Forgotten hardware: how to urinate in a spacesuit

Hunter Hollins

Advan in Physiol Edu 37:123-128, 2013. ;
doi: 10.1152/advan.00175.2012

Adv Physiol Educ 37: 123–128, 2013;
doi:10.1152/advan.00175.2012.

Forgotten hardware: how to urinate in a spacesuit

Hunter Hollins

National Air and Space Museum, Smithsonian Institution, Washington, District of Columbia

Submitted 26 December 2012; accepted in final form 11 March 2013

Hollins H. Forgotten hardware: how to urinate in a spacesuit. *Adv Physiol Educ* 37: 123–128, 2013; doi:10.1152/advan.00175.2012.—On May 5, 1961, astronaut Alan Shepard became the first American to fly in space. Although the National Aeronautics and Space Administration (NASA) had discounted the need for him to urinate, Shepard did, in his spacesuit, short circuiting his electronic biosensors. With the development of the pressure suit needed for high-altitude and space flight during the 1950s, technicians had developed the means for urine collection. However, cultural mores, combined with a lack of inter-agency communication, and the technical difficulties of spaceflight made human waste collection a difficult task. Despite the difficulties, technicians at NASA created a successful urine collection device that John Glenn wore on the first Mercury orbital flight on February 20, 1962. With minor modifications, male astronauts used this system to collect urine until the Space Shuttle program. John Glenn's urine collection device is at the National Air and Space Museum and has been on view to the public since 1976.

history of physiology; space physiology; urine collection

FROM A POSTCARD to the National Aeronautics and Space Administration (NASA):

> February 1, 1961
> Dear Sir,
> In our science class we were talking about the first man that would go into space and we would like to know where they go to the toilet when there [sic] up in space and there's no gravity.
> Yours truly,
> Brenda Kemmerer
> Box 77
> Cherryville, Pennsylvania (12)

Brenda and her friends in science class wondered, as children still do today, but in 1961, scientists and technicians at the National Aeronautics and Space Administration (NASA) discounted the problem. Dr. Freeman H. Quimby, of the Office of Life Science Programs at NASA, replied to Brenda that "the first space man is not expected to have 'to go'" (19). The expectation of technicians was that the astronaut would urinate just before they closed his pressure suit and then hold it until he was on the rescue ship (10). For the first American space flight on May 5, 1961, NASA did not give astronaut Alan Shepard a urine collection device (UCD), and during his 4-h wait on the launch pad, he had to urinate in his pressure suit. No one knew what effect this bodily need would have on the mission, but after some rumination, the launch pad team told him to "do it in the suit" (30).

Despite the obvious, all humans have to urinate, and the agencies coordinating astronaut health and safety had a hard time creating systems to handle human waste or even discussing it in other than simplistic terms. To be fair, it was difficult to develop ANYTHING space related in the 1950s. Space was still the realm of "Buck Rogers" type fiction, and to many deemed unworthy of funding. In addition, the National Advisory Committee on Aeronautics (NACA), Air Force, Army, and Navy were independent organizations, with their own funding, their own missions, and their own priorities. NACA had been working since the end of World War I to make flying safer, and the United States (U.S.) Congress would not transform it into NASA until 1958. The Air Force excelled in experimental high-altitude, high-speed flight and was the "unquestioned leader in aerospace medicine and biotechnology" (18). The Army had Werner von Braun and his rocket team as well as the Luftwaffe physicians captured under Operation Paperclip. The Navy had the most influential training facility: the centrifuge at the Aviation Medical Acceleration Laboratory in Johnsville, PA, as well as the Naval School of Aviation Medicine in Pensacola, FL. Without coordination, progress came in fits and starts, and the services did not routinely share information gained from experience.

During the early 1950s, engineers developed the pressure suit for high-altitude flying and spaceflight. This suit encased the human body for survival. Early astronauts consumed a low-residue diet to limit bowel movements, eliminating the need for technicians to develop systems to handle feces in flight. Doctors and engineers did learn how to handle the collection of urine soon after the pressure suit was developed, but NASA did not use these developments for the initial Mercury flights. Only men, it must be noted, piloted the early U-2s, high-altitude test planes, and Mercury capsules. Gus Grissom followed Alan Shepard as the second Mercury astronaut, and John Glenn was the third astronaut and the first American to orbit the earth in 1962. It would take an entire year after Brenda mailed her postcard that astronauts finally had a way "to go." Glenn wore a UCD. There has been little published information on who made Glenn's UCD or how it worked, but it is in the collection of the National Air and Space Museum (see Fig. 1).

The Pressure Suit

Space or its high-altitude equivalent is lethal to the human body. The primary goal of pressure suits is to keep the pilot or astronaut alive, both by providing a constant pressure in which the body can function and by circulating adequate oxygen for breathing. The pressure suit also has to accommodate the proper collection and storage of human waste, a task vital to the successful completion of manned aerospace missions (20). The human body needs pressure to survive, and as one climbs higher above sea level, the pressure of the air on the body decreases. At sea level, there is ~14.7 pounds per square inch (PSI) of pressure. In Denver, CO, the external pressure on the body is ~12 PSI. Pressure continues to decrease as altitude increases, until there is no pressure at all. Early practitioners of aerospace medicine believed that the body would actually explode without enough pressure (1). Today we understand

Address for reprint requests and other correspondence: H. Hollins, Space History, MRC 311, National Air and Space Museum, Smithsonian Institution, PO Box 37012, Washington, DC 20013-7012 (e-mail: hollinsh@si.edu).

Fig. 1. Urine collection bag from John Glenn's Mercury Flight. [From the National Air and Space Museum, Smithsonian Institution, Washington, DC.]

that only blood vessels rupture, not the entire body. Death, however, remains the outcome.

The human body can function with much less than 14.7 PSI. Breathing pure oxygen, the human body can remain viable with pressures as low as 3 PSI, and engineers designed pressure suits to provide 3–5 PSI depending on how much time the pilot would remain in low pressure and how quickly the pilot needed to return to a normal pressure (27). A rapid change from high pressure to low pressure causes decompression sickness: the dissolved nitrogen gas in the blood forms bubbles, and as the bubbles move through the bloodstream, they cause severe pain and even death. To prevent decompression sickness, high-altitude pilots and astronauts breathe 100% oxygen. In addition, they "prebreathe" oxygen for 90 min before the flight begins to remove excess nitrogen from their bloodstream (17).

In the early 1930s, Wiley Post worked with B.F. Goodrich of Akron, OH, to invent the first American pressure suit for aeronautics. It was for use during his high-altitude flights aboard his Lockheed Vega, the *Winnie Mae*. Post and the engineers at B.F. Goodrich developed a "light-weight, compact, personal-sized, pressurized environment that would be compatible with his existing aircraft" (31). Post's suit maintained a pressure of 3 PSI and eventually allowed him to attain altitudes of 50,000 ft. His oxygen was stored in a container that fed his suit through a tube. It is important to note that the suit was secondary to the craft. As long as the craft was primary, human needs would be met in a continuously evolving, codeveloped, and marginally satisfactory manner. Through the early space program, scientists, engineers, and users worked together to refine the interface between man and machine, solving problems in a contingent fashion, pushing ideas and back and forth until a passable solution was achieved (14).

After World War II, with the Cold War already in full swing, the U.S. embarked on not only missile and rocket development but also rapidly engaged in developing faster and faster aircraft. Without NASA to coordinate their efforts, the various military services would independently work to find solutions to common problems. To support the new aircraft, the U.S. Air Force initially concentrated its efforts on partial-pressure suits. The U.S. Navy, on the other hand, would emphasize "omni-environmental full-pressure suits to combine altitude and [water] immersion protection" (23). In 1946, the David Clark Company of Worcester, MA, developed the S-1 partial-pressure flight suit that Chuck Yeager would wear while breaking the sound barrier on October 14, 1947. This was not a full-pressure suit, but one that foreshadowed developments the David Clark Company would achieve during the next few years.

In 1954, two developments would spur rapid change. In November, the U.S. Central Intelligence Agency (CIA) received authorization to proceed with the Lockheed CL 282 program, later renamed the U-2, the high-flying spy plane, a version of which still operates today. Then, in December, the NACA signed a memorandum of understanding with the Air Force and Navy to develop the X-15, an aircraft designed to exceed three times the speed of sound and operate near the upper limits of the atmosphere. The X-15 program required a full-pressure suit; significantly, engineers did not integrate a UCD into the suit until 1970.

Early test pilots and astronauts had to wear their pressure suits while working inside a cramped cockpit. The early pressure suits were difficult to put on, and once they were on, the pilot or astronaut could not open them until the mission was complete without risking the mission or, worse, death. Dr. Col. Donald D. Flickinger and Dr. William Randolph "Randy" Lovelace, medical advisors for the U-2 program, asked the David Clark Company to create the suits to keep U-2 pilots alive. "The technology that enabled U-2 pilots to operate for extended periods in reduced atmospheric pressure would later play a major role in the manned space program" (17). The David Clark suits were bulky and uncomfortable. The first versions of this suit did not offer urine collection, and the second generation used an in-dwelling catheter, which is a tube threaded up the length of the penis inside the urethra and into the bladder (17). With the in-dwelling catheter, urine drains continuously through the tube into a collection device, removing the physical need to urinate. This solution is poor. An in-dwelling catheter is very uncomfortable, and the procedure creates opportunities for damage to internal membranes, which can lead to infections. It was not until 1955 that engineers integrated an external UCD into the suit for urine collection. The CIA is a closed community, and the information gathered for successful flights remains within that agency. Although the CIA, NASA, and U.S. military shared the same contractors and medical advisors (Flickinger and Lovelace were integral in creating the NASA astronaut corps), historical documents do not illustrate significant transfer of technology from within the CIA out to other agencies.

The U.S. Navy contracted with B. F. Goodrich and Arrowhead Rubber in the 1950s to produce a pressure suit for pilots. The first phase was the Mark III, with the later Mark IV becoming the prototype for NASA's Project Mercury. In 1959, NASA went to Wright Patterson Air Force Base to evaluate the existing pressure suits under development, and while the David Clark Company and International Latex Corporation were contenders for the contract (astronauts of Gemini and Apollo programs would eventually use their suits), NASA chose the B.F. Goodrich Mark IV for Mercury pilots (27). NASA had decided that astronauts needed the capability to maneuver Mercury capsules, but since the astronauts had the protection of the capsule except during an emergency, existing pressure suits were sufficient. There would be no extravehicular activity (space walks) until the Gemini program. Using existing designs also allowed for a more expeditious delivery of the product. Modification of the Mark IV suits included adding an aluminum layer to the outside and custom fitting to minimize bulk in the small capsules. Delivery of the customized suits took place on October 1, 1959.

The UCD of the Dawn of the Space Age

In American culture, now and in the 1950s, the norm for an adult is to have control over their body, and public display or discussion of removing our normal waste products is generally not accepted. "Urinary incontinence can have a significant detrimental effect on a person's body image and self-esteem because it undermines society's norms relating to body control" (9). Many UCDs were developed for general use not related to aeromedical concerns. A patent for a UCD, granted in the U.S. in 1952, states that the invention is for "eliminating distressing and mortifying consequences" (5). In 1957, a group of British inventors developed a UCD that could have benefited American pilots and astronauts. The device was to be worn inside the pressure suit "or equipment whose position or body harness makes normal urination highly inconvenient or impossible." The device attached to the penis and directed the urine to bags of absorbent material, which would hold the urine until the end of the mission. Although this invention hints at future absorbent technologies used on the Space Shuttle for urine collection, NASA reports do not mention this device. The application is also interesting in that it illustrates the level of discomfort with language conjuring male sexuality and urination. The device (Personal Sanitary Conveniences) "enables the wearer to pass water when necessary without subsequent discomfort or embarrassment. According to the present invention, the improved urination device comprises an impervious receiver adapted to make resilient liquid-tight contact with the wearer's person around the urinary duct" (24). In his landmark survey of sexuality in 1948, Alfred C. Kinsey noted that "The English are more or less justly reputed to be the most completely clothed people in the world, and Americans have been slow in breaking away from the English tradition" (13).

Before the first Mercury flight, in 1960, the Air Force sponsored a study on human waste collection in a space capsule. For the Mercury missions, fecal collection was not required, but the study stated that during the Mercury missions the collection and storage of urine would be required. The study looked at contemporary literature and devices related to urine collection and determined that the waste tubes and bottles used for urine collection in military aircraft were not sufficiently reliable due to leakage. Engineers decided that devices used in hospitals to collect urine from bed-ridden male patients were completely adequate and that they were available off the shelf. The device created a tight seal with the penis to prevent leaks and had a backflow prevention device, one that worked in the laying down position (7). UCDs did exist but do not appear to have been used by NASA in testing or in flight.

As soon as B.F. Goodrich delivered the pressure suits to NASA, technicians put them through rigorous testing. McDonnell Aircraft Company conducted 257 manned hours of testing on the complete environmental system, including the pressure suit. Part of the test was a complete 28-h manned test. It must be that the human subject for this test needed to urinate, although the available documentation makes no mention of this. In October of 1960, engineers also installed the pressure suit control system at the Johnsville Centrifuge for an additional 134 h of manned testing under simulated flight (29).

With pressure suit testing complete, the astronauts went into space with or without a UCD. "The short-mission durations [for Mercury] made it entirely feasible to collect all the voided urine in a single container within the suit and to recover it after astronaut recovery" (4). Allan Shepard flew on *Freedom 7*, Mercury-Redstone 3, on May 5, 1961. As his flight was only to be 15 min, despite the text from Dr. Charles A. Berry (Chief of the Center Medical Operations Office), they did not take into account that he might need to urinate. During the event, Shepard spent 4 h on the launch pad and eventually needed to relieve himself into his suit. Regardless of how much time spent on the pad, Mercury astronauts were suited up for 4 h before launch and for at least 1 h for the flight and rescue operation. Engineers had designed, and subjects had tested, the Mercury environmental control system (both the capsule and pressure suit) that maintained life support for 28 h. Shepard spent 8 h in his suit, due to launch delays, and eventually the loose urine in his suit short circuited the electronic medical data sensors attached to his body (10). Regarding urination in the Mercury capsule, NASA submitted a report to the U.S. Congress on April 28, 1961, days before the launch, stating that "A container for liquid waste is located near the entrance hatch" (6). Even if there had been a container near the hatch, it certainly would not be usable by the astronaut, as he was strapped into his form-fitting couch with little room to move (see Fig. 2). NASA had not appreciated the pilot's possible need to urinate but needed to maintain the public and political perception that all was in order.

For the second suborbital flight on July 24, 1961, Gus Grissom piloted *Liberty Bell 7*, Mercury-Redstone 4, and technicians integrated a UCD into his suit. In *This New Ocean: a History of Project Mercury*, the authors stated the following: "Another welcome addition to the suit was a urine reservoir fabricated the day before the flight. Although during his flight,

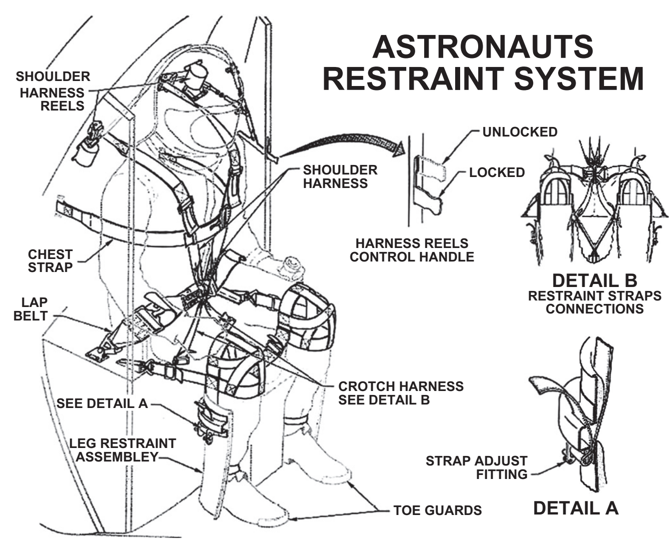

Fig. 2. Illustration of the restraint for an astronaut in the Mercury capsule. [From McDonnell Aircraft Corporation, Report no. 8242, October 9, 1961, Fig. 22, p. 44.]


Fig. 3. Astronauts Walter M. Schirra, Jr. (*center*; seated), command pilot, and Thomas P. Stafford (*center*; standing), pilot, Gemini VI prime crew, go through suiting up exercises in preparation for their forthcoming flight. The suit technicians are James Garrepy (*left*) and Joe Schmitt (*right*). [From the National Aeronautics and Space Administration, Johnson Space Center, Houston, TX.]

Grissom would find the contraption somewhat binding, it did work" (26). Possibly, in hopes that he would not need to try out the new device, technicians withheld Grissom's morning coffee, knowing that it acts as a diuretic (8). According to popular history, Dee O'Hara, the medical nurse for the Mercury program, went out and bought a condom and a girdle, which she fashioned together to make a UCD for Grissom to wear during his flight (30). This story fits nicely with the "can do" spirit of 1950s America; however, Grissom actually wore two pairs of rubber pants, which contained his urine between the layers (10). After the flight, NASA agreed, "to make more rigid demands on urine collection" (29). Mercury Status Report no. 11 for the period ending July 31, 1961, states that "intensive work has been underway on UCDs and several approaches have been developed; one such device was successfully used on the MR-4 flight" (25a). In June of 1961, just before Grissom's flight, NASA hired James McBarron to oversee the existing B.F. Goodrich contract to develop a UCD for the Mercury astronauts. B.F. Goodrich had earlier produced a device, but many of the test subjects had rejected it because of leaks (15).

As mentioned in the historical literature, "little has been published describing the efficacy and success of in-flight urination systems" (28). International Latex Corporation, however, prepared a complete technical report for the Air Force and published it in August of 1961. The report is interesting on many levels, and it encompasses all the primary issues related to urine collection and storage related to the use of pressure suits. The unit was to be compatible with a full-pressure suit, nonirritating to the skin, and comfortable even through normal body movements. It would collect up to 72 h worth of urine outside of the suit. According to the author of the study (20), the difficulty in creating a successful urine collection device was not the interface with the penis. For the study, they surveyed the market (as was done for the 1960 study) and found that simple personal urinals created for people with impaired bladder control or people without access to public urinals, such as policemen, already existed and worked well. For the study, they purchased a rubber urinal from Rexall Drug Company. What was difficult for the engineers was removing the urine from inside the pressure suit. Urine would not flow away from the astronaut without gravity or a difference in pressure between the suit and the capsule. For the success of the unit, engineers developed a complex valve to allow the astronaut to increase the pressure inside the suit during urination, which would force the urine away from the urinal device, through the tubing and into the storage container.

John Glenn made the first Mercury orbital flight on February 20, 1962, aboard *Friendship 7*, Mercury-Atlas 6. After the previous Mercury flight, the Mercury Progress Report stated that "A satisfactory UCD has been developed and evaluated for immediate flight requirements," and Glenn used it (14a). While in flight, just before reentry, Glenn voided 800 ml of urine, or ~27 oz, into his UCD (a very full bladder) and reported that his body functioned normally and he experienced normal sensations (11). Despite what Glenn reported about normal


Fig. 4. Roll-on-cuff, developed by James McBarron. [From the National Air and Space Museum, Smithsonian Institution, Washington, DC.]

sensations, he did pass a far above average amount of urine during his single urination in space. There is a large degree of variation in how much urine each individual's bladder can hold, with the average being ~600 ml or 20 fluid oz (the current size of a soda bottle). Nerves sense when the bladder is full. Usually we need to urinate when our bladder is one-third full, but this stage is often ignored. When the bladder is two-thirds full, the need "to go" becomes more acute. When the bladder reaches its capacity, you feel pain and discomfort (21). Glenn was not experiencing normal sensations and should have gone sooner. "'In zero gravity, the urine doesn't collect at the bottom of the bladder. Only when the bladder is almost completely full do the sides begin to stretch and trigger the urge. And by then the bladder may be so full that it's pressing the urethra shut'" (21). If the bladder is not emptied when full, urine may leak out, and repeated episodes of not emptying the bladder when full can result in permanent damage to the sphincter valves, causing general incontinence.

Although Glenn did not understand the physics and physiology of urination in space, he was wearing the first in a long series of NASA UCDs. As B.F. Goodrich had not been able to produce a successful UCD, McBarron and his team, consisting of Al Rochford and Joe Schmitt of the Manned Spaceflight Center Suit Laboratory, developed the first successful UCD used by the Mercury astronauts. The suit laboratory was responsible for ensuring that the astronauts were properly equipped (see Fig. 3). McBarron modified condoms to create an external catheter, which he referred to as a "roll-on-cuff" (see Fig. 4). McBarron purchased various brands of condoms and used himself as a test subject until he found the brand that would not leak. He then worked with the manufacturer to produce his custom design. The manufacturer produced a roll-on-cuff made of a stronger material and in the size range McBarron specified. Unlike a prophylactic, McBarron's roll-on-cuff was open at the end, which stretched around the opening in a storage bag. A nylon strap secured the roll-on-cuff to the storage bag. McBarron created the storage bag by heat sealing polyethylene into the desired shape. For Glenn's mission, his tight-fitting undergarment held the bag in place. At the end of the flight, a spring-loaded metal clamp closed the roll-on-cuff to prevent the urine from leaking. The system that the NASA engineers developed for Glenn, while modified along the way, would be the system used for all U.S. astronauts wearing a pressure suit, continuing into the early Shuttle flights (16). John Glenn's UCD is in the collection of the National Air and Space Museum, and the urine storage bag has been on view in the Apollo to the Moon gallery since 1976.

All Is Fair in Love and War

Space is a very hostile environment for human beings. Our complex bodies function well, for the most part, within the habitable zone of the Earth's atmosphere. When we merge our bodies with machines in efforts to investigate new places beyond where our bodies can function, there will always be difficulty. Humans can tolerate less than ideal environments. The body can weather discomfort, and even pain, but at some point, damage occurs, and this point varies from individual to individual (25). In a survey done in 2010, 60% of pilots flying for the U.S. Air Force U-2 Reconnaissance Squadrons operating out of Beale Air Force Base in California reported problems with the UCD that they wore, including poor fit, leaking, and skin damage from extended contact with urine (28). It is the job of the engineer/physiologist to ensure that the man-machine interface promotes the health and safety of the human body.

Alan Shepard's flight on May 5, 1961, was soggy and uncomfortable. Brenda and her friends were right to wonder about his need "to go." Shepard's flight was also successful and glorious–America had put a man in space. It would be an oversimplification to state that NASA was wrong for not providing Shepard with a UCD; truthfully, it was not "forgotten." NASA had consolidated the various space program activities in the U.S. to be victorious in the Space Race. There was so much new technology to integrate into the space program during the Cold War, and in times of conflict and exploration, we ask the human body to do more.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

AUTHOR CONTRIBUTIONS

Author contributions: H.H. conception and design of research; H.H. drafted manuscript; H.H. approved final version of manuscript.

REFERENCES

1. **Armstrong HG.** *Principles and Practice of Aviation Medicine*. Baltimore, MD: Williams & Wilkins, 1939.
4. **Berry CA.** Aeromedical preparations. In: *Mercury Project Summary Including Results of the Fourth Manned Orbital Flight, May 15 and 16, 1963.* Washington, DC: National Aeronautics and Space Administration, 1963, p. 203.
5. **Crew BL.** *Surgical Apparatus*. US Patent 2,610,630, filed January 25, 1951 and issued September 16, 1952.
6. **Dembling PG.** *Mercury-Redstone III, Suborbital Manned Flight*. *Congressional Brief*. Washington, DC: Office of Congressional Relations, National Aeronautics and Space Administration, 1961. [This was also stated in a NASA News Release, no. 61-88, Mercury-Redstone-3, 4-3, April 26, 1961.]
7. **Des Jardins J, Zeff JD, Bambenek RA.** *Waste Collection Unit for a Space Vehicle, MR 1092, Technical Report 60-290, 1-25, May 1960.* Wright-Patterson Air Force Base, OH: Wright Air Development Center, Aerospace Medical Division, Air Force System Command, 1960.
8. **Douglas WK.** Flight surgeon's report for Mercury-Redstone missions 3 and 4. In: *Results of the Second U.S. Manned Suborbital Space Flight, July 21, 1961*. Washington, DC: Manned Spacecraft Center, National Aeronautics and Space Administration, 1961.
9. **Geng V, Bonns E, Eelen P, Seidler C, Cobussen-Boekhorst H.** *Good Practice in Health Care. The Male External Catheter*. Arnhem, The Netherlands: European Association of Urology Nurses, 2008.
10. **Grimwood J.** *Mercury Pressure Suit Development. U.S. Government Memorandum to Lee N. McMillion, November 1, 1963*. Houston, TX: NASA Johnson Space Center Space Suit Files, Box 1, Mercury Pressure Suit Development Correspondence folder, 1963.
11. **Johnson RS, Samonski FH Jr, Lippitt MW, Radnofsky MI.** Life support systems and biomedical instrumentation. In: *Results of the First United States Manned Orbital Space Flight, February 20, 1962*. Washington, DC: Manned Spacecraft Center, National Aeronautics and Space Administration, 1962, chapt. 3, p. 87–89.
12. **Kemmerer B.** *Postcard to NASA, February 1, 1961*. Washington, DC: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, 1961.
13. **Kinsey AC, Pomeroy WB, Martin CE.** *Sexual Behavior in the Human Male*. Philadelphia, PA: Saunders, 1948, vol. 1.
14. **Lantry DN.** *Space Suits: Artifacts, Symbols, and Vehicles*. Reston, VA: Mutual Concerns Conference, 2012.

14a. **Manned Spacecraft Center, National Aeronautics and Space Administration.** *Project Mercury, Status Report No. 12 for Period Ending October 31, 1961*. Washington, DC: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, 1961.

15. **McBarron JW II.** *Interview by K. M. Rusnak on April 10, 2000* (online). http://www.jsc.nasa.gov/history/oral_histories/m-n.htm [20 March 2013].
16. **McBarron JW II.** *Interview by H. Hollins on November 9, 2012*.
17. **Pedlow GW, Welzenbach DE.** *The CIA and the U-2 Program, 1954–1974*. Washington, DC: History Staff, Center for the Study of Intelligence, Central Intelligence Agency, 1998.
18. **Pitts JA.** *The Human Factor: Biomedicine in the Manned Space Program to 1980*. Washington, DC: NASA SP-4213, 1985.
19. **Quimby FH.** *Reply to Brenda Kemmerer*. Washington, DC: Office of Life Science Programs, *NASA* Historical Reference Collection, NASA History Office, NASA Headquarters, 1961.
20. **Redden RJ.** *Urine Collection and Disposal Device for Pressure Suit. Technical Documentary Report No. 61-329, Contract No. AF 33(616)-7344*. Wright-Patterson Air Force Base, OH: International Latex Corporation for Biomedical Laboratory, Aerospace Medical Research Laboratories, Aerospace Medical Division, Air Force System Command, 1961.
21. **Roach M.** *Packing for Mars: the Curious Science of Life in the Void*. New York: Norton, 2010.
22. **Roth NG, Symons JJ, Cohen D, Wheaton RB.** *Human Waste Collection and Storage During Aerospace Flight, Technical Documentary Report No. SMRL-TDR-64-3, Contract No. AF 33(657)-9131*. Wright-Patterson Air Force Base, OH: Whirlpool Corporation for Life Support Systems Laboratory, Aerospace Medical Laboratory, Aeronautical Systems Division, Air Force System Command, 1964.
23. **Sears WJ.** High- altitude pressure protective equipment: a historical perspective. In: *Raising the Operational Ceiling: a Workshop on the Life Support and Physiological Issues of Flight at 60,000 Feet and Above*. San Antonio, TX: Brooks Air Force Base, 1995, p. 121–132.
24. **Silverstone J, Smith RS.** *Personal Sanitary Conveniences*. US. Patent 2,976,869, filed January 13, 1958 and issued March 28, 1961.
25. **Smith GB Jr.** Environmental biology. In: *Proceedings of the NASA-University Conference on the Science and Technology of Space Exploration*. Chicago, IL: National Aeronautics and Space Administration, 1962, vol. 1, chapt. 33, p. .

25a. **Space Task Group, National Aeronautics and Space Administration.** *Project Mercury, Status Report No. 11 for Period Ending July 31, 1961*. Washington, DC: NASA Historical Reference Collection, NASA History Office, NASA Headquarters, 1961, p. 395.

26. **Swenson LS Jr, Grimwood JM, Alexander CC.** *This New Ocean: a History of Project Mercury*. Washington, DC: National Aeronautics and Space Administration, 1966.
27. **Thomas KS, McMann HJ.** *U.S. Spacesuits* (2nd ed.). London: Springer-Praxis, 2012.
28. **Von Thesling GH, Coffman CB, Hundemer GL, Stuart RP.** In-flight urine collection device: efficacy, maintenance, and complications in U-2 pilots. *Aviation Space Environ Med* 82: 116–122, 2011.
29. **White SC, Johnson RS, Pesman GJ.** *Review of Biomedical Systems for MR-3 Flight*. Washington, DC: Conference on Medical Results of the First U.S. Manned Suborbital Space Flight, NASA/NIH/NAS, 1961.
30. **Wolfe T.** *The Right Stuff*. New York: Farrar, Straus & Giroux, 1979.
31. **Young A.** *Spacesuits: the Smithsonian National Air and Space Museum Collection*. Brooklyn, NY: Powerhouse Books, 2009.