Hall AL, Martin RJ. *Prolonged exposure in the Navy full pressure suit at "space equivalent" altitudes.* Aerosp Med 1960; 31:116–22.

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Prior to the experiments described in this Classic paper, full pressure suits had only been used operationally for brief periods of time, but would soon need to be reliable enough to be used for much longer periods in upcoming manned spaceflights. "Where space begins" had been determined physiologically several years earlier in a landmark paper by Dr. Strughold (8). The "space equivalent" altitude was stated to be 50,000 ft, as physiologic support requirements at that altitude were the same as in deep space (9).

Previous studies had indicated that breathing 100% O_2 would not produce oxygen toxicity if the pressure was below 425 mmHg (8.2 psi) (1), but experience with that had been minimal and it was still unconfirmed. At this time, there were still several concerns regarding use of a full pressure suit above 50,000 ft:

- Could man tolerate a pressurized suit for prolonged periods?
- Would detrimental pulmonary effects occur from continuously breathing 100% O_2?
- Could man function in the suit above 50,000 ft?
- What psychological and physiological changes would occur?

In this study, a naval aviator-flight surgeon wore a Mark III Mod II Navy full pressure suit (3.5 psi) in an altitude chamber for 76 h at altitude equivalents up to 170,000 ft. More than 72 h was spent above 30,000 ft and 47 h above 80,000 ft. Fluid balance, caloric intake, O_2 consumption, and leak rates were measured. The suit was well tolerated, with the biggest problem being the effects of the low-humidity O_2 on the oro-nasal pharynx. The subject also complained of uncomfortable pressure points over the feet, both shoulders, and the posterior neck. He was able to move his arms, hands, and head adequately, but noticed that his finger movements were very restricted above 140,000 ft. Post-exposure studies showed that his psychological battery, chest X-ray, EKG, and blood and urine tests were all normal. Physical examination showed erythematous mucous membranes and a pustular dermatitis. Most importantly, pulmonary functions were unchanged and there was no evidence of oxygen toxicity.

Background

The USAF School of Aerospace Medicine had demonstrated that men could function in a sealed cabin at 18,000 ft (7.4 psi) with 40% O_2. This was first demonstrated for 24 h in 1956 and then for 1 wk in 1958. The USAF Project Manhigh had used a sealed gondola at a pressure altitude of 23,500 ft (5.8 psi) with 60% O_2 for 24 h. A full pressure suit at a pressure altitude of 35,000 ft (3.46 psi) with 100% O_2 had only been experienced operationally for less than 12 h.

The first pressure suit had been developed by Russell M. Colley at B.F. Goodrich in 1934 for Wiley Post, who flew it successfully to 47,000 ft. Although technological advances were made during World War II, an operational pressure suit was not developed. The David Clark Company then produced a partial-pressure suit for use in USAF experimental aircraft, the X-1 in 1946 (T-1) and then the first full pressure suit for the X-2 (Model 4). Those suits had poor mobility, high leakage rates, and lacked automatic pressure control. Meanwhile, the U.S. Navy worked with B.F. Goodrich on omni-environmental full pressure suits, driven by requirements for the U-2. One of those early models was the Model H Full Pressure Suit. Developed in March 1954, its single-headpiece configuration marked a great step forward in the design of full pressure suits. In August 1954, that suit was worn for 11 h in an altitude chamber to 80,000 ft. The "Mark" series of U.S. Navy full pressure suits that followed solved some important problems concerning mobility, leakage, and full pressurization. One of the most important developments was an aneroid device that maintained precise suit pressurization (2). The Mark I suit (1956) was bulky, but set the stage for the lighter Mark III with an improved internal ventilation system. The Mark IV went into production in 1958 as the standard high altitude issue for U.S. Navy squadrons and became the basis for NASA's early Earth-orbital space suit. The Mercury prototype suits were Mark IV suits reworked for better thermal regulation and provision of biomedical monitoring.

Comment

To understand the success of the Mark suit series, it is helpful to revisit the early history of pressure suit development (3, 7, 10) beginning with Wiley Post. By 1934 it had become obvious to Post that his aircraft, *Winnie Mae*, could not remain competitive unless he could take advantage of high altitude winds to achieve faster ground speeds (7). While he recognized that the future of aviation lay in pressurized aircraft, the plywood hull of *Winnie Ma*e could not be pressurized, so he conceived of an individual pressure suit. After a static test of his first suit failed, Post worked with Russell Colley to build a second suit with elbow and knee rings to allow limited movement. When Post became stuck in the suit, it had to be cut open and was destroyed. Colley went on to build Post a third suit, which was tested in secret at Wright Field in 1934 and was later used for Post's stratospheric flights.

For Colley, who had once wanted to design women's clothing but ended up a mechanical engineer at B.F. Goodrich, working with Post allowed him to apply his expertise while revisiting his thwarted career path. This collaboration, a full decade before significant pressure suit work was done elsewhere, put Goodrich at a significant advantage later when the military (and then NASA) took an interest in pressure suits.

During World War II, driven by rising military interest in high-altitude flight, companies like B.F. Goodrich, the David Clark Company (DCC), and International Latex Corporation (ILC) competed to develop high-altitude pressure suits that could win them future contracts. At the same time, the National Bureau of Standards (NBS) acted not only as a clearinghouse to disseminate information to the pressure suit companies, but also carried out some of its own fundamental work on mobile pressure suits and related life support technologies.

Near the start of World War II, Arthur S. Iberall had joined the NBS in the Mechanics Division, run by Hugh Dryden. By 1946, Iberall had contributed to the development of an apparatus to deliver oxygen for breathing, cryogenic storage systems, guidance systems, and a high-speed dental drill. In 1947, encouraged by the Navy (Iberall T, Robbins E. The story of achieving mobility in a pressurized space suit. Unpublished manuscript; 2003), the NBS funded Iberall to begin work on the development of a full pressure suit (10). Iberall provided a new conceptual and theoretical basis for improved pressure suit mobility, which he termed "Lines of Non-Extension." His concept was that skin stretches when there is body movement, but only in certain directions; there are lines along which our skin does not stretch and they can be used to restrain the large forces generated by pressurizing a suit without impairing mobility. Iberall published his ideas in a classified report in 1951 (4) and completed two prototypes that used a "net" layer to restrain the suit pressure bladder (10). Iberall left NBS in 1954 to develop a full pressure suit at the Rand Corporation for the X-15 program. The ILC submission, which included support from Goodrich, faired well, but was less mobile than the Rand and DCC submissions.

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Ultimately the DCC won the contract with its XMC -2 DC suit that appeared to be based in part upon Iberall's NBS classified government technical reports (5, 6). This is not necessarily a story of intrigue, however, as part of Iberall's role at the NBS had been to disseminate the art and science of pressure suits to all participating pressure suit companies.

Like the Post-Colley collaboration, X-15 suit development benefited immensely from close collaboration between the pilot (in this case, Scotty Crossfield) and suit developers. However, there were differences between the Colley and Iberall approaches. While a skilled mechanical engineer, Colley apparently attributed his inspiration for space suit mobility to nature, particularly in the body form of the tomato worm. This influence can be seen as early as the 1943 Goodrich XH-5 prototype suit (10). In contrast, Iberall took a more theoretical approach that achieved superior mobility, which he emphasized over other practical considerations. Iberall's work has gone largely unrecognized, but it represented a substantial and important advance and likely contributed to the early mobility advantages of the Rand and DCC entrants in the X-15 suit competition.

Around the same time as the X-15 competition, Goodrich focused on developing pressure suits for the Navy that led to the Mark line of suits. These suits achieved moderate mobility and, by the Mark IV iteration, had eliminated hard points and offered easy donning and doffing, features that contributed to their selection for the Mercury program. Nevertheless, the fierce competition continued: DCC soon won the contract for the Gemini program and ILC later built the Apollo suits. This competition, with a common purpose, continues to this day.

This Classic paper was the first demonstration that a human could function for relatively long periods in a full pressure suit of the type that could take humans into space.

REFERENCES

1. Fenno RM. Man's milieu in space: a summary of the physiologic requirements of man in a sealed cabin. JAM 1954; 25:612–22.
2. Gell CF, Hays EL, Correale JV. Developmental history of the aviator's full pressure suit in the U.S. Navy. Aviat Med 1959; 30:241–50.
3. Harris GL. Origins and technology of the advanced extra-vehicular space suit (AAS History Series). San Diego, CA: Univelt; 2001.
4. Iberall AS. The experimental design of a mobile pressure suit. Journal of Basic Engineering 1970; 92:251–64.
5. Iberall AS. Fundamental considerations in the design of mobile pressure suits . Washington, DC: National Bureau of Standards report to the Safety Equipment Branch, Airborne Equipment Division, Bureau of Aeronautics, Navy Department; April 1951.
6. Iberall AS. Development of a full pressure altitude suit. Wright-Patterson Air Force Base, OH: Wright Air Development Center; June 1958. WADC Technical Report 58–236.
7. Mohler SR, Johnson BH. Wiley Post, his Winnie Mae, and the world's first pressure suit. Smithsonian Annals of Flight, Number 8. Washington, DC: Smithsonian Institution Press; 1971.
8. Strughold H. Atmospheric space equivalence. J Aviat Med 1954; 25:420–4.
9. Strughold H, Haber H, Buetner K, Haber F. Where does space begin? Functional concept of the boundaries between atmosphere and space. J Aviat Med 1951; 22:342–57.
10. Thomas KS, McMann HJ. U.S. spacesuits. Chichester, UK: Springer/Praxis Publishing; 2006.