7 August 1970

FINAL REPORT
STUDY OF
MOBILITY AND RESTRAINT DEVICE
CONCEPTS FOR
FUTURE MANNED SPACE SYSTEMS

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FINAL REPORT
STUDY OF
MOBILITY AND RESTRAINT DEVICE CONCEPTS FOR FUTURE MANNED SPACE SYSTEMS

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FOREWORD

This report was prepared by the Grumman Aerospace Corporation under Contract NAS9-10456, "Study of Mobility and Restraint Device Concepts for Future Manned Space Systems", for the Manned Spacecraft Center of the National Aeronautics and Space Administration. The work was performed under the technical direction of the Habitability Technology Section, Spacecraft Design Office, of the Manned Spacecraft Center, with Mr. V. Sova acting as Technical Monitor and Contracting Officer Representative.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

Man's mobility and body movements are functions of gravity. Although he is a creature and a captive of Earth, he has, in the past several years, overcome Earth's gravity and has extended his sphere of operations into the weightless domain of outer space where his movements are unrestricted. Prior space ventures, however, used vehicles whose very design limited man's movements.

We are rapidly approaching the time when spacecraft interiors will offer greater latitude of movement, and when travelers will not receive the present astronauts' exhaustive training. Since the vehicles used by future space travelers will be considerably more spacious than current versions, they must be so equipped as to facilitate and/or restrain man's mobility in response to the demands of particular circumstances.

This report represents one of the initial steps taken to satisfy the need for development of mobility and restraint devices in future manned space systems.

The objectives of the study were to:

- Evaluate the applicability of existing and/or proposed concepts for mobility/restraint systems.
- Develop new concepts for mobility/restraint systems applicable to long-duration manned spacecraft.
- Establish a basis for determining areas requiring future development.

The study was limited to applications for broad classes of earth orbital space stations and logistic spacecraft for the 1973-1978 time period:

- Operating at an altitude of 100 to 300 nautical miles
- In conditions from zero to one earth gravity
- With a crew compartment atmosphere of 5.0 - 14.7 psia (minimum partial pressure of oxygen 3.5 psia)
- With a crew size of 6-100
- With a 30 day to 10 year mission duration

The study was conducted during the seven month period between 7 January 1970 and 7 August 1970, including a six month study effort and one month report period.

The major tasks performed to meet study objectives were:

- Literature search
- Establishment of mobility and restraint requirements for long term, large spacecraft operations
- Synthesis and development of concepts for mobility and restraint devices
- Evaluation and selection of recommended concepts
- Development of parametric data to establish design characteristics, spacecraft interfaces, and associated penalties
- Assessment of development and implementation factors

SUMMARY OF RESULTS

Study results have been integrated into a Mobility and Restraint Handbook, SMA-14S-101, which provides the designer of mobility and restraint equipment with a single reference source covering:

- Requirements rationale
- Requirements for mobility and restraint devices
- Concept evaluation procedure
- Description and assessment of recommended mobility and restraint device concepts

The study resulted in the selection of 18 mobility and restraint device concepts for inclusion in the Mobility and Restraint Handbook. A description and assessment of each concept selected may be found in the Selected Concepts section of this report.

RECOMMENDATIONS

This "Study of Mobility and Restraint Device Concepts for Future Manned Space Systems" has focused on identification of concepts for application in future manned space vehicles, with primary reference to two aspects: suitability to man's mobility/restraint needs imposed by the space system gravity environment, and feasibility with respect to schedule and engineering constraints. However, the following three major areas should be investigated before final design of a functioning mobility/restraint system for integration in a manned space vehicle:

- Refinement of Mobility/Restraint requirements
- Man/Equipment/Vehicle Interface definition
- Concept/Design selection for preliminary design

REFINEMENT OF MOBILITY/RESTRAINT REQUIREMENTS

Established requirements for mobility/restraint devices should be refined from a total manned space systems approach. These requirements should be concerned with the integration of concepts selected from this study into a functional system designed for use within, and for transit to, the various facilities of a manned space system, and within constraints imposed by the mission and the space system design configuration. The facilities of particular concern to this study include:

- Work
- Food preparation and serving
- Living
- Services

MAN/EQUIPMENT/VEHICLE INTERFACE DEFINITION

The man/equipment interfaces that will influence the mobility/restraint equipment's ultimate configuration should be defined to implement the concepts depicted in this study. It is essential to specify acceptable physiological and anthropometric criteria, sound human engineering principles, and the use of qualified materials, to insure safe, reliable, and efficient designs. The equipment/vehicle interface or distribution and the location of each device in a mobility/restraint system will be determined by the activity, distance, or task to be performed. Thus, the size and area allocation of future manned space systems will have a major effect on selection of concepts for development and in definition of a specific mobility/restraint system.

CONCEPT/DESIGN SELECTION FOR PRELIMINARY DESIGN

From the concepts recommended as feasible methods of satisfying mobility/restraint requirements, selection of appropriate concepts to comprise a mobility/restraint system should be made. These selected concepts should then be subjected to more detailed study and analysis leading to preliminary design of a mobility/restraint system.

Since, in most instances, mobility/restraint systems require structural interface with the vehicle, it is essential that preliminary design information be developed rapidly and in sufficient detail for inclusion in the basic design of future manned space systems.

CONDUCT OF THE STUDY

The study was accomplished in accordance with the Study Flow Plan and Schedule shown in Figures 1 and 2 . The major tasks performed to meet study objectives were:

- Literature search
- Establishment of mobility and restraint requirements for long term, large spacecraft operations
- Synthesis and development of concepts for mobility and restraint devices
- Evaluation and selection of recommended concepts
- Development of parametric data to establish design requirements, spacecraft interfaces, and associated penalities
- Assessment of development and implementation factors

Study results were integrated into a Mobility and Restraint Handbook to guide designers of future manned space systems.

LITERATURE SEARCH

A literature search (compiled during this study and presented in a Bibliography/Synopsis Report No. SBR 14S-101) was conducted to consolidate applicable documentation of reduced gravity simulation tests and manned spacecraft flight experience. Information contained in this report was obtained from:

- NASA Scientific and Technical Information Facility
- Defense Documentation Center
- Grumman Aerospace Corporation Engineering Library
- Personal Files of Grumman Personnel

A review of literature search results exposed requirements and existing concepts for mobility and restraint devices.

ESTABLISH MOBILITY AND RESTRAINT REQUIREMENTS

To establish requirements for mobility and restraint devices, it was necessary to insure understanding of space environmental effects (at zero and artificial gravity conditions) on man. This was accomplished by examining man's ability to walk at various gravity levels,

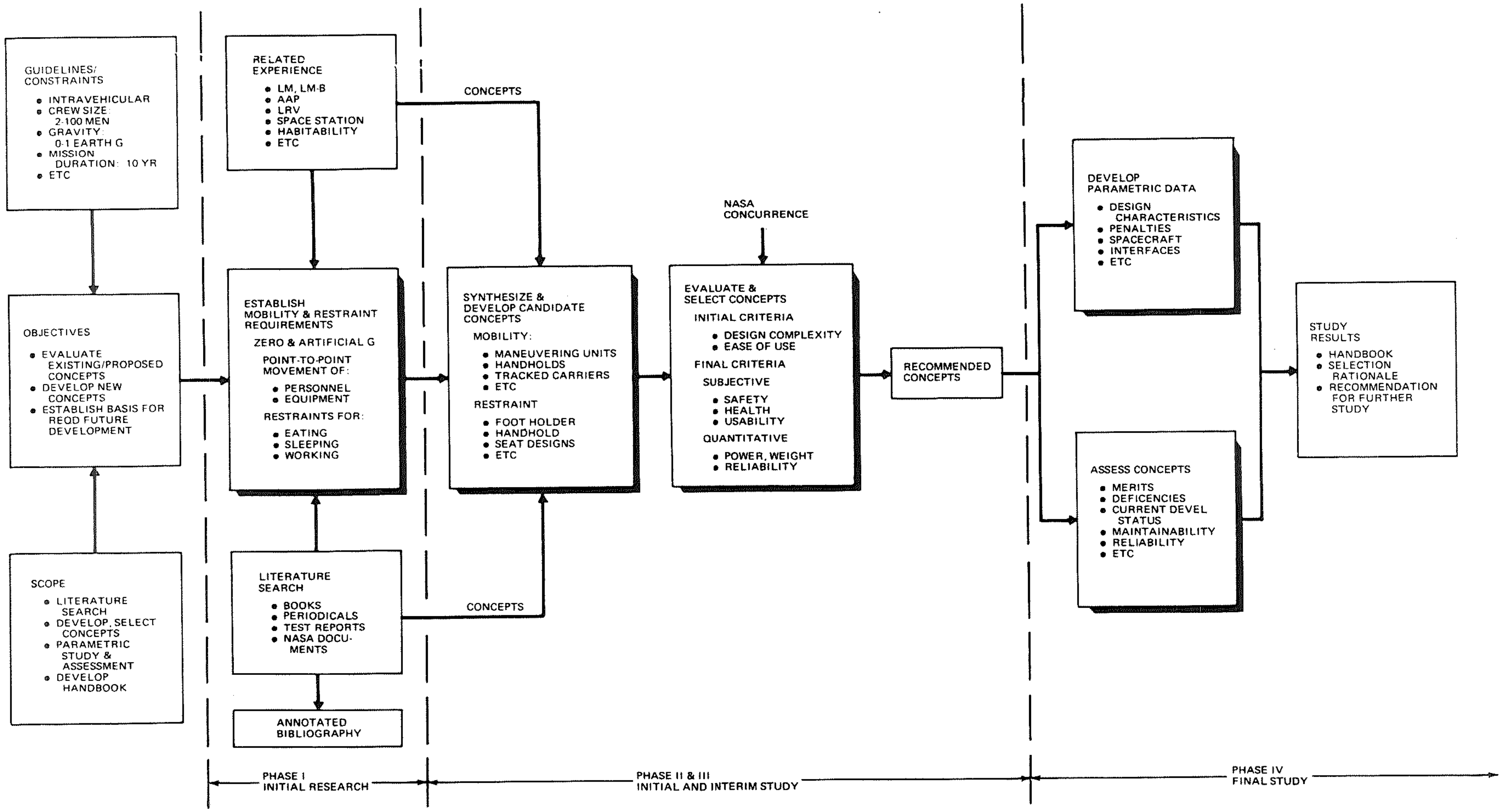
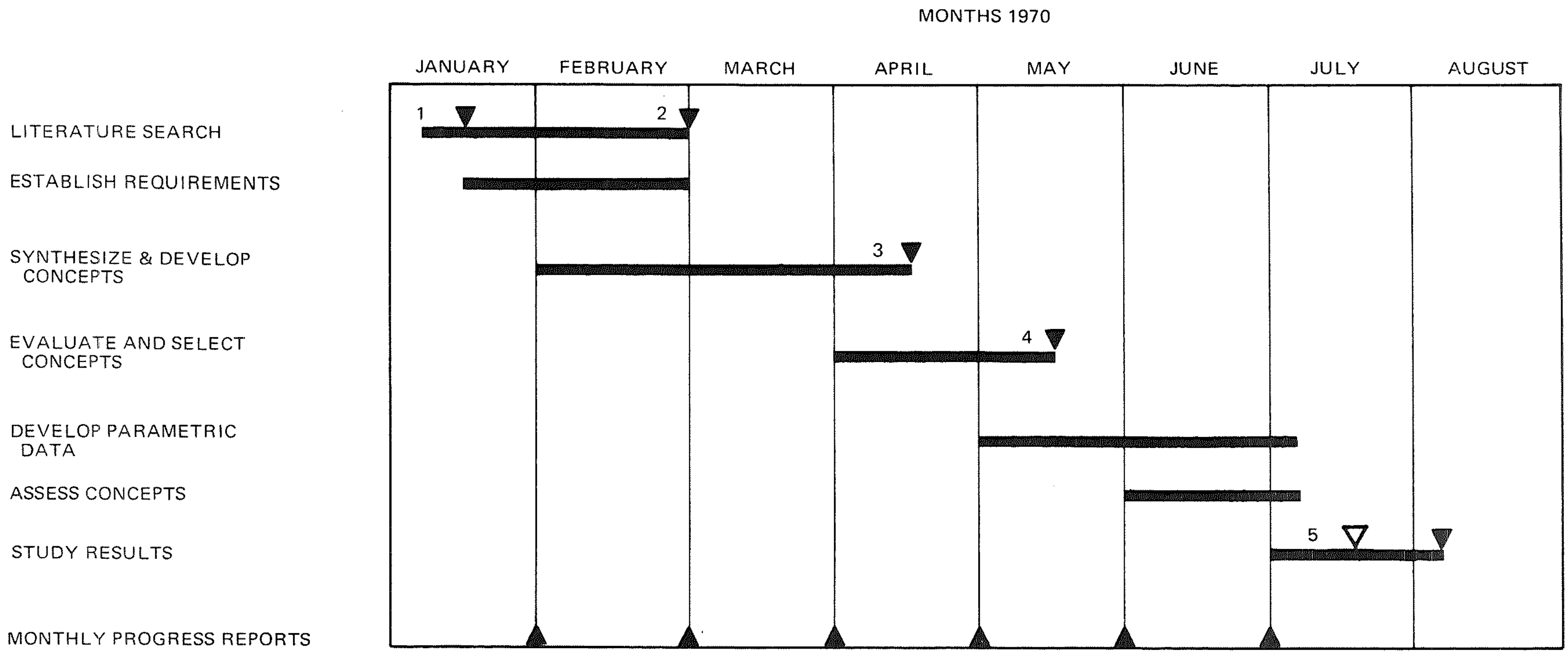


FIG. 1 STUDY FLOW PLAN



1.	FINAL STUDY PLAN	SPL-14S-1
2.	BIBLIOGRAPHY/SYNOPSIS REPORT	SBR-14S-101
3.	CONCEPTS REPORT	SRP-14S-101
	REQUIREMENTS DOCUMENT	SRP-14S-102
4.	EVALUATION REPORT & JOINT NASA SELECTION	SRP-14S-103
5.	HANDBOOK	SMA-14S-101
	FINAL STUDY REPORT	SRP-14S-104
	CONTRACT SUMMARY REPORT	SRP-14S-105

FIGURE 2 MOBILITY AND RESTRAINT SCHEDULE

since the gravity environment limit beyond which he can not walk, unaided, is of vital concern to the designer of mobility and restraint devices.

An investigation conducted under reduced gravity (Reference: Force Analysis of Walking at Reduced Gravity, (MECH/GA-64-1 (N65-20613), D. E. Beebe, USAF), measured the longitudinal and vertical surface reaction forces for a number of walking subjects. This investigation showed that a certain force pattern exists for walking at one-g. At lower levels of gravity, the capability to walk approaches walking at one-g when the shape of the force pattern is similar. Below 0.12 g, no force pattern existed. It was concluded that the lowest level of gravity at which man could walk, unaided, was 0.12 g.

Next, a review was conducted and kinematic diagrams were generated to insure an appreciation of man/machine interface characteristics - particularly for restraint device consideration - at both zero and artificial gravity levels.

Literature search documentation was reviewed in order to benefit from results of past experience in reduced gravity environments and manned spacecraft.

The foregoing tasks served as the basis for a knowledgeable judgement as to the activities and situations that man might experience in future manned space systems.

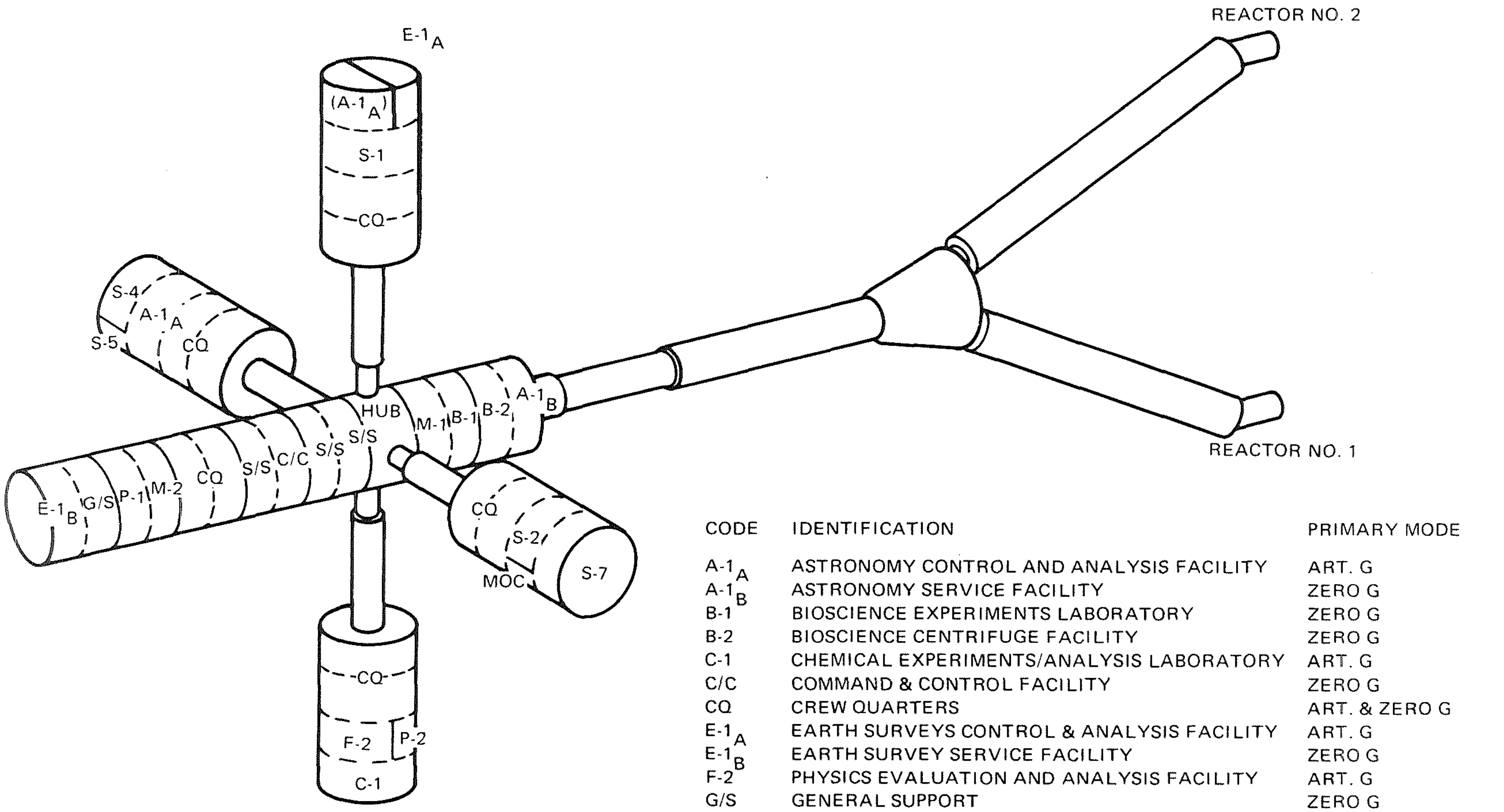
A representative space system configuration (Figure 3) was chosen as a baseline from the Space Station/Base, Phase B effort, in order to establish these activities and situations.

These activities and situations were then analyzed to determine specific mobility and restraint needs as a basis for the requirements document included in the Mobility and Restraint Handbook (SMA-14S-101).

Mobility requirements were defined as they related to activities within selected volumes, work spaces, or floor areas. Restraint requirements were defined for situations and activities demanding a finite expenditure of time in a given location or position.

SYNTHESIS AND DEVELOPMENT OF CANDIDATE CONCEPTS

Mobility and restraint device concepts were derived from a review of literature search results and syntheses responsive to the spectrum of established requirements.



CODE	IDENTIFICATION	PRIMARY MODE
A-1$_A$	ASTRONOMY CONTROL AND ANALYSIS FACILITY	ART. G
A-1$_B$	ASTRONOMY SERVICE FACILITY	ZERO G
B-1	BIOSCIENCE EXPERIMENTS LABORATORY	ZERO G
B-2	BIOSCIENCE CENTRIFUGE FACILITY	ZERO G
C-1	CHEMICAL EXPERIMENTS/ANALYSIS LABORATORY	ART. G
C/C	COMMAND & CONTROL FACILITY	ZERO G
CQ	CREW QUARTERS	ART. & ZERO G
E-1$_A$	EARTH SURVEYS CONTROL & ANALYSIS FACILITY	ART. G
E-1$_B$	EARTH SURVEY SERVICE FACILITY	ZERO G
F-2	PHYSICS EVALUATION AND ANALYSIS FACILITY	ART. G
G/S	GENERAL SUPPORT	ZERO G
M-1	BIOMEDICAL & BEHAVIORAL LABORATORY	ZERO G
M-2	BIOMEDICAL LIFE SUPPORT LABORATORY	ZERO G
MOC	MISSION OPERATIONS CENTER	ART. G
P-1	SPACE PROCESSING LABORATORY	ZERO G
P-2	SPACE PROCESSING ANALYSIS FACILITY	ART. G
S-1	PHOTO SUPPORT FACILITY	ART. G
S-2	OPTICS SUPPORT FACILITY	ART. G
S-4	ELECTRONICS CALIBRATION & REPAIR FACILITY	ART. G
S-5	MECHANICAL REPAIR FACILITY	ART. G
S-7	DISPENSARY	ART. G
S/S	SUBSYSTEMS	ZERO G

FIG. 3 SPACE STATION CONCEPT BASELINE CONFIGURATION

The literature search results identified concepts in various stages of development, ranging from the Gemini and Apollo programs' flight qualified hand rails, to the Electrostatic/ Aerodynamic Drag Work Table experiment (M 507), to be evaluated in Skylab.

Mobility and restraint concepts generated during the study were synthesized in response to the requirements previously established.

During the course of the study a total of 58 concepts were derived. Twenty-eight resulted from the literature search, and 30 were proposed by the study team.

EVALUATION AND SELECTION OF CONCEPTS

The candidate concepts were subjected to two successive evaluations to develop a list of recommended concepts. The first evaluation was primarily concerned with functional feasibility and applicability, while the second included quantitative and subjective criteria.

Initial Concept Evaluation

The following functional groupings were established to facilitate evaluation against the established mobility and restraint requirements.

Mobility Concepts

- Hands Only
- Feet Only
- Moving Conveyances

Restraint Concepts

- Mid-Torso
- Lower Torso
- Full Body
- Temporary
- Small Equipment

The concepts in each functional group were then judged on the basis of the following five criteria, weighted as indicated:

Weighting Factor	Criteria
4	Functional Characteristics
4	Applicability for Intended Use
3	Reliability
2	Maintainability
1	Weight

Weighting factors were so chosen as to give equal but preeminent value to concept Function and Applicability. Reliability, Maintainability, and Weight were subordinated in the order indicated.

Within each of the five criteria, a rating value of five (5), four (4), three (3), two (2) or one (1) was assigned; five (5) being the most, and one (1) being the least acceptable or desirable.

This provided the means for assessing concepts against requirements, and for ranking the various concepts within each functional group.

Interim Concept Evaluation

Following the initial evaluation, 34 remaining concepts were subjected to an interim concept evaluation. Evaluation of concepts was accomplished in a manner similar to that previously performed except for a more comprehensive rating procedure.

Those concepts recommended for further consideration were evaluated with regard to the following weighted quantitative and subjective evaluation criteria:

Evaluation Criteria	Weighting Factors
Power Consumption	5
Relative Weight	1
Reliability	10
Safety	
Flammability Potential	7
Emergency and Failure Considerations	6
Potential for Personnel Injury	10
Susceptibility of Equipment or Spacecraft to Damage	2

Evaluation Criteria	Weighting Factors
Health and Physiology	
Microbial Flora Control	8
Toxicity	9
Usability	
Comfort and Convenience	8
Simplicity	5
Degree of General Applicability	4
Spacecraft Integration Implications	3
Extent of Development Required	1

Weighting factors were assigned to denote the relative importance of evaluation criteria in determining the total rating for each concept. The weighting factors were established by a survey of study team members; the most important of the criteria being assigned a value of ten (10), the least a value of one (1).

Within each of the criteria, a rating value of five (5), four (4), three (3), two (2), or one (1) was assigned as in the initial evaluation; five (5) being the most, and one (1) the least acceptable or desirable.

CONCEPT SELECTION

On completion of the interim evaluation a list of 32 concepts, including six previously qualified on Gemini and Apollo, were recommended for consideration during the Final Study phase. From this list, 18 were selected at a NASA/Grumman study review meeting on 3 June 1970. Selection was made on the basis of feasibility, crew acceptability, prior flight qualification, or were considered the best risks for further development efforts.

Concepts selected were:

- Handrails
- Handholds
- Inflatable Mid-Torso Restraint
- Rigid Waist Tethers
- Flexible Waist Tethers
- Leg Rail

- Net Type Sleep Restraint
- Suction Shoes
- Astrogrid Shoe
- Magnetic Shoes
- Fixed Foot Restraint (Dutch Shoes)
- Portable Handrail
- Ladder/Rail Combination
- Double Rail Elevator
- Air Cushion Cargo Transport
- Moving Ladder Conveyor
- Linear Induction Mobile Handhold
- Electrostatic/Aerodynamic Drag Work Table

DEVELOPMENT OF PARAMETRIC DATA

Parameters considered pertinent to relating mobility and restraint concepts to the mission profile were categorized as independent or dependent variables. A matrix of the 18 selected concepts versus the dependent variables was prepared to aid in organizing the identification of the independent variables.

Theoretical analyses, literature search, engineering analysis and professional judgment were then used to establish a mathematical expression for the relationship between each concept's independent and dependent variables. These relationships, including their derivation, rationale, and graphic representations are presented for each selected concept in the Mobility and Restraint Handbook (SMA-14S-101).

ASSESSMENT OF SELECTED CONCEPTS

Each of the concepts selected was assessed on an absolute basis. The advantages and disadvantages were explored and evaluated and each concept's merits and deficiencies were enumerated. These are presented in the Mobility and Restraint Handbook (SMA 14S-101) and are intended for use as a guide in selection of a concept for a specific task.

SELECTED CONCEPTS

A description and assessment of each concept selected for inclusion in the Mobility and Restraint Handbook (SMA-14S-101) follows.

HANDRAILS

DESCRIPTION

Handrails with a rectangular or oval cross-section were evaluated as excellent mobility aids for Gemini and Apollo. It was determined that these rails should be set off from the surface at least two inches to permit ease of use. They may run the entire length of travel desired or may be in sections. They also offer good purchase for temporary restraint. The parallel handrails as shown provide much better control than the single handrail, although the single rail is adequate.

Source

Lockheed Missiles and Space Corporation Crew Systems Status Report #CS-1, 4/18/69

Testing

Qualified - Used on Gemini and Apollo

HANDHOLDS

Description

Handholds can be either recessed or protruding depending on use intended. For mobility, the recessed type would be better since they don't present "elbow knockers". For restraint, the protruding type would probably afford a better purchase and are excellent temporary restraints. The protruding type is usually 1/2 to 1 1/2 inches in diameter and 4 1/2 inches inside width, set off the surface at least 2 inches.

Source

Lockheed Missiles and Space Corporation Crew Systems Status Report #CS-1, 4/18/69

Testing

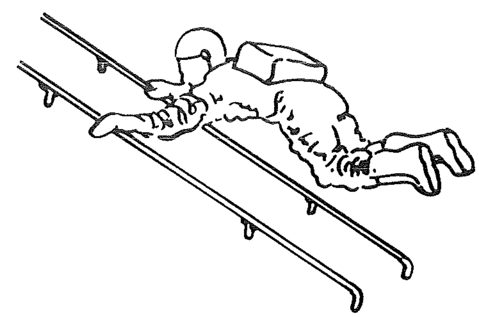
Qualified in flight on Gemini and Apollo

Merits

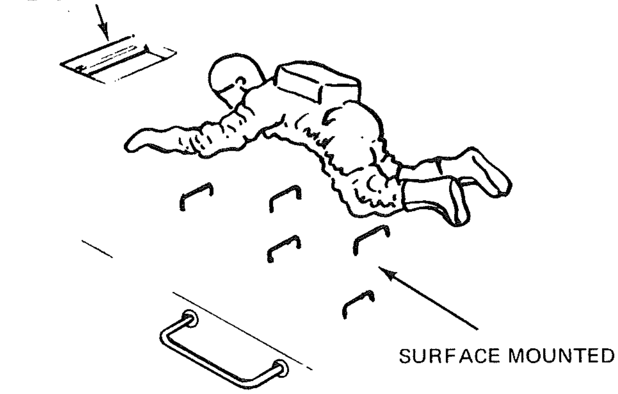
- Requires no electrical power
- Light weight
- Durable
- Reliable
- Simple
- Maintenance Free
- Applicable at all levels of gravity
- Positive control

Deficiencies

- Requires use of one or both hands
- Difficult to manage large packages
- Structural interface with vehicle - should be incorporated in vehicle design



HANDRAILS



HANDHOLDS

FIG. 4 HANDRAILS AND HANDHOLDS

Handrails and handholds have been fully developed and flight qualified during the Gemini and Apollo programs. Handrails have proven to be the most simple and effective method of zero gravity translation across a surface.

Handrails and handholds provide excellent temporary restraint for transition to a hands free restraint system. They also provide ready made attach points for tethers, and can be used for stability aids throughout the vehicle.

INFLATABLE MID TORSO RESTRAINT

Description

The restraint shown consists of a spring steel frame on which is mounted an inflatable form. By spreading the restraint frame, the person positions his mid section within the restraint. The inflatable bladder has the ability to provide pressure for force resistance while still maintaining ability to adapt to different body shapes and proportions. By anchoring the person's hips and buttocks, the restraint allows freedom of legs, feet, arms, head and torso.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- Uses no electrical power
- Broad applicability
- Usable in all gravity levels
- Simple
- Light weight
- Provides familiar pressure of chair

Deficiencies

- Fixed location
- Requires means of inflation

The simplicity and maintenance-free design of the Inflatable Mid Body Restraint should result in a reliable restraint applicable in a variety of "sitting' situations, i.e., console operation, laboratory, etc. Concept development is estimated at six months to one year.

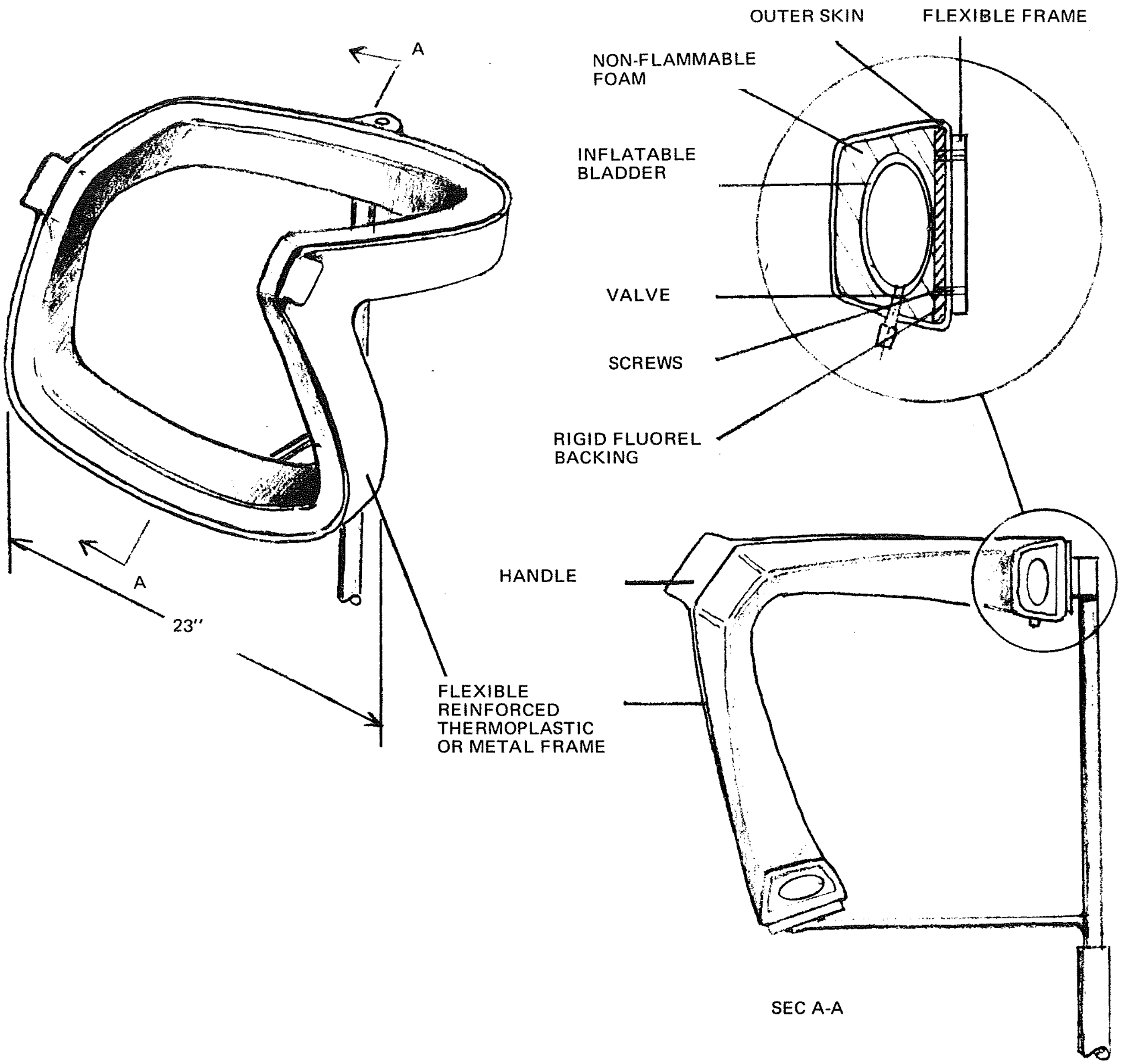


FIGURE 5 INFLATABLE MID-TORSO RESTRAINT

RIGID WAIST TETHER

Description

This concept consists of a telescoping, rigid tube affixed to the waist tether belt with a slide similar to that shown for the D-ring. The rigid tube has a ball-joint on the slide, permitting the tether to swivel at the user's waist. Once extended to the length desired, the collet clamp can be tightened by use of the nut, or the tension spring can be used to apply the required forces. This tether can be used in pairs with swiveling pin-pins which can be locked into receptacles anywhere in the spacecraft, or a rigid pin can be used to attach one tether to the slide assembly as a mobility aid.

SLIDE ASS'Y - RIGID TETHER

Description

The sketch shows the slide assembly intended for use with the Telescoping Rigid Tether and the Waist Tether Belt. The slide is attached to a standard handrail via spring loaded rollers and employs a tether attach point which is also spring loaded. The tether attach arm (pressure arm) applies a downward force to the user through the rigid tether, affording him the necessary traction to propel himself by walking. This slide, with minor modifications, could be arranged to accept a pallet for transporting equipment.

BELT - WAIST TETHER

Description

Shown here is the belt and attachment for waist tethers. The attachment pictured is a D-ring and slide, intended for use with the flexible tethers. The slide is just wide enough to prevent twisting on the belt. The user can position the D-ring slide at any point on the belt, thereby giving himself extra body twisting ability. This belt can be used for either the flexible or rigid waist tethers.

Source

Grumman Aerospace Corporation

Testing

None

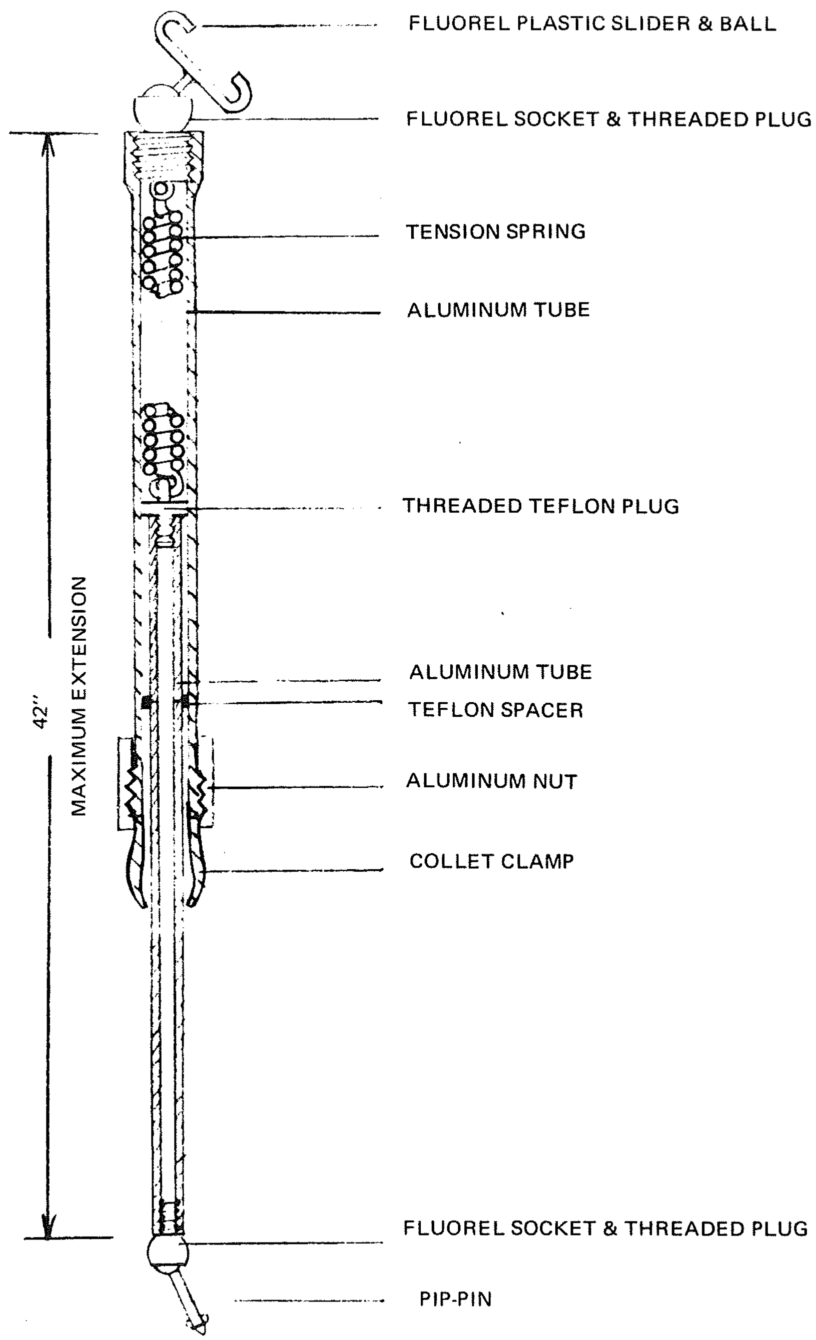


FIGURE 6 RIGID WAIST TETHER

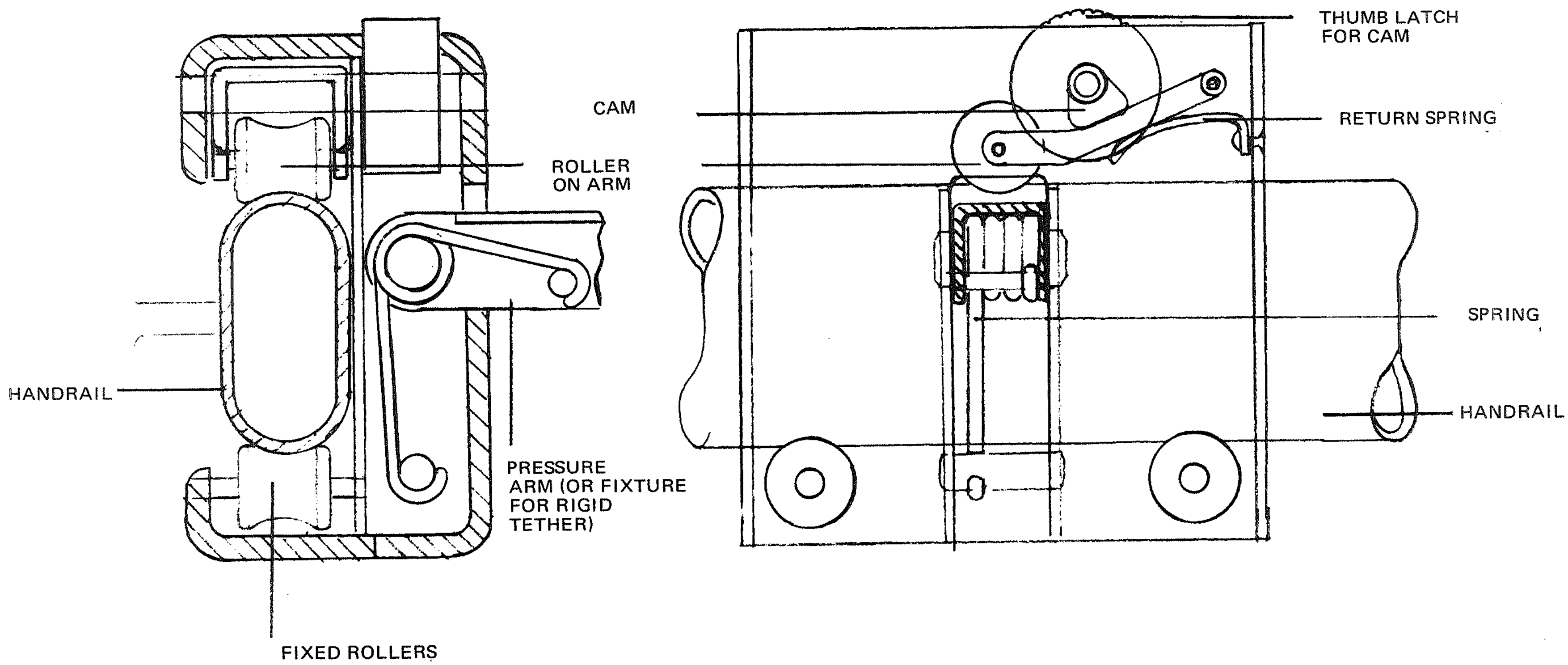


FIGURE 7 SLIDE ASSEMBLY - RIGID TETHER

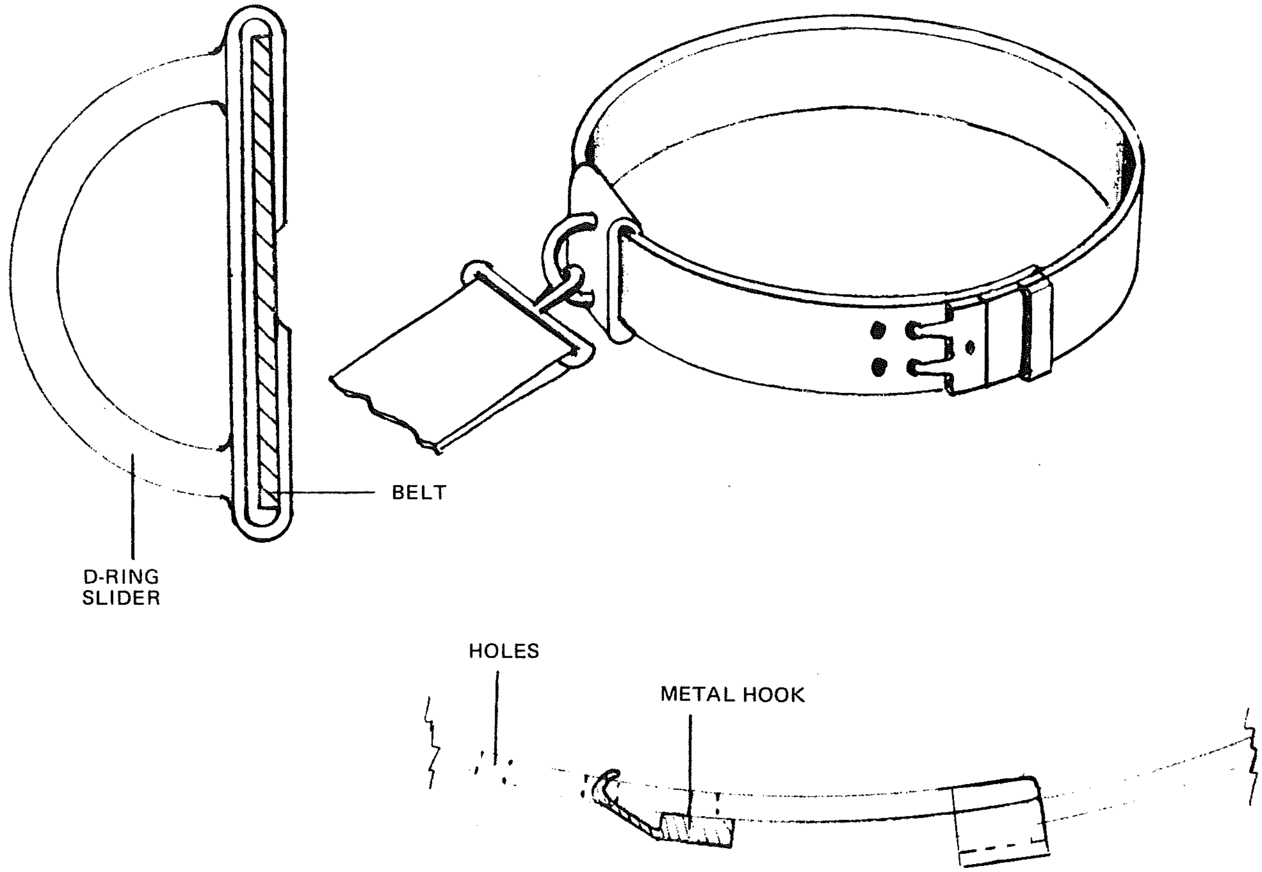


FIGURE 8 WAIST TETHER BELT

Merits	Deficiencies
• No electrical power required	• Mobility range limited to handrail system
• Restraint system provides gravity substitute force enabling hands free mobility	• Simultaneous two way traffic requires parallel systems
• Can be used for transporting equipment	• Maintenance required
• Removable from handrail for stowage	• Tolerance critical to prevent binding

The Rigid Waist Tether employs a rigid tether connected to a handrail mounted slide and a belt worn by the user. The slide assembly/rigid tether connection is spring loaded to exert a downward force on the tehter providing a gravity substitute force enabling near normal walking by the user.

The simplicity of the design combined with periodic maintenance and inspection should insure a reliable system. Concept development would require an estimated six months to one year.

Application of the Rigid Tether is intended for zero gravity work stations where limited mobility is required, or for hands-free mobility in long passageways. In instances where hands-free mobility is not required, grasping the rigid tether with one or both hands will provide the user with the capability of compression walking without having to physically complete the belt/tether connection.

Rigid tethers can be used in zero gravity situations where it is necessary to maintain a location and position not allowing use of the flexible tether.

FLEXIBLE WAIST TETHERS

Description

This restraint system consists of the waist tether belt, with two D-ring slides worn by the user, and two tethers which attach to the D-rings via. spring clips. The other end of the tethers can be attached to fixed rings on the interfacing work areas, or to suction cups (much the same as those used by glaziers to transport panes of glass) which can be affixed to any smooth surface in the vehicle. By adjusting the tethers to provide a force component downward, the user can restrain himself for successful performance of many tasks.

Source

Grumman Aerospace Corporation

Testing

None

Merits

- Requires no electrical power
- Applicable for tasks requiring exertion of high torques
- Minimizes effort required for body control
- Limited mobility superior to that of foot restraint
- Broad variety of configurations adaptable to many applications

Deficiencies

- Requires structural attach fittings and personnel harness or belt attachment
- Mobility limited by tether length
- Usually requires both hands for connect/disconnect

Waist tethers developed and qualified on Gemini EVA were on the flexible tether type, limiting movement within an evelope determined by tether length, or providing a gravity substitute force by interaction of the users legs placing the tethers in tension.

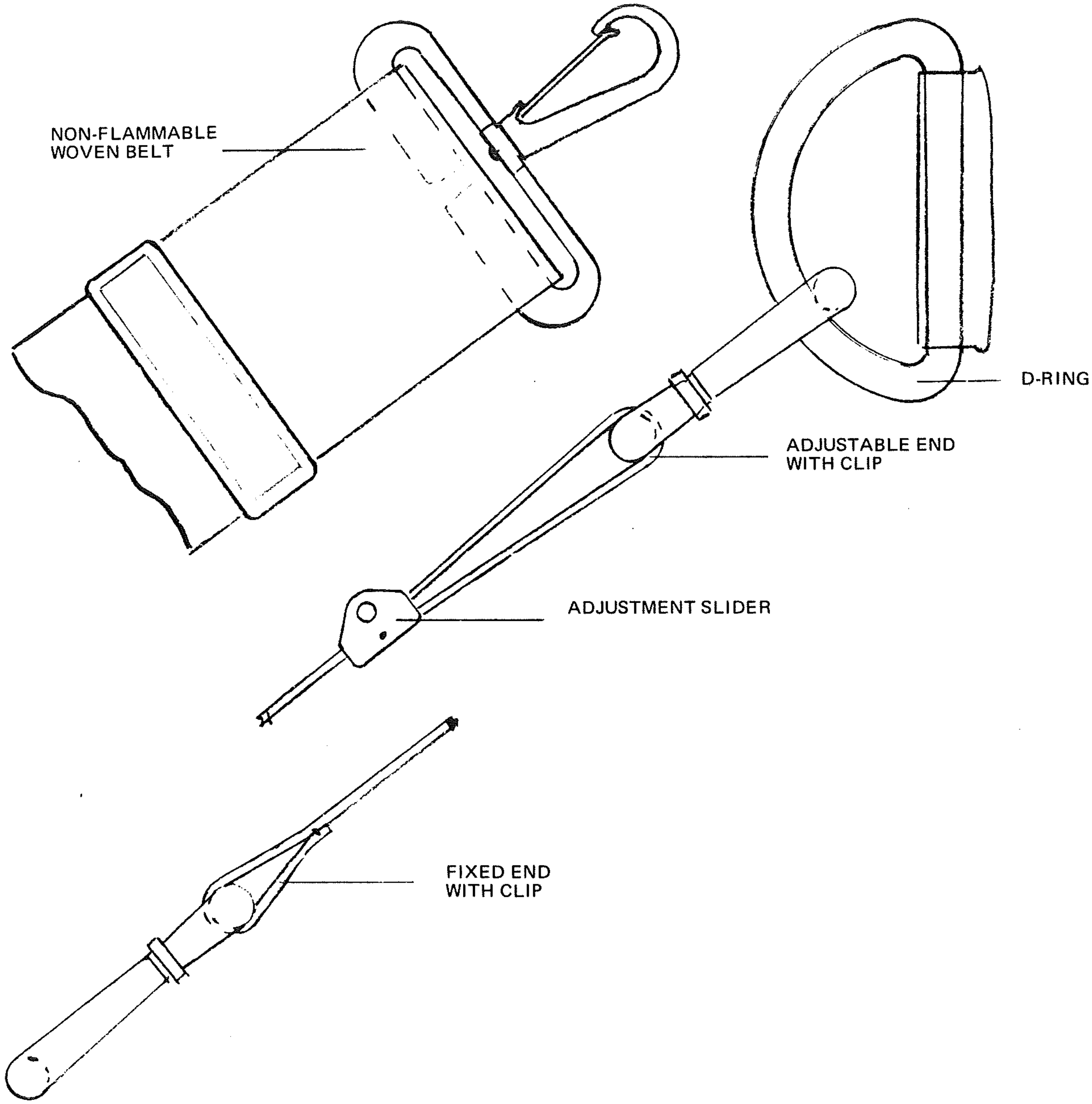


FIGURE 9 FLEXIBLE WAIST TETHER

LEG RAIL RESTRAINT

Description

The restraint apparatus consists of two rigid rails used in conjunction with outermost edge of control panels. With toes hooked under the bottom rail and knees over the top rail, the crew member can obtain three point restraint by employing slight body pressure on the edge of the console or work station.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- Requires no electrical power
- Does not restrict movement of trunk, arms or head
- Light weight
- Simple Design
- Applicable for zero g "sitting"

Deficiencies

- Not usable in artificial g environment
- May cause pressure points after prolonged use

The simplicity of this restraint system should result in a reliable maintenance-free design applicable in zero gravity "sitting" situations. Concept development should require less than six months.

Modifications of concept by deleting approximately an 8 inch section in the middle of the knee rail would enhance applicability for dressing or body cleaning in zero gravity environments.

The toe restraint may be incorporated into the console or work bench and produce another variation of this system.

Early development testing could easily be accomplished as a parasite test on a zero g KC-135 flight.

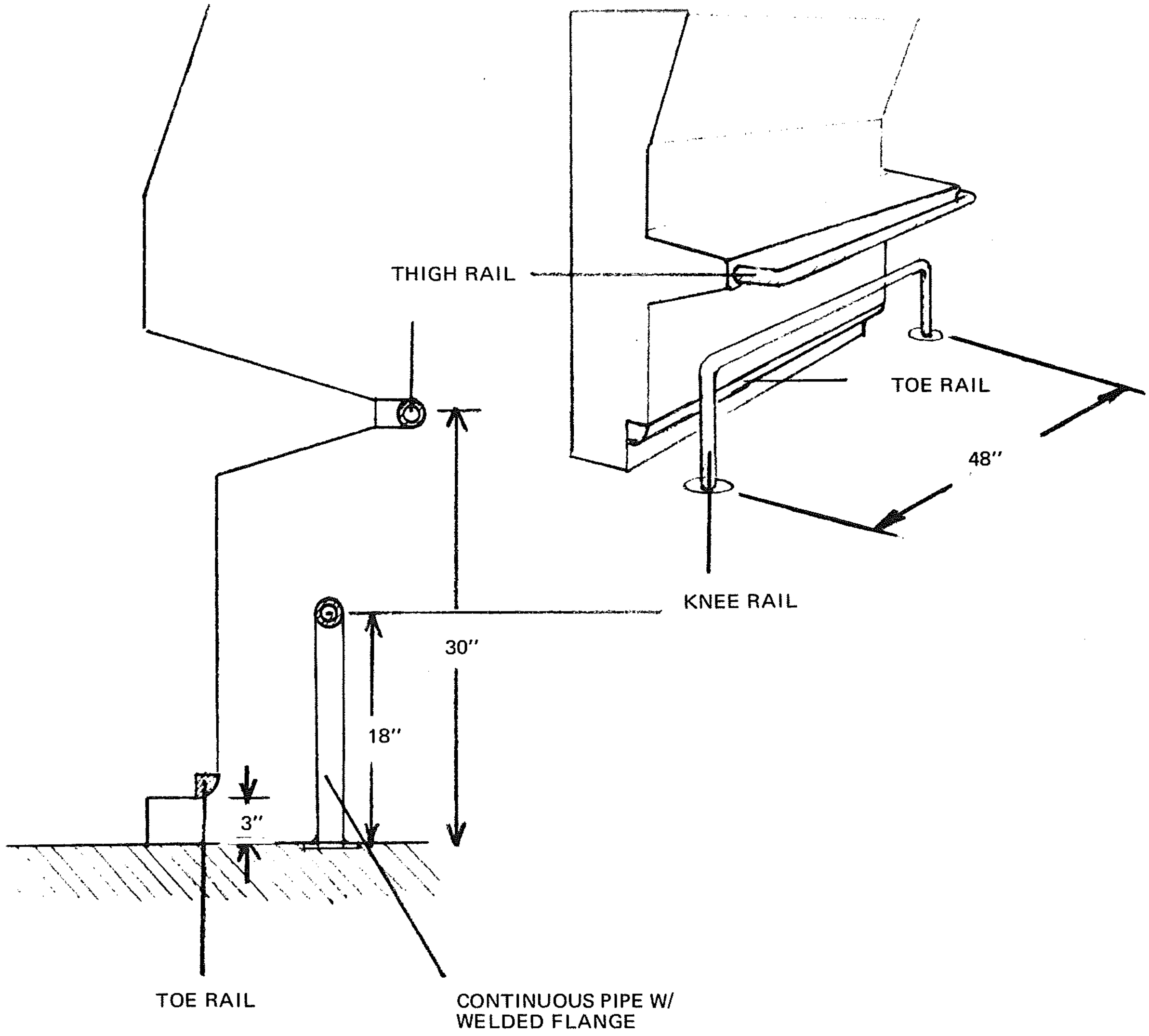


FIGURE 10 LEG RAIL RESTRAINT

"NET TYPE" SLEEP RESTRAINT

Description

Essentially a "Net Type" restraint of an elasticized webbing which applies a light pressure over the body. This keeps the crewman in place and provides some tactile stimulation somewhat the same as a blanket here on earth. This device could be used with a bunk type bed or hammock and would open like a book. The crewman would position himself in his bunk and draw the "blanket" over himself and hook it to the under part.

Source

GAC Report #FSR356A-46, 10/68 "Moving Around in Zero G"

Testing

None known to date.

Merits

- Provides tactile stimulation of a blanket
- Usable in all gravity levels
- Ease of access for linen change
- Stowable with bunk made
- Rapid entry and exit

The simplicity of this concept should insure good reliability. Periodic maintenance is expected to be limited to linen changes and net replacement as required. Concept development is estimated at six months.

A pedestal stand and modification of the net restraint would provide an examination table and restraint for the zero g medical dispensary.

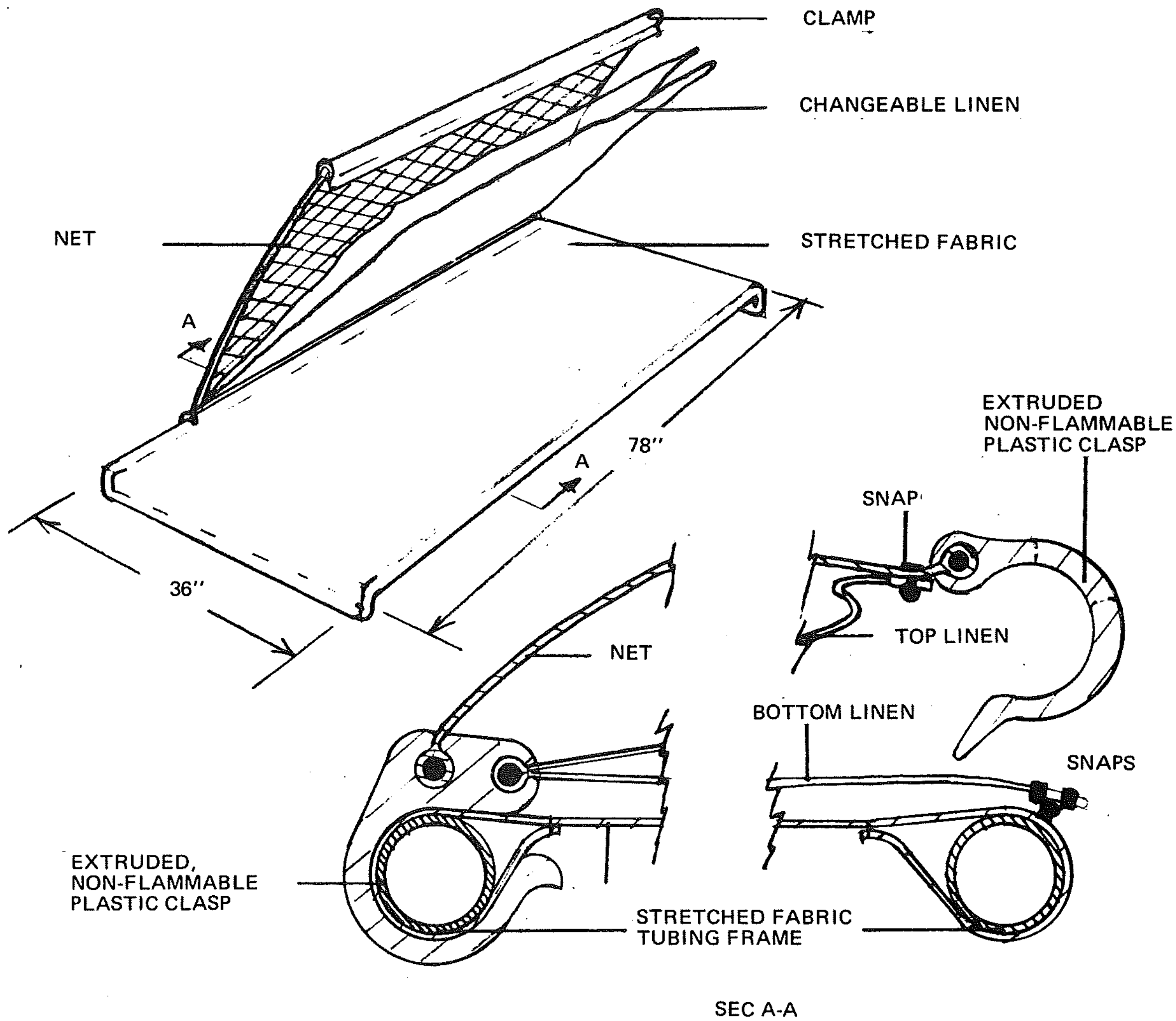


FIGURE 11 NET-TYPE SLEEP RESTRAINT

SUCTION SHOES

Description

This concept incorporates suction diaphragms on the soles of shoes. The suction diaphragms are activated by placing the shoe on a smooth surface and twisting the foot, which operates a large-pitch screw mechanism to draw the vacuum between the diaphragm and the floor. As the shoe twists, the suction cup remains in a fixed position on the floor. By returning the foot to the normal position, the vacuum can be eliminated.

This concept is primarily intended as a short duration restraint system with possible use as a short range mobility aid.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- Uses no electrical power
- Simple to use
- Restraining force derived from existing ambient pressure
- Broad applicability
- Primarily intended for short range mobility or restraint in zero gravity--may be worn in artificial g environment
- May be added at any time
- Restraint of each foot provides redundancy

Deficiencies

- Requires smooth, clean surface for proper function
- Restraint duration dependent on leakage rate
- Restraint loss occurs without warning
- Maintenance required
- Footwear equipment requires individual assignment for fit and hygiene
- Requires temporary restraint for initial engagement
- Training required for proper foot movement

Reliability of the suction shoe would be inherently good based on mechanism simplicity. Maintenance would be limited to periodic suction diaphragm replacement. Concept development is estimated at six months to one year.

Requirements for floor smoothness compatible with use of suction shoes must be established by test. Smoothness requirements would determine the cost penalty incurred by implementation of this concept. A weight penalty is not anticipated.

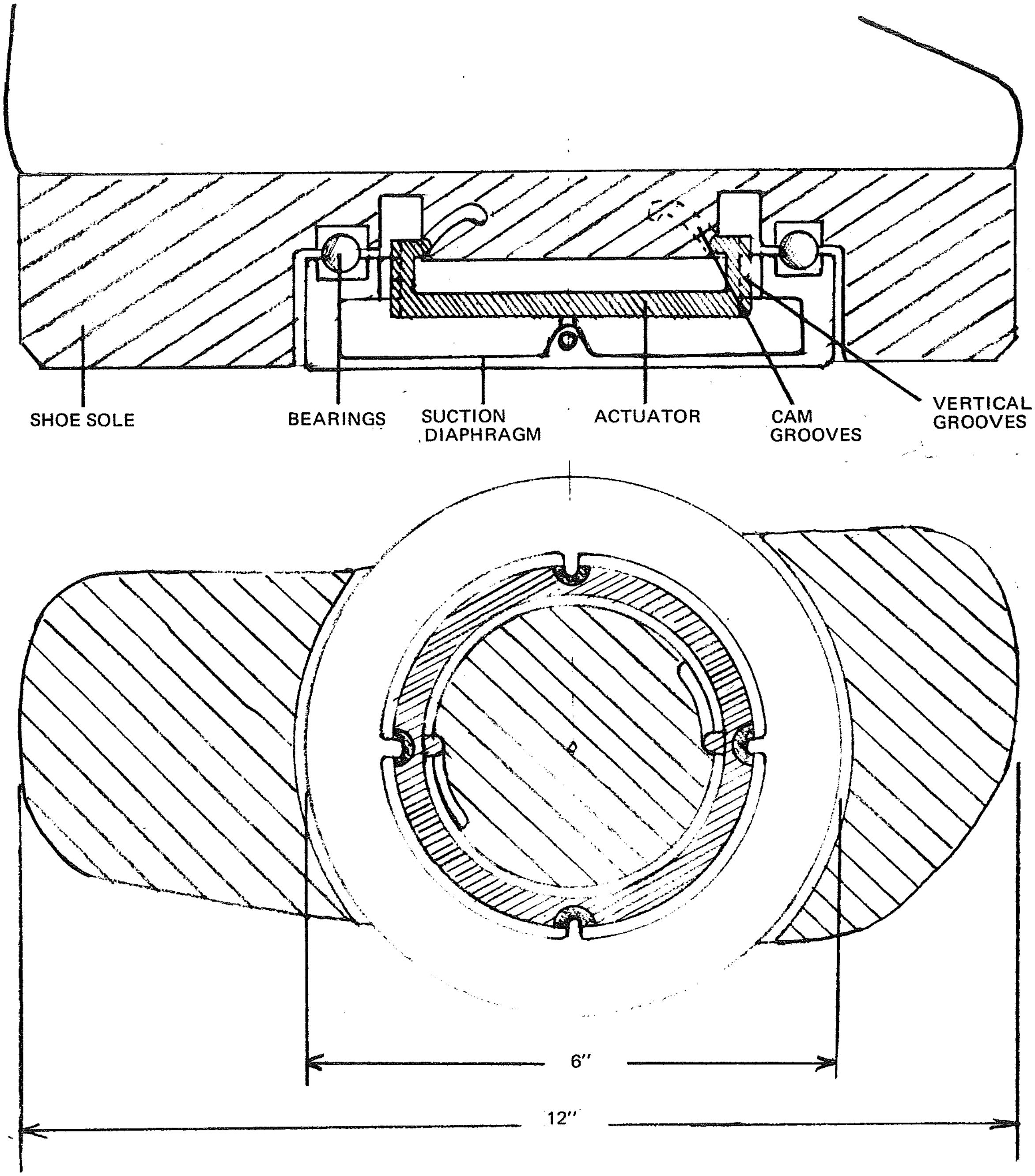


FIGURE 12 SUCTION SHOES

ASTROGRID SHOE RESTRAINT

Description

The restraint system consists of a floor grid surface of trianglar holes in a hexagonal array. Shoes are provided with interfacing, positive triangular shapes or cams, which are mounted off the mid-sole of the shoe. The system acts as both a restraint and a mobility device. The person inserts the cam of the shoe into a triangular hole in the floor grating. By then twisting the shoe a given amount, the shoe becomes securely fastened to the grating. The hexagonal array of triangular floor openings allows for the widest possible directions of movement.

Source

McDonnell-Douglas (for AAP workshop)

Testing

Neutral Buoyancy KC-135 Zero "G" Flights

Merits

- Positive restraint - excellent for activities requiring high torque
- Provides short range mobility at/between work stations
- Retention of restraint without conscious effort
- Foot restraint does not impede mobility or dexterity of rest of body

Deficiencies

- Footwear can be worn only in zero gravity
- Triangular grid surfaces are integral part of restraint
- Individual footwear required for proper fit and hygiene
- Handholds should be provided for temporary restraint while engaging restraint system

This concept has been developed for, and will be evaluated aboard Skylab. Pending the results of those tests, comments on its worth will not be made here. The concept has shown to be feasible in prototype and the only real test of its value will be its performance under prolonged zero "g" conditions aboard Skylab.

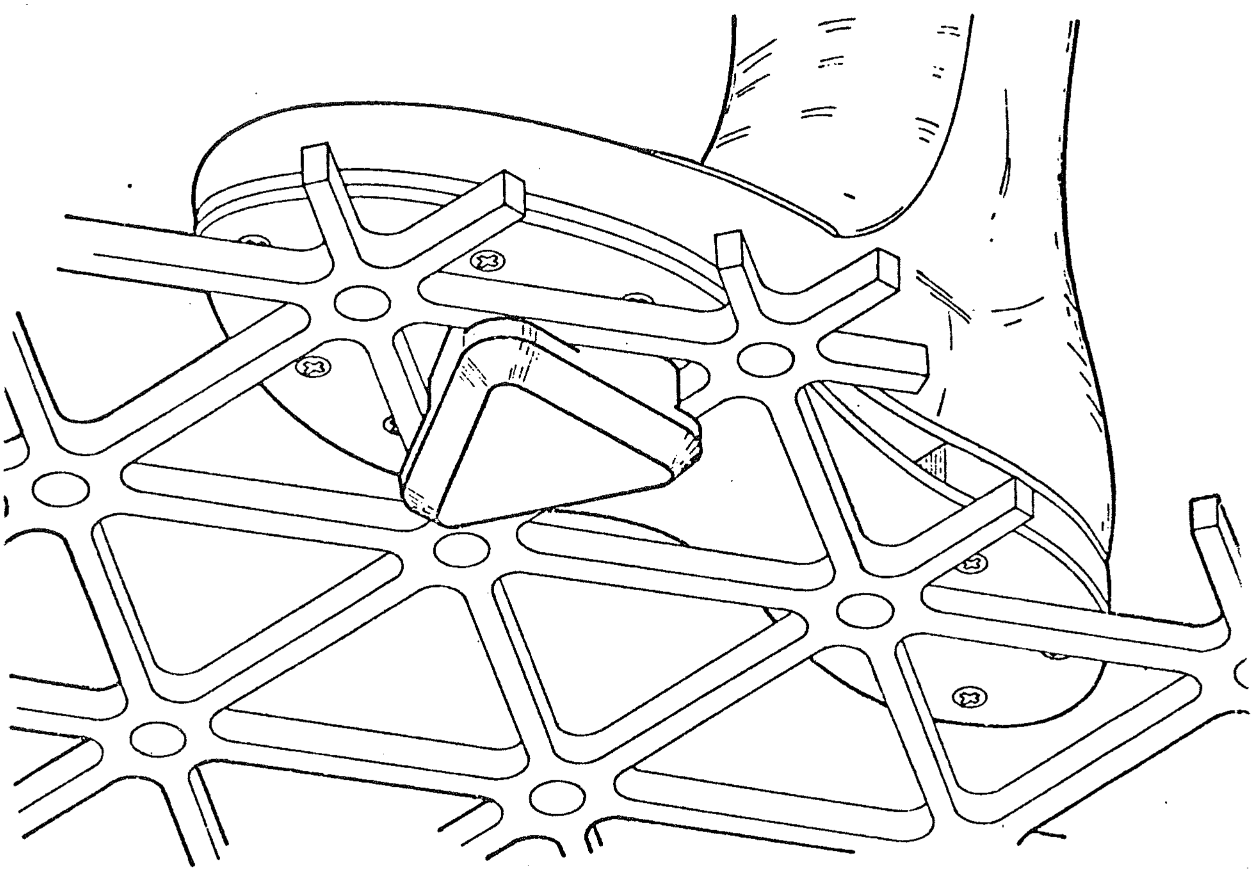


FIGURE 13 ASTROGRID SHOE RESTRAINT

MAGNETIC "SHUFFLER" SHOE

Description

This concept uses a shuffling technique (sliding one foot forward on a low coefficient of friction surface) maintaining constant contact with the floor. The propelling force will originate from the high coefficient of friction surface in the heel area of the foot. The low coefficient of friction and high coefficient of friction materials are Teflon and Viton, respectively. The use of these materials in conjunction with the distributed attractive force not only provides the user with stability in shuffling and performing tasks, but allows easy separation from the floor when free float is desired.

The shoe consists of a fabric upper part in a loafer design, with the magnets imbedded in the sole and heel portions. A strap with D-ring arrangement is attached to the shoe and routed over the instep to permit lifting the heel magnet from the floor.

Source

Martin Marietta Corporation (NASA Contract #NAS-9-9336)

Testing

Ground tested in neutral buoyancy tank and on air bearing zero-g simulator. Flight evaluation in KC-135 zero-g.

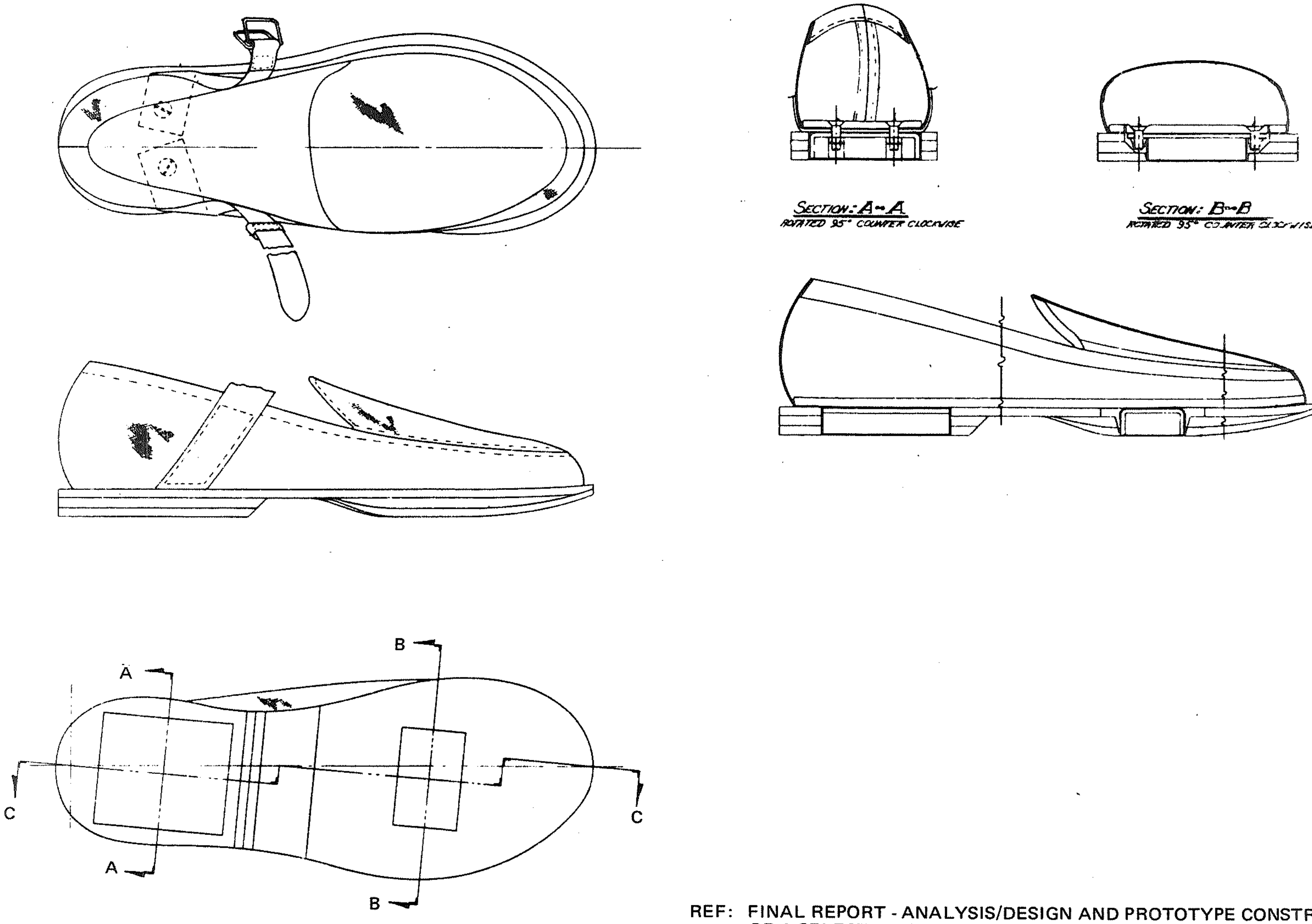
Merits

- No electrical power requirements
- Footwear can be worn in artificial gravity environment and serve as primary footgear

Deficiencies

- Soft iron floor is an integral part of restraint system - excessive weight penalty for other than limited application
- Incorporation of this concept would require shielding of instrumentation and displays, complicating construction pre-launch and onboard checkout of vehicle
- Requires individual issue to each crewman

The magnetic shoe (shuffler) developed under NAS 9-9336 would require periodic spray application of Teflon to the sliding surface of the footwear. Initial test evaluation on KC-135 zero gravity flight number 3/3/70A-015Z determined:



REF: FINAL REPORT - ANALYSIS/DESIGN AND PROTOTYPE CONSTRUCTION OF A SELECTED MOBILITY AND RESTRAINT DEVICE, NOV 1969, CONTRACT NAS 9-9336, MARTIN MARIETTA CORP (MCR-69-507)

FIGURE 14 MAGNETIC "SHUFFLER" SHOE

- In the opinion of the test subject, the "shuffling" method of walking was quite unnatural and required constant attention on his part.
- Practical application would be limited to work stations which require limited amount of translation by the operator.

The use of this concept would also be limited by the high weight penalty imposed by the requirement for iron flooring.

This concept, if it is to be considered at any time, requires more development to overcome some inherent problems such as fit to crewmen, and the attractive force of the magnets.

FIXED FOOT RESTRAINT (DUTCH SHOES)

Description

The diagram shows a top view of two rigid shoe restraints which can be fixed to any surface. The user restrains himself by inserting his feet into the restraint and rotating the toes outward until both toes and heels are held under the rim of the restraint. He can then resist work forces through reaction points at his heels and toes.

Source

NASA Report #CR-1334, May 1969 "A Study of Astronaut's Work Capabilities in Weightless Conditions".

Testing

Flown on Gemini 12 - fully developed and qualified.

Merits

- Rapid entry and exit from restraint
- Simplicity
- Qualified on Gemini and Apollo
- Excellent for work stations requiring high torque expenditure

Deficiencies

- Mobility completely restricted
- Structural interface with vehicle
- Requires conscious effort to retain restraint
- Handhold provision desirable for restraint entry

The Dutch Shoe restraint was fully developed and qualified for use on Gemini and Apollo flights. It was rated by the pilots as the best overall restraint for localized work in zero "g". This restraint can be used very effectively in conjunction with handholds or waist tethers. It may be permanently fixed in required locations or made portable, to be fastened in place only when required.

The simplicity of use and design make this restraint very reliable and maintenance free.

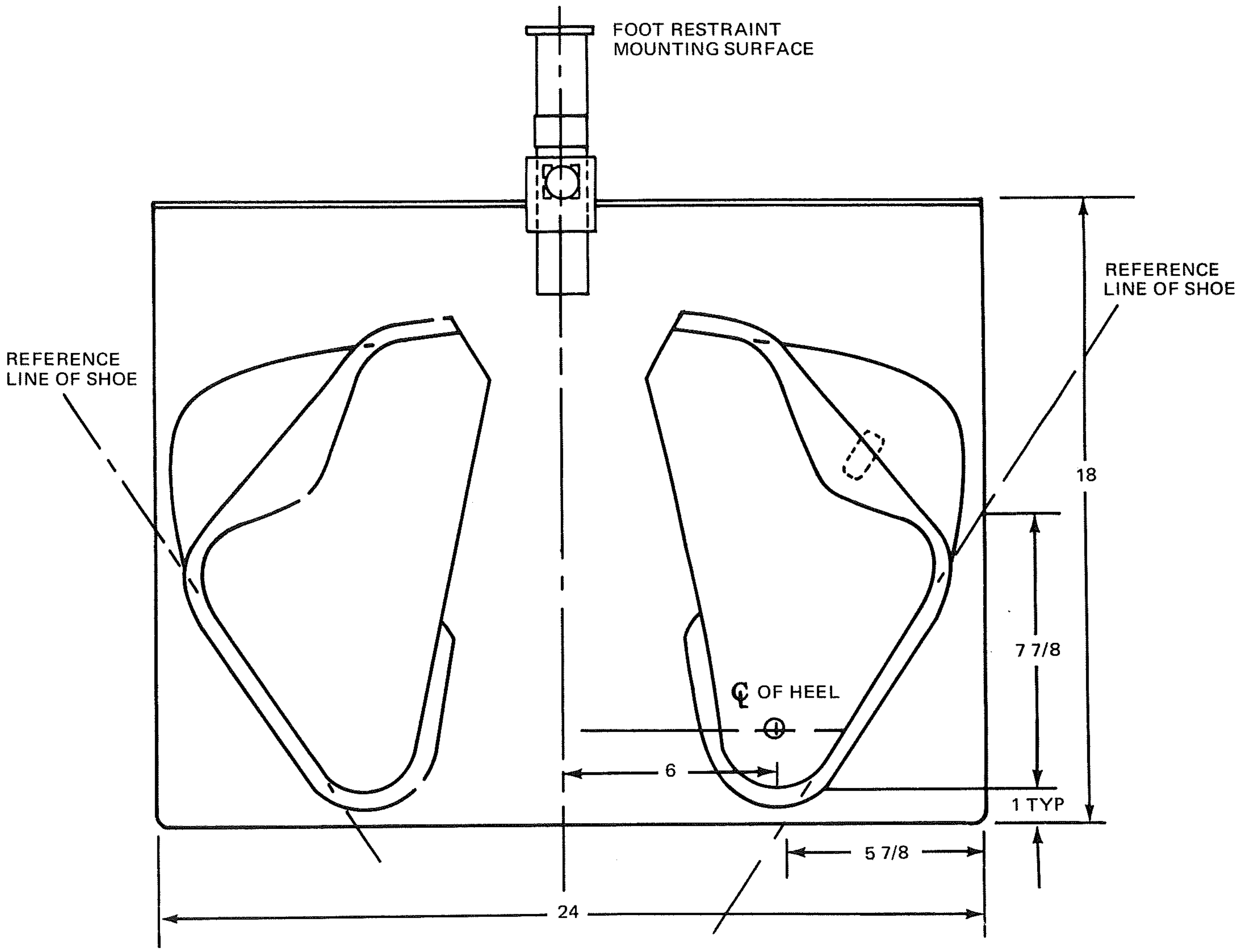


FIGURE 15 FIXED FOOT RESTRAINT (DUTCH SHOES)

PORTABLE HANDRAIL

Description

This concept as shown could be carried retracted, and when required, extended to wedge between walls, equipment racks, etc., as a temporary restraint device whenever needed. The user could place it under his arm or use it over his shoulder as a compression standing device. The ends may have bearing pads, suction cups or other attachments.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- No electrical power required
- May be incorporated without modification of vehicle design

Deficiencies

- Must be carried by user
- Requires approximately parallel opposing surfaces for application
- Requires use of one hand/arm for restraint

The simplicity and freedom from maintenance should insure a high reliability. Concept development would require an estimated six months.

This restraint concept is primarily applicable to areas where permanently installed restraint systems are not feasible because of infrequent use. Use of three portable handrails would provide a portable leg rail restraint system.

Early development testing could easily be accomplished as a parasite test on a zero "g" KC-135 flight.

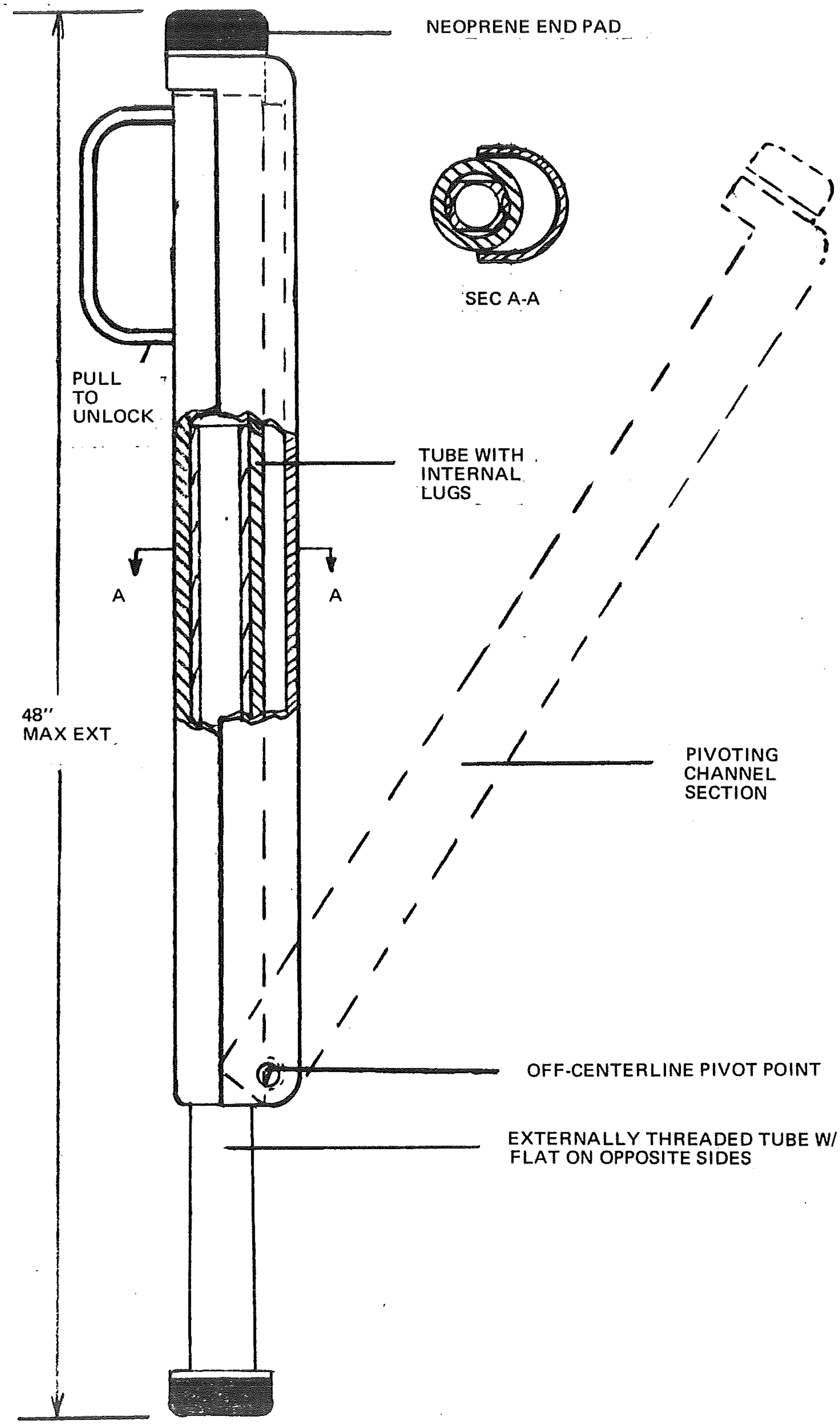


FIGURE 16 PORTABLE HANDRAIL

LADDER AND RAIL COMBINATION

Description

The ladder shown is made from individual rungs bent in the shape shown. A vertical handrail extends the length of the ladder as shown. The bent shape of each rung allows continuous gripping of the vertical handrail during ascent and descent of the ladder.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- Uses no electrical power
- Simple - Durable
- Reliable
- Maintenance free
- Usable in all gravity levels
- Light weight
- Ladder concept qualified at lunar gravity (LM)
- Positive control of direction and velocity

Deficiencies

- Requires at least one hand
- Direction of ladder traffic determined by coriolis effect in artificial gravity environment--requires dual installation or access to both sides of ladder
- Difficult to transport large packages
- Structurally attached to vehicle
- Location and required passageways should be included in basic design

The ladder/rail combination is intended primarily to provide short-range interlevel mobility for personnel. The vertical rail enables personnel carrying small packages in one hand to safely ascend or descend without the necessity of losing support contact by rung to rung hand transfer.

The high reliability and maintenance free design combined with relatively light weight and volume requirements make the ladder/rail a prime candidate for incorporation as backup for a powered inter-level mobility system.

The ladder/rail application as envisioned is limited by the length of the vertical rail between structural ties. This can be circumvented by utilizing (a vertical rail with a modified U shape permitting structural support) as required, without degrading the intended application.

Since both elements of the ladder/rail have been previously qualified on Gemini and Apollo, development time of the combination should be minimal.

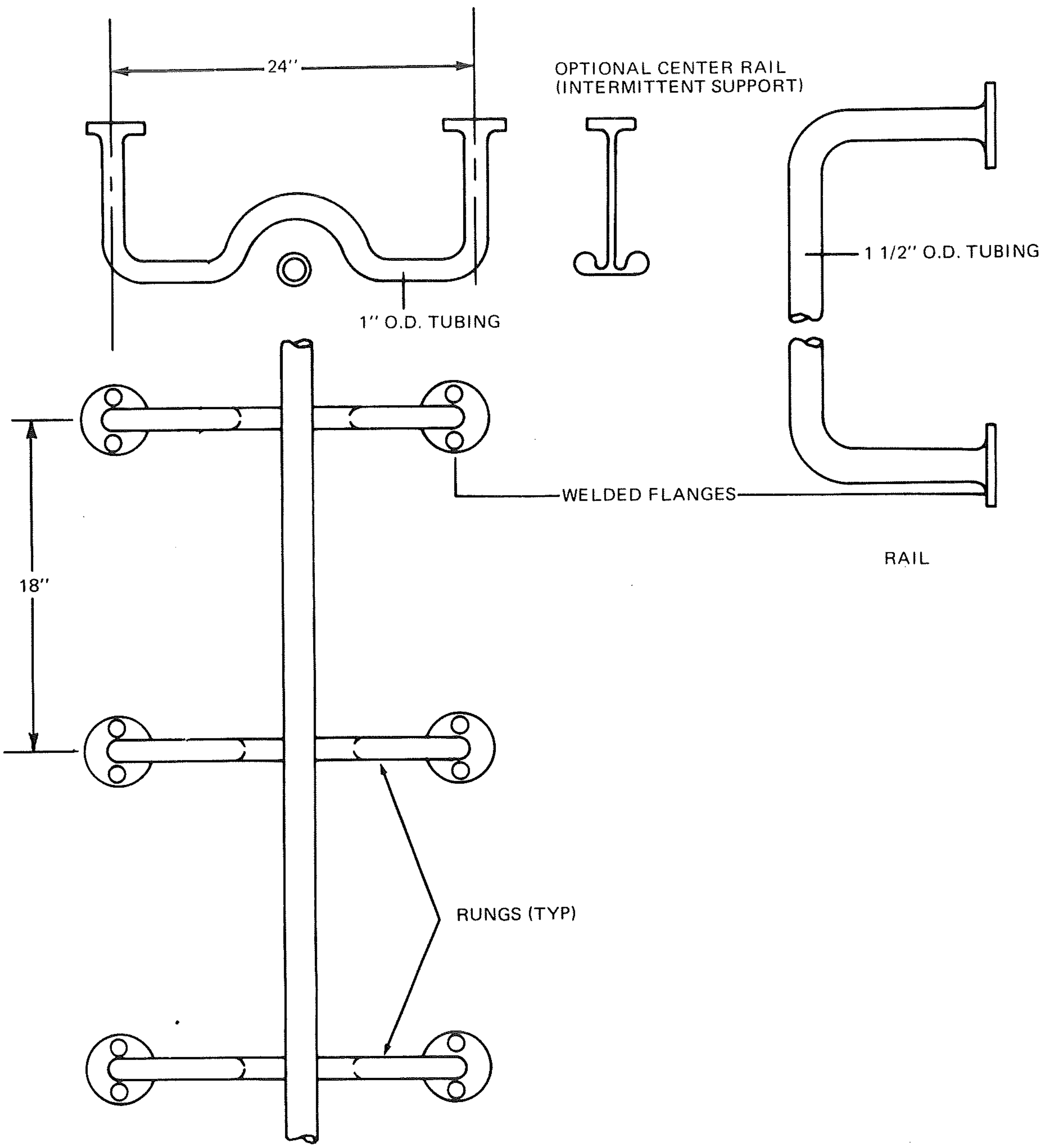


FIG. 17 LADDER/RAIL COMBINATION

DOUBLE RAIL ELEVATOR

Description

The concept shown is for an inter-deck elevator for artificial-g conveyance of cargo and crew. It consists essentially of two rails with a cable operated lift platform mounted to move along the rails.

Source

Specific source unknown.

Testing

Unknown

Merits

- Simplicity of operation
- Provides inter-level transportation for personnel and equipment
- Positive control of direction and velocity

Deficiencies

- Requires electrical power
- Requires specialized maintenance
- Redundant means of inter-level transport required

The double rail elevator concept would provide inter-level transport for equipment and personnel in an artificial gravity environment. Periodic maintenance and inspection would be required to insure safety and reliability. Concept development for flight application is estimated at one year.

Positive control of elevator platform velocity requires cable connection of the drive mechanism in both directions of movement. The cables and their associated weight may be eliminated by integration of the drive mechanism in the lift platform, and incorporation of guide rails with integral rack gears.

The worm gear reduction gearing in either version provides a fail-safe condition in case of power failure.

The effect of the elevator on the inertia balance of the rotating space system must be considered.

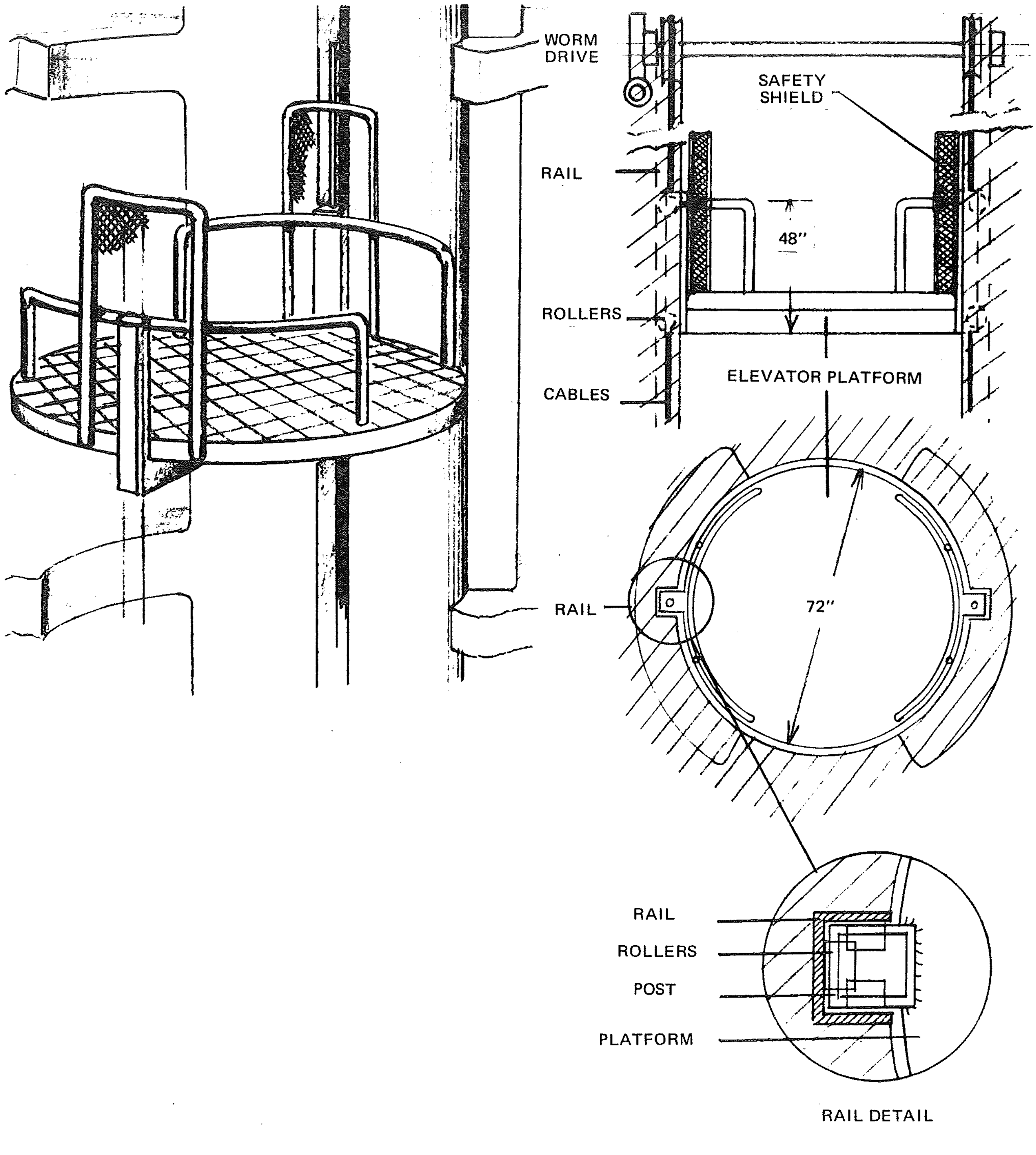


FIGURE 18 DOUBLE-RAIL ELEVATOR

AIR CUSHION CARGO TRANSPORT

Description

This concept involves a universal pallet with built-in air cushion pads for use as a dolly. A combination tiller and positively directed fan air source interlocks with the bottom of the pallet providing a source of air to the air pads, and a handle or tiller for guiding the movement of the pallet across the floor.

Source

Grumman Aerospace Corporation

Testing

None for space vehicles - used extensively as air bearings for simulations.

Merits

- Simplicity of operation
- Positive control of direction and velocity of large packages
- Little manual effort required in movement of heavy packages
- Air cushions can be incorporated in base of equipment
- "Low Pressure" pads can use vacuum cleaner for air source
- Fail safe

Deficiencies

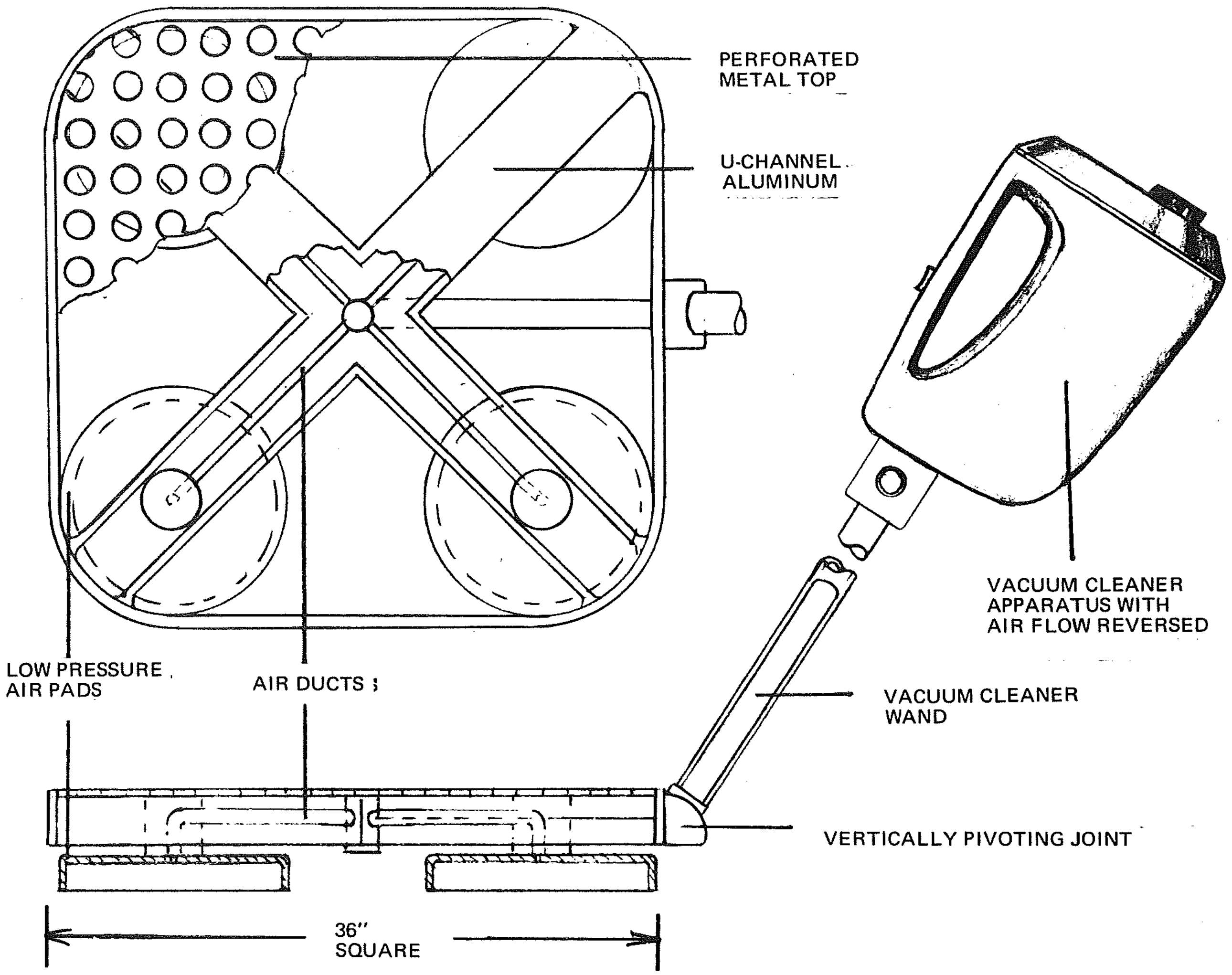
- Electrical power required
- Requires continuous surface
- Critical adjustment required for functional optimization
- Distance equipment can be moved would be limited by electric power cable length unless batteries are used

The air cushion cargo transport will provide friction free movement of heavy packages in an artificial gravity environment.

The air cushions can also be built into the base of equipment, while the air source can double as a vacuum cleaner.

Equipment weight would be distributed over the air cushion's total area. The deck surface's load bearing capability would thereby be less than that required for caster-mounted equipment.

Maintainability and reliability depend primarily on the source of air or gas used, since the air cushions can be expected to be maintenance-free and have high inherent reliability because of the simplicity and static mode of operation.



REF: MECHANICAL DEVICES FOR ZERO GRAVITY SIMULATION
VAUGHN H. YOST, NASA-MSFC

2ND NATIONAL CONFERENCE ON SPACE MAINTENANCE AND EXTRAVEHICLUAR ACTIVITIES, 6-8 AUGUST 1968; P. VII.7.1 - VII.7.23

FIGURE 19 AIR CUSHION CARGO TRANSPORT

MOVING LADDER/CONVEYOR

Description

The concept shown consists of an electrically driven conveyor belt fitted with ladder rungs. It could be used for long range transfer of personnel or equipment. It could probably be put to best use for hub to rim travel and should be oriented so that coriolis forces would aid in keeping the personnel or equipment on the ladder when descending or ascending. Personnel could hold on with hands and feet, while equipment could be easily strapped to it.

Source

Specific source unknown

Testing

Unknown

Merits

- Provides inter-level transport for personnel and small packages
- Rapid entry and exit
- Ladder provides redundant inter-level transport in case of power failure
- Access to both sides of ladder provides simultaneous two way traffic

Deficiencies

- Requires electrical power
- Maintenance required
- Must be incorporated in basic vehicle design

Time required for concept development is estimated at six months to one year. Basically a conveyor belt, reliability would be good with periodic maintenance and inspection.

There would be no change in the inertia balance of a vehicle caused by movement of the conveyor alone. However, movement of large equipment would cause a change in inertial balance. Provisions for securing the equipment to the conveyor would also be required.

This type of transportation system can be utilized in one of two ways:

1. Running continuously
2. Running as required (same as an elevator)

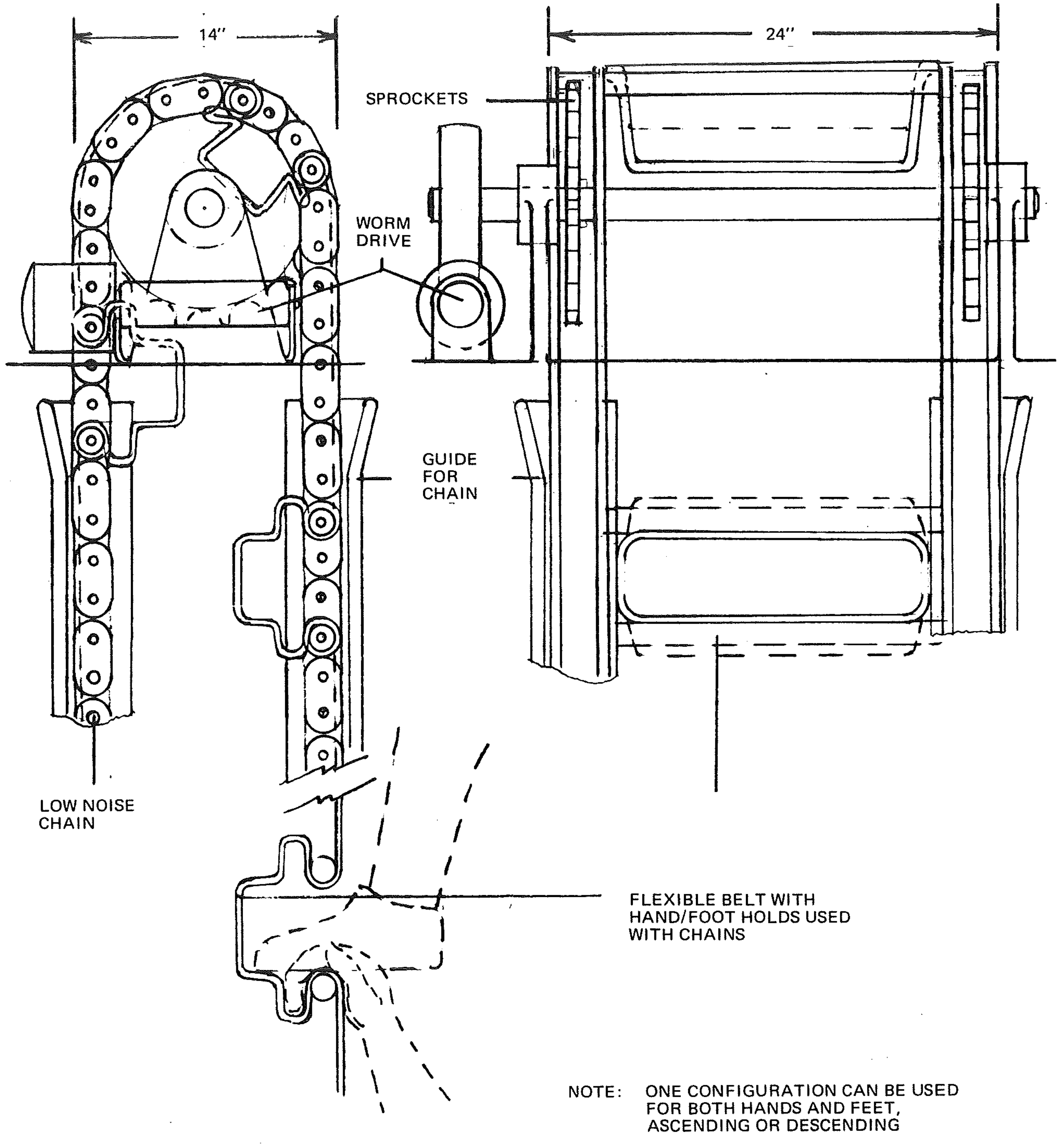


FIGURE 20 MOVING LADDER CONVEYOR

When looking at the computations and resulting curves for power requirements, it becomes obvious that this system has an extremely high power requirement when allowed to run continuously. This method of operation would also require a motor and gear box design that would be highly efficient with no load, which would increase the weight and cost of the system.

If operated as an elevator with start/stop capabilities, the motor and gear box design would be highly efficient when operating under a load and there would be no operating time unloaded. This allows a lighter and less expensive system which requires less total power to operate.

LINEAR-INDUCTION MOBILE HANDHOLD

Description

This concept employs a linear induction motor with a handhold attached to be propelled along a railing which provides electrical power, directional guidance, and also acts as the armature of the induction motor. A three position switch (forward, off, reverse) controls the motor, is integral with the handhold, and is operated with the thumb.

By grasping the handhold and activating the switch, the person can propel himself in either direction along the rail.

Source

Grumman Aerospace Corporation

Testing

None (New Concept)

Merits

- Positive control of direction and velocity
- Manual effort limited to holding on.
- May be applied to equipment transport
- Simplicity of operation

Deficiencies

- Electrical power required
- Requires one hand to operate
- Electromagnetic field generated requires RFI shielding of instrumentation and communication systems
- Flexibility limited by rail system
- Simultaneous two way traffic requires parallel system
- Application should be incorporated in basic vehicle design

The linear induction mobile handhold is intended to provide inter-level, long range mobility in a zero gravity environment. Since the propulsion force of the handhold does not involve rotating parts, the system reliability would primarily be a function of the power source. It is expected maintenance would be limited to brush and slide bearing replacement or refurbishment.

Estimated development would require approximately one year.

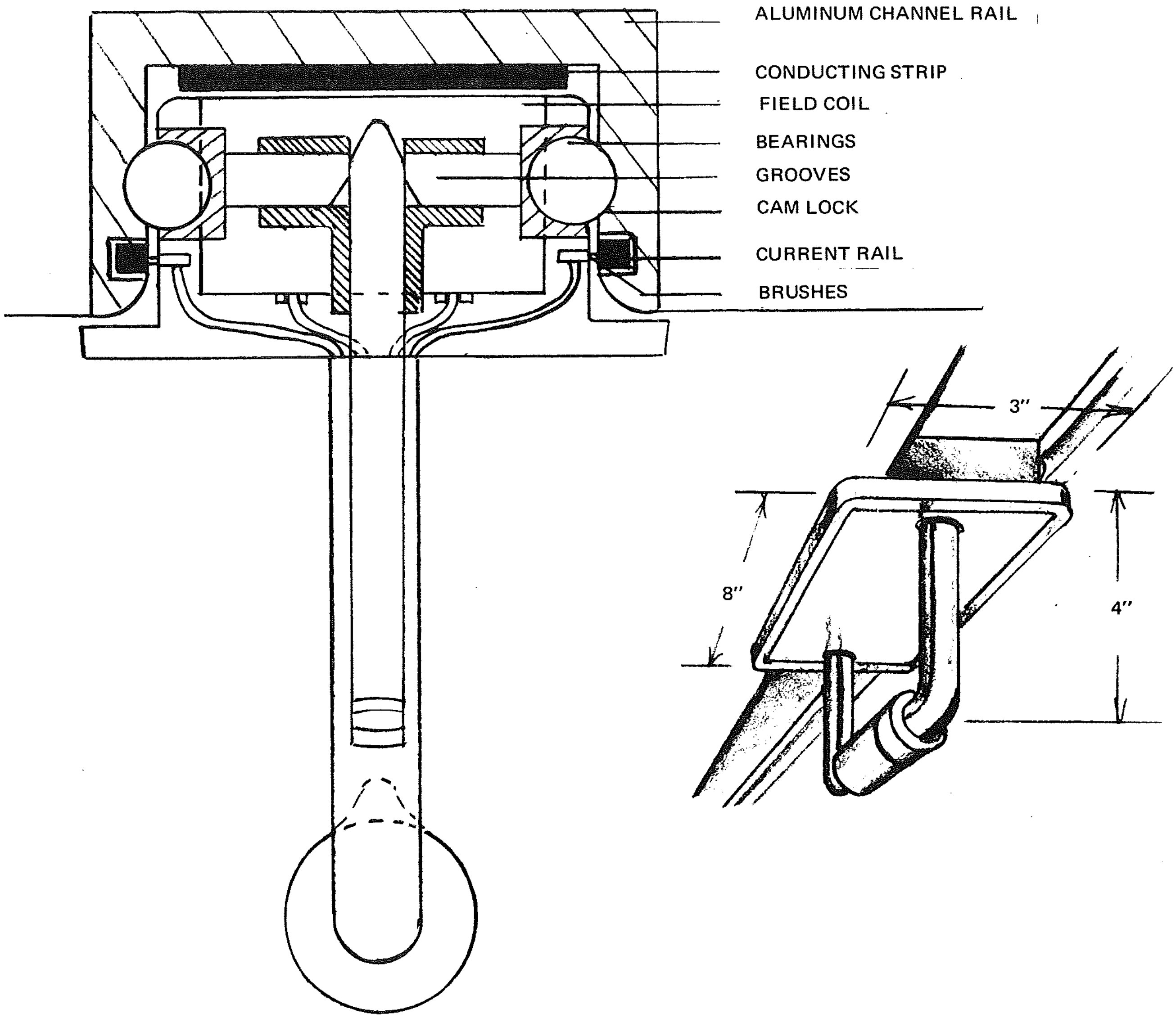


FIGURE 21 LINEAR INDUCTION MOBILE HANDHOLD

The major shortcoming is that common to all rail or trolley systems. Simultaneous two way traffic requires either parallel systems or a switching arrangement, and would require relatively large turn radius, or separate unit for each new direction of travel.

As envisioned, handholds would be stowed at each boarding station in quantities designed to meet demands.

ELECTROSTATIC/AERODYNAMIC DRAG WORK TABLE

Description

The apparatus shown is a combination aerodynamic drag and electrostatic work surface. The electrostatic apparatus consists of an ion source mounted directly above a swing-away electrostatic table. An electrostatic potential is applied between the table and the ion source. Articles may be restrained by spraying them with ions, which enables them to be attracted by the opposite charge on the table surface.

The aerodynamic drag restraint surface is a grid built into a large Venturi-like section, in which a fan is mounted. The fan pulls cabin air down through the grating. Articles are thus restrained by the aerodynamic drag forces created by the moving air.

Source

MSFC--Chrysler

Testing

None to date. Feasibility stage only.

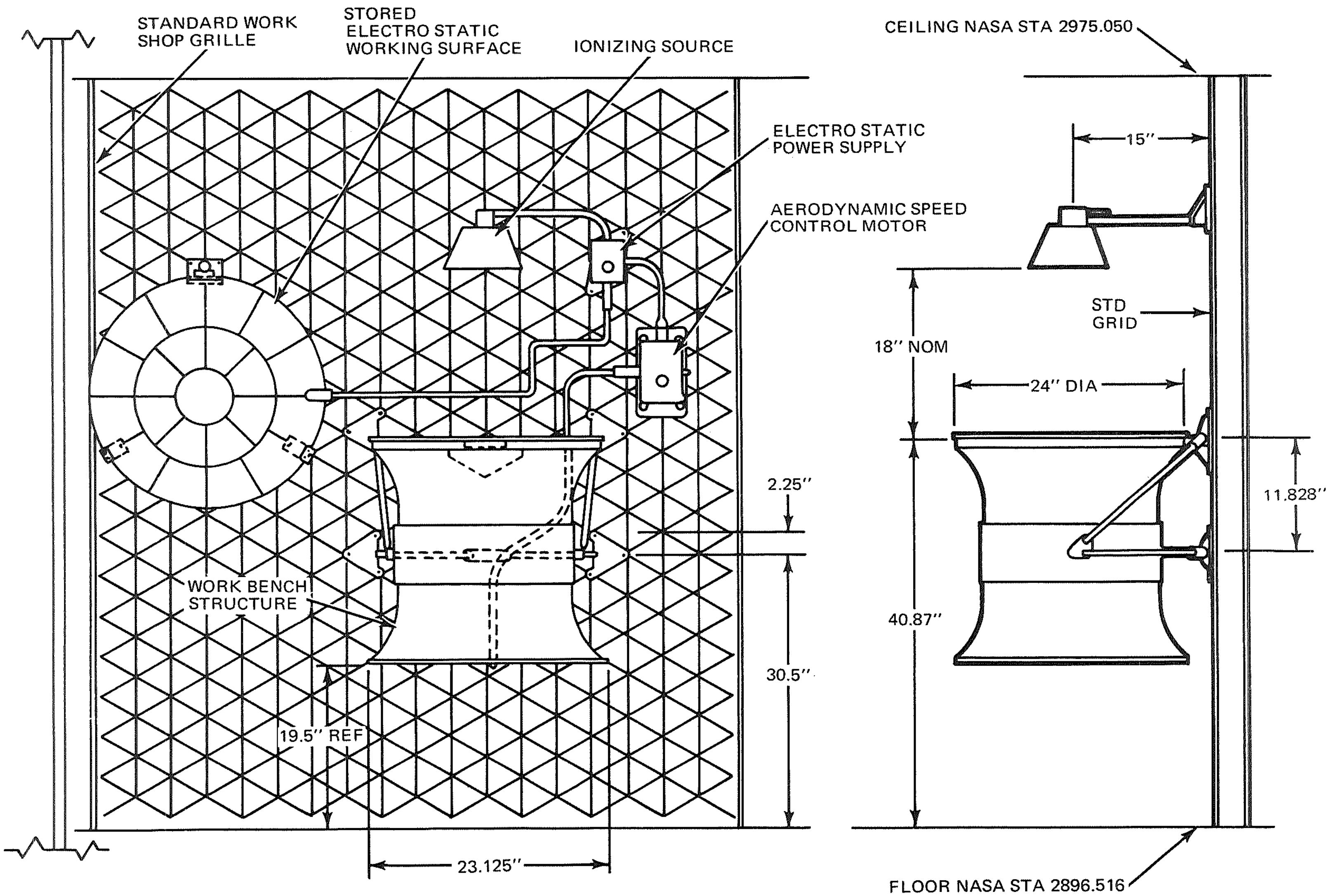
Merits

- Provides tool retention on work bench without necessity for tool tethers, velcro, bungee cord, etc.

Deficiencies

- Weight Penalty
- High power requirements for aerodynamic drag work bench

This concept is being developed by Chrysler Corporation as an experiment onboard Skylab. Pending the results of those tests, comments on its worth will not be made here. The concept has shown to be feasible and the only real test of its value will be its performance in Skylab.



REF: 1. STUDY OF AN ELECTROSTATIC ZERO GRAVITY WORK BENCH PROTOTYPE - CRYSLER CORP., SPACE DIVISION (N69-37369, NASA CR-10238; CONTRACT NAS 8-21385)
2. EXPERIMENT REQUIREMENTS DOCUMENT FOR GRAVITY SUBSTITUTE WORK BENCH (EXPERIMENT M-507), 1/6/70, NASA MSFC

FIGURE 22 ELECTROSTATIC/AERODYNAMIC DRAG WORK TABLE

WEIGHT STATEMENTS

Weight statements for each of the selected mobility and restraint concepts with the exception of the Electrostatic/Aerodynamic Drag Work table (Experiment M 507) for the Skylab, are included as required by contract.

SPACECRAFT DETAIL WEIGHT STATEMENT

PAGE ______ OF ______

CONFIGURATION | BY | DATE

Reference MIL-M-38310A or SP-6004

FOR CODE

FOR SYSTEM

FOR ITEM OR MODULE

CODE	DESCRIPTION	UNITS: CLASS (E, C, A)	VOLUME FT³ EACH	POWER WATTS EACH	WEIGHT LB EACH	LOCATION EACH ORBIT REF. SYSTEM: X	Y	Z	TOTALS: QUANTITY	WEIGHT CODE GENERATION: SECOND	THIRD	FOURTH
	HANDRAILS		0.005/FT	–	0.85/FT	(NOTE 1)						
	HANDHOLDS		0.005	–	0.85	(NOTE 1)						
	INFLATABLE MID-TORSO RESTRAINT		0.4	–	3.2							
	RIGID WAIST TETHERS		0.8	–	7.5							
	FLEXIBLE WAIST TETHERS		0.2	–	2.0							
	LEG RAIL		0.2/FT	–	1 LB/FT							
	NET TYPE SLEEP RESTRAINT		1.2	–	1.0							
	SUCTION SHOES		0.5/PR	–	2.0/PR							
	ASTROGRID SHOE		0.03/PR	–	2.4/PR	(NOTE 1)						
	MAGNETIC SHOES		0.03/PR	–	4.5/PR	(NOTE 2)						
	FIXED FOOT RESTRAINT (DUTCH SHOES)		0.7	–	12.1	(NOTE 1)						
	PORTABLE HANDRAIL		0.8	–	1.5							
	LADDER RAIL COMBINATION		0.3/FT	–	1.6/FT							
	DOUBLE RAIL ELEVATOR		19.6/FT	16400	135 + 6.4/FT	(NOTE 3)						

NOTES:

	SECOND	THIRD	FOURTH
PAGE TOTALS			
TOTALS FROM PAGE ____			
SUBTOTALS			
FIRST GENERATION SYSTEM TOTAL			

MSC Form 1522C (Mar 70) NASA — MSC

SPACECRAFT DETAIL WEIGHT STATEMENT

PAGE ______ OF ______

CONFIGURATION | BY | DATE

Reference MIL-M-38310A or SP-6004

FOR CODE

FOR SYSTEM

FOR ITEM OR MODULE

CODE	DESCRIPTION	CLASS (E, C, A)	VOLUME FT^3 EACH	POWER WATTS EACH	WEIGHT LB EACH	LOCATION EACH ORBIT REF. SYSTEM X	Y	Z	QUANTITY	TOTALS WEIGHT CODE GENERATION SECOND	THIRD	FOURTH
	AIR CUSHION CARGO TRANSPORT		3.0	210	18.0							
	MOVING LADDER/CONVEYOR		2.2/FT	7700	80 +	(NOTE 4)						
					3.2/FT							
	LINEAR INDUCTION MOBILE HANDHOLD		0.6 +	500	8.0 +	(NOTE 4)						
			0.25/FT		0.8/FT							
	NOTES											
	1. REF: MATRIX REPORT "SELECTION OF											
	SYSTEMS TO PERFORM EXTRAVEHICU-											
	LAR ACTIVITIES" VOL.1 PART 3											
	4/70 NAS 8-24834											
	2. REF: MARTIN MARIETTA CORP. FINAL											
	REPORT MRC 68-507 NAS 9-9336											
	3. ASSUME 2000 LB LOAD CAPACITY											
	(PEAK POWER REQUIRED)											
	4. ASSUME 1000 LB LOAD CAPACITY											
	(PEAK POWER FOR ACCELERATION)											

NOTES:

PAGE TOTALS			
TOTALS FROM PAGE ____			
SUBTOTALS			
FIRST GENERATION SYSTEM TOTAL			

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