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This volume contains papers dealing with Biotechnology - presented at the Space Shuttle Technology Conference, held at Phoenix, Arizona, March 18, 1971.

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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.

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 the program. The symposium on which this publication is based was held at Phoenix, Arizona during the week of March 15, 1971 and was the second report in the areas of Biotechnology as well as Operations, Maintenance, and Safety. The Symposium goals are 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, they offer an opportunity to identify the responsible individuals engaged in the program. The Symposium sessions are intended to confront each presenter with his technical peers as listeners.

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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CONTENTS

N71-35260

BIOTECHNOLOGY

SPACE SHUTTLE ORBITER ENVIRONMENTAL CONTROL

AND

LIFE SUPPORT SYSTEMS

O. T. Stoll
Space Division of
North American Rockwell Corporation
Downey, California

A. O. Brouillet
Hamilton Standard
Division of United Aircraft
Windsor Locks, Connecticut

ABSTRACT

The Space Shuttle Orbiter Environmental Control and Life Support System is presented. The rationale leading to selection of concepts is stressed. The concept trades were based on an anticipated 1977 initial orbiter flight, ten years operation and a baseline mission support requirement of four men for seven days. The paper reflects a summary of concept selection work completed by the North American Rockwell Space Division Team, under contract to NASA, Manned Spacecraft Center. Hamilton Standard provided support to this study.

THE SPACE SHUTTLE

The Space Shuttle is to be a fully reusable two-stage transportation system for manned earth orbiting operations. It is designed to take off vertically and land horizontally. The Space Shuttle will consist of two vehicles - a booster and an orbiter. The booster carries the cargo-filled orbiter piggy-back to the fringe of space, then separates and flies back to a landing site and lands horizontally.

The orbiter, with its payload, continues into earth orbit to provide space station support operations or perform independent space operations. After completion of the mission,deorbit takes place and the orbiter lands horizontally. Figure 1 illustrates the basic shuttle mission. The primary purpose of the shuttle is to reduce the expense of space travel to less than 1/10th of today's cost.

PHASE B STUDY TASKS

The functional requirements of the orbiter Environmental Control and Life Support Station (ECLSS) can be satisfied by a number of alternate concepts. The primary tasks of the first six months of the Phase B study contract were to determine design requirements and criteria, establish a baseline system, and evaluate alternate concepts to the various requirements. This paper provides a description of the chosen ECLSS concepts and their selection rationale.

REQUIREMENTS AND DESIGN CRITERIA

The primary requirement for the ECLSS and all other systems is to provide a low cost reusable system. The cost of development is of particular concern and for this reason, whenever possible, previously developed concepts will be utilized. The concepts are to be based on 1972 state-of-art criteria, and require minimum maintenance and refurbishment, provide turnaround in two weeks or less, and support 100 missions over a ten-year period.

The ECLSS must provide the following functions:

A. Shirt-sleeve environment for the crew and passenger compartment.

B. Food, water, oxygen and storage and disposal of trash and human waste. Where required, provide environmental control of equipment in and outside the crew compartment.

The subsystems that provide these functions must have the performance capabilities to meet the requirements of Table 1.

TRADEOFF STUDIES

The functions of the ECLSS can be satisfied by more than one concept or method. Therefore, to trade the alternates against each other, a concept was selected as the baseline and the others traded against this concept. The baseline concept and the alternates are shown in Table 2.

- SEVEN DAY MISSION - 270 N MI X 55 DEG INCL
- 2 CREW -- 2 PASSENGERS
- SPACE STATION SUPPORT

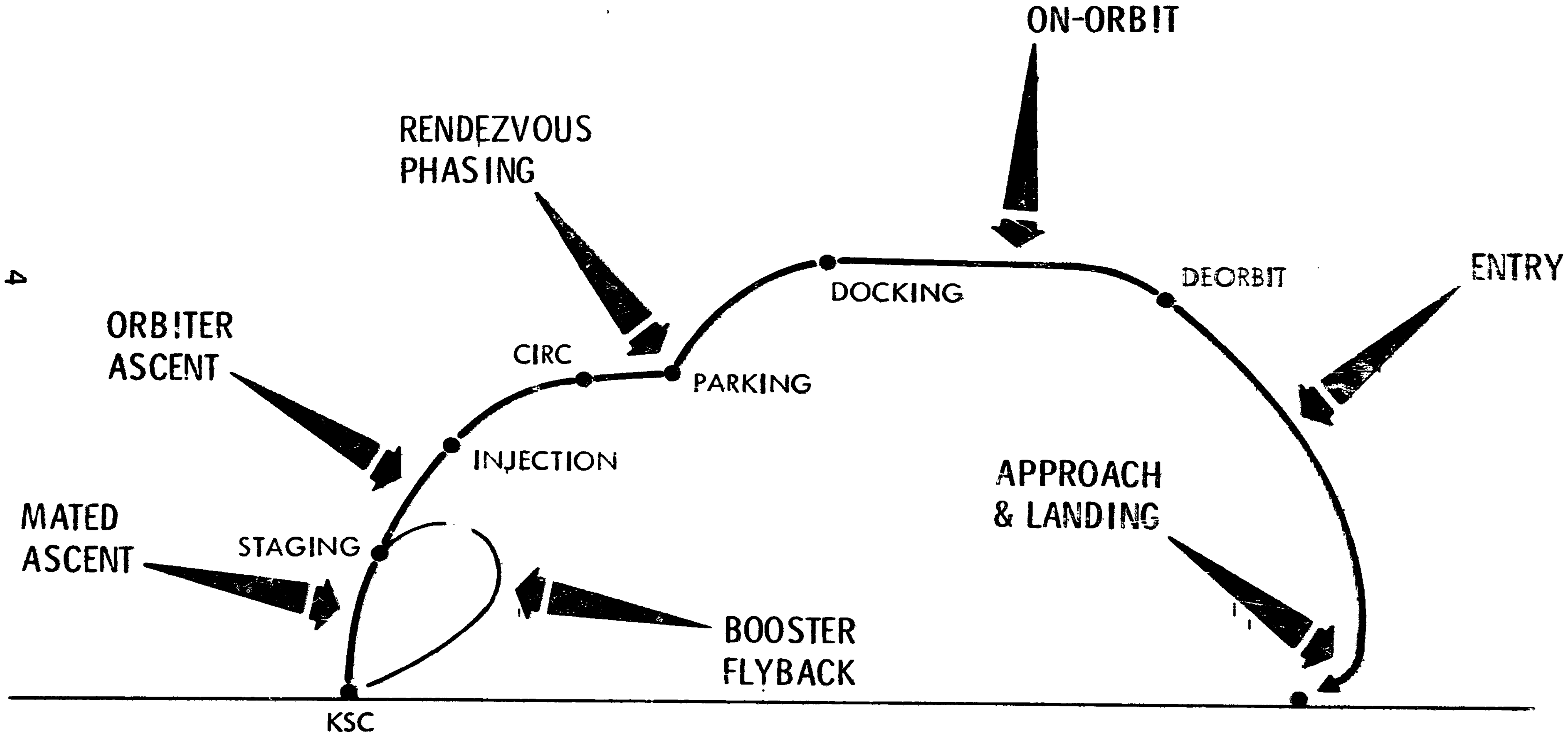


FIGURE 1 -- BASELINE REFERENCE MISSION PHASES

TABLE 1. DESIGN REQUIREMENTS & CRITERIA

Functional Requirements (Design Point)

Cabin Total Pressure (Normal)	14.7 PSIA
Oxygen Partial Pressure (Normal)	3.0 to 3.4 PSIA
Carbon Dioxide Partial Pressure (Max. Normal)	7.6 mm Hg
Cabin Temperature (Selectable)	65 - 75°F
Cabin Humidity	46 - 57°F D.P.
Trace Contaminants (Max. on each contaminant)	0.1 TLV

Design Loads

Heat Loads

Hydraulic System (Heating) (BTU/Hr)	0 - 15,000
Fuel Cell Cooling (Max. - BTU/HR)	36,000
Metabolic Heat	
Sensible (BTU/Man-Hr)	345
Latent (BTU/Man-Hr)	205
Wall and Window	-8,800 to +2400 BTU/HR
Electronics Cold Plate Load	20,460 BTU/Hr
Electronic Air Load	12,200 BTU/Hr
Water Consumption	6.91 lb/Man-Day
Urine Production	3.58 lb/Man-Day
Feces Production	.25/lb/Man-Day
Cabin Leakage Rate	7 lb/Day

Failure Mode

The system, except for pressure vessels such as tubing and tanks, in the event of failure, shall be designed to fail operational and fail safe with the second failure.

The major trade evaluation criteria were cost (emphasizing cost prior to first orbital flight), weight, power required, and volume. These factors were determined for the baseline and alternate concepts, generally at the design point, and the evaluations made. A description of the concepts and their evaluation is provided below.

WASTE MANAGEMENT

Three Waste Management Subsystem (WMS) concepts were evaluated as possible candidates for the Shuttle orbiter. The major design consideration in this evaluation was the collection of solid human waste. The basic concepts were:

(a) A collection bag is provided for insertion in a canister which has sufficient air flow to produce detachment and entrainment. The bag is manually sealed and placed in a storage compartment.

(b) An integrated collection and storage container of sufficient capacity for a seven-day mission. For extended missions, it can be removed when full, replaced, and remotely stored.

(c) A collection bag, which is manually placed in a waste receiver, is provided for waste collection. After an expended bag is sealed, the waste receiver semi-automatically rotates 90° and ejects the bag into a storage chamber. Following ejection the receiver returns to its original position.

The integrated collection and storage container was selected for the Orbiter WMS. Its stage of development is the most advanced, as well as having the greatest aesthetic attractiveness. A similar system has been proposed for the Orbital Space Station, which offers significant commonality potential for equipment as well as procedures.

A rotary separator urine collection concept was selected over the hydrophobic bag separator/collection approach for two reasons: 1) handling requirement is undesirable; 2) Skylab program has not been successful in developing this concept. The rotary separator concept requires no handling by the crew, is being developed by Hamilton Standard for Skylab, and has been selected for SSP. Urine collection tanks may or may not be employed, depending upon overboard dumping limitations.

HUMIDITY CONTROL

The following Humidity Control Concepts were evaluated:

(a) Condensing heat exchanger

(b) Desiccant adsorption with vacuum desorption

(c) Desiccant adsorption with vacuum desorption and ullage save pre-pump

The condensing heat exchanger concept utilizing a 3-fluid, stainless steel heat exchanger. A wick water separator collects condensate and wicks it to a hydropholic transfer disc from which it is pumped to the condensate collection system. The condensing heat exchanger is oversized to provide a sensible heat exchanger coolant inlet temperature high enough to prevent condensation. A single latent/sensible heat exchanger was not considered due to the associated penalty with providing a cabin heating capability.

An isothermal, vacuum regenerable, four-bed silica gel desiccant humidity control concept was considered. This concept desorbs its water vapor to space vacuum. The addition of heaters and/or pumps to achieve desorption at sea level conditions significantly increases launch weight. Humidity control is achieved by process flow bypass. A pre-desorption pump-down approach was considered to conserve ullage gas during orbital operation, but provided no advantage for the baseline 7-day mission.

The condensing heat exchanger concept has the advantages of being lighter and less complex than the desiccant approach. Additionally, the condensing heat exchanger will perform normally for all phases of orbiter missions, including ferry flight. During space station docked operation, the condensing system can inhibit its overboard dumping by storing its condensate, whereas the desiccant cannot desorb without dumping its collected water vapor to space vacuum. Studies have shown that although increasing the heat transport loop radiator outlet temperature, as is allowed by the use of the desiccant, decreases the radiator fixed weight; the increased fixed weight of the desiccant over the condensing heat exchanger and the added weight of other heat exchangers more than offsets the radiator weight savings and causes the total system weight to increase. The desiccant system also requires significant specialized GSE to dry the beds out between flights. For these reasons, a condensing heat exchanger is selected for humidity control.

CARBON DIOXIDE ODOR AND TRACE CONTAMINANT CONTROL

Two flight qualified concepts for CO_2 control were evaluated. Lithium Hydroxide (LiOH) has flown on BIOS, Apollo LM and Apollo CM. Canisters can be designed to contain LiOH and activated charcoal to control CO_2, odors and trace contaminants. The reaction of LiOH with CO_2 produces water vapor and some heat.

Molecular sieve CO_2 control systems have been developed for the MOL and Skylab programs. The 3 bed concept investigated uses a two-section bed, the front section being a silica gel pre-dryer and the back section the CO_2 adsorber section. The pre-dryer bed is operated isothermally by use of 80°F coolant. The molecular sieve (Linde 5A) section desorbs adiabatically. This concept requires separate charcoal canisters for odor and trace contaminant control. With the use of the molecular sieve concept, supplemental CO_2 control is required for atmospheric operation, i.e., Ferry, Pre-Launch, Atmospheric flight. An ullage save pump-down version of the molecular sieve system was also investigated because of the relatively high amount of nitrogen co-adsorbed and subsequently lost on the molecular sieve at 14.7 psi cabin operating conditions.

The major disadvantages of the molecular sieve concept relative to LiOH are:

1. Higher development cost

2. Higher weight has an impact on total vehicle weight

3. Development of the Lithium Hydroxide elements is still required since the elements are required for ground operations, pre-launch, loading and ferry.

4. The system cannot be "off loaded" for short flights or when only the crew will be aboard.

5. More complex than the LiOH system.

The major advantages of the Molecular Sieve are:

1. Lower recurring costs (only charcoal canisters required for each flight)

2. Lower payload penalty for the long duration missions

The major advantages of the Lithium Hydroxide system are:

1. Lower development cost

2. Lower weight

3. More flexible elements can be off-loaded for short missions and when the passengers are not carried or added for longer or passenger carrying missions.

Both systems will meet the requirements; however, the Lithium Hydroxide system provides less weight and DDT&E costs. It is recommended that initially the LiOH system be employed. However, since the molecular sieve system is being developed for Skylab and other Space Station programs, it is recommended that the vehicle design not preclude installation of this system later in the program for longer duration flights.

THERMAL CONTROL

The Shuttle Orbiter Crew Compartment requires temperature control to remove sensible heat from the crewmen, walls, windows, and electrical and electronic equipment. The heating of the compartment air may be required particularly in the local areas near the tunnel heat shorts and windows.

The concepts which can collect this heat and transfer to the coolant transport loop are heat exchangers with fans, "coldwalls" with fans or a combination of both. The coldwalls consist of coolant transport tubing attached to the walls or wall panels. The heat is then directed to these panels by radiation and forced convection. For cabin heat exchangers, the heat is transmitted to the heat exchangers by forced convection. The exchanger cools the cabin air which must collect the heat from the walls by convection. This then, by necessity, causes the walls to run, five to ten degrees or more, hotter or colder than the air. The occupants then either feel cool when the cabin air is being warmed, or warm when the cabin air is being cooled.

The cooling requirements show that a cold wall/fan concept will not supply sufficient cooling because of the high electrical heat load on the cabin air and the limited areas where cold walls can be located.

The evaluation determined that the use of cold walls could not significantly reduce the cabin heat exchanger system. However, a weight saving could be realized in the amount of insulation required to prevent overcooling the cabin prior to launch, and excessive temperatures after entry.

HEAT REJECTION

During ground operations, atmospheric flight, and orbital flight, waste heat must be removed from the compartment and rejected.

The following concepts were evaluated for waste heat rejection:

- GSE Heat Exchanger
- Sublimator
- Radiator
- Hydrogen Evaporator
- Cryogenic Heat Exchanger
- Ram Air Heat Exchanger
- Freon Evaporator
- Ammonia Evaporator
- Air Cycle
- Vapor Compression Cycle

It is desirable to have one unit which will serve as a heat sink for all operational phases with no supplemental cooling required. Four units which will operate for all phases are the hydrogen, Freon, and ammonia evaporators, and the vapor cycle subsystem. In order for these units to serve as a heat sink for a complete mission, a sufficient quantity of consumables would be required to be onboard at launch. The study indicated the consumable weight and program cost would be greater than using a different concept for each mission phase. Therefore, for application to the space shuttle orbiter, these units can best be used for supplemental cooling, or for atmospheric flights of short duration only.

The ram air heat exchanger and the air cycle systems can be used during atmospheric flights. The ram air system will require supplemental cooling at design flight speeds. This cooling may be supplied by a unit such as

TABLE 2

HEAT SINK PARAMETRIC COMPARISON

CONCEPT	SUBCONTRACTOR			NORTH AMERICAN			VEHICLE		TOTAL COSTS		TOTAL
	Weight Lbs.	Power Watts	Volume Ft^3	Weight Lbs.	Power Watts	Volume Ft^3	Non Rec Cost $\$x10^{-6}$	Rec Cost $\$x10^{-6}$	Non Rec Cost $\$x10^{-6}$	Rec Cost $\$x10^{-6}$	Cost $\$x10^{-6}$
GSE HX (1)	10.0	0	0.25	20.0	0	0.06	0	0	1.400	0.860	2.260
Sublimator (3) (2) (1)	120.0	10.0	4.0	51.0	0	0.91	0	0	2.986	3.546	6.532
Radiator (1)	1020.0	10.0	85.0	5.0	0	0.03	-5.889	-3.533	1.517	6.719	8.236
H_2 Evap (1) (2)	100.0	10.0	2.5	50.0	0	0.87	0	0	4.668	9.254	13.922
H_2 Fuel HX	60.0	10.0	1.0	5.0	0	0	-0.618	-0.370	3.036	5.645	8.681
Ram Air HX	35.0	0	1.0	115.0	0	7.0	0	0	4.762	1.745	6.507
Freon Evap (2) (3)	259.0	10.0	21.0	51.0	0	0.87	+1.040	+0.624	3.638	7.471	11.109
NH_3 Evap (2) (3)	79.0	10.0	7.0	51.0	0	0.87	-0.130	-0.078	2.468	6.769	9.237
Air Cycle	185.0	0	6.0	148.0	0	8.1	+1.190	+0.714	8.692	8.102	16.794
Vapor Cycle	350.0	15000.0	3.6	40.0	0	0.8	-0.065	-0.039	3.855	6.309	10.164

1 Baseline

2 Weights do not include consumables.
Consumables required are as follows:
Water Sublimator = 25 lbs/hr Water
H_2 Evaporator = 30 lbs/hr H_2
Freon Evaporator = 380 lbs/hr Freon 12
NH_3 Evaporator = 45 lbs/hr Ammonia
Vapor Phase = 160 lbs/hr O_2& H_2

3 Weights include tankage penalty for 4 hours operation.

the evaporators indicated above. The air cycle system will provide sufficient cooling capacity for all atmospheric flights.

For space flights, the radiator will reject all heat unless limited by radiator area. For peak loads or radiator failure, supplemental cooling is supplied by a water sublimator. The sublimator will also provide cooling during the period of time the radiator is not on stream at the start of the orbital flight and just prior to reentry. For the sublimator, water is supplied from the water generated by the fuel cells.

Heat sink capability for ground operations may be supplied by the evaporators or by GSE. A GSE onboard heat exchanger can also be used for cooling during docked operations, with the heat from the orbital vehicle being rejected through the space station heat transport system.

The evaporator/heat exchanger discussed above utilizes cryogenic hydrogen, (300°R), from the ACPS and dumps the hydrogen overboard after using.

Table 2 provides the weight, power, volume and cost data for these heat rejection concepts. The selected heat rejection subsystem is composed of the following units:

1. A GSE heat exchanger to operate during all ground operations.
2. A hydrogen evaporator to provide heat sink capabilities during all atmospheric operations.
3. A combination radiator-sublimator be installed to operate for all space operations.

The above combinations will supply all heat rejection capabilities at the least cost and weight, and, in addition, will provide greater flexibility for meeting extended flight requirements.

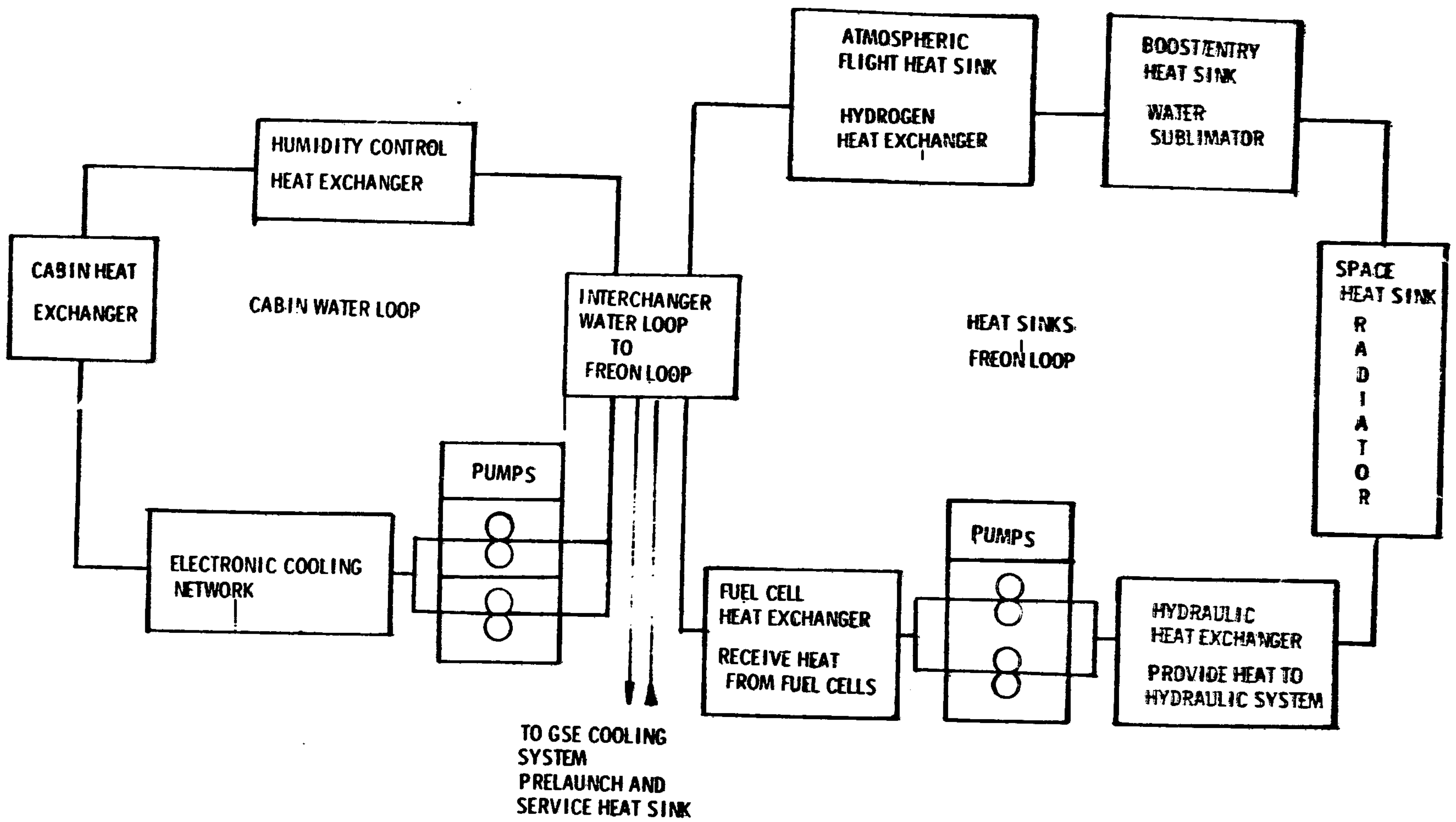
SYSTEM DESCRIPTION

The tradeoff resulted in the selection of the concept shown in Table 3.

Figure 2 shows the integration of the heat transport, heat rejection, temperature control, humidity control, and CO_2 control functions. With this arrangement toxic coolants are kept from the manned cabin and a low freezing temperature coolant is provided for the heat rejection equipment in a manner similar to the Space Station Prototype (SSP) approach. A single, six fluid interface heat exchanger allows either water loop to function with either F_{21} loop without switching valves. The GSE function doubles as the space station interface for docked operations. The sublimators perform all heat rejection functions that the radiator cannot at altitudes of 100,000 ft or greater. The hydrogen evaporators provide heat rejection at altitudes below 100,000 feet. For Ferry Flight, if cryogenic hydrogen is not available, a Freon vapor compression package will be "strapped on", and connect at the GSE interface.

TABLE 3 - TRADE STUDY SELECTION

FUNCTION	CONCEPT
CO_2 Control	LiOH
Humidity Control	Condensing Heat Exchanger, Replaceable wick water separator
Heat Transport	Dual loop (H2O cabin loop, F21 Heat Rejection)
Trace Contaminant Control	Activated Charcoal
Temperature Control	Forced Convection Heat Exchanger
Fuel Cell Heat Rejection	Integrated with F21 Loop
Heat Rejection	Space Radiators Sublimators Hydrogen Evaporators
Atmosphere Pressure & Composition Control	Total Pressure Regulators with selectable O_2 or N_2 source
Waste Management	Feces - Vacuum Dry Collector with Slinger Urine - Air Entrainment, rotary separator, overboard dump and/or holding tank
N_2 Diluent Storage	Carbon Composite, high pressure, filament wound tanks
Food Management	Aluminum Cans, Thermostabilized, rehydratables, wafers, beverages



PRIMARY AND SECONDARY LOOP IDENTICAL EXCEPT TWO PUMPS IN EACH PRIMARY LOOP AND ONE IN EACH SECONDARY LOOP

FIGURE 2 -- COOLANT TRANSPORT LOOP

In the cabin loop, a heating mode is achieved by use of heat picked up at the electronic cold plates. Minor cold walls in the ceiling and floor of the cabin are employed to reduce insulation requirements, and have little effect on the cabin thermal requirements.

The integrated vacuum drying waste management subsystem (Figure 3) concept is selected for space shuttle. It provides feces, urine and small trash collection, processing and storage. Feces and solid wastes are collected, vacuum dried and stored in one container. Urine is collected separately stored and dumped overboard. This subsystem may be common in design to space station equipment because the concepts are a derivative of the current SSP and Skylab equipment.

The food packaging system employs the use of protective overcans, essentially cylindrical in shape in which food serving cans, dehydrates and drink packages are stored. These canisters are designed to prolong storage life and endure pressure variation, vibration, ground handling, launch and characteristic impact loads associated with the Shuttle Orbiter program.

The foods have been categorized as follows: thermostabilized, rehydratables, wafers, and beverages. Packaging concepts include aluminum cans with pull-out lids and plastic beverage packs.

The galley complex contains a unique freezer-locker compartment. This compartment serves as a locker for the 7-day mission but may be replaced by a freezer for extended missions. The galley also provides an oven, food storage, trash storage, hot and cold water supplies, and utensil storage.

The cabin pressure control subsystem shown in Figure 4 consists of plumbing, controls and regulators to provide a two gas (oxygen and nitrogen) atmosphere at 10 or 14.7 psia. Oxygen for normal makeup is supplied from the fuel cell oxygen storage system and nitrogen from 3000 psi storage tanks. Two identical systems are provided with a maximum flow rate of seven pounds per hour. An emergency oxygen supply system is provided which provides oxygen at 55#/hr from the Attitude Control Propulsion Storage System.

The fire extinguisher is a domed stainless cylinder about ten inches high with a seven inch nozzle and handle. The cylinder contains a polyethylene bladder capable of expelling two cubic feet of foam in approximately 30 seconds. The extinguishing agent, which is an agueous gel (hydroxymethyl) cellulose), is pressurized to a maximum pressure of 250 psi at 140F. Freon is utilized on the opposing side of the bellows bladder to act as the expulsion agent. NASA has fire ..ection systems studies in work and the results of these studies will define the system for the orbiter.

CONCLUSIONS

The concept selection is indirectly sensitive to a number of factors which, in a phase B study, are subject to change. The length of the missions is one which, if shortened, could justify elimination of the space radiator and the water sublimators and replace the CO_2 and humidity control with an

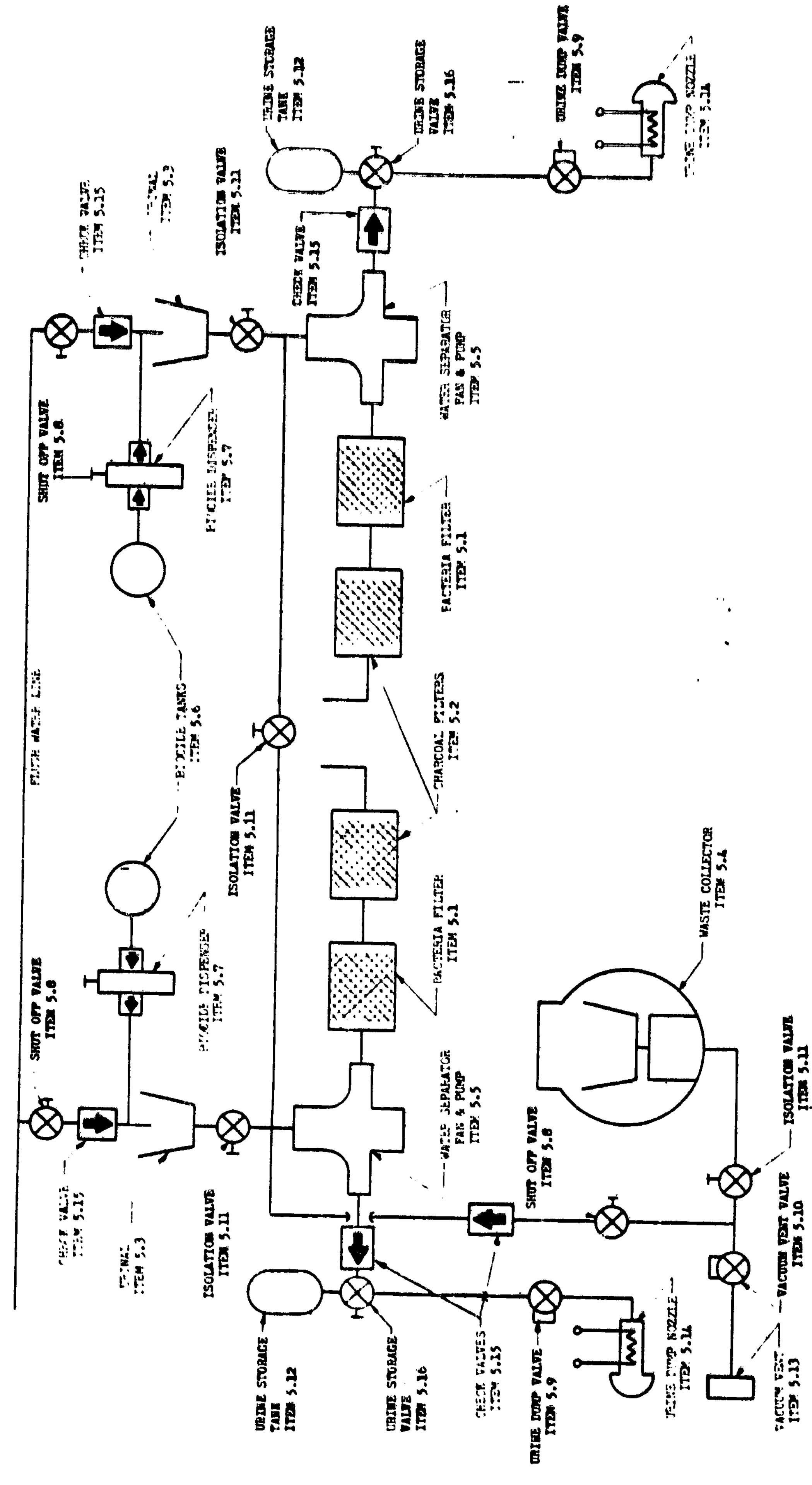


FIGURE 3 -- WASTE MANAGEMENT SUBSYSTEM

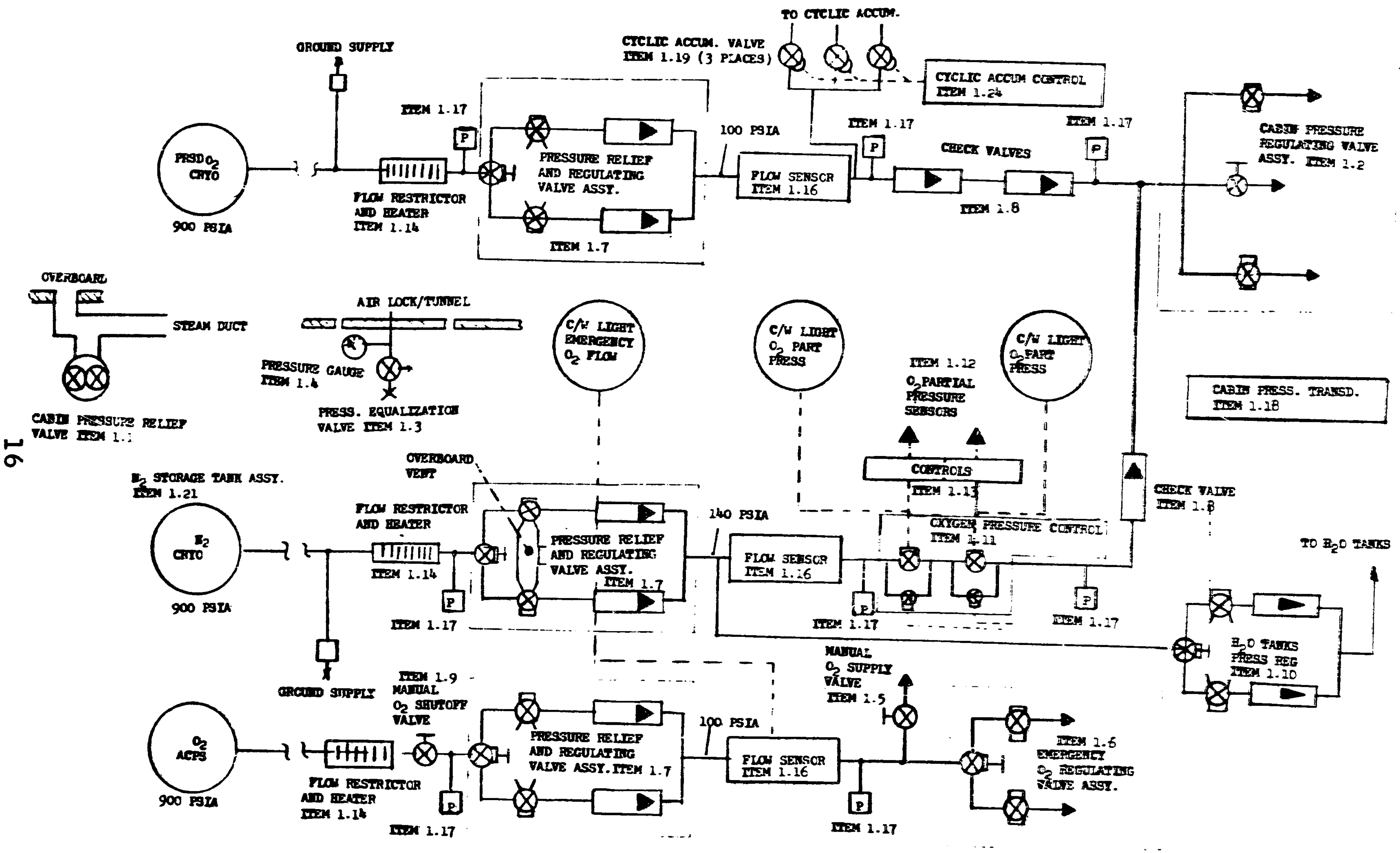


FIGURE 4 -- PRIMARY ATMOSPHERIC PRESSURE CONTROL AND SUPPLY SUBSYSTEM

open loop system. Lengthening the mission may require that the radiator be of a larger size and the CO_2 removal be accomplished by using the molecular sieve concept.

The "mission mix" (length of missions, kind of missions, number of passengers per mission), influences not only the concept selection but number of systems and system size. For example, one system with large capacity components could be installed when carrying a number of passengers and replaced with smaller components when carrying a smaller number of passengers. An alternate would be modular systems, of which two or more would be installed for maximum number of passengers and one would be used when no passengers were carried.

A number of study contracts are now in work under NASA and Air Force direction which will define the missions and dictate concept selection. The waste management is an example. Prototype development and fabrication are underway on the Space Station Prototype System Contract. The waste collector satisfies the Shuttle needs and commonality usage will reduce the cost. Another is the Fire Detection System for pressurized and unpressurized bays. Work is now underway in this area and should have an impact on the concept selection. While the major part of the concept selection is complete, effort will be continued in all areas with emphasis on Food Management, Waste Management, Fire Detection and system size.

In conclusion,

- The ECCLS design will provide provisions for incorporation of more economical concepts as they are developed.

- The system can be refurbished and maintained using airline maintenance concepts.

- State-of-the-art concepts will be used and a system will be provided at costs below previous space vehicle systems.

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EVALUATION OF AN ENERGY ABSORBING CREW SEAT INTEGRATED WITH A ROCKET EXTRACTION SYSTEM

Richard Carpenter

NASA, Flight Research Center

N71-35268

ABSTRACT

Consideration has been given to equipping the scaled prototype shuttle vehicle with a lightweight energy absorbing seat integrated with a crew extraction rocket. Such a system would provide protection for low velocity vehicle impacts and also offer a means of escape during higher velocity conditions. This system has been developed and fabricated at the Flight Research Center (FRC). The energy absorbing seat has been tested in a dynamic impact laboratory with satisfactory results. The escape system has been evaluated by extracting dummies by tractor rockets from a typical cockpit configuration. These tests indicate unsatisfactory performance during high roll rates.

INTRODUCTION

The NASA FRC is presently in the design stage for a one-third scale prototype shuttle vehicle based on the delta wing concept which is intended for launch from a B-52 aircraft. The Center is pursuing several technological development areas to facilitate this design stage. In the biotechnology area, flight experiments to establish minimum but adequate visibility envelopes are being conducted. Also, investigations of crew thermal and pressure protection systems and crash and escape systems are being conducted. In this latter area two different concepts were selected as candidates for consideration; an ejection seat and an energy absorbing seat integrated with extraction tractor rocket. Performance characteristics of ejection seats are understood to the point that further experimental work was not considered necessary to evaluate the application of these seats to the scaled prototype shuttle. In the event this candidate is selected, consideration is being given to the F-106 ejection seat as modified for use in the XT-2 Japanese Fighter and specifications for this seat are available from the FRC.

However, experience was lacking in the use of a flight-qualified crew seat capable of absorbing energy and integrated with a tractor rocket to extract the crew member during an emergency. Certain physical characteristics of this type system, such as being lightweight and simple in design, were considered attractive enough to warrant an experimental investigation of actual performance characteristics.

This paper briefly discusses the FRC's experience related to the design, fabrication and testing of an energy absorbing seat integrated with an extraction tractor rocket.

GENERAL DISCUSSION

Experience pertinent to energy absorbing design and testing techniques was obtained through the design and fabrication of a dynamic impact laboratory (ref. 1) and the fabrication and testing of an energy absorbing seat for use with the Flex wing vehicle (ref. 2) previously flown at the FRC.

Evaluation of a lifting body crash led to an energy absorbing seat design that lowered the pilot to a position where his head is below the structural level of the fuselage and would, consequently, provide an added measure of protection to the head.

This film clip (1)* shows a lifting body crash landing. The vehicle exhibits a high roll rate in excess of 200 degrees per second during the crash sequence. The pilot miraculously lived through this crash and the worst bodily damage was to the head; he has permanently lost the use of one eye.

Consequently, the seat shown in Figure 1 was designed to lower the pilot's head to within the top fuselage level while simultaneously absorbing energy by the use of a cyclic strain attenuator (CSA). The CSA used has a total stroke distance of 11 inches and is designed to start lowering the pilot and absorbing energy at approximately 10 g's, depending on the pilot's weight.

Several dynamic impact tests were made to verify design:

This first film (2) shows a 25-foot per second impact with a high vertical component. This design satisfactorily absorbed energy but did not lower the head to the desired height. The seat was repositioned within the fuselage frame allowing for an adequate outside viewing envelope and impacted again at the same test conditions illustrated by this second test sequence. This design was considered adequate for lowering the pilot to a height sufficient to provide improved head protection.

Figure 2 illustrates where three-axis accelerometers were used during the impact testing. As may be seen, there is a three-axis accelerometer located in the head, the pelvic region, the seat, and directly below the seat on the fuselage frame. The data to be discussed shall only include vector accelerometer readings from the pelvic region and from the vehicle frame which best illustrate the energy absorption characteristics of this total system.

Figure 3 shows acceleration versus time as measured at the vehicle frame and within the pelvic region of the dummy. The impact velocity for this test is approximately 25 feet per second with vehicle frame peak g readings of approximately 86 g's and a peak pelvic reading of 30 g's.

*See reference 3 for details on obtaining film.

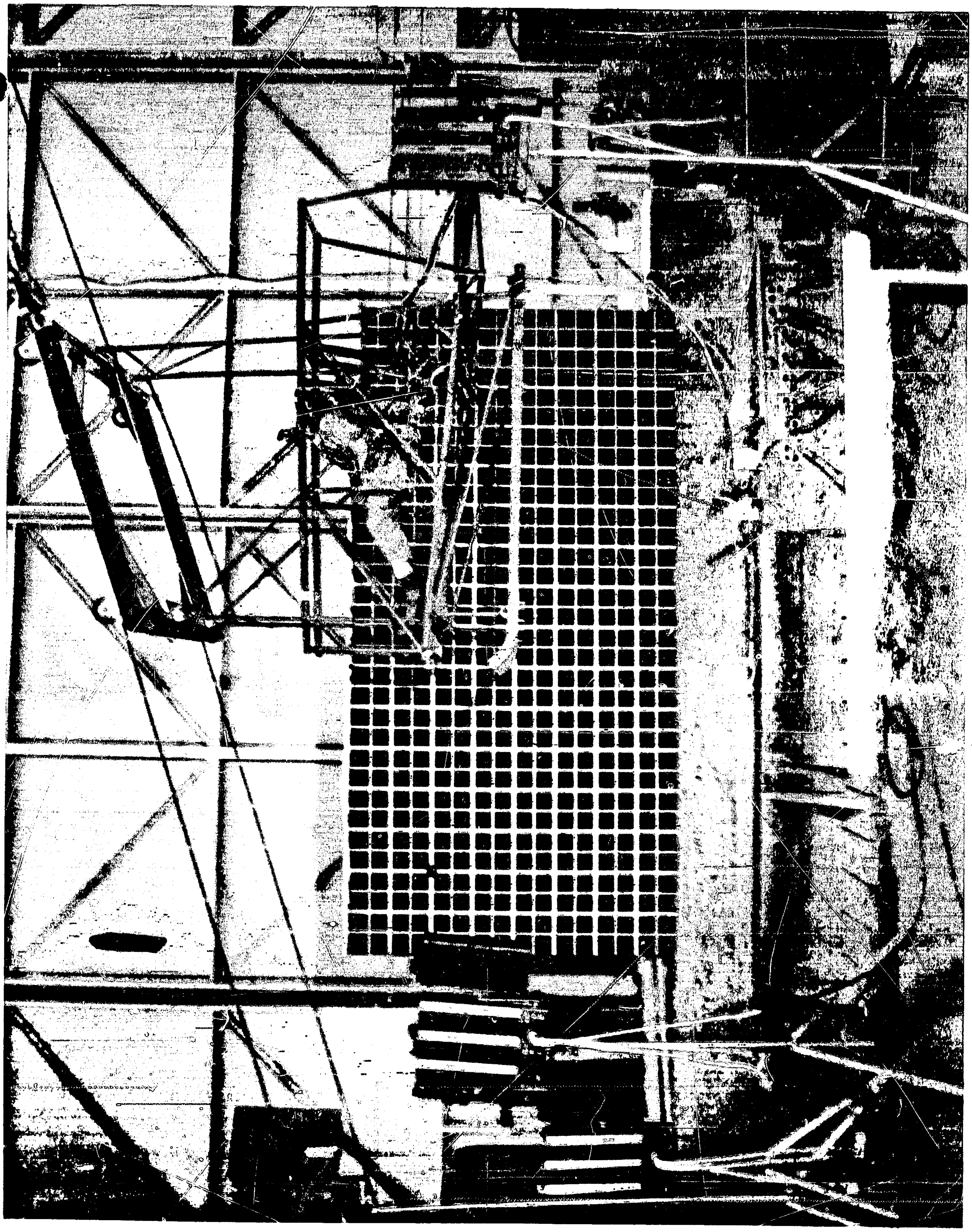


Figure 1

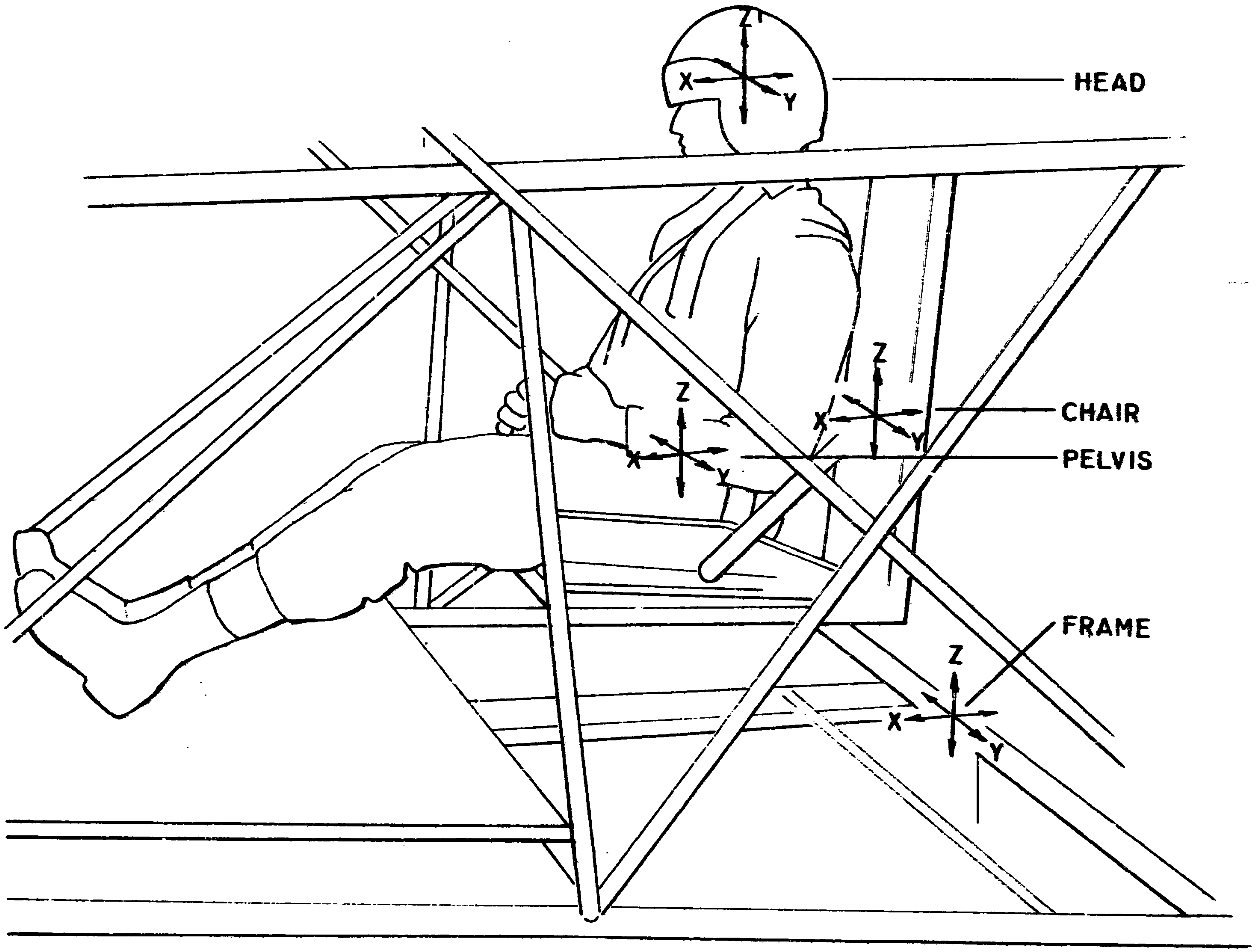


FIGURE 2

TYPICAL ACCELEROMETER ARRANGEMENT

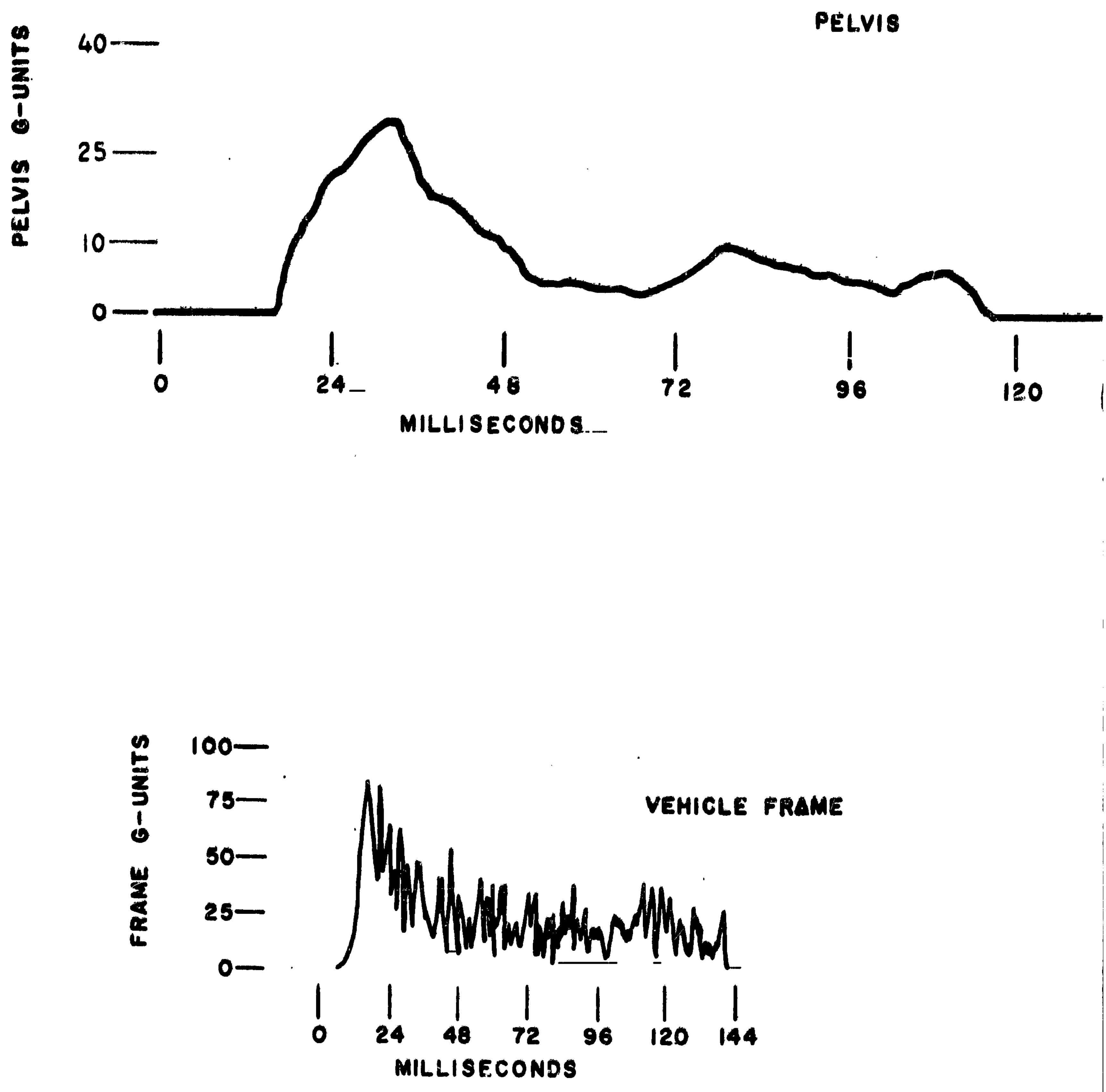


FIGURE 3

SHUTTLE SEAT IMPACT TEST
ACCELERATION VECTOR SUM MAGNITUDE FOR THE VEHICLE FRAME AND PELVIS

However, the energy absorption characteristics of the CSA are better shown by transforming these data into the frequency domain. Figure 4 illustrates the relative difference of the spectral amplitude in g-seconds between the frame and pelvic acceleration levels as a function of frequency. Note that the high energy levels are in the low frequencies for both the frame and pelvis, where for the frame near the DC level the energy level peaks are about 2.25 g-seconds and the pelvis peaks at 0.8 g-seconds; as indicated, the energy level for the pelvis readings has decreased by a factor of three.

Figure 5 shows the gain factor which is the ratio of the amplitude in g-seconds of the pelvis to the frame. That is, for values less than zero, the pelvis experiences less transfer of energy through the frequency range until 75 hertz, at which time the values fluctuate around zero.

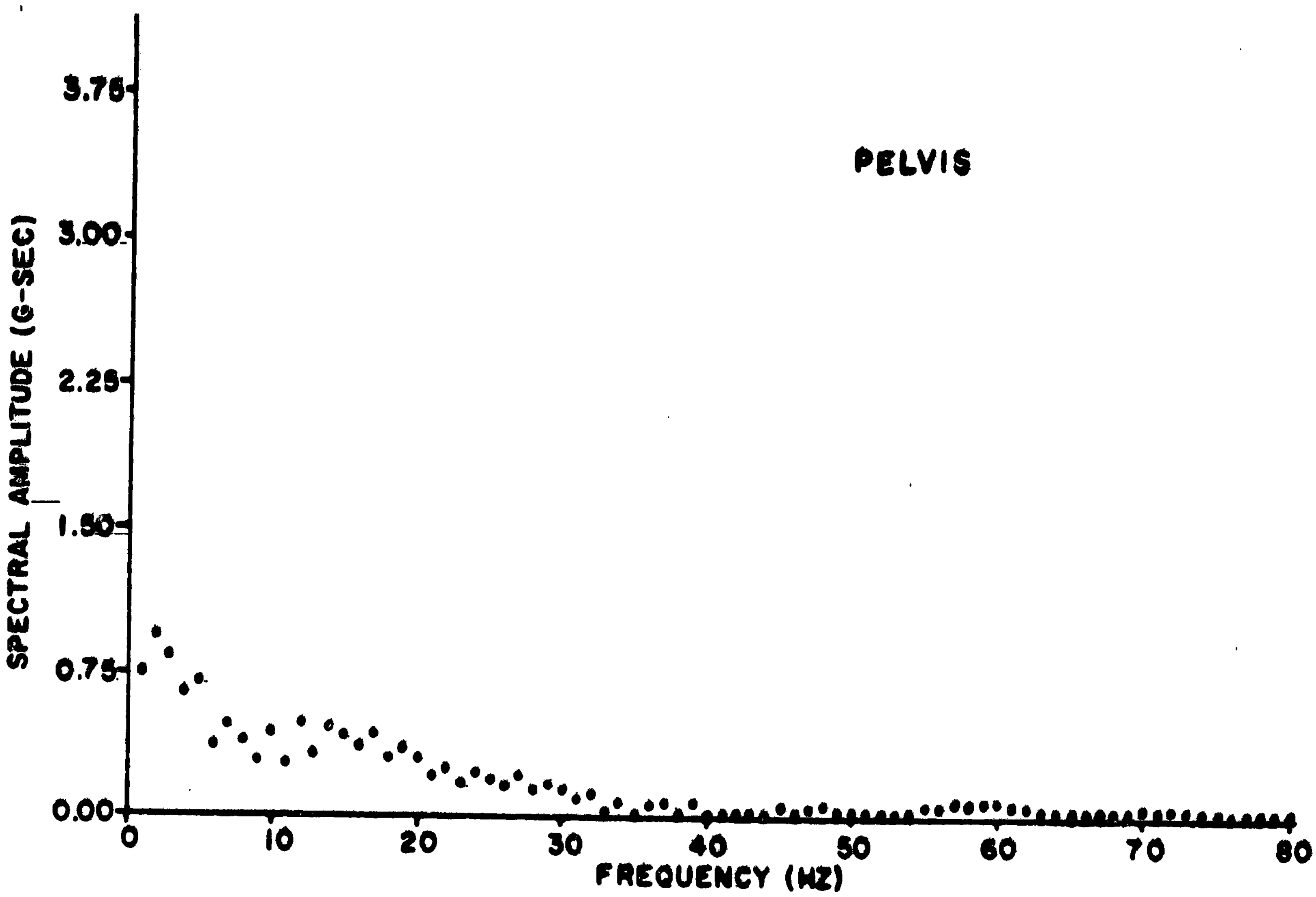
But as may be seen from Figure 4, there is essentially no energy in the system above 75 hertz. These data indicated that the energy absorbing characteristics of this seat were adequate for the available stroke range of 11 inches. At the conclusion of the impact testing, the program moved into its second phase which involved integrating this seat with a tractor rocket system capable of extracting a crew member during an emergency.

Figure 6 shows a tractor rocket mounted on its launcher attached to the back of the seat. During an emergency the pilot pulls a single handle between his legs which blows away the canopy and pneumatically launches the rocket which is attached by a 10-foot line to the pilot harness. When the rocket reaches the end of the 10-foot line, the rocket is ignited and pulls the pilot from the vehicle with a 1,000 pound-second impulse. During the sequence, the seat pan drops and the seat slides up rails to guide the pilot from the vehicle during the extraction.

This high-speed photography film clip (3) illustrates a successful extraction at 0/0 conditions when the vehicle is in a stable configuration. However, as mentioned, experience at the FRC with research vehicles such as the X-15 and lifting bodies during emergencies has demonstrated that high roll rates are probable.

This film clip (4) is an example of a rapid buildup of rates to values in excess of 270 degrees per second. This is a mockup of an actual X-15 emergency reconstructed from telemetry data. In this case, the vehicle and pilot were lost, but as may be noted from the control movements, the pilot attempts to control the aircraft until the last instant when high spin rates in excess of 270 degrees per second are reached in approximately 400 milliseconds.

It is our firm belief that a crew emergency egress system must be capable of operating at high roll or spin rates; consequently, a series of performance tests were accomplished to evaluate the performance characteristics of the extraction rocket under simulated roll rate conditions.



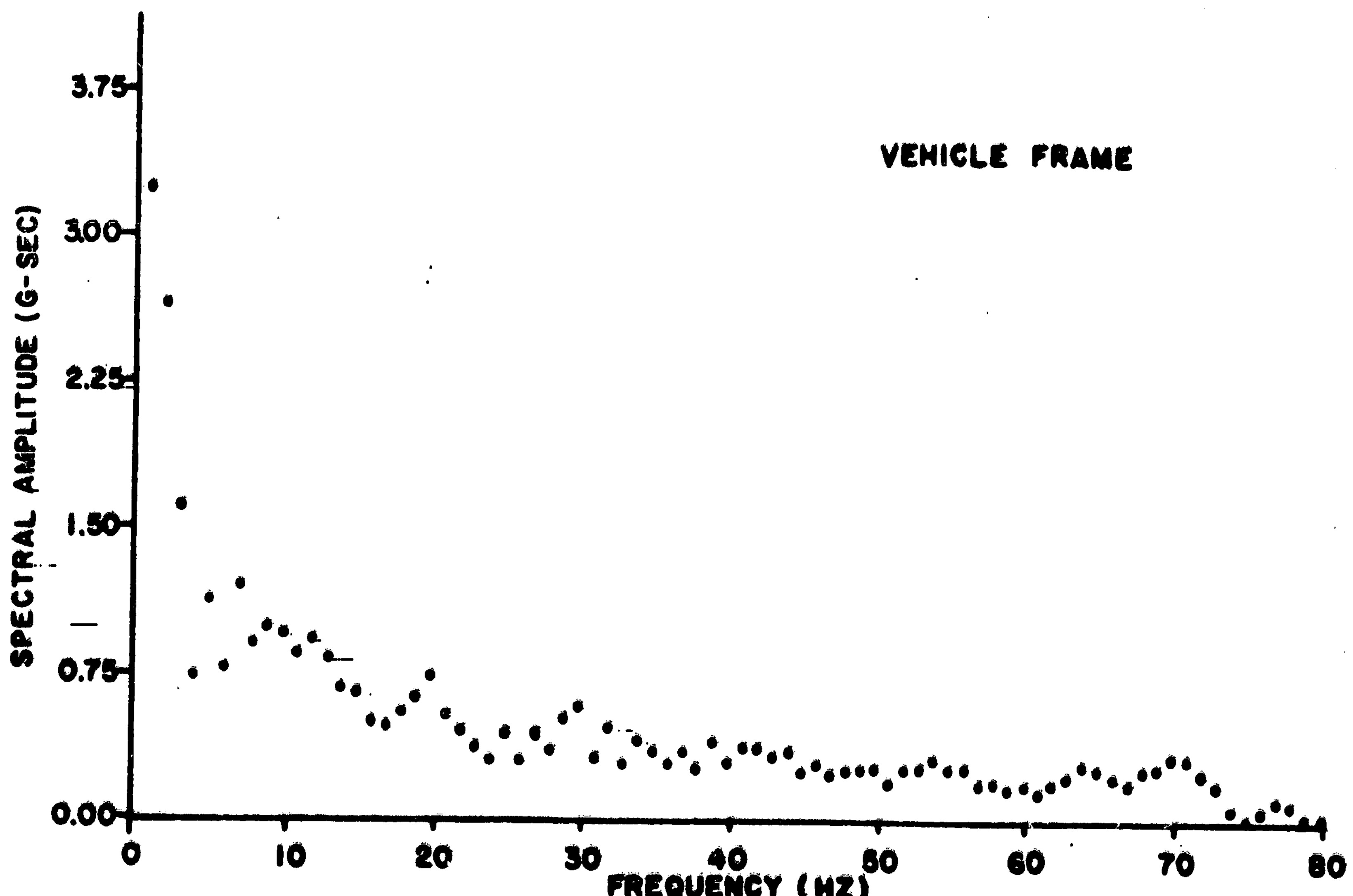
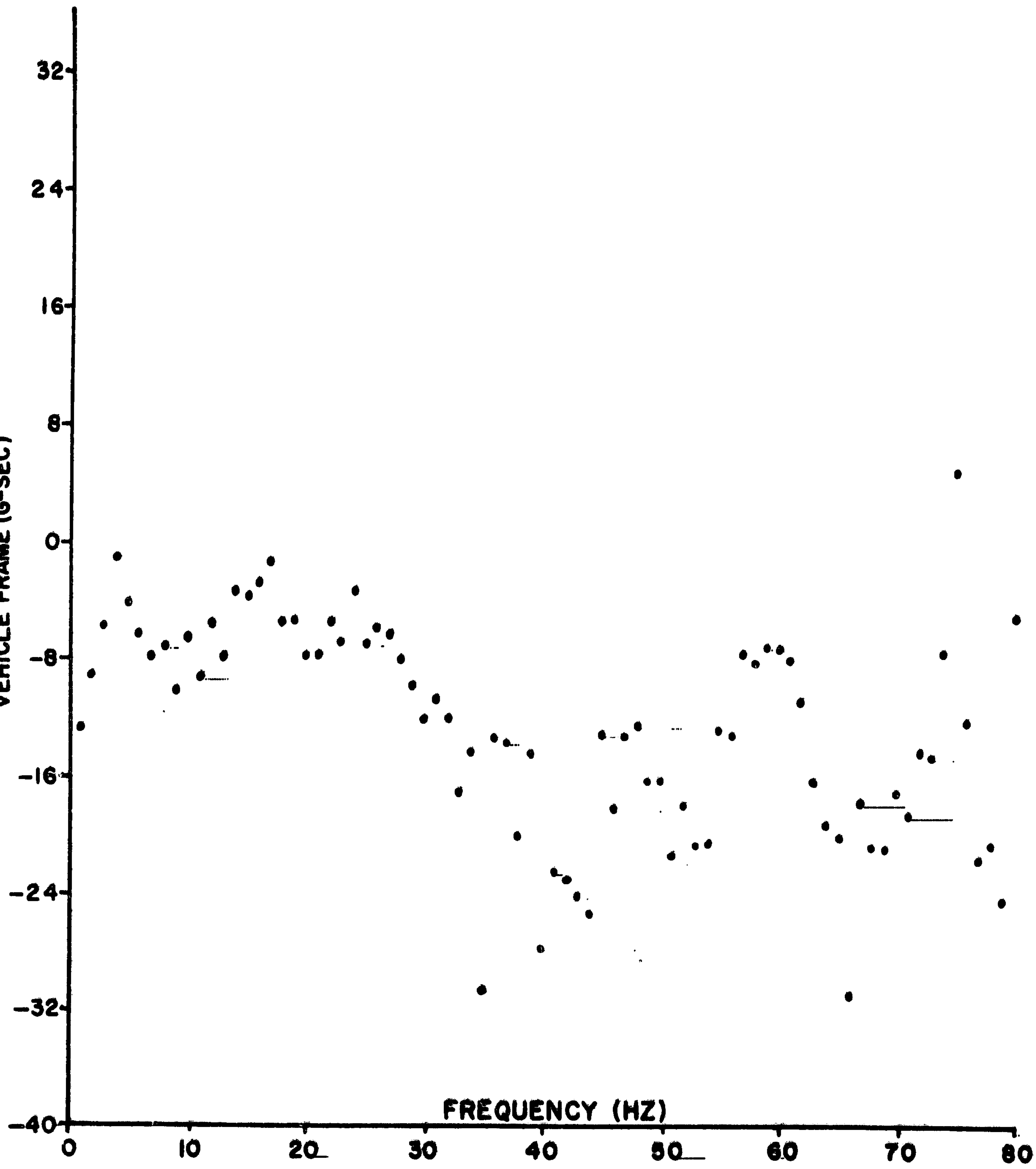


FIGURE 4 SHUTTLE SEAT IMPACT TEST
AMPLITUDE SPECTRUM VS FREQUENCY



SHUTTLE SEAT IMPACT TEST

GAIN BETWEEN PELVIS AND FRAME

FIGURE 5

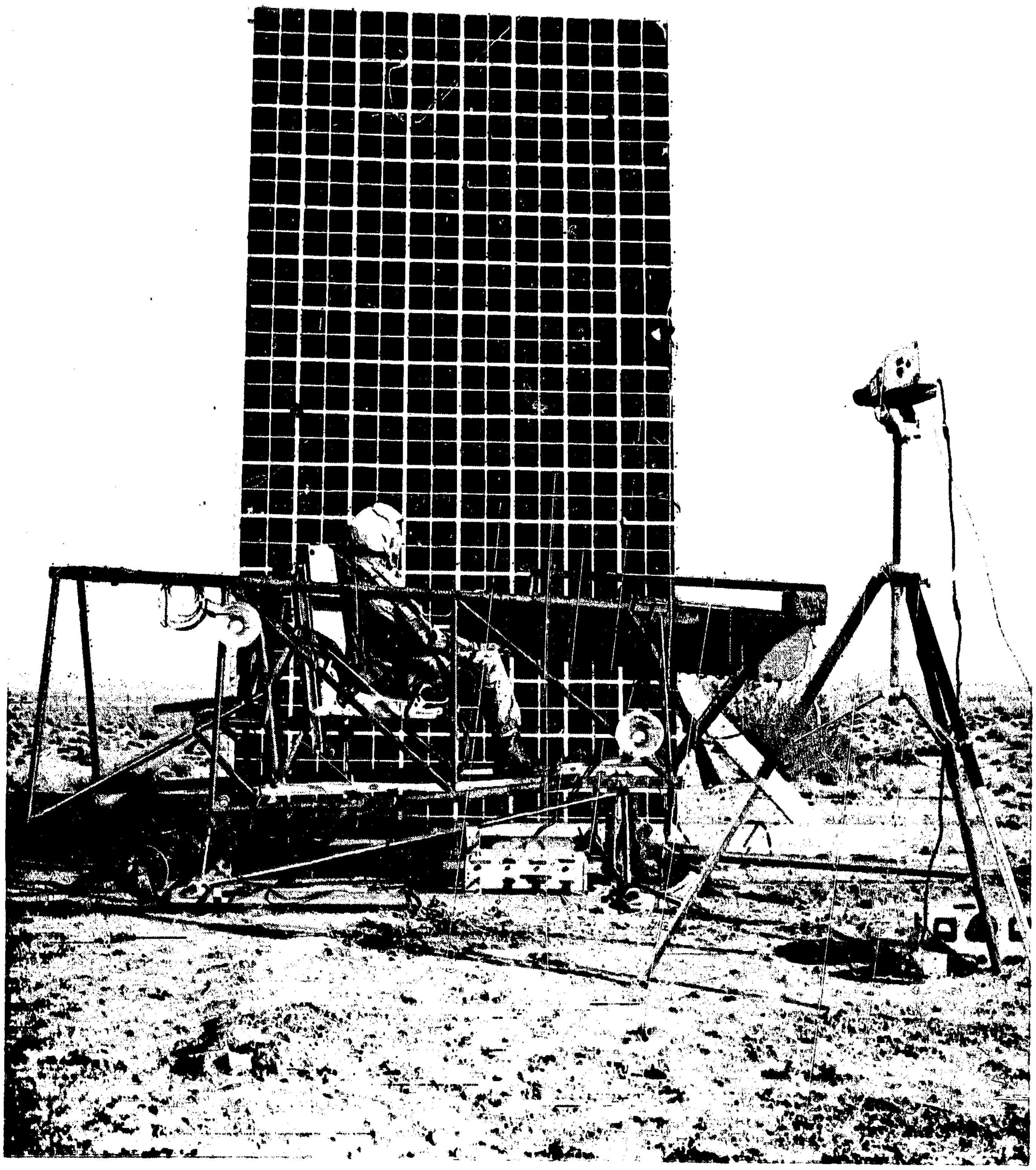

NASA
E-22495
NASA
Flight Research Center
Edwards, California

Figure 6

Figure 7 illustrates the technique used to statically simulate a roll condition. The thrust vector of the rocket was displaced laterally from zero degrees in increments to 45 degrees.

The theoretical graph shown in Figure 8 shows corresponding aircraft roll rates as a function of rocket tilt or lateral displacement in degrees. Three firings were performed corresponding to a 60-degree per second, 80-degree per second, and 125-degree per second roll rate.

This high-speed photography clip (5) illustrates the conditions of extraction at these various roll rates:

At 60 degrees per second the dummy was extracted without any problem.

At 80 degrees per second the dummy was slammed hard against the right side of the cockpit and dented the side of the fuselage.

At 125 degrees per second the dummy was again slammed hard against the frame. The accelerometers mounted in the thorax indicated a side acceleration of 80 g's sustained for 15 milliseconds.

Figure 8 shows the theoretical estimate of aircraft roll rate versus rocket tilt angle and our three test points corresponding to roll rates of 60 degrees per second, 80 degrees per second, and 125 degrees per second together with the time required for the various events to occur.

Two events are plotted. The top function indicates the roll rates achievable by the tractor rocket if the feet clear the cockpit. The second function provides the roll rates possible if only the torso is considered necessary to clear the cockpit.

However, our experimental tests indicated another factor, shown in Figure 9, by plotting egress time versus rocket tilt angle. Due to the additional horizontal force component caused by the dummy pressing against the side of the cockpit, the egress time increased for increasing roll rates. As indicated, from a stable 0/0 condition to a roll rate of 60 degrees per second the egress time increased 23 milliseconds and from the stable condition to an 80-degree per second roll rate the egress time increases to 54 milliseconds. For 125 degrees per second, the delay time involved in leaving the cockpit is 66 milliseconds.

When these experimental data are plotted together with the theoretical estimate (Figure 10), it is evident that the actual roll rates within which this system can operate in this cockpit are reduced. A 73-degree rocket tilt angle corresponding to a roll rate of approximately 200 degrees per second is the theoretical maximum above which a tractor rocket cannot extract a pilot. Extrapolation of actual experimental data indicates that actual possible roll rates for a tractor rocket extraction from this type cockpit are definitely less than 200 degrees per second and probably nearer 160 degrees per second, and this is not considered adequate for flight vehicles

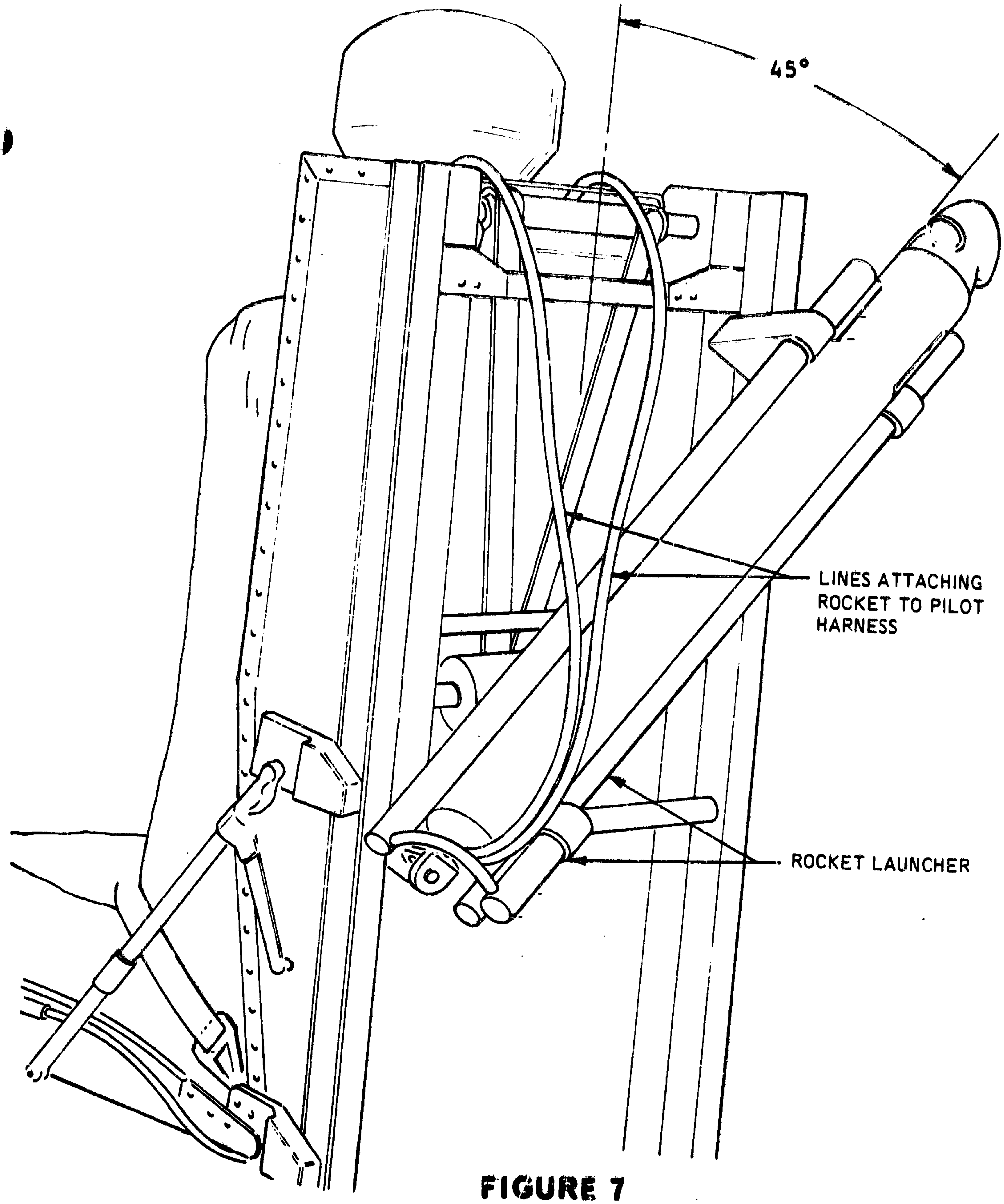


FIGURE 7

SEAT BACK VIEW SHOWING LATERAL DISPLACEMENT OF THE ROCKET THRUST VECTOR

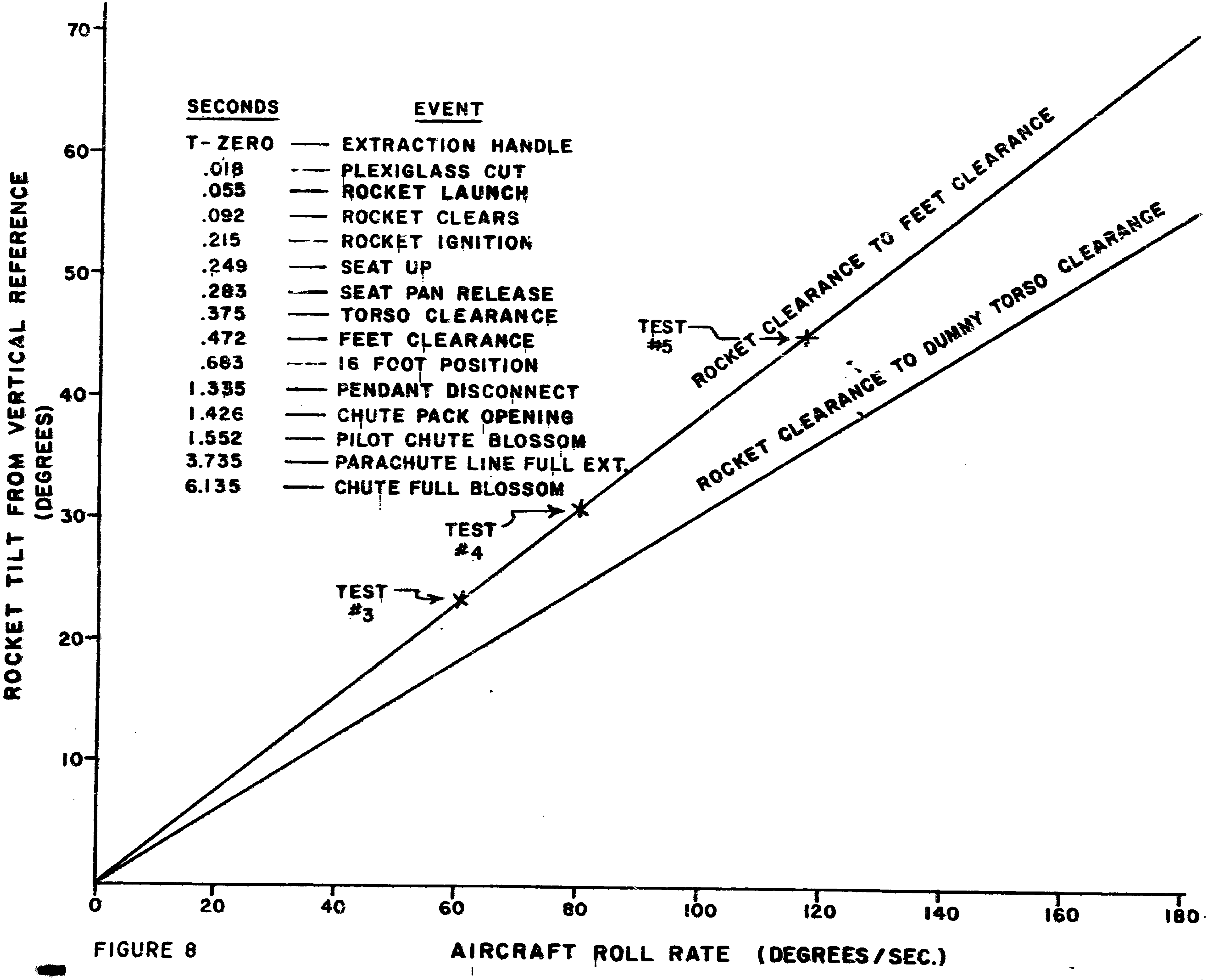

SECONDS
EVENT
T-ZERO — EXTRACTION HANDLE
.018 — PLEXIGLASS CUT
.055 — ROCKET LAUNCH
.092 — ROCKET CLEARS
.215 — ROCKET IGNITION
.249 — SEAT UP
.283 — SEAT PAN RELEASE
.375 — TORSO CLEARANCE
.472 — FEET CLEARANCE
.683 — 16 FOOT POSITION
1.335 — PENDANT DISCONNECT
1.426 — CHUTE PACK OPENING
1.552 — PILOT CHUTE BLOSSOM
3.735 — PARACHUTE LINE FULL EXT.
6.135 — CHUTE FULL BLOSSOM
ROCKET CLEARANCE TO FEET CLEARANCE
ROCKET CLEARANCE TO DUMMY TORSO CLEARANCE
TEST #3
TEST #4
TEST #5
ROCKET TILT FROM VERTICAL REFERENCE (DEGREES)
AIRCRAFT ROLL RATE (DEGREES/SEC.)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
180

FIGURE 8

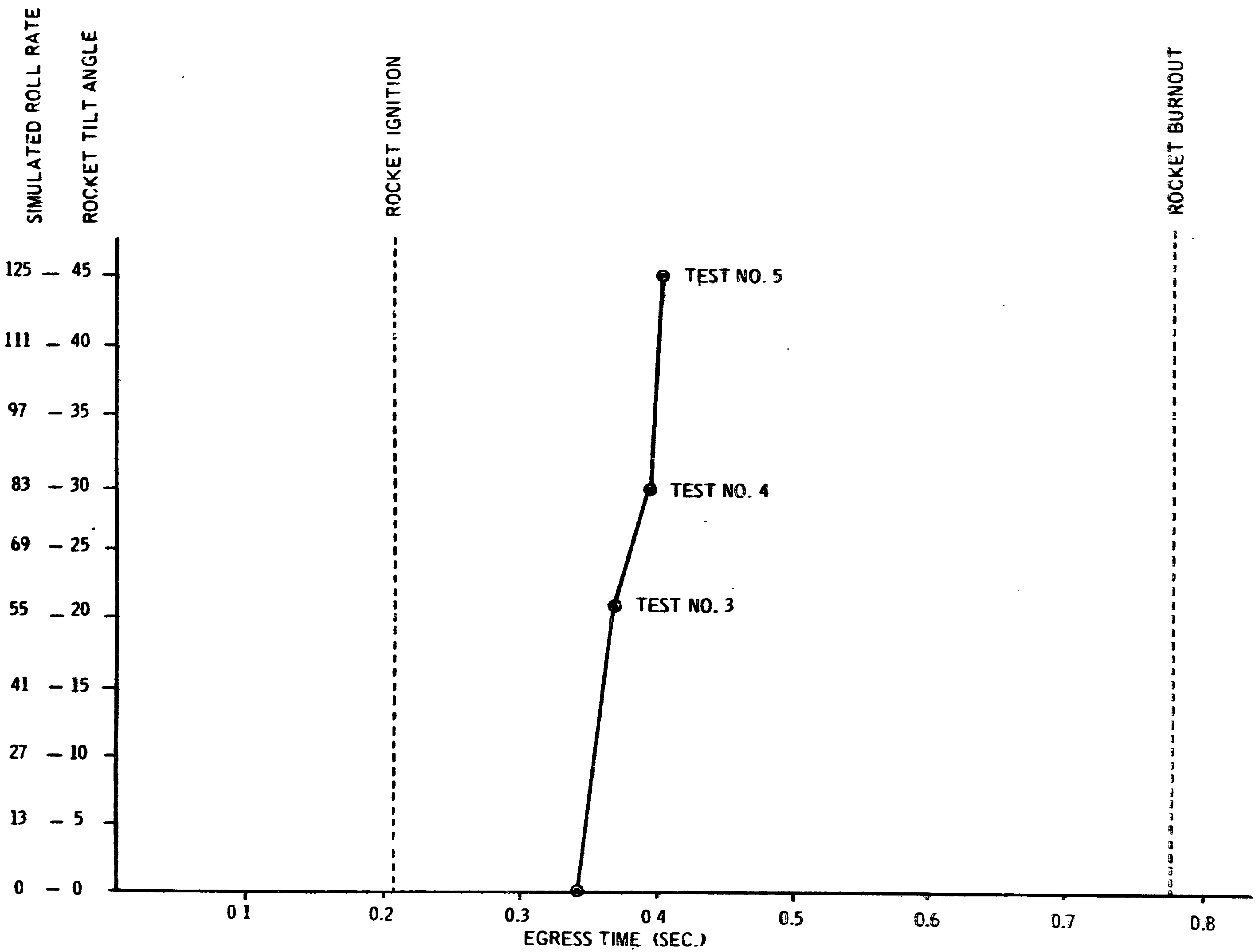

SIMULATED ROLL RATE
ROCKET TILT ANGLE
ROCKET IGNITION
ROCKET BURNOUT
125 — 45
111 — 40
97 — 35
83 — 30
69 — 25
55 — 20
41 — 15
27 — 10
13 — 5
0 — 0
TEST NO. 5
TEST NO. 4
TEST NO. 3
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
EGRESS TIME (SEC.)

FIGURE 9

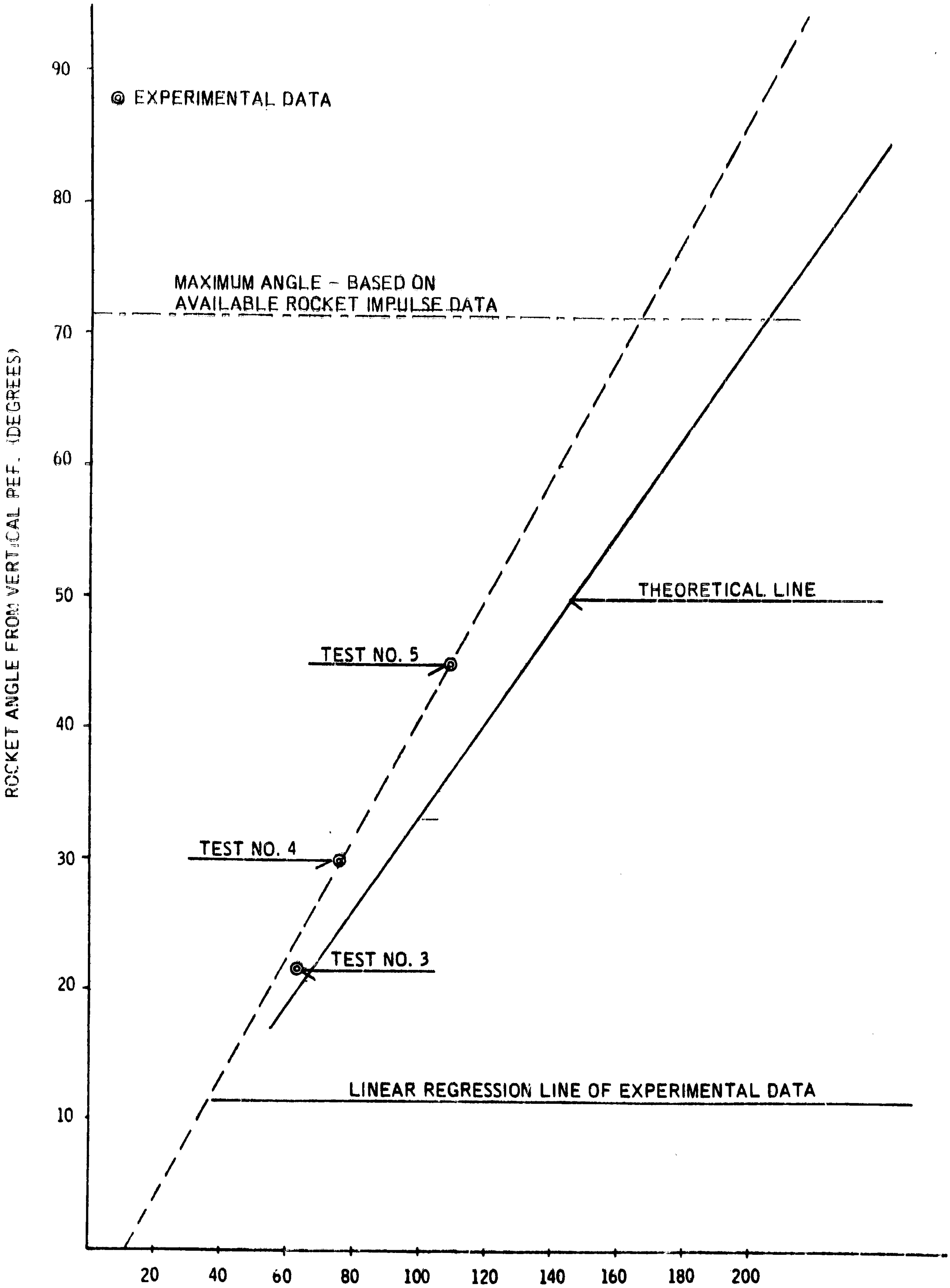


Figure 10. SIMULATED ROLL RATE (DEGREES/SEC.)

that are aerodynamically unstable in roll or capable of high roll rates particularly in view of the high side forces exerted against the dummy as he left the cockpit. These side forces seem to become significant at a simulated roll rate of 80 degrees per second.

CONCLUSIONS

1. Nonejection seat designs allowing improved head protection by lowering the pilot are now within the state-of-the-art.

2. By integrating energy absorbing techniques into the seat lowering mechanism, a significant amount of impact energy can be prevented from reaching the pilot.

3. The energy absorbing seat can be integrated with a crew extraction rocket and will perform reliably at a stable 0/0 condition and at relatively low roll rates.

4. The tractor rocket egress system is not recommended for use with flight vehicles where high roll rates can be expected.

5. This type seat and egress system is not recommended for use on the scaled prototype shuttle vehicles where roll rates in excess of 200 degrees per second can be anticipated.

6. The recommendation now being considered for the crew egress system for the scaled prototype shuttle is to use the F-106 ejection seat as modified for the XT-2 Japanese Fighter.

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2. Carpenter, Richard: "Description of an Energy Absorbing Seat Designed for Medium-Velocity Impacts." Presented at the Annual NASA Safety and Risk Management Conference, Lewis Research Center, September 30-October 1, 1970.

3. "Film for the Joint AIAA Space Shuttle Development Testing and Operations Conference/NASA Shuttle Technology Conference, March 15-18, 1971, in Phoenix, Arizona." May be obtained from National Aeronautics and Space Administration, Flight Research Center, P. O. Box 273, Edwards, California 93523, Attn: Biomedical Programs Division.

THE FLASH EVAPORATOR FOR TRANSIENT HEAT LOADS

J. L. Gaddis

Vought Missiles and Space Company

N71-35268

INTRODUCTION

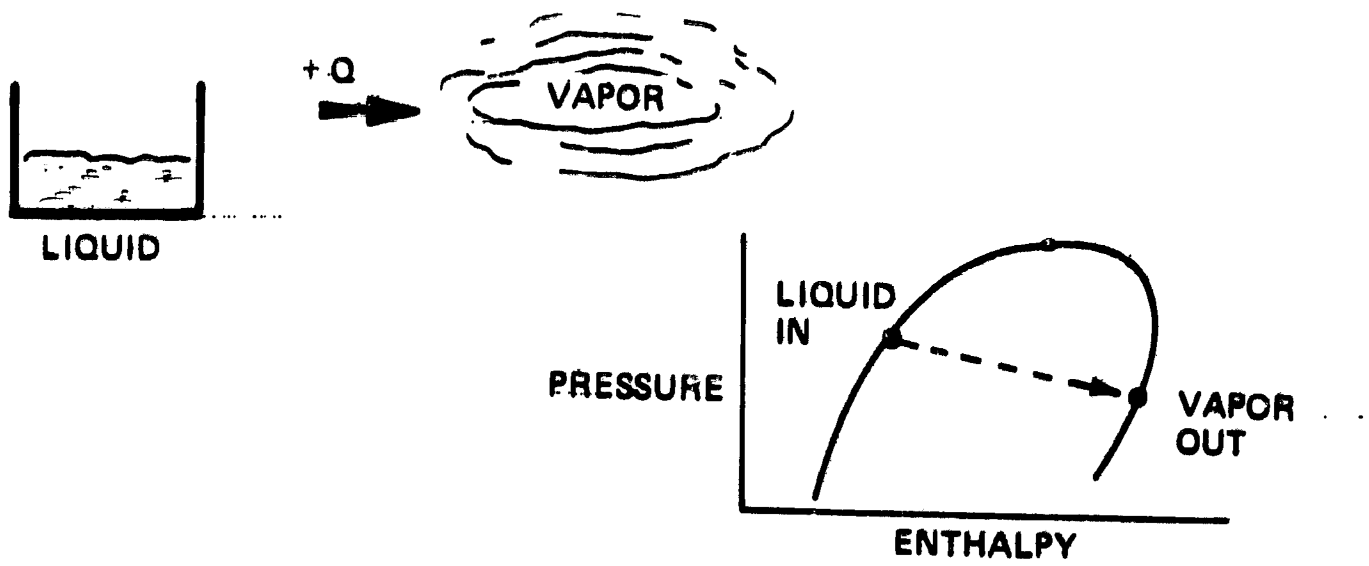
The thermal control system for the shuttle is being projected to include an expendable heat sink to augment the radiator and to provide primary heat rejection during atmospheric flight phases. Any device must demonstrate certain features to warrant its development for shuttle usage. These include high efficiency, capability to meet the high load transients as well as steady state, capability to respond quickly after dormant periods and to assume dormant operation, and sufficient simplicity to insure superior reliability. In addition to these requirements, it is attractive to obtain a single device which can utilize various evaporants. This document reports an investigation of the feasibility of a liquid spray flash evaporator concept intended to satisfy the objectives outlined.

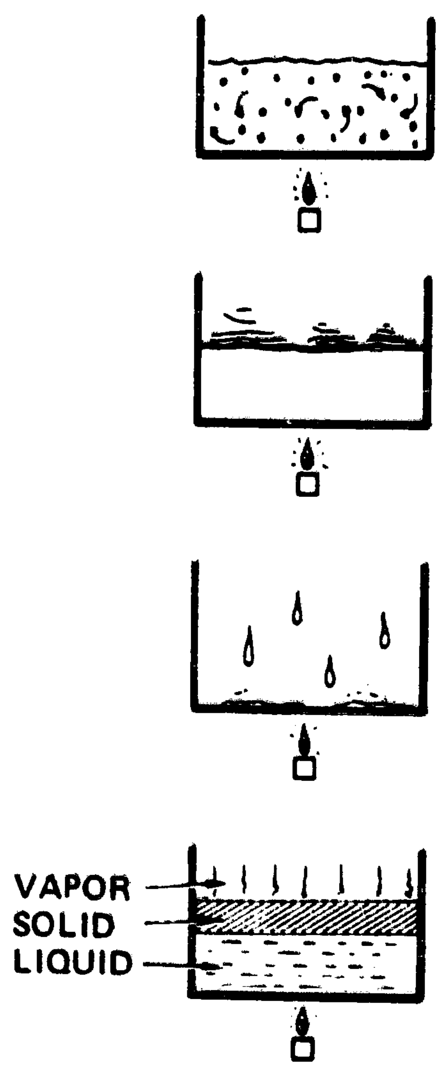
OBJECTIVES

1. Heat Load 0 - 25000 BTU/HR, inlet temperature ramps of 5 degrees per minute.
2. Outlet temperature range 35 to 45 F.
3. Evaporants H_2O, NH_3 or R-22 in pertinent pressure range.
4. Accelerations 0 - 4 g.
5. No backpressure control.
6. Heat rate control by supply rate modulation.
7. High enthalpy of vaporization.

VAPORIZATION PROCESSES

A liquid changes to a vapor with the addition of heat by any of several mechanisms. Devices associated with these mechanisms have associated with them a necessary rate control variable. In the case of the droplet evaporation device, the heat rate control by supply modulation is considered to be especially attractive from a simplicity standpoint when compared to backpressure control. It compares favorably with the sublimation device having an excellent rate control mechanism which is penalized to accommodate intermittent operation. Thus, it is attractive to pursue a device which evaporates liquids by the droplet evaporation mechanism. See Figure 1.





MECHANISM	RATE CONTROL VARIABLE
BOILING	BACKPRESSURE
POOL EVAPORATION	BACKPRESSURE
DROPLET EVAPORATION	SUPPLY RATE
FREEZING & SUBLIMATING	ICE THICKNESS (SELF REGULATING)

Figure 1. Vaporization Processes

DROPLET IMPINGEMENT

Several phenomena may occur during single droplet impingement of a three phase, single component fluid. The particle could freeze in transit with a corresponding inability to efficiently vaporize it. The particle could impinge on the wall as a liquid and evaporate, boil gently, or boil violently. In either of the first two the entire droplet can evaporate efficiently, while a significant fraction of the liquid in the latter case could be ejected. Finally, the liquid could be supplied faster than the evaporation with accumulation resulting. The bounds of desired operation are considered violated when the droplets freeze or when accumulation is encountered. The violent boiling will probably result in a fluid selection criterion rather than a design problem. The limits of freezing and accumulation will be estimated using both experimental and analytical techniques. See Figure 2.

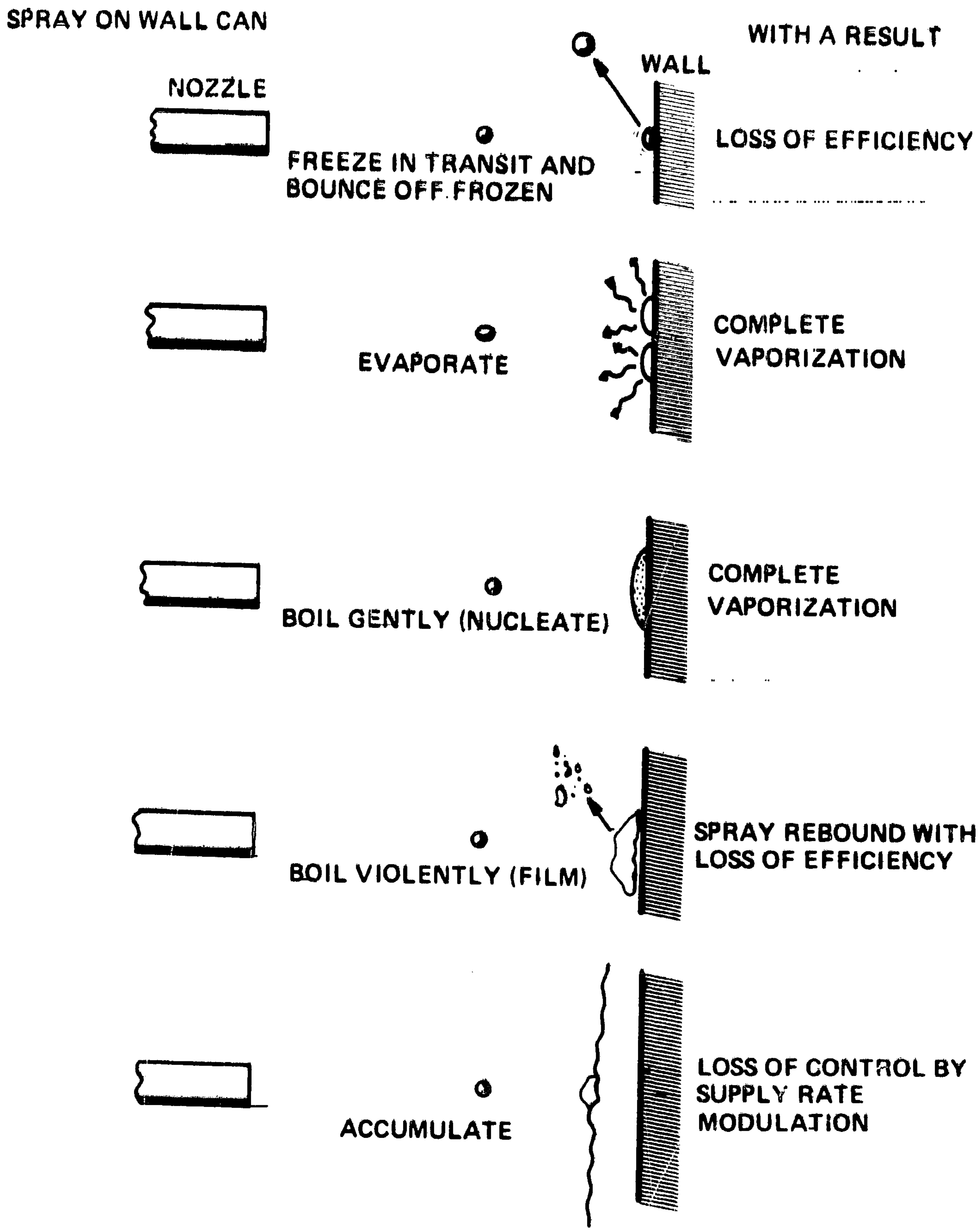


Figure 2. Droplet Impingement

WATER FREEZING CHARACTERISTICS

The time required to freeze a particle in flight may be analyzed using any of several approximate techniques. Figure 3 shows the length of time to complete freezing for water particles at various ambient conditions. The typical size of particles obtained from an atomizing nozzle is about 100 microns which would freeze in a distance of about one foot under vacuum conditions with a velocity of 50 feet per second. Raising the pressure from zero to a saturation temperature of 10°F produces nearly twice the distance to freezing. Thus, both the length of path, velocity, and ambient pressure have significant effects on the condition of the particle.

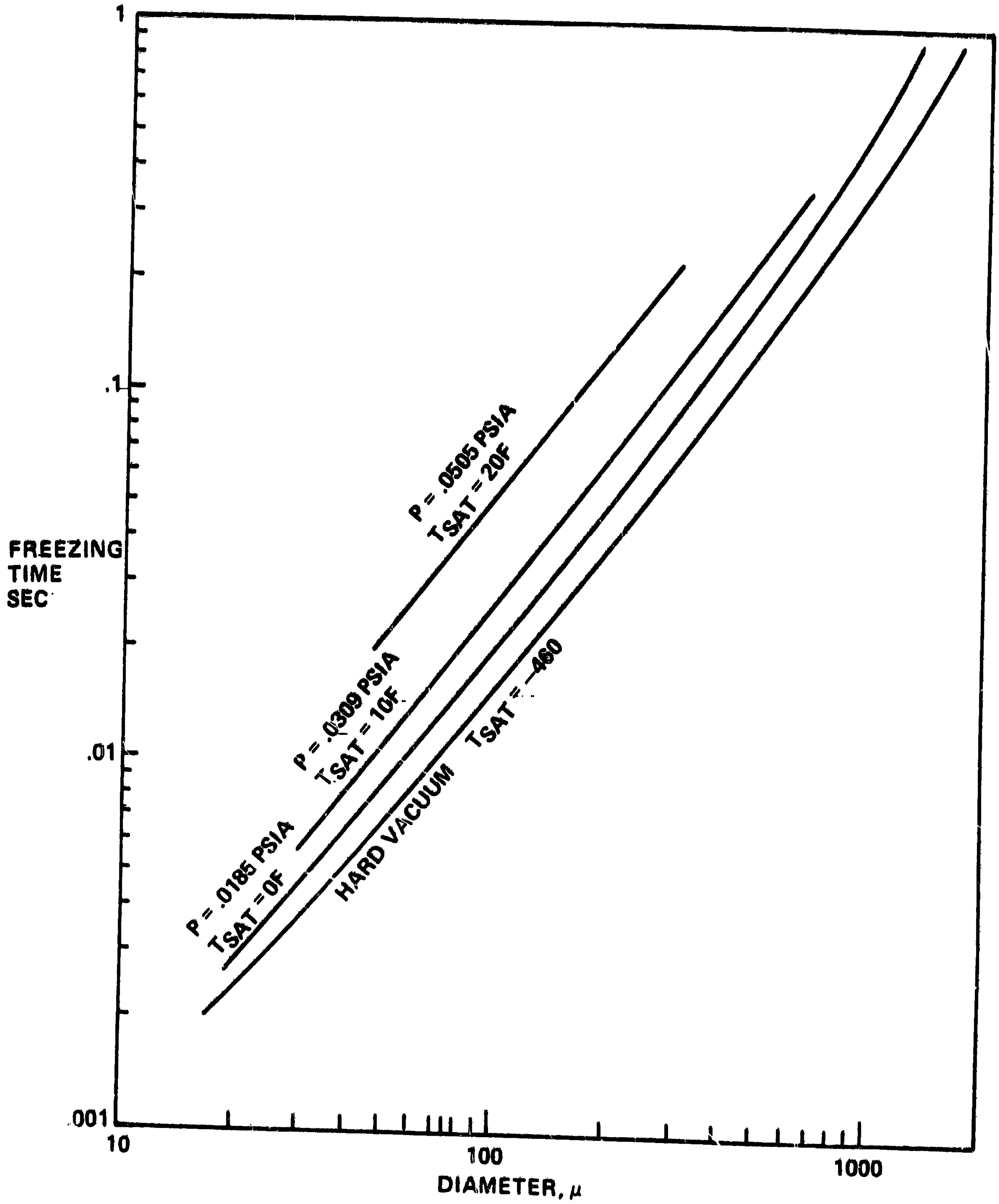


Figure 3. Water Freezing Characteristics

FLOODING TENDENCY OF SUPPLY VERSUS EVAPORATION RATES

The possible flooding of the evaporator surface has been analyzed by evaluating the characteristic supply time and evaporation time. See Figure 4. The characteristic supply time may be calculated as the time required to produce an equal number of particles and targets. These targets are a size such that a particle at target center will be hit by a second particle when the latter falls within the target. The characteristic evaporation time is calculated from a direct heat transfer solution. The evaporator is expected to flood whenever the supply time is less than the evaporation time. The excess in supply time over evaporation time provides for margin against variations in supply flux, etc. Within the range of droplet sizes expected, a one square foot evaporator is more than adequate to prevent flooding for water. The only evaporants (R-22, NH_3) have relatively similar characteristics.

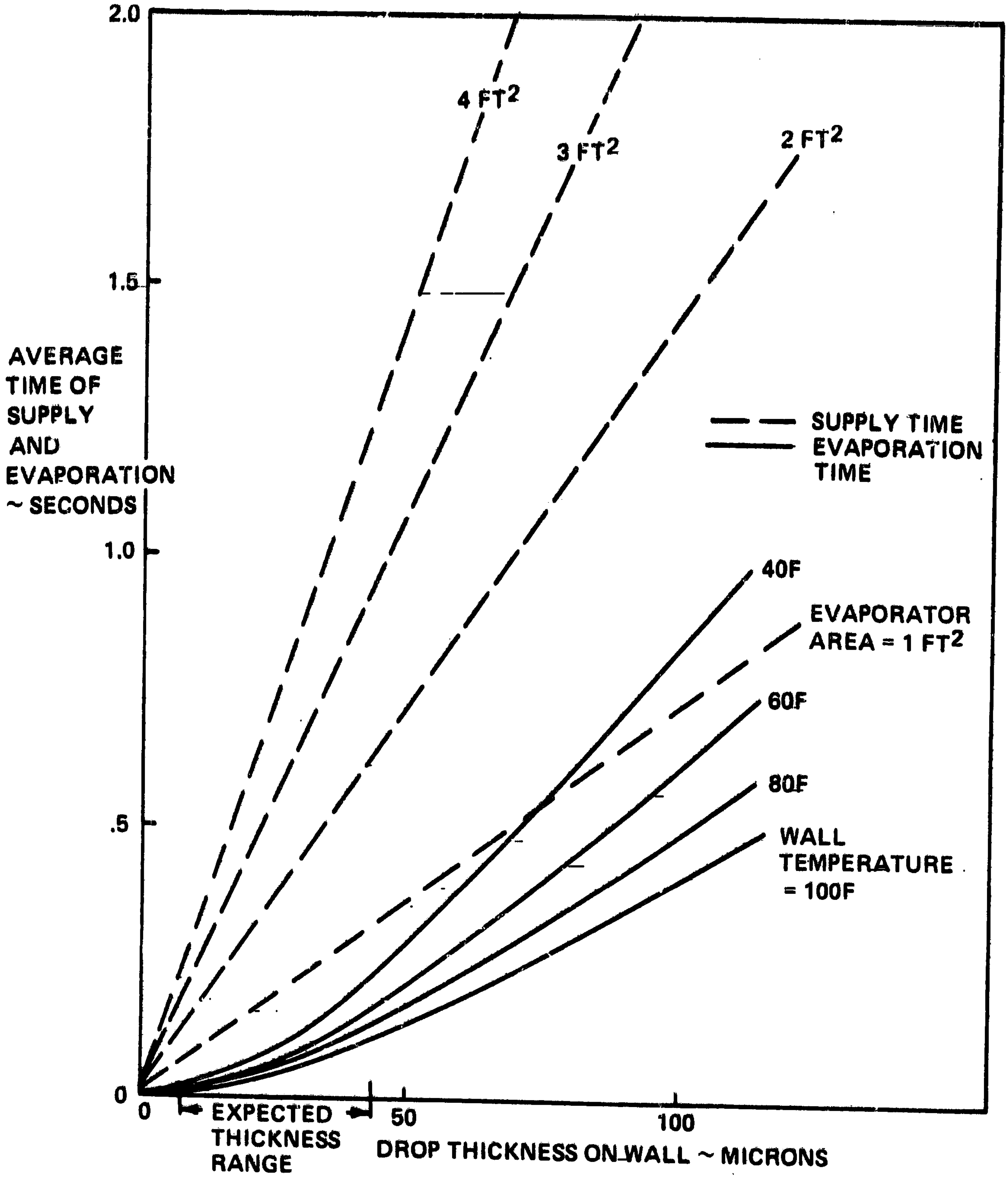


Figure 4. Flooding Tendency of Supply Versus Evaporations Rates

LIMITS OF DESIRED OPERATION

From the foregoing, the range of evaporator size and particle size may be calculated in which the evaporator will have the postulated single droplet evaporation mode. The parameters listed have such a strong effect (particularly the ambient pressure) that many sets of charts would be required to completely describe the situation. Particle freezing is a more formidable problem since the sizes at which the spray accumulates are actually much less than can be accommodated by the transport side heat transfer. This transport side design impact is the strongest sizing parameter in the system and will be illustrated shortly. See Figure 5.

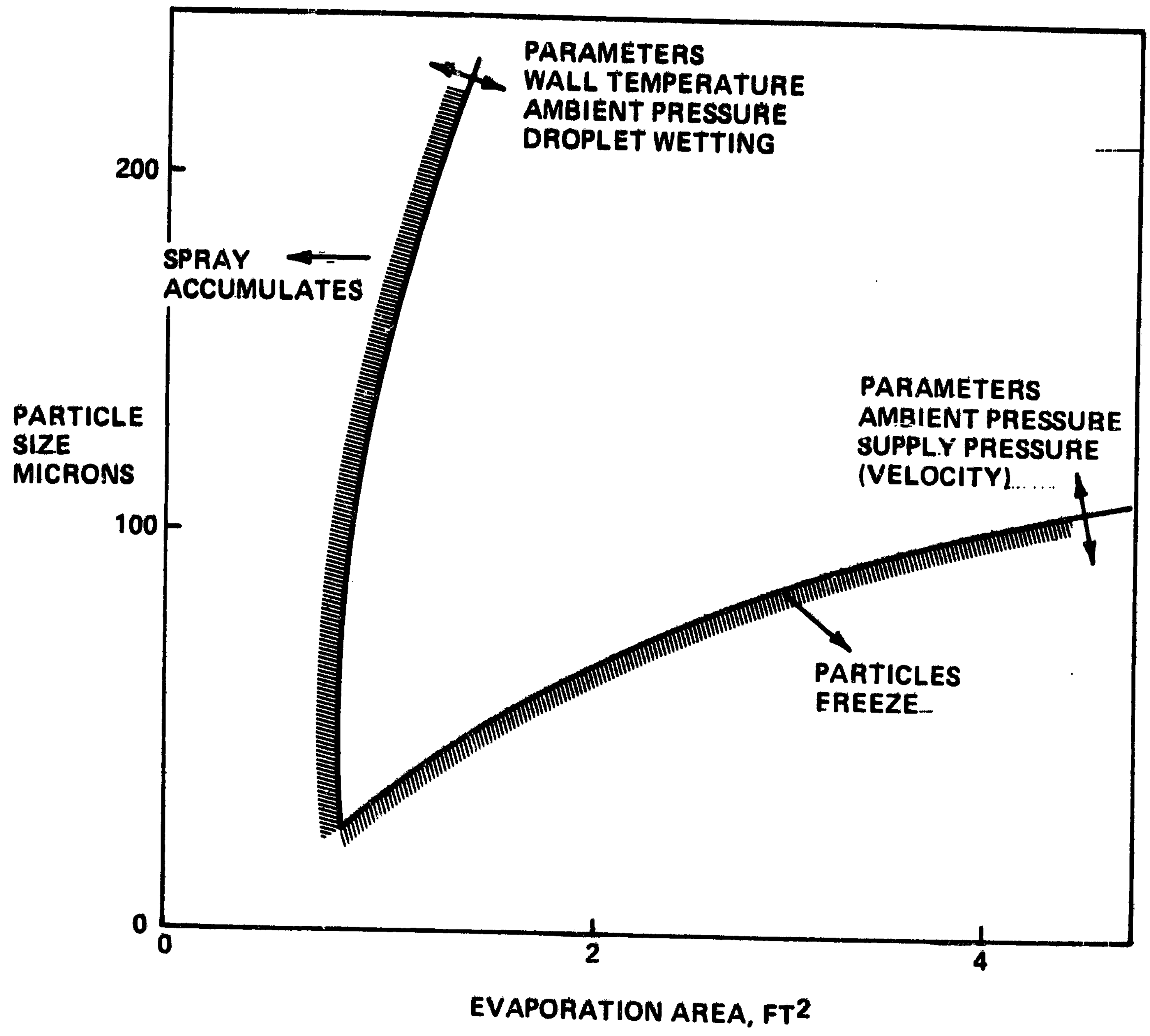


Figure 5. Limits of Desired Operation

EXPLORATORY TEST

An experiment was contrived to evaluate the effect of the basic parameters. The test objective was to establish the efficiency potential which each evaporant, to evaluate 4g effects, and to gain insight into operational problems associated with nozzle freezing, etc. The energy used to evaporate the fluid was extracted from the heat storage of a heavy test article. The simulated evaporator at a uniform high temperature was sprayed for a short interval and then allowed to reach equilibrium. The energy release calculated from before and after temperatures was divided by the expended evaporant weight to yield the enthalpy of evaporation actually obtained. This enthalpy could then be analyzed according to the appropriate parameters to account for the losses. See Figure 6.

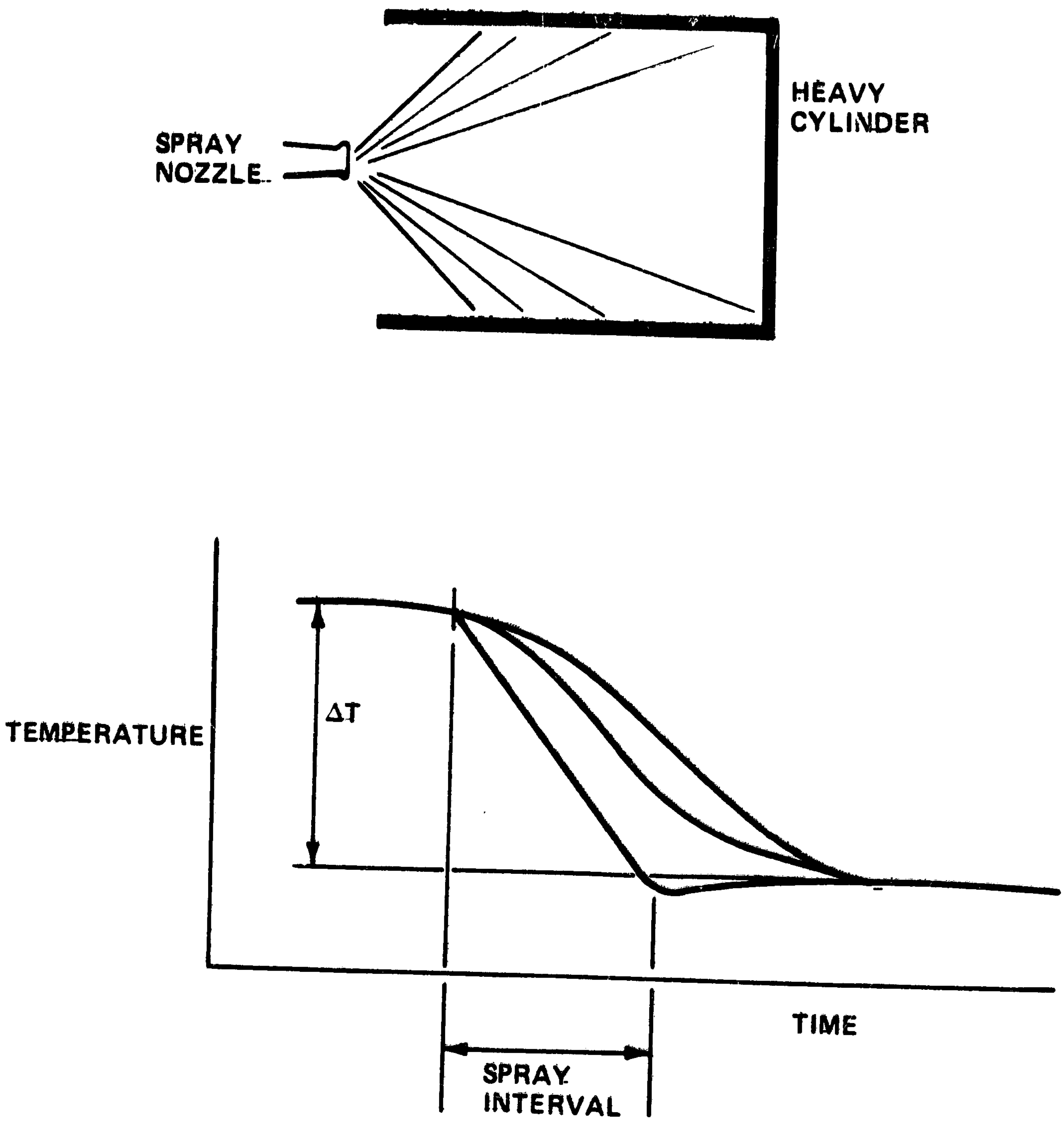


Figure 6. Exploratory Test

EXPLORATORY TEST RESULTS

The exploratory test results for water were found to form two relatively distinct data groups. At low ambient pressure, particles were observed to rebound from the evaporator wall, suggesting, together with the measured low efficiency, that the particle freezing had caused a reduction in efficiency. At higher ambient pressures, the efficiency was observed to decrease when the wall temperature approached the saturation temperature. This result is interpreted to indicate some flooding during the run. See Figure 7.

While reasonably high liquid use efficiencies were obtained with water, both the Freon 22 and NH_3 never achieved high efficiency. Some of the cause for this loss was a direct carryover of liquid droplets entrained in the vapor flow.

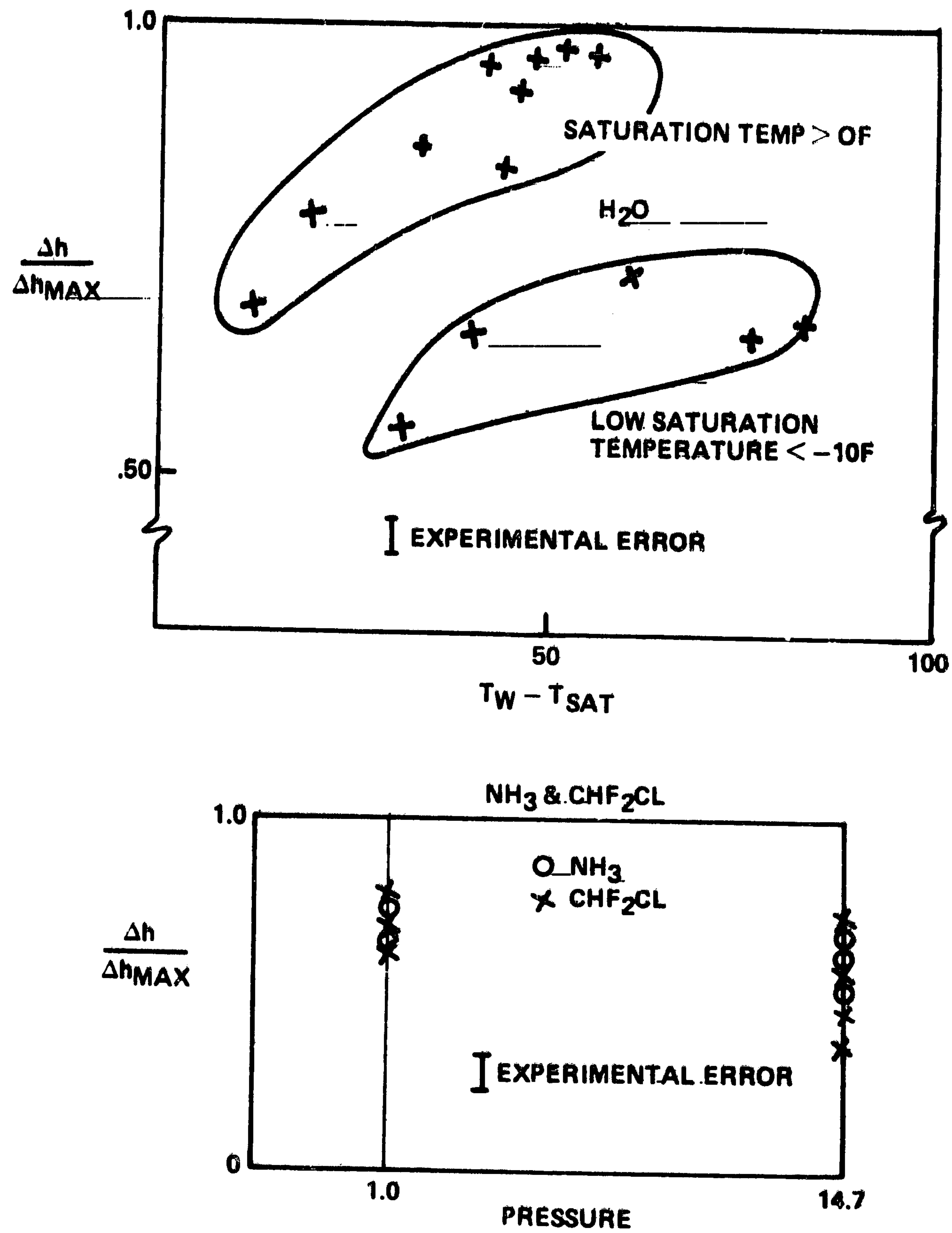


Figure 7. Exploratory Test Results

TRANSPORT FLUID SIDE DESIGN

A simple heat transfer and pressure drop calculation for the series tube evaporator heat exchange surface yields a result as illustrated in Figure 8. The transport fluid in this calculation is Freon 21 which is anticipated for the shuttle application. A similar plot results for water but tends to lower values of pressure drop and temperature difference.

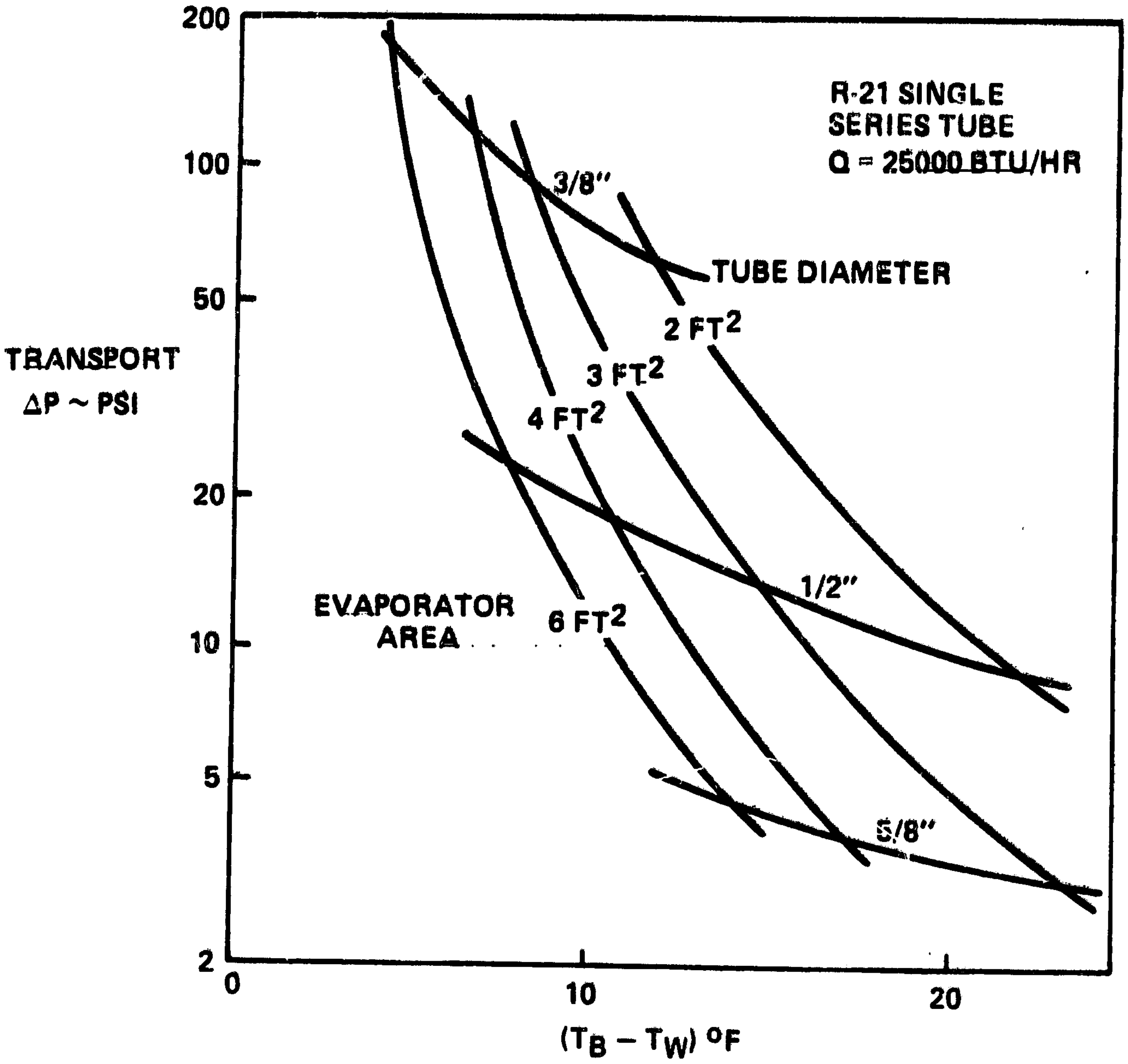


Figure 8. Transport Fluid Side Design

PARALLEL FLOW PATH OPTIMIZATION

A calculation of the previous type can be made for multiple tubes in parallel flow for Freon 21 transport fluid. By choosing the unique value of tube size and evaporator area which yield a selected pressure drop and temperature difference, one may determine the number of paths which yields the smallest evaporator. From such an exercise the area is found to be about 4 square feet for the 25000 BTU/HR device. This area could be decreased somewhat if an increased fin effect could be incorporated into the heat exchange surface. See Figure 9.

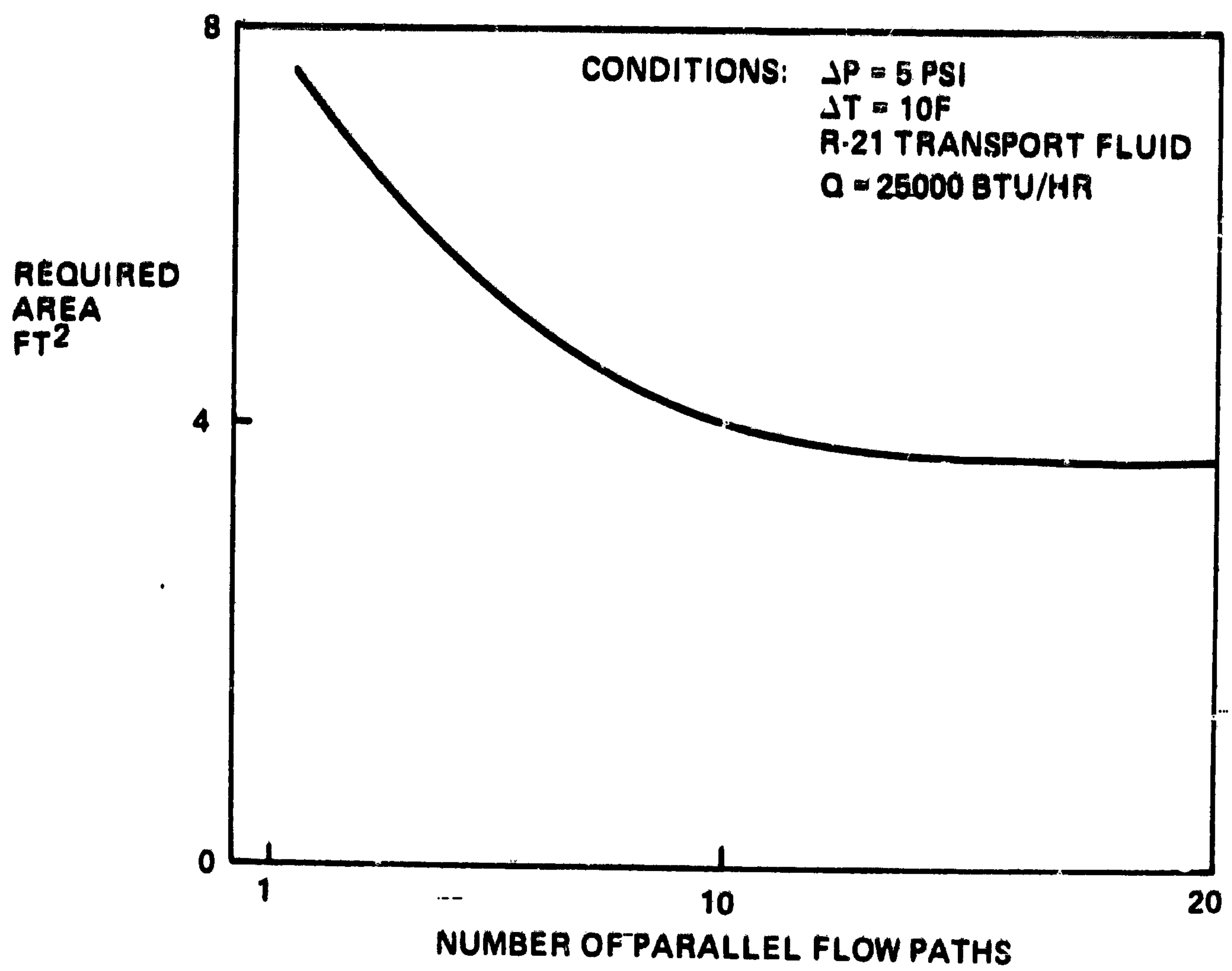
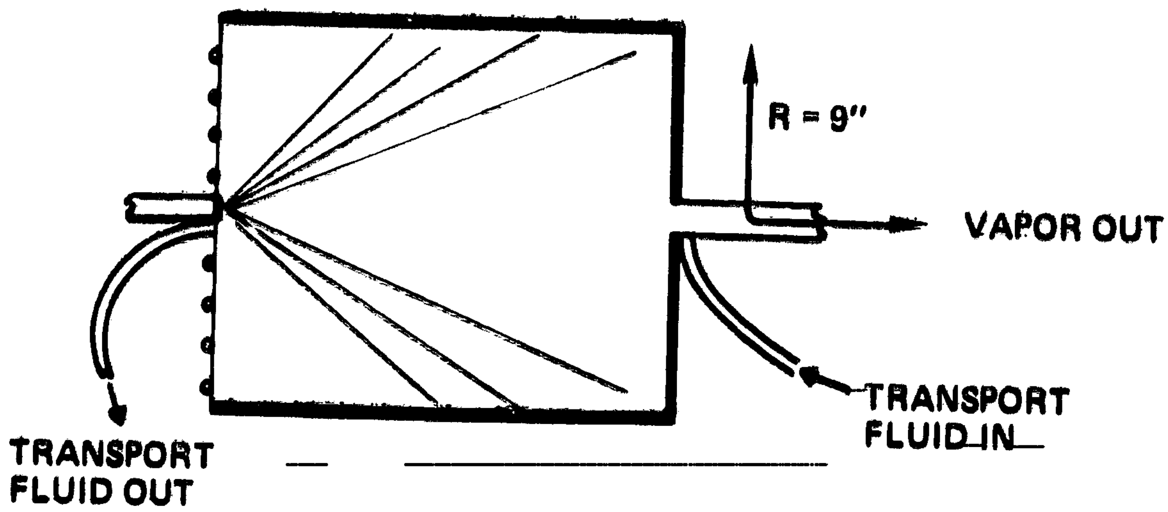


Figure 9. Parallel Flow Path Optimization

EVAPORATOR CONFIGURATIONS

With the addition of the transport fluid loop considerations, a pair of evaporators was constructed. See Figure 10. The active area of these evaporators was about 4 square feet with the anticipated spray pattern. Each of these evaporators is a fabricable configuration, and each tends to skew the spray flow differently allowing for differences in spray distribution. To provide the ambient pressure required for high efficiency, an exit hole was sized to choke the flow supplied at the desired pressure.



CYLINDER CONFIGURATION

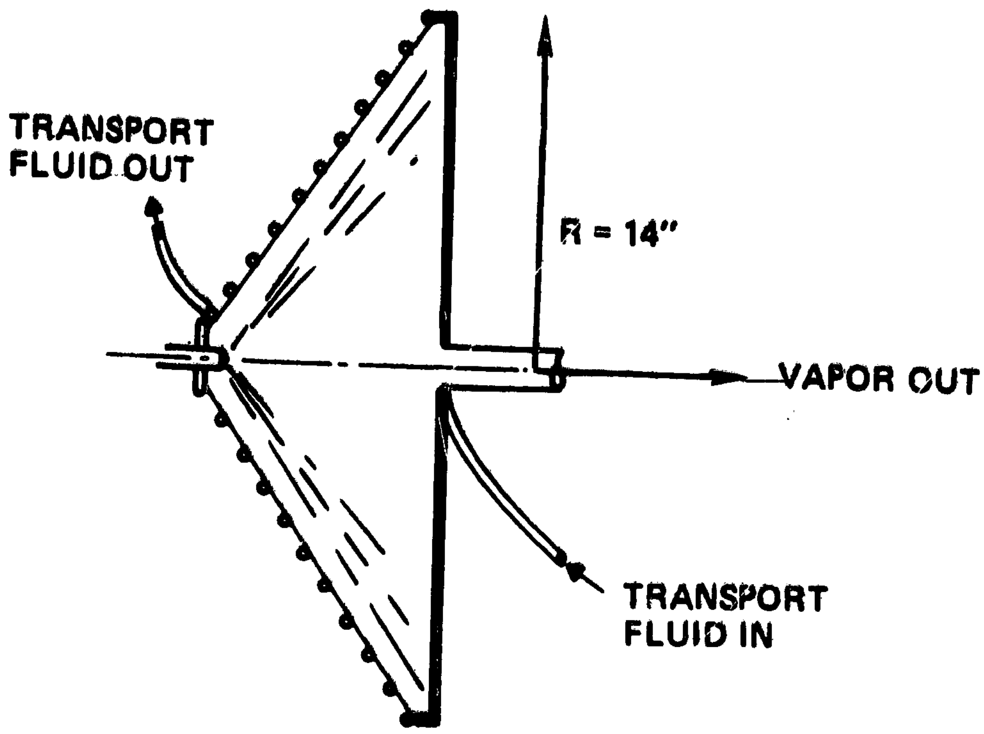
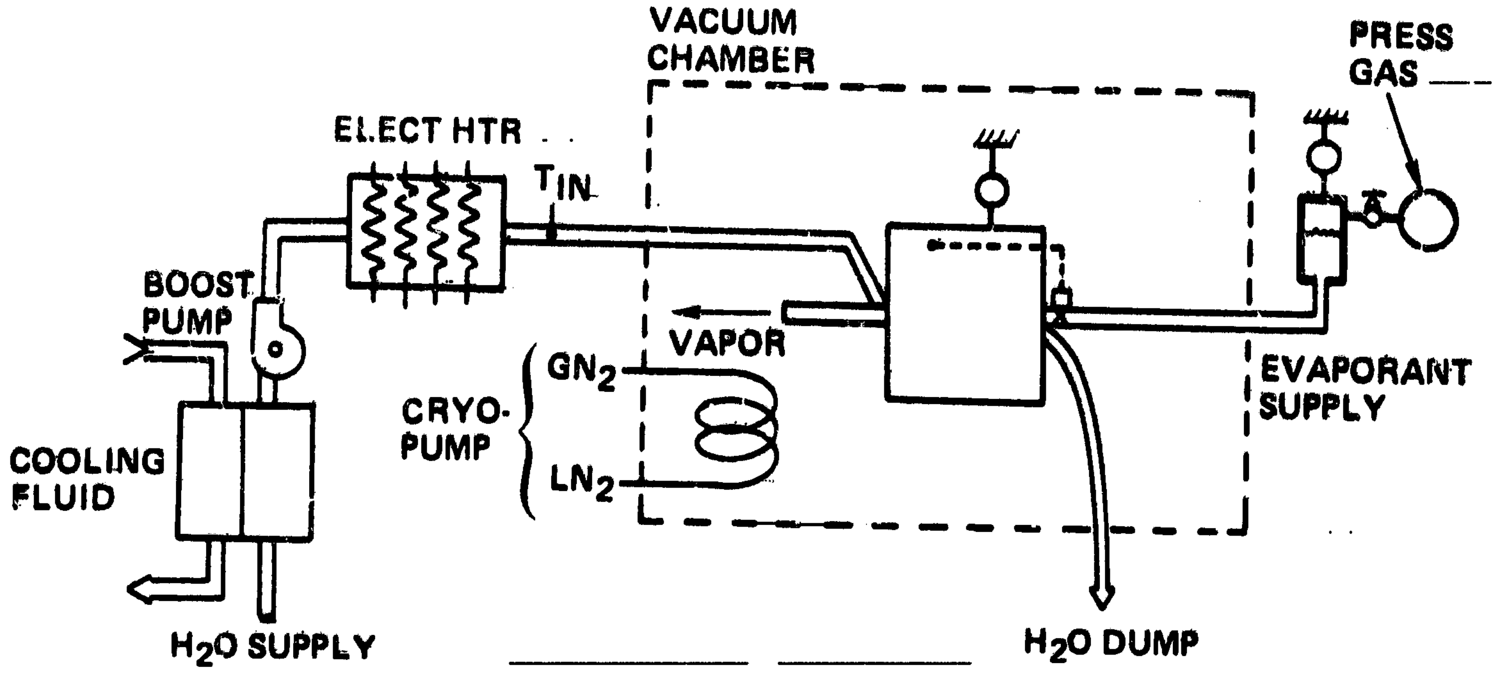


PLATE CONFIGURATION

Figure 10. Evaporator Configurations

TEST SETUP AND CONDITIONS

The evaporators were installed in a vacuum chamber which was maintained at low pressure primarily by a liquid nitrogen cryopump. Test cell pressures below 0.02 psia assured choking of the exit port during operation. Actual pressures ranged between 10 and 1000 microns Hg (.0002 and .02 psia) except during exceptional circumstances. The water used as transport fluid was preconditioned by a cooling fluid and an electrical heater to achieve one of the two illustrated inlet temperature profiles. The evaporant was supplied using a pressurant gas at regulated pressure. See Figure 11.



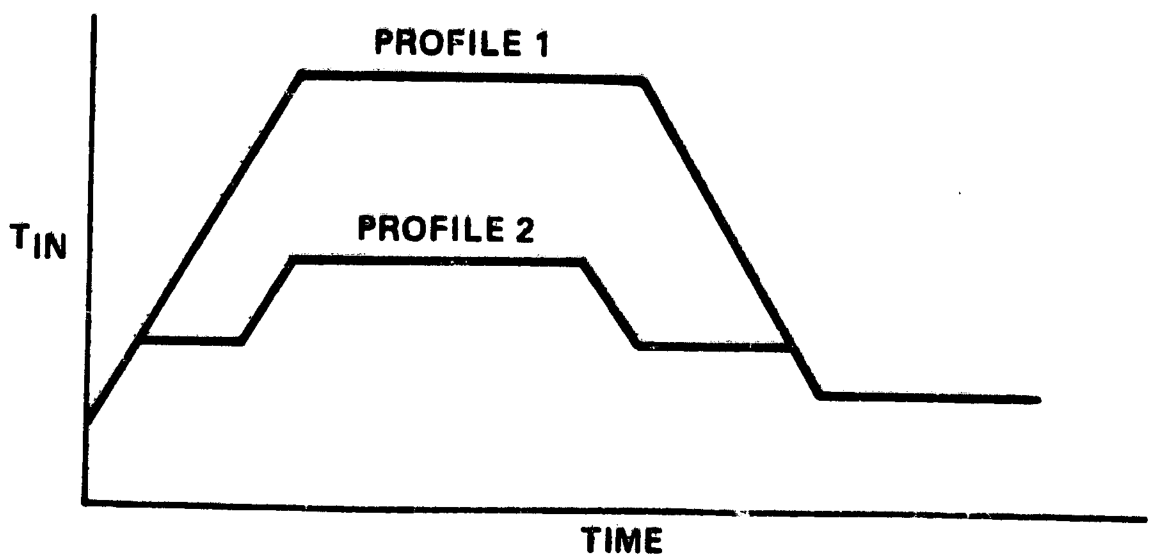


Figure 11. Test Setup and Conditions

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CYLINDER TEST INSTALLATION

The non-insulated cylindrical evaporator is shown installed in the chamber in Figure 12. Construction detail of the evaporator showing the rectangular tubing welded together is shown clearly. At the right is the evaporant supply line and valve, while on the left is a plexiglas tube simulating the vapor vent line. This tube accumulated up to an estimated 1/8 inch frost during testing. The evaporator was suspended from a load cell which could detect a one ounce accumulation within the evaporator.

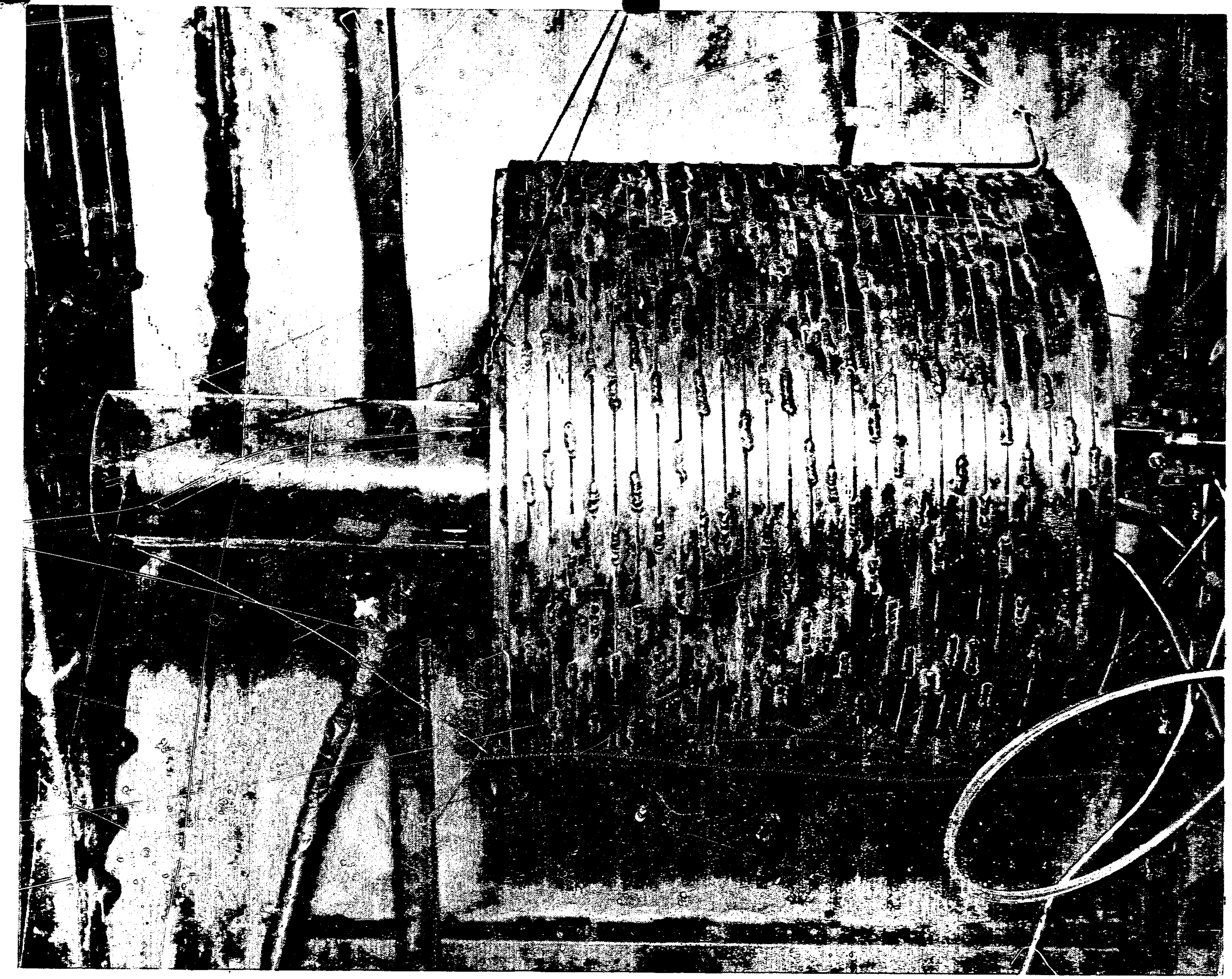

Figure 12. Cylinder Test Installation

TYPICAL RESULTS: H_2O

Results for water are as anticipated, with the evaporator's outlet temperature bounded between 35 and 45 degrees. An average of all results obtained indicates that about 93 percent of the injected water was evaporated at the predicted enthalpy rise. The only problem during testing was associated with evaporant freezing on the nozzle. This problem was circumvented by a gas nozzle purge of the liquid hold up, or by simply replacing stainless steel with a brass nozzle. Heating the nozzle was not effective in eliminating freezing. See Figure 13.

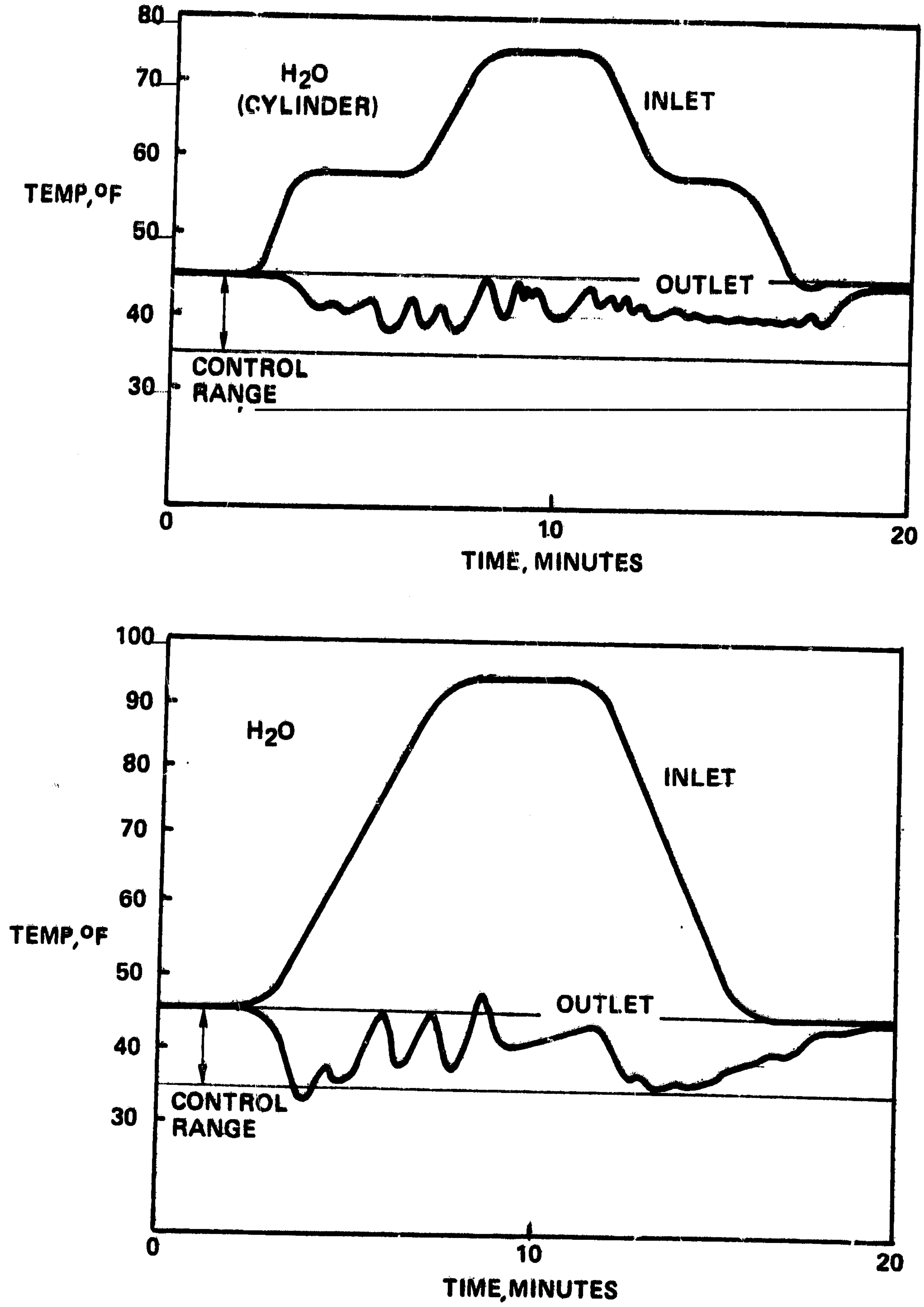

Figure 13. Typical Results: H_2O

TYPICAL RESULTS: R_{22} OR NH_3

Results for Freon 22 and Ammonia were similar to each other, with each having spray distributions which were disturbed significantly by vapor flow paths. The outlet (and interior) temperatures varied over wider ranges and incipient freezing of the transport fluid occurred in two modes. First, at low load the highest cooling position drops rapidly to freezing while the outlet is comparatively warm. As the cool pulse nears the outlet, the interior sensor is quite warm so that recycling to "on" may produce freezing at the outlet. This freezing was eliminated on all but one configuration by dual sensor control. However, the outlet temperature swings past the prescribed 35 to 45 degree control range. Some type of predetermined pulse length control could be expected to easily eliminate these swings if they are found to be excessive. Also, the use of Freon 21 as transport fluid is expected to result in lower amplitude temperature variations. See Figure 14.

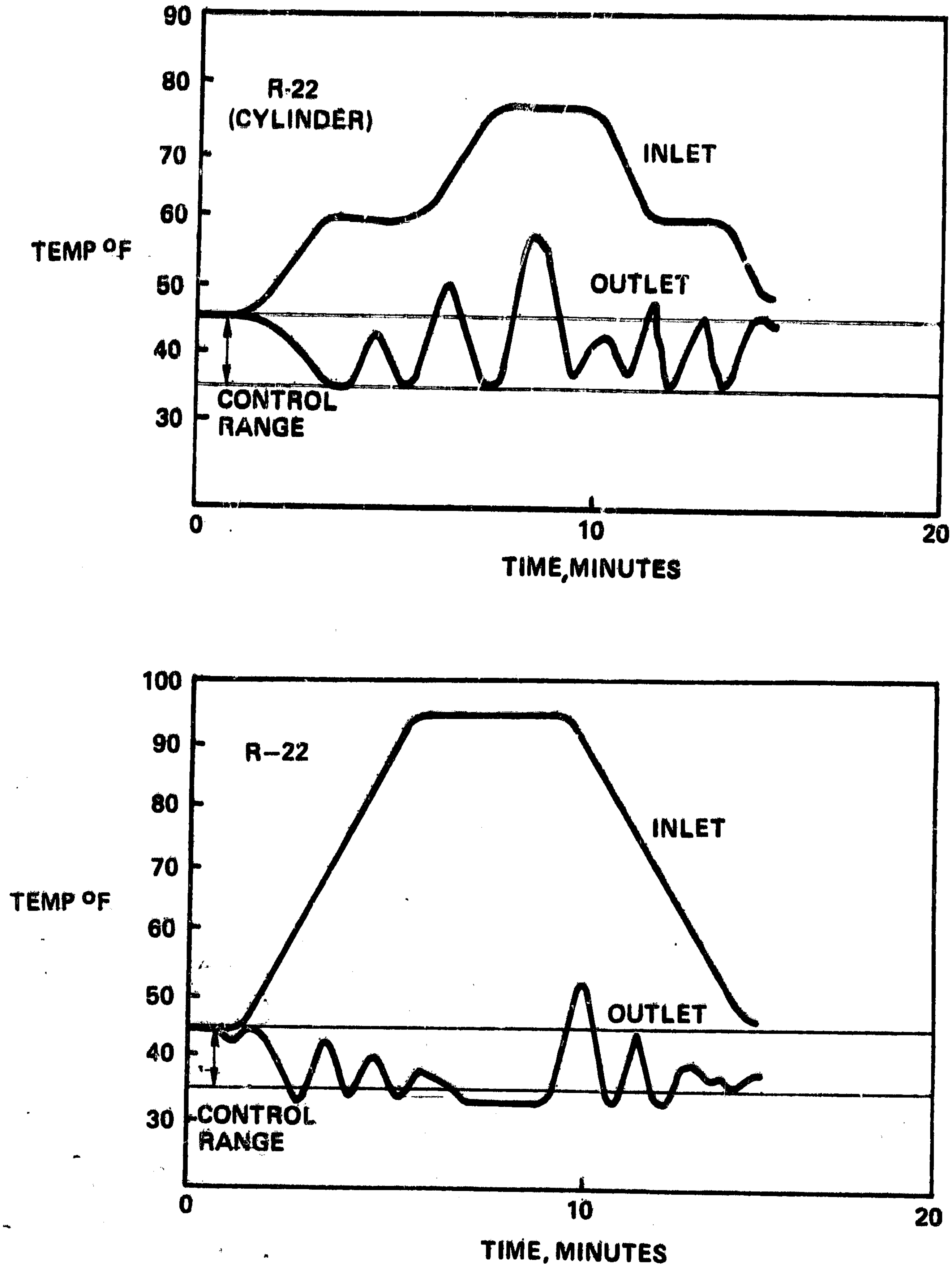

Figure 14. Typical Results: R_{22} or NH_3

SIGNIFICANT RESULTS

1. High enthalpy of vaporization achieved in single device for three evaporants.

   H_2O: 9 Runs, Δh = 965 BTU/LB (93%)

   R-22: 5 Runs, Δh = 62.5 BTU/LB (90%)

   NH_3: 4 Runs, Δh = 357 BTU/LB (80%)

2. No penalty associated with response from and assumption of quiesent condition.
3. Demonstrated capability of inlet temperature ramps up to 8 degrees per minutes.
4. Supply rate modulation control demonstrated.
5. Overloads of 75 percent demonstrated.
6. Demonstrated outlet temperature range 34 to 46 for water, 33 to 60 for R-22, 34 to 55 for NH_3.
7. Acceleration (mean) of 1 to 3.3 g documented in preliminary test, with at most a moderate efficiency loss.

CONCLUSIONS

In conclusion, this program has indicated the feasibility of a spraying flash evaporator with

1. High efficiency capability.
2. Operation without active back pressure control.
3. Control by supply rate modulation for heat load transients.
4. Capability to assume dormant operation with instant reactivation.
5. Operation with multiple evaporants in a single device.

It is recommended that the development of the evaporator concept be continued, toward providing availability for shuttle incorporation.

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RECENT RESULTS FROM ZERO 'G' CARGO HANDLING STUDIES

By Gary P. Beasley
NASA - Langley

N71-35269

INTRODUCTION

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

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

LRC SHUTTLE MAN/MACHINE STUDY PROGRAM

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

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

SHUTTLE PROBLEM-DEFINITION STUDY CONTRACT

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

LANGLEY RESEARCH CENTER SHUTTLE MAN/MACHINE INTEGRATION STUDIES

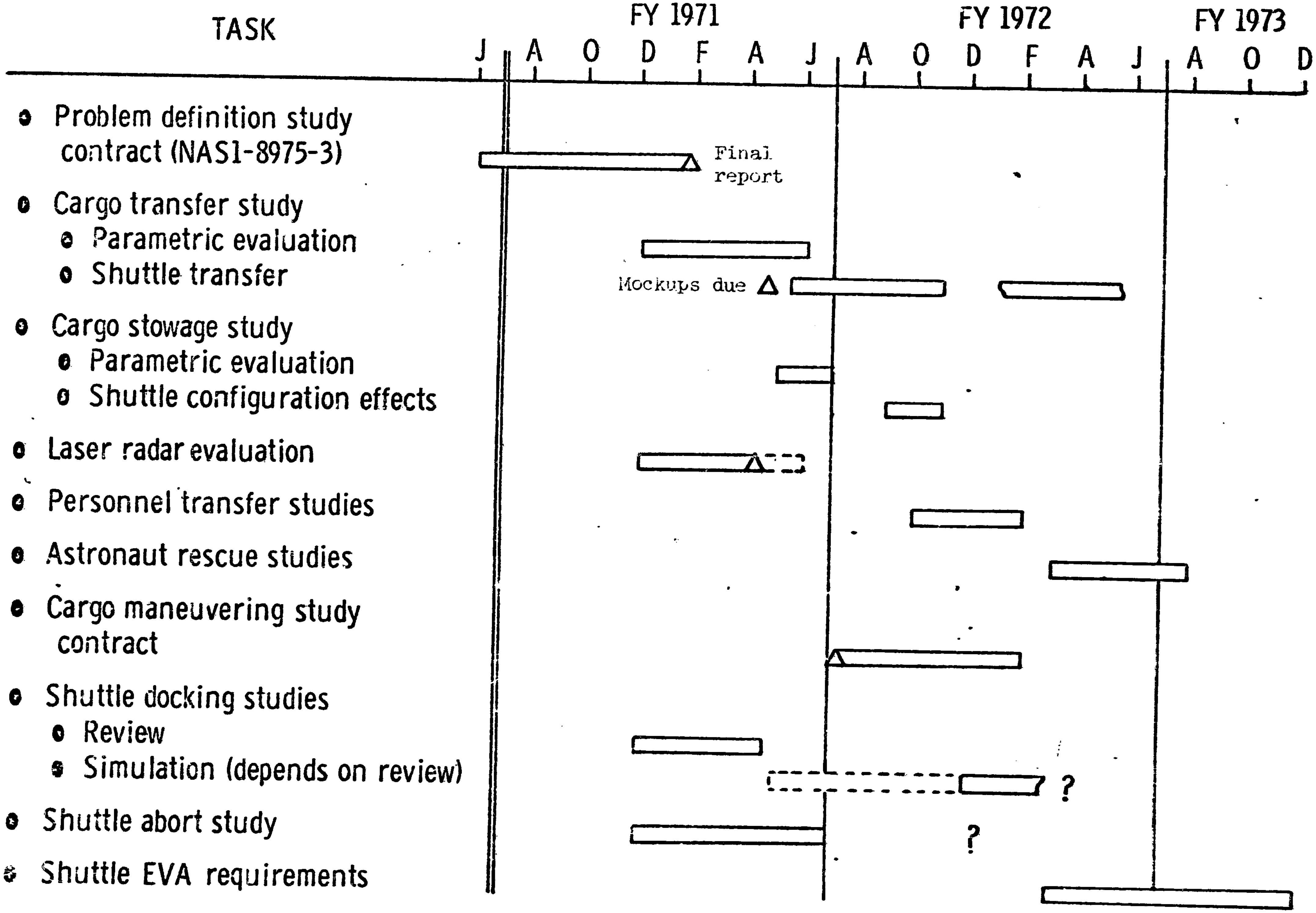


FIGURE 1.

PROBLEM DEFINITION STUDY CONTRACT

CONDUCTED BY ENVIRONMENTAL RESEARCH ASSOCIATES

REPORTED IN NASA CR-111847

SCOPE OF STUDY

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

FIGURE 2.

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

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

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

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

CARGO EXPERIMENT FUNCTIONAL PRIORITY

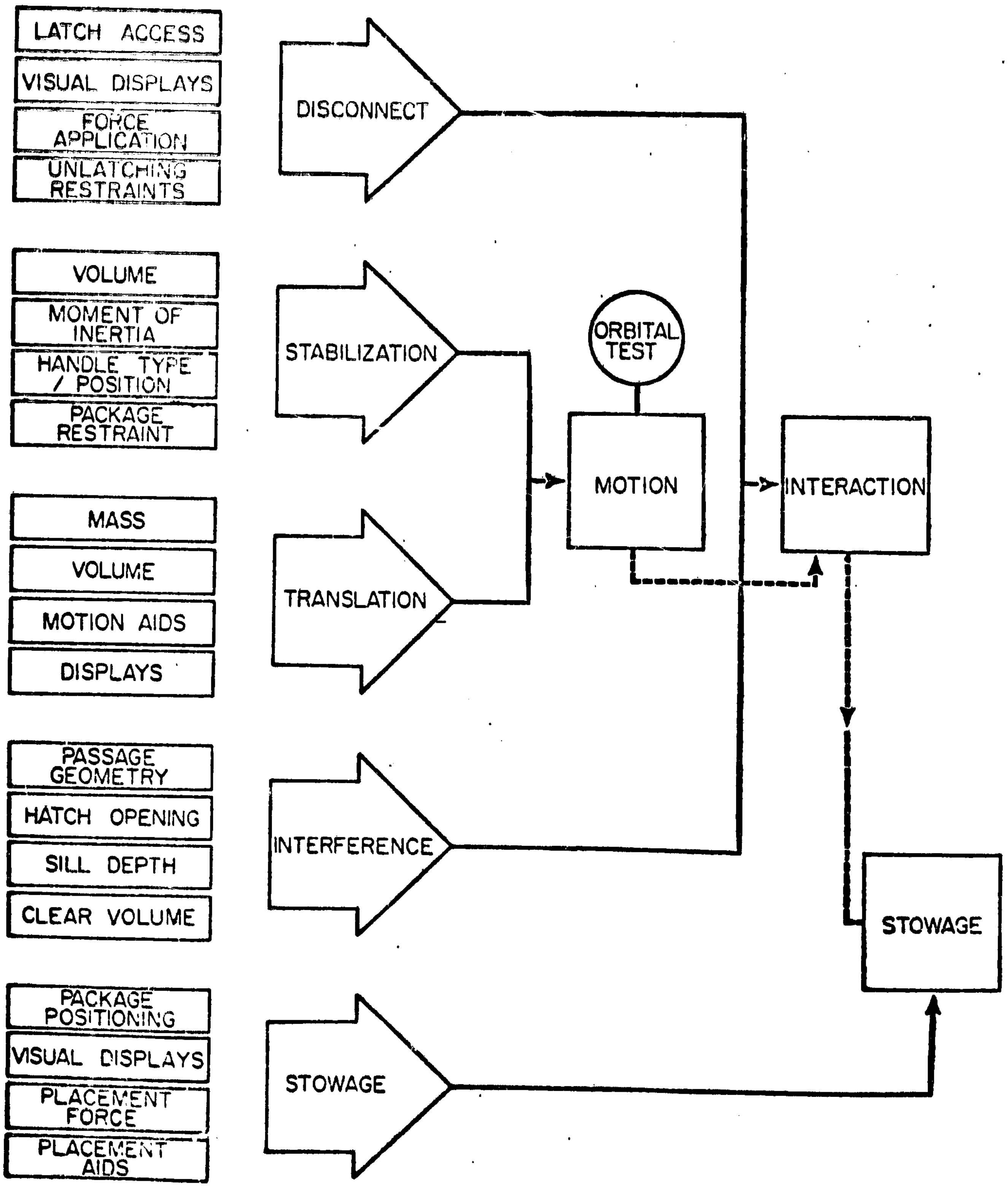
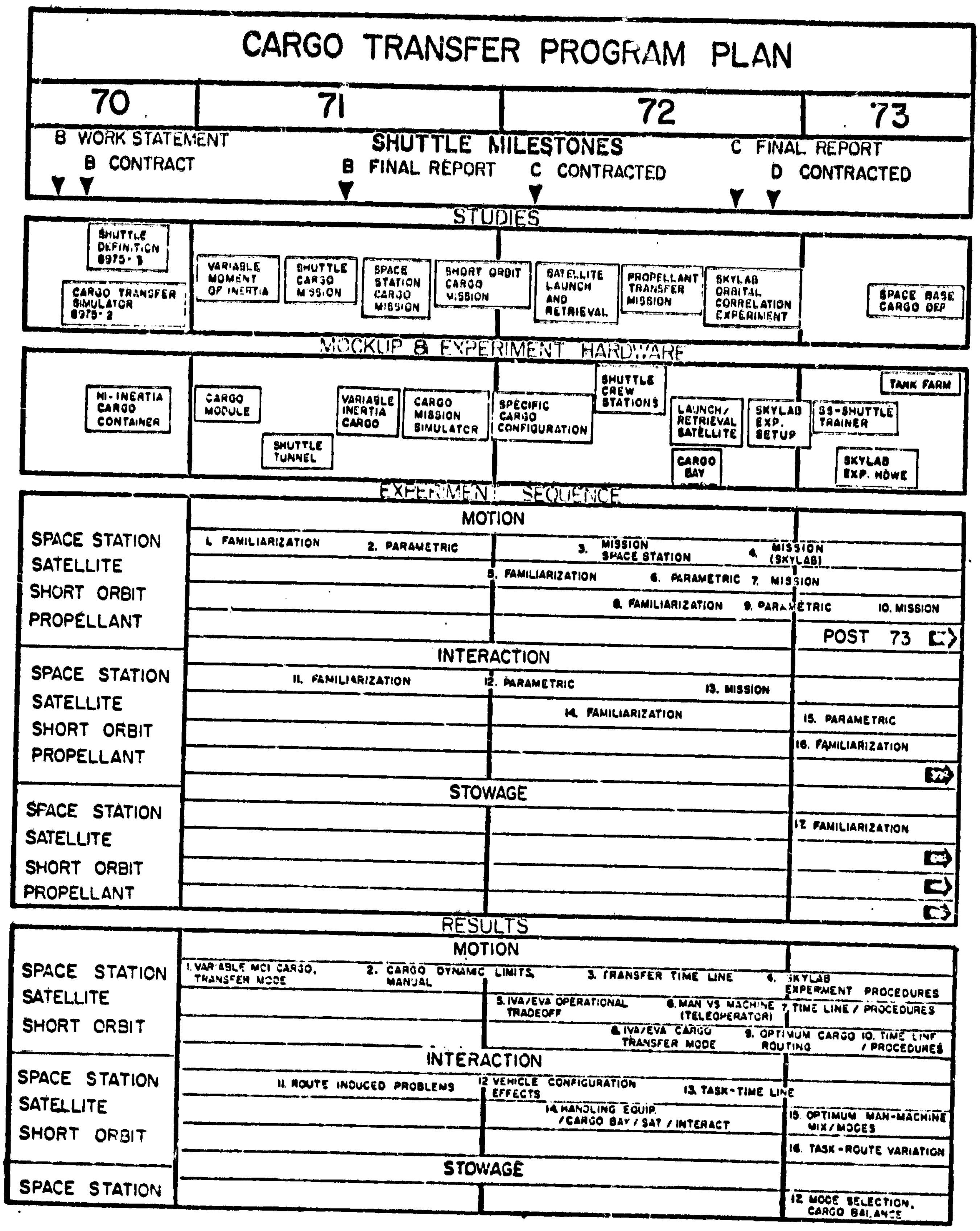


FIGURE 3.


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

FIGURE 4.

HUMAN PERFORMANCE - PACKAGE DENSITY INTERFACE

VOLUME / CUBIC FEET

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

COMBINED SPACE STATION CARGO COMPLEMENT

FIGURE 5.

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

LRC CARGO TRANSFER PARAMETRIC STUDY

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

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

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

CARGO TRANSFER PARAMETRIC STUDY
(STUDY PARAMETERS)

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

FIGURE 6.

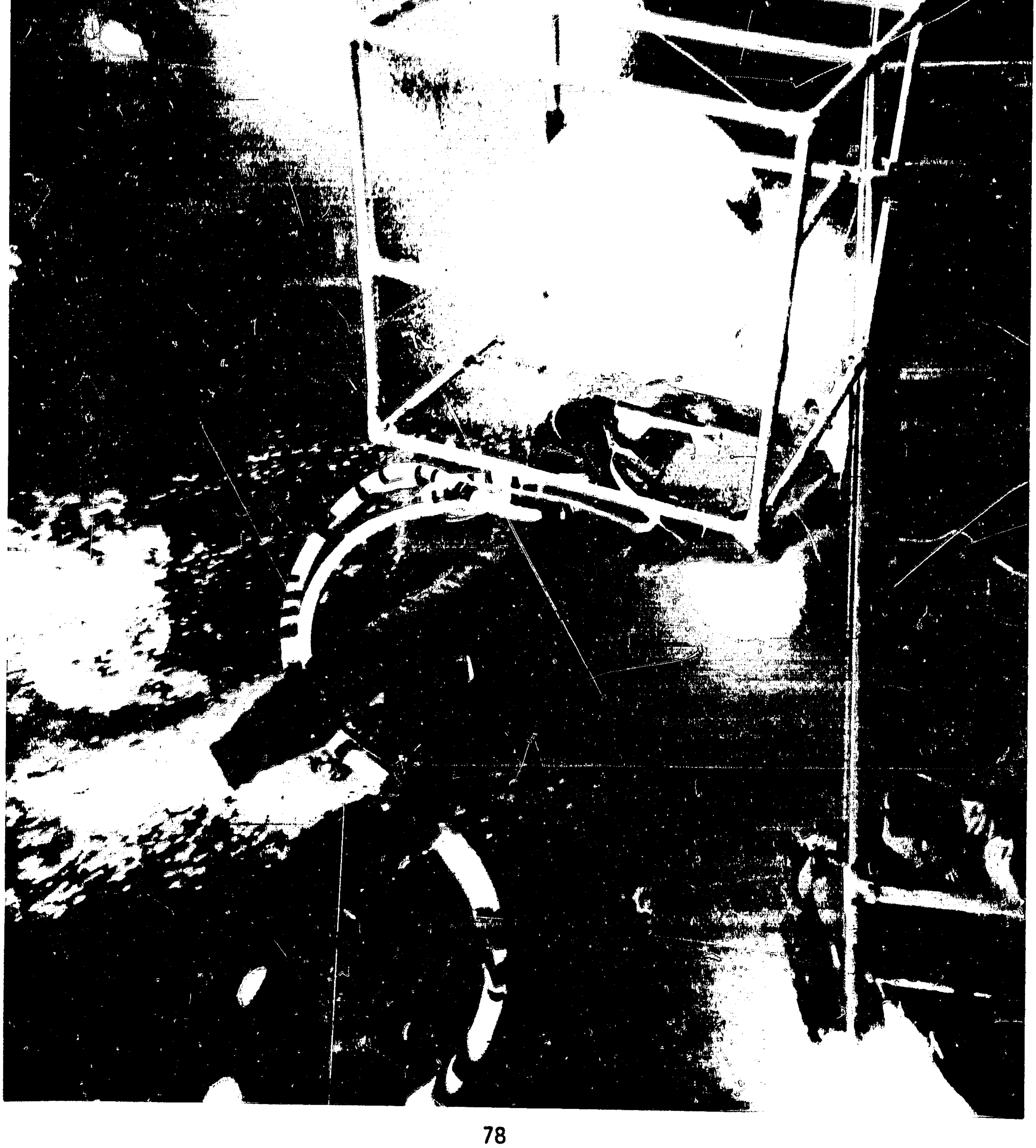
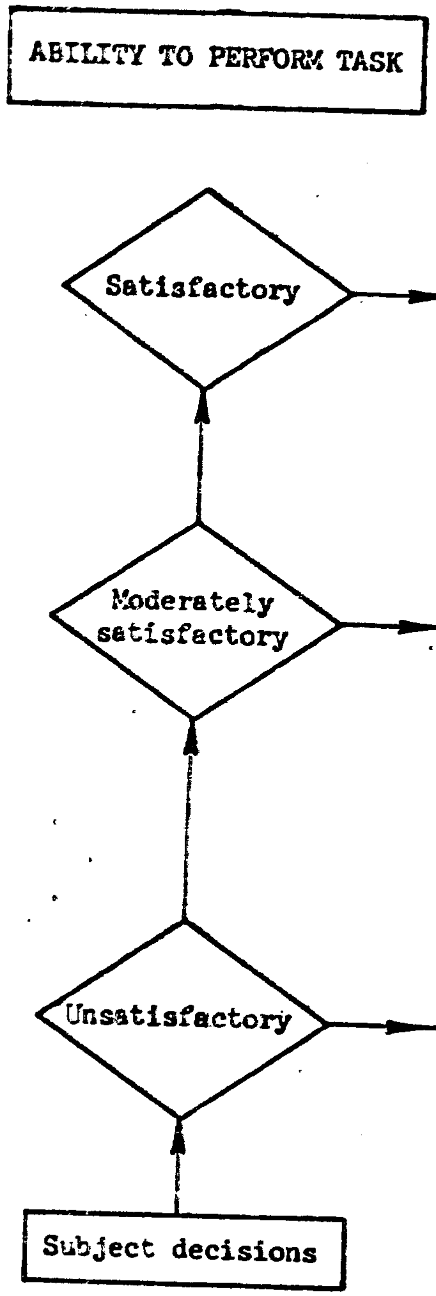


FIGURE 7.

SUBJECT RATING SCALE



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

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

FIGURE 8.

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

PRELIMINARY RESULTS

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

FIGURE 9.

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

CONCLUDING REMARKS

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

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

N71-35220

SUBSYSTEM TRADE-OFF

ENVIRONMENTAL CONTROL AND LIFE SUPPORT

FOR

ORBITER PHASE B CONTRACTOR

John Jasin (McDonnell Douglas)
Ronald Augusti (Hamilton Standard)

A description of an Environmental Control and Life Support (ECLS) subsystem for the Space Shuttle Orbiter will be presented.

Included in the description is the approach to subsystem evaluation, candidates chosen for review and candidates selected for integration into the vehicle design. Those areas within the ECLS which require advances in technology or new technology have also been identified. The selected configuration is consistent with overall program goals of maximum performance and value with a minimum of development and cost.

INTRODUCTION

The Environmental Control and Life Support (ECLS) subsystem in the orbiter provides a habitable environment for crew and equipment in the hostility of space. The ECLS must provide for the functions of:

- Shirtsleeve Environment
- Water Management
- Atmosphere Gas Supply
- Atmosphere Revitalization
- Waste Management
- Equipment Thermal Control

A block diagram of the subsystem is shown on Figure 1. The ECLS is active during the mission phases of launch, ascent, on-orbit, entry and landing, and supports two pilots and two cargo handlers. Ground Support Equipment (GSE) is utilized during prelaunch, launch and post landing activity.

The four man capacity allows for a wide latitude of mission capability ranging from seven days to thirty days. ECLS extended mission capability is achieved by the addition of modular equipment that is the same as the equipment provided in the orbiter. Provisions for this equipment addition are provided in the initial subsystem design.

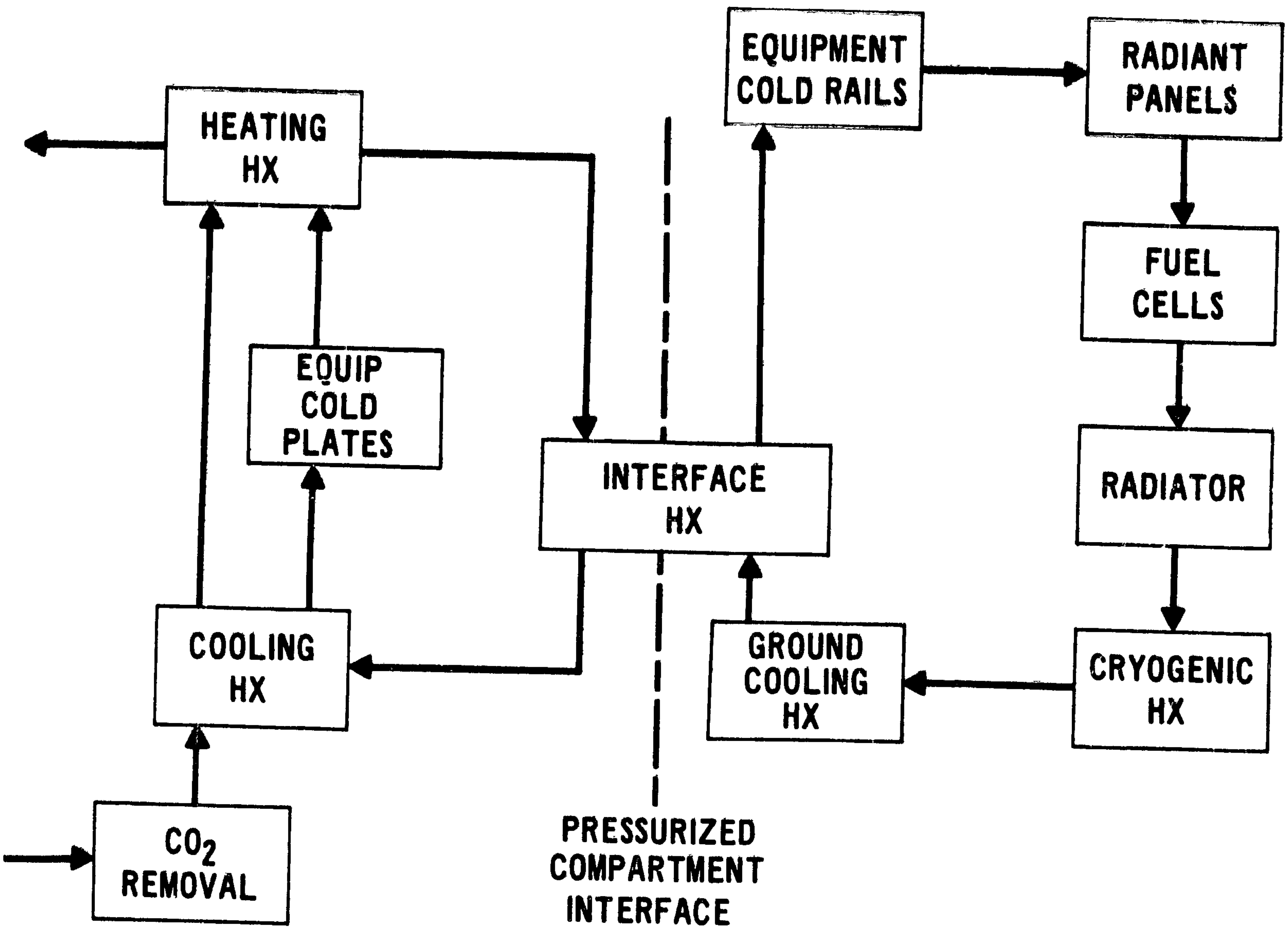


Figure 1. Orbiter ECLS Subsystem Block Diagram

REQUIREMENTS

Major requirements affecting ECLS design and the parameter value used in our approach are summarized in Table 1.

Subsystem cost is a major factor in the selection of a design. As an overall requirement, the candidates for evaluation have to be cost effective in addition to meeting performance requirements.

SUBSYSTEM DESCRIPTION

A description of the candidates selected for study for each of the ECLS assemblies is presented herein. The candidates are compared by using a set of selection criteria. The criteria are divided into three-groups-absolute, quantitative, and qualitative. All candidates must meet the absolute criteria of performance, safety, reliability and availability or they are eliminated from further consideration. The quantitative criteria are related to cost and include weight, power consumption and expendables. Qualitative criteria are composed of complexity, flexibility, maintainability, and life.

Some of the approaches, being basically a tabulation of present state-of-the-art, do not require formal evaluation.

Atmospheric Storage Assembly - Several potential candidates exist for atmospheric storage. These include subcritical, supercritical and high pressure gas. Further, combinations of storage supplies for separate subsystems using the same media such as the hydrogen/oxygen fuel cell also exist. Table 2 presents the results of the nitrogen storage portion of atmosphere storage study, conducted to determine the optimum storage configuration. Two 3000 psia filament wound composite tanks are selected for nitrogen storage on the basis of safety and equivalent cost. Table 3 shows the study results of separate versus common oxygen storage and whether that storage should be cryogenic or gaseous. The system selected utilizes the Orbit Maneuvering System subcritical storage tank for supplying oxygen during normal operation. In the event oxygen cannot be supplied to the ECLS, a 3000 psia tank of filament wound composite material construction will supply oxygen at normal use rates for a 48 hour period.

Atmosphere Pressure Control Assembly - Cabin pressure and composition control is maintained by a Skylab type two-gas controller and tripley redundant pressure relief valves. The Skylab controller is chosen because its developed and qualified status results in a lower orbiter ECLS cost.

TABLE 1

ORBITER ECLS DESIGN REQUIREMENTS

NUMBER OF CREW	4
METABOLIC HEAT	650 BTU/MAN-HR
OXYGEN USAGE	1.84 LB/MAN-DAY
CO_2 PRODUCTION	2.20 LB/MAN-DAY
URINE PRODUCED	3.45 LB/MAN-DAY
MISSION DURATION	7 DAYS (NOMINAL)
TOTAL MISSIONS/ VEHICLE	100

VEHICLE LIFE	10 YEARS
CABIN PRESSURE	10 & 14.7 PSIA
OXYGEN PARTIAL PRESSURE	3.1 PSI
CO_2 LEVEL (NOMINAL)	5.0 MM Hg
CABIN TEMPERATURE	65–75°F
HUMIDITY (DEW POINT)	46–57°F
CABIN LEAKAGE	3.5 LB/DAY

TABLE 2

ATMOSPHERE STORAGE STUDY SUMMARY

GAS	NITROGEN STORAGE			
	CRYOGENIC		HIGH PRESSURE	
CANDIDATE	SUBCRITICAL	SUPERCRITICAL	TITANIUM TANK	FILAMENT WOUND TANK
CANDIDATE NO.	6A	6B	7A	7B
HIGH PRESSURE GAS TANKAGE MATERIAL SELECTION				7B
CRYOGENIC VS HIGH PRESSURE GAS STORAGE				7B

TABLE ·

ATMOSPHERE STORAGE STUDY SUMMARY

GAS			OXYGEN STORAGE							
CANDIDATE	OMS · EMERGENCY		COMBINED FUEL CELL & ECLSS				SEPARATE FUEL CELL & ECLSS			
	STAINLESS STEEL TANK	FILAMENT WOUND TANK	SUB-CRITICAL	SUPER-CRITICAL	STAINLESS STEEL TANK	FILAMENT WOUND TANK	SUB-CRITICAL	SUPER-CRITICAL	STAINLESS STEEL TANK	FILAMENT WOUND TANK
CANDIDATE NO.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
HIGH PRESSURE GAS TANKAGE MATERIAL SELECTION		1B*				3B				5B*
CRYOGENIC VS HIGH PRESSURE GAS STORAGE				2B						5B
COMBINED VS SEPARATE STORAGE FOR FUEL CELL & ECLSS O_2		1B								

*SELECTED BY SIMILARITY WITH 3B

Total cabin pressure is controlled by redundant absolute pressure regulators which can be manually selected for 10.0 or 14.7 psia operation. The multi-purpose range will support both Space Station rendezvous and potential EVA missions. The cabin pressure relief valves are also manually set for either 10.0 or 14.7 psia. These valves relieve cabin atmosphere overboard during launch and allow pressurization of the cabin during entry.

Partial oxygen pressure is maintained within prescribed limits and is controlled by redundant pO_2 sensors and normally closed solenoid valves on the nitrogen supply inlet.

Ventilation Provisions - Three redundant fans in the air distribution system provide ventilation. Air is drawn into the cabin air loop, through the carbon dioxide processing unit, conditioned for both humidity and temperature, and then returned to the cabin. The process flows for four men which are required for suitable humidity and CO_2 control are also adequate for cabin ventilation thus negating the need for multiple cabin fan installations.

Carbon Dioxide Removal & Humidity Control Assembly - Several approaches to carbon dioxide and humidity control are available for use. Those considered during the CO_2/humidity control study for orbiter application are:

- Lithium Hydroxide and Condenser
- Lithium Hydroxide and Desiccant
- Molecular Sieve and Condenser
- Molecular Sieve and Desiccant
- Solid Amine

Table 4 presents a summary of the trade-off results. Lithium hydroxide, in conjunction with a condensing heat exchanger, is selected for orbiter application. Each cartridge contains four man days worth of LiOH and activated charcoal and is replaced on a prescribed basis.

The area of CO_2 and humidity control may be considered for advancement in control techniques. Although a LiOH and condenser assembly is adequate and is chosen on the basis of cost through first flight, a more flexible system could be achieved with solid amine or desiccant. These approaches become attractive if multiple crew and varying mission duration mixes are considered.

TABLE 4

CO_2 AND HUMIDITY CONTROL SUBSYSTEM COMPARISON

SUBSYSTEMS	RANKED 1 TO 5, LOWEST TO HIGHEST	
	WEIGHT	COST
LiOH/CONDENSER	1	1
LiOH/DESICCANT	4	4
MOLECULAR SIEVE/CONDENSER	3	3
MOLECULAR SIEVE/DESICCANT	5	5
HS–B	2	2

Trace Contaminant - Control of contaminants is achieved in the orbiter by means of cabin leakage and activated charcoal. A cabin leakage of 3.5 pounds per day will control most of the trace gases. Activated charcoal is used to remove the larger molecules of organic contaminants. Activated charcoal is chosen on the basis of Gemini, Apollo and LM experience.

Heat Transport Assembly - Redundant water loops within the crew compartment and redundant Freon 21 coolant loops external to the crew compartment provide thermal control for crew and equipment. Heat generated within the crew compartment by the crew, $LiOH/CO_2$ reaction, avionics and other equipment, and radiation to the cabin wall is picked up by circulating water loops and transferred via interface heat exchangers to the equipment loops. The equipment loops, in addition to removing heat from the cabin, provide thermal control for the avionics equipment, fuel cells, and the landing gear wheel wells. Heat is removed from the equipment loops by the space radiator during the orbital mission phase. During the ascent and entry phases heat is removed by redundant cryogenic hydrogen heat exchangers. Hydrogen is chosen for its availability throughout the mission phases and its cooling efficiency, as shown in Figure 2.

Each of the redundant crew compartment loops has two pumps for circulating the water through the condensing and cabin heat exchangers for removal of moisture and temperature control of the atmosphere, and through cold plates and cold rails for heat removal from the avionics equipment located within the compartment. Two pumps are provided in each of the redundant equipment loops. One pump operation is necessary to provide cooling for normal orbital heat loads. For the higher heat loads encountered during ascent, entry and short orbital periods, two pumps are required. Two pumps in one loop or one pump in each loop provide the necessary cooling.

The cryogenic hydrogen heat exchanger is a potential candidate for early development. This approach is a key element in the thermal control portion of the subsystem design. Investigation is required in the areas of control, sizing and atmospheric operation.

Space Radiator Assembly - The radiator is a deployable panel which is stowed under the cargo bay door during launch and entry. In orbit, the cargo bay door is opened, the radiator is deployed, and the cargo bay door is closed. Prior to entry, the procedure is reversed. The radiator is constructed of aluminum with a low α/ϵ coating to effect radiation from both sides of the panel. The two dimensional tube pattern, combined with a bypass stagnation heat load control, provides a wide heat load range.

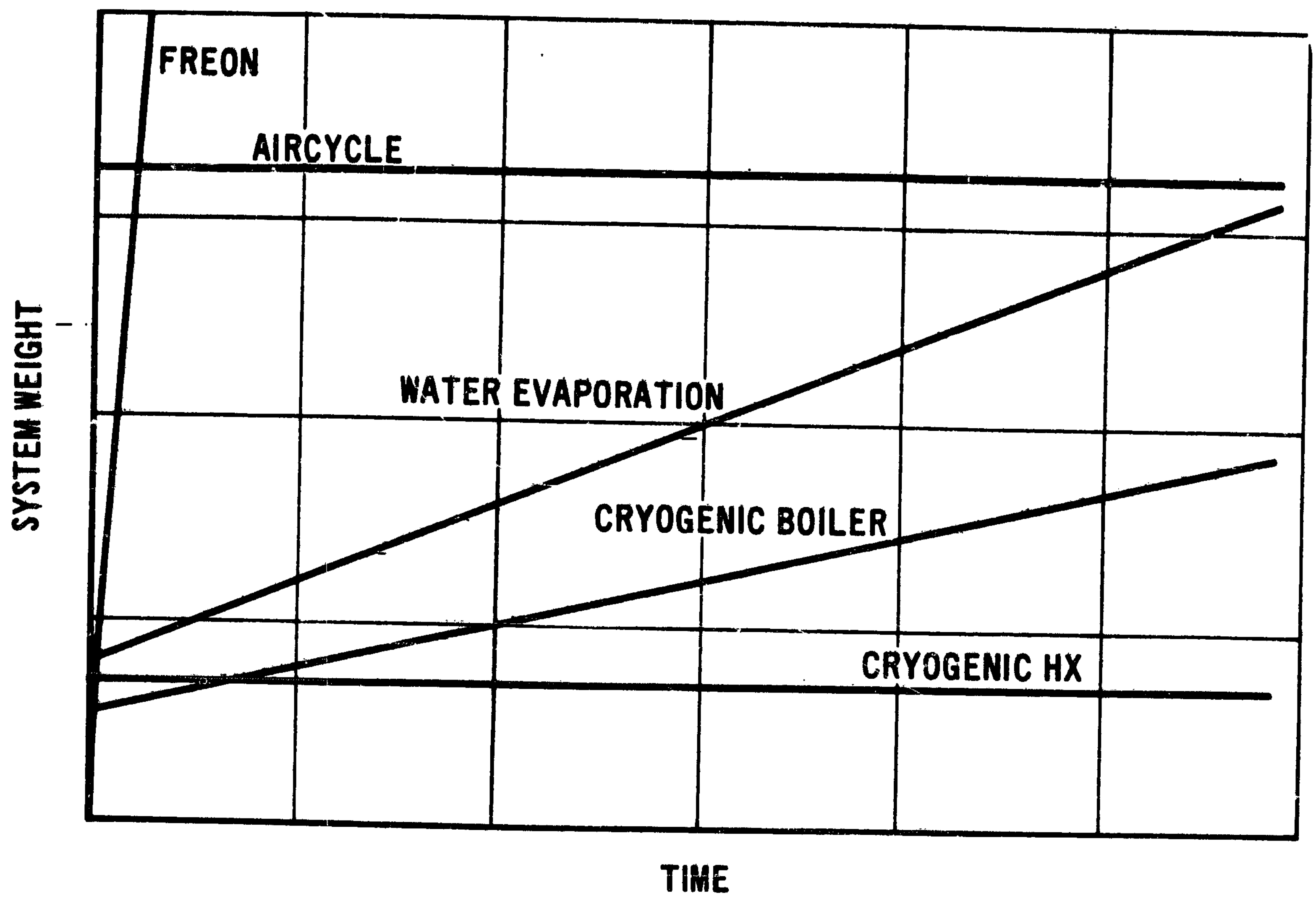


Figure 2. Environmental Control and Life Support Comparison of Cooling Approaches

Water Management - Included in water management are storage and dumping of fuel cell product water, provision of drinking water and the bacteriological control of the subsystem. The storage tanks are sized to preclude overboard dumping in the vicinity of the Space Station. Automatic operation is provided with the capability of manual override.

Both pasteurization and chemical addition are being considered for bacteriological control pending the outcome of detail design. The Skylab water system design and monitoring approach are available for adaptation into the orbiter. Skylab uses an iodine injection system in conjunction with a test solution which determines an adequate iodine content.

Waste Management Assembly - The waste management assembly provides for feces, urine and small trash collection, processing and storage. The major concern in waste management design is the area of crew acceptability. Existing waste collection systems, either in the concept or breadboard stage, are of two types. These are integrated vacuum drying and manual transfer with vacuum drying. Of the two, the integrated vacuum drying approach is more acceptable from a crew acceptability standpoint. Since the orbiter does not presently have a requirement for medical monitoring, the bag collection with manual transfer and drying is not warranted. The system selected for integration into the orbiter is similar to that used on the Space Station Prototype (SSP). In that system, feces and solid waste are collected, vacuum dried and stored in one container. Additional effort is required in the development of waste management system determining the impact of both sexes in the crew and passenger contingent.

Fire Extinguishing - Portable fire extinguishers are provided in the crew and passenger area. Some developmental work is required to verify use in zero "g". The-units contain 2-5 pounds of carbon dioxide in accordance with the standard on aircraft hand fire extinguishers. A design margin is provided in the lithium hydroxide in the event a unit is discharged. The pCO_2 indicator provides visual indication to the crew as a safe pCO_2 level is achieved. Oxygen masks are worn during this period which is less than five hours. Additionally, the capability to purge the cabin with nitrogen is available. Nonflammable materials are used throughout the crew and passenger area to minimize the risk of fire.

DESIGN APPROACH

Aircraft philosophies and practices are applied to the orbiter ECLS design which result in a subsystem that meets the Space Shuttle maintainability requirements of short turnaround, ease of refurbishment and maintenance, including unscheduled maintenance. A minimum cost subsystem with maximum flexibility of design is achieved through commonality of high cost equipment. Potential ECLS orbiter and booster candidates for commonality include:

- Cabin Pressure Relief Valves
- Booster Air Tank and Orbiter Emergency Oxygen Tank
- Cryogenic Heat Exchangers
- Cooling Umbilicals
- Crew Equipment

The capability of extravehicular activity, although not directly provided in the orbiter design, was considered to the extent that it can be included in future program requirements.

Subsystem flexibility is provided in the form of dd-on equipment which results in the capability to extend the orbiter mission duration.

CONCLUSIONS

The Environmental Control and Life Support subsystem provided for the Space Shuttle Orbiter satisfies the program goal of maximum performance and value, with a minimum of development and cost. This achievement is attained primarily in two ways, the first being maximum use of existing spacecraft components that meet the exacting requirements of a reusable Space Shuttle vehicle, and secondary, utilizing common or similar components and assemblies in the orbiter and booster to minimize program development costs.

The orbiter ECLS design definition has identified some areas requiring new or advancements in development. These are primarily in the fields of composite materials for pressure vessels, regenerative sorbents for humidity control, cryogenic heat exchange and its associated control, waste management and the impact of both sexes on crew make-up, and finally, spacecraft fire extinguishers for 1 "g" and zero "g" application. None of the above areas, nor the subsystem defined for the Space Shuttle orbiter, require major advances in technology along with their associated costs. Pursuit of the design definition described above will result in a viable system for the Space Shuttle Program.

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PRELIMINARY RESULTS OF SPACE SHUTTLE EC/LSS STUDIES

Lenwood G. Clark and Robert S. Osborne

NASA Langley Research Center
Hampton, Virginia

N71-35271

INTRODUCTION

The purpose of this paper is to indicate overall status of the Langley Research Center program on space shuttle environmental control/life support systems (EC/LSS), present preliminary results of studies being conducted, and provide a current assessment of technology advancements required.

LRC Program Status

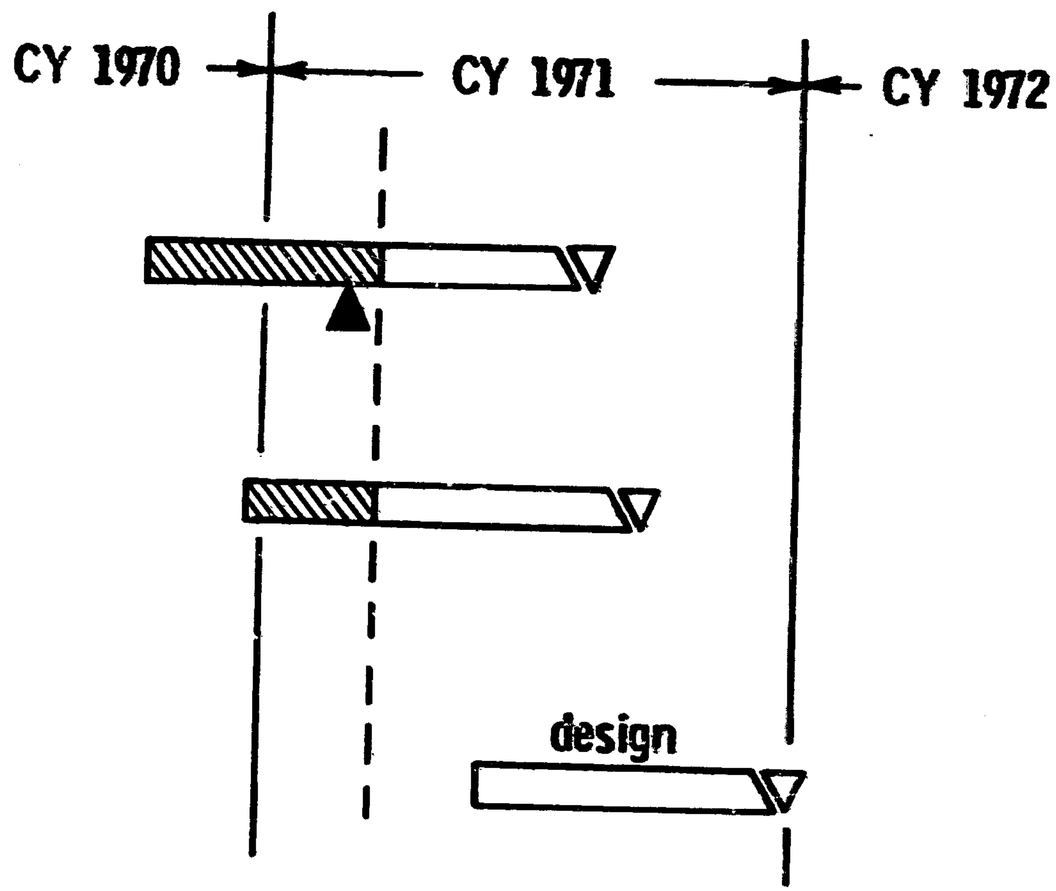
Primary elements of the program currently consist of two contracted EC/LS systems studies and design of a flight trace contaminant sensor system. Other Langley research activities not supported directly by shuttle funding also have application to shuttle life support problems and will be identified later.

The Hamilton Standard effort includes conducting subsystem trade-off studies, assembling a conceptual system, and identifying pacing technology for shuttle orbiter EC/LS. It is about 50 percent complete and, as noted by the recent milestone, a midterm progress report has been published.

Lockheed is concentrating on four orbiter EC/LSS problems: cargo module system concepts, shuttle/space station interfaces, integrated cabin thermal control for all mission phases, and subsystem reusability. This contract has been underway for only about three months and results are limited.

The design phase of the contractual effort to develop a multi-gas trace contaminant sensor system will be initiated shortly.

LRC PROGRAM STATUS



EC/LS SYSTEMS STUDY
NAS1 - 10359
HAMILTON STANDARD

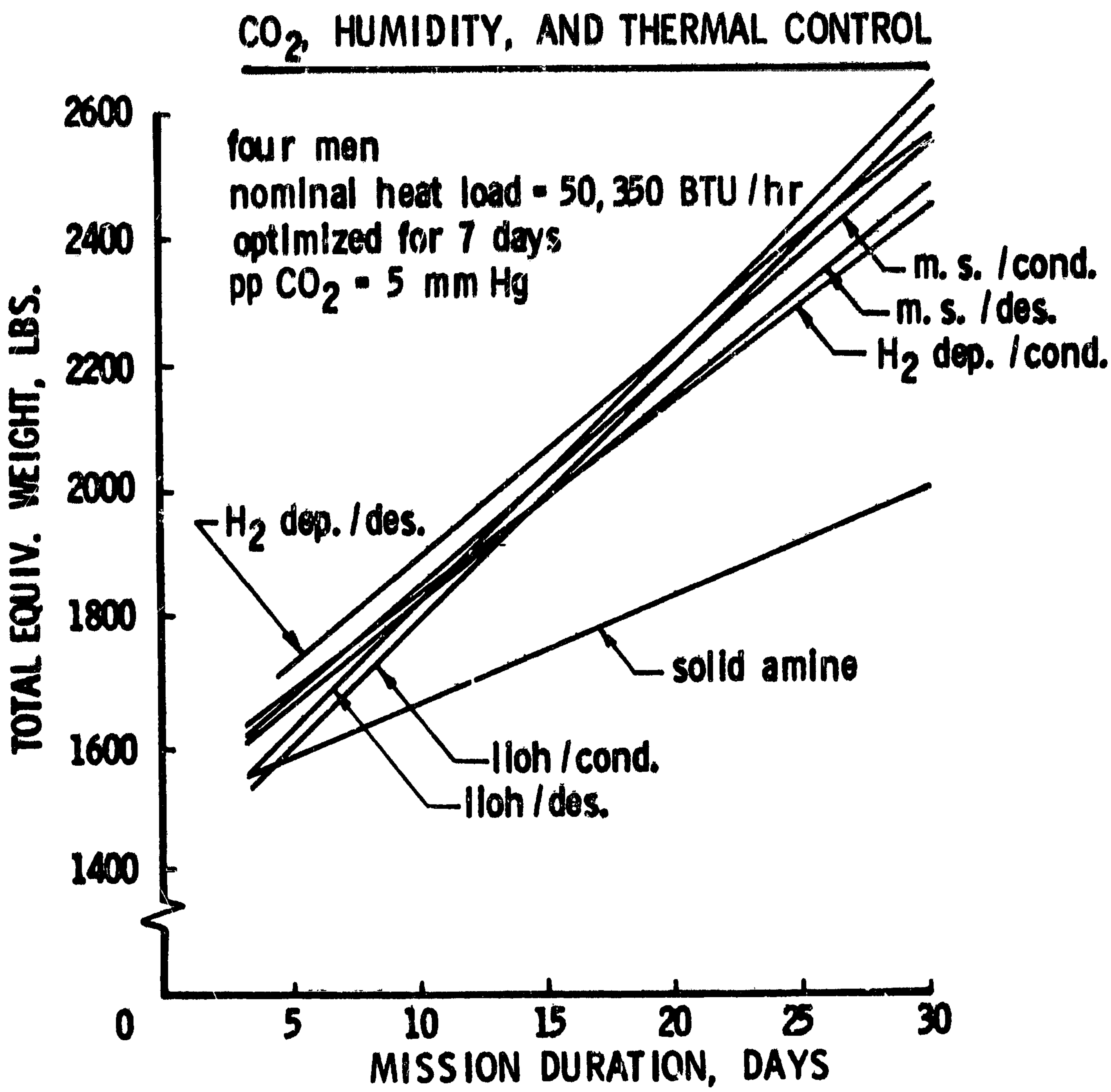
EC/LS CRITICAL PROBLEMS STUDY
NAS1 - 10478
LOCKHEED AIRCRAFT CORP.

FLT. TRACE CONTAM. SENSOR
NAS1 -
PERKIN ELMER CORP.

CO_2, Humidity, and Thermal Control

Much of Hamilton Standard's effort to date has involved subsystem trade-off studies. The most extensive of these studies is in the area of CO_2, humidity, and thermal control. In this case candidate concepts which include all of these EC/LS functions are being evaluated since most CO_2 removal methods also control or affect humidity and have an impact on the cabin temperature control system. One aspect of this evaluation is shown in the figure where the total equivalent weight (includes hardware weight, power and heat rejection penalties, expendables, etc.) of a number of concepts varies with mission duration. These calculations include consideration of a typical heat rejection system for a nominal heat load (includes metabolic, avionic, wall, and fuel cell loads). The increase in weight with time reflects ullage losses, bakeout requirements, and expendables although some additional penalty is incurred for operation beyond the 7-day design point for some of the concepts.

Systems considered include lithium hydroxide, molecular sieve, and H_2 depolarized concepts, each with either condensing heat exchangers or desiccants, and a solid amine concept which collects both CO_2 and water vapor and is regenerated by vacuum desorption. The figure indicates that the solid amine concept is the lightest system for missions longer than about 4 days. Other factors, however, ranging from safety to cost to maintainability must be considered in the selection process. For example, during the reentry and ferry mission phases, only the LiOH/condenser and the H_2 depolarized/condenser concepts actively control CO_2 and humidity, while the other concepts must rely on either cabin transients or auxiliary equipment. Additionally, the LiOH/condenser concept is developed and proven with the added advantage of fewer parts and lower initial cost. On a cost-through-first-flight basis, the expendable LiOH/condenser concept would be chosen; however, on a total-program (10 years) cost basis, the regenerable solid amine system would be chosen.



CO2, HUMIDITY, AND THERMAL CONTROL
four men
nominal heat load = 50,350 BTU/hr
optimized for 7 days
pp CO2 = 5 mm Hg
2600
2400
2200
2000
1800
1600
1400
TOTAL EQUIV. WEIGHT, LBS.
m. s. /cond.
m. s. /des.
H2 dep. /cond.
H2 dep. /des.
solid amine
lioh /cond.
lioh /des.
0
5
10
15
20
25
30
MISSION DURATION, DAYS

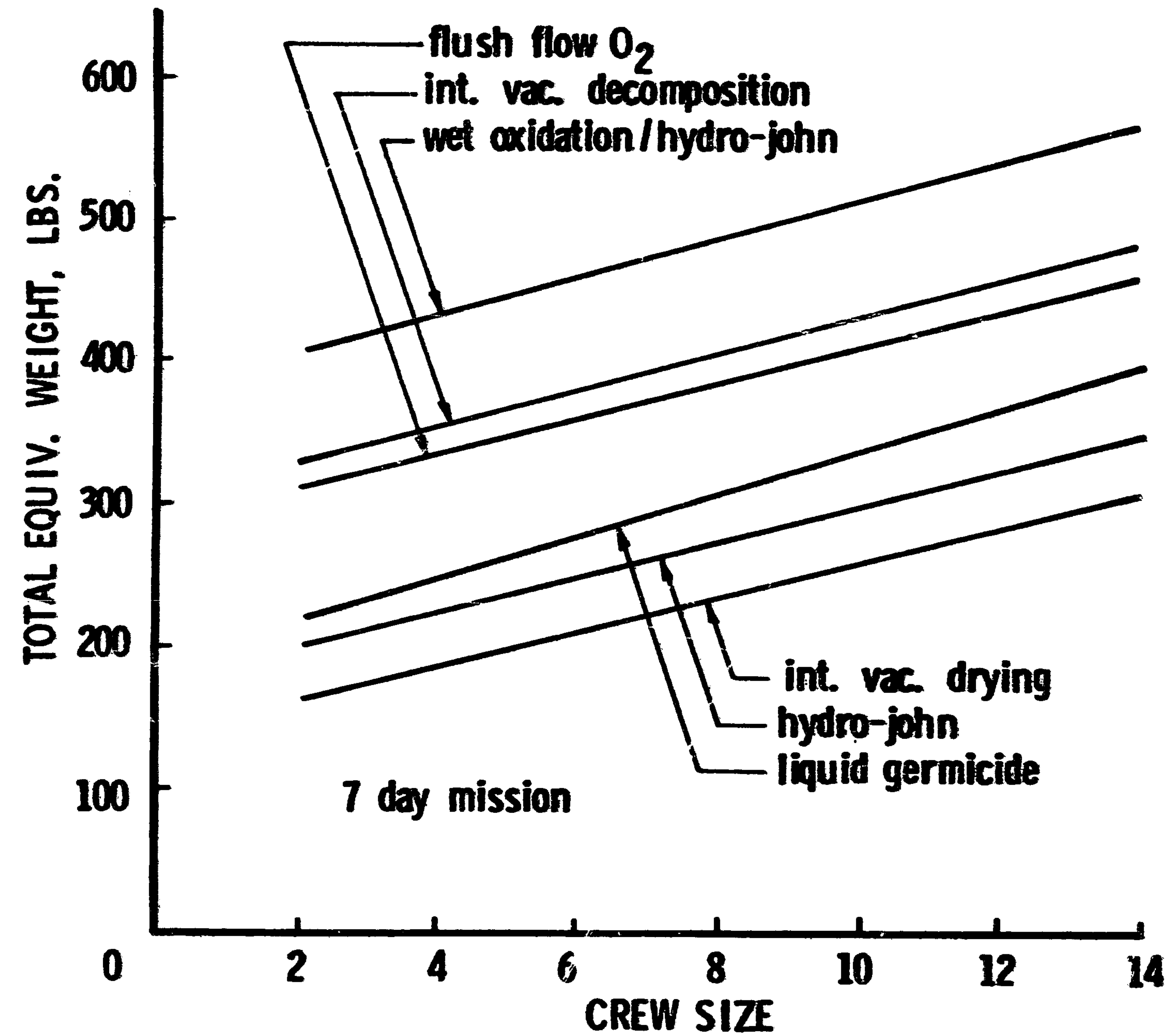
Waste Management

Another example of the subsystem trade-off studies being conducted by Hamilton Standard involves the selection of a shuttle waste management system. In this case the use of a conventional sitdown commode is considered as the only practical feces collection system. Such a system would involve no manual handling of fecal material and thereby should be highly acceptable to crew and passengers both practically and aesthetically.

The figure shows the weight penalty of six candidate concepts as a function of crew/passenger size for a 7-day mission. An integrated vacuum drying concept in which waste material is collected, processed, and stored in a single unit has the lowest weight followed by the Hydro-John and liquid germicide concepts. All of the other concepts involve high-temperature processing and use a high rate of expendables and/or power. They also require two collectors for processing in order that the waste decomposition process can take place and cool down before reuse.

The vacuum drying concept using tissue wipes is the selected system not only because of its low weight and volume, but also because it is a relatively simple system with good reliability and mission flexibility. The number of waste management units required will depend upon not only the number of crew or passengers, but on their location in the shuttle vehicle.

WASTE MANAGEMENT



Technology Recommendations

As noted previously, one of the primary objectives of the Hamilton Standard EC/LS systems study is to identify pacing technology items. The figure indicates a technology forecast of items that have been identified as warranting further development in order to provide improved flexibility for achieving a low-cost, technically optimized shuttle EC/LSS. Subsystem trade-off studies have been conducted in five areas and some 14 pacing technology items identified. These conclusions are, however, tentative and are subject to change as the study progresses and the total EC/LSS is defined and optimized. One change has already been made in that the selected humidity control water separator is now an elbow separator configuration instead of the wick separator indicated.

One item of special interest is the need for a realistic shuttle orbiter contaminant model. Current models are based on space station technology and do not generally consider the great variety of possible shuttle missions with the attendant variety of passengers, cargoes, and experiments. The reasons why other specific items are listed are too lengthy to be discussed here, but are found in the interim progress report previously mentioned and will be covered in detail in the final report due to be published in September of this year. It is interesting to note that most, if not all, of these items are presently being pursued to some degree. NASA Langley, as a part of its advanced technology program, is conducting and sponsoring applicable research and development in a number of these areas. For example, the trace contaminant absorption capability of "Purafil," a potentially useful material, is being conducted under contract NAS1-9506 with Texas Tech University, and in the water management area, breadboard water quality monitoring equipment is being produced under Contract NAS1-10382 with Aerojet General.

TECHNOLOGY RECOMMENDATIONS (NAS1 - 10359)

CO_2, Humidity and Thermal Control

- Solid Amine
- H_2 Depolarized Cell
- Face Wick Separator

Atmospheric Contamination Control

- Purafil
- Model Definition

Water and Waste Management

- Urinal - Male
- Commode - Male/Female
- Zero "G" Tanks
- Quantity Sensor
- Quality Monitor

Atmospheric Storage and Pressure and Composition Control

- Composite Material Tanks
- Partial Pressure Sensors - O_2 and CO_2

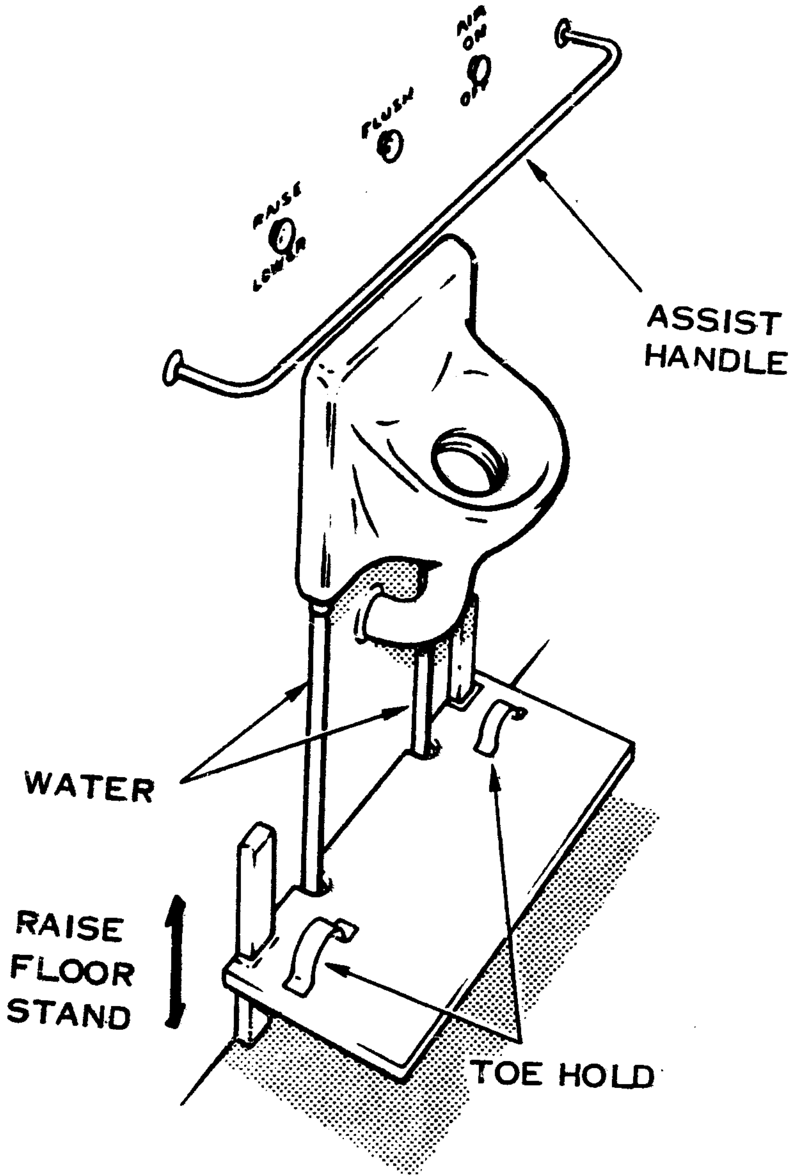
Heat Rejection

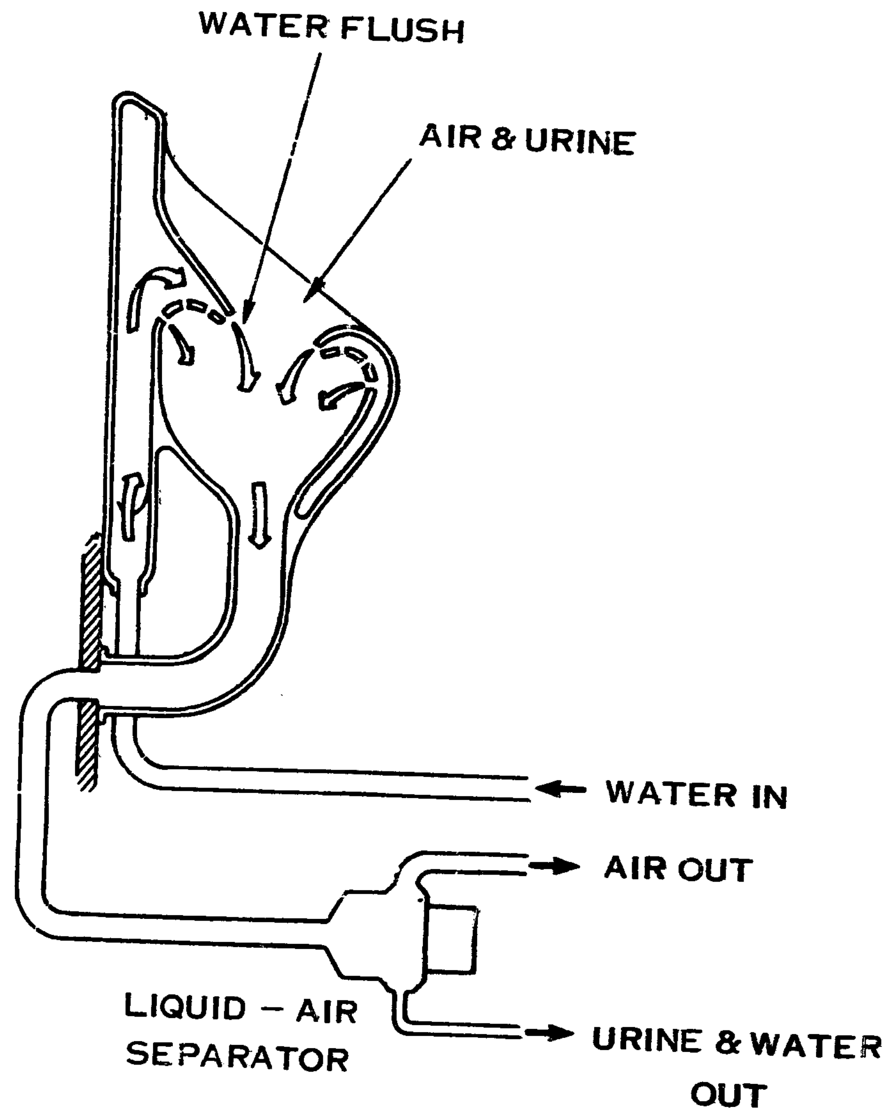
- Cryogenic Heat Exchangers
- Evaporators

Air Flow Urinal Concept

The waste management subsystem for the shuttle requires a number of technological advances to improve crew/passenger acceptability. The Hamilton Standard artist's concept shown illustrates a new, more conventional, height adjustable, wall-mounted urinal which eliminates body contact with the urine collection device. An air stream within the collector facilitates urine collection and delivery to the separation system. Appropriate filters are used for odor and bacteria control of the air and a water flush is incorporated within the urinal. The requirement for urine collection tanks will depend upon overboard dumping limitations.

AIR FLOW URINAL CONCEPT



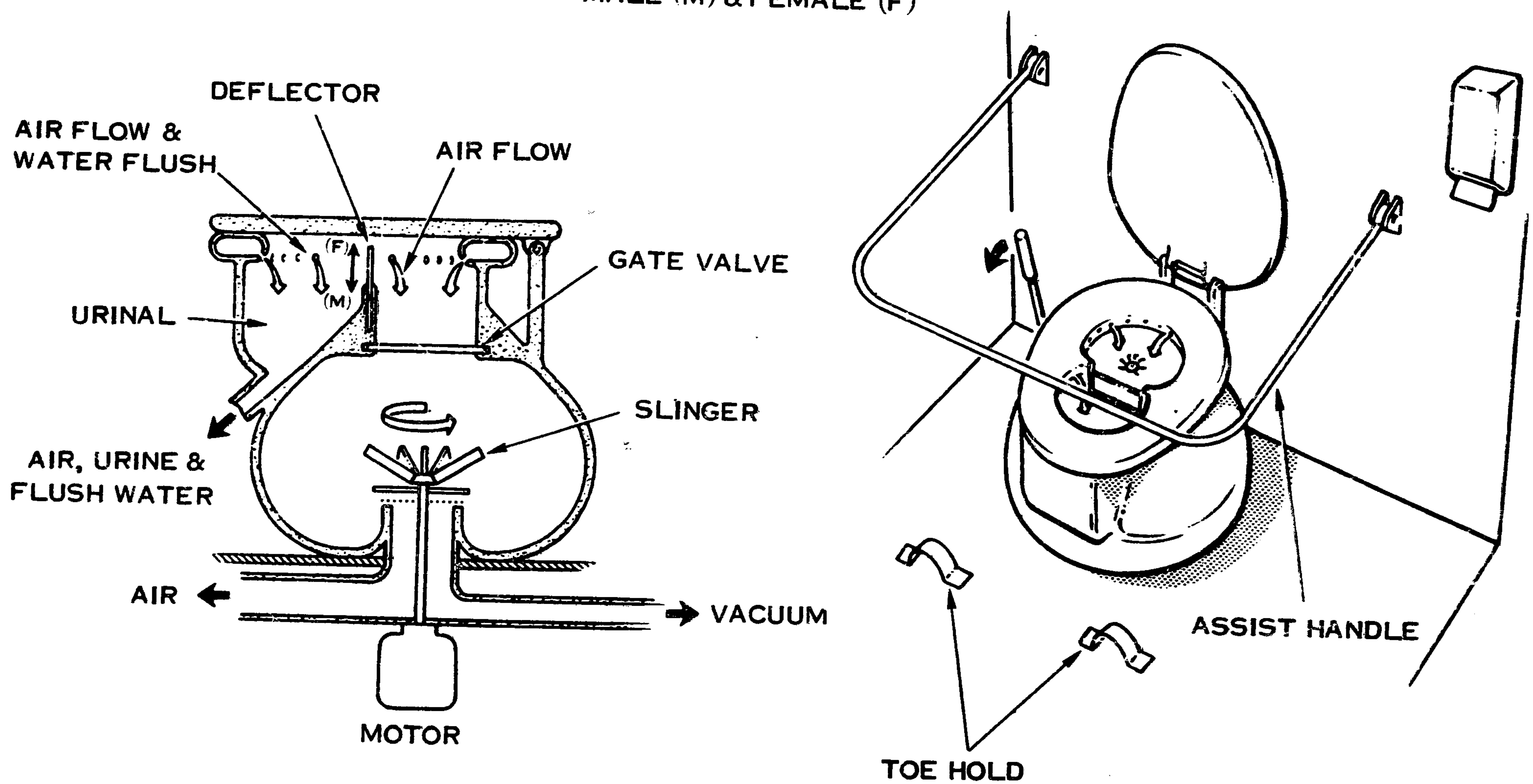


Split-Flow Commode Concept

The waste management subsystem for the shuttle should accommodate both males and females and be as conventional and earthlike as possible for crew/passenger acceptance and convenience. The Hamilton Standard artist's concept shown illustrates a zero "g" commode concept for meeting shuttle requirements. Basically, the unit consists of an air flow urine collector (similar to that previously illustrated) integrated with a feces collector. The two collectors are separated by a deflector which is positioned down for male use and up for female use. Separate collection of urine is desirable since it can be readily stored and/or disposed of to vacuum. Fecal collection is aided by air flow into the unit where the feces are shredded by a motor-driven slinger and then vacuum dried. As with the urinal, appropriate filters are used for odor and bacteria control.

SPLIT-FLOW COMMODE CONCEPT

MALE (M) & FEMALE (F)



Cargo Module EC/LSS

Initially, Lockheed has used system cost as a basis for selecting the best type of EC/LSS for the shuttle payload or cargo module. The study was based on an assumed 13-year traffic model recently generated by the NASA Space Station Task Force. As shown, the model includes 93 flights wherein passengers are located within the module. Another assumption was that a four-man, 7-day EC/LS would be used for the forward crew compartment of the orbiter, and that development costs for that unit are covered in the basic shuttle development cost.

Customized 2-, 6-, and 12-man systems were considered and compared in various combinations with single or multiple four-man units to fulfill requirements for individual flights. Results of this cost-effectiveness study show that the basic four-man EC/LSS modularized for payload application is the optimum approach. Other parameters such as flight frequency and scheduling, mission length, and system weight and volume will be considered later during the course of the contract in order to provide a complete analysis.

CARGO MODULE EC/LSS

- **Objective** - optimize design for 13 year mission traffic model*
- **Results** - use basic four-man units modularized for payload application

* Traffic Model

20	12-passenger transfer flights
24	6-passenger transfer flights
49	2-passenger cargo/experiment flights
93	flights

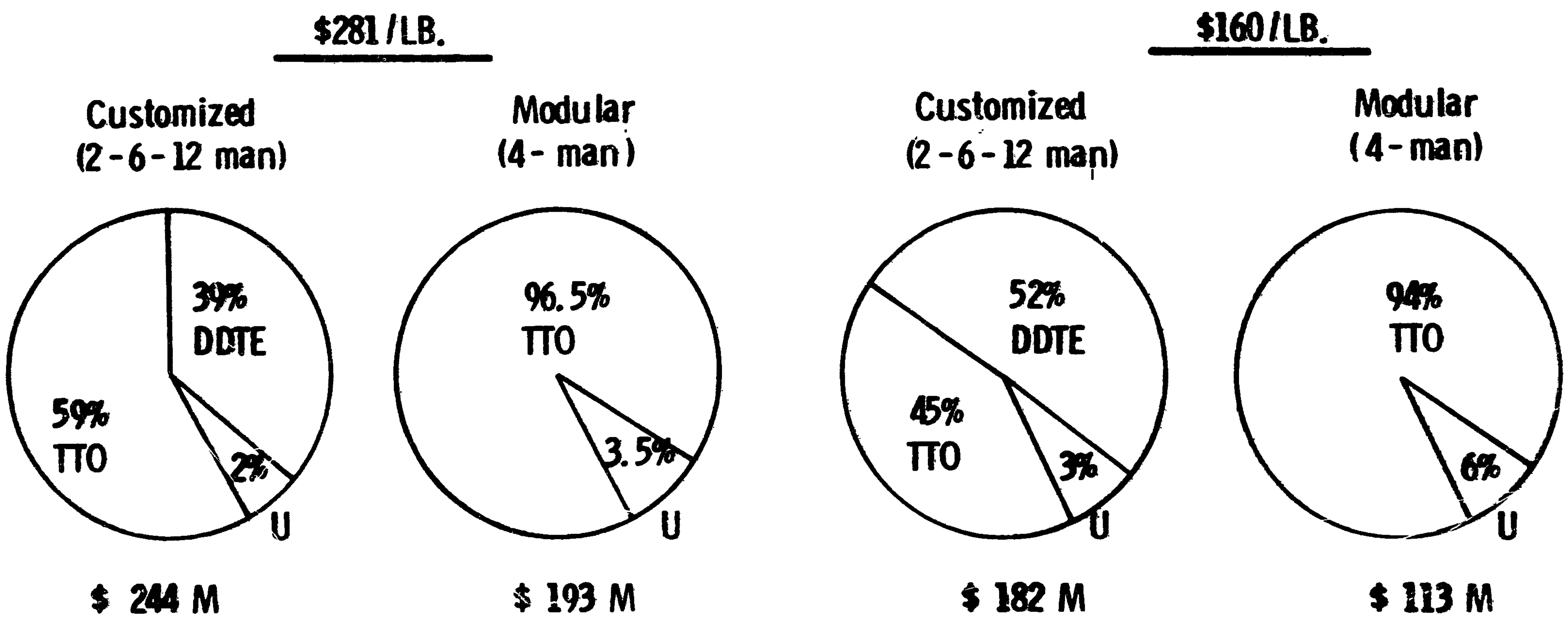
Cargo Module EC/LSS Cost Comparison

The cost comparison for the customized and modular approaches to cargo module EC/LSS for the total of 93 flights is presented graphically for two different values of cost per pound for transportation to orbit. These values of $281/pound and $160/pound represent a range currently under consideration by shuttle system planners.

In both comparisons, estimated launch weight and unit costs are lower for the customized systems. However, the large added cost of design, development, test, and evaluation results in the total estimated cost of these systems being substantially greater than for the modular units. It should be noted that significance should be attached only to the differences in cost. Absolute costs could be altered about equally in all cases when one considers costs of system integration and maintenance, for example. It is also significant that the cost of DDT and E estimated for the customized systems could be reduced as much as 50 percent without altering the conclusions reached.

CARGO MODULE

EC/ LSS COST COMPARISON



$$\left.\begin{array}{ll}\text{DDTE} & \text{— Design, Development, Test, Evaluation}\\ \text{U} & \text{— Unit}\\ \text{TTO} & \text{— Transportation To Orbit}\end{array}\right\}\ \text{Costs}$$

Shuttle/Space Station EC/LSS Interfaces

Work by Lockheed in this area has been very limited to date. The chart makes only two points. First, early in the space station mission, if the station EC/LSS is designed for 12 men and only 6 are onboard, the station system can accommodate the shuttle orbiter relief crew of six men. However, after the station crew has grown to 12 men, presence of the six-man shuttle transfer crew will result in an 18-man load on the station EC/LSS for as long as 5 days. The problem will be even more severe for a 12-man transfer. The station EC/LSS will then require either support from the shuttle system or an overdesign capability from the station system itself. The other point is that, for reasons of crew safety, the shuttle must be maintained ready to leave the station under emergency conditions at any time while docked.

Integrated Thermal Control

Only a limited effort has been conducted to date to define a cabin or internal thermal control system for shuttle orbiter launch, on orbit, reentry, cruise, landing, and ferry mission phases. Early results indicate onboard fuels can be used as heat sinks and provide advantages for the reentry, cruise, and ferry phases.

It would also be desirable for several reasons (reentry heating and cargo door operations, for example) to offer an alternative to the customary practice of rejecting heat to space from a radiator located on the inside of the shuttle cargo doors. An attractive concept for this purpose is the cryhocycle system. The cryhocycle has been proposed by both Lockheed and Grumman and consists of collecting waste cabin heat and utilizing it in a turbine generator to produce electrical power. Hydrogen is used as the working fluid. Theoretically, such a system would eliminate the need for fuel cell power systems as well as radiators for heat rejection. A disadvantage would be losing the availability of fuel cell water to meet crew and passenger needs.

SHUTTLE/SPACE STATION EC/LSS INTERFACES

- **Objective** - determine system interdependence, crew activities
- **Results** - station crew growth requires (1) support from shuttle system; (2) station overdesign
  - docked shuttle "ready", but dormant

INTEGRATED THERMAL CONTROL

- **Objective** - determine best system for all mission phases
- **Results** - use H_2 as heat sink for reentry, ferry
  - "Cryhocycle" promising

EC/LSS Reusability

Lockheed has conducted a survey of maintenance practices of TWA, United, and Eastern Airlines to determine applications to shuttle EC/LSS quick turn-around and reusability. Onboard aircraft system monitoring methods used include AIDS (Aircraft Integrated Data System), ADAS (Automatic Data Acquisition System), and MADAR (Malfunction, Analysis, Detection, and Repair). This kind of data acquisition is recommended on the shuttle by including EC/LSS fault isolation data. Also, critical parameters such as those for aircraft engines are monitored continuously by the airlines and trend data are analyzed for corrective action by ground facilities. For the shuttle, EC/LSS parameter trend data should be included in the system.

The airlines schedule maintenance on a nonflight interference basis and will not delay flights to repair minor items. They also perform repairs and overhauls on the basis of failures rather than time in service. They have found that replacement on a time schedule does not preclude failures, especially since most difficulties occur near the beginning of the operational life of a component. Another practice is to remove and replace a failed unit rather than try to repair it on the aircraft. If a problem cannot be isolated, all suspected components are removed and replaced. All this maintenance philosophy is recommended for application to the shuttle.

In addition, airline experience has shown that actual operating hours of equipment such as that used for EC/LSS are high. In some cases, component life is of the same magnitude or greater than the operating life of the shuttle itself. This enhances the confidence level of reliability to be expected for the shuttle.

EC/LSS REUSABILITY

- Objective - quick turnaround, maximum reuse
- Results - based on airline practice survey

Airline	Shuttle
On-board monitoring (AIDS)	Include EC/LSS
Trend analysis	Analyze EC/LSS trends
Non-interference maintenance	Airline philosophy
Failure-basis maintenance	Airline philosophy
Replace instead of repair	Airline philosophy
High actual operating life	Enhances confidence level

Typical life:

Manual valves	indefinite
Heat exch.	30-40,000 hrs
Temp. controls	10,000
Compressors	3,000

Flight Trace Contaminant Sensor System

This development program is intended to furnish a flight-qualifiable sensor which will be capable of identifying and quantifying contaminants present in a closed atmosphere. This essentially self-contained analytical system is applicable to the monitoring of a broad spectrum of gaseous organic and inorganic compounds having molecular weights of up to mass 140. The hybrid sensor consists of two main units: an accumulater cell inlet system and a mass spectrometer analyzer system.

The accumulator cell inlet system consists of from one to three gas/vapor sorption units. Each cell contains a given amount of a particular sorbent which is capable of quantitatively adsorbing the low level atmospheric contaminant(s) from an air stream passing through the cell. It effectively concentrates the adsorbed compound(s) to a level that permits quantitative evaluation. When the adsorption cycle is complete, the residual cabin atmosphere is removed from the cell and the contaminants are desorbed by the application of heat to the cells. The gases leave the cell and enter the mass spectrometer by means of the inlet leak between the cell and the mass spectrometer. The exact number of cells employed for a given operation will depend upon the degree of analytical monitoring desired.

The mass spectrometer anticipated for use is the Nier-Johnson double focusing mass spectrometer. This instrument uses a 90° electric and a 90° magnetic sector and is presently near optimum in terms of flight design.

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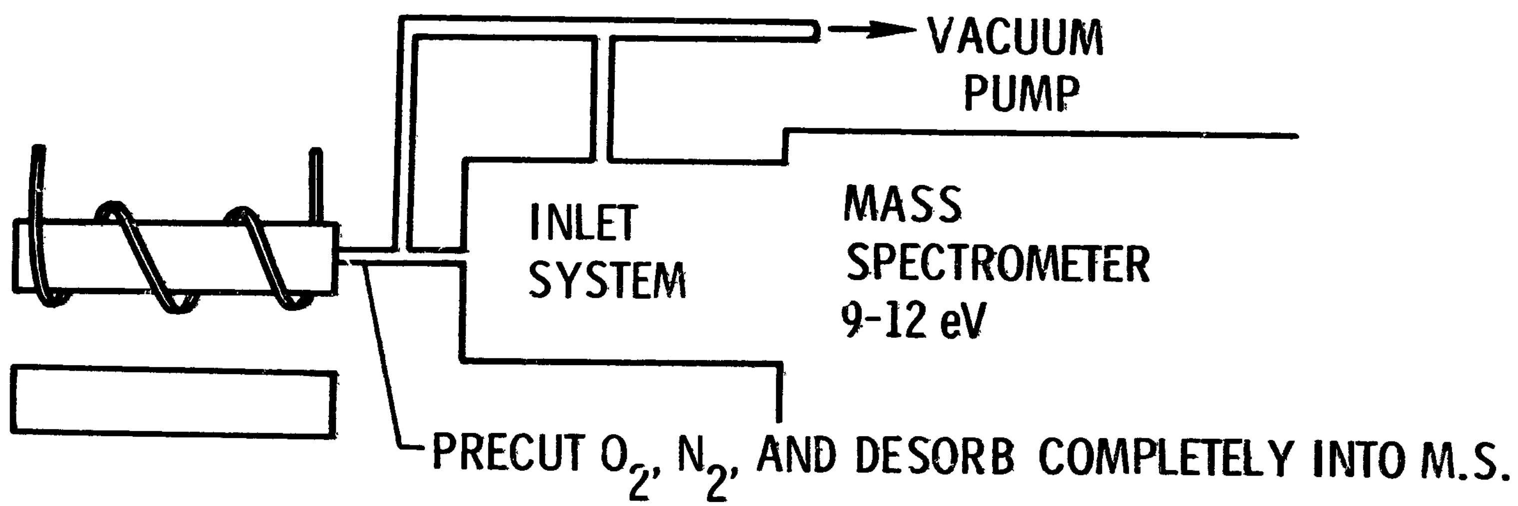
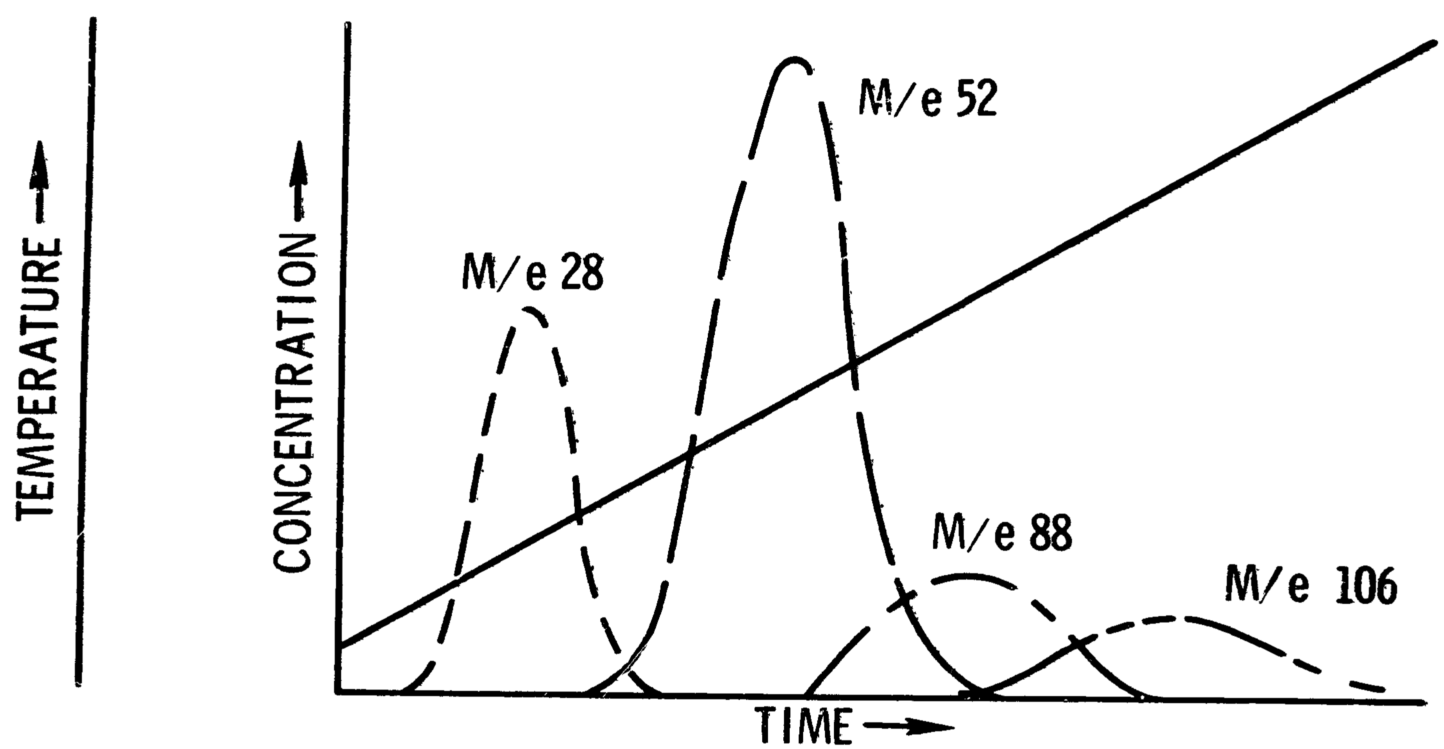
FLIGHT TRACE CONTAMINANT SENSOR SYSTEM





Concluding Remarks

The shuttle mission is a relatively short one, normally 7 days, and generally an open-cycle or expendable environmental control/life support system can be used. The technology for such a system is available from a combination of Apollo spacecraft and aircraft hardware.

However, while such a system might be satisfactory for very early shuttle flights, certainly a more sophisticated system should be pursued for the large bulk of the routine operational flights. It is here that improvements in technology can result in reduced costs, reduced weight, simpler systems, and increased passenger acceptability.

A solid amine system for removal of carbon dioxide and humidity control, for example, can save weight and ultimately reduce costs as compared to the lithium hydroxide/condensing heat exchanger combination. The cryhocycle thermal control concept, if developed and utilized, could replace the troublesome heat rejection radiator as well as the fuel cells required for electric power and result in a simpler, more reliable, and possibly lighter weight system. And certainly the development of more earthlike male and female urine and feces collection devices would result in the increased passenger acceptability which will be necessary if the shuttle is to become part of a routine and widely utilized space transportation system.

CONCLUDING REMARKS

- EC/LSS TECHNOLOGY FOR THE SHUTTLE IS AVAILABLE

BUT - - -

- IMPROVEMENTS IN TECHNOLOGY CAN RESULT IN
  - REDUCED COSTS
  - REDUCED WEIGHT
  - SIMPLIER, MORE RELIABLE SYSTEM
  - INCREASED PASSENGER ACCEPTABILITY

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DEVELOPMENT OF A BLADDERLESS TANK FOR SPACE SHUTTLE

Clauss Feindler

Grumman Aerospace Corporation

N71-35272

INTRODUCTION

Requirements for water management for the Space Shuttle are largely undefined, and only the basic metabolic requirement--3 lb/man-day--can be assumed. Water to meet this and other requirements may either be stored or be available from the fuel cells if these are selected as the electrical power supply. Even in the latter case, some water storage will be required for transition periods, as a backup in case of temporary fuel cell failure, and for marginal cooling.

The degree of purity and potability of stored water can vary according to its use. It seems likely that all drinking water must be sterile in accordance with NASA/MSC Specification SD-200. The water quality required for other uses, such as body washing and toilet flushing, are undefined.

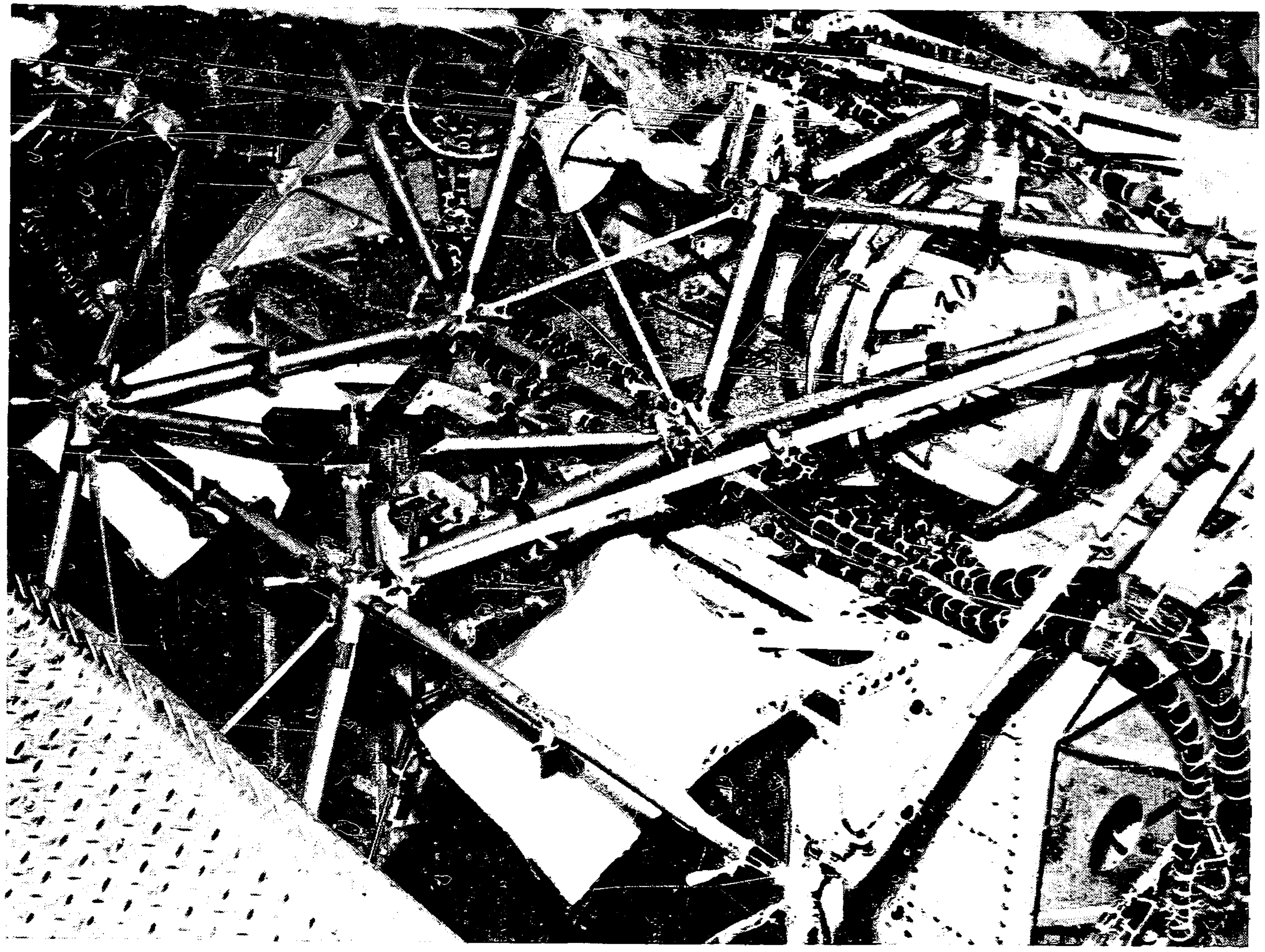
In any case, the bacterial content of stored water must be controlled. The ease of bacterial control depends in part upon the characteristics of the tank in which the water is stored. If the tank can be rendered sterile before use, the stored water can be kept sterile much more easily. Then the tank itself must contribute to--or at least not detract from--the effectiveness of bactericidal measures employed to maintain water quality during Space Shuttle operation. In addition, the tank should be amenable to accurate measurement of water quality.

The potable-water technology used in the Lunar Module was first reviewed in the light of these requirements. The LM bladder-type tanks were adequate for that vehicle, but it seemed to us that bellows tanks offer greater possibilities in satisfying the long-term requirements of the Space Shuttle program. This paper summarizes the results of our studies and the present state of development of bellows-type tanks for long-term potable water storage.

LM ASCENT STAGE BLADDER TANK

The two tanks containing the water used for drinking, food reconstitution and cooling are outside the pressure hull on opposite sides of the docking adaptor.

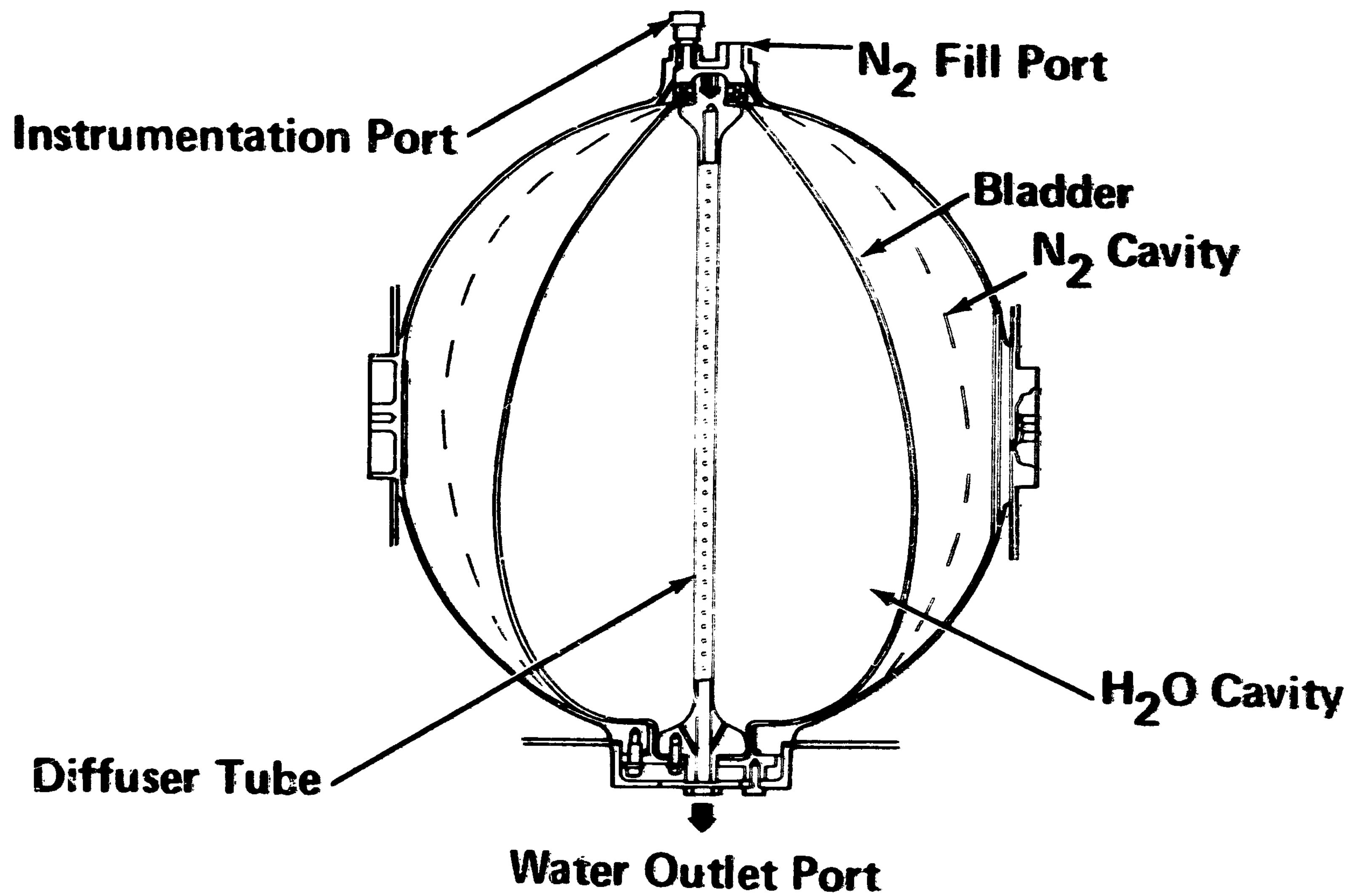
LM ASCENT STAGE BLADDER TANK



BLADDER TANK - LUNAR MODULE/ASCENT STAGE

Approximately 42.5 lb of water are contained inside the bladder at launch time. Nitrogen gas in the cavity between shell and bladder provides the pressure necessary to expell water on demand from the astronauts. This pressure varies as a function of volume, and in case of high Δ p's in the water distribution network, not all water can be expelled. The instrumentation port communicates with pressure and temperature transducers, the signal, of which is electronically integrated for volume indication by the WQMD (Water Quantity Monitoring Device). The tank is manufactured by welding together two identical hemispherical shells spun from aluminum. The bladder and stand pipe assembly is inserted through the "bottom" opening. The bladder is made of silicone rubber which can be permeated by iodine and nitrogen. Once assembled, the bladder must be kept wet and pressurized to avoid collapse and resultant bonding.

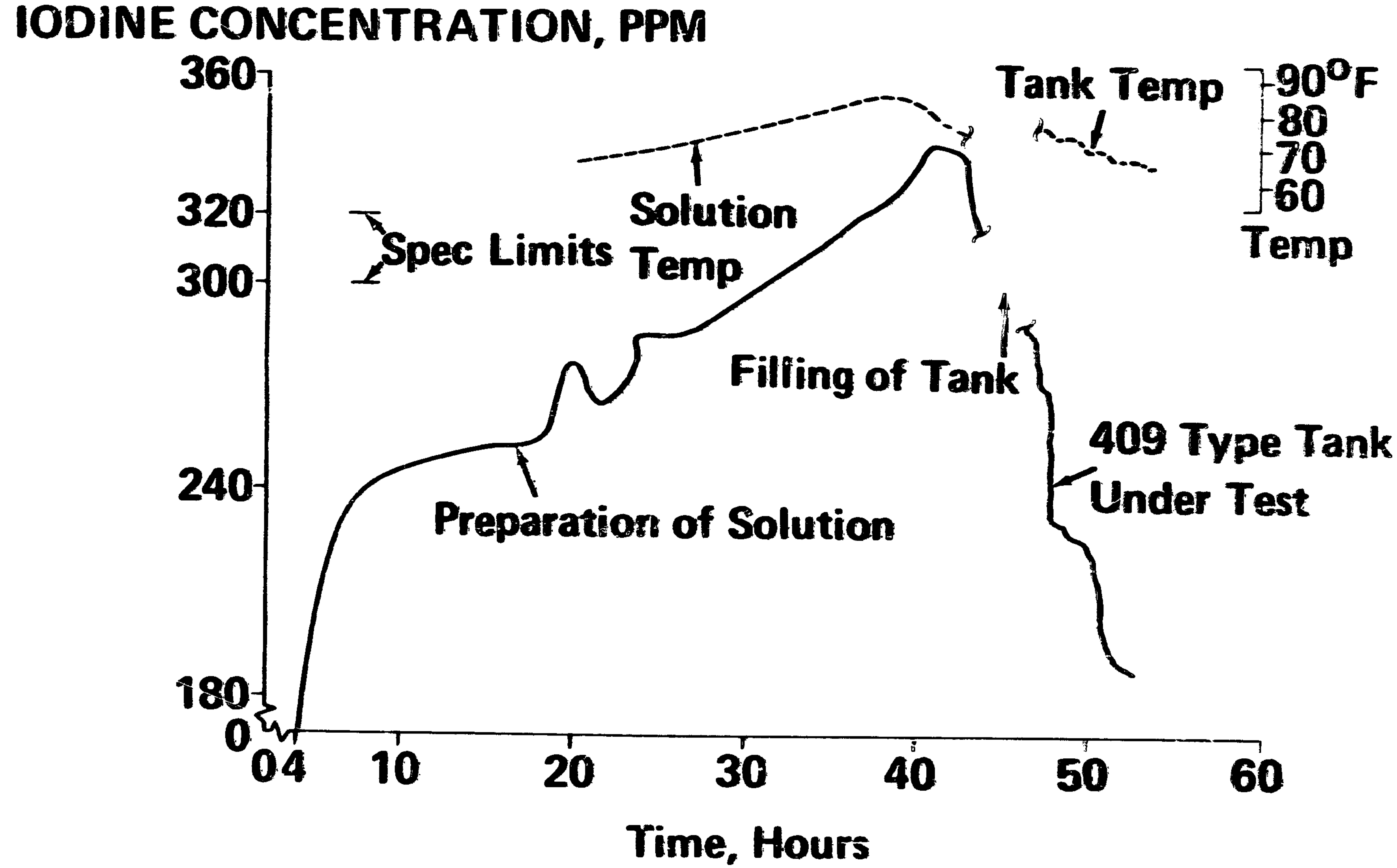
BLADDER TANK – LUNAR MODULE/ASCENT STAGE



BLADDER TANK - IODINE SOAK

Iodine is put into the tank for sterility control; it has a tendency to leave its aqueous solution, permeate through the bladder and find its way to the aluminum shell where it reacts with the aluminum through cracks in its protective coating. Depletion is rather drastic and attempts have been made to satisfy the aluminum's reaction capability by soak procedures. Prior to launch, iodine is concentrated at the 300 to 320 PPM level in deionized water which is pumped into the bladder. Within 10 hours the concentration is cut by approximately 50% without any signs of stabilization. Because of this lack of success this procedure has been cancelled by the LM Program.

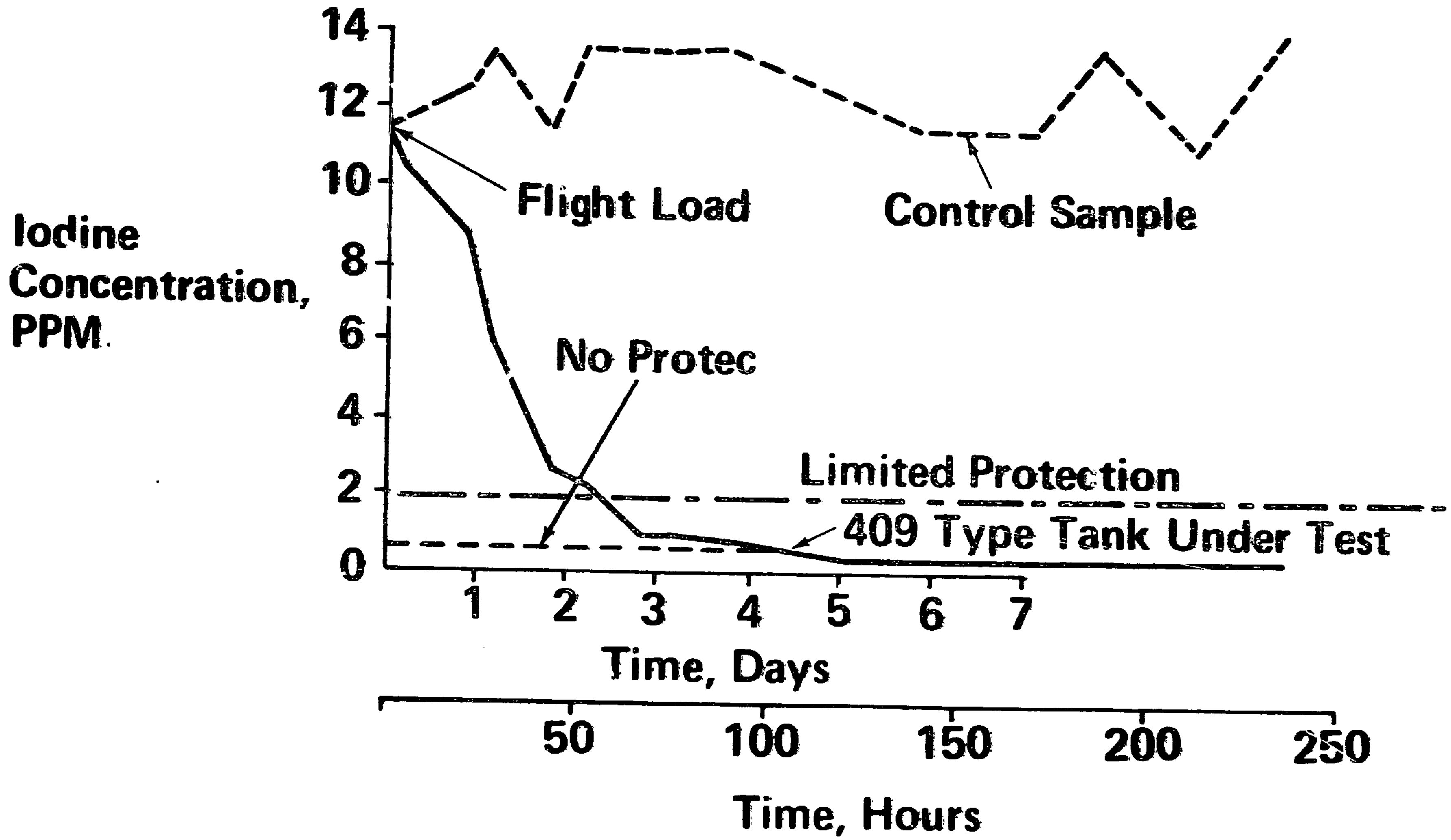
BLADDER TANK – IODINE SOAK



BLADDER TANK - IODINE DEPLETION

The current practice is to load the bladder with deionized water (NASA/MSC Spec PF-1C) which contains approximately 11.5 PPM iodine. At this level taste and odor are noticeable, but effective bacterial kill in water and exposed surfaces is assured. Within 3 days the iodine concentration diminishes to approximately 2 PPM. At this point, according to the flight profile, the astronauts have arrived on the moon and will begin to use the water. At the 5-day mark the concentration may have fallen below the 0.5 PPM level at which sterility cannot be assured. The iodine depletion function is fairly predictable even though it may vary from tank to tank. The 2.0 - 0.5 PPM range is satisfactory in taste and odor, but some investigators have expressed doubts as to its reliability in retaining sterility.

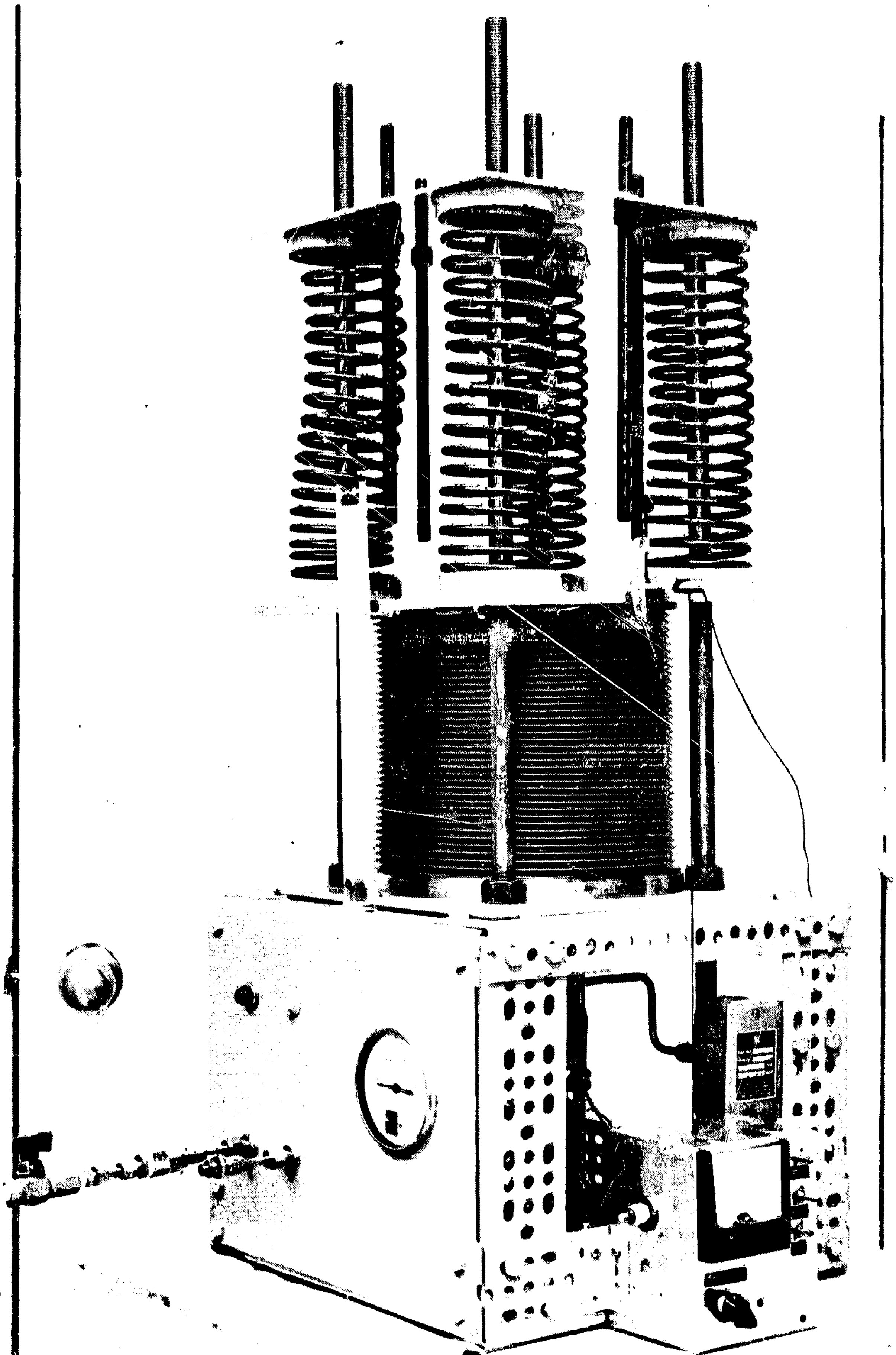
BLADDER TANK – IODINE DEPLETION



BELLOWS TANK TEST SETUP

The bellows tank tested was designed by Sealol Inc. for the storage and expulsion of propellants in the auxiliary propulsion system of the Saturn SIVB stage. It was lent to Grumman Advanced Development to investigate its suitablity for potable water service in the Shuttle. The tank was mounted on a chassis and equipped with the necessary fitting and controls. Provisioning of quick disconnects, front, and a linear potentiometer, right side, were advantageous. Since the tank came without an external pressure dome, constant rate coil springs were used to provide a positive expulsion force.

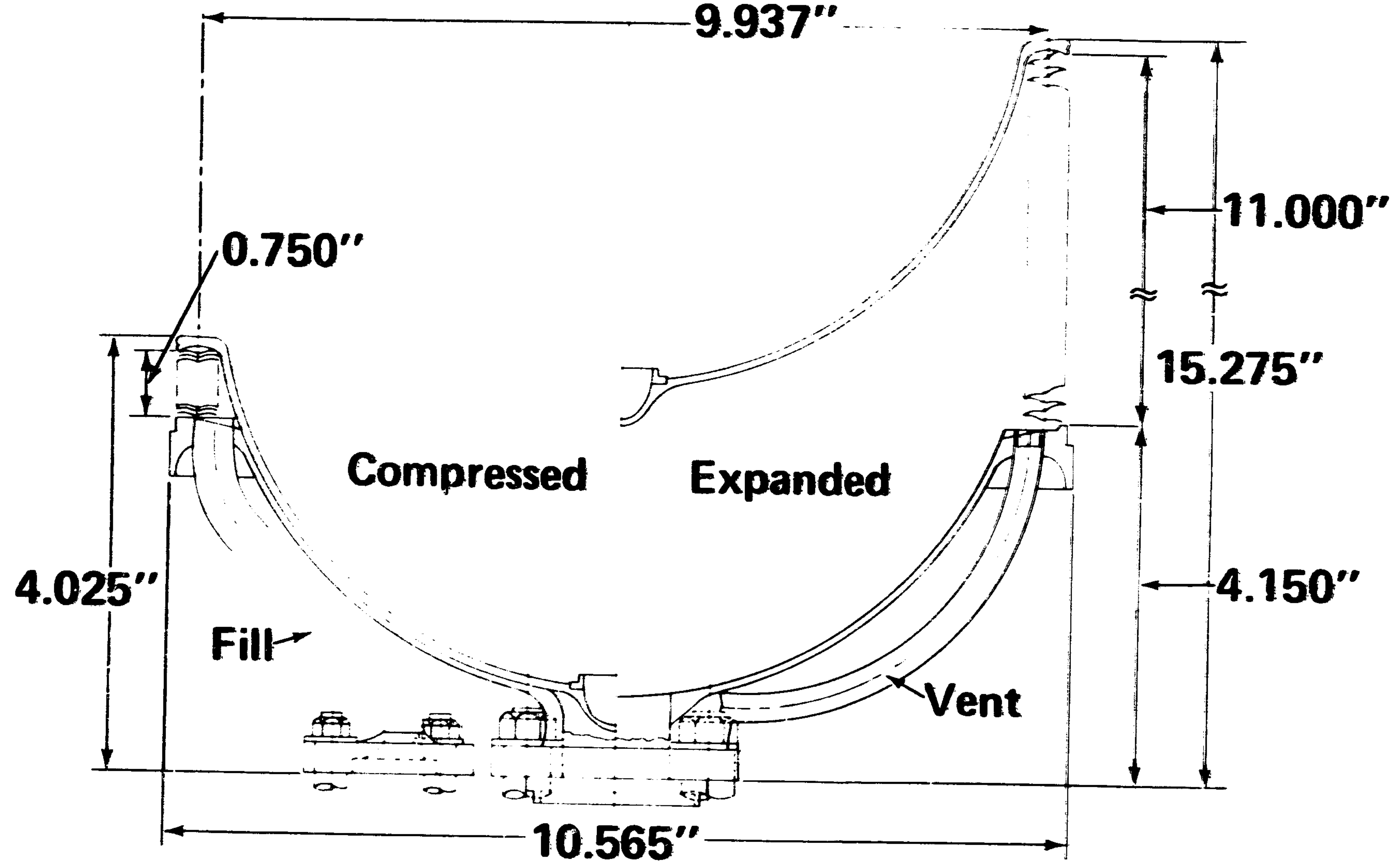
BELLOWS TANK TEST SET-UP



BELLOWS TANK-SATURN SIV B

The bellows, key component of the bellows tank assembly, was fabricated by welding together 37 convoluted bellows in the "nesting ripple" pattern. This pattern was used because of its long stroke capability and good pressure resistance. From a compressed height of 0.75" the bellows will expand to 11" when fully stroked to store 29.3 lbs of water. The bellows were made of 0.006" thick 347 stainless steel. Plastic deformation reduces the remaining strength with each cycle which is not significant since 1,000 life cycles are routinely exceeded, and bellows can be redesigned for elastic deformation. For best corrosion resistance Hastelloy-C is recommended; commercially pure titanium will double the strength-to-weight ratio of steel.

BELLOWS TANK — SATURN S IV B



COMPARISON OF DESIGN FEATURES: BLADDER TANK VS BELLOWS TANK

FEATURE	BLADDER TANK	BELLOWS TANK
Dry Weight (Pressurizable Ass'y)	5.3 lb (Optimized)	16.8 lb (Not Optimized)
Basic Configuration	Sphere 14.8" OD	Cylinder 10.6" OD 15" L
Adjusted Gross Volume (Cylinder)	3,370 in^3	1,350 in^3
Expulsion Capacity (Water)	42.5 lb	28.9 lb
Expulsion Efficiency	98.3%	99.3%
Weight Efficiency	89.0%	63.3%
Spatial Efficiency	34.9%	58.9%
Materials	Aluminum & Rubber	Stainless Steel
Pressure Differential	15 psid	7 psid (No Pressure Dome)

COMPARISON OF OPERATIONAL FEATURES: BLADDER TANK VS BELLOWS TANK

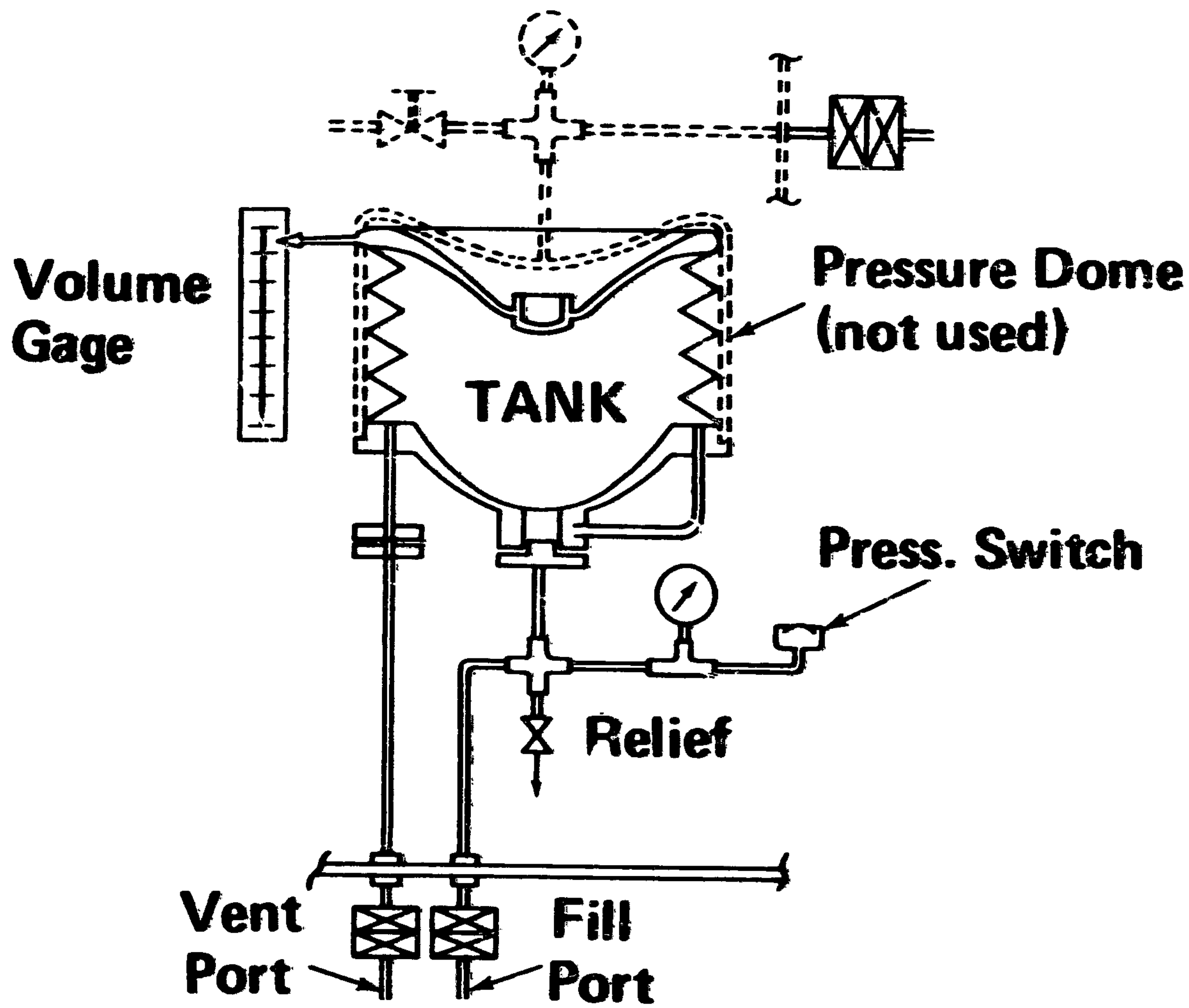
FEATURE	BLADDER TANK	BELLOWS TANK
Phase Separation	o Irregular & Permeable Membrane o Bactericide Depletion o Water Gasification o Corrosion Hazard	o Regular & Impenetrable Membrane o Minor Corrosion Hazard
Microbial Protection	o Cannot Be Autoclaved <u>In Situ</u> o Bactericide Required o Odor & Taste Problems	o Can Easily Be Autoclaved <u>In Situ</u> o No Bactericide Required o Odor, Taste Not Noticible
Cleaning	o Assembly Difficult To Clean o Organic Solvents Cannot Be Used	o Assembly Can Be Cleaned <u>In Situ</u> o Strong Organic Solvents Permissible
Storage	o Bladder Requires Special Storage Fixture o After Ass'y, Bladder Must Be Kept Moist & Pressurized To Prevent Bonding	o Unlimited Shelf Life
Volume Monitoring	o P & T Transducers o Requires Calculation o Setting of Reference Conditions	o Linear Potentiometer o Simple & Accurate o Not Affected By P & T

BELLOW TANK-FLUID-MECHANICAL SCHEMATIC

In the test set-up a pressure switch with both audio and visual alarms and a relief valve were required to protect the bellows. In the absence of a pressure dome, line pressure during filling and steaming becomes the differential pressure effective across the unsupported bellows. A pressure dome would be fed by a constant pressure gas supply to expel the liquid volume at constant pressure as opposed to the present practice of variable pressure expulsion. Additionally, the pressure dome, perhaps with a teflon liner, will provide circumferential guidance for the bellows.

From a contamination control view point the many components and interconnecting fittings are undesirable. Note especially the "dead ended" pressure switch line. Mechanical volume gaging can be obtained by either observing gage pressure, or by reading the indicator attached to the upper endplate.

BELLOWS TANK — FLUID—MECHANICAL SCHEMATIC



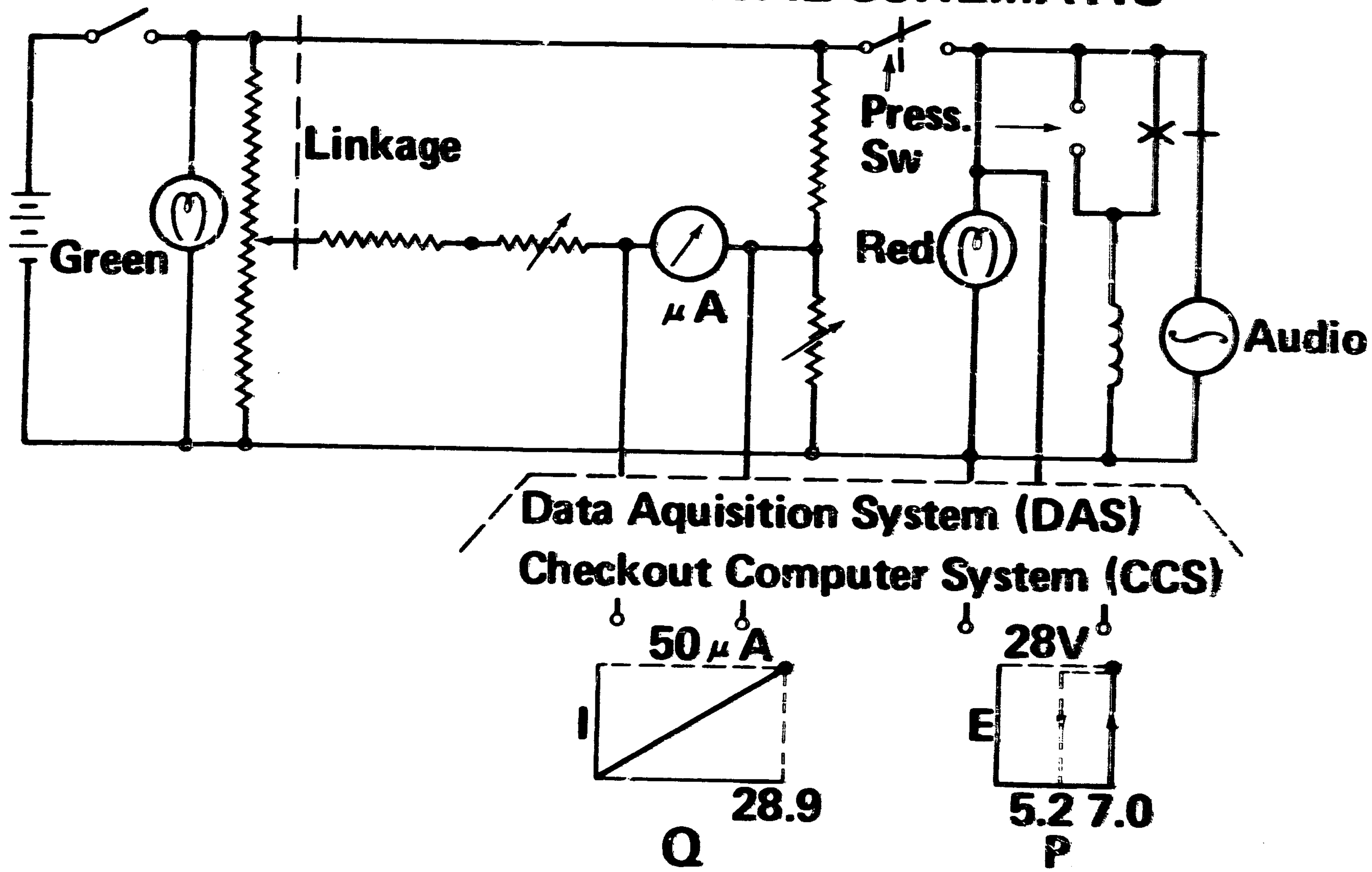
BELLOWS TANK - ELECTRICAL SCHEMATIC

A Model # 4046-1 potentiometric displacement transducer, manufactured by the Controls Division of Research Inc., was linked to the upper end plate by means of a shaft and pulley arrangement to adapt its stroke to that of the bellows. Two other potentiometers permit null and gain adjustment of the microameter such that full-scale deflection corresponds to the bellows stroke or to the volume actually expelled, whichever is preferable.

The pressure switch when actuated by a rising tank water pressure will actuate the visual and andio alarms. A latching relay will lock in the audio alarm until the attendant will depress the reset button.

The vehicle data acquisition system will receive two types of signals: (1) 50 uA corresponding to a full tank loaded with 28.9 lbs of water, (2) 28V DC corresponding to overpressurization if the water pressure exceeds 7 psig. Due to the hysteresis of the pressure switch the alarm will stay on until pressure is reduced below 5.2 psig.

BELLOWS TANK – ELECTRICAL SCHEMATIC



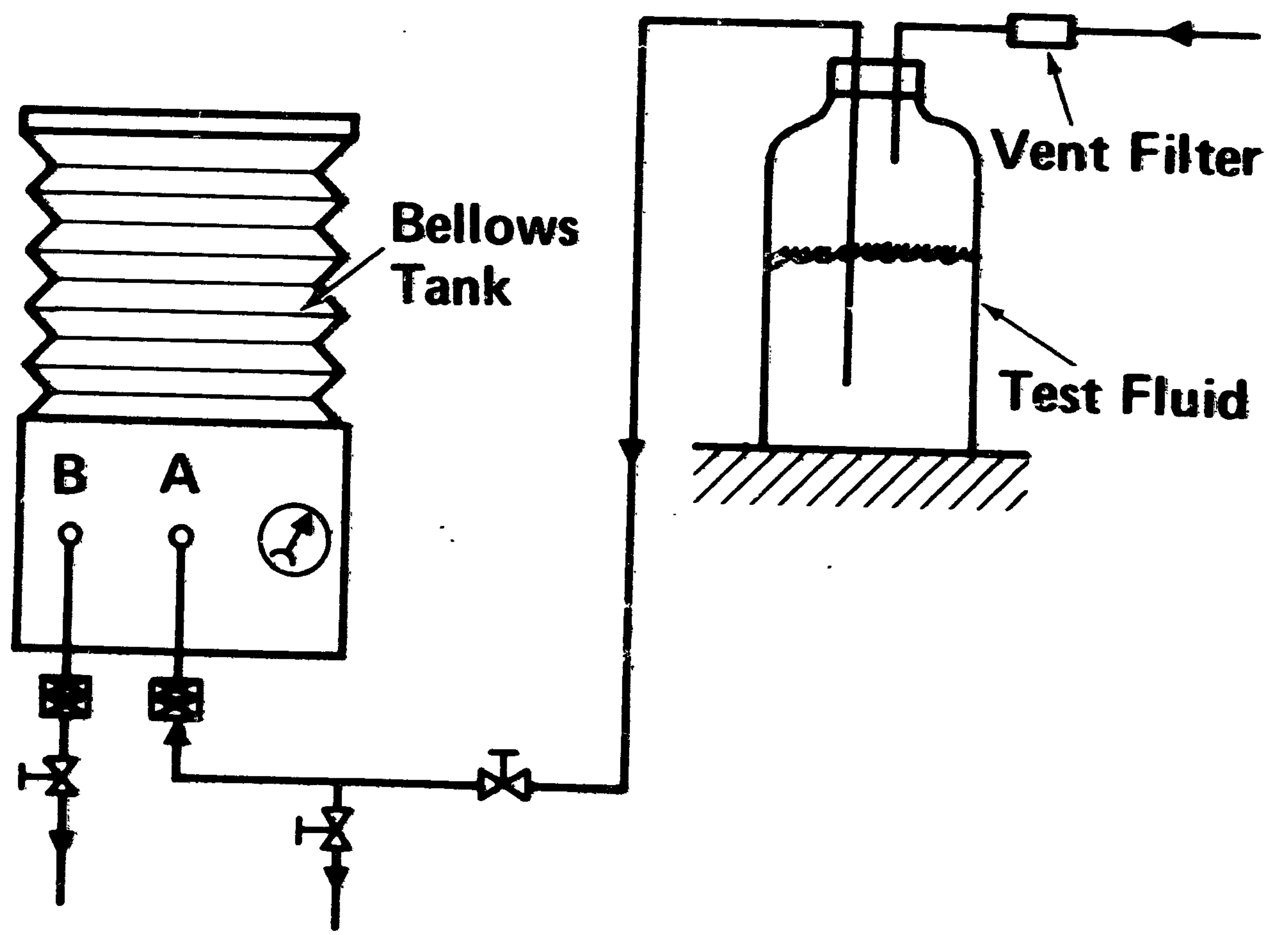
BELLOWS TANK – MICROBIOLOGICAL TEST OBJECTIVES

SCHEDULE	TEST NUMBER	PROCEDURE	OBJECTIVE
Phase A	1; 2	• Sterilize tank in "as received" condition • Load with sterile water under aseptic conditions	• Evaluate effectiveness of sterilization protocols I & II
Phase B	3; 4; 5; 6	• Innoculate with pure cultures • Apply sterilization protocol • Load with sterile water under aseptic conditions	• Establish survival of pure microbial cultures in tank • Eliminate contamination • Verify sterility
Phase C	7	• Challenge tank with mixed innoculum • Apply sterilization protocol • Load with sterile water under under aseptic conditions	• Establish survival of mixed microbial cultures in tank • Eliminate microbial contaminants • Verify sterility • Determine duration of sterility
Phase D	8	• Contaminate tank with mixed innoculum • Apply sterilization protocol • Load with sterile water under aseptic conditions • Withdraw samples at frequent intervals • Subject tank to random vibration loads and temperature cycles	• Eliminate microbial contamination • Verify sterility • Retain sterility for long duration while environmental conditions change • Prove that frequent withdrawals (in conformance to special protocol) do not interfere with sterility
Phase E	9; 10; 11 12,[1] 12,[2]	• Fill with contaminated wash and laundry water • Apply sterilization protocol II • Repeat in case of failure • Apply new sterilization protocol, Protocol III	• Induce contamination normally found in waste waters • Demonstrate survival of normal microbial contamination in tank • Eliminate microbial contamination • Verify sterility • Demonstrate the adequacy of sterilization protocol II & III in dealing with systems failures • Attempt integration with water reclamation system and check retention of sterility

SELECTION OF MICROBIAL CONTAMINANTS FOR CHALLENGING BELLOWS TANK

ORGANISM	CLASSIFICATION	CHARACTERISTICS
Ps. aeroginosa	gram negative rod	• Potential human pathogen, found in the intestinal tract • Common water contaminant; has consistently been a problem in closed water systems (McDonnell/Douglas & Ben Franklin) • Proliferates rapidly, resistant to many disinfectants
B. subtilis	gram positive rod	• Spore former, theoretically a more resistant organism • Representative of organisms found in dust & dirt
S. aureus	gram positive coccus	• Serious human pathogen • Would be collected in wash water of carriers
E. coli	gram negative rod	• Indicators of fecal contamination • Expected to appear after breakdown in water reclamation systems
S. marcens	gram negative rod	• Survives & proliferates at lower temperatures • Often found in water supplies • Convenient marker organism because of its characteristic color on growth media.

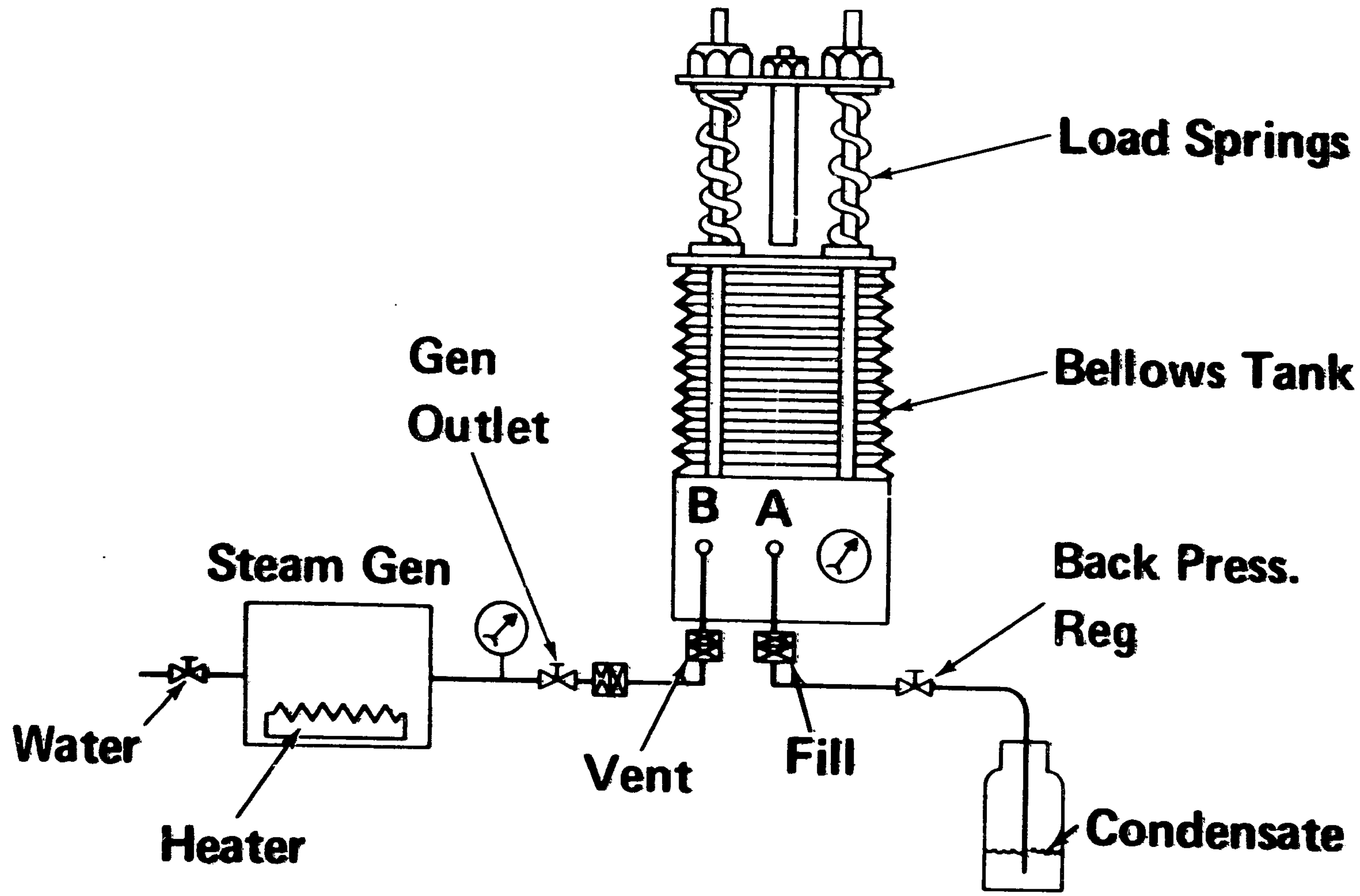
BELLOWS TANK – FILL CONFIGURATION FOR CONTAMINATION TESTING



BELLOWS TANK - STERILIZATION CONFIGURATION

A 3kW electrical steam generator was used to build up pressure inside the bellows against the setting of the back pressure regulator. The steam pressure caused the bellows to expand and opened the convolutes for penetration. Due to heat losses to ambient and heat layering on the inside condensation occurred. The steam feed line was connected to the higher vent port to avoid bubbling through the condensate which had collected at the lower fill port. It was not possible to determine the temperature gradient, but it is assumed that the mean temperature corresponded to the saturation pressure read off the tank gauge. The maximum allowable pressure differential across the bellows limited this procedure to approximately 21.2 psia and 232°F.

BELLOWS TANK – STERILIZATION CONFIGURATION



BELLOWS TANK – STEAM STERILIZATION PROTOCOLS

IDENTIFICATION	STEAM APPLICATION CONDITIONS			RESULTS
	PRESSURE	TEMPERATURE	DURATION	
I	20.2 psia	228°F	75 min	Not successful: contaminated at 0 hours
II	21.2 psia	232°F	125 min	Successful: Sterile for 7; 21; 22; 103 days with challenges by pure and mixed cultures but only limited success with wash and laundry waste water
III	21.2 psia	232°F (added insulation)	210 min	Successful: Sterile for 42 days after challenge with highly contaminated wash & laundry waters.

BELLOWS TANK SUMMARY OF MICROBIOLOGICAL TEST RESULTS

TEST	TEST FLUID	CHALLENGE	PROTOCOL	RESULT
A-1	Autoclaved dist water	Random, unidentified	I	Contaminated @ 0 hours
A-2	Autoclaved dist water	Residual from A-1	II	Sterile for ≧ 21 days
B-3, -4, -5, -6	Autoclaved dist water	Pure Cultures	II	Only Ps. aeruginosa survived as pure culture & posed real challenge Sterile for ≧ 7 days
C-7	Autoclaved dist water	Mixed Cultures	II	Sterile for ≧ 22 days
D-8	Autoclaved dist water	Residual from C-7	II	Sterile for ≧ 103 days in in spite of frequent withdrawals & changing environmental conditions
E-9	Wash water solution	Predominantly coliform, other organisms not identified	II	Sterile for > 7 days Contaminated @ 14 days.
E-10	Residence laundry water & synthetic wash water	Predominantly coliform, other organisms not identified	II	Sterile for > 3 days Contaminated @ 8 days
E-11	Autoclaved, distilled water	Residual from E-10	II	Contaminated @ 0 hours
E-12,1	Autoclaved, dist water	Residual from E-11	III	Sterile for ≧ 42 days
E-12,2	Reclaimed water	Random, unidentified	-	Contaminated @ 4 days

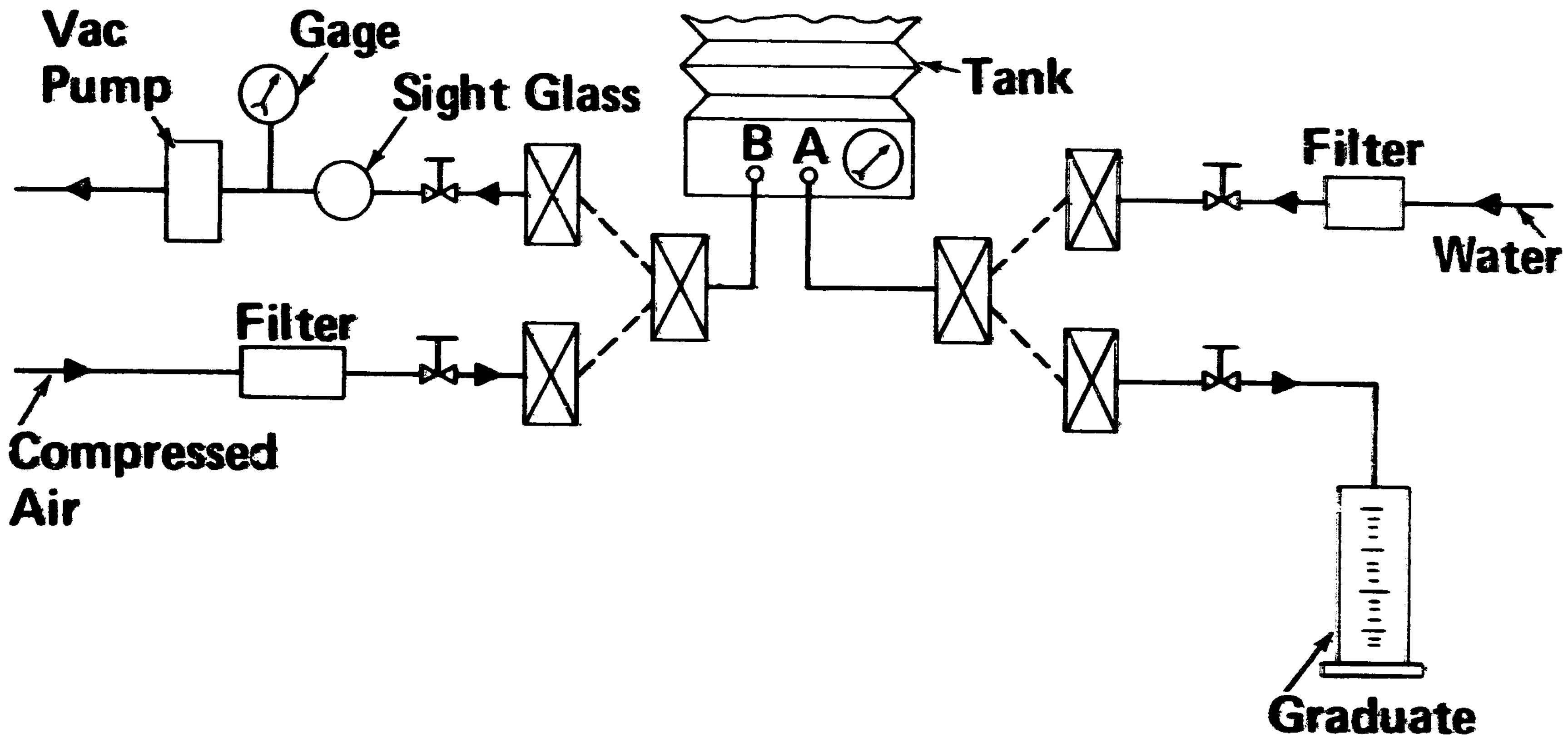
Note: ≧ means no contamination appeared, test simply terminated.

BELLOW TANK-FILL CONFIGURATION FOR VOLUMETRIC TESTING

A vacuum pump was used to collapse the bellows and remove all entrapped air from the vent port while a water supply was connected to the lower fill port. Complete air removal was indicated by the appearance of water in the suction line of the pump. With the vent port closed, water was pumped under pressure into the tank until the bellows came to rest against its mechanical stop.

The water supply was disconnected, the sampling valve was connected and water withdrawn into a 1,000 ml graduate. Mechanical weights were added to the top plate to assist the coil springs in expelling the water. After the bellows was collapsed, the compressed air through the vent port was used to drive out small quantities of residual water from the passage ways and interconnecting lines. Expulsion efficiency was defined as the ratio of the water expelled by the bellows to the total volume measured with the graduate.

BELLOWS TANK – FILL CONFIGURATION FOR VOLUMETRIC TESTING



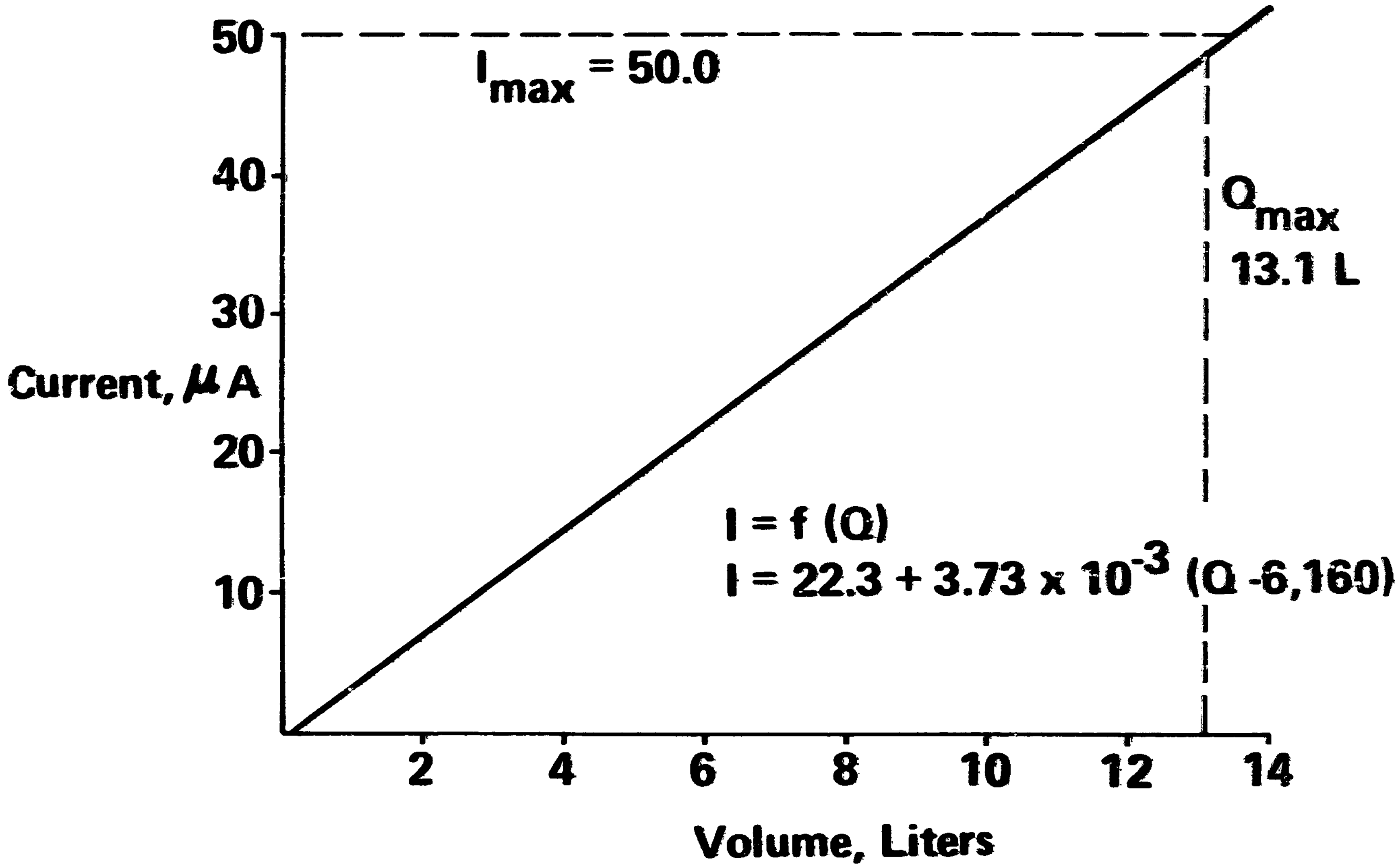
METER VOLUME SIGNAL

The volume meter signal was recorded for specific volumes as measured with 1,000 ml graduates during two complete test runs. A regression analysis was performed on the 40 measurements taken which resulted in the straight line relationship of $I = 22.3 + 3.73 \times 10^{-3}$ (Q - 6,160). The standard deviation was calculated for the residuals:

$$^{3}Sxly = \pm 2.05\ \mu A; \quad FSD = 50\ \mu A = I_{max}$$

Which means that 97% of all observations can be expected to fall within the band of ± 4.1% of full scale deflection. This is the net deviation which results from the combined effects of linearity of the potentiometer (0.35% claimed by manufacturer), guidance of bellows and linkage and error on part of the observer.

METER VOLUME SIGNAL



CONCLUSIONS

- Mixed cultures and waste waters from hygiene and laundry sources represent a valid microbiological challenge.
- Steam application (Protocol III: 21.2 psia, 232^{o}F & 210 minutes) is effective in sterilizing during launch preparations and after system's failure.
- Repeated <u>in situ</u> sterilizations can be accomplished with ease and pose no additional problems.
- Frequent withdrawals do not affect tank sterility if proper protocol is adhered to.
- Diversity of materials and component designs used in construction of test set up was not observed to interfere with sterility in any traceable way.
- Sterility can be retained for 100-day periods which are sufficient for Shuttle, Skylab II and Space Station applications.
- Tank is suitable for both use by crew onboard launch vehicle and delivery to orbit as part of resupply mission.
- Even though no physical/chemical testing was documented, no adverse odor, taste or coloration effects were observed.
- Volume metering by means of a linear potentiometer is both simple and accurate.
- Design and operations analysis indicates superiority of bellows tank to bladder tank in all aspects except weight effectiveness.
- In view of past flight qualifications and new aerospace applications presently being developed, the tank is considered as an acceptable development risk for the Shuttle.

RECOMMENDATIONS

- Repeat selected tests and perform full range analysis of physical and chemical parameters to ascertain if
  - tank material remains completely inert
  - high temperature associated with steaming creates additional chemical contamination
- Conduct new tests to check compatibility with bactericides (iodine, chlorine, silver)
- Modify tank design by adding light-weight pressure dome with insulation to determine
  - gas requirements for constant pressure expulsion
  - reduction in heat losses and condensation
  - minimum sterilization protocol required (higher temperature & pressure, shorter application period)
- Integrate tank electro-mechanically with operational water management system to
  - identify interface problems with data acquisition & checkout computer systems
  - monitor water inventory status and perform real time mass balances.
  - demonstrate compatibility with on-line potability monitors
  - investigate effectiveness of in situ sterilizations of complete systems
- Use tank as reservoir for bactericide generator concept which will provide protection to ancillary components in water management system

BELLOWS TANK* APPLICATIONS

PROGRAM	CONSTRUCTION MATERIAL	TANK SIZE	APPLICATION	DESIGN REQUIREMENTS
Agena B	St St'l 347	10.4" OD 48 " Stroke 16 GAL.	Auxiliary Propulsion System	Operating Life 500 cycles Ultimate Life 1,000 cycles
Saturn SIVB	St St'l 347	10.6" OD 15" Stroke 3.4 GAL.	Auxiliary Propulsion System (Oxidizer & Fuel)	Operating Life 500 cycles Ultimate Life 1,000 cycles (Plastic Deformation)
Grumman Adv. Development	St St'l 347	10.6" OD 15" Stroke 3.4 GAL.	Potable Water Storage, Waste Water Storage, Decontamination Techniques	Operating Life 500 cycles Suitability for Steam Sterilization
Skylab II	St St'l 321	23' OD 47 Stoke 75 GAL.	Potable Water Delivery & Storage	Operating Life 100 cycles Ultimate Life 200 cycles Expected Life 1,000 cycles Low Iodine Absorption
Supersonic Transport	Inconel 718	27.5" OD 20" Stroke 48 GAL.	Hydraulic Accumulator	Operating Life 20,000 cycles (Elastic Deformation)
Symphonie Satellite	Titanium	8.3" OD 8.7" Stroke 1.8 GAL	Auxiliary Propulsion System (Fuel Storage & Expulsion)	Light Weight

* Tanks designed and made by Sealol Inc. of Providence, Rhode Island 02905