Final Report for the

PROPOSAL FOR A ZERO-GRAVITY TOILET FACILITY FOR THE SPACE STATION

A design project by students in the Department of Aerospace Engineering at Auburn University under the sponsorship of the NASA/USRA University Advanced Design Program.

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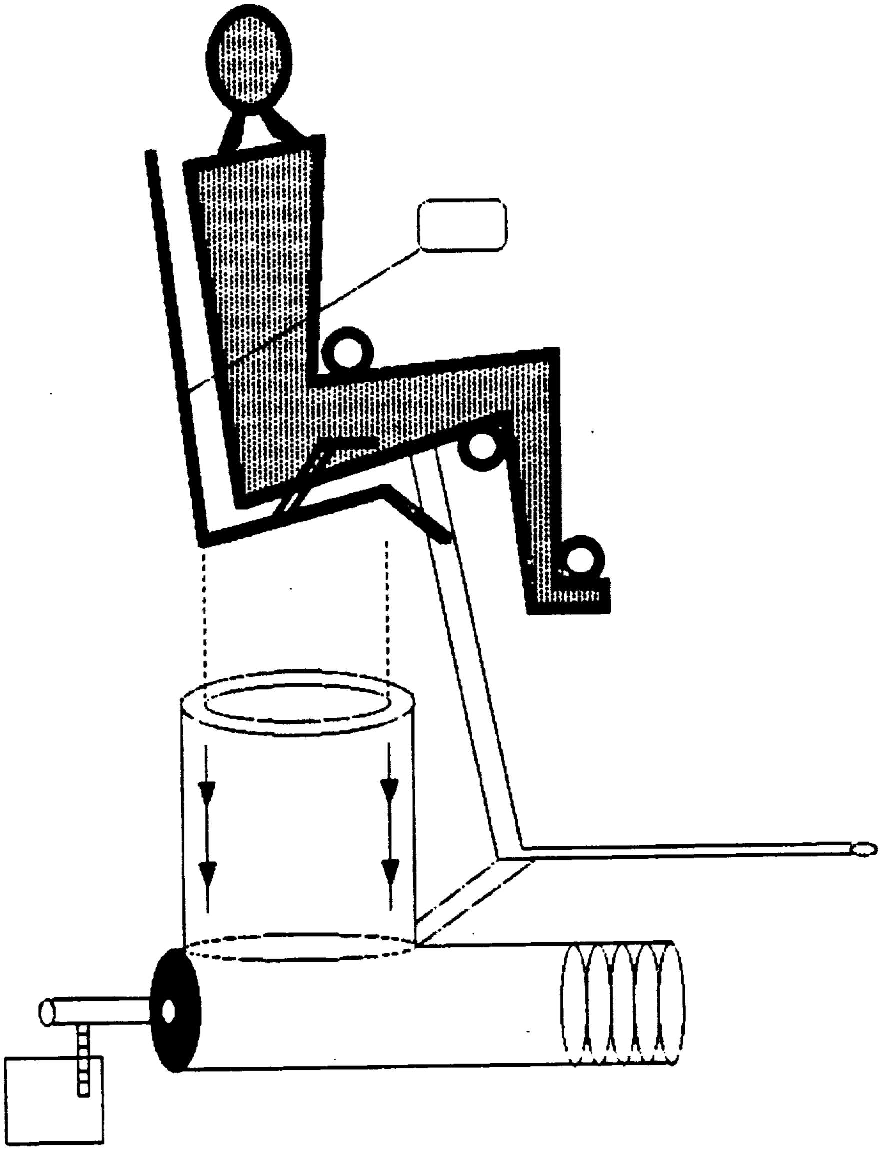
Aerospace Engineering
Auburn University
Auburn, Alabama

Proposal For A Zero-Gravity Toilet Facility For The Space Station



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Date submitted: 19 April 1989

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PROPOSAL SUMMARY

This proposed toilet facility (See Figure 1a) has a straightforward design. It has few moving parts and is easily maintained. Air and water flow provide sanitary movement of the waste. The toilet's chambers are coated with Teflon which, along with the water flow, makes it self-cleaning. An added disinfectant called Betadiene kills any bacteria that may form on the chamber walls. The chair is contoured to take into account the neutral body position and the necessary strain position for defecation. Restraints at the ankles, knees, and midsection hold the body in the chair. The waste is stored in discs of Gortex material which are inside a replaceable storage chamber. This chamber can be removed, capped and stored until eventual return to Earth.

STATEMENT OF PROBLEM

NASA's Space Station is scheduled to begin operating in the mid 1990's. The station's crew of eight will be up for ninety days at a time. Since it is a long term environment for the astronauts, everyday activities taken for granted on Earth must be seriously addressed for space. Proper human waste elimination is essential to effective human operations in space or on earth. Included in the category of "proper human waste elimination" is both urination and fecal elimination. Having a toilet facility that successfully meets everyone's needs is critical.

RELATED EXPERIENCES

There are two existing zero-g toilet facilities with operational experience: the Skylab toilet built by Fairchild and the Space Shuttle toilet built by General Electric. The Skylab toilet stored all waste in individual bags to be later examined on Earth by doctors and scientists. The storage facilities for the waste took up huge amounts of space. The toilet also had poor anthropometrics; it did not take into account the neutral body position or any other body position. The toilet's seat was unnaturally mounted flush against the wall, thus making any excretory procedures very awkward and psychologically unappealing. (1:33)

The Space Shuttle's toilet also presents problems. It is designed for short term use and is not self-cleaning. It also has problems with odors. (2:180) The seat is not designed well and cannot be adapted to different sizes of astronauts, making it hard to maintain a good seal. The system uses spinning tines which chop the waste and sling it against the walls of the toilet compartment. The idea of excreting on a rotating blade is psychologically unappealing; also, feces may bounce off of the tines and onto the users buttocks. Odors are abundant because the waste is smeared in a chamber beneath the seat. Since the waste is stored in the toilet compartment it has to be manually cleaned out after each flight. Finally, the storage capacity is appallingly small. Overall the shuttle's toilet has proven to be unreliable, breaking down on several occasions.

DESIGN CONSIDERATIONS

The following considerations are taken into account for the design of this toilet facility: (3:10.3-1)

A. Reliability and maintainability -- System servicing and repair tasks are neither pleasant or mission productive. Therefore, the system should be as reliable as possible and require a minimum of repair time. Scheduled maintenance and servicing times, including unloading and refurbishment, should be kept to a minimum.

B. Ease of use: The system should be simple and quick to use and should be readily available for emergencies such as vomiting or diarrhea. As a design goal, the facilities should be used like and require approximately the same amount of time for use as equivalent Earth facilities.

C. Acceptance: The body waste management systems must be both psychologically and physiologically acceptable to the crew members. An unacceptable system can result in deliberate restriction or modification of the diet by the crew and possible nutritional deficiencies.

D. Microgravity considerations: Gravity plays an important role in the removal of feces from the body during defecation in a 1-G environment. A substitute must be provided in a microgravity environment.

E. Volume and mass of body waste products: The fecal collection devices shall accommodate 14 oz of fecal matter by weight and 18 in^3 by volume per person per day. The capacity to accommodate a maximum of 61 in^3 of diarrhea discharge shall be provided. The maximum volume of expelled vomitus can be 61 in^3 of solids and fluids. This is with a fully distended stomach. The average volume of vomitus is more likely to be 12 to 31 in^3.

F. Anatomical considerations: The body protuberances of the pelvis, ischial tuberosities, support the seated body in one-g conditions. In reduced gravity conditions, seat contours and restraints can help the crew member to locate the ischial tuberosities and thereby properly position the anus and uretha in relation to the collection devices. If air flow is used to provide the force for entrainment of feces and urine, it may be necessary to minimize the opening size. It has been found in both 1-G and microgravity conditions that it is possible to defecate through a 10 cm (4 in) diameter opening, although significant problems have been noted with this small an opening. (3:10.3-2) Dimensions of the body that should be considered for design of waste management facilities are shown in Figures 1b & 1c.

G. Body posture: The following are considerations for determining the body posture during body waste management functions:

1. Urination - There is no evidence to suggest that posture has any effect on easing the act of urination.
2. Defecation - The act of defecation involves the use of the stomach muscles; squatting increases abdominal pressure. The body should be positioned so that these muscles are supported

and not strained. In 1-G conditions this position is optimized with the knees higher than the buttocks.

OVERVIEW

The use of few moving parts with a basic mechanical design will make this facility reliable and easy to maintain. The astronaut only needs to follow a simple procedure list to use the toilet and will not require any extensive ground training as with the current shuttle system. The system can be used repeatedly, with no waiting time between uses, which guarantees availability for emergencies. The proposed toilet is naturally shaped and is located on the floor of the rack and is the same height as an Earth toilet (See Figure 2). Since this toilet will be reliable and easy to use, the astronauts will accept it as a valuable asset to the space station.

AIRFLOW

Since the space station operates in a microgravity environment a force is needed to replace the role gravity serves in defecation. A moving airflow will provide this force.

There are two 'vents' for the air to enter the fecal chamber. The detail of the vents are further explained in the disposal and storage section and the corresponding figures. This air comes from the ambient air in the toilet compartment. The air is pumped by a fan that is powered by a brushless motor. After the air is exhausted from the storage chamber, it is channelled through a charcoal filter and out into the ambient space station air.

The primary vent directs air towards the base of the seat. This provides the necessary excrement force. A secondary vent provides a directed airflow to help move the water flow (See Figure 3). A sheet of air will be aimed almost parallel to the water flow. This will aid in keeping the water against the sides of the chamber.

At first it was thought possible to place the exhaust vents at the joint between the fecal chamber and the settling chamber. It was determined that this would cause a vortex which would not allow the waste to pass through to the settling chamber. Basically, the flow would just stop before it got to the settling chamber for compacting. It would also cause the vents to become clogged. Now, the air is exhausted through three vents at the head of the storage chamber; these vents are equally spaced around the circumference of the chamber (See Figure 4). Manifolds, sealed by silicone rubber gaskets, will be attached to the outside of the vents to provide the airflow. They will be attached by latches, allowing them to be removed easily when the chamber is full. The vents are each 9 inches long by 1 inch wide and are formed of a taught layer of Gortex heat sealed to a rigid plastic screen. This will assure that no liquid can pass through the air vent. (See Figure 5) The tension in the material will prevent the squeegee on the disk from tearing the material. Since these vents are a part of the storage chamber, they are removed when the chamber is full. A cap that covers the entire head of the storage chamber, including the vents, will be placed on the chamber preventing any possible biohazard.

WATER FLOW

This facility is unique in that it is self-cleaning. The major innovation is a dynamic water layer along the sides of the fecal chamber.

The space stations water supply will provide the water necessary to operate the toilet. Utility runs are located in the stations module (See Figure 6). The amount of water used is not of paramount concern since the space station recycles used water. Even if it was a concern, the toilet only uses about two gallons a day.

The water will be injected at the head of the fecal chamber by an annular pipe (See Figure 3). In the absence of gravity, surface tension will be the primary force acting on the layer of water and will keep the flow attached to the sides of the chamber. The airflow will drive the water down the length of the fecal chamber. Just above the gate valve, which separates the fecal chamber and the settling chamber, the water will be drawn off through a slot.

The sheet of water will be assumed to be 1/16 inch thick and travel down the fecal chamber at approximately 3 inches per second. This determines a flow rate for the water at 3.5 cubic inches per second. To ensure proper drainage of the water, the drain slot will be 1/8 inch wide will turn the water by means of a curved surface to insure that the water continues to cling to the fecal chambers and does not separate and go down into the settling chamber. (See Figure 3) The fecal chamber widens below the slot to help prevent interference with waste transmission. The toilet will use approximately 0.9 gallons of water per minute (see appendix B). This should not prove to be a major problem since the space station will recycle water.

For the normal flush mode, the water will run in the toilet for 5 seconds. then the water flow will be diverted to the urinal for 5 seconds. Once the water stops flowing the air will continue to run for an additional 5 seconds to guarantee that the water does not escape. When the air quits flowing, the gate valve will be closed. This will signal the piston to begin. The air will continue to flow in the urinal for the duration of the piston action. When the piston is fully retracted, all flows cease.

In the event of diarrhea, the water will be continuously flowing because it is needed for sanitation. A 5 minute use of the facility will use approximately 4.5 gallons of water. Given a 0.5% loss this would come to approximately 3 ounces. Any loss during the process will be driven down into the storage chamber. Since the Gortex is waterproof, this won't be a problem.

A single button will operate the normal flush mode. This will be connected to an electronic switching unit that will actually control the valves. A switch will be used to select the desired mode (Normal or Diarrhea). In the event that safety considerations preclude the use of the electronic switch, a mechanical system could be designed. Such a system would use a knob that would activate a timer. The knob could be locked into place for the diarrhea mode.

URINAL

A urinal for a microgravity environment is a simple device. It consists of a funnel at the end of a suction tube. However, there are several drawbacks to this type of system:

1) The best funnel design for the male is a conical funnel 3 inches long and 2 1/8 inches in diameter, while the most favorable funnel for the female is an oval shape. (3:10.3-4)

2) Air entrainment for the male urinal is directly through the open end of the funnel. In contrast, since the female urination is less directed, the female funnel should use angled air openings to give a vortex action to the airflow. (See Figures 7 & 8)

3) Since female and male astronauts must have different funnel designs due to anatomical considerations, each crew member must have an individual funnel for hygiene reasons. These individual funnels must be connected to the suction tube before use, and after use they must be removed and cleaned out before being stored. This system has obvious drawbacks, the major one of which is convenience and ease of use.

The best solution is to optimize a design that can be used by both men and women with equal effectiveness; an egg shaped funnel three inches deep (See Figure 9). It will seal effectively against the female anatomy where angled air outlets will provide the necessary vortex flow (See Figures 7 & 8). For male use, the funnel is moved forward and up along a track. Each crew member can optimally position the funnel. During male use, the urinal will not seal against the body and allow air to enter along the sides of the funnel.

To provide for adequate hygiene, the lip of the funnel will have an annular tube to inject a water and disinfectant mixture to clean the funnel. This arrangement is similar to that of the fecal chamber, however the urinal will only require a flow rate of 0.37 gal/min (see appendix B). During the flush process the water would be shut off to the fecal chamber and started in the urinal. This provides for the possible use of a simple valve between the water line leading to the fecal chamber and the water line leading to the urinal.

DISPOSAL AND STORAGE

Originally the head of the piston was to be covered with a sheet of latex or plastic. The covered piston would push the waste into the storage chamber, and a heating element would seal the sheet to a plate in the rear of the storage chamber. Each time the facility was used, a new plastic sheet would be sealed to the previous one in the chamber, thus making small packets. Upon further study and consideration, this idea was determined to be impractical. It increased the power requirement (i.e. needing to support a heating element).

A new system has been adopted which uses preformed discs: these are plastic rings 0.233 inch thick, 10 inches in outer diameter and 9.5

inches in inner diameter with a Gortex sheet in the center of the ring (See Figure 10). The rings will be manufactured in two pieces, the male coupler and the female coupler. The Gortex sheet will be heat sealed between the two, embedding it within the ring. The Gortex will have adequate slack to allow for large or odd shaped waste products. The size of the storage diskette is based on the waste volume criteria per person for a 24 hour period. Thus, an average use of one to two times per day insures that the capacity is not exceeded. Also taken into consideration was vomitus and diarrhea. Since their volumes tend to be larger than that of a normal defecation, a special disk will be developed that is three times the thickness of the normal disk. Gortex is a breathable liquid proof material used in the production of parachutes, waterproof clothing, and sleeping bags. The ring itself is made of rigid plastic.

Each time the facility is used one of these discs is manually placed in a slot behind the settling chamber. (See Figure 4) The piston pushes the disc into the storage chamber while the outer edge of each disc scrapes the cylinder walls for cleaning purposes (See Figures 11 & 12b). Each disc locks onto the previous one. These discs will be stored in a dispenser next to the facility. The last Gortex disc will be reinforced with a rigid plastic to prevent accidental tearing of the Gortex when the chamber is removed (See Figure 12a). The motor used to drive the piston also presented problems. NASA requires that no sparks be emitted on the Space Station. An explosion-proof, alternating current, 1 hp

Baldor motor will be used to drive the piston. The motor will run on a 210 volt line supplied by the space station in the utility runs. The motor will have no arcing, will be permanently lubricated and will have casing on the wires. Any paint used on motor parts will be nontoxic. A motor will also be used for the air pump. It is specially designed with no brushes so that no sparks are emitted, and it is fail safe.

A start switch on the side of the toilet activates the motor. The motor drives the piston by using a telescoping screw with three twelve inch long shafts contained within each other. Another problem encountered was determining a way for the piston to sense when to stop driving the disc. The solution to this problem is the use of a governor. A governor will sense the applied force. The basic idea of the motor is similar to that of a trash compactor; it will be reversible. At first the motor pushes the piston. When the governor switch senses a certain amount of resistance, the motor will shut off and reverse, retracting the piston.

The storage chamber is attached to the settling chamber so the discs can move in a flush fashion through both tubes. It has a seal between the two chambers and locks into place by a set of three latches similar to those on a tool box. Latches are used because they can be handled with only one hand and easily manipulated in space unlike a screw or a wrench (See Figure 13). Once the storage chamber is full (this being when the precounted discs reach the end of the supply) removal procedures can begin. The space station rack can be rotated away for servicing allowing for easy removal of the storage chamber. The user then unlatches the storage chamber and places a cover onto it. The cover latches to the storage chamber in the same fashion.

The cover will allow for the free flow of air through a charcoal filter which will vent any decomposition gases such as methane into the logistic module's ambient atmosphere. The charcoal filter will insure that there is no odor problem, while the space station's air recycling system will remove the methane to prevent any hazard. Bacteria buildup is not perceived to be a problem, since studies by Hamilton Standard showed no significant buildup for a 90 day period. The Hamilton Standard study used feces stored in a Gortex bag.

GATE VALVE

Between the fecal and storage chambers is a sliding assembly called a gate valve. This valve is basically two of the interfaces between the 6 inch diameter fecal chamber and the perpendicularly mounted 10 inch settling chamber joined together (See Figures 14a and 14b). One of the interfaces has a 6.25 inch diameter opening between the two chambers. This is used during defecation. The other interface has no opening. This seals the chamber and allows for smooth passage of the piston during its operation. The two connected interfaces slide along a rail from the open to closed positions. When the toilet is not in use, the valve is kept in the closed position to prevent odors from escaping. When the assembly is closed. the "defecation interface" protrudes from the front of the toilet, allowing for easy cleaning.

ANTHROPOMETRICS

The absence of gravity in space on the space shuttle or space station creates a unique seating problem for defecation. Effective anthropometrics must be used to overcome this unique problem. Comfort, ease of use, and design simplicity are the three main parameters that were considered during the anthropometric design process.

In the zero-gravity environment the body assumes a position known as the neutral body position (See Figure 15). This is the position that the human body will naturally tend to return to when displaced. Although the neutral body position puts the least strain on the stomach muscles in zero-G, this position is not conducive to the defecation process. The optimal position for defecation is a squatting or seated position that increases abdominal pressure. To overcome the body's natural tendency to remain in the neutral body position, several restraints are used to place the astronaut in the best position for defecation without straining the abdominal muscles.

Application of logical designs with applied concepts was used to narrow the choice of options. The current ideas were checked with earlier applied designs. The restraining system consists of a combination of handles, foot and lap restraints, and also knee and ankle braces (See Figure 16). The construction of these devices is based upon the construction principles of athletic conditioning equipment (i.e. Nautilus) that similarly require support and restraint to maintain body positioning while in use. Utilization of these principles accounts for the simplicity of design and ease of use.

The restraint primarily responsible for holding the astronaut down on the seat is the lap restraint (See Figure 17). Its design is very simple and straightforward. It consists of a curved lightweight bar hinged at one end with a nylon strap attached as shown. The unhinged end is pulled down and secured with a latch positioning the nylon strap across the astronaut's pelvic girdle above the groin area where the urinal is positioned. This type of restraint already exists and is in use on amusement park rides. This restraint was chosen over other lap restraints because it does not interfere with the use of the urinal. The restraint is very effective because it is comfortable and secure under the action of several negative G's Therefore, it is more than adequate for use in zero-gravity. The second major source of restraint is the combination of the knee and ankle brace. The knee brace acts in combination with both the lap restraint and ankle brace to provide support and position the buttocks for proper contact with the toilet seat. The knee brace is adjustable in the vertical position to accommodate persons of varying stature (See Figure 16). The ankle brace is attached to the knee brace by a friction lock, which keeps the ankle brace locked down to keep the feet from floating up. This also helps to maintain proper contact with the seat.

The foot restraints and handles act as auxiliary restraints for the system. The foot restraints are used to aid in entering and exiting the facility. They are the main source of restraint during the clean up period. The handles are used to enter and exit the facility as well as to position oneself when locking down the primary restraints.

The final consideration of the Anthropometrics area is the seat itself. The backrest is contoured to fit the average person while the seat is a unique design (See Figure 18). The seat consists of a doughnut shaped ring partially filled with fluid. The density of the fluid inside the ring is such that when a person sits on it the buttocks will force the fluid forward to the groin region to assist in forming a tight seal with the toilet. This feature is advantageous for both males and females.

OPERATION OF TOILET

To understand the operation of the toilet facility, a step by step plan has been developed.

1. Insert waste disc. (See Figure 4)
2. Float into a position facing away from the toilet and insert feet into opening.
3. Disrobe.

4. Pull up knee brace. (See Figure 16)

5. Rotate the ankle brace downward.

6. Use handles to place your buttocks onto the seat.

7. Pull down the lap restraint and lock (simply pull into latch). (See Figure 17)

8. Position the urinal.

9. Open the gate valve between the fecal chamber and the settling chamber. (See Figure 14a and 14b) This turns on the air flow for both the toilet and the urinal.

10. Defecate

11. Raise the lap bar

12. Use the mirror to check that everything goes down properly. (See Figure 13)

13. Clean yourself

14. Activate the flush mode (this will start the water flow in the toilet and switch it to the urinal after 5 seconds. The air flow in the toilet will continue for about 10 seconds.)

14. Close the slide plate. (See Figure 14a and 14b)

15. Start the piston.

16. Raise ankle bar and maneuver out of the facility.

COST PROPOSAL

The cost of this facility is calculated by the bottom-up method. The individual prices have been overestimated by 15% to allow for budget overruns and inflation. The price for two 1 horsepower motors will be $800.00. The fecal and settling chambers will have to be specially cast, so there will be an additional cost for the machining of these parts. The estimated cost per tube is $2,500.00. Since there are no off the shelf pistons available, one will have to be machined to meet the criteria. A major factor in the piston design is the telescoping screw. The total cost for the piston and screw is estimated to be approximately $5,000.00. The force governor will cost approximately $1,000.00. The remaining parts of the facility (restraints, cushions, levers, etc.) will add up to a significant percentage of the total price. All of the component costs add up to less than $20,000.00. Labor costs will be $20,000.00. This is 2000 hours of labor by hourly employees earning $10.00 an hour. While expensive for a toilet, this is still significantly less than the million dollar shuttle toilet. The price is broken down further in Table 1. The breakdown is general and does not include welding costs, transportation costs, cost for fittings, electrical wires, activation switches, etc.

TESTING

The proposed testing plan for the facility is a three phase process. First a one-G prototype will be used to determine if the fundamental engineering concepts are sound. The second phase is to test a zero-G model on a series of parabolic airplane flights. The brief periods of microgravity that these flights provide will insure that the concepts that can't be simulated by a one-G prototype will work. Finally, a full scale development model will be tested on the Space Shuttle. The best way to do this is by obtaining space on the SpaceHab module, which will be regularly flown on the shuttle in the 1990s.

Table 1

PARTS	NUMBER OF ITEMS	COST PER ITEM (in Dollars)	TOTAL PRICE (in Dollars)
NONRECURRING COSTS:			
1 hp Engine	2	400	800
Fecal Chamber	1	2500	2500
Settling Chamber	1	2500	2500
Cushions	2	100	200
Seat	1	300	300
Latches	7	15	105
Handles	4	25	100
Rollo Rocker Belt	1	150	150
Friction Lock	1	100	100
Unbreakable Mirror	1	100	100
Tubing	45 feet	2 per foot	90
Piston	1	5000	5000
Governor	1	1000	1000
Flush Activator	1	1000	1000
Urine Separator	1	1000	1000
Labor	----	----	20000
Incidentals	----	----	5000
TOTAL			40045
RECURRING COSTS (BASED ON 90 DAYS)			
90 Day Supply of Disks	1080	2	2160
Storage Chamber	13	200	2600
Incidentals	----	----	1000
TOTAL			5760

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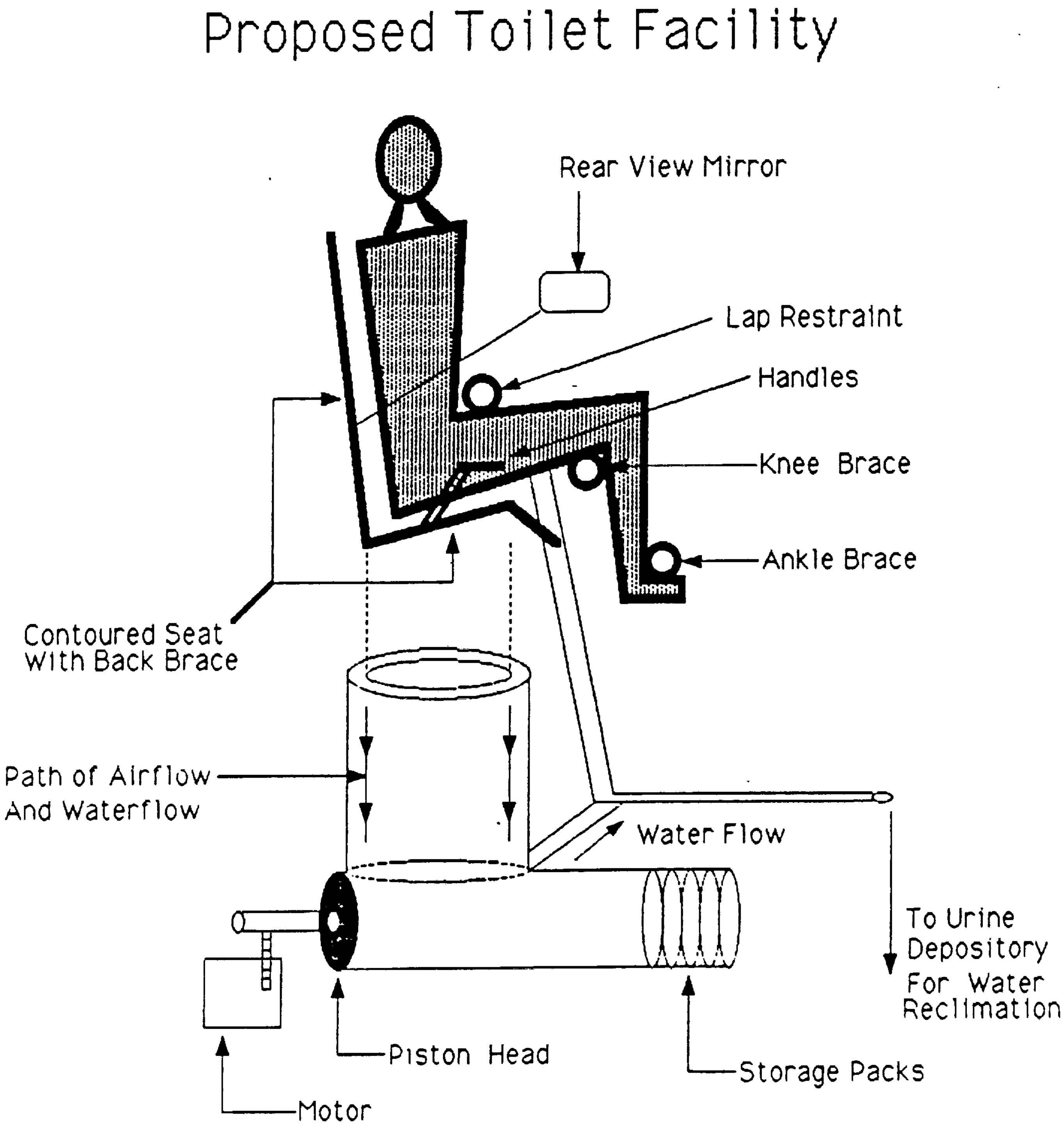
Appendix A

Figures



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Date Designed: 2 August 1988
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Figure 1a: Proposed Toilet Facility

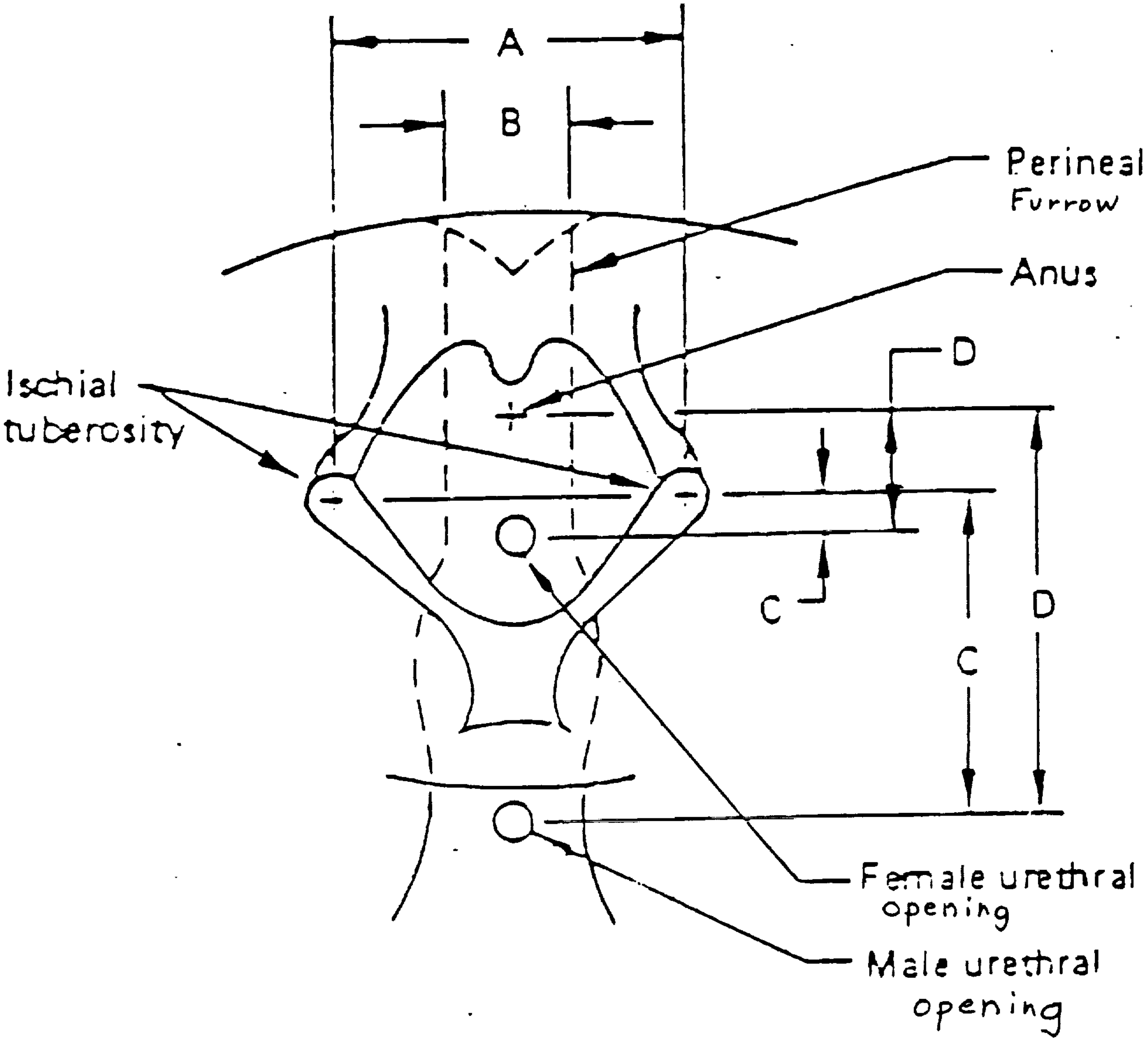

Figure 1b: Anatomical Dimensions of Body

Dimension	Description	Dimension range cm (inches)	
		Male	Female
A	Lateral separation of ischial tuberosity	10 to 14 (4.0 to 5.5)	11 to 16 (4.3 to 6.2)
B	Width of perineal furrow	7.5 to 9 (3.0 to 3.5)	7.5 to 9 (3.0 to 3.5)
C	Anterior/posterior separation between tuberosities and exterior urethral opening	13 to 27 (5 to 10.6)	6 to 9 (2.5 to 3.7)
D	Anterior/posterior separation between anus and external urethral opening	15 to 30.5 (6 to 12)	9 to 11.5 (3.5 to 4.5)

Figure 1c: Table of Anatomical Dimensions of Body

Cross Section of Habitat Module on the Space Station

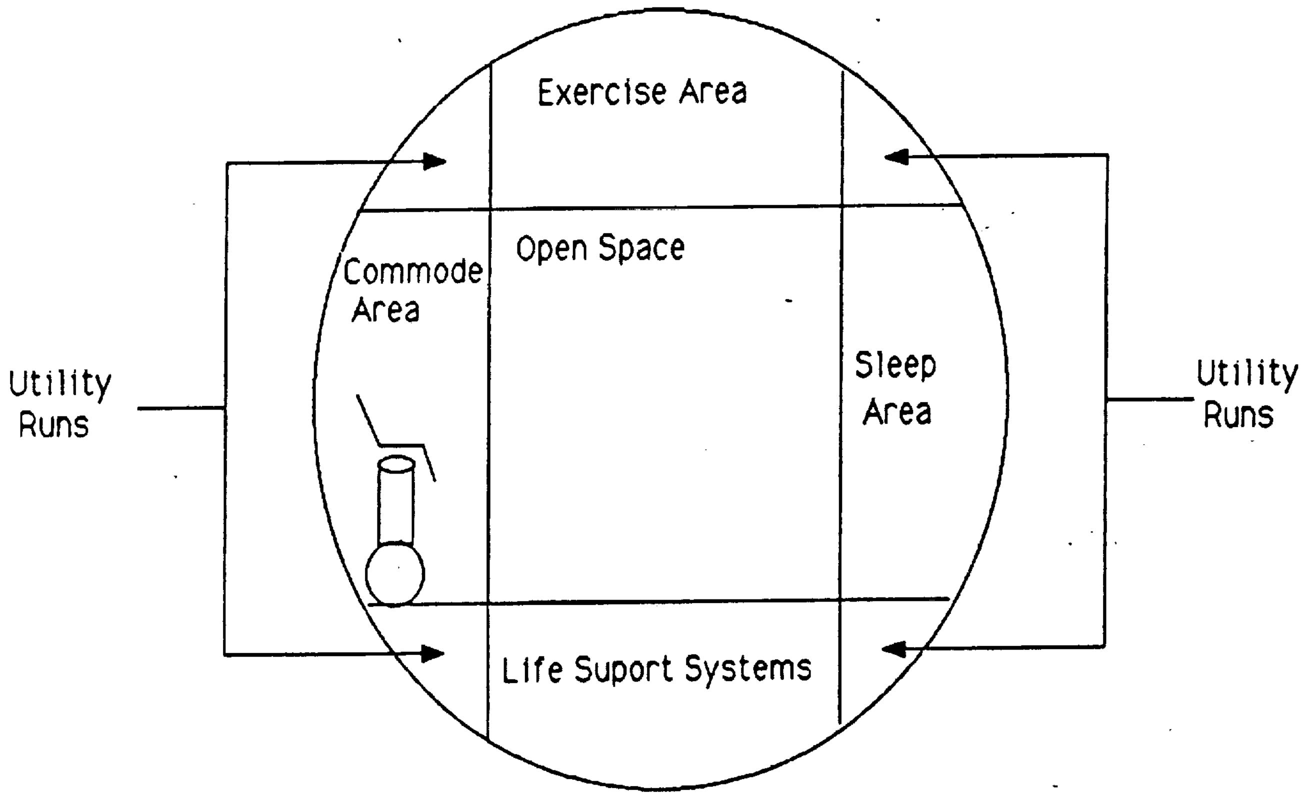

Figure 2: Cross Section of Habitat Module of Space Station

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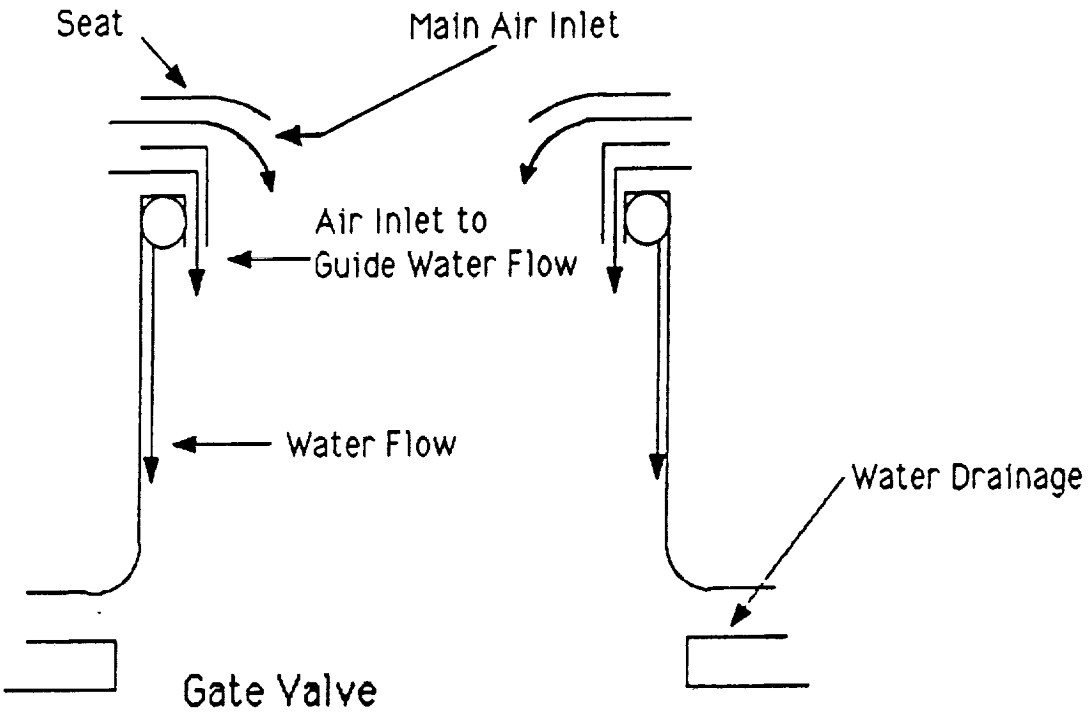
Air and Water Flow Arrangement



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Designed By: Mark E. Harrison
Date Designed: 6 November 1988
Scale: None

Figure 3: Air and Water Flow Arrangement

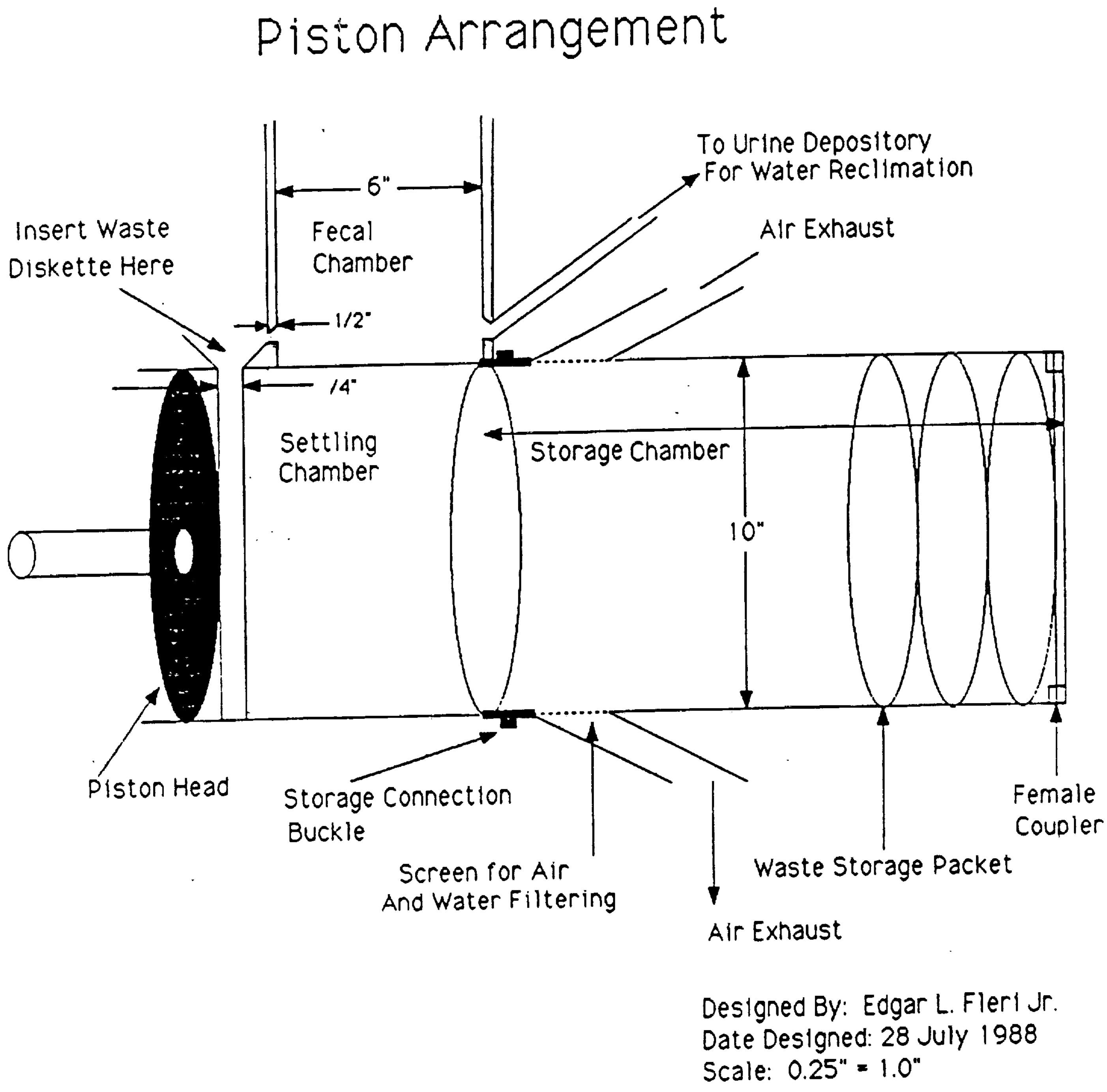


Figure 4: Piston Arrangement

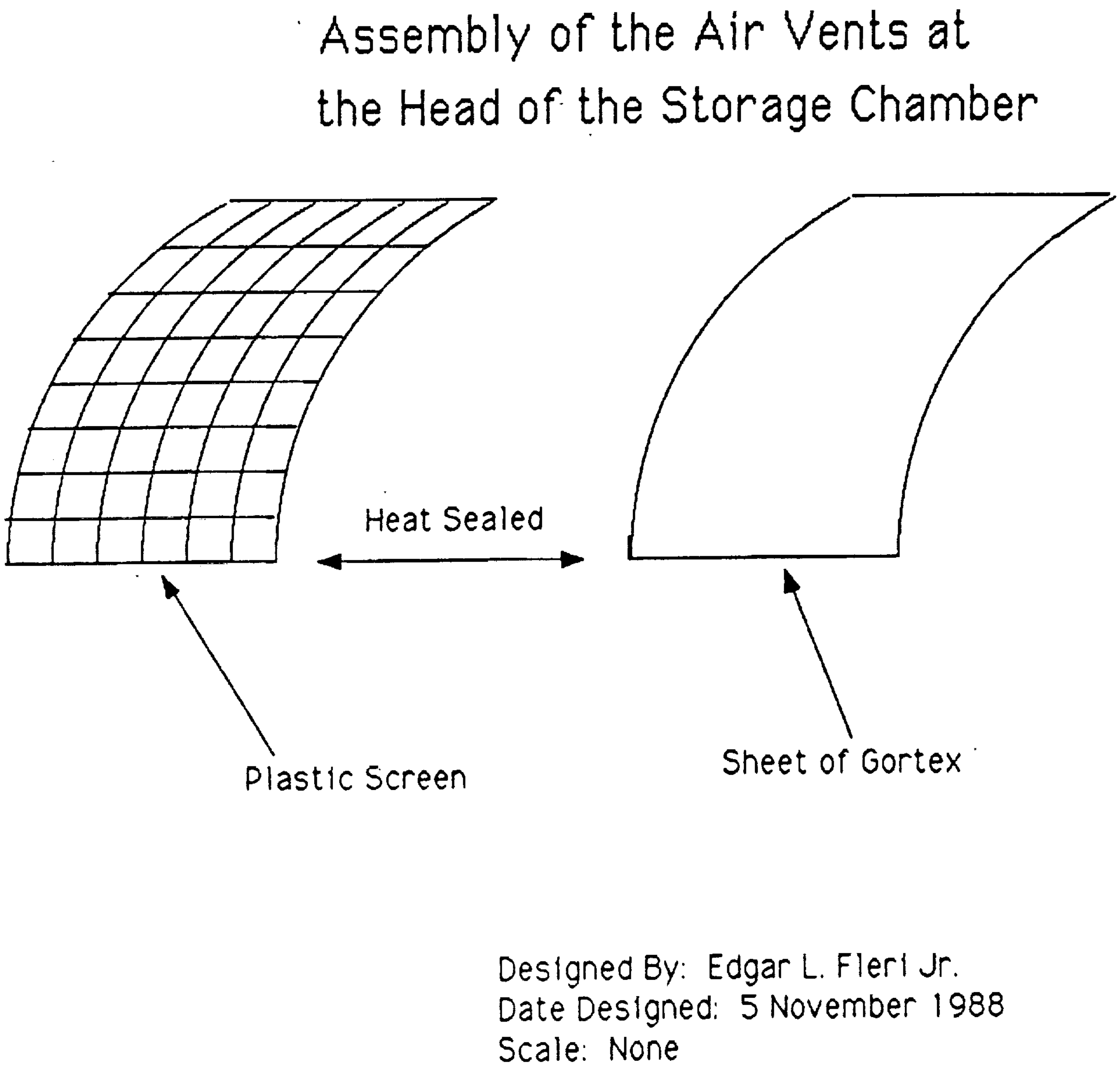
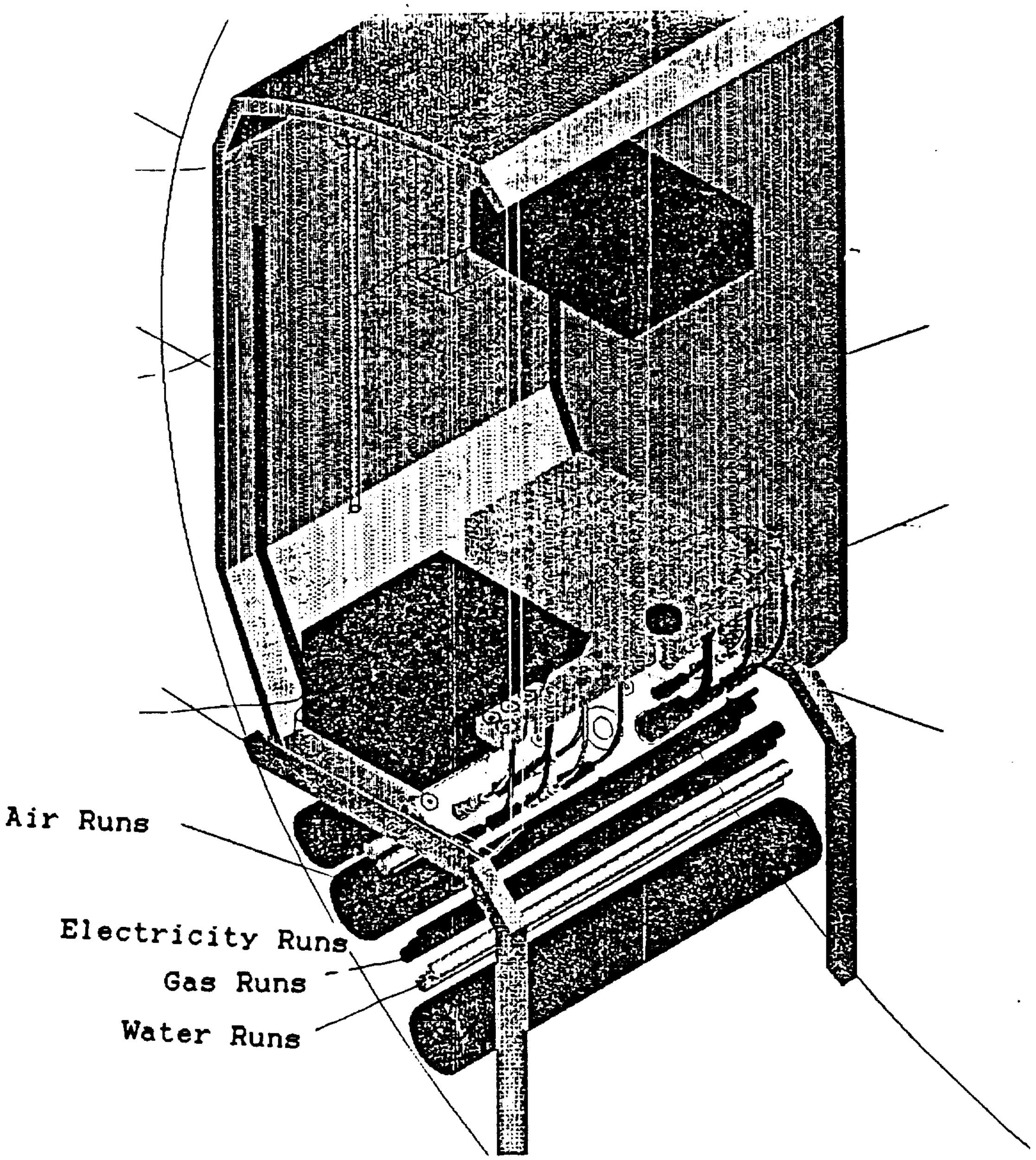


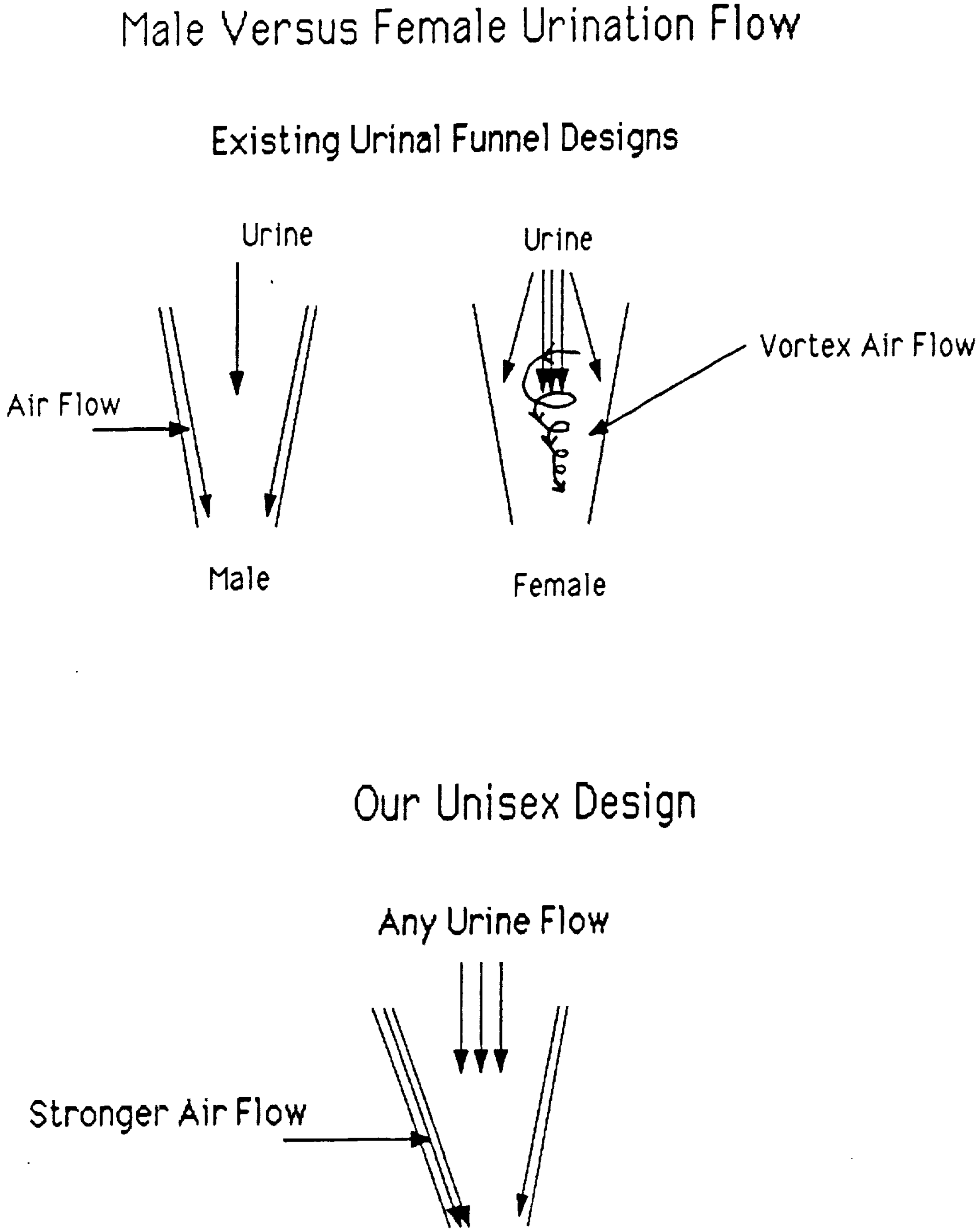
Figure 5: Assembly of the Air Vents at the Head of the Storage Chamber

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH



Designed by: NASA
Figure Supplied By Marshall Space Flight Center
Scale: none

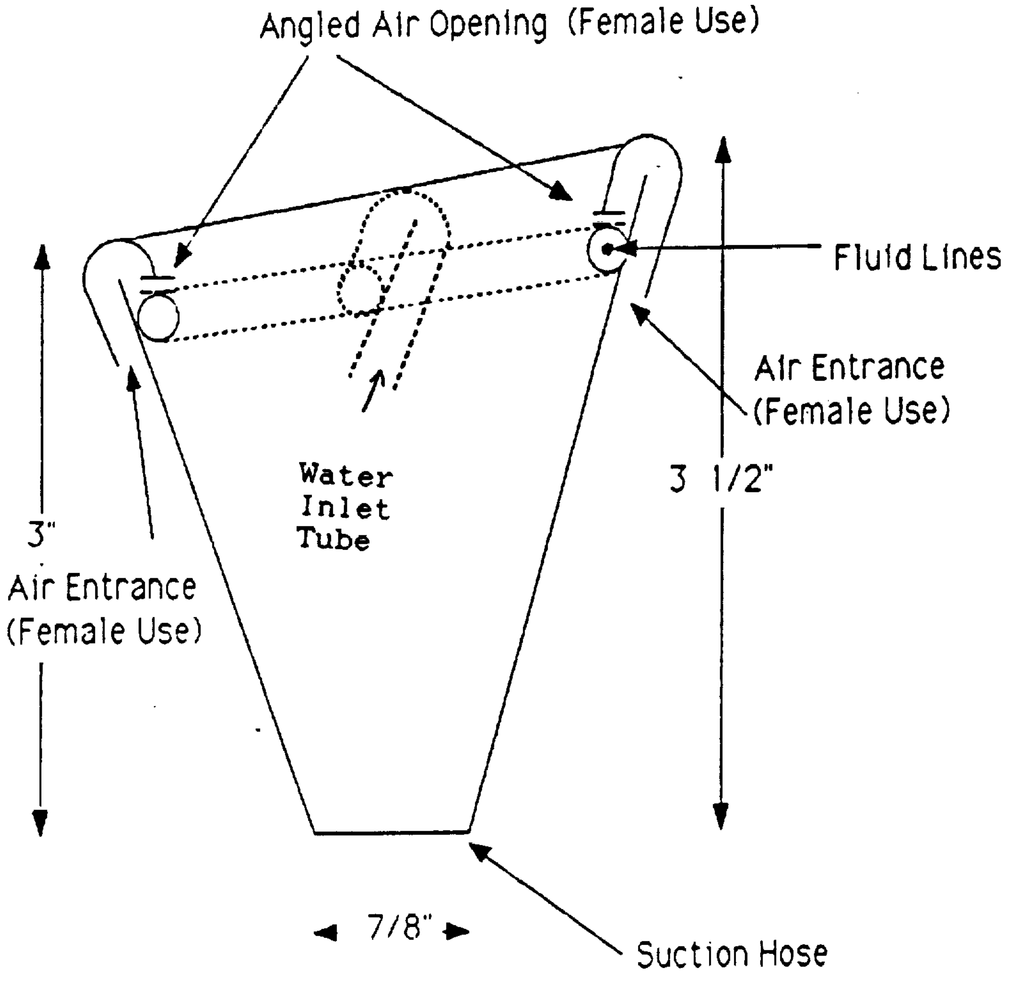
Figure 6: Utility Runs in the Space Station Module



Designed By: Edgar L. Fleri Jr
Date Designed: 31 October 1988
Scale: None

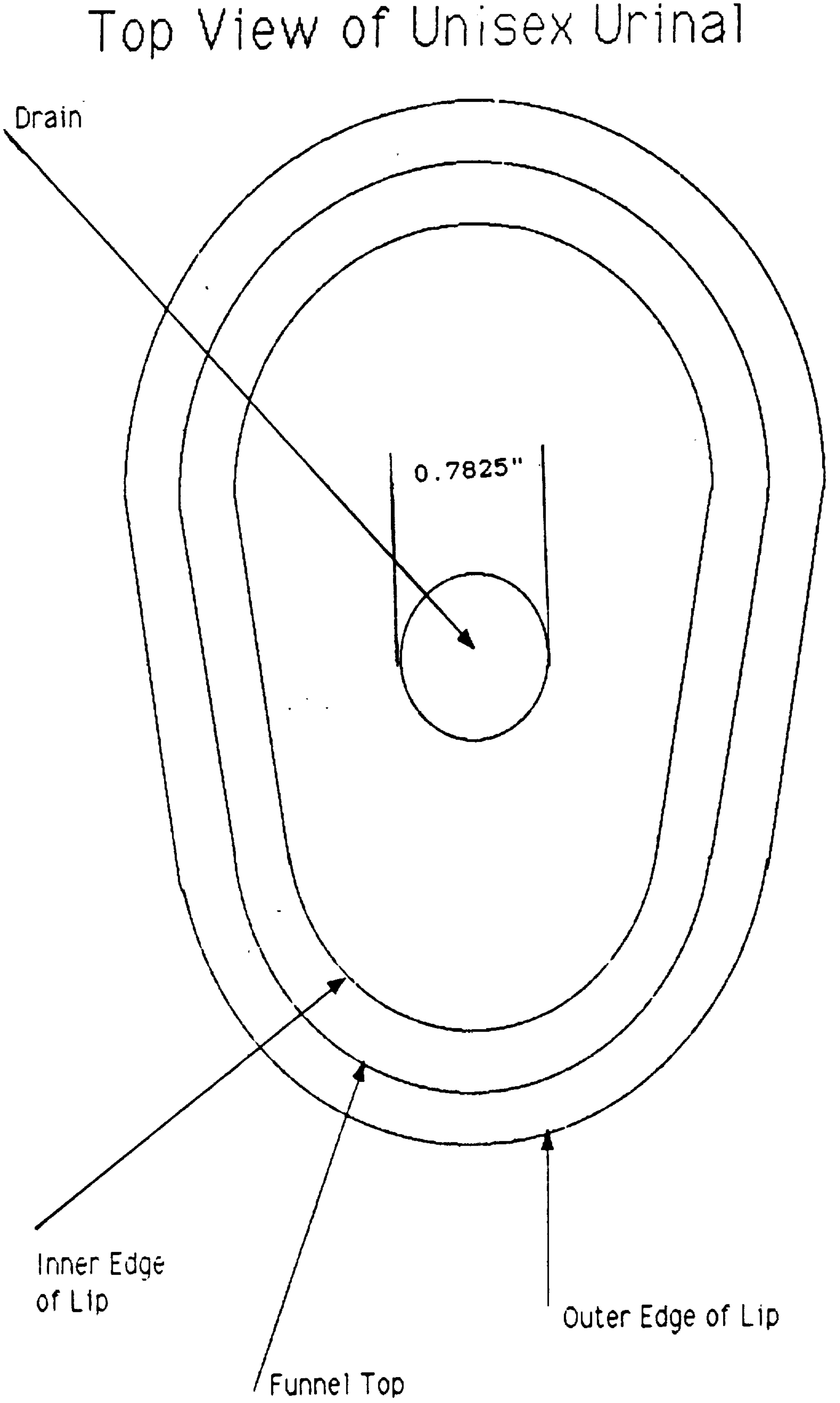
Figure 7: Male Versus Female Urination Flow

Side View of Urinal



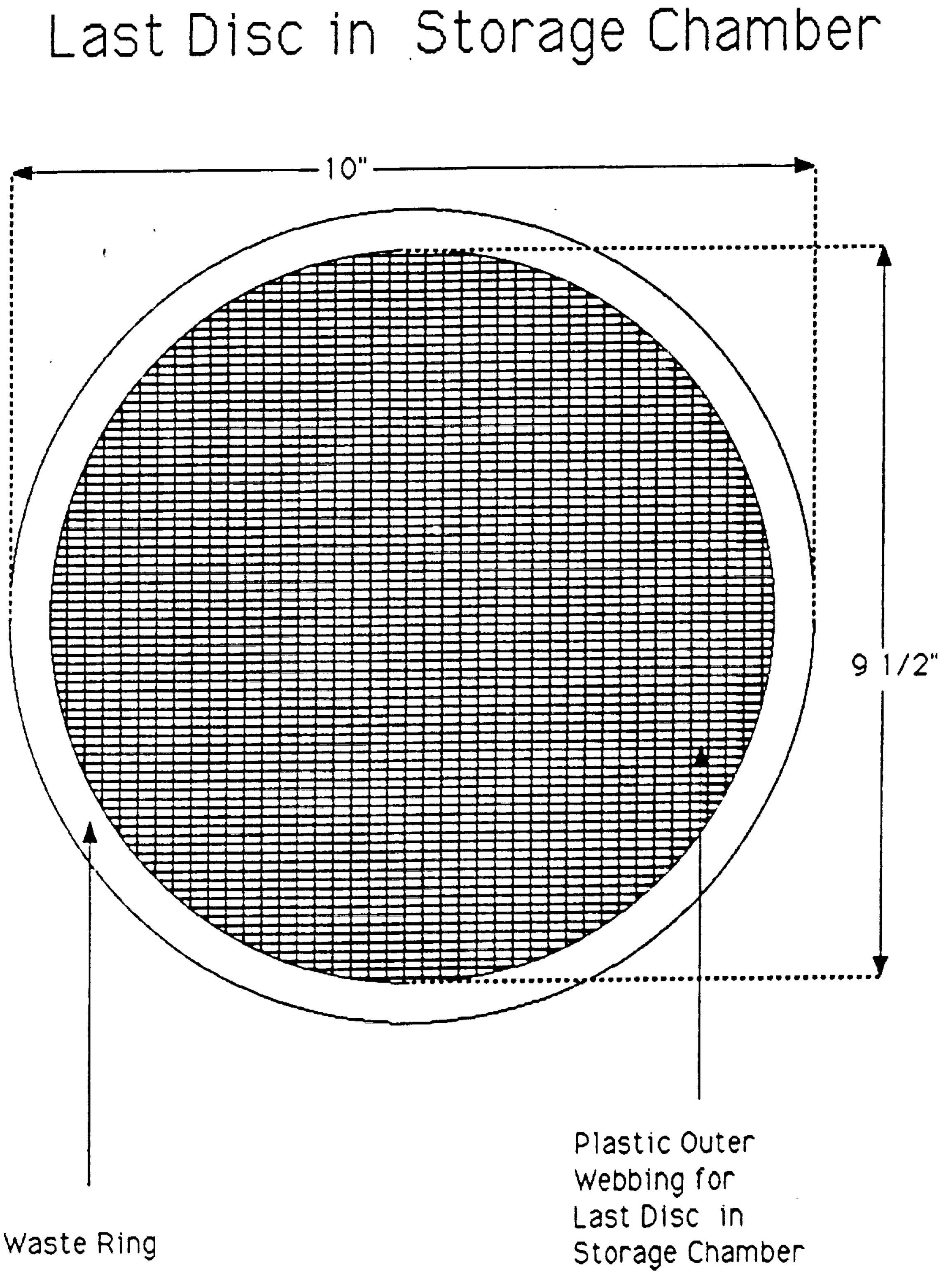
Drawn By: Edgar L. Fleri Jr.
Designed By: Mark E. Harrison
Date Drawn: 19 November 1988
Scale: 1" to 1"

Figure 8: Side View of Urinal



Designed By: Mark E. Harrison
Drawn By: Edgar L. Fleri Jr.
Date Designed: 18 November 1988
Scale: 2" to 1"

Figure 9: Top View of Unisex Urinal

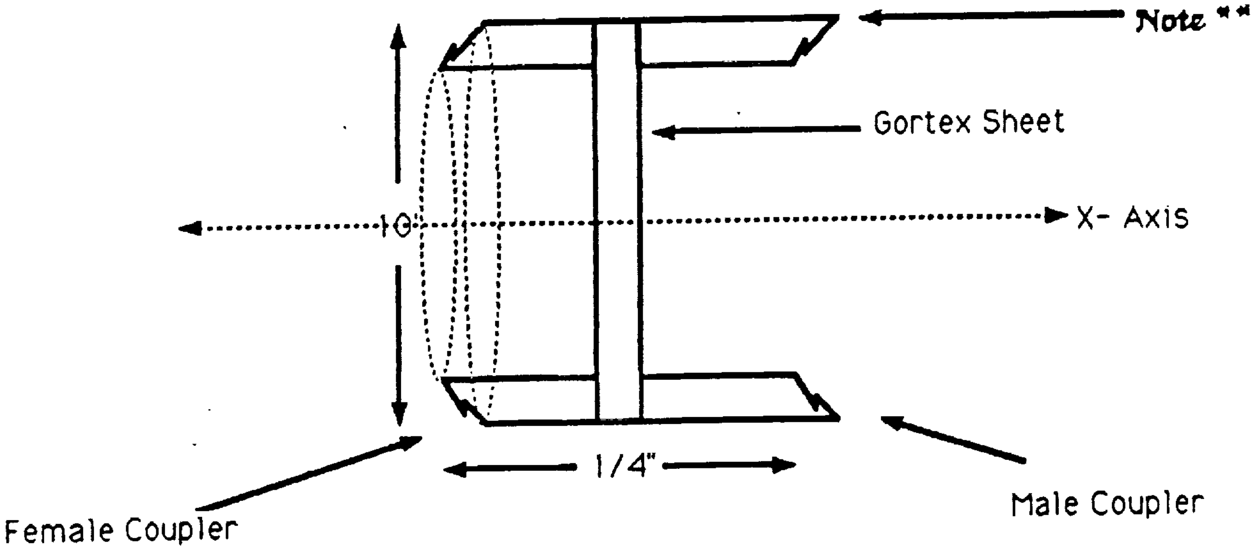


Designed By: Edgar L. Fleri Jr.
Date Designed: 8 November 1988
Scale: 1" to 2"

Figure 10: Last Disc in Storage Chamber

Side Cutaway View of A Waste Disc

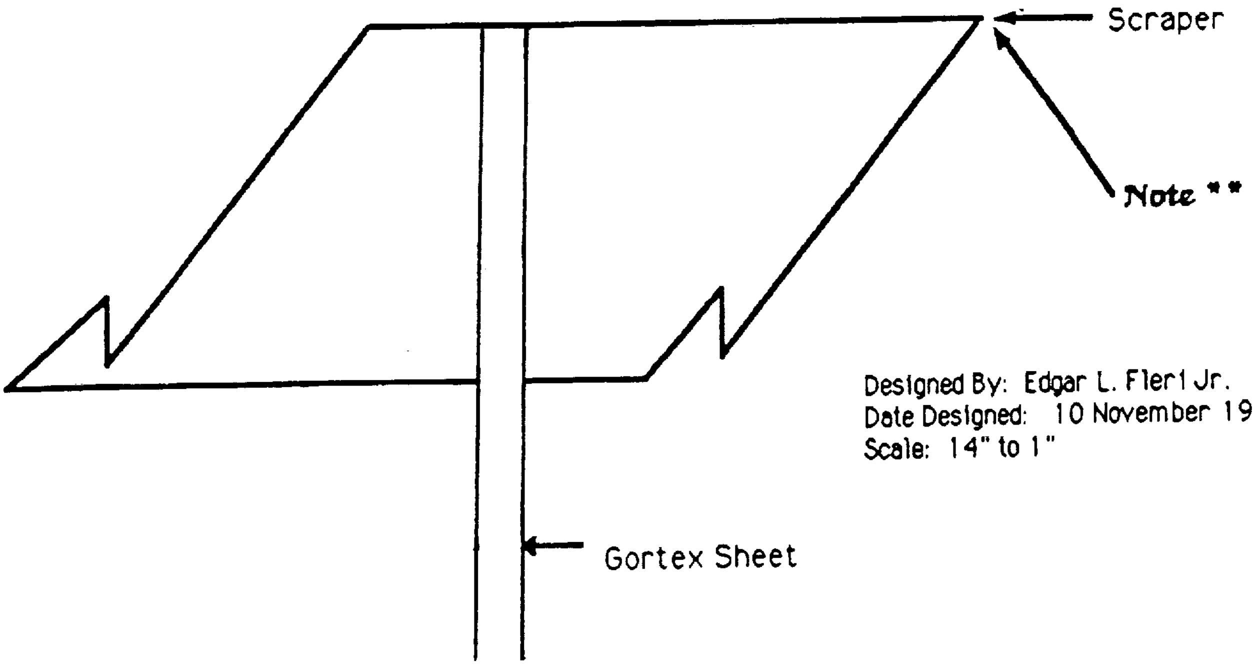
The Disc is revolved around the X- Axis



Designed By: Edgar L. Fleri Jr.
Date Designed: 10 November 1988
Scale: None

Closeup of the Male-Female Coupler

(Cutaway View of a Waste Ring)

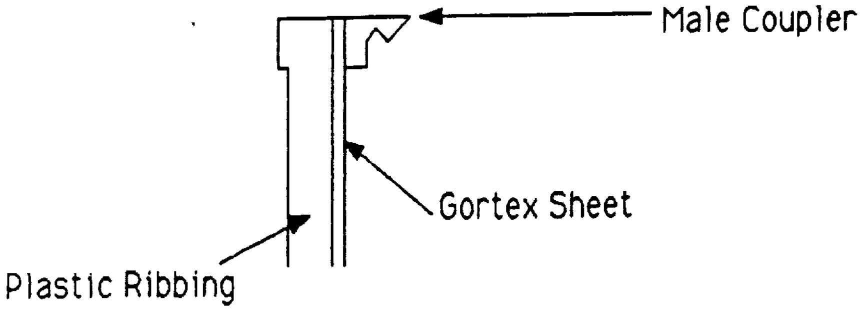


Designed By: Edgar L. Fleri Jr.
Date Designed: 10 November 1988
Scale: 14" to 1"

**These Two Points are the Same

Figure 11: Cutaway and Coupler Views of Waste Disc

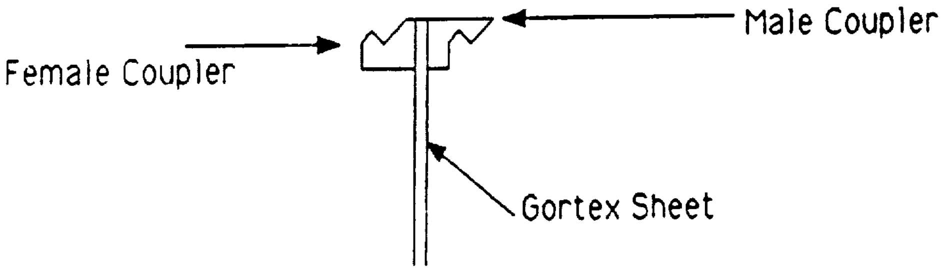
Side View of Last Waste Disc



Designed By: Edgar L. Fieri Jr.
Date Designed: 13 November 1988
Scale: None

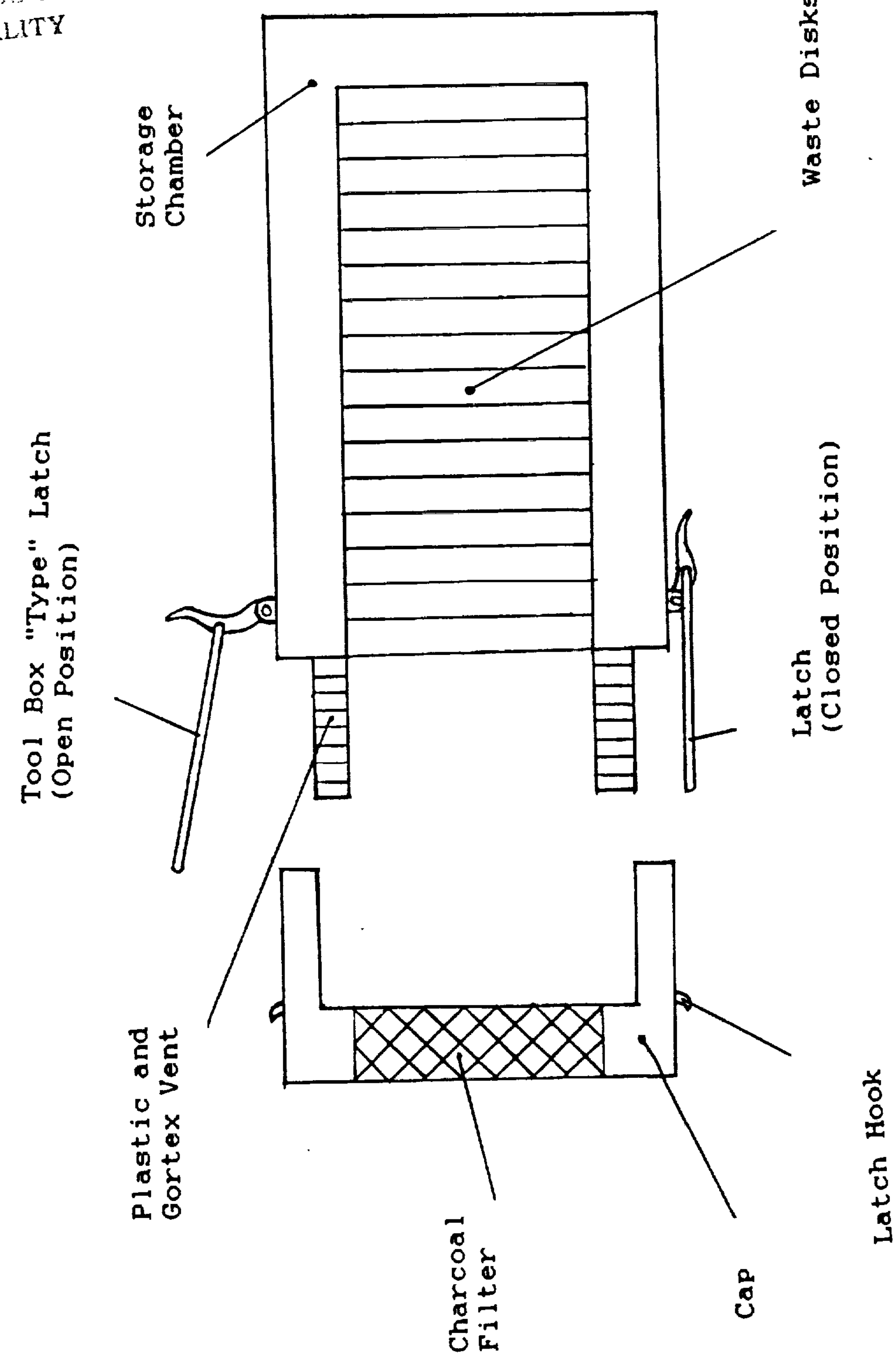
Figure 12a: Side View of Last Waste Disc

Side View of Regular Waste Disc



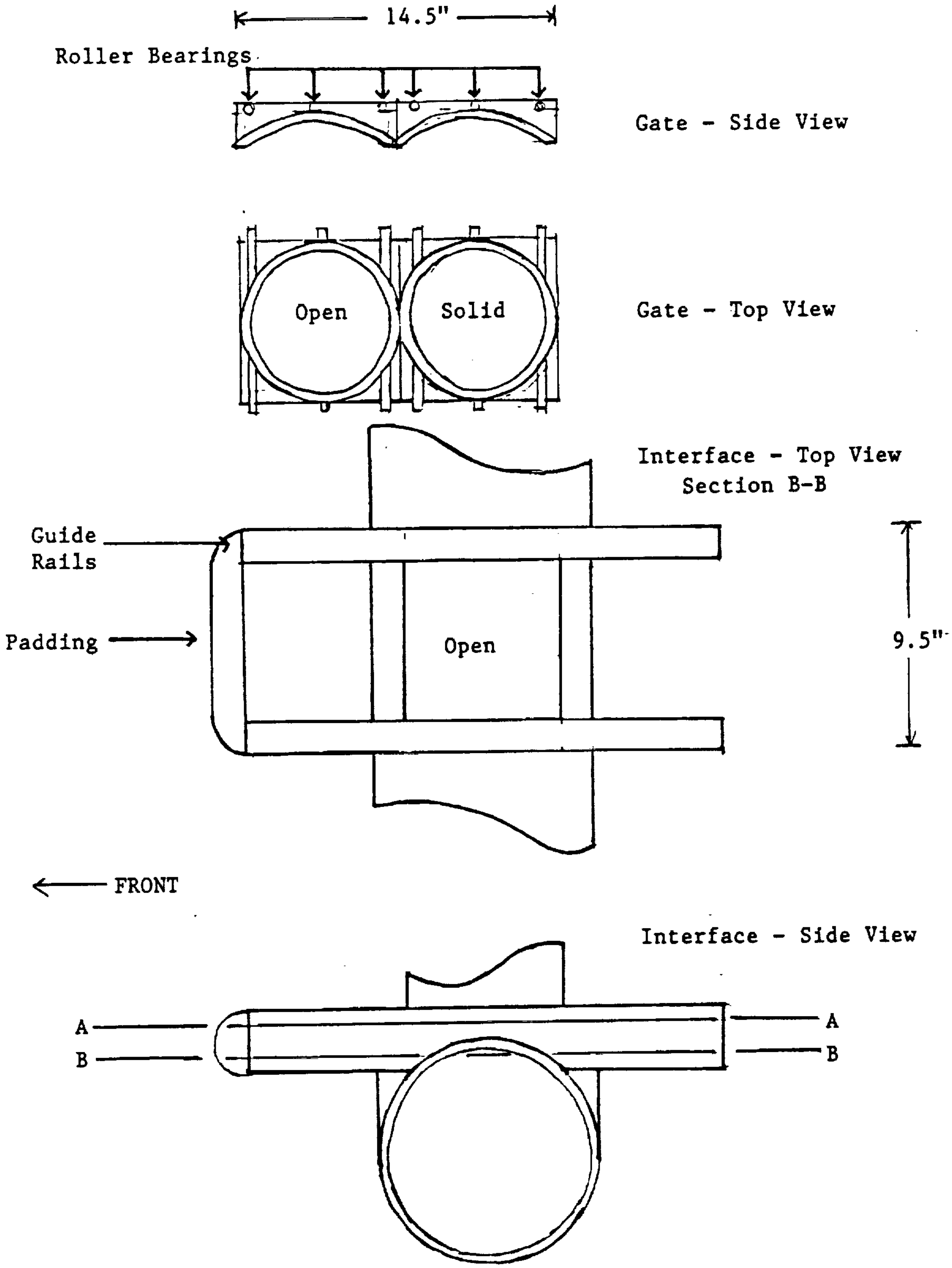
Designed By: Edgar L. Fieri Jr.
Date Designed: 13 November 1988
Scale: None

Figure 12b: Side View of Regular Waste Disc



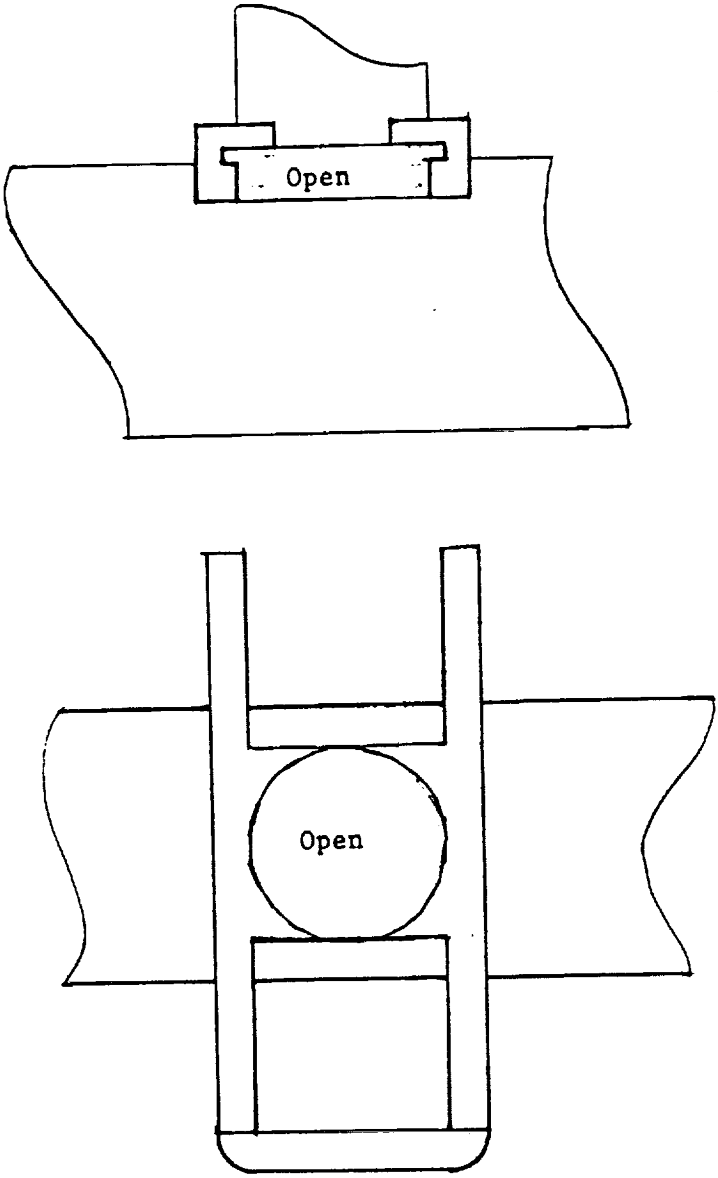
Designed by: Mark E. Harrison
Date Drawn: 30 January 1989
Scale: None

Figure 13: Storage Chamber and Cap



Designed by: Mark E. Harrison
Date Drawn: 28 November 1988
Scale: none

Figure 14a: Gate Valve



Interface - Front View

Interface - Top View
Section A-A

Designed by: Mark E. Harrison
Date Drawn: 28 November 1988
Scale: none

Figure 14b: Gate Valve

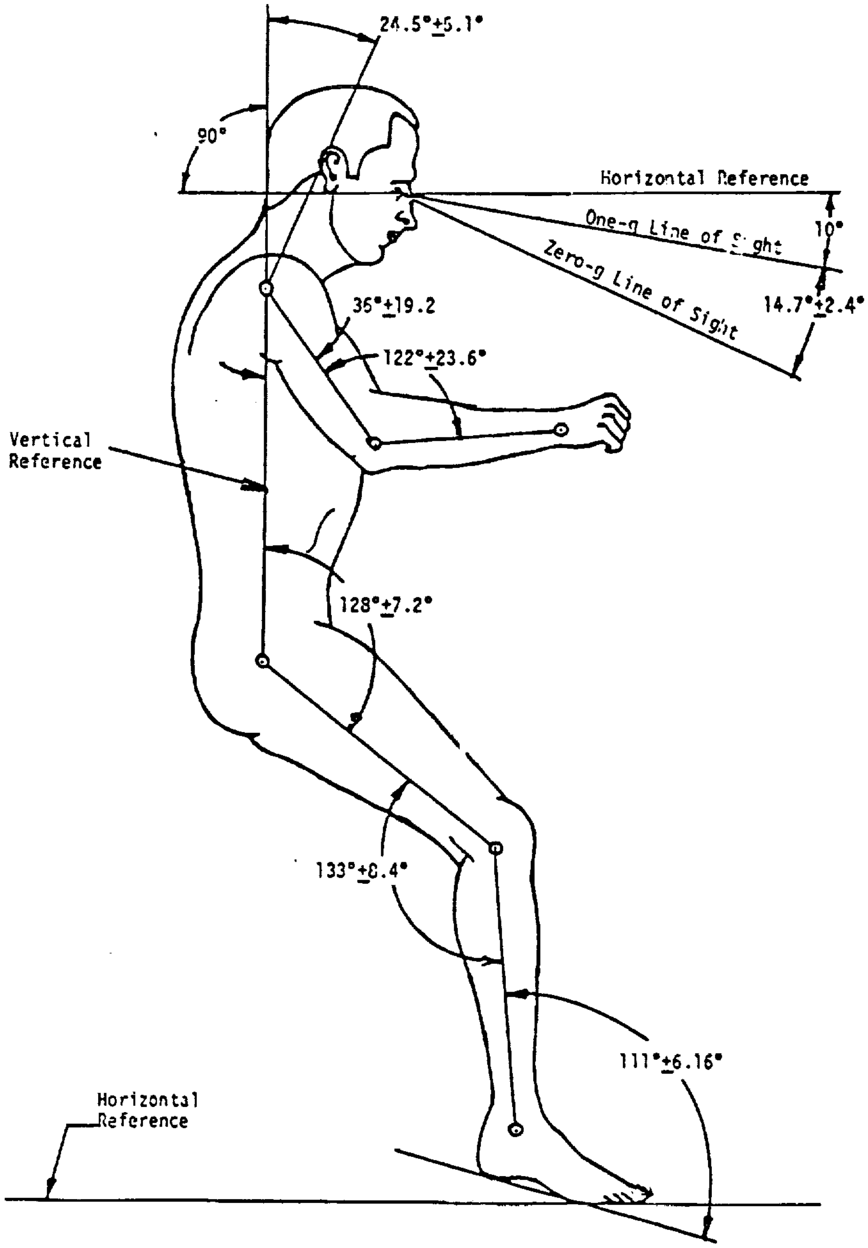
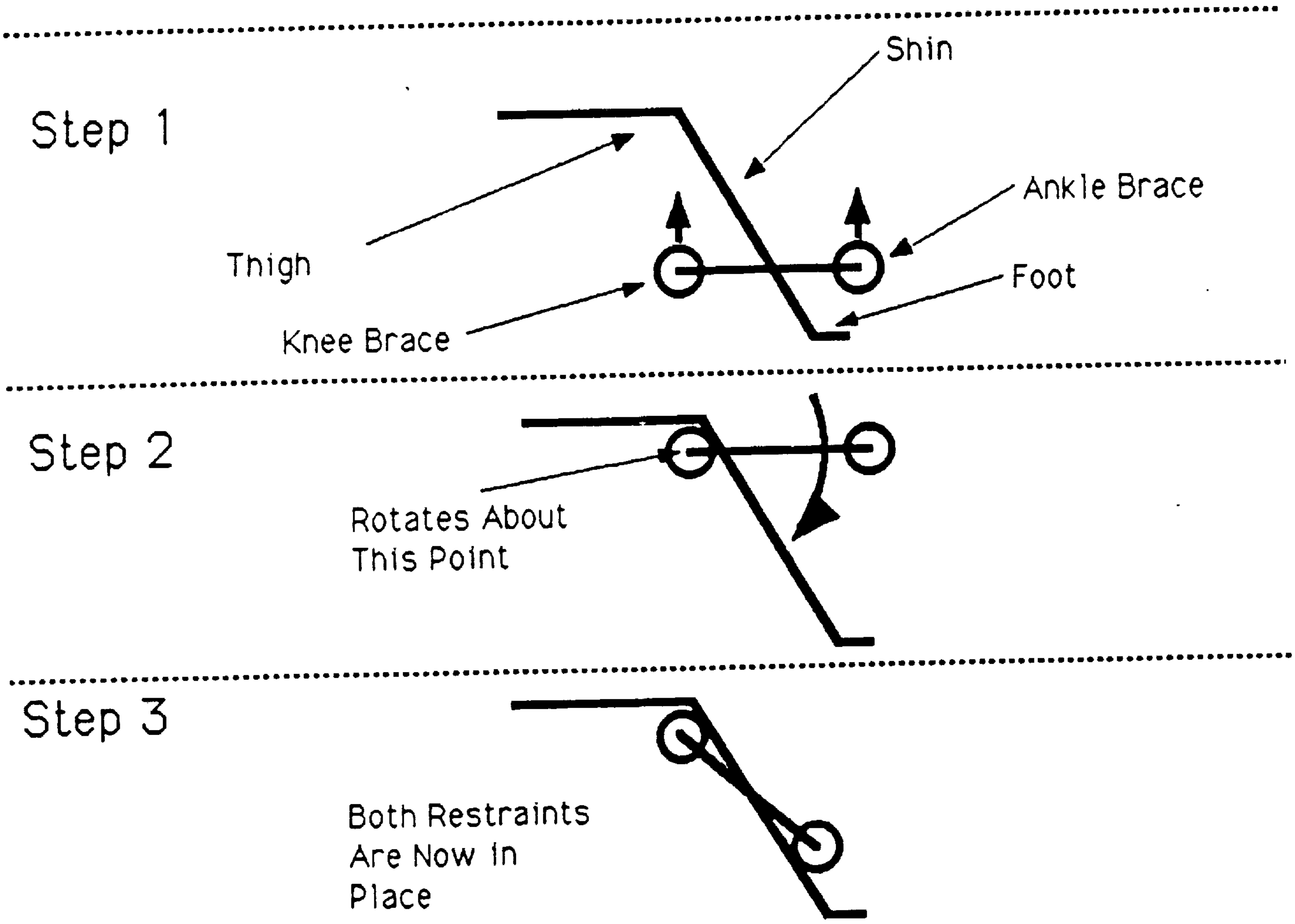


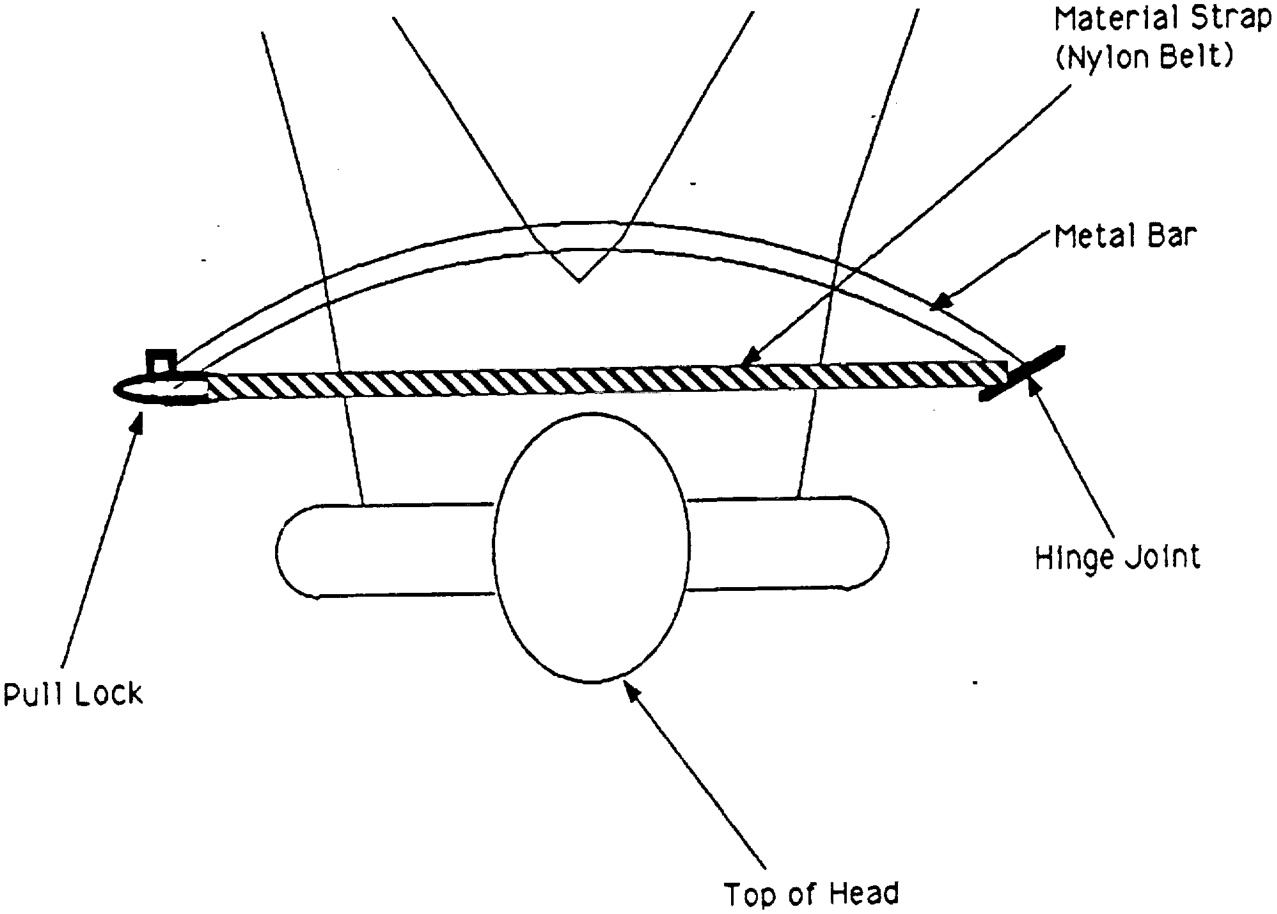
Figure 15: Neutral Body Position (1: 277)



Designed By: Gregory J. Meyer
Drawn By: Edgar L. Fleri Jr.
Date Designed: 16 November 1988
Scale: None

Figure 16: Operation of Ankle and Knee Brace

Top View of Proposed Lap Restraint



Designed By: Gregory J. Meyer
Drawn By: Edgar L Fieri Jr.
Date Designed: 16 November 1988
Scale: None

Figure 17: Top View of Proposed Lap Restraint

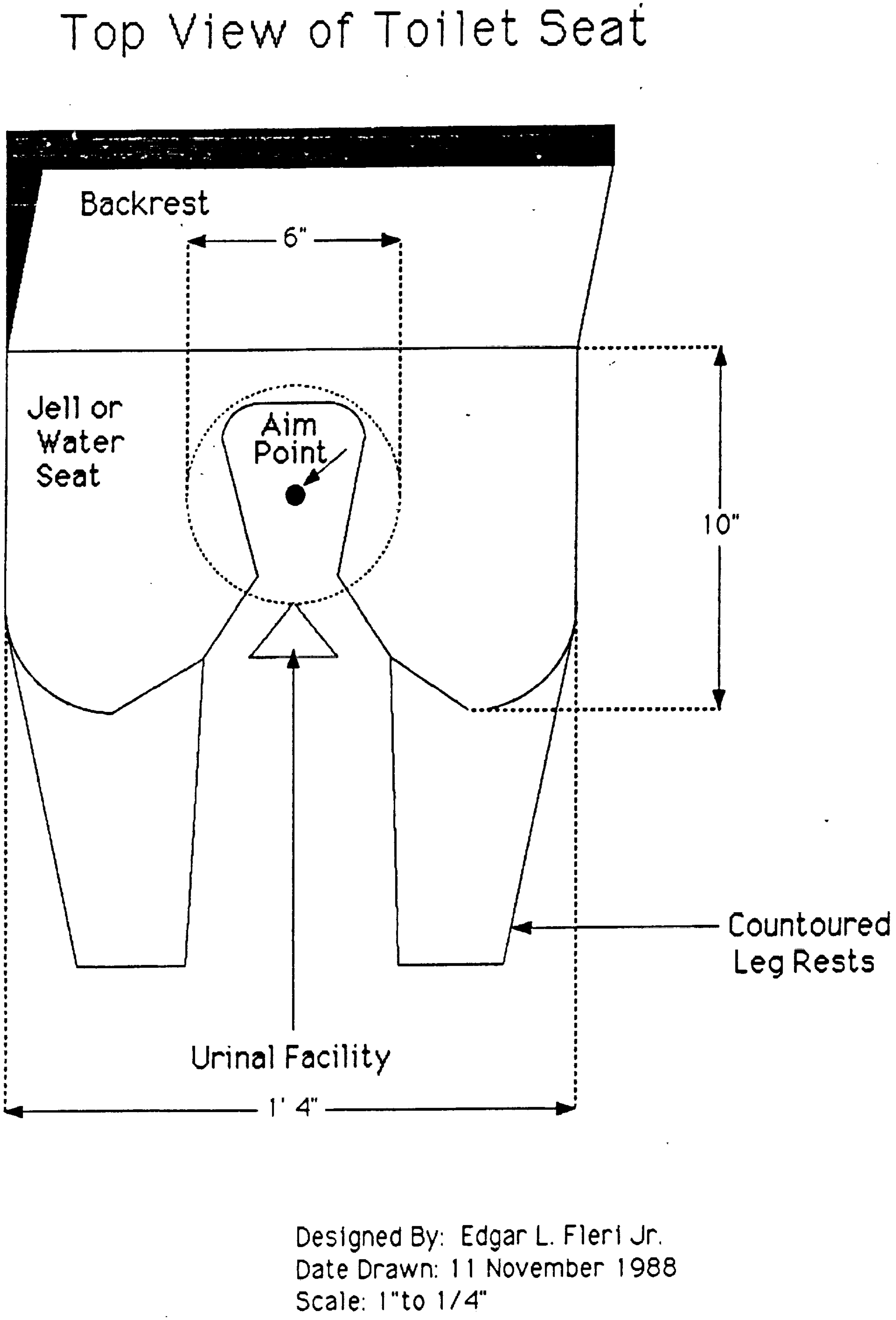
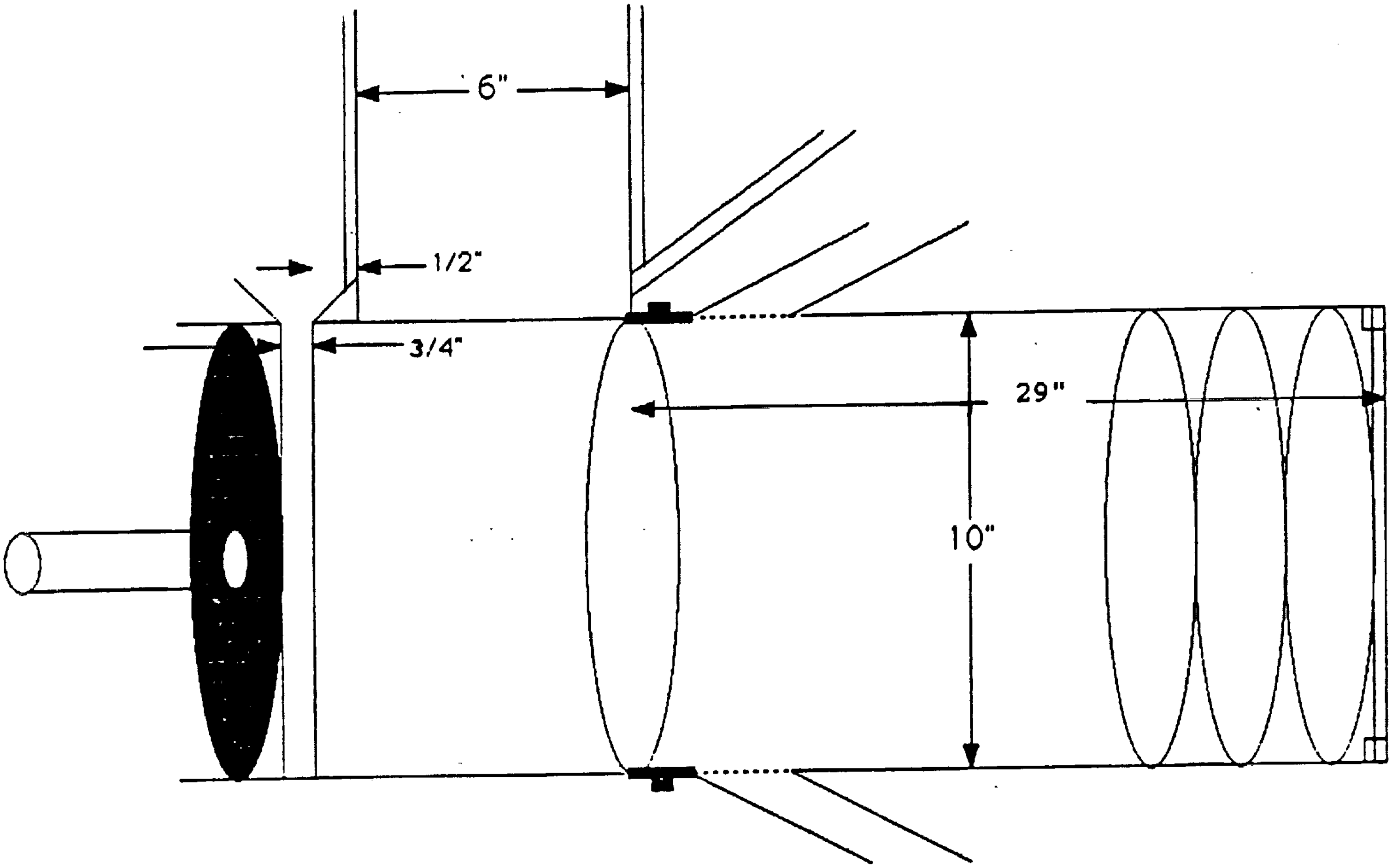


Figure 18: Top View of Toilet Seat

Piston Dimensions



Designed By: Edgar L. Fieri Jr.
Date Designed: 28 July 1988
Scale: 0.25" = 1.0"

Figure 19: Piston Dimensions

Appendix B

Calculations

CALCULATIONS

AIR FLOW RATE:

Since no information was available on entrainment force necessary for efficient operation of the toilet, existing data was extrapolated for our facility. The data used was for the Hamilton Standard toilet. This design uses eight inch diameter Gortex bags to store the waste. The airflow rate for the Hamilton Standard toilet is 35 cfm (cubic feet per minute). (5) This value was extrapolated from an eight inch diameter passage to the six inch diameter passage in our facility using a simple area ratio:

$$(A_{6-in}/A_{8-in})xFlow_{8-in}=Flow_{6-in}$$

$$(28.27in^2/50.27in^2)x35cfm=19.69cfm$$

This value is rounded to 20 cfm for simplicity.

The air flow rate for the Hamilton Standard urinal is 10 cfm. The urinal is driven by a fluid/air separator. These separators are commercially available. Since our urinal is of similar shape, we have adopted 10 cfm as our urinal air flow rate.

WATER FLOW RATE:

As stated, all calculations were based on a 1/16 inch thick layer of water. This is based on experiments in a one-G environment: The thickness of a layer of moving water was measured and the thickness of a layer of still water was also measured. The average of the two was taken since the water layer in zero-G would be thicker than a similar layer in one-G.

In spite of this, the value of 1/16 inch is probably an overestimation. Again, simple formulas were used to derive the data. The circumference of the chambers were multiplied by the thickness of the water layer and then this was multiplied by the vertical flow distance per second. Three inches per second was used for this latter quantity. This surface speed is assumed to provide adequate cleaning.

Flow Rate=2x(3.14x3.0in)x(1/16in)x3inches/second=3.53in^3/sec

Converting to gallons per minute yields approximatly 0.9 gallons/min.

For the urinal a similar method was used. This yeilded 0.37 gal/min. Since the urinal tapers at the base, care must be taken to assure that the water can drain properly. The area determined by multiplying the circumference by 1/16 inch is used to determine the diameter of the circular drain necessary for proper drainage. This came to 0.7825 in diameter.

DISC THICKNESS:

The thickness of the waste disc was determined from the maximum waste volume for a 24 hour period (18.3 in^3). (3:10.3-4). This along with the 10 inch inside diameter of the storage chamber gives a disk thickness of 0.233 inches.

HEIGHT OF FECAL CHAMBER:

The height of the fecal chamber was determined from the popliteal height of the 95 percentile American male. This distance is measured from the bottom of the foot to the back of the knee joint. (6:110-117) From this distance (19.488 in) the 11 inch outside diameter of the storage chamber was subtracted, giving a distance of approximately 8.5 inches. This will provide adequate space for use by all sizes of people.