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SPACELAB 4 - PRIMATE EXPERIMENT SUPPORT HARDWARE

✓ Paul R. Fusco and Richard J. Peyran

ABSTRACT

A squirrel monkey feeder and automatic urine collection system have been designed to fly on the Spacelab 4 Shuttle Mission presently scheduled for January 1986. Prototypes of the feeder and urine collection systems have been fabricated and extensively tested on squirrel monkeys at the National Aeronautics and Space Administration's (NASA) Ames Research Center (ARC). The feeder design minimizes impact on the monkey's limited space in the cage and features improved reliability and biocompatibility over previous systems. The urine collection system is the first flight qualified, automatic urine collection device for squirrel monkeys. Flight systems are currently being fabricated.

INTRODUCTION

The changes in fluid and electrolyte balance that occur during spaceflight are among the most prominent physiological changes induced by weightlessness. Evidence from premaned spaceflights suggest that weightlessness produces an abnormal distribution of body fluids leading to higher than normal excretion of sodium and potassium electrolytes. A new study using squirrel monkeys to examine the mechanisms responsible for the fluid shifts and changes in electrolyte balance is scheduled for the Spacelab 4 Shuttle flight, and will be conducted jointly by NASA/ARC, Harvard Medical School, and the University of California at Riverside. To satisfy the mission objectives, it is necessary to furnish a squirrel monkey cage system that not only provides for the animal's health and well-being, but also provides researchers with an accurate determination of urine output volume and content.

ARC has developed a spaceflight squirrel monkey cage system that will meet all of the mission and experimental objectives (Figure 1). This paper will focus on two of the most challenging and critical subsystems of the cage. Both of these systems have to meet the rigid materials and safety requirements imposed upon flight hardware, and the biocompatibility requirements necessary to maintain the health of the monkey in both 0-g and 1-g environments.

URINE COLLECTION SYSTEM REQUIREMENTS

Discussions between the principal investigators, the animal care consultants, and the engineering design team resulted in the following list of design requirements:

- The system must be biocompatible with male squirrel monkeys and capable of functioning properly for up to 10 days

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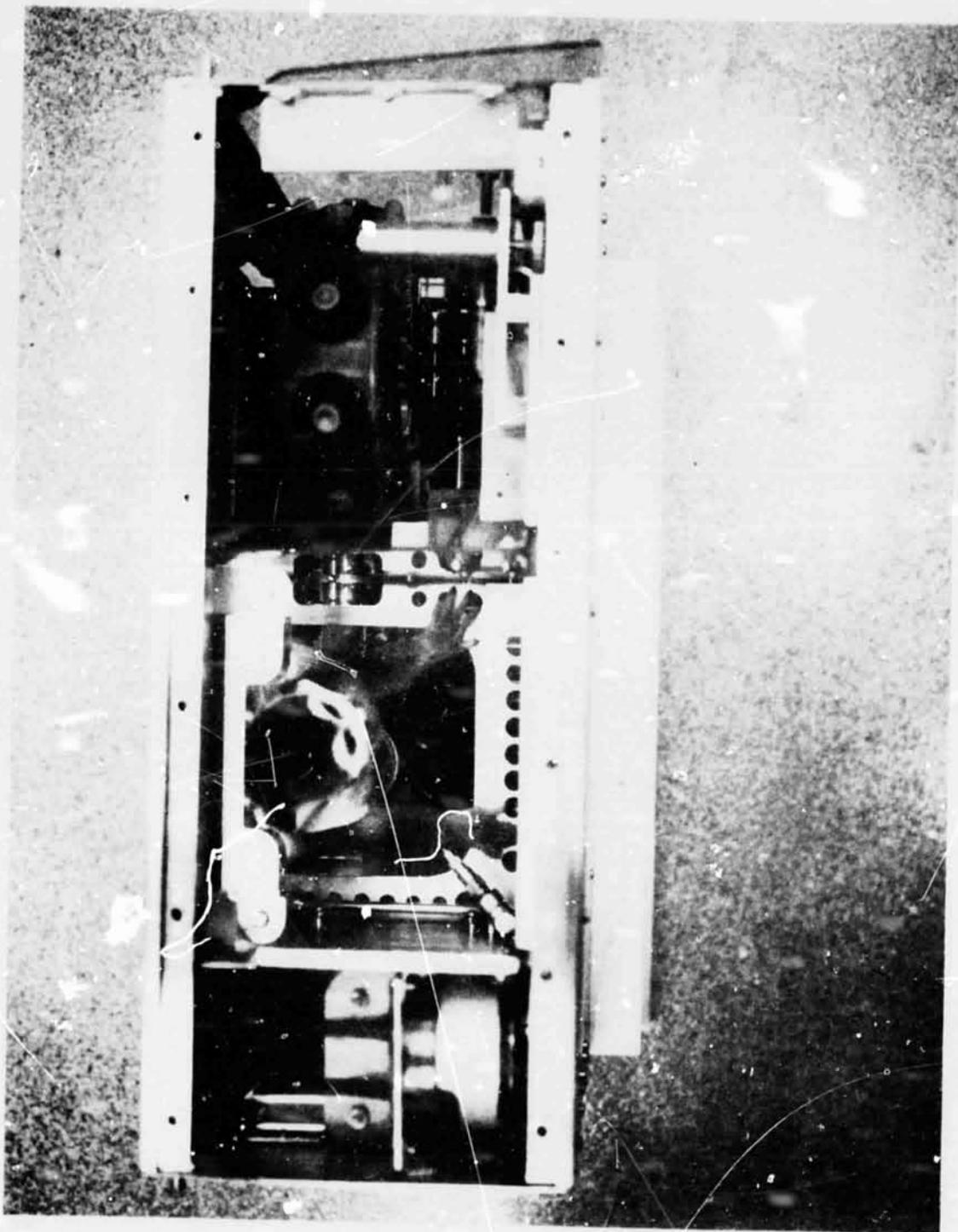


Figure 1. SL-4 Primate Cage Assembly

- The collection system must automatically collect total urine output every 4 hours
- Sample sizes may range from 0-30cc and must be totally collected with not more than 0.2cc of uncollected fluid
- The system must require minimal crew maintenance (approximately 5 minutes per monkey, once every 24 hours)
- The collection system must be compact and fit into an existing space in the primate cage
- The system must be capable of unattended operation for up to 36 hours to meet prelaunch manpower requirements
- The collection system must be capable of functioning in 0-g and 1-g environments
- The system must be lightweight, but capable of surviving extensive vibration testing at high g-levels
- All materials and lubricants must be flight approved

URINE COLLECTION SYSTEM DESIGN

APPROACH

The design of the urine collection system was divided into two integrated areas: design of the monkey-to-collector interface, and design of an automatic collector mechanism. The design of the monkey hardware interface required an evaluation of several design approaches. The most common method used to collect urine, and the one used on previous spaceflights, has been to use indwelling catheters. This approach, however, has some serious disadvantages including a high incidence of urinary infections when the catheter is left unattended for many days. Other problems include discomfort to the monkey, and difficulty with fluid movement in 0-g. As a result, it was decided that every effort should be made to develop an external catheter system that would have little, or no, influence on the monkey's natural urinary functions.

Several different collector mechanism designs were initially developed. Some used stationary collection tubes organized in a rectangular grid with a moveable nozzle that could index to the proper tube at 4-hour intervals. Problems with this approach included the need for multiple motors and a complicated control system to ensure proper indexing of the nozzle. In addition, storage of collection tubes in a flat rectangular grid did not provide efficient usage of the available space. It was determined that the space available could be used more efficiently by a system that employed a stationary nozzle and a round carousel assembly that could rotate nine storage tubes past the nozzle.

SYSTEM OPERATION

The operation of the urine collection system is shown in Figure 2. The monkey urinates at will into an external transfer tube which acts as short-term storage and a connection between the monkey and collection valve. At 4-hour intervals the collection mechanism is activated, which rotates the proper collection container into position and then translates forward. The forward motion moves the collection container towards the collection valve, forcing a needle at the end of the collection valve through the rubber septum in the end of the collection container. The collection containers are evacuated so that they will draw fluid out of the soft, collapsible transfer tube. A small (1.6 mm I.D.) tube connects to the urine valve and runs inside the larger transfer tube to prevent the vacuum from collapsing the transfer tube at the urine valve and sealing off the remainder of the tube. After a 20 second dwell time, the collection mechanism is again activated and the carousel assembly is retracted from the collection valve. The collection valve is spring loaded to close off and prevent any fluid from escaping when the carousel is not in contact with it.

Every 24 hours the flight crew can remove the carousel assembly from the collection mechanism and install fresh, empty collection containers into the carousel. The carousel is then reloaded into the collection mechanism for the next cycle.

TRANSFER TUBE

The design of the transfer tube is shown in Figure 3. The tube fits over the monkey's penis and is supported in place by an additional flange garment which straps to the monkey. The tube is fabricated from silicone rubber and has a wall thickness of approximately 0.25-0.38 mm. The tube was originally fabricated in a mold that required a two-part compound, because air and moisture were sealed out of the mold. Tear strength of the tube, however, was poor. A search for a higher strength, flight acceptable material resulted in the selection of Dow Corning compound #3144 RTV. The difficulty with the 3144 compound, however, was that it required moisture to cure and the mold was virtually sealed. A new fabrication process was developed using a mandrel the exact size and shape of the transfer tube. The 3144 compound was thinned with moisture-free naphtha to a viscosity that could be sprayed. The solution was then sprayed over a slowly rotating mandrel until cured. The finished part was then rolled off the mandrel.

COLLECTION VALVE

The urine collection valve, which provides the interface between the transfer tube and the collection containers, also serves as a penetration through a Lexan partition which seals the cage's instrumentation area from the monkey's area. The valve body forms a 90° angle (Figure 4) to minimize intrusion into the monkey's area of the cage. The valve plunger is spring loaded to provide fluid seal when not engaged with

URINE MANAGEMENT SYSTEM

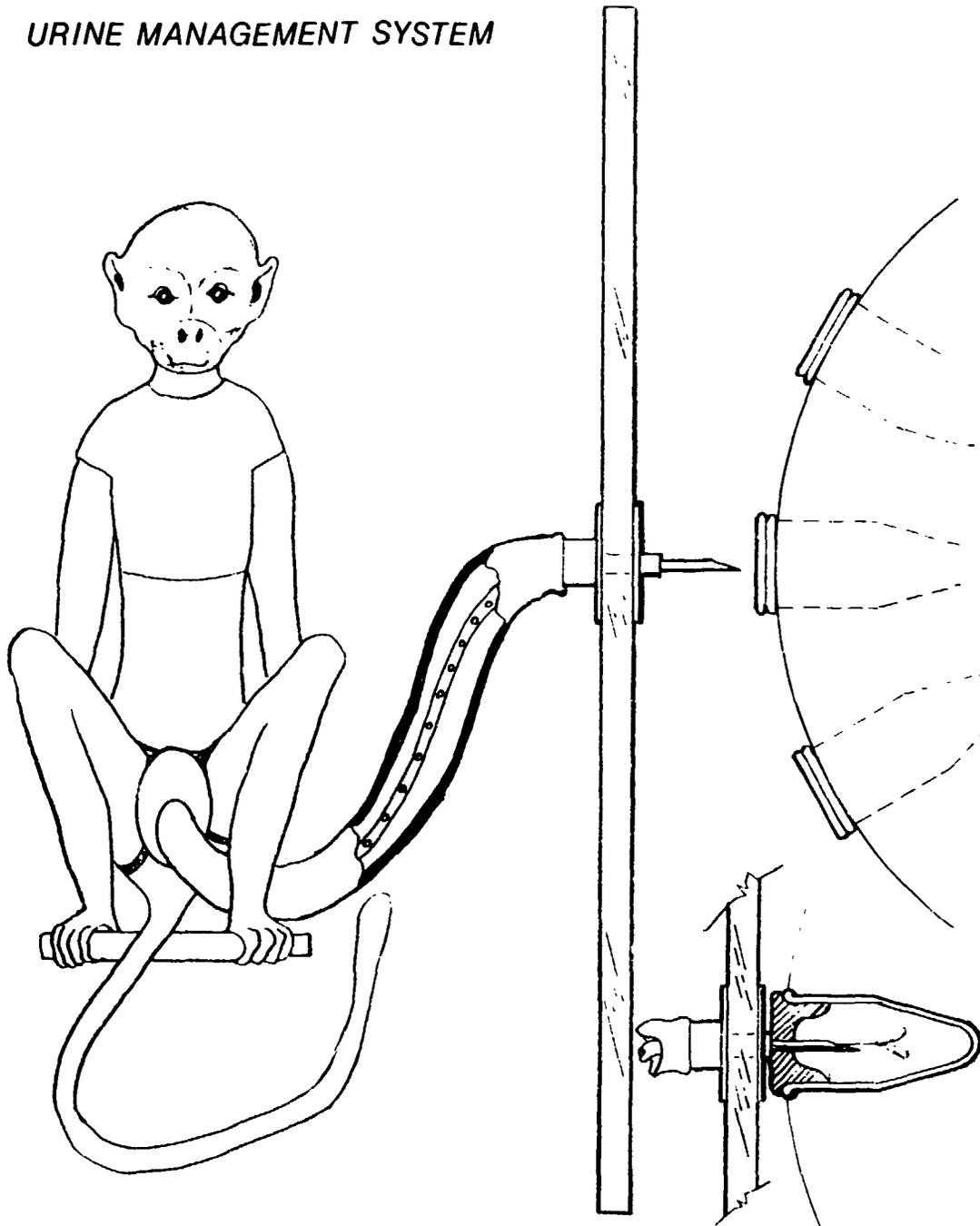


Figure 2. System Operation Schematic

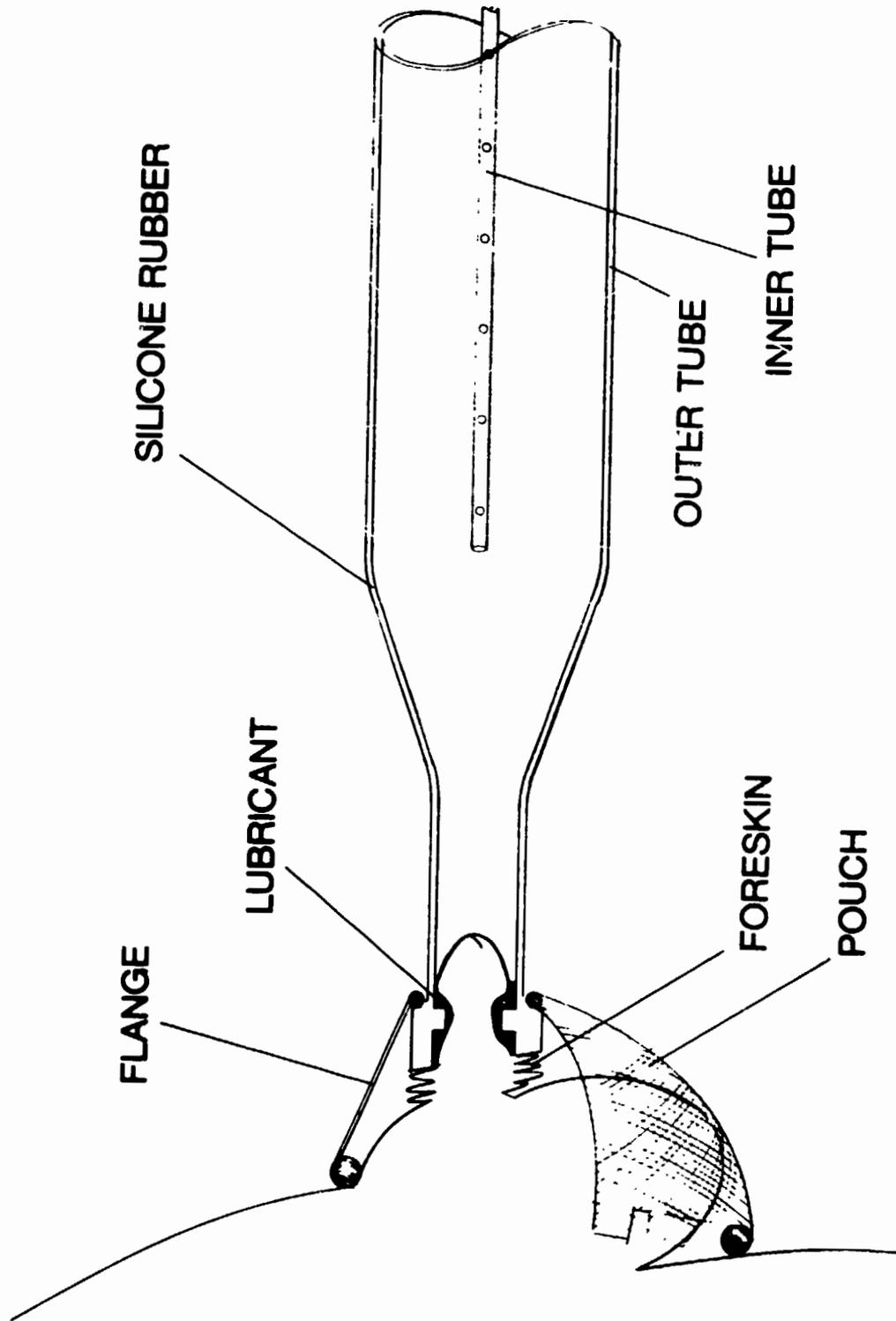


Figure 3. Tube Design

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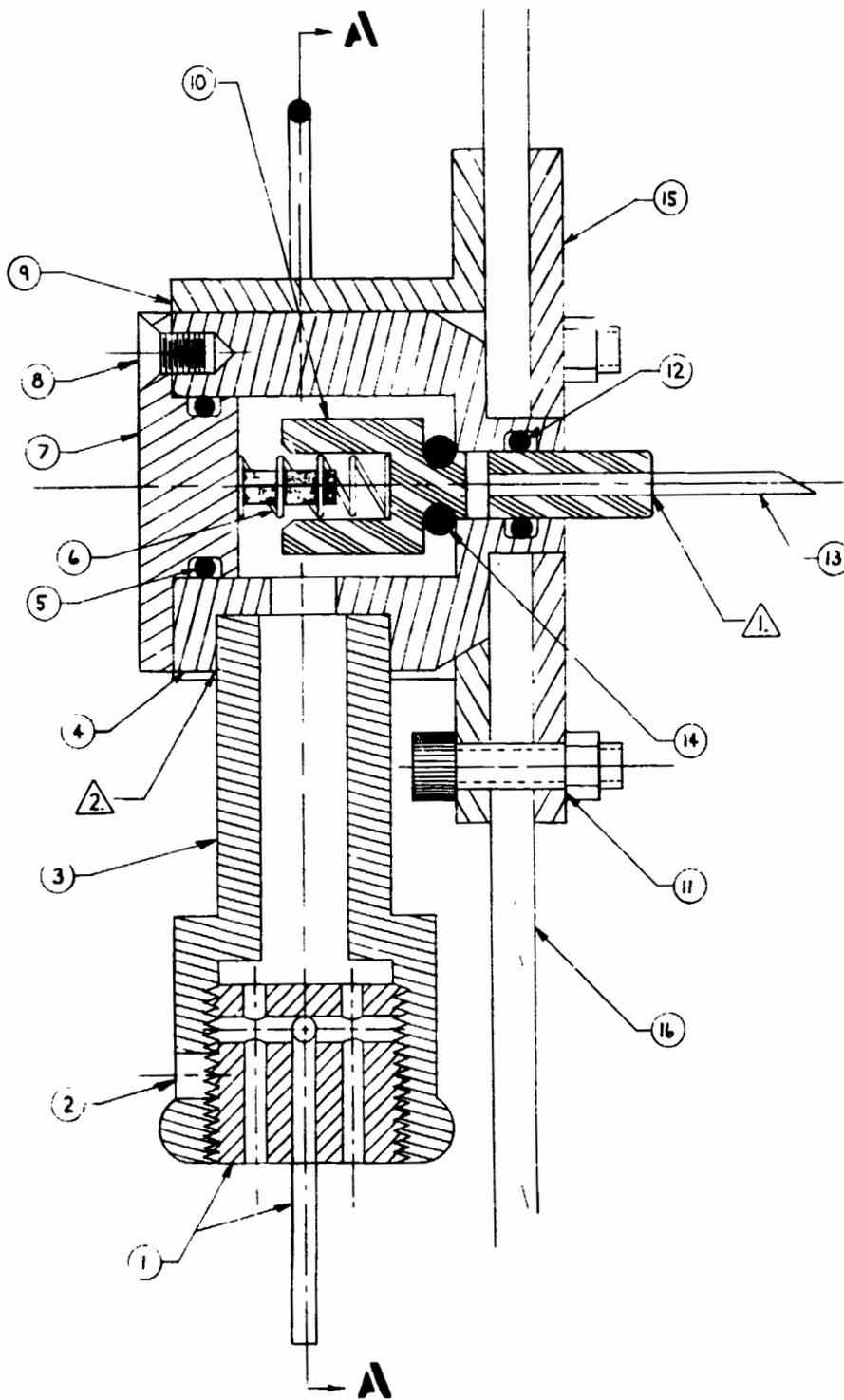


Figure 4. Urine Valve Assembly

a collection tube. A 20-gage needle, brazed into the end of the plunger enables the valve to penetrate the rubber septum on the collection containers.

COLLECTION MECHANISM

The collection mechanism is made up of three subassemblies: the collection containers, carousel assembly, and the carriage assembly. A collection container is shown in Figure 5. The container is made from Pyrex glass with a Lexan collar and a rubber stopper. The total volume of each container is 35cc. Each container is evacuated to approximately 29.0 inches of mercury, which yields a maximum fluid capacity of 33.5-cc. The collar is designed with a circumferential groove as seen in Figure 5, which enables it to be locked into the carousel assembly by a cam activated lock wire.

The carousel assembly shown in Figure 6 is capable of holding nine collection containers. Each container can be individually locked in, or released by rotating a slotted cam actuator. The assembly is made from Lexan with an aluminum geneva gear mounted on one side. An aluminum axle through the center of the carousel sits in three saddle supports on the carriage assembly, and is held secure by a pit pin through the center saddle support.

The carriage assembly is shown in Figure 7 and Figure 8. The purpose of the assembly is to rotate the carousel to the proper location for alignment of the collection valve with a stopper on the desired collection container. The carriage must then move the carousel linearly forward until the needle on the collection valve punctures the rubber stopper on the collection container. After a short dwell time, during which fluid is drawn through the collection valve into the collection container, the carriage moves the carousel back away from the valve. After clearing the tip of the needle the carousel is rotated halfway to the next location.

Initial designs of the carriage assembly called for two motors to accomplish the dual motions of the carousel. One motor would rotate the carousel to the proper location, and a second motor would rotate a lead screw driving the carriage in linear motion. High cost for space-flight electric motors and a complicated control system made this design undesirable. The final design, which couples a scotch yoke mechanism with a nine slot geneva mechanism, was developed which requires only one motor and a simple control system. A schematic of the system is shown in Figure 9a. A 3 rpm ac synchronous motor is directly coupled to the primary gear, which has a cam bearing located 15 mm from its rotational axis. The cam bearing rides in a slot on a stationary part of the carriage. The two parts perform as a scotch yoke mechanism with a total linear travel of 30 mm. Engaged with the primary gear is the geneva drive gear. This gear is the same size as the primary gear so that a 1:1 ratio is maintained. The geneva drive gear was designed to mesh with the nine slot geneva gear mounted on the carousel assembly. As the geneva drive gear makes one full revolution, the carousel

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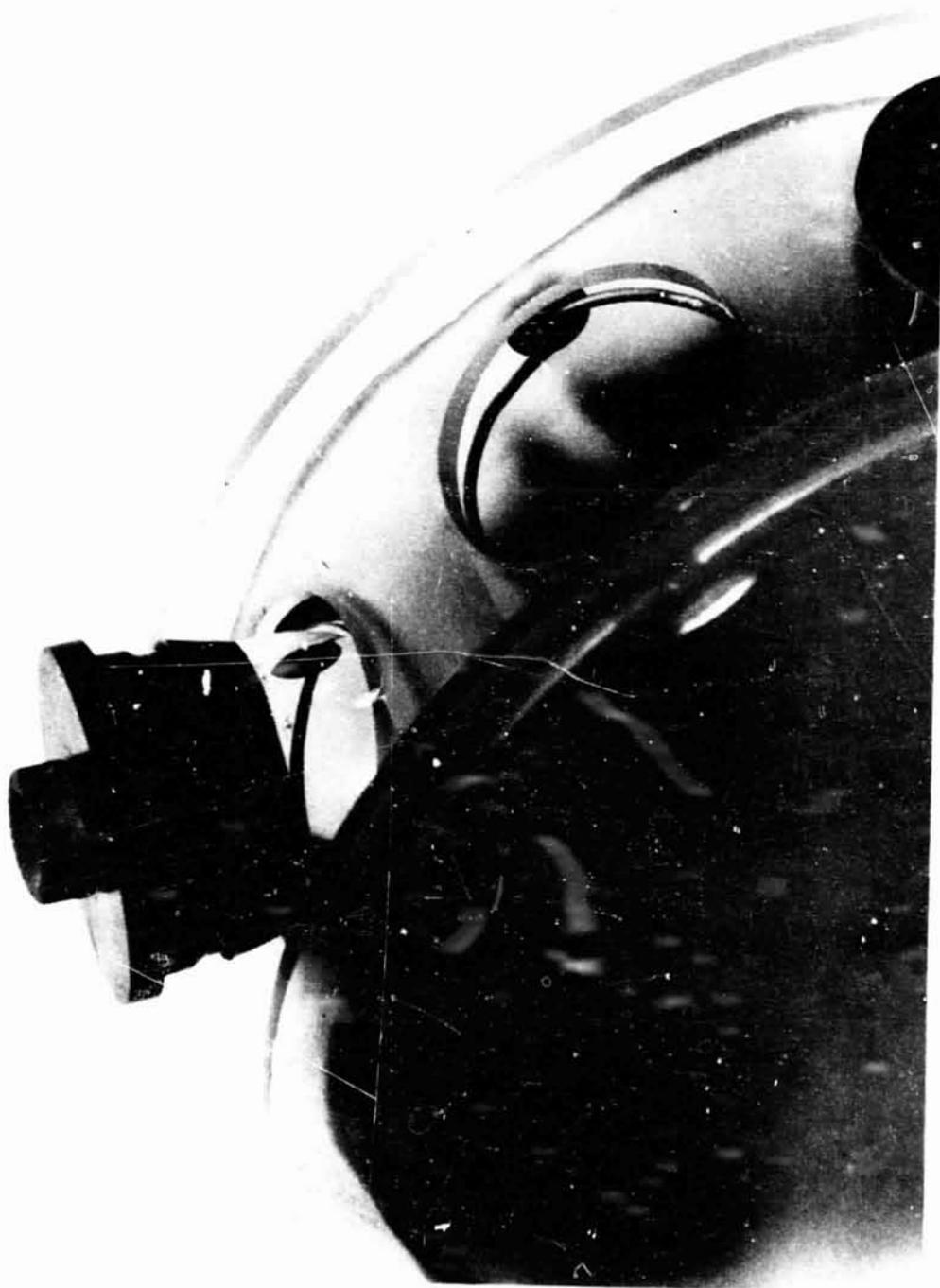


Figure 5. Collection Container and Carousel!

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Figure 6. Carousel Assembly

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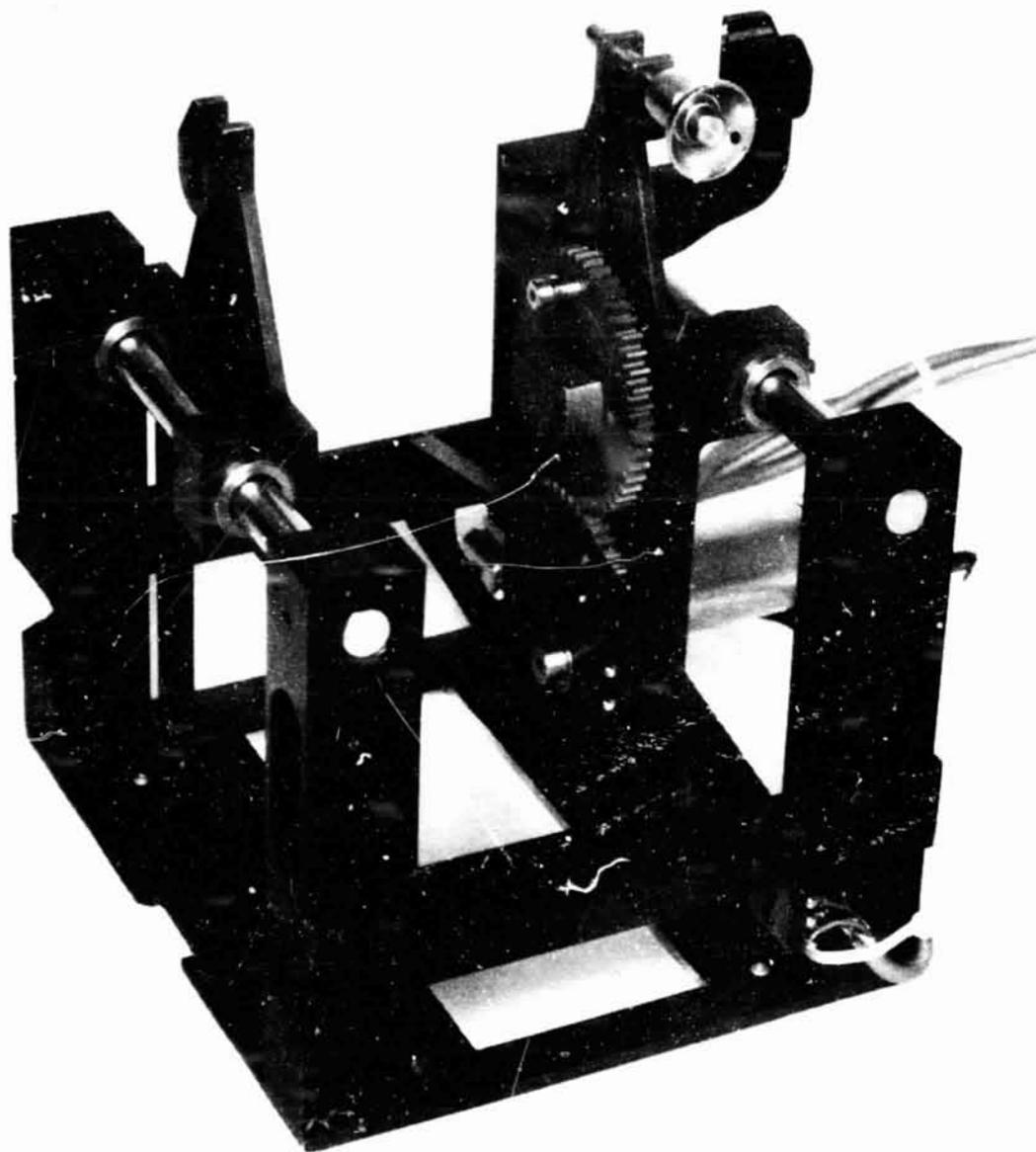


Figure 7. Carriage Assembly

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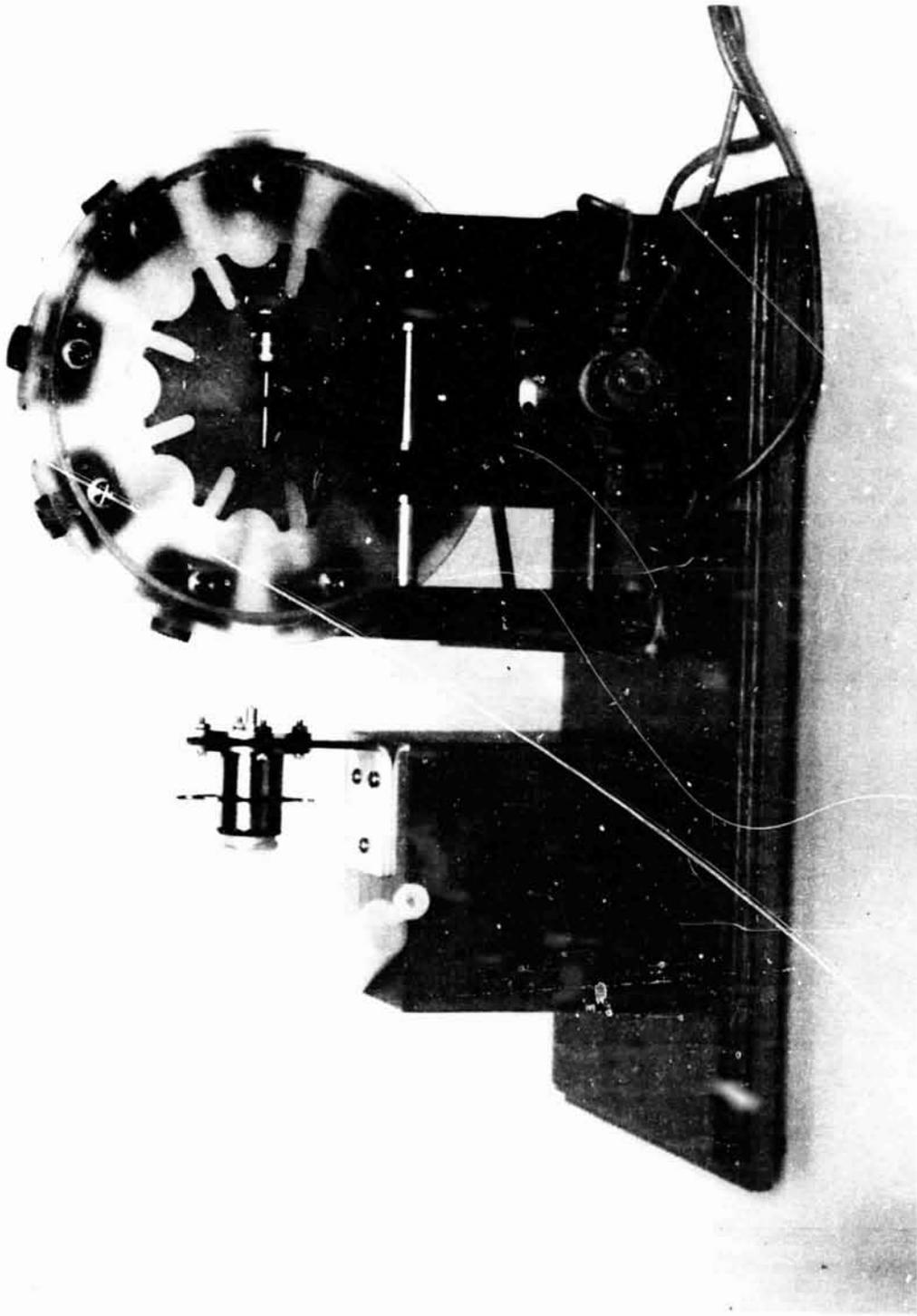


Figure 8. Carriage and Valve Assembly

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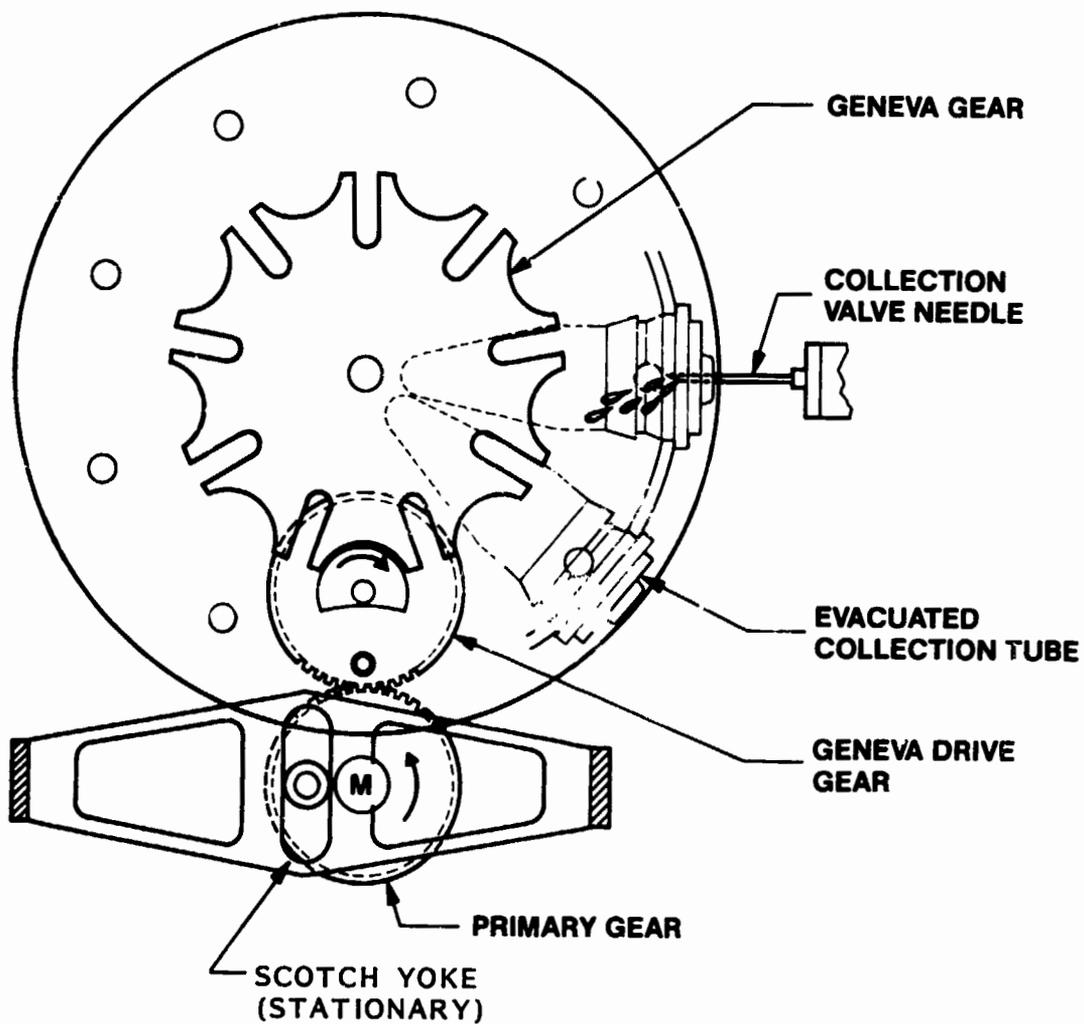


Figure 9a. Carousel Translation, No Rotation

is rotated exactly 40° . Actual rotation of the carousel occurred during only 136° of primary gear rotation. The remaining 224° of rotation is used by the scotch yoke mechanism to provide linear motion of the carousel without rotation.

By correctly timing the two gears it is possible to obtain rotation of the carousel followed by approximately 24 mm of nonrotational, linear travel into the collection valve needle. Figures 2a, 9b, and 9c show the three stages of operation. In Figure 9a, the carousel has moved its full travel into the collection valve. Figure 9b shows the carousel moved back away from the needle and just ready to start rotation. Figure 9c shows the carousel just as rotation is completed and linear movement toward the needle is in progress.

FEEDER DESIGN REQUIREMENTS

In addition to the urine collection system previously described, an effort was directed to create a squirrel monkey-feeding system that met a number of experiment objectives which included the following:

- Cage Integration - The feeder must integrate with the existing Spacelab primate cage.
- Size - Shape and size must minimize impact on the monkey's extremely limited space in the primate cage.
- Capacity - Replaceable food cartridges must hold a minimum of 600 190 mg, spherically shaped, food pellets--the minimum capacity acceptable. Crew time constraints are such that 72 hours could elapse before a feeder cartridge change could be made. The monkey usually consumes approximately 200 pellets per day.
- Biocompatibility - This requirement covers the parts of the design that interface with the monkey and affect his well being. Some of these include quiet feeder operation, a method of holding the food pellet in 0-g prior to the monkey retrieving it when he desires, and a properly designed tap switch for the monkey to advance the feeder on demand.
- Mechanical Design - The design must meet strict design requirements that cover materials requirements, structural design limits, and system reliability.
- Improvements - The feeder needed to be an improvement over previously designed feeders. One problem of some pellet type feeders is the tendency to crumble the pellets so only partial pellets are delivered to the monkey. Also food fines (dust) resulting from broken pellets could jam the feeder and halt its operation. The new feeder minimized these potential problems.

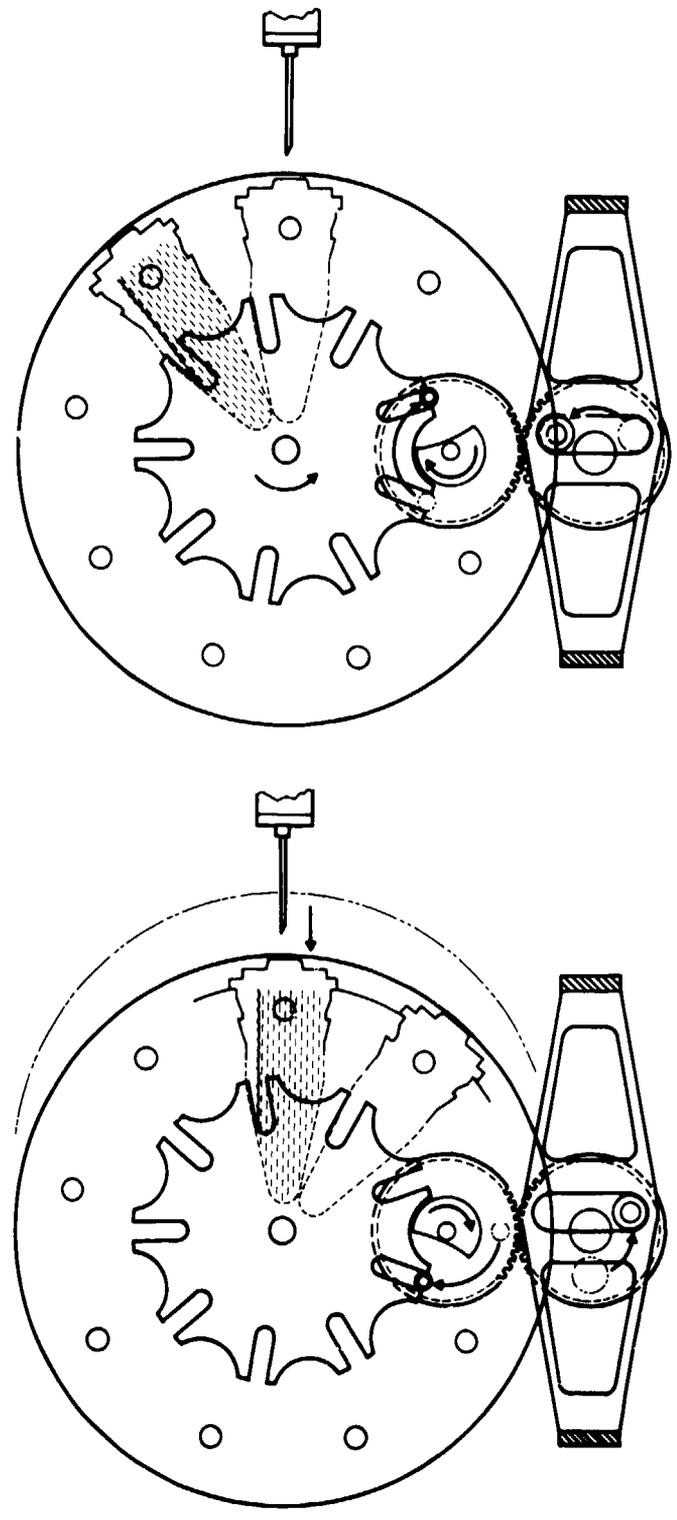


Figure 9b. Carousel Translation and Rotation
Figure 9c. Carousel Translation, End of Rotation

FEEDER DESIGN

The Monkey Feeding System designed at NASA ARC meets the design constraints imposed by the experiment and previously outlined. The system delivers one, whole, 190 mg food pellet to the monkey on demand. Food cartridges, each holding 600 pellets, are replaced during the flight by the payload specialist. The food cartridge is removed from the cage by opening the cage door (Figure 10).

The feeder cartridge (Figure 11) incorporates an endless chain made up of stainless-steel barrels, cut from seamless tubing, and joined by Lexan connecting links (Figure 12). A food pellet is loaded into the center of each barrel. The chain is routed through the feeder cartridge around aluminum sprockets with a pitch diameter of 2.72 cm (1.07 in) (Figure 13). On one end of the feeder eight sprockets freewheel; on the opposite end seven sprockets are motor driven to advance the chain. The driven chain sprockets are keyed to shafts which are all ganged to turn together by a system of spur gears (Figure 14). The pinion gear of the feeder drive motor engages a single idler gear, and as the motor turns, the chain advances, driven by seven sprockets. Driving the chain from multiple sprockets minimizes backlash and windup of the system during operation. The feeder motor is mounted permanently in the cage (Figure 15) and remains in place when a cartridge is removed. The motor is a small ac synchronous motor delivering 1.27 N-m (180 oz-in) torque at 3 rpm output speed.

The chain is advanced by the motor on the monkey's demand by a tap switch located in the monkey's compartment (Figure 16). As the chain moves, a passive, spring-loaded toggle removes the food pellets from the chain (Figure 17). The pellet is retained in a transparent, Lexan food receptacle covered with a flexible, Dacron reinforced, Silastic septum (Figure 16). The septum is slotted and the monkey can reach through to retrieve a food pellet when he desires.

A control box, located in the cage, can be adjusted to preset the number of taps required to advance the feeder (1 to 99 taps per pellet). The minimum time between feeder advances can also be set (1 to 99 seconds per pellet). This prevents a hyperactive monkey from emptying the cartridge in a very short time, and allows feeder operation to be adjusted to a particular monkey's behavior.

PROTOTYPE DEVELOPMENT

A one fifth capacity prototype was designed to demonstrate the feasibility of the endless chain feeder concept. This prototype was used to test the chain design, materials selection, and chain assembly procedures. Reliability of the system was checked using actual lab tests with squirrel monkeys (Figure 18) with the feeder mounted on a test stand. Several problems were found in the original design. The chain tended to bind occasionally going around the sprockets, and the pellet

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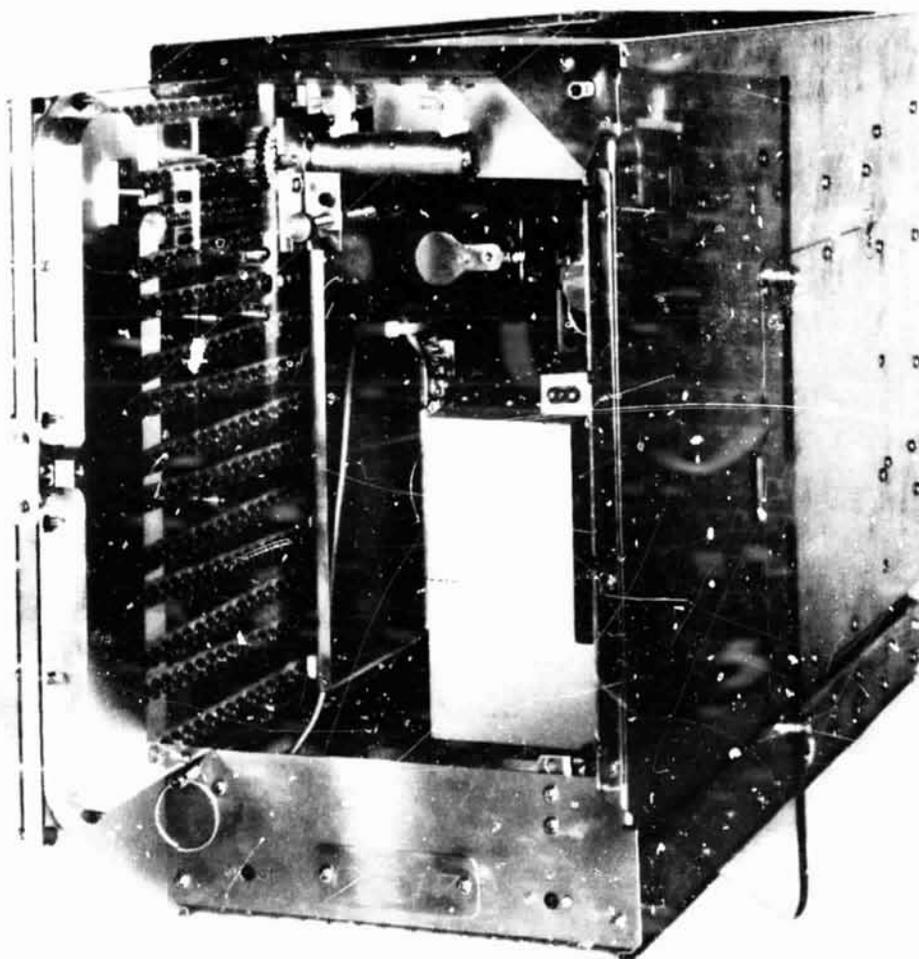


Figure 10. Feeder Cartridge and Cage

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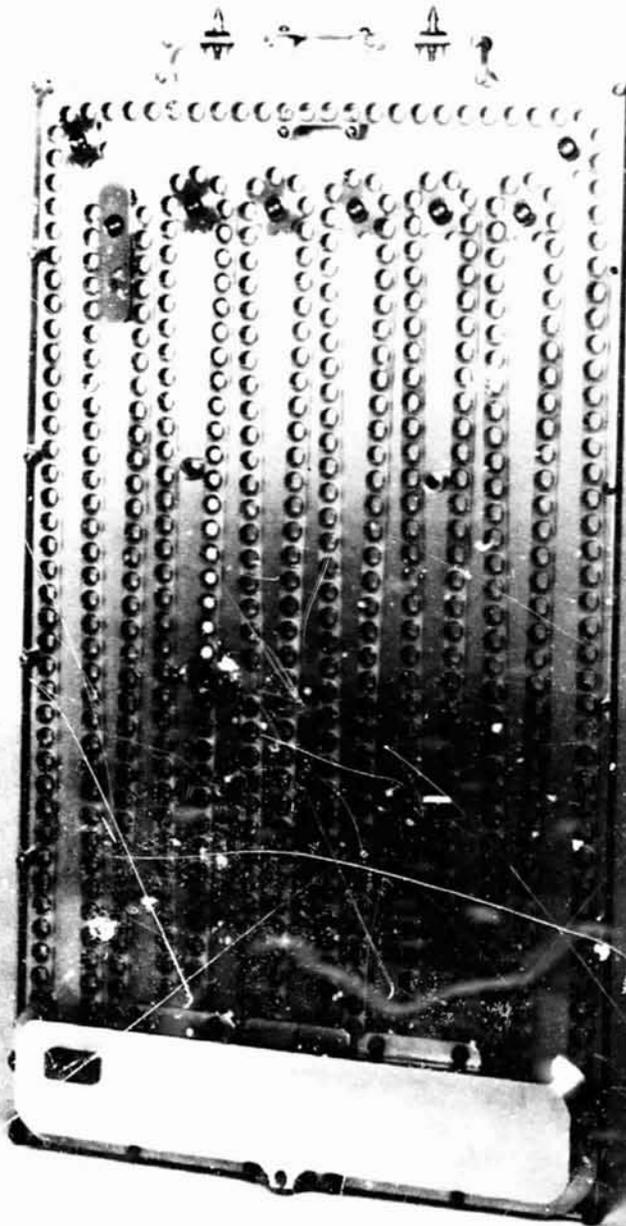


Figure 11. Feeder Cartridge

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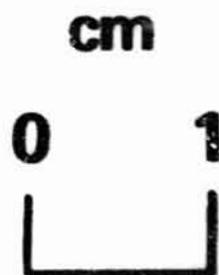


Figure 12. Feeder Chain Details

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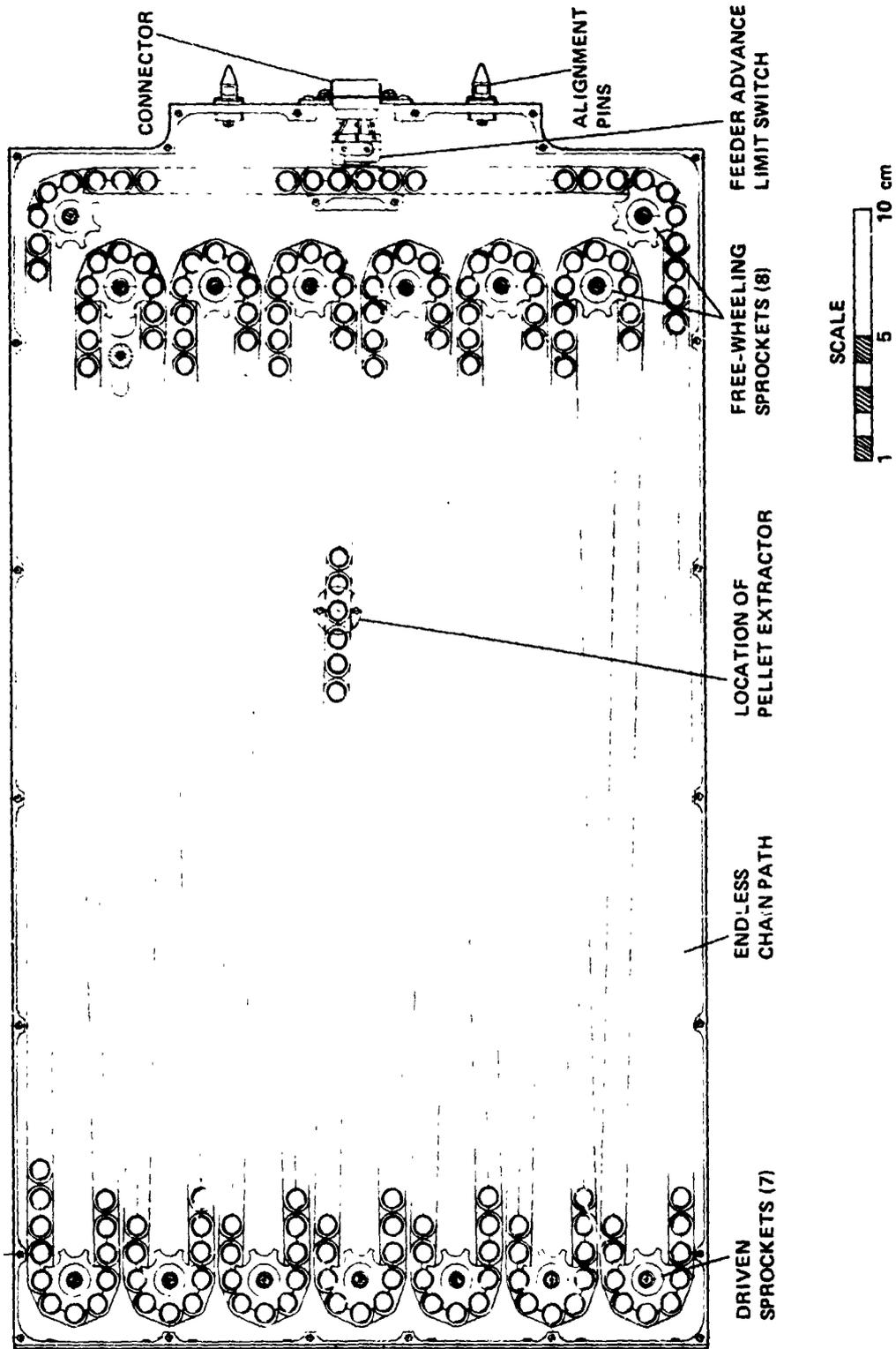


Figure 13. Internal Configuration

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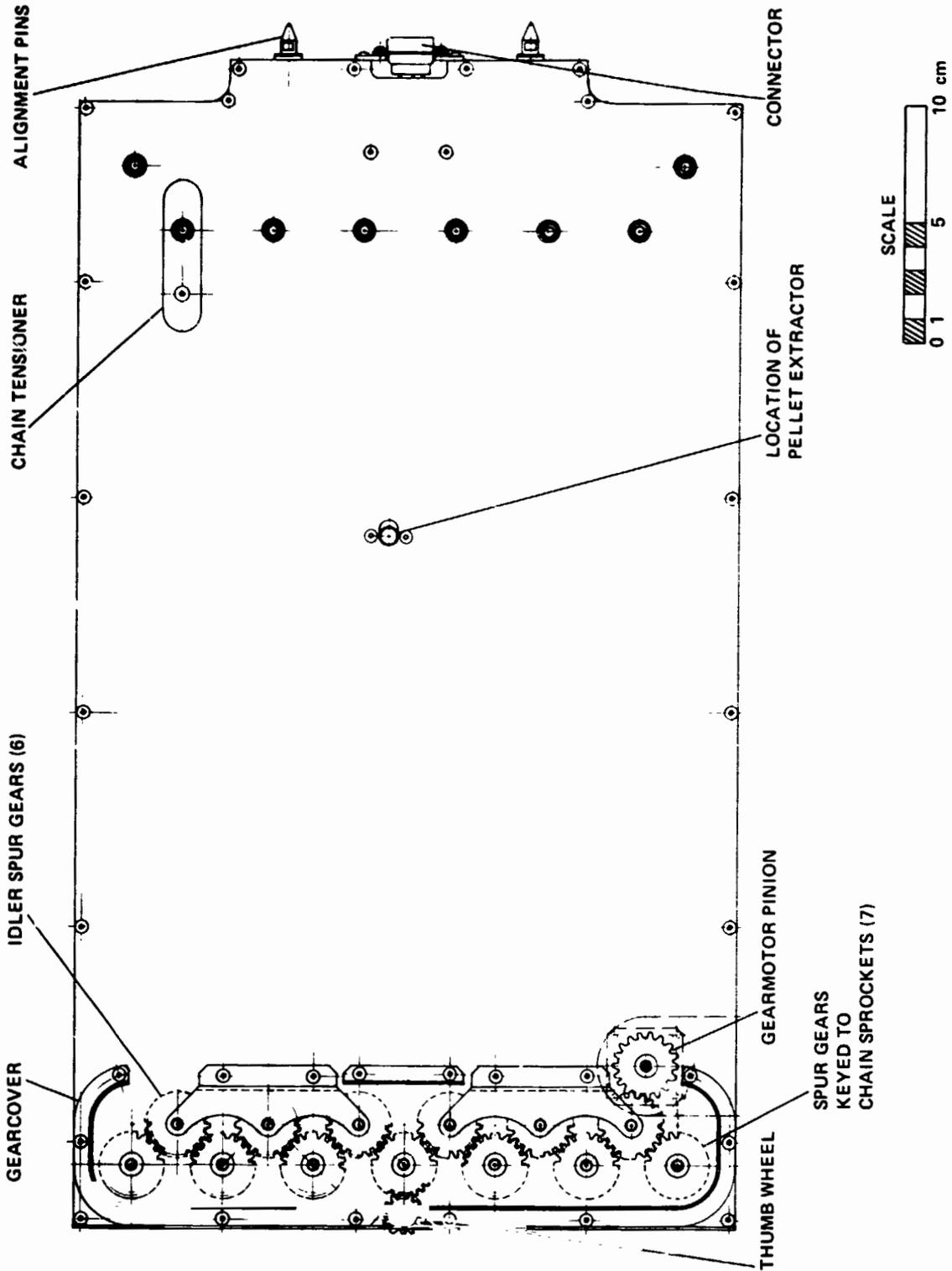


Figure 14. External Configuration

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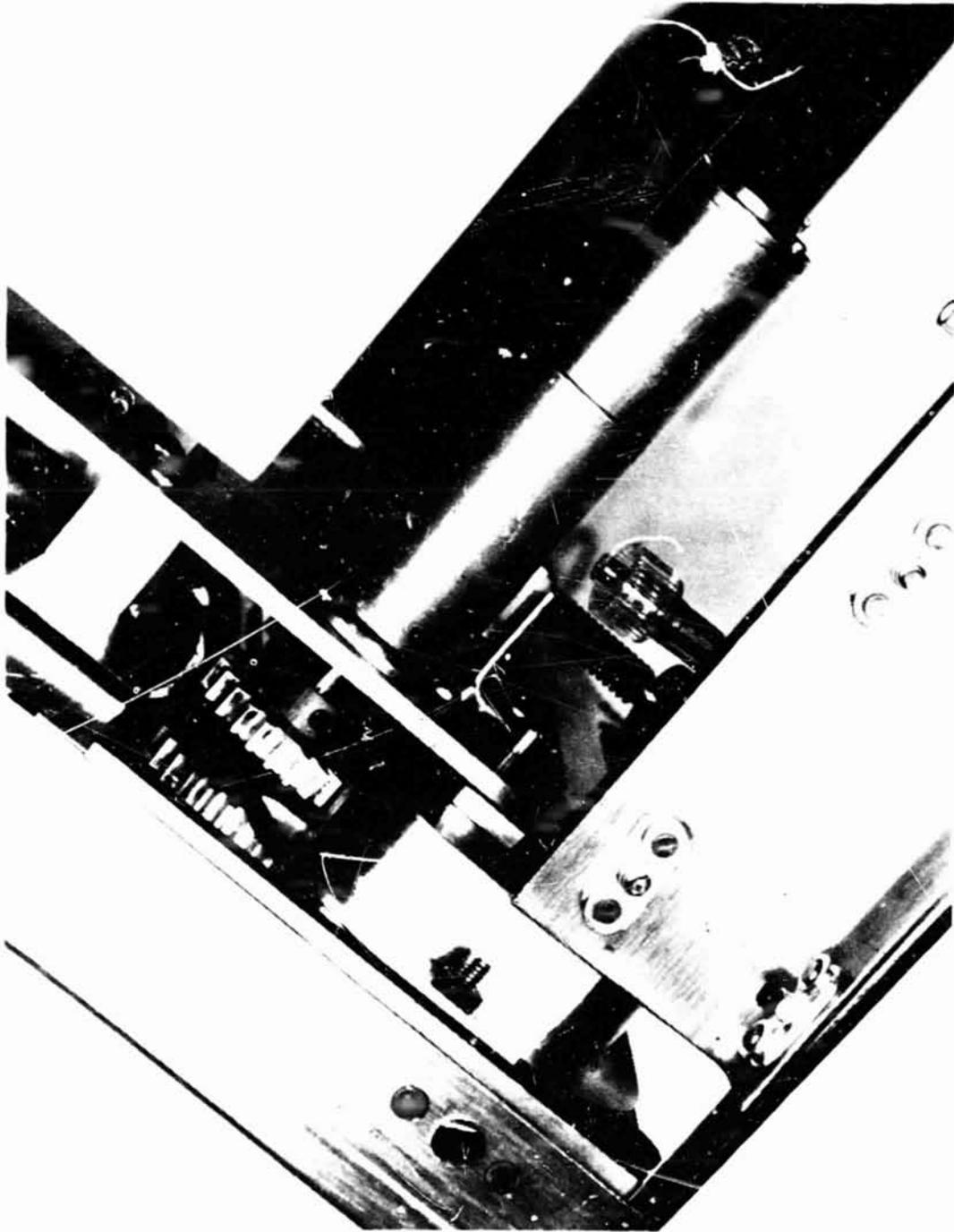


Figure 15. Feeder Motor Installation

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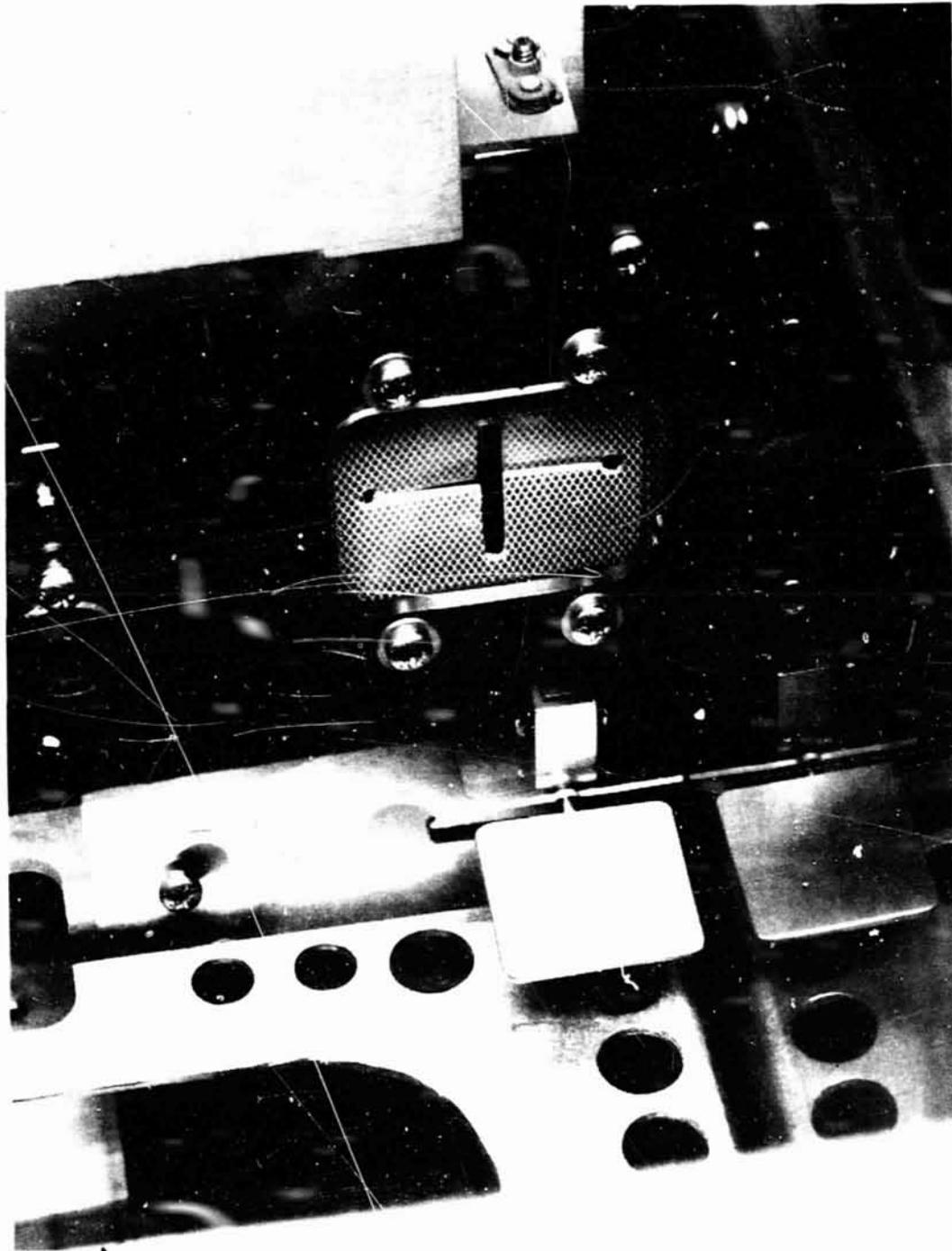


Figure 16. Tap Switch and Food Box

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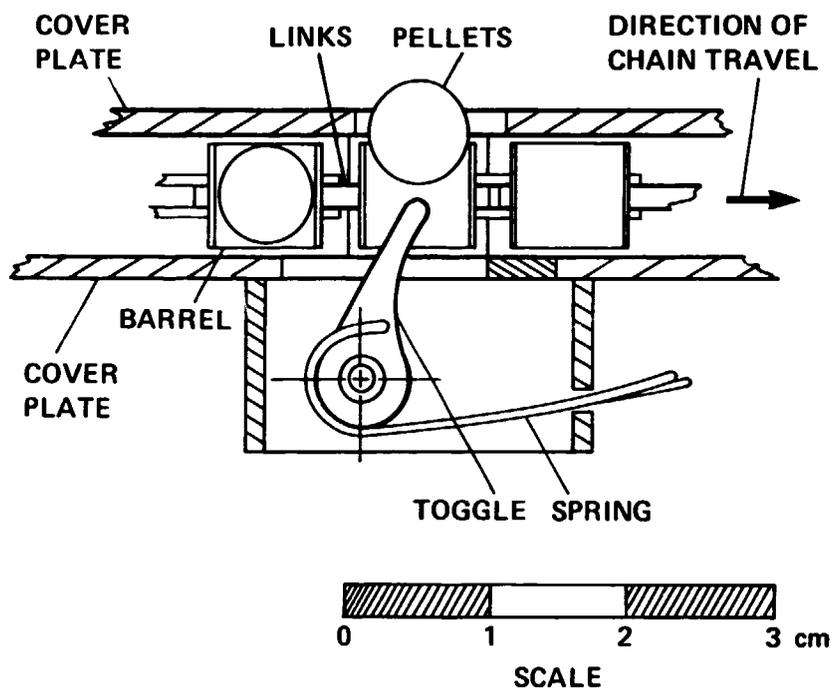


Figure 17. Pellet Extraction System

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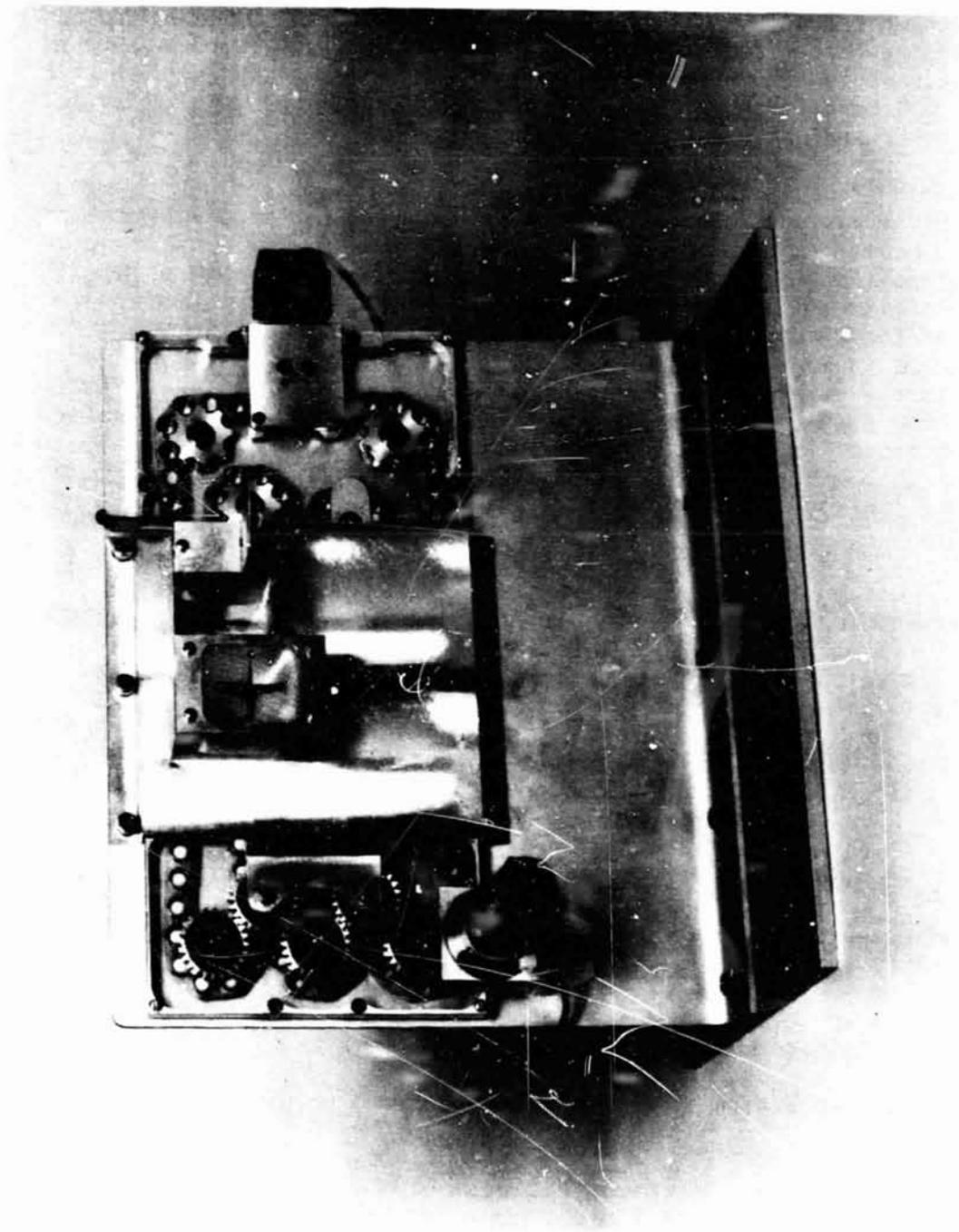


Figure 18. Test Feeder

removal spring broke from fatigue early in the testing. The original chain design consisted of two 0.152 cm (0.060 in) thick links snapped onto each barrel. The links were staggered from barrel to barrel. As the chain was tensioned the barrels tended to cant slightly, impairing their ability to pass around the sprockets. The chain design was revised by replacing the staggered links with a single 0.152 cm (0.060 in) thick link sandwiched between two 0.076 cm (0.030 in) thick links. This made a symmetrical chain which ran smoothly around the sprockets, and allowed the barrel design to remain unchanged. The pellet removal spring was radiused to eliminate a stress concentration that existed at a sharp 90° bend in the original design. With these changes, the prototype feeder performed perfectly in the lab.

Before production of 24 flight feeders, a full size flight prototype feeder was constructed. This feeder was used for cage integration and vibration testing to qualify the hardware for flight. To reduce the cost of fabricating chain links for the production feeders (21,000 links required), an injection mold was developed. The mold has eight cavities for links that are 0.097 cm (0.038 in) thick. Originally 0.076 cm (0.030 in) thick links were molded; however, it was difficult to maintain the tolerances required (+ or -0.0051 cm thick). The thicker links are easier to mold, and a single mold can be used to produce all the chain links required (three 0.097 cm thick links form the chain rather than a single 0.152 cm thick link sandwiched between two 0.076 cm thick links).

CONCLUSIONS

The endless chain feeder system and the urine collection system form a reliable experimental package that meets all the requirements of the Spacelab 4 mission. The urine collection system has several important features, including:

- The first totally automatic urine collection system for space-flight application on squirrel monkeys.
- A leak-proof system that provides up to 10 days service without any observable irritation.
- Compact design and use of only one motor for improved reliability and reduced complexity.
- Carousel assembly makes once-a-day changeouts of collection containers quick and easy.

The feeder design also incorporates several unique features including:

- Slim design (maximum thickness 2.42 cm) that minimizes the impact on monkey's limited space in the cage.

- Each food pellet is separated from other pellets, reducing chafe and excessive food fines (dust) which could accumulate and jam the feeder. In addition, the low contact force on the pellets reduces the possibility of crushing a pellet before delivery to the monkey.
- The food cup, which retains the food pellet until the monkey retrieves it, may be repositioned without significantly changing the feeder design. This will enable the feeder system to be easily adaptable to other cage configurations on future flights.

At present, fabrication of 12 flight urine collection systems and 24 feeders is underway. These units will be used for flight, ground testing, and training.