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Practicing for space underwater: inventing neutral buoyancy training, 1963–1968

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Neutral buoyancy's value was far from obvious when human spaceflight began in 1961. Starting in 1964, Environmental Research Associates, a tiny company in the suburbs of Baltimore, developed the key innovations in an obscure research project funded by NASA's Langley Research Center. The new Houston center dismissed it until a mid-1966 EVA crisis, after which it rapidly took over. In parallel, NASA Marshall Space Flight Center developed many of the same techniques, as did many large aerospace corporations, yet the long-run technological impact of corporate activity was near zero. Because ERA and Marshall's pioneering activities led to the two long-running NASA training centers at Houston and Huntsville, those two organizations deserve primary credit for the construction of the neutral buoyancy technological system.

Almost every day, somewhere in the world, astronauts or cosmonauts are practicing for EVA (extravehicular activity or 'spacewalking') underwater. At the Neutral Buoyancy Laboratory of the Lyndon B. Johnson Space Center in Houston, TX, crewmembers rehearse procedures in a gigantic, 6-million-gallon (23-million-liter) pool holding full-size mockups of multiple modules of the International Space Station (ISS). Opened in 1997, it superseded earlier tanks built at the National Aeronautics and Space Administration's premier human spaceflight centers. Russian cosmonauts train at the Hydrolab in Star City, outside Moscow, a large facility built in 1980; European Space Agency astronauts work in Houston, and also at their own tank at the European Astronaut Centre, Cologne, Germany; Japanese astronauts at the Tsukuba Space Center near Tokyo. China recently opened a facility at the Chinese Astronaut Research and Training Center in Beijing, to prepare for EVAs from its Shenzhou spacecraft and Tiangong stations.[1] In short, 'neutral buoyancy training' (so-called because the spacesuited astronauts are weighted to be neutrally buoyant, simulating weightlessness) has become normal technology. Indeed, it is absolutely critical to the success of numerous human spaceflight programs. Assembling the ISS, or repairing the Hubble Space Telescope, would have been impossible without it.

Neutral buoyancy's value was far from obvious when human spaceflight began in 1961, however. NASA at first took no interest in training its astronauts this way. Beginning in 1964, Environmental Research Associates (ERA) a tiny company in the suburbs of Baltimore, MD, developed the key innovations in an obscure research project funded by NASA's Langley Research Center (LaRC) in Hampton, VA. The new Houston center (then named the Manned Spacecraft Center or MSC) dismissed it until a mid-1966 EVA crisis, after which it rapidly took over. In parallel, NASA Marshall Space Flight Center (MSFC) in Huntsville, AL, developed many of the same techniques, as did many large aerospace corporations. Some, notably Boeing and General Electric, made large investments in neutral buoyancy, and experimented with an alternate suit technology, yet the long-run technological impact of that major corporate activity was near zero. Because ERA and Marshall's pioneering activities led to the two long-running NASA training centers at Houston and Huntsville, which in turn influenced other space agencies, those two organizations deserve primary credit for the construction of the neutral buoyancy technological system.

We have chosen the term *technological system* because neutral buoyancy was invented in the 1960s less as a new technology than as an assemblage of existing technologies, tacit knowledge, and safety practices. In technological systems theory, originating from the work of Thomas P. Hughes, the term has been confined almost exclusively to large systems like electrical power networks and military-industrial projects. On this model, NASA's human spaceflight complex can be considered a technological system, and the EVA problems that arose in the mid-1960s, to use Hughes' military metaphor, were a *reverse salient* that required organizational and technological fixes. But no fundamentally new technological devices were required to construct neutral buoyancy training, although some local and specific innovations were needed. Rather, local innovators and *system builders*, to use another Hughesian term, assembled existing, often commercially available technologies like scuba equipment, full-pressure suits, cameras and swimming pools, and matched them with

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the experienced-based cultures needed to make neutral buoyancy workable and safe. As a concession to the differences in scale, neutral buoyancy could perhaps be called a *small technological system*, a sub-component of a larger system.[2]

The events that led to this critical innovation have only begun to emerge recently in popular accounts and have never been subject to scholarly examination. The older official NASA histories and key astronaut memoirs barely mention neutral buoyancy's origins and often inaccurately, while a recent semi-popular history by David J. Shayler, *Walking in Space*, gives a partial account of the Baltimore story in a few paragraphs.[3] The full dimensions of the ERA story began emerging after 2012 in popular articles written by, or in the cooperation with, the surviving founder of the company, G. Samuel Mattingly, who died in November 2014.[4] Marshall's early work has scarcely been treated at all, and when it has, authors have mostly noted MSFC Director Wernher von Braun's stealthy construction of a giant tank in Huntsville through a legally dubious end-run around the NASA procurement system in the late 1960s.[5] Due to scant surviving documentation, the Marshall story remains difficult to tell, in contrast to somewhat richer material on ERA, but this article will attempt to examine both stories and draw some conclusions about the contingent and improvised creation of the neutral buoyancy technological system.

The problem of weightlessness

'Weightlessness,' 'zero-gravity' and 'zero-G' are the terms most often used to connote the state of freefall experienced during orbital or coasting flight in space. ('Microgravity' is now the usual technical term – denoting the microscopic accelerations that exist even while floating in an apparent absence of gravity.) The existence of this phenomenon was well known in early space advocacy and science fiction, but was mostly wished away with devices like magnetic shoes and rotating space stations. After World War II, however, it gradually became an area of concern for the new discipline of space medicine, growing out of aeromedicine as rocket and jet aircraft entered service and human spaceflight became more and more imminent.[6]

In the United States, the formation of NASA out of the National Advisory Committee for Aeronautics (NACA) in fall 1958 and the simultaneous creation of one of its first programs, Project Mercury, made the impact of weightlessness on astronaut performance suddenly a real question. Foremost was simply the ability to perform in a cockpit while weightless. Some physicians conjured frightening scenarios of basic human functions like sight and swallowing failing, which contributed to engineering decisions to make the first U.S. human spacecraft, Mercury, to be largely automated. (Its Soviet counterpart, Vostok, was entirely automated, and required a special override code to unlock the controls.) Leaving the capsule and performing work in space was not feasible and preparations could be put off until a later program.

From the origins of space medicine, it was obvious to researchers that water immersion was one possible way to simulate weightlessness. Among the many physiological experiments conducted were ones by Dr. Duane Graveline of the School of Aerospace Medicine at Brooks Air Force Base in San Antonio, TX in the early 1960s. He had subjects in scuba wetsuits and aviators' full pressure helmets spend extended periods of time underwater in a specially constructed tank.[7] Informal experiments with scuba-equipped divers probably were the first attempts to simulate EVA work underwater, but these have been largely undocumented. (The Aqualung, invented in World War II occupied France by Jacques Cousteau and Émile Gagnan, was the breakthrough that made scuba, an acronym for 'self-contained underwater breathing apparatus,' feasible.)

For NASA, it was not a concrete problem until the Mercury program ended in 1963 and managers needed to formulate training plans for the two-man Gemini spacecraft, which would demonstrate key objectives, including EVA, needed for the Apollo lunar landing goal set by President John F. Kennedy in 1961. On January 30, 1964, Mercury astronaut Donald K. 'Deke' Slayton, who had become MSC Assistant Director of Flight Crew Operations after he had been medically disqualified for spaceflight, issued a Gemini EVA training plan. It is noteworthy as much for what did not happen as did. He quickly dismissed weightlessness in aircraft flying parabolas (which is not a simulation, but actual freefall for some seconds as the aircraft coasts over the peak in its trajectory). Instead:

> The only practical means of simulating the overall effects of reduced gravity for relatively long periods of time is by water immersion. A fairly realistic simulation of some of the techniques and problems in accomplishing extra-vehicular activities can be accomplished by submerging the Boilerplate #201 in the Ellington tank. The flight crews can then don SCUBA equipment and practice such tasks as egress, ingress, opening and closing the spacecraft hatches and maneuvering over the spacecraft.[8]

MSC used a water tank at nearby Ellington Air Force Base, outside Houston, to train astronauts to make ocean exits out of their spacecraft. Boilerplate #201 was the first Gemini simulator, only recently delivered for water-tank and open-water training exercises. It was intended for use in rough water and even inverted and partially submerged, so full immersion would not have been impractical.

Yet Slayton's suggestion was discarded for reasons not documented in surviving MSC records. He does mention another new tool: frictionless, air-bearing surfaces, in which an astronaut would stand or be placed on a disk generating an air current above a very smooth surface. In theory, it was a 'five-degrees of freedom' simulator (the only dimension of movement missing would be vertical to the surface), but in practice the astronaut could move about on the floor in only one body orientation at a time. Such a simulator came into service at MSC in 1965, but it appears to have been useful only for practicing with handheld maneuvering guns or jetpacks.[9] Aircraft zero-G training became the primary method; 'water immersion' was ignored. Perhaps the need to train all astronauts in scuba,