABITABILITY - MINIMUM FATIGUE
  - DIVERSION

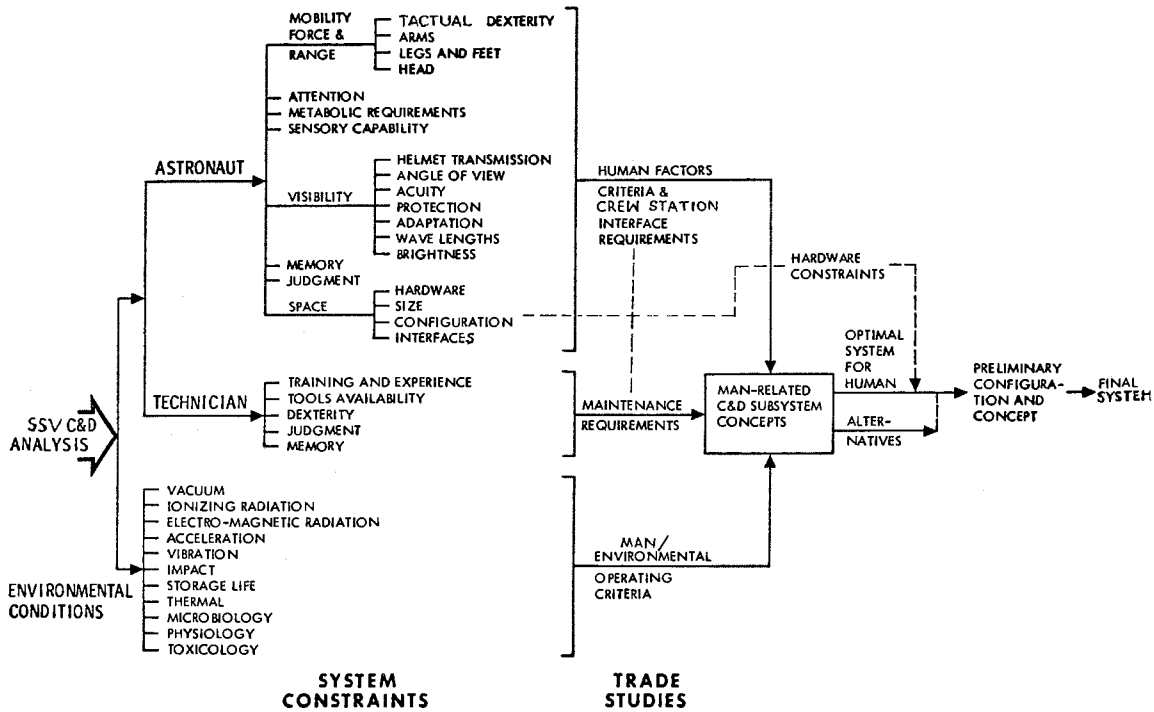
DESIRABLE EXTERNAL VISUAL ENVELOPES (LOW CROSS RANGE ORBITER)



BASELINE FLIGHT SIMULATION RUN, DEPICTING ROTATING SPACE BASE RENDEZVOUS AND DOCKING. DOCKING OPERATIONS WILL REQUIRE EXTENSIVE SIMULATION, WHETHER MANUAL OR AUTOMATIC, TO INSURE DYNAMICS COMPATIBILITY DUE TO LARGE MASSES INVOLVED AND DEVELOPMENT OF ESSENTIAL CONTROL - DISPLAY/EXTERNAL VISION PARAMETERS.

THE CONTROL-DISPLAY SUBSYSTEM DEVELOPMENT IS SUPPORTED BY A TRADE STUDY LOGIC AS ILLUSTRATED. SPECIALIZED REQUIREMENTS MUST BE CONSIDERED AS HEADS UP DISPLAY PRESENTATION FOR CRITICAL MISSION EVENTS OF DOCKING AND RECOVERY/LANDING OPERATIONS.

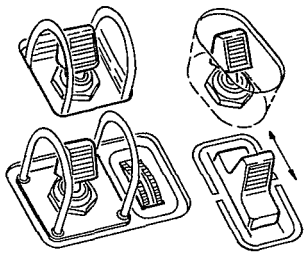
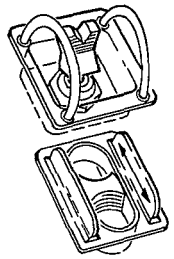
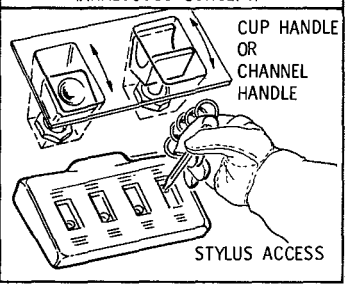
SSV C-D
HUMAN FACTORS TRADE STUDIES



HUMAN FACTORS CONTROL STUDIES MUST ENCOMPASS THE GAMUT OF UTILIZATION OF APOLLO TYPES TO ADVANCED CONCEPTS.

THE QUESTION OF OPTIONAL OPERATION UNDER PRESSURE - SUITED CONTINGENCY CONDITIONS IS OPEN FOR RESOLUTION.

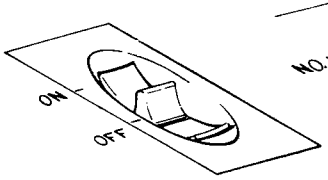
TYPICAL STUDY - CONTROLS

	APOLLO TYPES (EXACT COPY)	MINOR MODIFICATION (APOLLO SIMILARITY)	MAJOR MODIFICATION (ANALOGOUS CONCEPT)
EXAMPLE: TOGGLE SWITCH			
CONTROL CHARACTERISTICS	ACTION NOMENCLATURE FUNCTION (ON-OFF) PROTECTION THROW QUALIFICATION LIGHTING SIZE THROW RESISTANCE SHAPE CODE VOLUME COLOR MECHANISM ARRANGEMENT	ACTION NOMENCLATURE FUNCTION (ON-OFF) PROTECTION THROW QUALIFICATION LIGHTING SIZE THROW RESISTANCE SHAPE CODE VOLUME COLOR MECHANISM ARRANGEMENT	ACTION NOMENCLATURE FUNCTION (ON-OFF) PROTECTION THROW QUALIFICATION LIGHTING SIZE THROW RESISTANCE SHAPE CODE VOLUME COLOR MECHANISM ARRANGEMENT

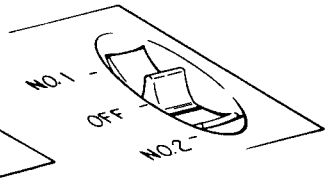
RETAINED CHARACTERISTIC REVISED CHARACTERISTIC

CONCEPTUALIZATION OF RECESSED SWITCH CONTROLS TO PERMIT UNIMPEDED MOBILITY WHILE STILL CONSERVING PANEL SPACE IS INDICATED. THE CONCEPT OF ORBITER-BOOSTER COMMONALITY/STANDARDIZATION SHOULD PREVAIL.

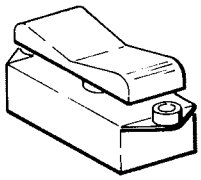
CONTROL SWITCH STANDARDIZATION CONCEPT EVALUATION



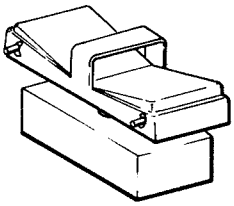
2 POSITION
PADDLE WHEEL



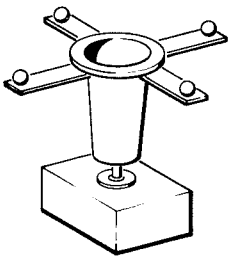
3 POSITION
PADDLE WHEEL



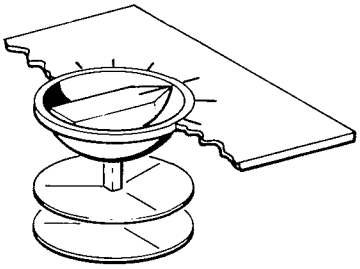
2 POSITION ROCKER



3 POSITION ROCKER
(CENTERING BAR)



MULTI-POSITION RECESSED
FINGER HOLE TYPE

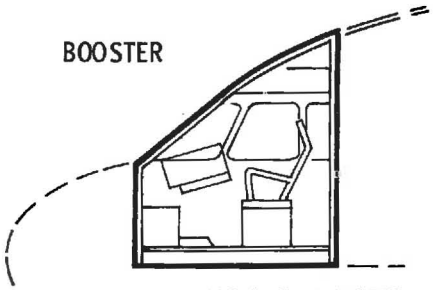


FLUSH MOUNTED
"CUP" TYPE

FLIGHT CONTROL STATION COMMONALITY BETWEEN ORBITER AND BOOSTER THROUGH STANDARDIZATION OF CONVENTION AND COMPONENTS (WHERE POSSIBLE) SHOULD BE AN ESSENTIAL OPERATIONAL REQUIREMENT. BESIDES OBVIOUS BENEFITS TO FLIGHT CREWS, PRELAUNCH CHECKOUT AND MISSION TURNAROUND IS DEFINITELY ENHANCED.

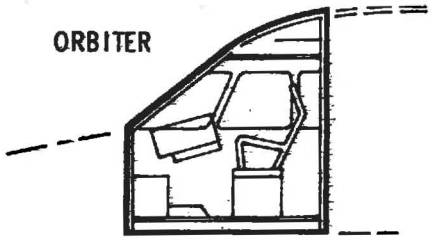
FLIGHT DECK COMMONALITY

BOOSTER

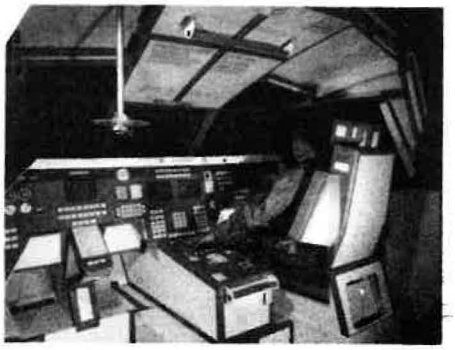


COMMON FORM FACTOR
- SIZE
- CONFORMATION
- BASIC LAYOUT

ORBITER



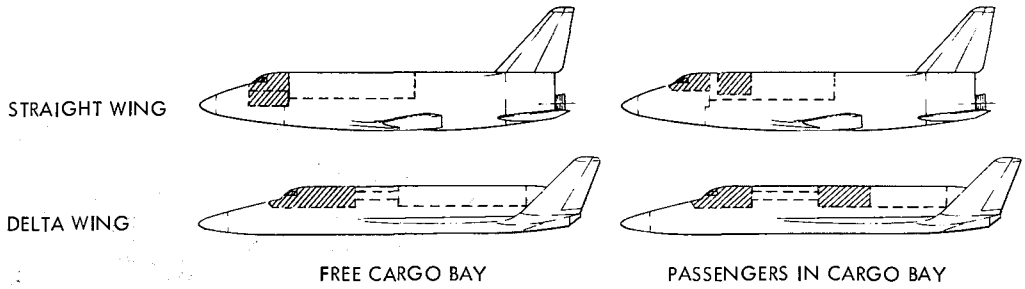
FLIGHT DECK



DETAIL
- DISPLAYS
- CONTROLS
- FURNISHINGS

A BASIC TRADE FACTOR IS THE LOCATION AND RELATIVE PLACEMENT OF PASSENGER COMPARTMENTATION. UTILIZING THE "INSIDE - OUT" APPROACH - DEFINING CREW PROVISIONS AND ACCOMMODATION ELEMENTS WITH OPERATIONAL VOLUME DETERMINATIONS - THE CREW AND PASSENGER SUBSYSTEMS ARE DEVELOPED PARALLEL WITH PRIMARY STRUCTURAL DESIGN.

PASSENGER COMPARTMENT TRADE



EC/LSS, FOOD WASTE MGMT	SCAR WEIGHT ON NON-PASS. FLIGHTS	MIN SCAR WEIGHT WITH PASS. MODULE REMOVED
STRUCT WT	PRESS. CREW/PASS. COMPT	SMALLER PRESS. COMPT
PAD ACCESS	DIRECTLY TO CREW/PASS. COMPT WITH CARGO DOORS CLOSED & INSPECTED	DIRECT ACCESS TO CREW COMPT PASS. ACCESS REQUIRES PORTION OF CARGO DOORS OPEN
EMERGENCY EGRESS	CREW & PASS. THRU QUICK-OPENING (APOLLO-TYPE) DOORS	CREW THRU QUICK-OPEN DOORS - PASS. THRU DOORS IN PRESS. SHELL PLUS DOORS IN CARGO DOOR
CARGO UTILIZATION	FULL CARGO BAY USEFUL AT ALL TIMES	FULL CARGO BAY USEFUL ONLY ON NON-PASSENGER FLIGHTS

SSV CREW HABITABILITY INDEX

REQUIREMENT:

ESTABLISH OPERATIONAL EFFECTIVE CRITERIA FOR PASSENGER AND CREW INTERIOR ACCOMMODATIONS AND PROVISIONS FOR NOMINAL AND EXTENDED MISSIONS.

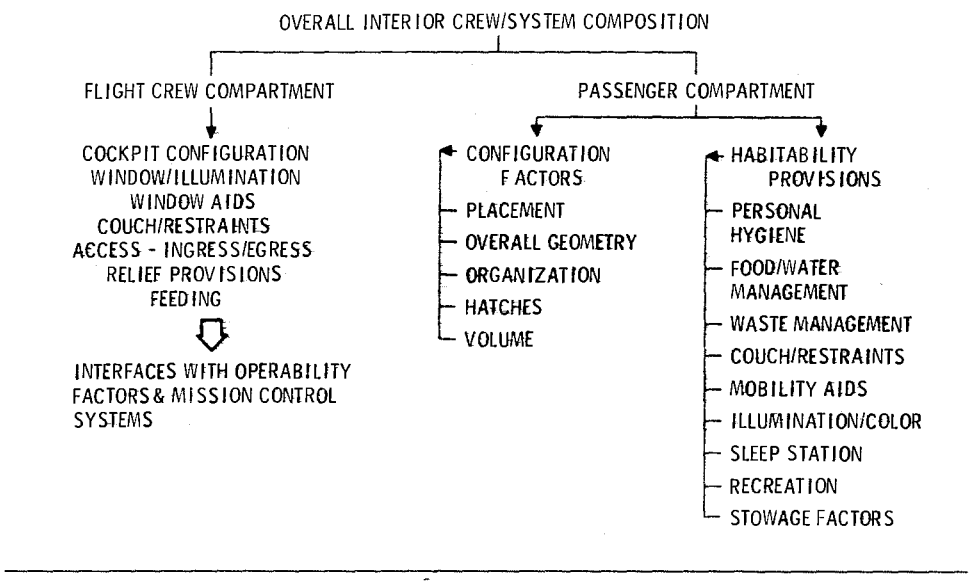
GROUNDRULE:

COMFORT LEVEL NECESSARY TO EFFECT ADEQUATE OPERABILITY AND SAFE ENVIRONMENT.

METHOD:

ANALYZE CREW HABITABILITY FEATURES, PROVISIONS, AND ACCOMMODATIONS FOR MANNED SYSTEMS - - AIRLINE - MILITARY TRANSPORTS - SPACE STATION/BASE. SELECT ELEMENTS AND BY TRADE STUDIES - DEVELOP ELEMENT DETAIL REQUIREMENTS.

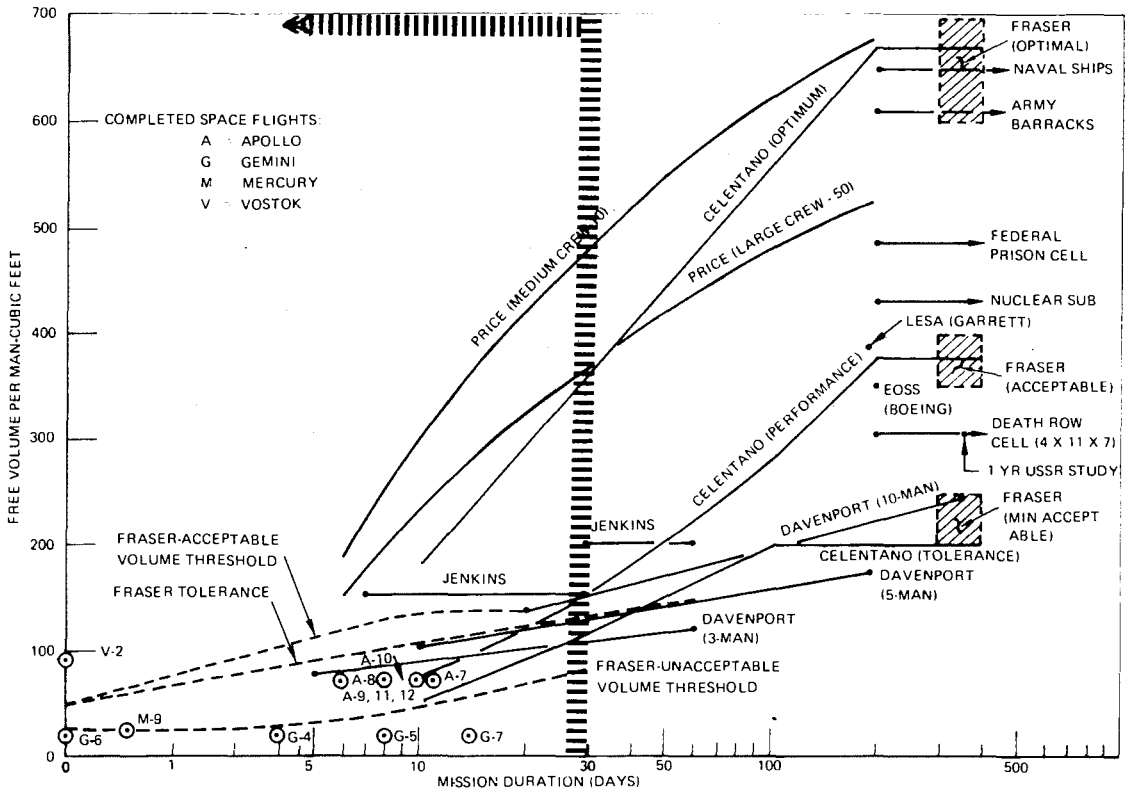
SSV CREW HABITABILITY INDEX ELEMENTS



A MAJOR HABITABILITY CONSIDERATION IS THE ALLOCATION OF VOLUMETRIC AREAS FOR CREW AND PASSENGERS FOR EXTENDED MISSION DURATIONS. THE BASIC SSV ORBITER MUST BE DEVELOPED TO ALLOW ADEQUATE VOLUME FOR EFFECTIVE HABITATION DURING THESE EXTENDED DURATIONS. WHILE INTERNAL CONFIGURATION FLEXIBILITY IS DESIRABLE AND RELATIVELY EASY TO ACHIEVE, AN ADEQUATE, BASIC SPATIAL ALLOCATION FOR THE CREW AND PASSENGER COMPLEMENT IS ESSENTIAL.

VOLUME / DURATION TRADE ENVELOPE

SSV ORBITER CREW & PASSENGER VOLUME / DURATION TRADE ENVELOPE



COMPARATIVE STUDIES OF LIVING SPACE FOR DIFFERENT DURATION CONFINEMENTS

CREW SURVIVAL AND SAFETY PROVISIONS

CONSIDERATIONS OF BASIC CREW SURVIVAL AND SAFETY ENCOMPASSES THESE KEY SAFETY FACTORS. OF SPECIFIC INTEREST IS THE OPERATIONAL OPTION OF "DESIGNING IN" PROVISIONS FOR A FLIGHT ESCAPE SYSTEM FOR INCORPORATION IN THE DEVELOPMENT TEST VEHICLES.

KEY SAFETY ITEMS

FIRE, TOXIC GAS

- MATERIALS SELECTION

INGRESS, EGRESS

- TIME: 60 SEC ON PAD
  90 SEC POST LANDING / FERRY
- PATHWAYS
- PROVISIONS

ABORT

- UNDEFINED

INFLIGHT ESCAPE

- PROVISIONS

SPACE RESCUE & SURVIVAL

PRIMARY CROSS RELATIONSHIPS ARE IDENTIFIED. OF INTEREST IS THE VARIETY OF CREW SYSTEM DETERMINANTS AFFECTING PRIMARY AND SECONDARY SPACECRAFT STRUCTURE.

SUMMARY OF CREW SYSTEMS IMPACT ON SSV DEVELOPMENT

DETERMINANT	VEHICLE/SUBSYSTEM EFFECT
○ CREW STATION AND ACCOMMODATIONS	VEHICLE FUSELAGE INTERIOR STRUCTURE STRUCTURAL LOADS
HABITABILITY COUCH/RESTRAINT	ECLSS, INTERIOR PROVISIONS, FOOD/WASTE MANAGEMENT, SLEEP STATIONS, PASSENGER PROVISIONS/COMPARTMENTATION
CREW C-D REQUIREMENTS	INTEGRATED AVIONICS SUBSYSTEM, ILLUMINATION, AND VISUAL AIDS
EXTERNAL VISION	WINDOW GEOMETRY/THERMAL PROTECTIVE SYSTEM
○ CREW SURVIVAL AND SAFETY PROVISIONS	VEHICLE FUSELAGE STRUCTURE, ECS, AND SUPPORTING MECHANICAL SYSTEMS
ESCAPE SYSTEMS-GROUND/AIR RESCUE PROVISIONS	
● CREW CARGO HANDLING (TBD) TRANSLATIONAL ASSISTS MOBILITY AIDS EVA AIDS	VEHICLE INTERIOR STRUCTURE, SUPPORTING MECHANICAL SYSTEMS AND ECS

SPACE SHUTTLE MAN-MACHINE INTEGRATION AND AEROMEDICAL TECHNOLOGY REQUIREMENTS

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McDonnell Douglas Corporation
St. Louis, Missouri

INTRODUCTION

THIS PRESENTATION CONSIDERS THE MAN-MACHINE INTEGRATION AND AEROMEDICAL TECHNOLOGY REQUIRED TO SUPPORT SPACE SHUTTLE. SHUTTLE-SPECIFIC INDEPENDENT RESEARCH AND DEVELOPMENT (IRAD) BEING ACCOMPLISHED BY MCDONNELL DOUGLAS CORPORATION (MDC) IS DESCRIBED ALONG WITH SHUTTLE-RELATED IRAD, CONTRACT RESEARCH AND DEVELOPMENT, AND HARDWARE DEVELOPMENTS. THE MDC BRIEFING IN OCTOBER 1969 TO NASA ON MAN-MACHINE INTEGRATION AND AEROMEDICAL TECHNOLOGY REQUIREMENTS FOR SHUTTLE IS REVIEWED AND RELATED TO THE FURTHER DEFINITION OF THE SYSTEM THAT HAS OCCURRED AND TO WHAT IS BEING DONE AND IS APT TO BE DONE DURING THE PHASE B SHUTTLE CONTRACT. IT IS CONCLUDED THAT EXISTING TECHNOLOGY ACTIVITIES TEND TO BE PIECE-MEAL AND NOT READILY ADAPTABLE TO THE CENTRAL ISSUES OF SHUTTLE. BASED UPON THIS SURVEY AND THE TECHNOLOGY GAPS, WE RECOMMEND DEVELOPMENTS IN THESE BROAD CATEGORIES:

MAN-MACHINE INTEGRATION

- Assuring Safe Operation
- Assuring Low Life Cycle Manpower Costs
- Assuring Versatile Mission Capability

AEROMEDICAL

- Passenger Characteristics and Selection Criteria
- Safety, Protection, Survival
- Microbiology and Radiobiology

A LIMITED AMOUNT OF SHUTTLE-SPECIFIC TECHNOLOGY IS BEING DONE BY MDC

- CONTROL-DISPLAY HUMAN FACTORS TECHNOLOGY

  Display Symbology, Format, and Color
  Electronic Control Concepts
  COM/NAV Tuning
  Auditory Warning and Signal Systems
  Peripheral Visual Displays

- TRAINING TECHNOLOGY

  Long-Term Skill Retention
  Information Retrieval Systems

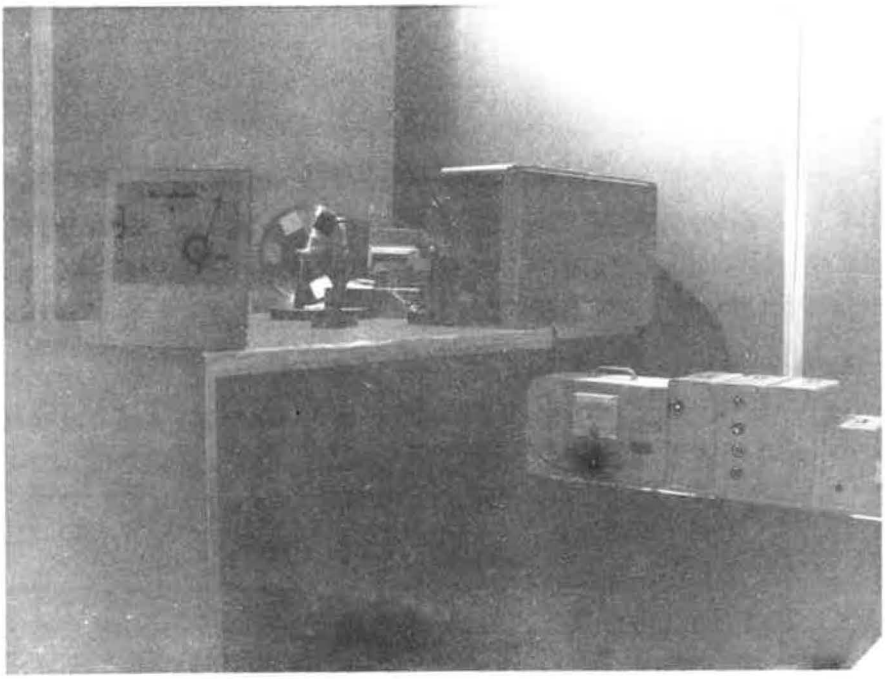
- MAN-MACHINE SYSTEM EVALUATION

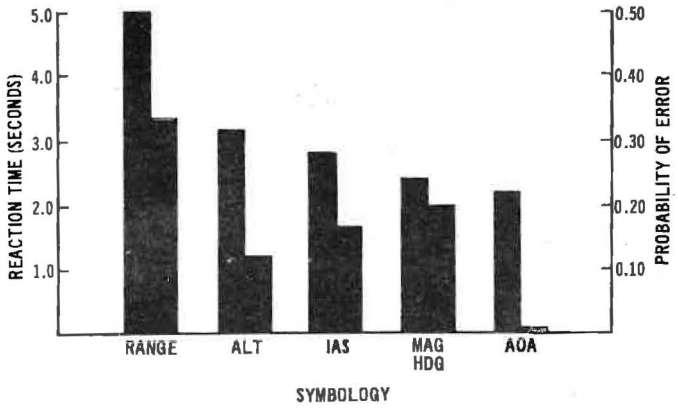
  Video Tape Techniques for Assessing Crew Functions
  Analytical Techniques for Defining Flight Crew Workload

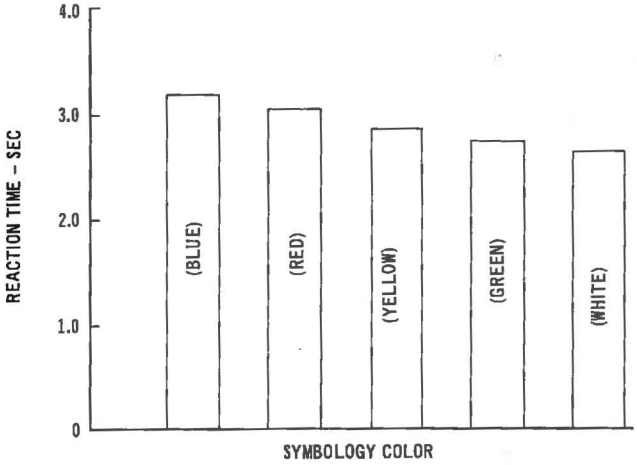
DISPLAY SYMBOLOGY, FORMAT, AND COLOR

CREW WORKLOAD AND POTENTIAL ERROR SOURCES CAN BE REDUCED BY INSURING LEGIBILITY AND COMPATIBILITY OF DISPLAY SYMBOLOGY.

AN INEXPENSIVE METHOD FOR ACCOMPLISHING PRELIMINARY STUDIES IS SHOWN IN THE FIRST ILLUSTRATION WHICH USES A RANDOM ACCESS SLIDE PROJECTOR, A MOVIE PROJECTOR, AND EQUIPMENT FOR MEASURING CREW PERFORMANCE. RESULTS ARE SHOWN IN THE SECOND ILLUSTRATION FOR A SIMULATED HEAD-UP DISPLAY (WHICH NOW MAY NOT BE USED ON SHUTTLE) WITH MEASURES OF BOTH REACTION TIME AND ERROR PROBABILITY FOR THE SYMBOLOGY USED FOR THE SEVERAL DISPLAY FUNCTIONS. THE EFFECT OF COLOR WAS ALSO INVESTIGATED AND LITTLE DIFFERENCE AS SHOWN IN THE THIRD ILLUSTRATION WAS DEMONSTRATED IN TERMS OF REACTION TIME. MORE DEFINITIVE SYMBOLOGY STUDIES CAN BE ACCOMPLISHED UNDER DYNAMIC CONDITIONS IN A SPACE SHUTTLE SIMULATOR.



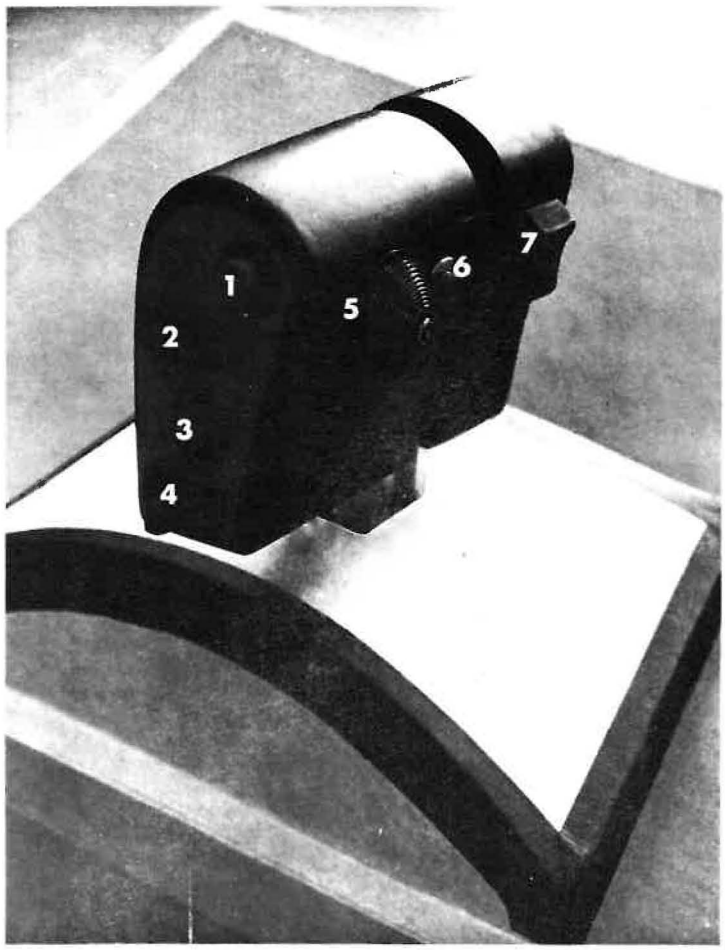

5.0
4.0
3.0
2.0
1.0
REACTION TIME (SECONDS)
0.50
0.40
0.30
0.20
0.10
PROBABILITY OF ERROR
RANGE
ALT
IAS
MAG HDG
AOA
SYMBOLOGY


4.0
3.0
2.0
1.0
0
REACTION TIME - SEC
(BLUE)
(RED)
(YELLOW)
(GREEN)
(WHITE)
SYMBOLOGY COLOR

ELECTRONIC CONTROL CONCEPTS

A MULTI-FUNCTION CONTROLLER IS SHOWN WHICH COMBINES DYNAMIC AND ISOMETRIC ELEMENTS FOR MODES SUCH AS TV MONITOR, RADAR ANTENNA, SHF ANTENNA, AND LASER ANTENNA AND CONTROLS SUCH AS AZIMUTH AND ELEVATION, LOCK, AND RANGE. ISOMETRIC ELEMENTS USE NON-MOVING PRESSURE SENSITIVE SWITCHES.

WELL-DESIGNED MULTI-FUNCTION CONTROLLERS REDUCE HAND SWITCHING AND MOVEMENT DURING CRITICAL MISSION PHASES. ISOMETRIC CONTROLS ALSO HAVE THE POTENTIAL FOR REDUCING FATIGUE AND IMPROVING PERFORMANCE UNDER ZERO-G AND ACCELERATION.



MODES

1. TV MONITOR
2. RADAR ANTENNA
3. SHF ANTENNA
4. LASER ANTENNA

CONTROLS

5. AZIMUTH AND ELEVATION
6. LOCK
7. RANGE

COM/NAV TUNING

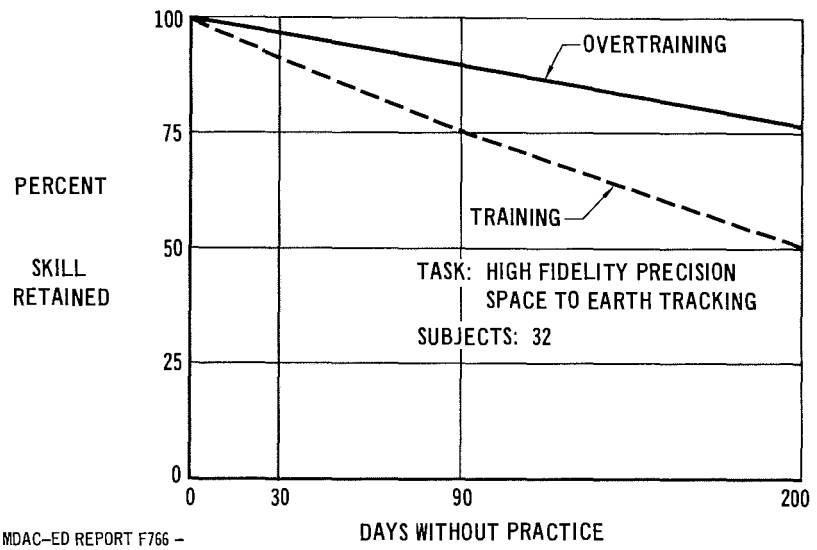
PART-TASK SIMULATIONS OF INTEGRATED COM/NAV SUBSYSTEMS HAVE BEEN CONDUCTED IN CONJUNCTION WITH INTEGRATED AVIONICS DEVELOPMENTS TO INVESTIGATE METHODS FOR REDUCING CREW WORKLOAD USING KEYBOARD TOUCH TUNING PROGRAMMING TECHNIQUES. THE SIMULATION SHOWN HAS THREE OPERATING MODES:

- Manual tuning
- Preset-tuning using frequency related codes
- Step-tuning with preset frequencies called up in sequence

PRELIMINARY RESULTS INDICATE STEP-TUNING PROVIDES A SIGNIFICANT IMPROVEMENT OVER CONVENTIONAL TUNING IN TERMS OF WORKLOAD AND ERROR REDUCTION. THIS CONCEPT HAS IMPLICATIONS FOR OTHER SYSTEM MANAGEMENT FUNCTIONS.

LONG-TERM SKILL RETENTION

THE RETENTION INTERVAL FOR VARIOUS TYPES OF SKILLS IS AN IMPORTANT FACTOR IN DETERMINING FREQUENCY AND AMOUNT OF TRAINING BEFORE, DURING, AND BETWEEN FLIGHTS. SEVERAL YEARS AGO MDC CONDUCTED AN EXPERIMENTAL STUDY FOR RETENTION INTERVALS UP TO 200 DAYS USING A HIGH FIDELITY SIMULATION OF AN IMAGE MOTION COMPENSATION TASK FROM A 100 NM ORBIT. THE RESULTS SHOWN HERE INDICATE LITTLE DECREMENT IN PERFORMANCE FOR THE FIRST 30 DAYS WHICH IS THE OUTSIDE RETENTION INTERVAL FOR SHUTTLE (INCLUDES DELAY BETWEEN TRAINING AND MISSION START). HOWEVER, THIS WAS FOR A PERCEPTUAL-MOTOR TASK WHICH IS RELATIVELY RESISTANT TO DECAY. WE ARE BEGINNING TO INVESTIGATE PROCEDURAL AND DECISION-MAKING TASKS ABOUT WHICH LITTLE IS KNOWN FOR RETENTION INTERVALS OF THE LENGTH REQUIRED FOR SHUTTLE. MECHANISMS FOR REDUCING SKILL LOSS SUCH AS WARMUP, TASK DESIGN, AND PERFORMANCE AIDS ALSO WILL BE STUDIED.



FROM: MDAC–ED REPORT F766 – CREW SKILL RETENTION FOR SPACE MISSIONS UP TO 200 DAYS

VIDEO TAPE TECHNIQUES FOR ASSESSING CREW FUNCTIONS

INITIAL DEVELOPMENTS SHOWN IN THE FIRST ILLUSTRATION WERE ACCOMPLISHED UNDER A USAF CONTRACT FOR DEVISING OBJECTIVE TECHNIQUES FOR TESTING AND EVALUATING MAINTENANCE ACTIVITIES.

THE TECHNIQUE IS NOW WIDELY USED AT MDC FOR ASSESSING BOTH MAINTENANCE AND FLIGHT CREW FUNCTIONS SUCH AS INGRESS-EGRESS, WEAPONS LOADING, SYMBOLOGY DEVELOPMENT, AND SIDE-STICK CONTROLLER STUDIES. PORTABLE CAMERAS ARE NOW USED AND A VERY LOW LIGHT LEVEL CAPABILITY IS AVAILABLE. MDC HAS PROPOSED THE USE OF THIS TECHNIQUE IN DETERMINING MANPOWER COSTS AND SKILLS FOR A NASA REFURBISHMENT COST STUDY OF A SHUTTLE THERMAL PROTECTION SYSTEM.

PRESENT DEVELOPMENTS SHOWN IN THE SECOND ILLUSTRATION ALLOW CODING AND ENCODING OF THE TAPE WHICH PERMITS RAPID RETRIEVAL OF SPECIFIC MATERIAL.

SOME SHUTTLE-RELATED TECHNOLOGY IS BEING DONE BY MDC

- WORKLOAD ANALYSES

  DC-10 Crew Workload Analyses
  A-4 Pilot Workload Task Analysis (USN)
  F-15 Pilot Digital Simulation Model (USAF)

- IN-FLIGHT MAINTENANCE CAPABILITIES

  90-Day Manned Test of a Regenerative Life Support System (NASA)
  DC-10 Fault Isolation Program

- HABITABILITY

  90-Day Manned Test of a Regenerative Life Support System (NASA)
  Individual and Crew Fatigue in a Simulated Complex Airborne Weapon System (USN)

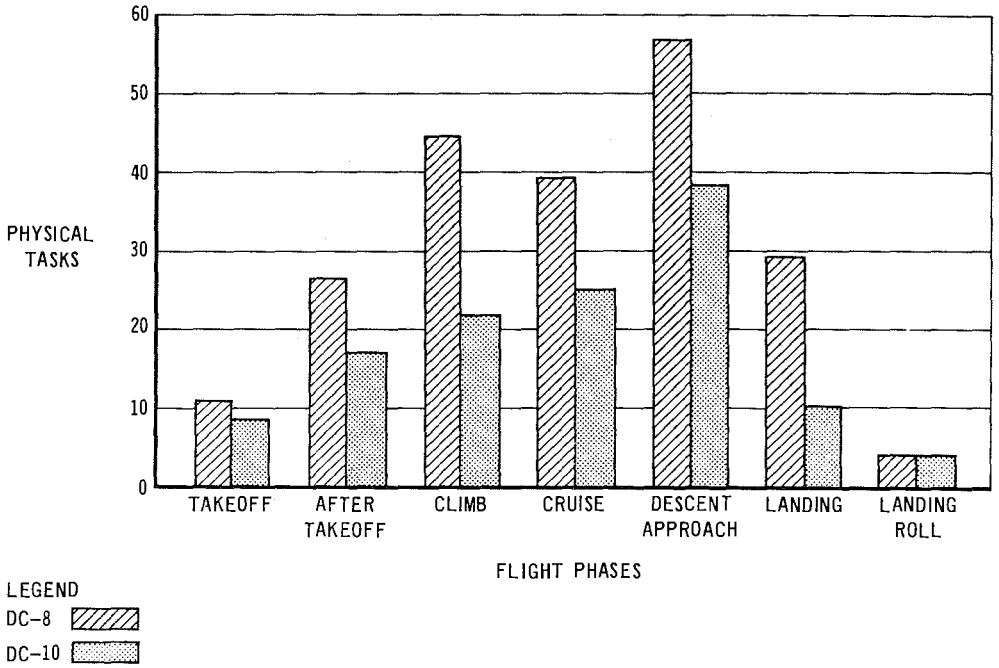
- MANPOWER COSTS IN DESIGN

  Human Resources Data in System Design Trade-Off Studies (USAF)

DC-10 CREW WORKLOAD ANALYSES

THIS IS A TECHNIQUE FOR ASSESSING RELATIVE LEVELS OF FLIGHT CREW WORKLOAD. THE CONTRAST BETWEEN THE DC-10 AND DC-8 ILLUSTRATES THE EFFECT OF THE DC-10 AUTOMATED FLIGHT SYSTEMS ON CREW WORKLOAD REDUCTION. PHYSICAL TASKS WERE DEFINED AS THE NUMBER OF DISCRETE CONTROL MOVEMENTS. OTHER ANALYSES CONSIDERED DISTANCE REACHED, TIMELINES, CONTINGENCY/ABNORMAL TASKS, AND SYSTEM OPERATION WITH AND WITHOUT AUTOMATED SYSTEMS.

DC-10 CREW WORKLOAD ANALYSIS
TOTAL CREW WORKLOAD



F-15 PILOT DIGITAL SIMULATION MODEL (USAF)

THIS DEVELOPMENT WAS USED FOR THE F-15 TO ASSESS PILOT WORKLOAD EARLY IN DESIGN AND TO ASSURE ONE-MAN OPERABILITY.

THE TECHNIQUE'S RELATIONSHIP TO TASK ANALYSIS, MAN-IN-LOOP SIMULATION, AND FLIGHT TEST IS SHOWN IN THE FIRST ILLUSTRATION AND A TWO DIMENSIONAL PLOT OF ONE TYPE OF OUTPUT DATA IS SHOWN IN THE SECOND ILLUSTRATION.

THIS TYPE OF TECHNIQUE IS IMPORTANT FOR SHUTTLE TO ASSURE TWO-MAN OPERABILITY WITH ONE-MAN BACKUP CAPABILITY.

ROLE OF DIGITAL SIMULATION IN ASSESSING CREW WORKLOAD

DESCRIPTIVE			EMPIRICAL	
TASK ANALYSES		DIGITAL COMPUTER ANALYSIS (MCAIR PILOT SIMULATION MODEL)	MAN-MACHINE SIMULATION (FLIGHT SIMULATOR)	OPERATIONAL VERIFICATION
FUNCTIONS ALLOCATION	ASSIGNS FUNCTIONS TO PILOTS AND EQUIPMENT	• CUEING INFORMATION	• COCKPIT DESIGN • AVIONIC EVALUATION • SYSTEM EFFECTIVENESS	• MAN-MACHINE INTERFACE • PILOT WORKLOAD • COCKPIT CONFIGURATION
TASK ANALYSIS	PRECISE DEFINITION OF TASKS THAT PILOT MUST DO	• MULTI-BIT INFORMATION • PARALLEL TASKS	• PILOT PERFORMANCE CRITERIA • EMERGENCY PROCEDURES • PILOT WORKLOAD • VALIDATION OF TIME LINES	• ESCAPE SYSTEM • VISION • COMFORT • LIGHTING • CONTROLS AND DISPLAYS
TIME LINE	EXAMINATION OF TASKS ON A TIME BASE WITH ESTIMATES OF TIME TO ACCOMPLISH	• MULTIPLE COCKPIT TRADE-OFFS		
LINK ANALYSIS	SHOWS RIGHT AND LEFT HAND MOVEMENTS TO ACCOMPLISH TASKS			
	INDICATES MANUAL TASK OVERLOAD	ANALYTICAL FEEDBACK LOOP		OPERATIONAL FEEDBACK LOOP

ADVANTAGES:

CHEAP & EARLY

DISADVANTAGES:

NOT PRECISE – MAN NOT IN THE LOOP, COMPLEX INTERACTIONS DIFFICULT TO PRODUCE

ADVANTAGES:

EARLY – ALLOWS RAPID MANIPULATION OF VARIABLES

DISADVANTAGES:

MAN NOT IN THE LOOP – APPROXIMATION ALTHOUGH MAN IS IN THE LOOP FOR SOME TASKS

ADVANTAGES:

QUANTITATIVE DATA
ALLOWS OBSERVATION OF PERFORMANCE
DUPLICATES MOST TASK VARIABLES
MAN IN THE LOOP
QUALITATIVE DATA

DISADVANTAGES:

VERY EXPENSIVE– DIFFICULT TO CHANGE CONFIGURATION BUT EASIER THAN ON AIRCRAFT

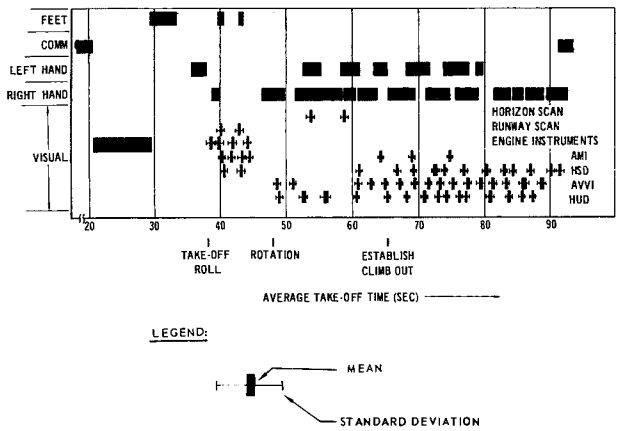
ADVANTAGES:

MOST REALISTIC– ALLOWS DUPLICATION OF OPERATIONAL ENVIRONMENT

DISADVANTAGES:

AFTER SYSTEM DESIGNED SUBJECTIVE REPORTS ONLY

TWO DIMENSIONAL PLOT OF PILOT WORKLOAD



90-DAY MANNED TEST OF A REGENERATIVE LIFE SUPPORT SYSTEM (NASA)

THE PRIMARY PURPOSE OF THIS OPERATIONAL TEST WITH A 4-MAN CREW IS TO DEVELOP A REGENERATIVE LIFE SUPPORT SYSTEM. HOWEVER, THERE ARE SEVERAL FALLOUTS FOR SHUTTLE IN THE MAN-MACHINE INTEGRATION AREA:

- In-flight Maintenance Capability Demonstration
  - Scheduled-unscheduled on-board maintenance
  - Replacement and cleaning of equipment
  - Use of on-board spares and tools
- Crew Performance Assessment
- Crew Scheduling Techniques
- Habitability Requirements
  - Food and waste management
  - Crew clothing and soft goods utilization
  - Atmospheric environmental effects

MCDONNELL DOUGLAS BRIEFED NASA IN OCTOBER 1969 ON SPACE SHUTTLE MAN-MACHINE INTEGRATION TECHNOLOGY NEEDS IN THE FOLLOWING AREAS:

- ELECTRONIC FLIGHT AND SYSTEM CONTROL/DISPLAY CRITERIA DEVELOPMENT
- LANDING DESIGN CRITERIA AND OPERATIONS DEVELOPMENT
- MISSION TASK DESIGN CRITERIA AND OPERATIONS DEVELOPMENT
- ONBOARD MAINTAINABILITY DESIGN CRITERIA AND PROCEDURES DEVELOPMENT
- HABITABILITY DESIGN CRITERIA DEVELOPMENT
- MANPOWER ECONOMY/SYSTEMS EFFECTIVENESS DETERMINATION
- CREW/PASSENGER SELECTION AND TRAINING REQUIREMENTS

CONCLUSIONS AND RECOMMENDATIONS

- EXISTING TECHNOLOGY ACTIVITIES TEND TO BE EMBRYONIC, PIECE-MEAL, AND NOT READILY ADAPTABLE TO THE CENTRAL ISSUES OF SHUTTLE WHICH IS TO DEVELOP A SAFE, LOW COST, AND VERSATILE TRANSPORTATION SYSTEM.
- SHUTTLE DESIGN AND OPERATIONAL CONCEPTS HAVE BEEN DEFINED FURTHER SINCE OUR OCTOBER 1969 TECHNOLOGY BRIEFING AND WE KNOW WHAT MAN-MACHINE INTEGRATION ACTIVITIES ARE APT TO BE AND NOT APT TO BE ACCOMPLISHED DURING PHASE B.
- REQUIREMENTS FOR A SAFE, LOW COST, AND VERSATILE DESIGN HAVE SIGNIFICANT HUMAN FACTORS IMPLICATIONS AND PERMIT MOST MAN-MACHINE AND AEROMEDICAL TECHNOLOGY ACTIVITIES TO BE ORGANIZED UNDER THESE HEADINGS AND MORE EFFECTIVELY DIRECTED TOWARDS THE CENTRAL DESIGN ISSUES FOR SHUTTLE.
- THESE DO NOT DUPLICATE SAFETY, VALUE ENGINEERING, OR DIRECT OPERATIONAL CONSIDERATIONS BUT COMPLEMENT THEM BY ALLOWING SPECIALIZED ATTENTION TOWARDS THE MANNED COMPONENT.
- THESE TECHNOLOGY ACTIVITIES MUST INCLUDE BOTH DESIGN CRITERIA AND AN APPLICATIONS FRAMEWORK THAT PERMITS CONTINUED SURVEILLANCE OF DESIGN, TEST, AND OPERATIONS TO AVOID EXPENSIVE, BRUTE FORCE APPROACHES LATER.

MAN-MACHINE INTEGRATION

1. ASSURING SAFE OPERATIONS

CONSIDERS WHERE THE MAN-MACHINE INTERFACE MIGHT CAUSE AN ABORT OR AN ACCIDENT - HUMAN ERROR IS PERVASIVE AND HAS BEEN A SIGNIFICANT PROBLEM AREA FOR MANNED AND UNMANNED AEROSPACE SYSTEMS.

- SURVEY PAST HUMAN ERROR/ACCIDENT EXPERIENCE TO PINPOINT POTENTIAL PROBLEM AREAS

  Aircraft
  Spacecraft
  Missiles

- RELATE PAST DATA/EXPERIENCE TO SHUTTLE EQUIPMENT AND OPERATIONS

  Flight Crew Activities
  Manufacturing and Assembly
  Servicing and Checkout

- DEVELOP SYSTEM FOR MONITORING CONCEPT DEVELOPMENT, DESIGN, TEST, AND OPERATIONS EMPHASIZING

  Identification of Potential Human Error Sources
  Malfunction Detection and Correction
  Human Error in Assembly and Checkout
  Critical Crew Tracking Tasks such as Approach and Landing
  Workload Analysis and Unburdening Devices
  Caution/Warning Display Priority Concepts

2. ASSURING LOW LIFE CYCLE MANPOWER COSTS

CONSIDERS THE IMPACT OF MANPOWER REQUIRED FOR OPERATIONS, MAINTENANCE, SERVICING, AND CONTROL ALONG WITH TRAINING AND SUPPORT REQUIREMENTS ON TOTAL SYSTEM COST - MANPOWER COSTS CAN BE OVER 50% OF THE LIFE CYCLE COST OF AN AEROSPACE SYSTEM.

- IDENTIFY PAST EXPERIENCE IN MANPOWER COSTS AND THEIR RELATIONSHIP TO SYSTEM DESIGN TRADE OFFS

  Spacecraft
  Transport Aircraft
  Missiles

- RELATE SHUTTLE DESIGN AND OPERATIONAL CONCEPTS TO PAST EXPERIENCE TO IDENTIFY AREAS OF POTENTIALLY HIGH MANPOWER COST

  Flight Crew
  Passengers
  Assembly, Launch, and Recovery
  Mission Control

- DEVELOP SYSTEM FOR CONTINUALLY AUDITING DESIGN IN TERMS OF MANPOWER COST THAT COVERS

  Manpower Factors in Design Trade-offs
  Qualitative Skill Requirements vs. Existing Skills
  Quantitative Manpower Requirements
  Manpower Loadings
  Training Costs

MAN-MACHINE INTEGRATION

3. ASSURING VERSATILE MISSION CAPABILITY

CONSIDERS DESIGN AND OPERATIONAL FEATURES THAT DO NOT UNDULY RESTRICT THE SHUTTLE UTILITY IN TERMS OF CREW/PASSENGER COMPLEMENT AND MISSION FLEXIBILITY - MANY DESIGN CONSIDERATIONS CONTRIBUTING TO VERSATILE CAPABILITY INVOLVE MAN-MACHINE INTEGRATION FACTORS BECAUSE SYSTEM USE CAN BE UNDULY RESTRICTED BY DESIGNING FOR A LIMITED SEGMENT OF THE POPULATION.

- IDENTIFY POTENTIAL MISSION FUNCTIONS AND CHARACTERISTICS OF FLIGHT CREW/PASSENGERS
- IDENTIFY MAN-MACHINE FACTORS IN DESIGN THAT COULD LIMIT POTENTIAL USE

  Habitability and Accommodations
  EVA/IVA Requirements
  Acceleration Profiles
  ECS Characteristics
  Anthropometric and Cultural Limits
  Interior Design for Cargo/Equipment
  Ingress, Egress, and Interior Mobility

- DEVELOP GUIDELINES FOR AUDITING DESIGN AND OPERATIONAL CONCEPTS TO AVOID UNDUE RESTRICTIONS

SHUTTLE AEROMEDICAL TECHNOLOGY REQUIREMENTS

THERE ARE FIRST ORDER AEROMEDICAL REQUIREMENTS WITH POTENTIAL IMPACT ON SHUTTLE DESIGN AND OPERATIONS. MAN-MACHINE AND AEROMEDICAL FACTORS ARE USUALLY INSEPARABLE AND RESOLVED BY MULTIDISCIPLINARY APPROACHES. MANY IMPORTANT AEROMEDICAL AREAS HAVE BEEN PREVIOUSLY MENTIONED IN THIS AND DETAILED IN OTHER PRESENTATIONS. ACCELERATION, EVA, HABITABILITY AND ECS CHARACTERISTICS EXEMPLIFY SOME OF THESE AREAS. THE FOLLOWING DATA SUMMARIZES AND REDOCUMENTS THE MORE IMPORTANT AEROMEDICAL TECHNOLOGY REQUIREMENTS FOR SHUTTLE APPLICATION.

AEROMEDICAL

1. PASSENGER CHARACTERISTICS AND SELECTON CRITERIA

ELABORATION OF FACTORS TO ASSURE SHUTTLE VERSATILITY AND MISSION CAPABILITY. THE SHUTTLE TRANSPORTED POPULATION CHARACTERISTICS MUST BE QUICKLY ESTABLISHED. AGE, SEX, PHYSICAL CONDITIONING AND "ALLOWED" DISEASE EXISTENCE OR POTENTIAL AS CRITERIA ELEMENTS CAN IMPACT SHUTTLE OPERATIONS.

- ACCOMODATING FEMALES AND FOREIGN NATIONALS
  - Anthropometry
  - Privacy
  - Latrine and Waste Management Systems
- PHYSIOLOGICAL TOLERANCES - ACCELERATION, HYPOXIA, DECOMPRESSION
  - Possible Space Station Degradation
  - Female Data Lacking
  - Older People, Incipient Degenerative Disease
- MEDICAL TREATMENT FACILITY REQUIREMENTS
  - Space Station Incurred Problems, Emergency Return
    - Accidents, as Trauma, Physiological
    - Disease Development, as Cardiovascular, Infectious
    - Existing Disease Decompensation, as Diabetes, Psychiatric

2. SAFETY, PROTECTION, SURVIVAL

LOW EVENT PROBABILITIES DO NOT ELIMINATE EMERGENCY SURVIVABILITY PROVISIONING. EMERGENCY CONDITIONS WHICH COULD OCCUR INCLUDE ECS FAILURE, DECOMPRESSION, CRASH, AND FIRE. ABSOLUTE PROTECTION IS IMPOSSIBLE, BUT INTEGRATING EXISTING AND ADVANCED TECHNOLOGY CAN IMPROVE CURRENT VEHICULAR PROVISIONS.

- INTEGRATED GARMENT
  - Fire Resistant Material
  - Metallic Mesh - Face, Head
  - Suit Pressure - Passive System, Inherent Water Flotation
  - Oxygen Pressure - Flexible Quick Don Helmet
  - Portable Emergency Life Support Systems
- CRASH DECELERATION SURVIVAL
  - Seat Design, Orientation
  - Advanced Restraint Systems
- ESCAPE
  - Problematical In Flight
  - Difficult on Ground

AEROMEDICAL

3. MICROBIOLOGY AND RADIOBIOLOGY

MICROORGANISMS AND IONIZING RADIATION ARE UBIQUITOUS ENVIRONMENTAL FACTORS THAT CANNOT BE ELIMINATED. POTENTIALLY PATHOGENIC MICROORGANISMS CAN CONTAMINATE LATRINE, POTABLE WATER AND FOOD PREPARATION FACILITIES. MATERIALS MAY BE DAMAGED BY OTHER TYPES OF ORGANISMS. INTERCHANGES BETWEEN SHUTTLE AND SPACE STATION ECOLOGIES MAY BE HAZARDOUS. REGARDING RADIATION, CREW PROTECTION AND EXPOSURE LIMITATIONS ARE REQUIREMENTS AS OPERATIONAL PLANNING ELEMENTS.

- MICROBIOLOGICAL HAZARDS DELINEATION
  - Ground-Based Confinement Studies
  - Spaceflight Microbial Monitoring, Identification
    - Water Systems
    - Environment
    - Personal
  - Clinical Correlation
- CONTAMINATION CONTROL
  - Water System Tanks, Plumbing, Filters
  - Environmental Fomite Decontamination
  - Personal Hygiene Provisions, Practices
  - Inflight Vs Ground Decontamination
    - Closed Ecology, Toxicology Considerations
    - Water Pasteurization - Large Power Requirement
    - Potential Ground Service Recontamination
- RADIATION ENVIRONMENT AND SHIELDING DATA REQUIREMENTS
  - Sharper, Tighter Radiation Environment Definitions
    - Low Earth Orbits
    - All Inclinations
  - Crew Compartment Shielding Characteristics
  - Computer Predicted Crew Doses
- DEFINITIVE CREW DOSE LIMITATIONS
  - Individual Missions
  - Allowable Cumulative Dosages
  - Emergency Dose Limitations
- OPERATIONAL IMPACT
  - Numbers of Crews Required
    - Initial Training
  - Rotational Cycles, Repeat Missions
    - Proficiency Training
  - Crew Retirement

SPACE SHUTTLE VEHICLE

ENVIRONMENTAL-THERMAL CONTROL AND LIFE SUPPORT TECHNOLOGY

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ABSTRACT

A description of various technical issues pertaining to the Space Shuttle will be presented.

A detailed presentation will be given on the design and performance problems of humidity control systems and of evaporative type heat exchangers. The problems associated with the orbital heat rejection systems will be discussed and the various possible concepts of sub-orbital cooling will be presented. The utilization of a space suit for personnel protection for early flight tests will be discussed and a possible suit design will be described. The current liquid and solid waste management systems will be described and essential modifications for space shuttle utilization will be defined. Non-metallic materials development programs will be reviewed and an attempt will be made to establish the requirements for these materials in the Shuttle type vehicle.

UNIQUE SSV ETC/LSS DESIGN CONSIDERATIONS

REUSABILITY

RAPID LAUNCH TURNAROUND

MINIMUM CREW PARTICIPATION AND GROUND SUPPORT

OPERATIONAL FLEXIBILITY (NUMBER OF CREWMAN, MISSION DURATION, PAYLOADS)

QUIESCENT ORBITAL OPERATION

EXTREME RE-ENTRY ENVIRONMENTAL EXPOSURE

TEST AND FERRY FLIGHTS

SSV ETC/LSS CRITICAL TECHNOLOGY AREAS

LAUNCH HEAT REJECTION

ORBITAL HEAT REJECTION

POST ORBITAL HEAT REJECTION

SYSTEMS INTEGRATION ANALYSIS

HUMIDITY CONTROL

BACTERIOLOGICAL CONTROL

WASTE MANAGEMENT

EMERGENCY PRESSURE PROTECTION

NON-METALIC MATERIALS

APPROACH AND STATUS OF EFFORT

IN EACH TECHNOLOGICAL AREA

LAUNCH HEAT REJECTION

(EVAPORATOR TYPE HEAT EXCHANGER)

ISSUES:

MULTIPLE STARTUP AND SHUTDOWN OF CURRENT APPROACHES DIFFICULT AND UNRELIABLE

PERFORMANCE DEGRADATION OF PORUS PLATES AND WICKS (CORROSION, PARTICULATE SENSITIVITY)

GROUND SERVICING OF WICKS

OPERATIONAL COMPLEXITY AND RELIABILITY OF WATER FEED SYSTEM

G - SENSITIVITY

HEAT LOAD RANGE RESTRICTIONS

EFFECT OF QUIESCENCE

APPROACH:

DEVELOP NEW CONCEPT

ESTABLISH THE FEASIBILITY OF A "FLASH" EVAPORATOR AND SIMPLIFIED FEED CONTROL SYSTEM BY LABORATORY TESTING

STATUS:

CONTRACT BEING NEGOTIATED

ORBITAL HEAT REJECTION

ISSUES:

- LAUNCH AND RE-ENTRY HEAT PROTECTION
- COATING LIFE AND REFURBISHMENT
- ORBITAL ATTITUDES
- HEAT LOAD RATIO
- DOCKED CONFIGURATION PERFORMANCE
- VEHICLE INTERFACE (RADIATOR AREA SIZE AND LOCATION)
- RADIATOR MATERIALS SELECTION
- MECHANICAL TEMPERATURE ELEVATION

APPROACH:

- INTEGRAL SKIN VERSUS DEPLOYABLE RADIATORS (e.g. INSIDE CARGO DOORS)
- NON-INTEGRAL, MODULAR (RAPID REPLACEMENT) DESIGN RADIATOR PANELS
- PROTECT AND/OR REFURBISH COATING
- INFLIGHT SERVICING
- VENT FLUID DURING RE-ENTRY
- UTILIZE METAL MATRIX COMPOSITE RADIATOR PANELS
- AVOID OR MINIMIZE ORIENTATION CONSTRAINTS
- INCORPORATE MECHANICAL REFRIGERATION SYSTEM

STATUS:

- PRELIMINARY IN-HOUSE COATING EVALUATION
- PRELIMINARY CONTRACTED STUDIES
  - OVERALL MISSION EVALUATION (COMPLETE)
  - TWO-DIMENSIONAL RADIATOR TEST (COMPLETE) 50:1 HEAT LOAD RATIO
  - MECHANICAL REFRIGERATION SYSTEMS (IN-WORK)

POST-ORBITAL HEAT REJECTION SYSTEM

ISSUES:

- SYSTEM CONCEPT SELECTION
- ENTRY HEATING/SOAKBACK EFFECTS
- VEHICLE INTERFACE
- MULTI-MISSION REQUIREMENT
- MAINTAINABILITY AND SERVICEABILITY

APPROACH:

- APPLY COMMERCIAL/MILITARY AIRCRAFT APPROACH
  - AIR CYCLE
  - RAM AIR COOLING
  - VAPOR COMPRESSION
  - EVAPORATIVE COOLING
- HYDROGEN HEAT SINK
- CONVECTORS

STATUS:

- PRELIMINARY CONTRACTED STUDIES
  - OVERALL MISSION EVALUATION (COMPLETE)
  - MECHANICAL REFRIGERATION SYSTEMS (IN-WORK)
  - SUB-ORBITAL HEAT REJECTION STUDY (IN-WORK)

SYSTEM INTEGRATED ANALYSIS

ISSUES:

- INTEGRATED ENVIRONMENTAL CONTROL CONCEPT TO ACCOMMODATE ALL MISSION PARAMETERS
- THERMAL CONTROL CONCEPT
- SYSTEM RELIABILITY AND MAINTAINABILITY

APPROACH:

- INTEGRATED ENVIRONMENTAL CONTROL CONCEPT
  - MODULAR ADD-ON ECLS SUBSYSTEM AND RADIATOR PANELS
  - LARGE FIXED ECLS AND RADIATOR WITH OFF LOADED EXPENDABLES
- THERMAL CONTROL CONCEPT
  - INTEGRATED SYSTEMS TRADESTUDY
  - RADIATOR OPTIMIZATION STUDY
  - SUBORBITAL COOLING OPTIMIZATION
  - MULTIPLE CIRCUITS WITH WATER INSIDE VEHICLE
- SYSTEM RELIABILITY AND MAINTAINABILITY
  - OVER CAPACITY EQUIPMENT
  - MODULAR REPLACEMENT
  - AUTOMATIC CHECKOUT AND MONITOR
  - SCHEDULED REPLACEMENT

STATUS:

- PHASE B CONTRACTORS DIRECTED TO ADDRESS ABOVE ISSUES
- INDEPENDENT CONTRACTED STUDY EFFORTS PLANNED DURING 1970

HUMIDITY CONTROL

ISSUES:

PERFORMANCE DEGRADATION OF WICK AND MECHANICAL SEPARATORS

PROCEDURAL PROBLEMS OF STARTUP OF WICK SEPARATORS

BACTERIAL GROWTH IN WICK SEPARATORS AND HEAT EXCHANGERS

GROUND SERVICING AND MAINTAINABILITY

QUIESCENT STORAGE CAPABILITY

CORROSION/FREEZING PROBLEM OF LIQUID WATER COLLECTION

INTERFACE WITH COOLANT SYSTEM

RADIATOR PENALTY (HEAT LOAD AND TEMPERATURE LEVEL)

APPROACH:

DEVELOP CHEMICAL REGENERATIVE DESICCANT ADSORBERS

DESICANT APPROACH SHOULD BE VIRTUALLY UNAFFECTED BY USE OR

QUIESCENT MODES

DESICCANT REFURBISHMENT WILL ONLY REQUIRE HEAT VACUUM OR DRYERS PURGE

VACUUM DESORPTION OF DESICCANT WILL PREVENT BACTERIA GROWTH

DESICCANT CAN BE REPLACED IF NECESSARY AS A CARTRIDGE, REQUIRING NO BREAKING OF LIQUID LINES

DESICCANT REDUCES LOW TEMPERATURE RADIATOR REQUIREMENT

DEVELOP REPLACABLE, NON-ROTATING WATER SEPARATORS

STATUS:

INHOUSE ANALYTICAL DESIGNS OF DESICCANT CONCEPT IN PROGRESS

DEVELOPMENT OF REPLACEABLE, NON-ROTATING WATER SEPARATOR UNDER NAS 9-10273

PROCUREMENT OF DESICCANT PROTOTYPE FOR VERIFICATION TEST

BACTERIOLOGICAL CONTROL

ISSUES:

WATER STERILIZATION AGENT SELECTION

BACTERIA GROWTH

WATER REPLENISHMENT/DILUTION

REACTION WITH SYSTEM MATERIALS

PROVIDE SIGNAL FOR CORRECTIVE ACTION

POSTFLIGHT SYSTEM DECONTAMINATION

APPROACH:

DEVELOP SPECIFIC ION ELECTRODE FROM LAB ITEM TO FLIGHT PROTOTYPE AND/OR UTILIZE LRC DEVELOPMENTS IN THIS AREA

DEVELOP SENSING INSTRUMENTS (CONTR NAS 9-10432)

STATUS:

LRC PROCUREMENT PENDING

MSC PROCUREMENT PLANNED FALL 1970

WASTE MANAGEMENT

ISSUES:

PSYCHOLOGICAL ACCEPTABILITY

SIMPLICITY OF DESIGN

SANITARY AND ODORLESS

POSITIVE RELIABLE OPERATION

CHEMICAL/GERMICIDE APPROACH

WASTE STORAGE

APPROACH:

URINE STORAGE AND SUBSEQUENT DUMP

AUTOMATE SKYLAB FECAL COLLECTION APPROACH

DEVELOP MORE CONVENTIONAL SYSTEM

STATUS:

ADVANCED COLLECTION WORK UNDER NAS 9-10237 BEING EVALUATED FOR SHUTTLE APPLICATION

PROCUREMENT OF PROTOTYPE IN EARLY 1971 CONTEMPLATED

EMERGENCY PRESSURE PROTECTION

ISSUE:

PROVIDE PROTECTION IN THE EVENT OF A CABIN DEPRESSURIZATION

BE AVAILABLE FOR FLIGHT TESTS AND EARLY OPERATIONS

DESIRE LIGHTWEIGHT, LOW-BULK, FLIGHT COVERALL TYPE GARMENT

APPROACH:

LIGHTWEIGHT PRESSURE SUIT

STATUS:

FULL PRESSURE SUIT

EIGHTEEN MONTH CONTRACT WILL BE AWARDED IN JULY 1970 (GARMENT IS TO WEIGH 12 POUNDS TOTAL)

DESIGN GOAL IS TO PROVIDE EMERGENCY PROTECTION IN A GARMENT WHICH ALSO PROVIDES LONG TERM, CONSTANT WEAR COMFORT

NONMETALIC MATERIALS

ISSUE: UTILIZING MATERIALS THAT ARE COMBUSTIBLE IN OXYGEN ENRICHED ENVIRONMENT BUT ARE NONCOMBUSTIBLE IN AIR BECAUSE OF THEIR DURABILITY CHARACTERISTICS.

APPROACH: THE AMBIENT AIR ENVIRONMENT WILL PERMIT THE UTILIZATION OF A VARIETY OF FLAME RESISTANT MATERIALS THAT COULD NOT QUALIFY FOR APOLLO USAGE. THE TECHNIQUES USED IN THE APOLLO PROGRAM WILL BE UTILIZED TO PROVIDE IMPROVED PERFORMANCE AND DURABILITY BY MEANS OF LABORATORY AND MOCKUP TESTING.

STATUS: A CURRENT PROGRAM IS BEING CONDUCTED TO IMPROVE THE FIRE SAFETY OF COMMERCIAL AIRCRAFT AND THE INFORMATION BEING OBTAINED CAN BE USED IN THIS PROGRAM.

CREW AND CARGO TRANSFER

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One important area of research intimately related to the space shuttle is that of personnel and cargo transfer. This area is important because it is involved, to some degree, in all proposed shuttle missions. To date, however, only limited study of the man/systems integration factors associated with shuttle transfer problems has been accomplished. Because of this lack of information and the general importance of the transfer capability to the shuttle program, NASA has initiated an effort to investigate the resolve shuttle transfer problems. This effort is being coordinated through the Shuttle Bio-Technology Working Group and is being conducted by groups from Langley Research Center and Marshall Space Flight Center. The centers will, in general, utilize unique in-house simulation facilities and capabilities in conjunction with problem definition studies by contractors to define and to study cargo and personnel transfer.

The purpose of this presentation is to indicate briefly, the scope of the problem, the objectives of the centers' programs and the type of information that will be developed.

Scope

The first figure indicates the scope of the transfer problem and the relative frequency of the shuttle missions based on present plans. The missions range from delivery of large varying cargoes and large numbers of personnel with varied training and physical background to a Space Station/Space Base to the placement, retrieval, and maintenance of satellites. The cargo varies from personnel and small packages to be transferred through personnel hatches and tunnels to bulk liquid transfer to a fuel storage area using techniques similar to aerial refueling on earth. The two most frequent missions are logistics support for the Space Station which involves a wide range of transfer considerations and the delivery of propellant which is limited as to transfer requirements. The other mission frequencies are significantly less and are related to specific orbital tasks. The lower frequency missions are important, however, to the overall shuttle usefulness.

The main point to recognize from this figure is that there are a large number of transfer functions required to accomplish the full range of shuttle missions and each needs to be thoroughly studied. It is also important to see that now is the time to begin providing answers to whether the transfers required can be done and how. Supplying these answers will require investigations considering potential cargo sizes, volume, etc; Shuttle and Space Station configurations; cargo handling techniques and aids; cargo module docking and transfer techniques; operational constraints; and man's capabilities.

NASA's Program

As mentioned earlier NASA has begun the investigation of these important considerations. Figure 2 presents a broad look at the combined activities of MSFC and LRC. The current activities include interface and coordination between the various groups involved, including both Phase B shuttle and space station contractors, design and fabrication of full-scale mockups for use in studies and monitoring of problem definition study contracts. Future activities will include in-house analysis and simulation of both Phase B and final shuttle configurations which will provide man-system integration criteria for the Phase B and C studies. In addition, the cargo transfer interface between the shuttle-space station will be evaluated; equipment and techniques which allow cargo transfer to be accomplished will be proposed and potential EVA requirements will be defined and investigated. These general activities are being implemented at the centers in the following manner.

Langley Activities.- The in-house activities at Langley for the next FY are shown on figure 3. These activities at the present time consist of the design and fabrication of full-scale mockups for both the water immersion facility (figure 4) and the Rendezvous Docking Simulator (figure 5). The initial water immersion mockups include a 15-foot-by-30-foot segment of the cargo module with all the various airlocks, hatches and tunnel proposed by Phase B contractors. Crew stations and space station interface mockups will follow as required. The first

mockup for the Rendezvous Docking Simulator will be for study of direct shuttle/space station docking and large vehicle handling qualities with the other potential modes to follow later in the year.

When the cargo module mockups become available in August, water immersion studies of passenger IVA transfer will begin followed by crew transfers in normal and emergency situations using both EVA and IVA techniques. These studies will address the adequacy of the proposed hatch and tunnel sizes, and configurations, airlock dimensions, and suggest potential techniques and aids.

The next study will investigate transfer of cargo through the various proposed tunnels, hatches, etc., of the shuttle and space station. The emphasis will be on a parametric look at volume, mass, moments of inertia, and their effect on transfer and establishment of cargo configuration and sizing criteria. Following that will be an investigation of the man/system integration problems associated with transfer of fuel from the shuttle to an orbital fuel dump using hoses. This will be aimed primarily at providing data on man's capability to perform the EVA function and the aid required.

Separate from the water immersion studies will be a parametric investigation of the various potential shuttle/space station/space tug/cargo module docking and station keeping problems using the six-degree-of-freedom Rendezvous Docking Simulator. This study will consist of simulating the visual scene during the docking and station keeping tasks under a variety of vehicle inertia, mass, thrust capability, etc., conditions. Out of these studies will come parametric information on

man's ability to perform the piloting function and indications of visual or instrument aids required to accomplish the various docking and cargo module transfer tasks. The Langley team has had experience in this support area, having solved Gemini and Apollo problems in docking (direct and remote TV), spacecraft handling qualities and pilot control and visual aids. No new major facilities are required in order to carry out the proposed work.

In the future follow-on vehicle-specific docking and water immersion work will be done as the final shuttle configuration emerges as well as new water immersion studies of orbital rescue, and satellite placement, retrieval and maintenance.

In addition to the in-house work Langley has a shuttle personnel and cargo transfer problem definition study contract underway with Environmental Research Associates. This study was initiated May 20th of this year and it has two basic tasks as shown on figure 6. The first consists of review and evaluation of shuttle Phase A reports and Phase B proposals and tabulation and comparison of the review information. This will be done with an eye for commonality of proposed shuttle designs and vehicle capabilities. Also included is a determination of the state of the art of personnel and cargo transfer techniques and aids relatable to shuttle missions and analysis of transfer operations for typical mission profiles.

The second task will be to use the review information of the first task to develop an experimental plan for using LRC facilities in analytical and simulation studies of shuttle transfer problems associated

with all planned shuttle missions. The relative priority of task required to resolve transfer problems will be indicated as well as a preliminary breakdown into subtasks to be completed and specific simulators to be used.

Marshall Activities.- Marshall's in-house activities are well under way, with construction of a representative cargo transfer tunnel mockup, for use with an air-bearing simulator, nearing completion. The tunnel mockup, which is depicted in figure 7 is actually only a partial tunnel with transparent surfaces with the capability of being raised or lowered with respect to the air-bearing floor. In use, then, cargo packages attached to any of several proposed transfer devices (such as monorails, trolleys, etc.) can be supported on air bearings and transferred through the tunnel with minimum friction. One such transfer device, typical of those to be evaluated, is shown in figure 8. The schedule of events in the evaluation and use of the transfer device is shown in figure 9.

Marshall Space Flight Center has recently awarded a contract, outlined in figure 10, to Man/Factors, Inc., covering an analysis of shuttle/space station resupply mission cargo handling techniques. The results of this study will provide man/systems criteria for input to the Phase C effort. Included in the study will be analyses of man's capability to maneuver large packages in zero-g, both unaided and mechanically aided; crew stability/mobility requirements; interface requirements with transfer mechanisms and similar man/systems criteria.

Although actual simulations are not a part of this effort, requirements for simulations and applicable simulation modes, facilities and hardware will be identified.

Candidate systems, as many as are defined, will be evaluated for application to shuttle/space station missions using a systems analysis technique called "Performance Effectiveness Evaluation Scheme" (PEEVS) which was originally developed for EVA tasks but which lends itself nicely to this application.

As problem areas are defined in the study contract, additional mockups will be constructed both for the air-bearing simulator and for MSFC's 75-foot-diameter-by-40-foot-deep neutral buoyancy simulator. Manned simulations will then be conducted to answer these questions, to further define man's capabilities and to identify required support systems.

Concluding Remarks

In conclusion, NASA has initiated a program to define and develop the personnel and cargo transfer capabilities required to support the space shuttle missions. This program is being geared to provide information usable in Phase C shuttle studies and to develop techniques and systems necessary for the planned transfer tasks.

SHUTTLE PERSONNEL AND CARGO TRANSFER

MISSIONS AND CARGO TYPES

Cargo \ Mission	Space Station logistics support	Delivery of propulsive stages and payloads	Delivery of propellant	Short duration orbital missions	Rescue	Satellite placement and retrieval	Satellite service and maint.
• Personnel							
Crew	x	x	x	x	x	x	x
Passengers	x	x			x		
• Large equipment	x	x		x		x	
• Specialized use kits	x	x	x		x	x	x
• Dry container cargo	x	x			x		
• Liquid and gaseous cargo (small tanks)	x	x			x		x
• Bulk liquids			x				
Mission Frequency %	39	9	44	4	-	2	2

Figure 1.

NASA ACTIVITIES

CURRENT

- INTERFACE BETWEEN CENTERS AND PHASE B CONTRACTORS (LRC, MSFC, KSC)
- ESTABLISH CONTACTS WITH PHASE B SPACE STATION CONTRACTOR
- DESIGN AND FABRICATION OF SHUTTLE MOCKUPS
- MONITOR PROBLEM DEFINITION STUDY CONTRACTS

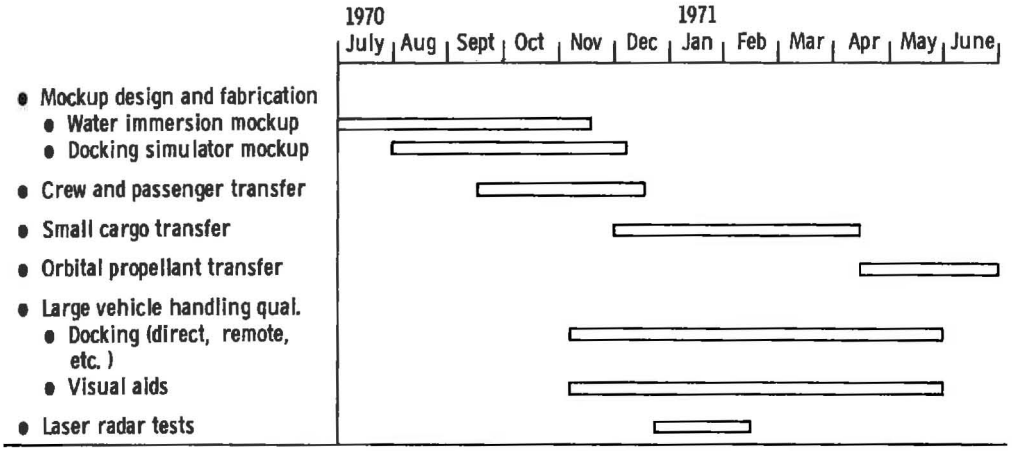
PLANNED

- CONDUCT IN-HOUSE ANALYTICAL AND SIMULATION STUDIES (USING FULL-SCALE MOCKUPS) TO EVALUATE INITIAL SHUTTLE CONCEPTS AND THE FINAL SHUTTLE CONFIGURATION
- PROVIDE MAN-SYSTEMS CRITERIA FOR PHASE B AND C STUDIES
- EVALUATE SHUTTLE/SPACE STATION CARGO TRANSFER INTERFACES
- PROPOSE EQUIPMENT AND TECHNIQUES AND PROTOTYPE TESTS TO ENABLE CREW, CARGO, AND PASSENGER TRANSFER AND DOCKING TO BE ACCOMPLISHED
- INVESTIGATE POTENTIAL EVA REQUIREMENTS

Figure 2.

LANGLEY IN-HOUSE ACTIVITIES

(FY 1971)



FY 1972 STUDIES

- Satellite placement and retrieval
- Satellite maintenance
- Orbital rescue
- Design specific docking studies

Figure 3.

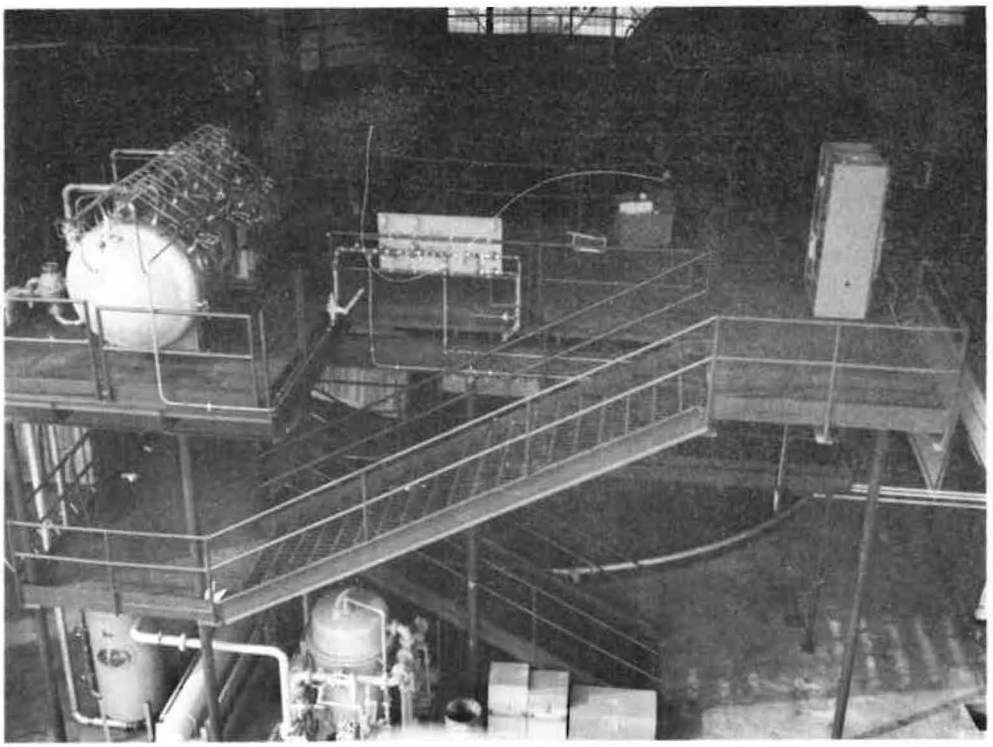


Figure 4.

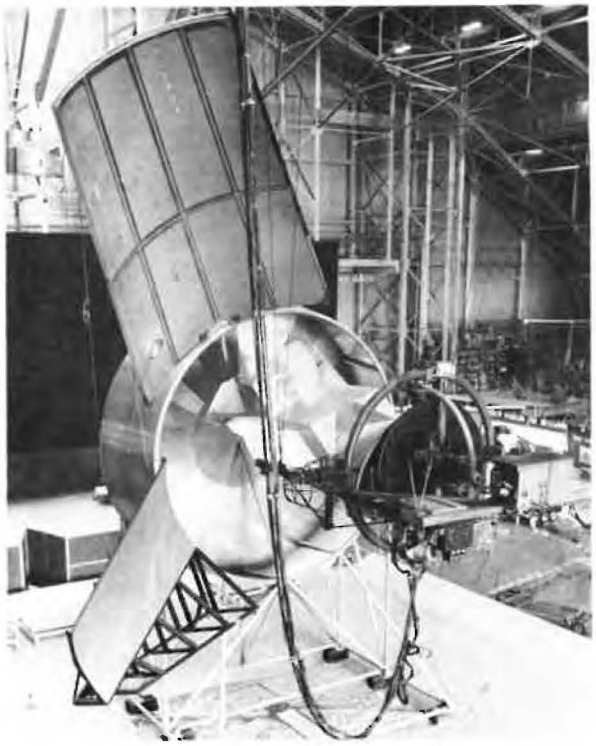


Figure 5.

LANGLEY PROBLEM DEFINITION CONTRACT

ENVIRONMENTAL RESEARCH ASSOCIATES NAS1-8975-3

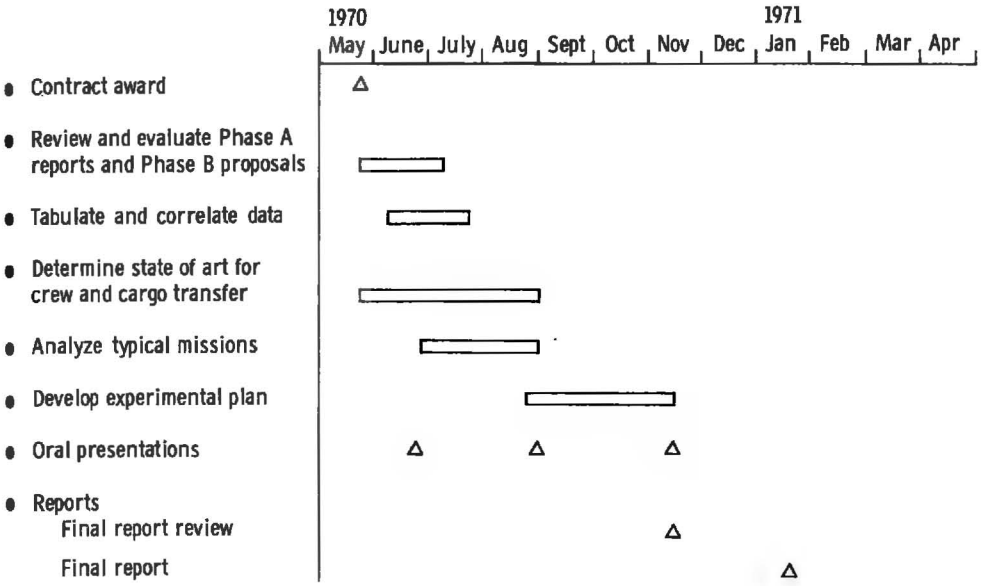


Figure 6.

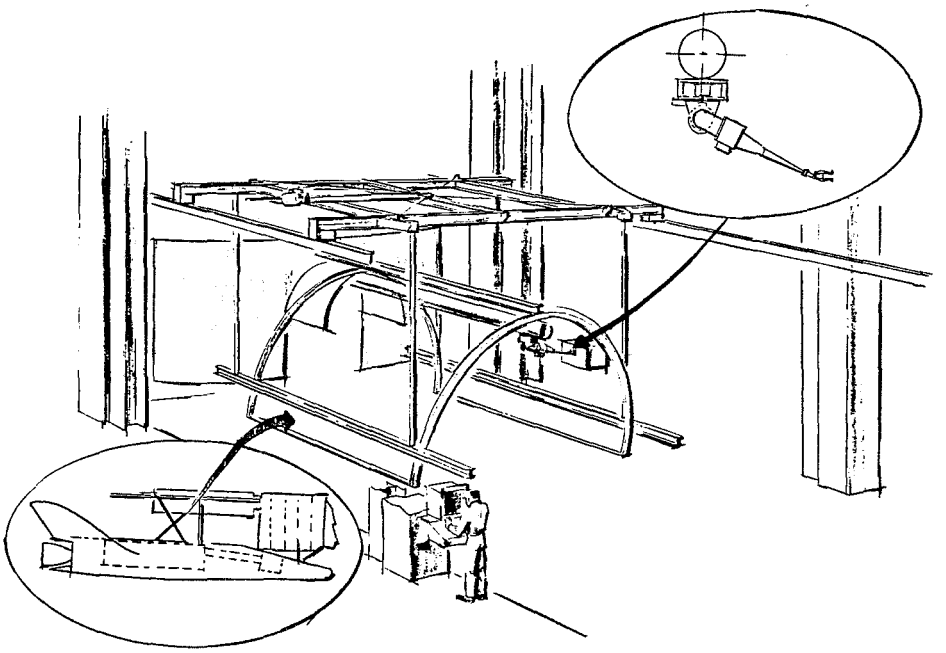


Figure 7.

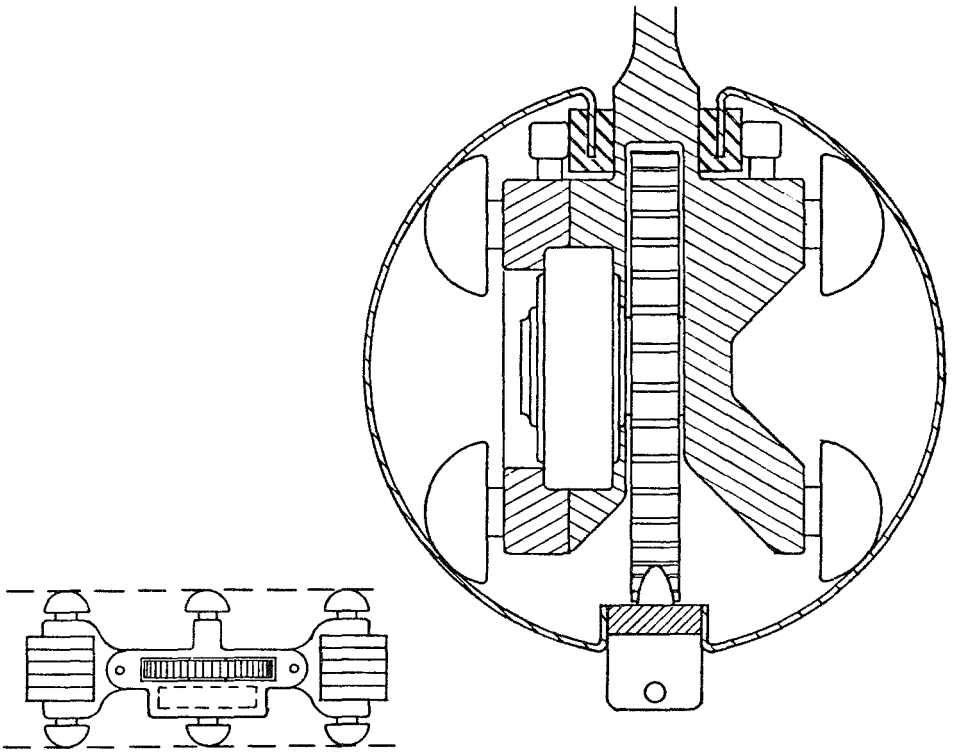


Figure 8.

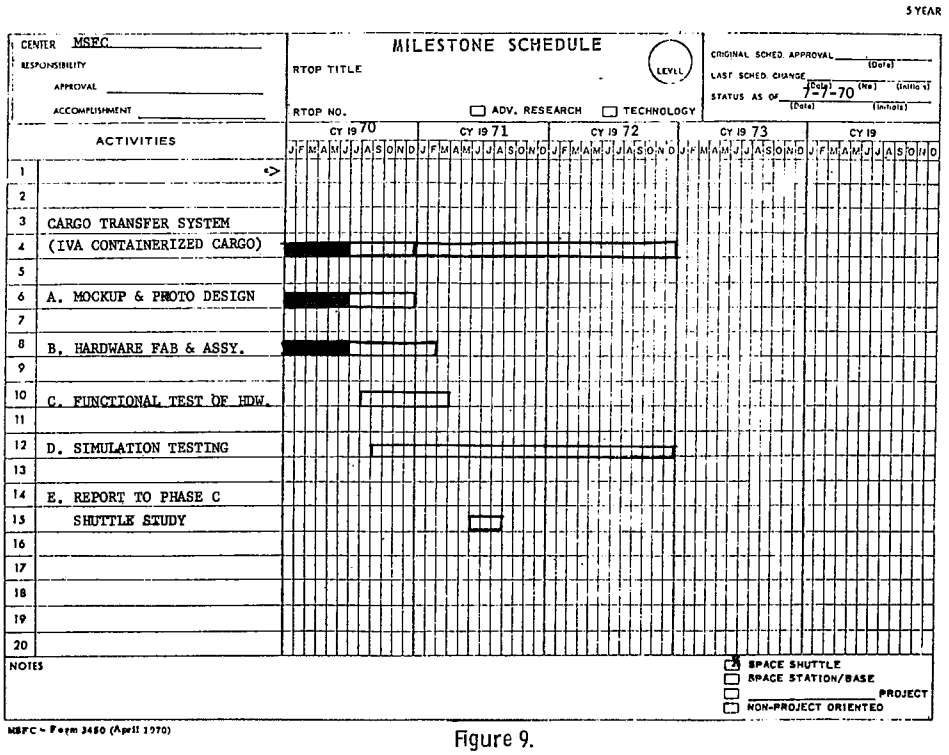


Figure 9.

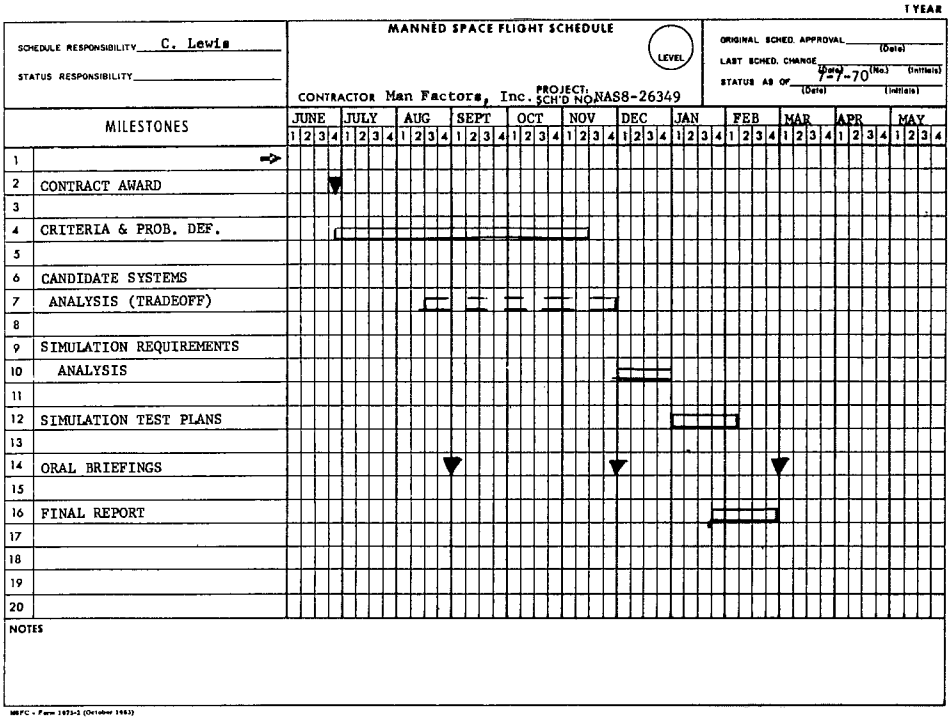


Figure 10.

APPLICATION OF CURRENT SPACECRAFT SIMULATION TECHNIQUES TO SHUTTLE

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Each successive Manned Space Program has utilized operational concepts developed on previous programs. It is appropriate then to review the Shuttle Program in this respect.

The first figure breaks down the Shuttle operational phases. In each phase there is some similarity to Gemini and Apollo. This infers that simulation techniques can be carried over and that much of the Gemini/Apollo equipment can be used.

In comparing these individual phases it becomes apparent that the operational crew interface is less complex than Apollo and probably not too different than Gemini. Certainly, the most obvious differences from Apollo are that the Shuttle crew needs to learn to navigate, maneuver, and handle emergencies in one vehicle and not two; and that the challenging landing task is in an earth atmospheric environment rather than a one-sixth g lunar vacuum.

We can review some of the operational differences which will affect crew procedures, simulation, and training.

Launch (Figure 2)

One of the most difficult operational phases for which to provide complete crew safety and operational procedures is the launch phase. One can hypothesize an infinite variety of launch problems, some of which he can handle (such as an inertial platform failure - Saturn V

can be manually flown in the event of Saturn platform failure); some which he can abort from (such as multiple engine failure at low altitude); and some where he can perform orbital insertion with the Apollo Service Module (such as SIVB engine failure).

The near-pad abort concepts were dictated to some degree by the booster explosion fireball size. The ejection seat was adequate for Gemini but not the Saturn V with its enormous fuel load. None of the previous programs had sufficient thrust/weight ratio in the second stage to fly near the pad. This situation is different for Shuttle, which has a thrust/weight ratio of approximately 1.6; the primary problem being separation and engine start time delay. It appears that about 7 seconds are required for orbiter separation and thrust buildup with this delay being a function of altitude and dynamic pressure. Development of these separation and abort procedures will be a major Shuttle simulation activity. One aspect of crew ability to handle malfunctions is rate of vehicle divergence in event of a propulsion or control failure. Because previous launch vehicles were aerodynamically unstable, they would diverge rapidly after propulsion or control failure. For a worst case combination of high wind shear with booster failure at maximum dynamic pressure, the crew could not react quickly enough to abort prior to Saturn V booster breakup. Consequently, an automatic abort system was included to handle failures through maximum dynamic pressure. The Gemini booster could withstand a higher angle of attack than Apollo, consequently, there was adquate time to manually eject prior to booster breakup. The Shuttle

booster is aerodynamically stable, therefore, in event of multiple engine failure one would expect to be able to safely coast through the high dynamic pressure region before separating and igniting the orbiter engines. The maximum Shuttle dynamic pressure is slightly over half that of Gemini/Apollo.

Maximum acceleration is similar to Apollo but less than half that of Gemini or Mercury. The 3 g Shuttle launch limitation is imposed by structural considerations. The crew and passenger seat position is such that acceleration is in the "eyeballs in" direction. Based on previous centrifuge simulations, man can withstand accelerations much higher than 3 g before vision is affected. The Mercury pilots all experienced 16 g in the centrifuge. This was the reentry acceleration after a suborbital launch abort. The Shuttle would maintain 3 g by throttling the engines or by sequential engine cutoff. Maximum acceleration would be only 5 g if the engines were not throttled. This level would be acceptable to the flight crew.

Entry (Figure 3)

The Gemini crews had no major concern regarding entry stability because the spacecraft would passively trim to the correct attitude if the control system failed. Apollo has two stable trim points - one with the heat shield forward and one with the parachute compartment forward. Because the spacecraft is more stable with parachute compartment forward, many of the launch abort simulations involve practice in orienting a tumbling spacecraft to the correct entry attitude. Entry

lift/drag ratio increases from Gemini to Shuttle, consequently, the corresponding peak dynamic pressures and accelerations are reduced. The frequency of the short period motions should be relatively low and easily amenable to real time simulation computations.

Because footprint control and heating are dependent on Shuttle trim attitude, a large number of entry Shuttle simulations will be planned in the training program.

Approach and Landing (Figure 4)

If we assume a power-off Shuttle approach, which is probably the way the approach should be planned, there is a point on the approach between 3 and 4 miles from touchdown where the lunar module velocity is the same as that of the Shuttle. The flight path angle is nearly identical, including the flare region to about 100 feet altitude. A significant portion of the LM approach was, in fact, simulated by a T-33 by incrementally deploying speed brakes, gear, and flaps. At about 4 miles, the LM pitch attitude permits visual acquisition of the landing site. Corresponding altitude is 7,000 feet.

It is also in this range of correlation that critical manual maneuvers are made by both LM and Shuttle to correct the final approach.

Ground-based radar, TACAN, and ILS will help the Shuttle target to the landing point. In this respect, the landing will be easier than the LM where the pilot is on his own during the final approach phase.

Guidance and Navigation (Figure 5)

Nearly half the Apollo training is devoted to guidance and navigation training. The command module has one G&N system and the LM has

two. Fortunately for the crew, one of the LM systems is similar to the command module system in terms of software and procedures.

This figure shows the scope of the software involved in the MIT G&N system in the command module. In each of the 42 programs, which the crew manually selects, he has an option of displays or maneuvers which he must manually request and software alarms which he must clear. Figure 6 shows the command module crew station with two G&N interface areas - the display and keyboard on the main panel and the navigation sighting station.

The computer key strokes required to accomplish the lunar mission total approximately 10,500.

It is expected that the operational complexity of the Shuttle system will be an order of magnitude less.

Apollo Flight Data File (Figure 7)

Another area where Shuttle crew procedures and training should be much simpler than Apollo involves use of onboard data. The Apollo onboard data package weighed 24 pounds and ranges from small cardboard cue cards which are velcroed to the instrument panel to an 8" x 10" flight plan book to long strip maps of the lunar surface. It is hoped that with the simpler Shuttle mission, where last minute changes are minimized, that a microfilm viewer can be used for much of this onboard data.

Apollo Training Simulators (Figures 8 through 22)

Figure 8 represents the equipment regularly scheduled for Apollo flight crew training. There, of course, is another group of R&D

simulators at the research centers, MSC, and at the contractor facilities, which play an important role in the R&D phases.

Figures 9 through 22 are photographs of the individual Apollo training simulators. An extensive study is underway to establish appropriate phasing of components of this hardware and software into the Shuttle effort. A prime consideration during this phasing is program priority, with Apollo and Skylab maintaining top priority at this time.

As in the case of the Apollo free-flight Lunar Landing Training Vehicle, a variable stability airplane (such as figure 23) will be a key element required for Shuttle approach and landing training.

Summary

In summary, it appears that the operational complexity and training requirements for Shuttle are similar to Gemini. With judicious conversion of existing Apollo equipment, the flight crews can be provided economical and early familiarization with Shuttle operations.

OPERATIONAL SIMILARITIES

GEMINI / APOLLO / SHUTTLE

- LAUNCH
- RENDEZVOUS
- DOCKING
- IVA / EVA
- DEORBIT
- ENTRY
- APPROACH & LANDING

LAUNCH COMPARISON

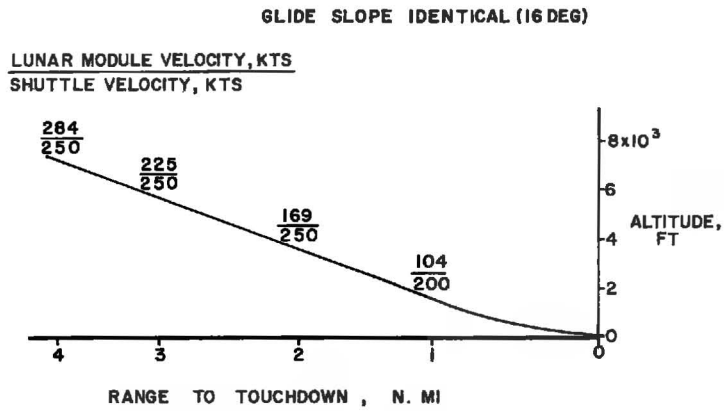
	GEMINI	APOLLO	SHUTTLE
PAD ABORT	EJECT SEAT	ESCAPE TOWER	ORBITER T/W >1
BOOSTER STABILITY	UNSTABLE	UNSTABLE	STABLE
MAXIMUM DYNAMIC PRESSURE, PSF	750	740	420
MAXIMUM ACCELERATION, G	7.4	3.5	3.0

ENTRY COMPARISON

	GEMINI	APOLLO	SHUTTLE
STATIC STABILITY	SINGLE POINT	TWO POINT	VARIABLE
MAXIMUM DYNAMIC PRESSURE, PSF	280	242	120
MAXIMUM ACCELERATION, G	4.5	3.2	2.5

Figure 3

APPROACH AND LANDING COMPARISON

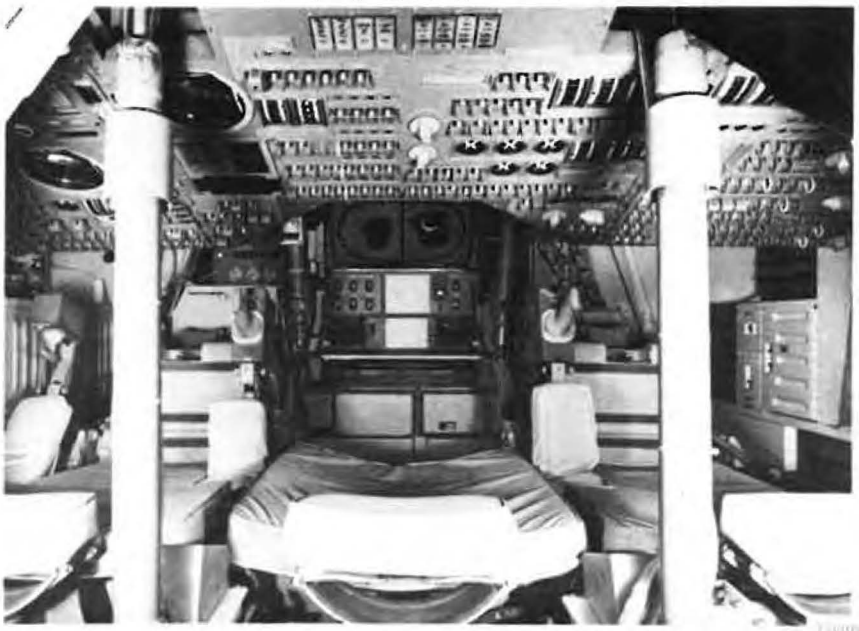


APOLLO COMMAND MODULE COMPUTER

- 42 PROGRAMS
  - PRELAUNCH 6
  - BOOST 2
  - COAST 5
  - PRETHRUST 9
  - THRUSTING 3
  - ALINEMENT 4
  - ENTRY 7
  - PRETHRUST (LM) 6
- 41 STARS
- 90 NOUNS
- 90 VERBS
- 65 ALARM CODES
- 23 ROUTINES

Figure 4

CMS CREW STATION



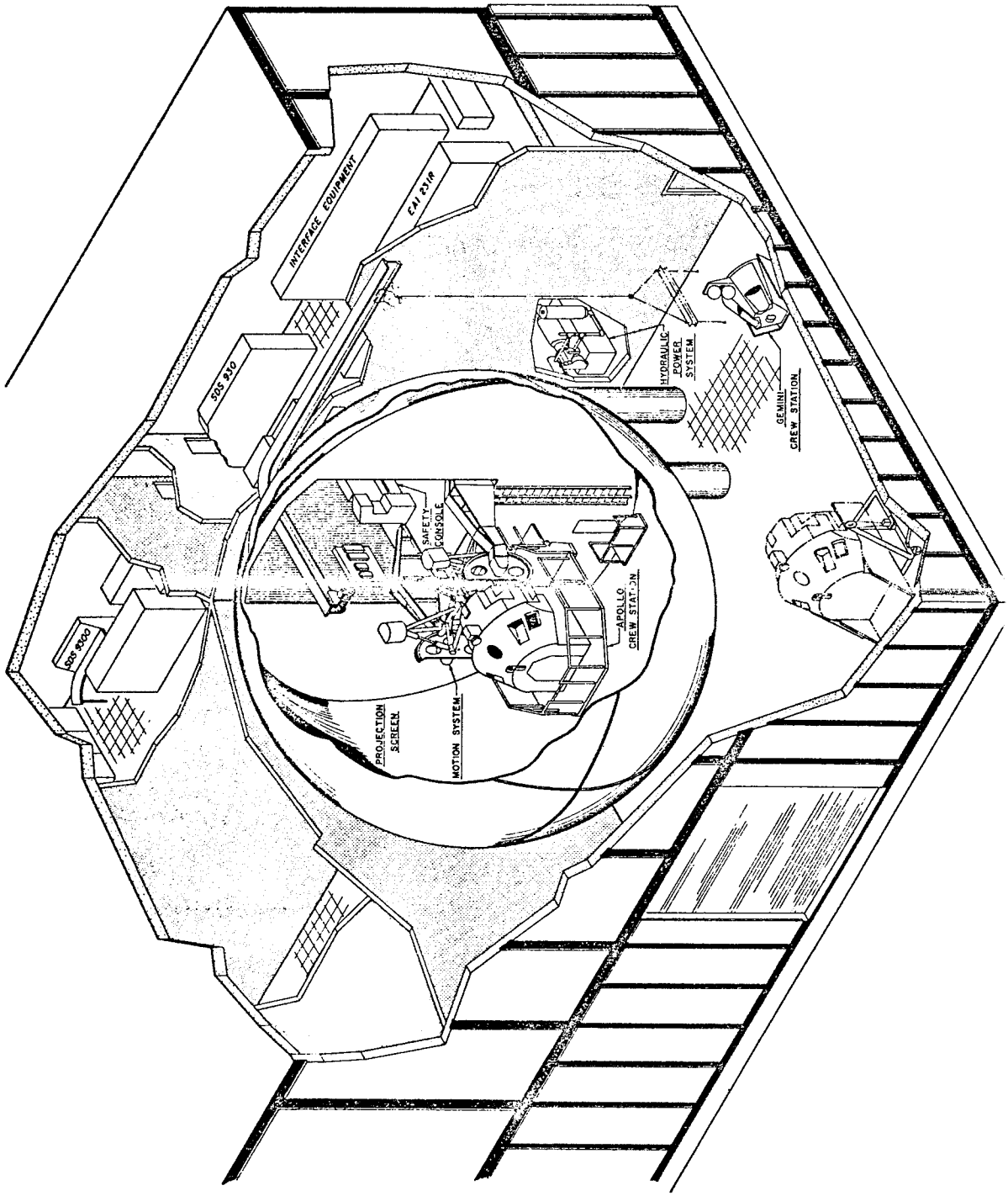
APOLLO FLIGHT DATA FILE

1. FLIGHT PLAN
2. TIMELINE INTEGRATED PROCEDURES
   - CSM LAUNCH CHECKLIST
   - CSM ENTRY CHECKLIST
   - CMP SOLO BOOK
   - CSM RESCUE BOOK
   - LM ACTIVATION CHECKLIST
   - LM TIMELINE BOOK
   - LM LUNAR SURFACE CHECKLIST
3. REFERENCE PROCEDURES
   - CSM G&C CHECKLIST
   - CSM SYSTEMS CHECKLIST
   - LM G&N DICTIONARY
4. DATA RECORDING DOCUMENTS
   - CSM UPDATES
   - LM DATA CARD BOOK
5. SYSTEMS DATA/MALFUNCTIONS
   - CSM SYSTEMS DATA
   - CSM MALFUNCTION PROCEDURES
   - LM SYSTEMS DATA
   - LM MALFUNCTION PROCEDURES
   - LM CONTINGENCY CHECKLIST
6. CREW AIDS
   - LUNAR GRAPHICS
   - STAR CHARTS
   - CSM CUE CARDS
   - LM CUE CARDS
   - MISCELLANEOUS

Figure 7

APOLLO TRAINING SIMULATORS	LAUNCH	RENDEZVOUS	DOCKING	IVA / EVA	DEORBIT	ENTRY	APPROACH & LANDING
DYNAMIC CREW PROC. SIM.	X				X	X	
COMMAND MODULE PROC. SIM.		X			X	X	
LUNAR MODULE PROC. SIM.		X					
TRANSLATION AND DOCKING SIM.			X				
WATER IMMERSION FACILITY				X			
KC - 135				X			
PARTIAL GRAVITY SIM.				X			
COMMAND & SERVICE MOD. MISSION SIM.	X	X	X		X	X	
LUNAR MODULE MISSION SIM.		X	X				X
LUNAR LANDING TRAINING VEHICLE							X
LUNAR LANDING TRAINING VEHICLE SIM							X

Figure 8


INTERFACE EQUIPMENT
CAI 231R
SDS 810
SDS 9000
SAFETY CONSOLE
PROJECTION SCREEN
MOTION SYSTEM
APOLLO CREW STATION
HYDRAULIC POWER SYSTEM
GEMINI CREW STATION

PROCEDURES DEVELOPMENT SIMULATOR Figure 10

TRANSLATION AND DOCKING SIMULATOR

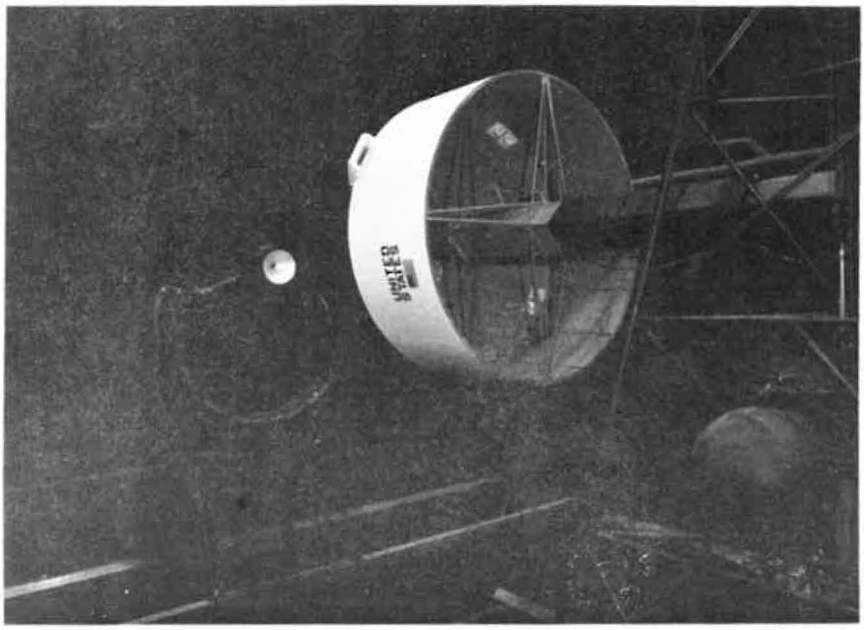


Figure 11

WATER IMMERSION FACILITY

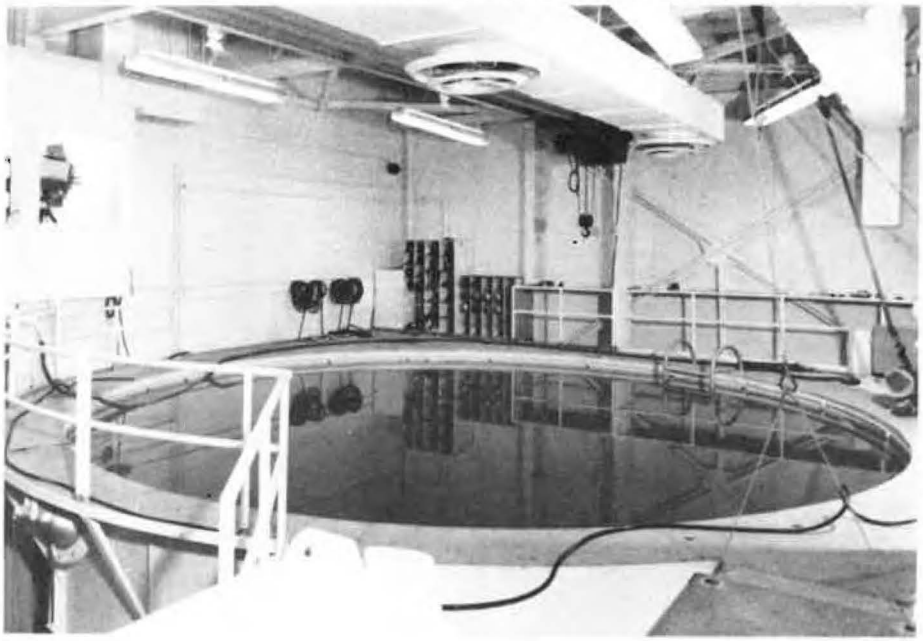
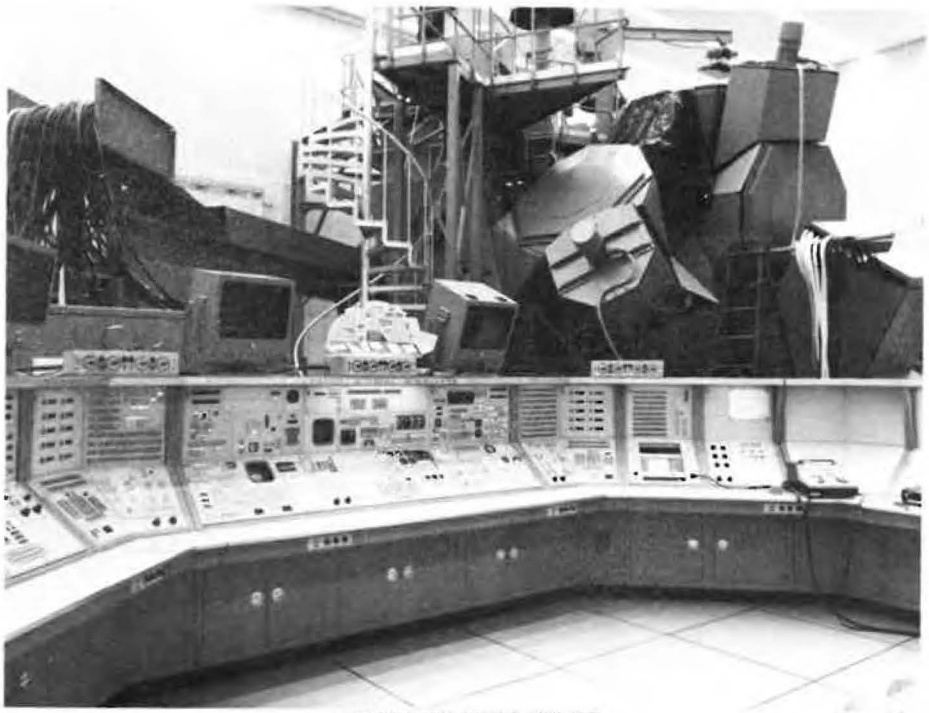


Figure 12

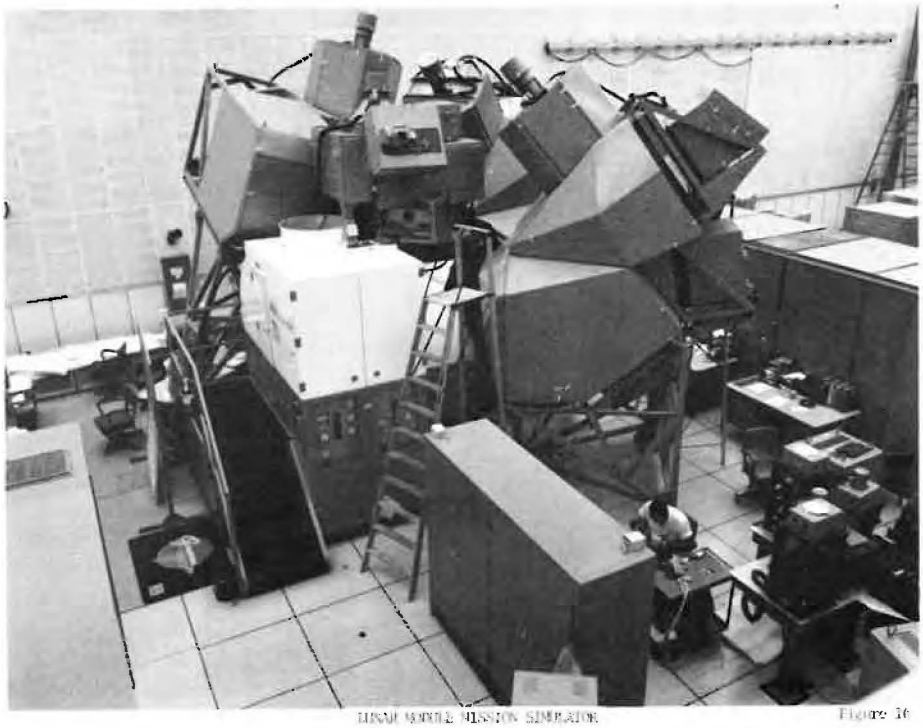
RL-135 Airplane

Figure 13

PARTIAL GRAVITY SIMULATOR Figure 14



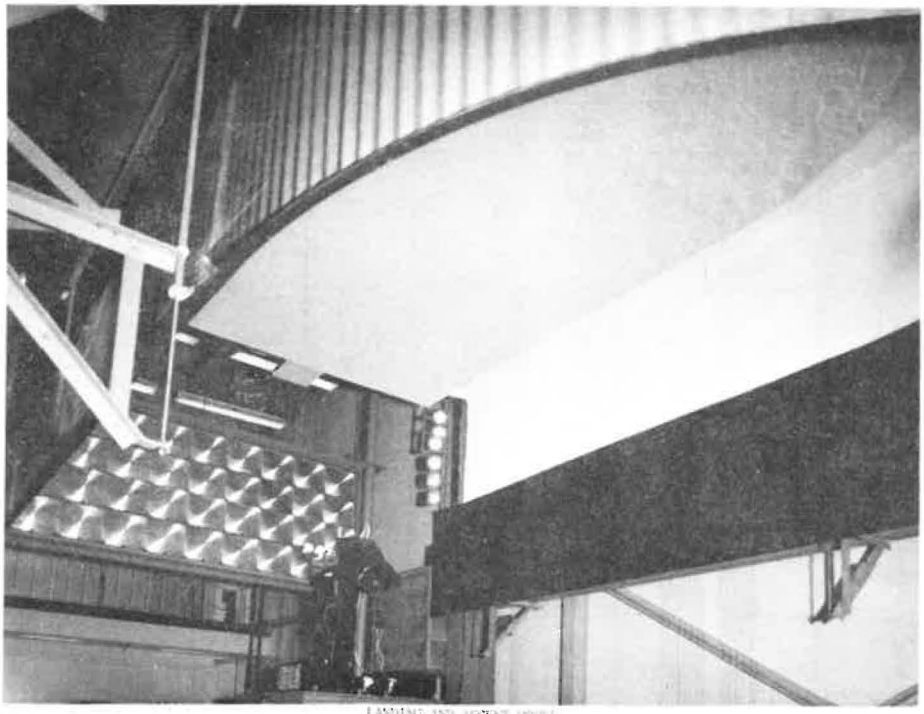
COMMAND MODULE MISSION SIMULATOR Figure 15



LUNAR MODULE MISSION SIMULATOR Figure 16

LMS CREW STATION

Figure 17



LANDING AND ASCENT MODEL

Figure 18

SCALE	MINIMUM AND MAXIMUM ALTITUDE	TOTAL FORWARD DISTANCE	TOTAL LATERAL DISTANCE	LANDING FIELD LENGTH/WIDTH ON MODEL ▷
1:1000	MIN 8.9 FEET MAX 6000 FEET	25,000 FEET 4.1 NM	14,000 FEET 2.3 NM	10 FEET / 3.6 IN
1:2000	MIN 17.8 FEET MAX 12,000 FEET	50,000 FEET 8.2 NM	28,000 FEET 4.6 NM	5 FEET / 1.8 IN
1:2750	MIN 24.5 FEET MAX 16,500 FEET	68,800 FEET 11.3 NM	38,500 FEET 6.3 NM	3 FT 8 IN / 1.3 IN
1:4000	MIN 35.6 FEET MAX 24,000 FEET	100,000 FEET 16.5 NM	56,000 FEET 9.2 NM	2 FT 6 IN / .90 IN
1:5000	MIN 44.6 FEET MAX 30,000 FEET	125,000 FEET 20.6 NM	70,000 FEET 11.5 NM	2 FEET / .72 IN
1:10,000	MIN 89.2 FEET MAX 60,000 FEET	250,000 FEET 41.2 NM	140,000 FEET 23.0 NM	1 FOOT / .36 IN

▷ BASED ON 10,000 BY 300 FEET RUNWAY

COMPARISON OF EFFECT OF VARIOUS MODEL SCALES

Figure 19

MISSION PARAMETERS	X-AXIS			Y-AXIS			Z-AXIS		
	L&A	SCALED TO REAL WORLD	MEETS SHUTTLE REQUIRE-MENTS	L&A	SCALED TO REAL WORLD	MEETS SHUTTLE REQUIRE-MENTS	L&A	SCALED TO REAL WORLD	MEETS SHUTTLE REQUIRE-MENTS
MAXIMUM RANGE	14 ft	9.2 nm	Yes, must be at least 4.2 nm	23 ft 7 in	15.5 nm	No, descent profile down range up to 50 nm	6 ft	4.0 nm 24,000 ft	Yes, landing visual occurs below 24,000 ft
MINIMUM RANGE	0	0	Yes	0	0	Yes	.107 in	428 in 35.6 ft	No, should be 25 ft or less
MAXIMUM VELOCITY	5.4 ips	1066 knots	Yes, must be at least 300 knots	6.0 ips	1185 knots	Yes, must be at least 300 knots	.46 ips	90.9 knots 153 ft/sec 9200 ft/min	Yes, should be 1000 ft/min or better
MAXIMUM ACCELERATION	1.02 ips^2	340 ft/sec^2	Yes, to be determined by dynamic tests	7.9 ips^2	2633 ft/sec^2	Yes, to be determined by dynamic tests	.783 ips^2	261 ft/sec^2	Yes, to be determined by dynamic tests
POSITION ERROR (STATIC)	.0312 in	124.8 in 10.4 ft	No, must be less than 8 ft	.062 in	248 in 20.7 ft	Yes, must be less than 30 ft	0.0 in	0	Yes

SHUTTLE PROFILE CASE FOR L&A SCALE OF 1:4000

Figure 20

Figure 21. - LUNAR LANDING TRAINING VEHICLE.

LLTV SIMULATOR

Figure 22

APPROACH AND LANDING SIMULATOR

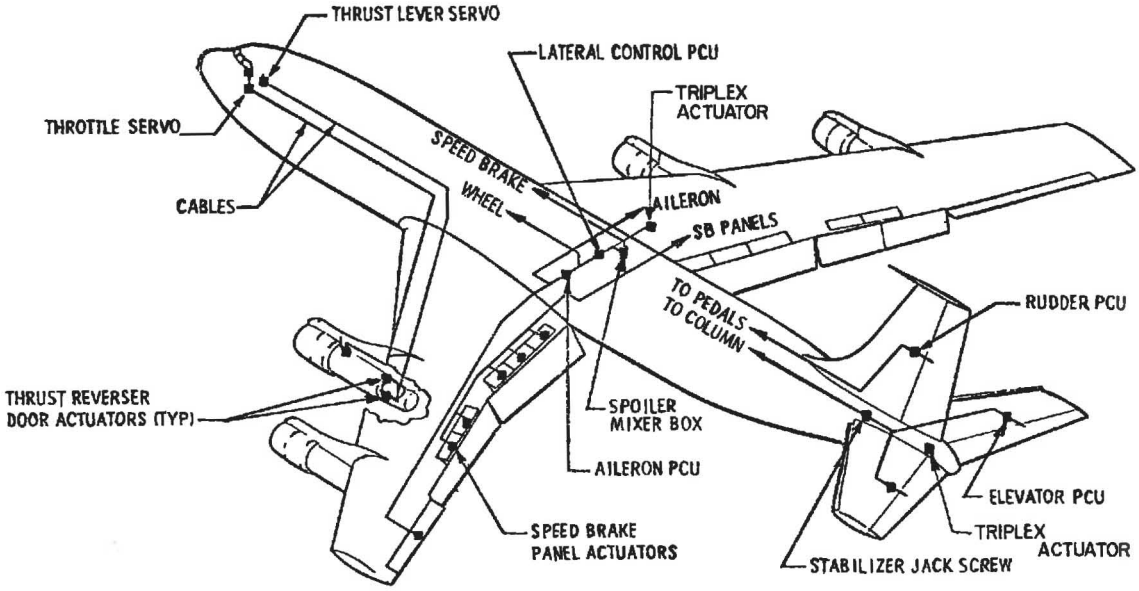


Figure 23

RESULTS OF PICTORIAL DISPLAY STUDIES WITH POTENTIAL APPLICATION TO ORBITER APPROACH AND LANDING

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Current plans are for completely automatic guidance and control of the space shuttle vehicle during the approach and landing phases of its return to earth. It is also intended that these phases of the craft's mission shall be accomplished under any condition of weather. In order to realize the increased reliability provided by the presence of the pilots on this craft, it is considered imperative that information on flight performance and progress be provided to the pilots by some system that is as independent of the primary control system as is feasible. The accepted nomenclature for such a system is--"Independent Landing Monitor" or simply ILM.

A class of candidate systems for an ILM is based on a cathode ray tube pictorial display of the terrain ahead of and below the vehicle. An imaging system such as radar or microwave scanners could provide such a pictorial display that would be completely independent of the primary guidance and control system. Such a display could also include information from airborne instrumentation such as altitude, airspeed, sink rate, etc., to reduce the amount of eye scanning required of the pilot.

The Man-Machine Integration Branch at the Ames Research Center has been conducting research on visual displays for pilot control of conventional aircraft for some time. Recent emphasis has been on the utilization of pictorial displays that were independent of the instrument landing system (ILS) for pilot monitoring and control during the approach and landing with zero visibility out the window. As indicated in the schedule of Figure 1, it is intended that this pictorial display research, which was initiated with displays for the all-weather landing of a light plane, will continue through displays for heavy jet aircraft, the high lift-to-drag (L/D) space shuttle and the low L/D space shuttle. The work was started using a light plane simulation to minimize the interaction effects of vehicle dynamics with a determination of the basic information requirements for flight path control to touchdown. Subsequent simulation of a DC-8 with a pictorial display has indicated that no complications will arise due to the more difficult-to-control dynamics.

Figure 2 is a typical pictorial display developed in this program. In this figure the picture of the runway is representative of that which would be presented through the microwave or radar imaging system. The Visual Approach System Indicator (VASI) lights would be produced also through the imaging system and would have their source in beacons located aside of the runway. The remaining information in the display, such as the horizon, heading reference, and digital readout data, would be derived from gyro sensors or other aircraft instrumentation.

The display of Figure 2 is one of several candidate displays devised in this program and was labeled Display Configuration II. Another display studied, Display Configuration III, was the same during the approach phase but with the addition of an aim point or velocity vector (the point where the craft would impact the ground if no changes were made to the flight path). Some results of simulated flights with these displays are shown in Figure 3. These data are from a balanced experiment with six airline pilots making 16 flights each at each display configuration. The simulated dynamics were those of a four place light plane with the throttle fixed to maintain an airspeed of 100 knots on the three degree glideslope. Turbulence, vertical drafts and crosswinds were included as perturbances. From this figure it is apparent that Display Configuration III yielded the best performance, particularily for the touchdown. In general, the airline pilots were very enthusiastic about the pictorial display concept, and the data indicate that these kinds of displays have potential for manual approaches and landings.

That such displays can be used to successfully monitor automatic approaches is a subject of a current investigation using a DC-8 simulation and airline captains certified for Category II approaches. It is recognized that some modifications in the display concepts may be required to make these kinds of displays suitable for monitoring as well as manual control.

It is believed that with only minor modifications, this display technology can be applied to the space shuttle mission, and Ames is preparing to perform research along these lines as indicated in Figure 1. A cockpit mockup of the space shuttle vehicle will be prepared with a panel mounted ILM, such as shown in Figure 4. The vehicle dynamics for the low cross-range, high L/D configuration and the high cross-range, low L/D configuration will be simulated on a computer. Piloted experiments will be conducted to determine the utility of various display concepts for monitoring automatic approach profiles and landings and for backup manual control. These experiments also will investigate some schemes for the monitoring of energy management.

In conclusion, it is believed that the fully automatic approach and landing system for the space shuttle vehicle should include an ILM. Since pictorial displays have shown promise in studies of manually controlled approaches and landings, it is recommended that such display concepts be considered for that vehicle. Display research at Ames will continue according to the time schedule of Figure 1 with the aim of optimizing an ILM for the space shuttle vehicle.

PICTORIAL DISPLAY RESEARCH SCHEDULE

TASK	VEHICLE SIMULATED	FY 1971 - quarter				FY 1972 - qtr	
		1st	2nd	3rd	4th	1st	2nd
ZERO VISIBILITY MANUAL APPROACH AND LANDING	LIGHT PLANE						
1200 ft VISIBILITY MONITOR AUTOMATIC APPROACH TO 100 ft DH	DC-8						
ZERO VISIBILITY MANUAL APPROACH AND LANDING	DC-8						
ZERO VISIBILITY MONITOR AUTOMATIC/ MANUAL APPROACH AND LANDING	SSV HIGH L/D						
ZERO VISIBILITY MONITOR AUTOMATIC/ MANUAL APPROACH AND LANDING	SSV LOW L/D						

Figure 1. Man-Machine Integration Branch space shuttle displays program.

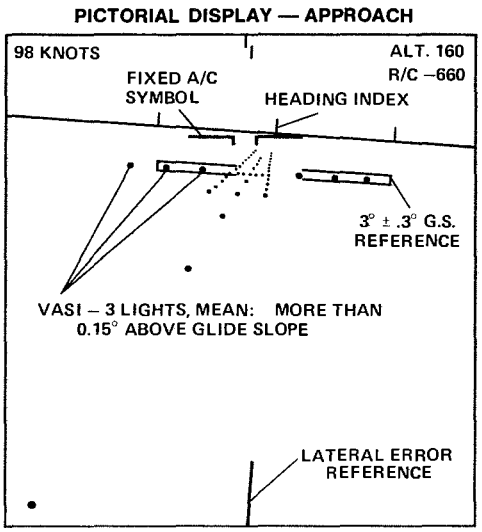
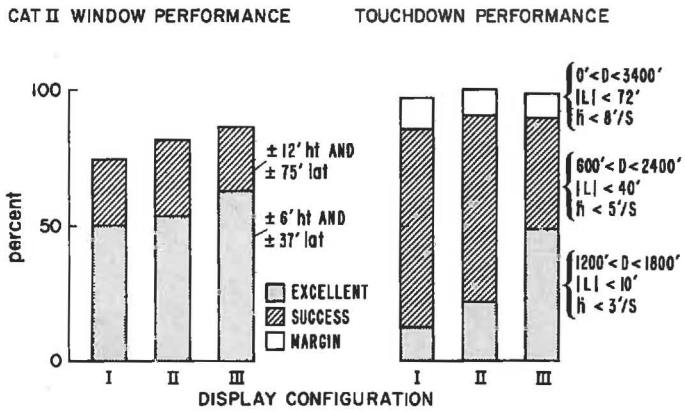


Figure 2. - Display Configuration II during an approach. Aircraft is to the right and slightly high of the desired flight path but the heading and pitch angles are appropriate to reduce flight path errors.



D = distance down runway
|L| = lateral deviation from centerline
$\dot{h}$ = sink rate

Figure 3. Manual control performance results. Six airline pilots made a total of 96 flights with each of three displays. Performance shown as the percent of flights falling within the categories indicated.

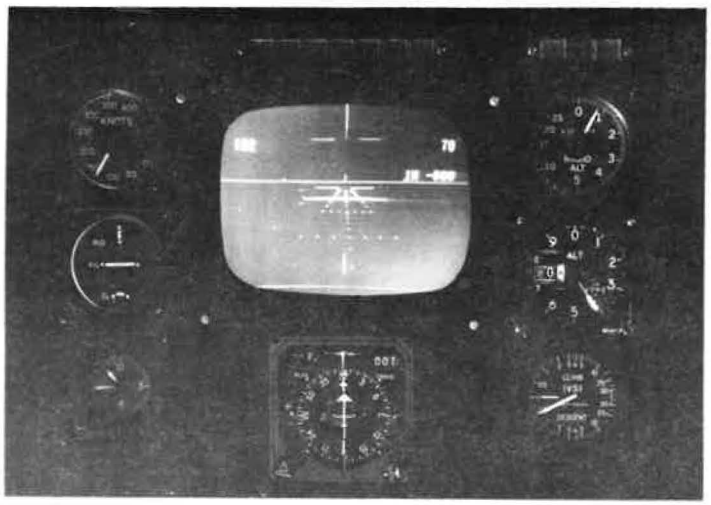


Figure 4. Panel mounted Independent Landing Monitor for the DC-8 CAT II approach study.