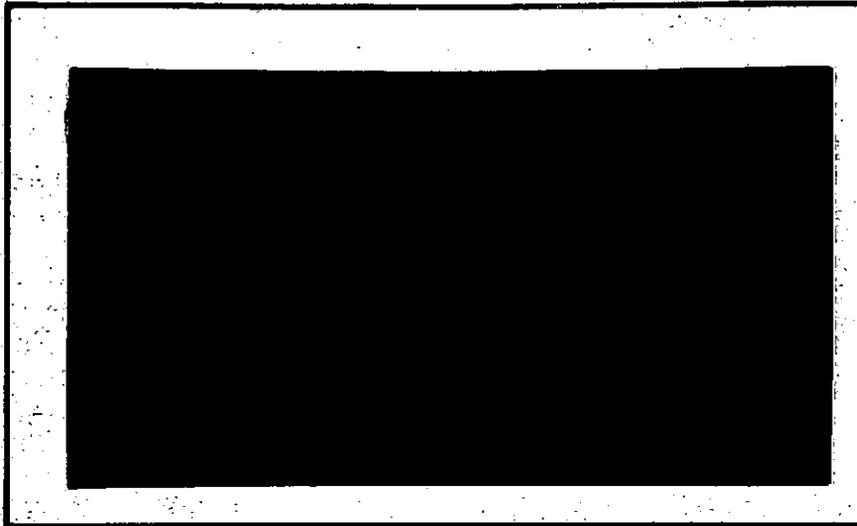


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REPUBLIC DIVISION



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DEVELOPMENT TESTING OF A
SHUTTLE URINE COLLECTION SYSTEM
DECEMBER 1973

Flight Tests Performed under
NASA-JSC Contract NAS 9-13694

FAIRCHILD

Fairchild Republic Company Farmingdale, L.I. New York 11735

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1.0 SUMMARY

Flight tests conducted in December 1973 demonstrated the ability of an unisexual urine collection subsystem to function in a "zero-g" environment. The urinal, which could be adjusted with three degrees of freedom, accommodated 16 female test subjects with a wide range of stature, as well as five male test subjects. The urinal was in intimate contact with the female and was contoured to form an effective air seal at the periphery. When positioned 2-4 inches forward, the urinal could be used for male collection and contact was not required.

Urine collection was effected by a jet directed air stream which proved capable of removing low velocity urine flow down to single drops. Air flow rates between $0.94(10^{-3})$ - $1.89(10^{-3})$ m³/sec (2-4 SCFM) were sufficient for satisfactory collection, with the higher flow being best. Three air jet configurations were tested with the jets angled upward from the plane normal to the urinal axis so that the air jets intercepted the labia in an elliptical pattern around the urethra. The pattern ranged from just tangent to an ellipse of axes 0.0445 and 0.0317 m (1 3/4 and 1 1/4 inches). The latter configuration gave consistently good collection, probably because it was more tolerant of variations in positioning.

Wetting of the female subject was minimal and comparable to that experienced in 1-G voiding and when the urinal was properly positioned there was no cabin contamination. Male collection was similar to 1-g collection and not difficult. Subjective comments by female subjects indicate that the urinal was comfortable and the air stream presented no problem at normal cabin temperatures. The collection system was simple to use despite the fact that most subjects had no familiarity with the system or indoctrination prior to the zero-g test.

The system positioned the female user in a semi-squat position designed to rotate the pelvis and directed the urine stream almost horizontally from the urethra. This position permitted positive and separate urine and fecal collection in a simple manner. Some subjects found this initial position "unnatural" but were comfortable when the foot position was lowered in later tests. Results of the zero-g tests indicated that the squat position could be further lessened, but requirements for good photographic coverage during the tests imposed a limit to ensure non-blockage of the side mounted camera.

The zero-g test results were similar in all important aspects to those tests conducted at 1-g.

Film documentation was obtained for all zero-g tests and form the basis for the technical discussion and conclusions reached in this report.

2.0 INTRODUCTION

The Space Shuttle waste management system required an advance in two aspects of waste management: The system must accommodate female as well as male users; the system must be as earth-like as possible and require no waste handling by the crew. This study primarily confronted the unisexual requirement and its impact on urinal design. Fecal collection required only a slight modification of the system proven effective in the Skylab mission. Fairchild Republic Company began design and ground testing of a unisexual urine collection subsystem in 1971. Results of this continuing effort led to the design of the system flown in zero-g tests in December 1973.

The primary objectives of the design were:

1. Minimize contamination of the user and cabin
2. Minimize power requirements for operation
3. Utilize MOL and Skylab experience for proven concepts
4. Produce a system that is simple, requires little training for use, and is easily adaptable for male and female users

The challenge in the urinal design was collection at low urine flow rates when there is no well-defined urine stream. Whereas the male generally posed minimal problems, female collection particularly at the start and end of micturition was more difficult.

The Fairchild approach was based on the use of a small intimate contact urinal (Figure 1) for the female using airflow as the driving force for urine collection. This was economically accomplished by the judicious placement of air jets around the periphery of the urinal.

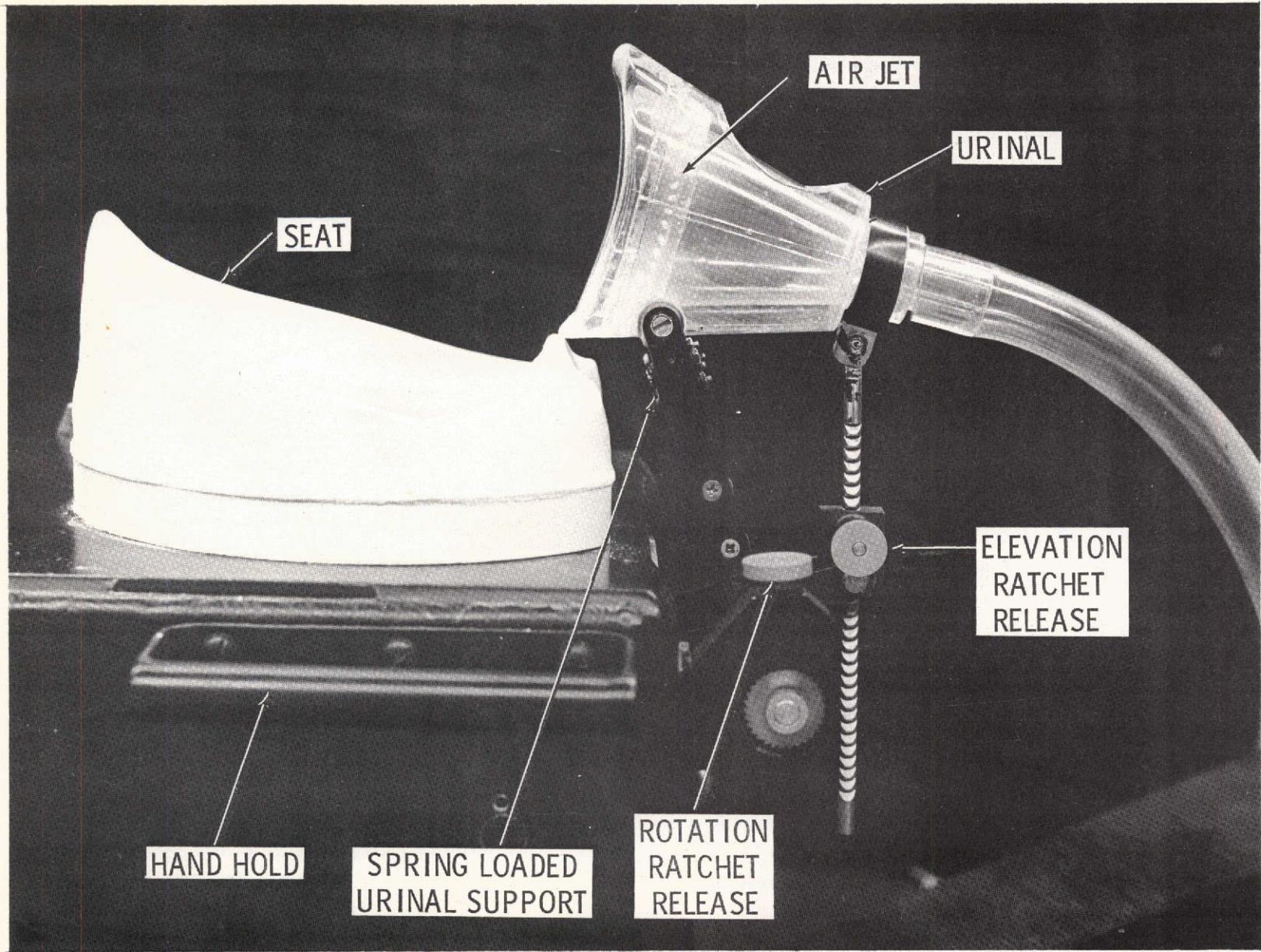


Figure 1. Urinal Position for Female Use

3.0 DESIGN APPROACH

The urinal design was primarily dictated by the requirements for female use. Any design that allowed re-positioning of the urinal for male use was likely to be satisfactory. The major design decision was the choice between an intimate contact urinal and a non-contact urinal.

A non-intimate contact urinal had appeal both from an esthetic view and from the similarity to an earth-like system. However, this approach had several major drawbacks. The urinal size was likely to be large and there was a possibility for major contamination of the user and the cabin. The large cross-sectional area for airflow required high airflow rates and consequently high power consumption.

By contrast, an intimate contact urinal could be small, limiting the skin area that could be wetted and excluding cabin contamination. Airflow required for the separation of urine from the labial surface and urine entrainment was not excessive, particularly when air jets were employed to produce high velocity flow at selected areas. The urinal should be cleaned between use, but its small size made clean-up possible without the expenditure of large volumes of fluids. An automatic flushing system and surface wipe could be utilized. The intimate contact urinal was therefore selected as the approach most likely to meet the design objectives.

An efficiently designed urinal would form an air seal when fitted to the female user. The urinal face must be contoured for a universal fit with a minimum of pressure so that it is both comfortable and easily sealed. The required urinal shape was developed from molds taken from a range of female test subjects and verified during subsequent 1-g testing. Both a hard and soft contoured urinal face were tried by the test subjects with a hard surfaced material selected as providing maximum comfort, security and sealing capability.

Both fecal and urine collection required air seals to produce air jet flow. To keep the urinal from protruding into the seat position, a semi-squat position was induced by foot supports so as to rotate the pelvis and the meatus of the urethra, producing an almost horizontal urine stream rather than the conventional downward vertical stream. The squatting position was in fact highly desirable from a physiological view. "An ideal seat would place the body in the position naturally assumed by man in primitive conditions. The seat should be low enough to bring the knees above the seat level." The squatting posture could to some extent replace the normal gravitational

*Quoted from A. Kira, "The Bathroom, Criteria for Design," Cornell University, 1966

assist to elimination. The aft end of the urinal in its most rearward position rested on the forward lip of the seat, thereby ensuring separate fecal and urine collections as both seals were maintained. See Figure 1.

4.0 LABORATORY AND GROUND TESTS

Ground testing of the urine collection subsystem was conducted in the laboratory and in cooperation with the staff and nurses at Brunswick Hospital, Amityville, New York. The test stand shown in Figure 2 provided a variable foot position and urinal support, and was used to establish the basic seating position.

The seat chosen was a modification of the Skylab seat redesigned to provide an air seal for the female user as well as the male. The redesigned seat and the semi-squat position provided the user with self-positioning capability on the seat without the need for special devices or assists. It was observed during tests that the female attained both urinal and fecal collection seals by achieving a comfortable urinal position based on the obvious contour of the urinal and seat.

The seat was adjudged to provide satisfactory comfort and support for both male and female users during the test program. The contoured shape was found to aid in actual defecations by its effect on spreading the buttocks.

With the anus centered in the fecal opening as viewed through the transparent fecal opening, Figure 2, the foot positions were varied to create a positive separation of urine and fecal collection. The position was required to allow side view photographic coverage of the urinal operation. The semi-squat position was selected based on extensive comfort tests with numerous subjects of varying stature and was easily adapted to during subsequent 1-g testing.

The urinal shape was chosen by utilizing the same subjects to test candidate urinals for comfort and fit, ease of positioning the urethra, and collection efficiency. Final refinements of the shape were made based on public molds of a number of seated test subjects. The essential similarity between molds made a single urinal shape usable by all subjects. There was no problem in obtaining an adequate air seal with a hard surface urinal. The urinal design in many cases facilitated good female collection by spreading the labia during contact and producing a well defined stream.

The jet configurations were initially established in laboratory tests employing a mechanical urination simulator. Jet size and angle were investigated. At high urine flow rates the stream passed virtually undisturbed through the region of air jet influence and was carried through the urinal. The tests investigated the low velocity-low expulsion force urine flow.

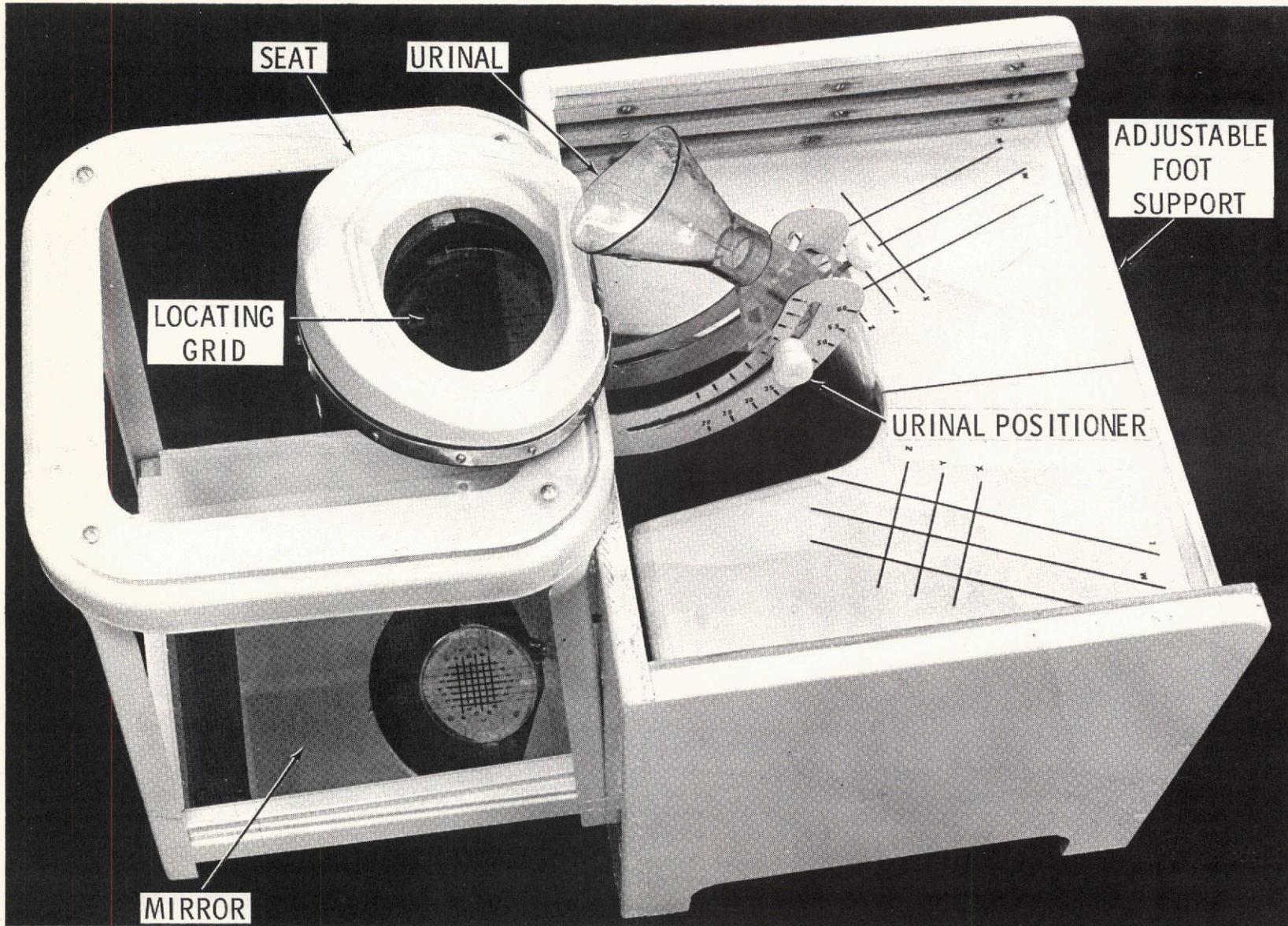


Figure 2. Development Test Stand

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As the urine flow rate was decreased the jets now affected the urine flow causing the formation of a conical spray with cone angle increasing with airflow rate. With a low urine flow rate and no airflow, large drops would form and roll down the skin. When airflow is introduced, the air jets prevented the formation of these drops and the urine was removed from the skin and entrained as droplets. However, if the air flow was too great, spraying and wetting of the skin surface resulted.

The air jets were angled upward above the plane of the jets to intercept the labial surface. If the angle was such that they intercepted the urine stream rather than the labial surface, splashing would occur. The uniformly spaced air jets shown in Figure 3 would create an airflow to shear urine from the labial surface, entrain it, and carry it down the urinal.

Urine collection tests were conducted at the Brunswick Hospital with 18 female test subjects for a total of 50 collections. These 1-g collections for the critical low urine flow rates were more difficult than zero-g collections, since the airflow must arrest the downward roll of urine drops as well as entraining them. It would be expected that lower airflow rates would be required at zero-g. The tests demonstrated that good collections could be made with little training or discomfort with a wide range of physical types. The results of these tests were documented in a motion picture film on file at Fairchild Republic.

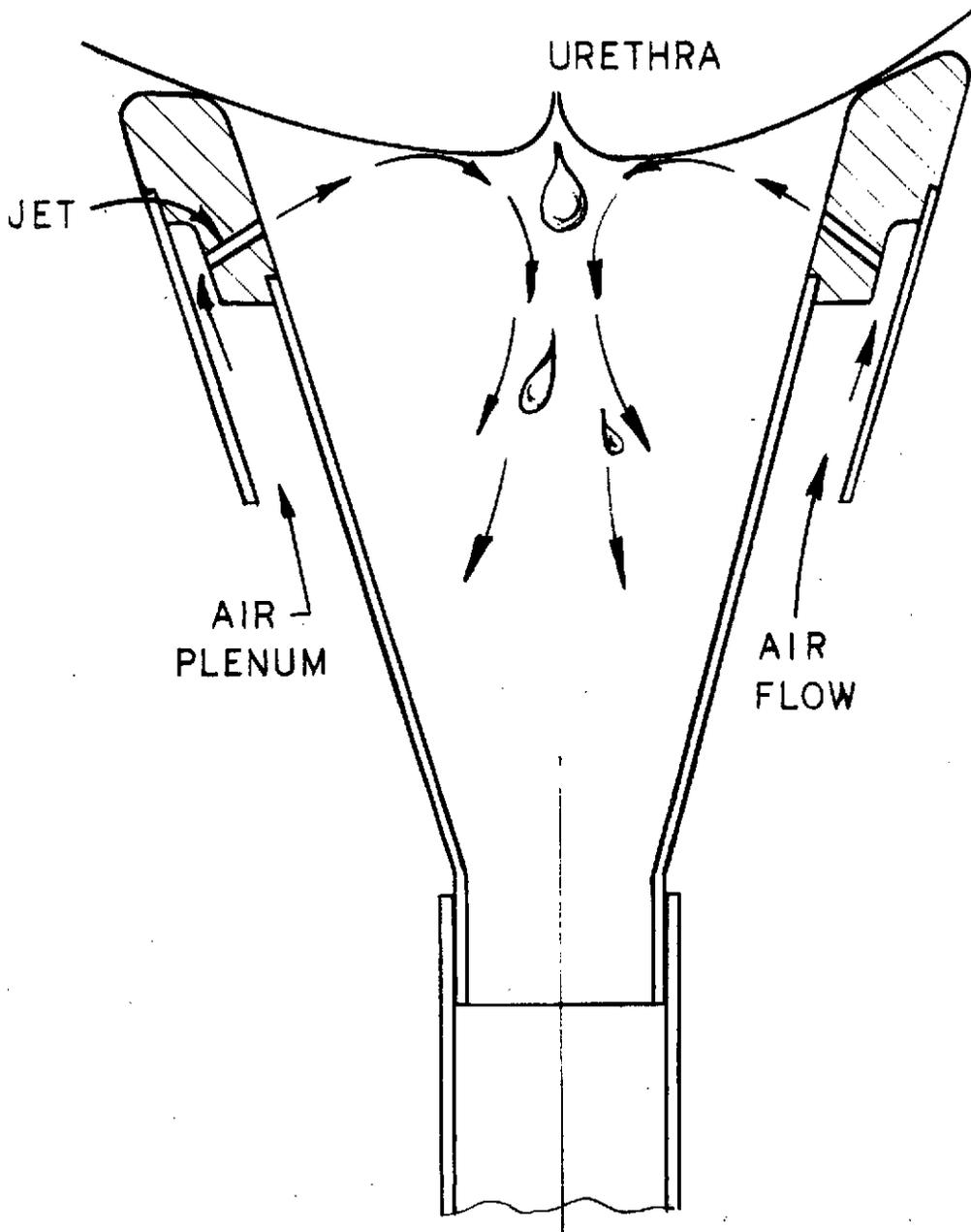


Figure 3. Air Jet Flow in Urinal

5.0 FLIGHT TEST

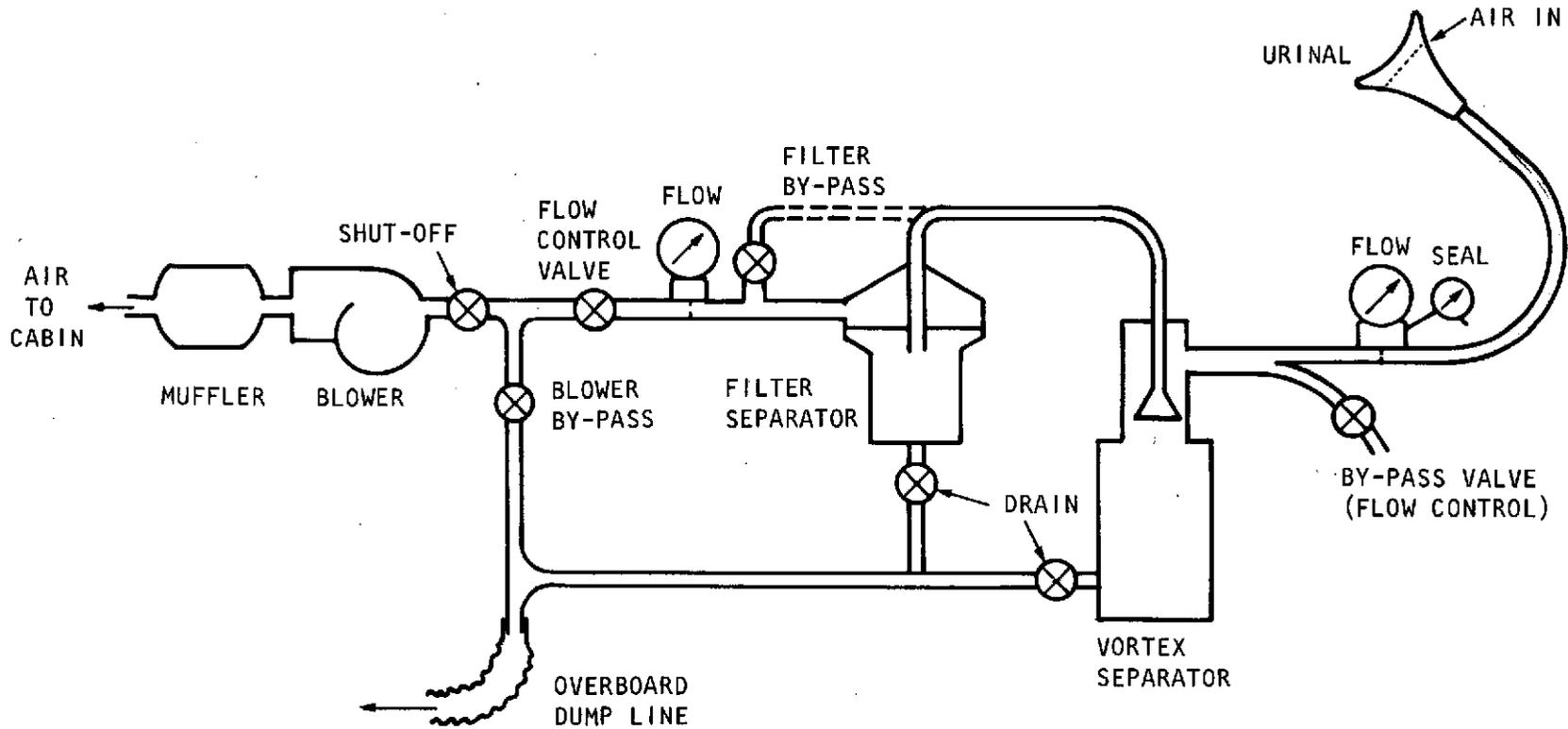
5.1 EQUIPMENT

The test hardware consisted of a test stand with a seat, foot positioner and restraints, hand holds and a lap belt, test urinal and support, urine-air separators and a blower, as shown schematically in Figure 4, and photograph Figure 5. The stand was enclosed for privacy and instrument gauges were mounted on the outside for photographic documentation and guidance of the test crew, as shown in Figure 6.

The test rig was provided with contingency fecal collection provisions but no fecal testing was attempted in the program due to the significant amount of prior zero-g tests and actual Skylab experience of the Fairchild design. In the Manned Orbiting Laboratory program, collections with a simulated feces dispenser were conducted in 249 zero-g parabolas. (Reference: FH/RAD report 103DRT005-03-01, 5 July 1968, "Zero-G Flight Development Test for Waste Management Subsystem Manned Orbiting Laboratory"). Human subjects were employed in zero-g testing for the Skylab program. (Reference FH/RAD report MS115T0009-04, 23 December 1969 "OW-Fecal Collection Unit Zero-G Functional Evaluation - Final Report"). The successful space flight use of the system developed in these tests is documented in McDonnell Douglas report "Skylab WMS Final Report" March 1974.

The test urinals are all of the same shape as depicted in Figure 1 and differ only in angle of jets above the jet plane. An outer shell forms an air plenum and protects the jets from obstruction by the thighs. The urinal support as seen in Figure 5 was fastened to the test stand below the seat and provided three degrees of freedom in adjustment. This adjustment was easily accomplished with one hand with the final position automatically locked in place thereby freeing both hands. Following urination an unlock release swung the urinal away and allowed free access for wiping.

Three specific jet angles were tested. Each urinal had thirty-six 0.0016 m (0.063 inch) jets spaced at equal angles around the periphery of the urinal. The jets enter the urinal wall 0.018 m (0.7 inches) below the opening at the sides, 0.025 m (1.0 inches) at the aft end, and 0.032 m (1.25 inches) at the forward end. The urinals, designated A, B, and C had jet angles of 28°, 16°, and 7° above the plane of the jets. The intersection of the projection of the jets and the labial surface forms approximately an ellipse. For urinal C, the flattest jet array the intersection is essentially tangent to the surface. The ellipse around the urethra formed by the intermediate



FLOW IS CONTROLLED BY BY-PASS VALVE, AND AT LOW FLOW, BY FLOW CONTROL VALVE
 FILTER BY-PASS, IF REQUIRED, REMOVES FILTER SEPARATOR FROM LINE
 BLOWER BY-PASS VALVE USES OVERBOARD DUMP LINE FOR AIR FLOW IF BLOWER FAILS

Figure 4. Schematic of Flight Test System

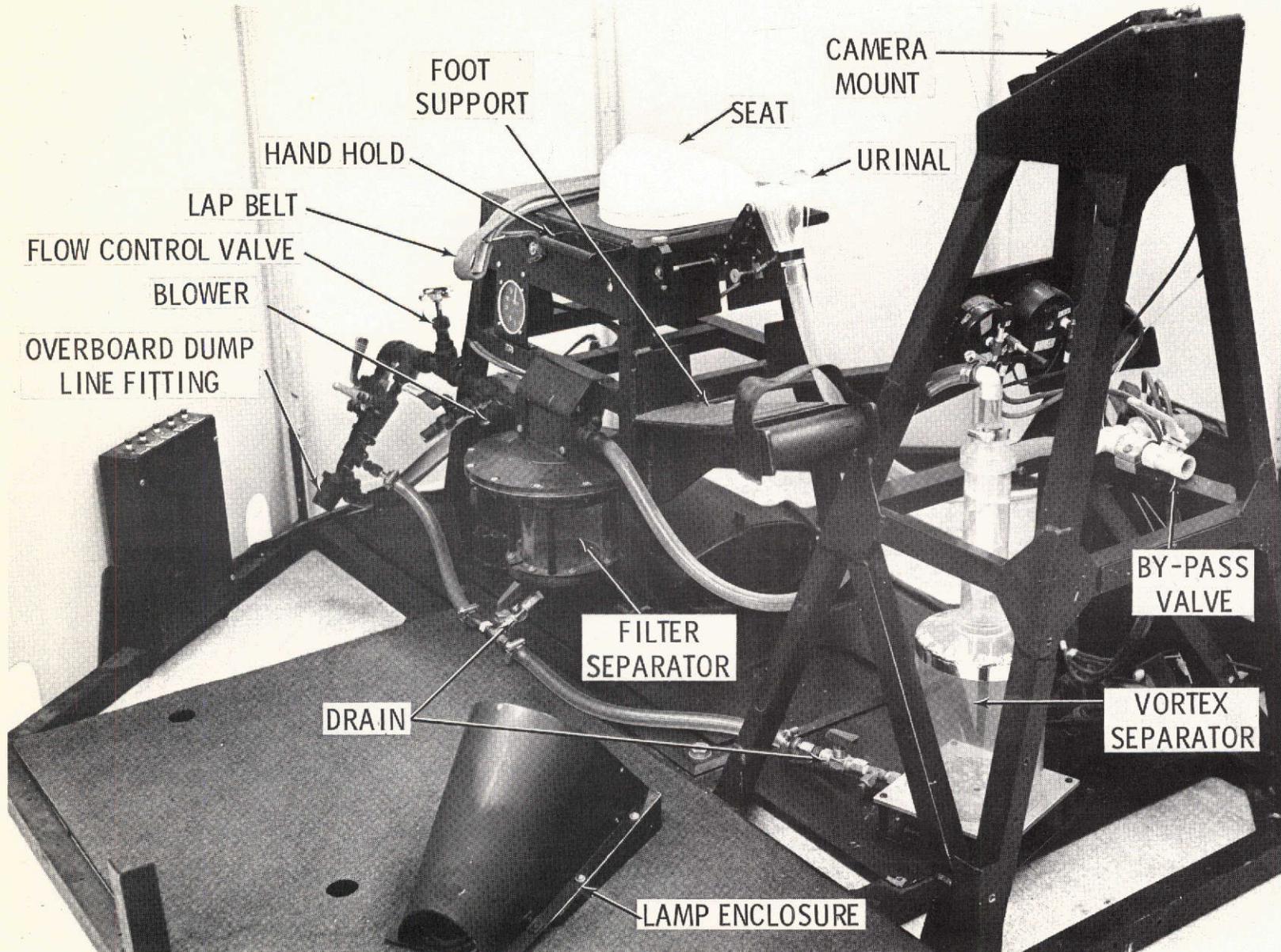


Figure 5. Zero-g Test Stand



Figure 6. Test Stand Enclosure

urinal B has axes of 0.0317 and 0.0191 m (1 1/4 and 3/4 inches). The greatest angle, urinal C formed an ellipse of axes 0.0445 and 0.0317 m (1 3/4 and 1 1/4 inches). See Figure 7.

Downstream of the urinal a Fairchild designed vortex urine-air separator Figure 8, was utilized as the primary separation mechanism. In series with the vortex separator was a membrane filter separator that acted as a back-up and measured any possible carry-over of urine thereby providing a measure of vortex efficiency. Finally, a blower exhausted air back to the cabin through a sound muffler. No attempt was made to pump urine from the separator during zero-g. After collection and measurement at 1G, urine was vented overboard.

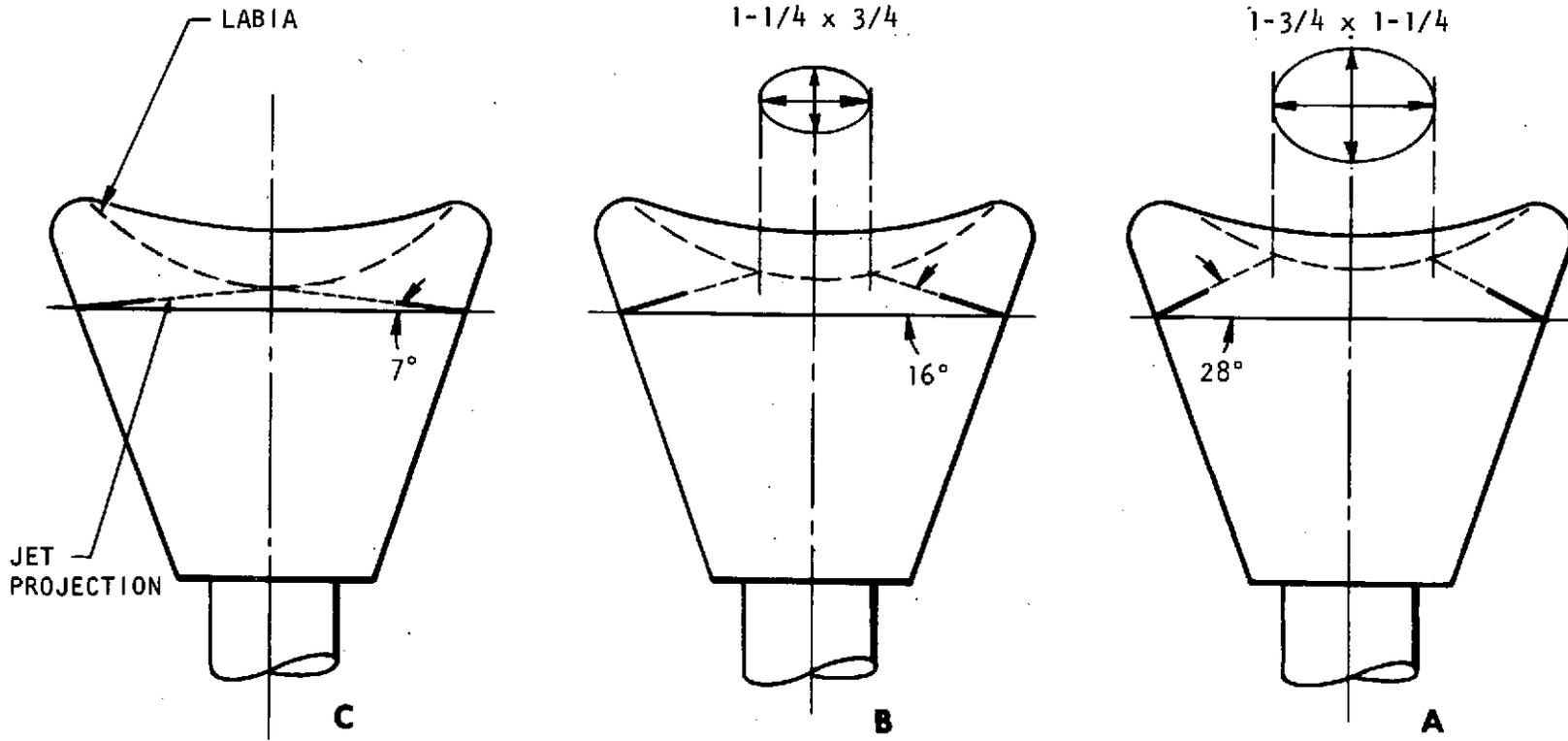
Airflow rate was measured using an orifice plate with parallel gauges inside and outside of the enclosure. The differential pressure across the urinal was also displayed and served as a measure of the urinal air seal for both test subject and test crew. A simultaneous decrease in "seal" pressure and increase of flow pressure implied that the subject did not have a urinal seal. Other instruments mounted outside the enclosure and photographically recorded included a cabin temperature gauge, altimeter, blower voltage gauge and an accelerometer for "zero-g" indication.

Two cameras recorded the urinations during the zero-g maneuver. One camera mounted in front of the subject looked downward at the front face of the urinal. The second camera placed to the subject's left and forward, sighted up below the thigh and knee. Windows in the urinal outer shell afforded a clear view of the collection.

5.2 PROCEDURES

Before each flight a test strategy was formulated in which an initial condition of urinal type and airflow rate was selected and a matrix of optional test conditions devised to guide the choice of subsequent test conditions based on the results of previous tests. The following test procedure was followed for each individual test:

- (1) The urinal type to be tested was installed and the test airflow rate set.
- (2) The senior USAF Reserve Flight Nurse volunteer selected the test subject on the basis of readiness.
- (3) The subject entered the test enclosure, removed her flight suit and mounted the test rig. She was equipped with a headset to communicate with the test director, flight director, and with the flight safety nurse who was stationed just outside the enclosure curtain.



JET INTERCEPT AROUND URETHRA FOR VARIOUS JET ANGLES

Figure 7. Jet Intercept Around Urethra for Various Jet Angles

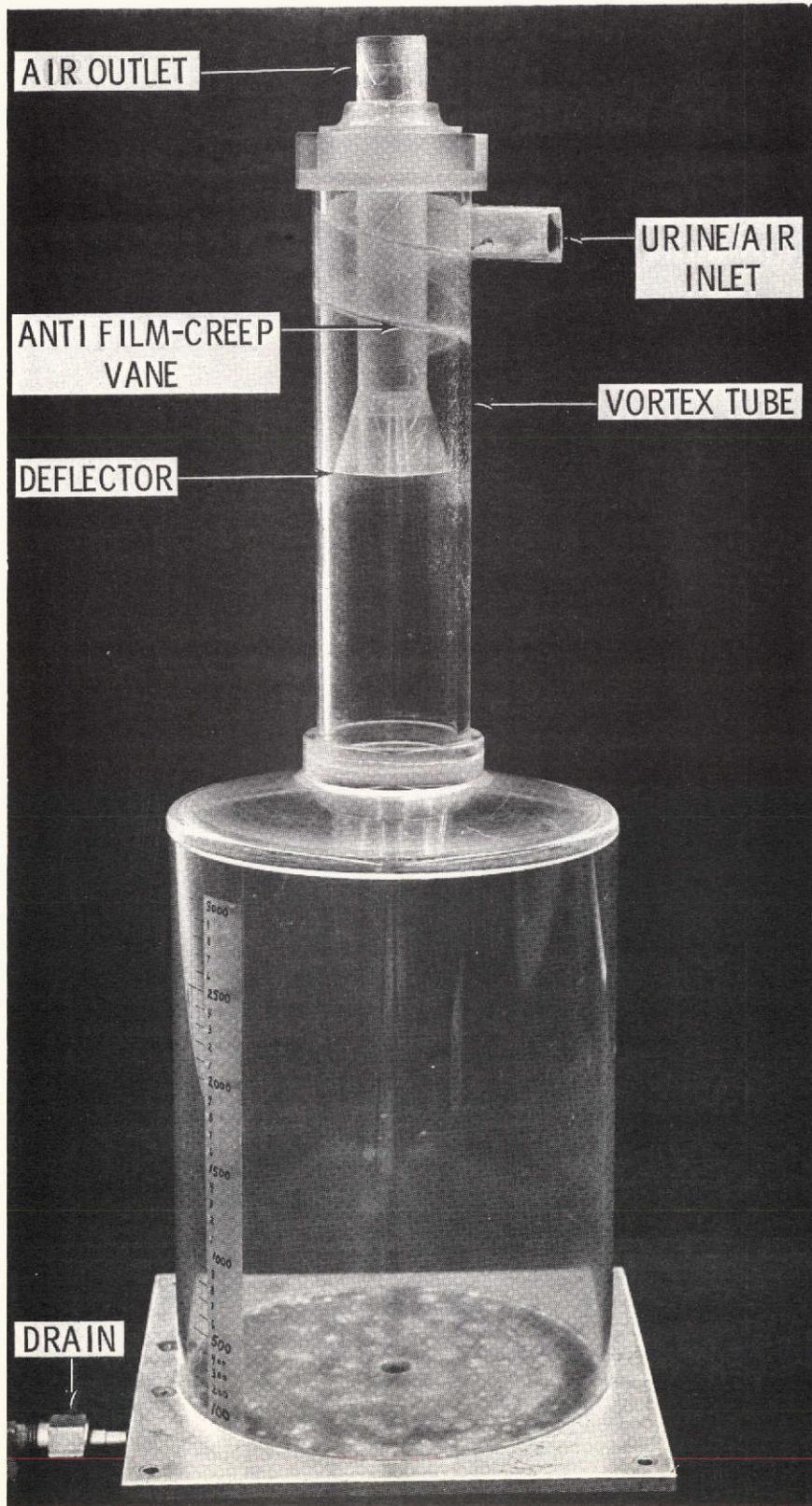


Figure 8. Urine/Air Vortex Separator

- (4) When the subject indicated readiness, the flight director gave the order to begin the parabolic maneuver.
- (5) At the onset of zero-g, lighting and cameras were automatically activated and the subject instructed to attempt a voiding.
- (6) During the parabola, the test conductors monitored the instrument panel to check airflow, urinal seal, and perturbations from zero-g. If a voiding occurred, it could be detected by fluctuations in seal and flow gauges. If a voiding terminated in the zero-g phase the subject was instructed to perform a zero-g wipe, which when weighed would serve as a basis for estimating the residual urine volume in the pubic area. The test director recorded any comments made by the subject.
- (7) At the end of the zero-g phase, the subject was instructed to interrupt a voiding if in progress, and in consultation with the test director made a decision to either terminate the test or continue directly into another parabola for the resumption of voiding or for another attempt. Up to eight parabolas were flown, as required, to complete the test.
- (8) Following the test, the subject dismounted, dressed, and discussed the test with the test director, while inside the enclosure the urine volume was measured and the urine dumped. The test rig was examined for any evidence of urine leakage and then cleaned in preparation for the next test. On the basis of the discussion with the test subject, the evidence in the enclosure, and any mitigating circumstances observed on the instrument panel, an estimate was made of the success of the run, and a decision made as to which option of the flight test plan to pursue.
- (9) At the conclusion of the flight, a debriefing was held in which the test subjects gave a written evaluation of their test in terms of comfort, ease of use, inhibitions, and contamination. General comments were also solicited.

6.0 TEST SUBJECTS

Sixteen female test subjects participated in the flight tests. They represented a fairly wide range of physical types varying in height from 1.52 to 1.75 m (60 to 69 inches) and weight from 49.0 to 72.6 kg (108 to 160 pounds). Potential female shuttle crew members are likely to fall within this range. None of the subjects had a history of urological disorder. A number of subjects were menstruating during the tests but there were no comments of any difficulty encountered. All subjects were able to adjust the urinal for a good seal without prior training. Table 1 gives the physical characteristics of the female test subjects.

The physical attributes of the male subjects were not considered a factor in successful male urine collection.

TABLE 1. PHYSICAL CHARACTERISTICS OF TEST SUBJECTS

<u>ID</u>	<u>Age</u>	<u>Weight</u>	<u>Height</u>
1	25	63.1 kg (139 lbs)	1.65 m (65 in.)
2	39	61.2 (135)	1.63 (64)
3	32	61.2 (135)	1.65 (65)
4	27	49.0 (108)	1.59 (62.5)
5	30	64.4 (142)	1.74 (68.5)
6	26	59.9 (132)	1.65 (65)
7	37	69.9 (154)	1.75 (69)
8	28	63.5 (140)	1.75 (69)
9	43	72.6 (160)	1.73 (68)
10	27	56.7 (125)	1.68 (66)
11	21	53.1 (117)	1.60 (63)
12	26	52.0 (115)	1.60 (63)
13	28	59.9 (132)	1.52 (60)
14	28	63.5 (140)	1.68 (66)
15	35	61.2 (135)	1.65 (65)
16	23	52.0 (115)	1.70 (67)

7.0 FLIGHT TEST RESULTS

Eight test flights were made between 3 December 1973 and 12 December 1973. Eighty-four tests were conducted during a total of 280 parabolas. Voiding was accomplished in 67 tests over a total of 145 parabolas. In general the testing was accomplished with a minimum of difficulty and the results showed that collection could be efficient without cabin contamination or excessive wetting of the pubic region.

The test conditions introduced some difficulty in evaluation in two respects. The 1-1/2 -2 g forces immediately before and after the zero-g parabola caused discomfort in a semi-squat sitting position designed for zero g. During the 'zero-g' portions of the flight there were some perturbations as well as a continuing tendency for a downward and rearward drift. Since the test subject was facing forward, the drift imposed a burden on the collection system, particularly at low airflow.

Most test subjects were introduced initially to the test rig during the flights without proper pre-flight indoctrination. All subjects were able to achieve an adequate urinal air seal despite the fact that the test films reveal that the urinal was not always positioned to best advantage. All test subjects found the urinal easy to adjust and comfortable.

The semi-squat position was considered by many subjects to be unnatural. Therefore, a lowering of foot height was accomplished after the third flight day. While this seating position allowed excellent photographic coverage and was adjudged to be significantly more comfortable than the original position, test films showed that a forceful urine stream impacted high on the urinal wall thereby indicating a still lower foot position was feasible. Subsequent 1-g testing showed that good collection was possible at a greatly reduced foot height.

The test matrix is given in Table 2 for the three urinal types and three airflows tested. The urinal type for male subjects was immaterial since the jets were essentially inoperative because of lack of contact.

Of the three urinal types as shown in Figure 7, Urinal A was considered to provide the best female collections. This urinal had the steepest jet angle, 28°, and least dead air space. It gave the largest interception ellipse, 0.0445 x 0.0317m (1-3/4 x 1-1/4 inches), around the urethra and could consequently easily accommodate large variations in positioning. Good results were obtained at all airflow rates tested with Urinal A. At low air flow collections were better than either of the lower jet angle

urinals, Urinal B, 16° jets, or Urinal C, 7° jets. Urinal A performance improved with increasing airflow and was excellent at the highest airflow. With the low angle urinals, whereas collection improved at intermediate airflow, the results were not uniformly good at the highest airflow rates. Apparently a shearing action by the air jets intercepting the urine stream or wetted labia causes splashing within the urinal. Urinal C with its air jets virtually tangent with the labial surface is particularly susceptible.

The tests were designed to produce the most data at the probable best airflow and to determine the lower limit of airflow for satisfactory collection. Higher airflows were not investigated because of flight time limitations. The $0.94(10^{-3})\text{m}^3/\text{sec}$ (2 SCFM) airflow rates, while producing some good collections, was probably the lower limit for collection.

TABLE 2. TEST MATRIX

Airflow	Female Subjects									Male Subjects		
	Urinal A			Urinal B			Urinal C			T	V	P
	T	V	P	T	V	P	T	V	P			
$0.94(10^{-3})\text{m}^3/\text{sec}$ (2 SCFM)	4	2	6	5	3	9	-	-	-	-	-	-
1.42 " (3 SCFM)	15	10	16	13	10	27	15	14	34	5	2	4
1.89 " (4 SCFM)	11	11	22	9	8	11	3	3	8	4	4	8
Totals	30	34	44	27	21	47	18	17	42	9	6	12

T = No. of Tests

V = No. of Voids

P = Total No. of Parabolas with Voids

The male collections, as expected on the basis of Skylab results, were uniformly good. Any urinal shape or airflow that gave satisfactory female collections would serve for male collection.

An estimate of urine residual volume in the pubic area was obtained by weighing the wipes that were made during zero-g. These wipes indicated a volume of approximately 0.5 ml. This compares favorably with ground testing results of 0.3 ml. A large quantity of wipes should not be required for clean-up.

8.0 CONCLUSIONS

The zero-g flight tests of the male/female urine collection system demonstrated that satisfactory collections could be made at modest airflow rates. The intimate contact urinal for female use assured that cabin contamination was avoided. The system required a minimum of training since positioning was easy and straightforward. The seating position will be modified for greater comfort.

9.0 RECOMMENDATIONS

9.1 SITTING POSITION

In view of the negative attitude toward the semi-squat position despite its functional advantages, the severity of the squat should be relieved to increase its acceptability. The flight test films reveal that the positive separation of urine and feces collection would be more than adequate. When a forceful urine stream was established, it often impacted high up in the urinal. Ground tests were undertaken after the flight tests to establish the extent to which the seating position could be modified and still result in good collections. Figure 9 shows the sitting posture selected as being both comfortable and efficient in collection. Zero-g use, in which collection is less difficult, is expected to be equally successful. Figure 9 also compares the revised seating position recommended for future use to the previous semi-squat positions and to the Skylab position.

9.2 URINAL TYPE AND AIRFLOW

Urinal type A with air jet angle of 28° is recommended as the basis of an ultimate Shuttle seat. It would be modified to accommodate a flushing system. The airflow rate recommended would be $1.9(10^{-3}) \text{ m}^3/\text{sec}$ (4 SCFM) with a tolerable variation of $\pm 0.5(10^{-3}) \text{ m}^3/\text{sec}$ (± 1 SCFM).

9.3 FUTURE WORK

9.3.1 Urine Transport

The tests verified the basic collection concept and provided the data required to design the Shuttle collector. There is one area in which additional work is required--the transport of urine from the urine/air separator to a storage tank at zero-g against a substantial back pressure. The vortex separator appeared to work efficiently in terms of urine carry-over in the air outlet line. What is required, is a control system to operate a urine transfer pump to minimize the residual urine volume in the separator and also minimize the air carry-over to the storage tank. Several urine level sensing techniques are feasible based on conductivity or the dynamic properties of the rotating urine in the separator. Zero-g flight test of a transport system would be desirable to verify its operation.

9.3.2 Urinal Flush System

For long term missions, urinal flushing between uses may require prohibitively large water volumes, unless a source of a suitable waste water (e.g. condensate) were

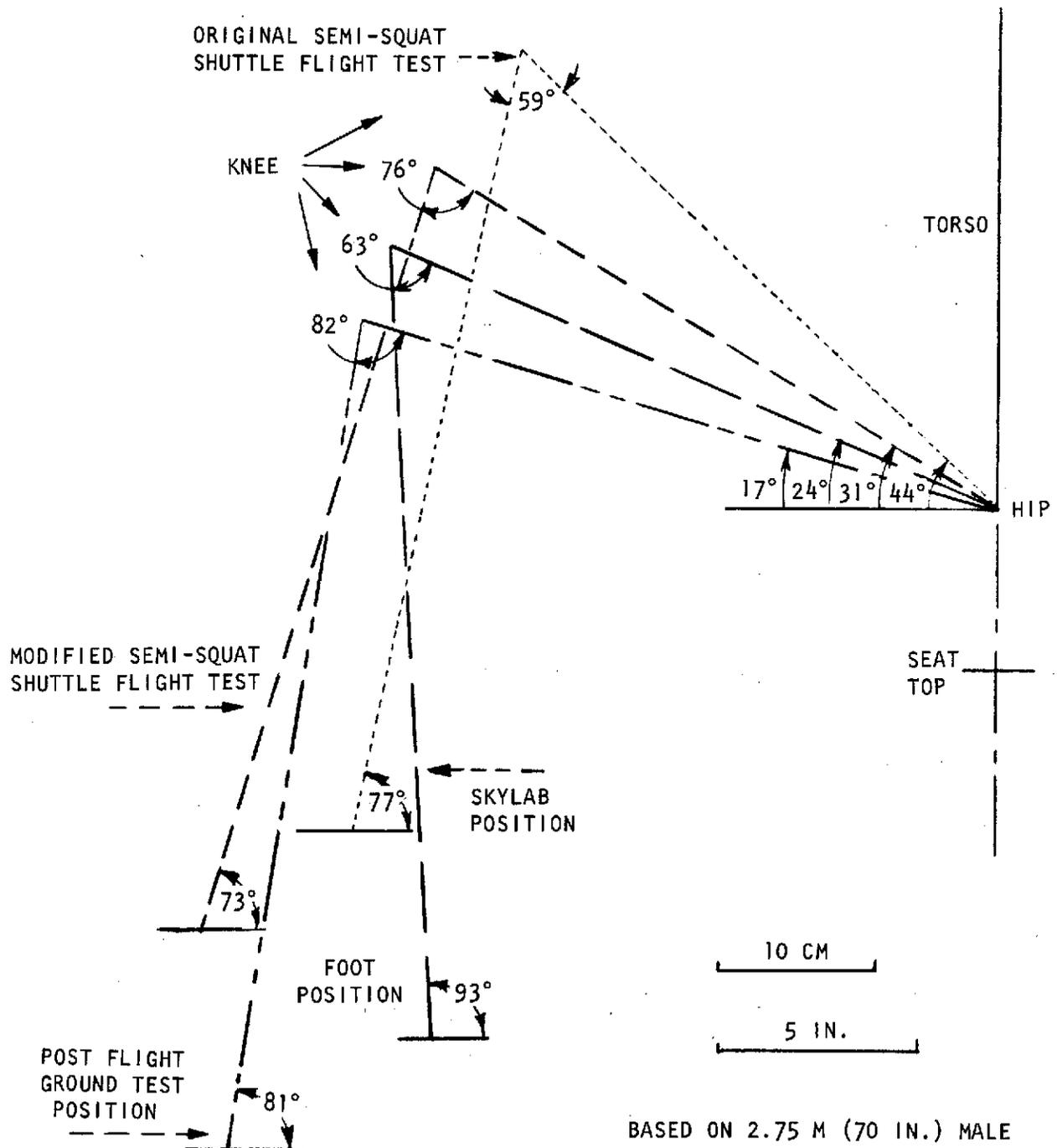


Figure 9. Post Flight Shuttle Sitting Position Compared to Flight Test

available. It may therefore be necessary to develop either an acceptable wiping technique or a re-usable flush system. Any system to be acceptable must be simple to operate, require a minimum of crew handling and be bacteriologically effective. In addition to cleaning the urinal the flush system may be required to inactivate the urine to prevent gas formation in the storage tanks.

A wipe system is probably the less complex approach but would have a lower crew acceptability. A recirculating system is complicated by the requirement for a liquid-gas separator. A zero-g test program would be desirable for any liquid flush system to demonstrate adequate coverage of the urinal walls and to optimize biocide quantities.