TECHNICAL NOTE

ADAPTATION OF WUK-90 HIGH ALTITUDE PRESSURE SUITS FOR REHABILITATION PURPOSES

Maciej ABAKUMOW[1], Krzysztof KOWALCZUK[2]

[1] Neures Poland, Warsaw, Poland.

[2] Department of Simulator Studies and Aeromedical Training, Military Institute of Aviation Medicine, Warsaw, Poland

Source of support: Own sources

Author's address: M. Abakumow, Neures Poland, Mrówcza 165 Street, 01-755 Warsaw, Poland, e-mail: rehabilitacja@neures.pl

Abstract: Integrating discoveries in military technology into civilian applications represents one of the most common combinations, since these include the technologies developed to, among other things, improve the bodily functions in extreme conditions. In addition, aviation technology is characterized by such parameters as lightness, ergonomics and durability. Adaptation of flight or space suits represents the application of solutions that in their original purpose were dedicated to enhance human capabilities under altered pressure and gravitational conditions. These suits, when properly adjusted, can be used in the rehabilitation of patients with neurological or orthopaedic deficits. The purpose of this publication is to show the most commonly adapted solutions based on HAP suits and space suits, as well as to demonstrate the process of adapting HAP *(High Altitude Protection*) suits of WUK 90 type (Type 90 High Altitude Pressure Suits) for therapy purposes. In rehabilitation applications, these suits are suitable for adaptation in therapy where the technical parameters of the devices allow to explore completely different therapeutic possibilities. Such devices, however, require adaptation to the needs of disabled people with orthopaedic injuries or mental disorders and specific conditions for rehabilitation, as was the case with the WUK suit, which after introducing technical modifications and adaptation solutions was given the name R-WUK (abbreviated from the Polish name "Rehabilitacyjny Wysokościowy Ubiór Kompensacyjny" (*Rehabilitation High Altitude Pressure Suit)*.

Keywords: WUK suit, R-WUK suit, ATLANT suit, ADELI suit, suit therapy, HAP suit

INTRODUCTION

The use of military technology solutions for civilian purposes represents a certain regularity. Elements of technological solutions that directly or indirectly derive from military applications are quite often found in other areas of everyday life, be it automotive, emergency medicine or clothing. This is associated with far greater funding for the development of solutions to increase the chances of human survival in extreme conditions, to raise the physiological capabilities of the body, or to reduce the advantage of the enemy. In this regard, at the forefront of modern solutions in the field of health and life protection are solutions from aviation technology, which are characterized by strength, lightness, ergonomics, as well as reliability. These elements provide inspiration for adapting technical solutions in everyday life. These were the very attributes that that have brought these solutions to rehabilitation, where lightness and durability of materials, design reliability and specificity of application play an important role. Yet sometimes the inclusion of space or aerospace technology comes nowhere near its principal application, e.g. space suits or G-suits designed to counteract the effects of prolonged lack of gravity or to counteract G-force or protect against the effects of reduced atmospheric pressure [17] have found their way into rehabilitation. The purpose of this article is to show the process of adapting HAP suits of the WUK-90 type (High Altitude Pressure Suits) for rehabilitation purposes as well as to show the most commonly adapted solutions based on HAP suits and space suits.

The first attempts to create pressure suits for aviators date back to 1934, and their creator was American pilot Wiley Hardeman Post, who went down in aviation history as a pioneer of stratospheric flight. The design itself resembled a classic diver's more than a pilot's outfit [14,10]. Work on clothing to reduce the negative effects of increased G-forces as well as thin atmosphere intensified during World War II. During this period, two directions of solutions clashed, the essence of which can be summarized as pneumatic and hydrodynamic directions. Water-based suits, due to their weight, lost the race to air-based suits at the time [3]. However, the greatest development of this type of clothing was forced by the use of jet propulsion in aviation, which was characterized by an increase in G-forces and an increase in the ceiling of combat aircraft. Spacesuit solutions developed in the period of space conquest where attempts were made to go into open space as well as to keep astronauts in a state of microgravity for a long time represent yet another category.

Space suit (Fig. 1) was primarily aimed at preventing loss of muscle and bone mass in cosmonauts, which, in a state of reduced or no gravity, made long-term space flight impossible. In addition, these factors made it necessary for cosmonauts to undergo rehabilitation after returning to earth [18]. The introduction of pressure solutions, or forcing muscles to work to prevent atrophy, has reduced this problem, allowing for longer space flight times. The assumptions of appropriate muscle tension and its correction, which was made possible by the PENGUIN suit, formed the basis for the adaptation of these suits for rehabilitation purposes (Fig. 2).

Fig. 1. PENGUIN space suit [5].

Fig. 2. PENGUIN suit elastic bands and pulleys system [5].

Fig. 3. ADELI rehabilitation suit [3].

The introduction of the use of spacesuits in therapy is to be traced back to the measures taken by the Russians with regard to cosmonauts who were in a state of microgravity for an extended period of time. The suits used in the rehabilitation of cosmonauts were designed to enhance muscle strength. This aspect attracted the attention and interest of the physiotherapist and led to the idea of using spacesuits in the therapy of patients with disabilities, especially those with cerebral palsy. These efforts led to the adaptation of the inner part of the PENGUIN-type space suit and the creation of a commercial version called the ADELI suit [3]. This suit (Fig. 3) is based on a system of elastic bands and pulleys that enhance the patient's ability to move in a controlled manner. The main goal inspiring the adaptation of the suit for rehabilitation purposes was the possibility of strengthening muscle movement or counteracting uncontrolled muscle tension, which in the case of cerebral palsy patients prevents the execution and learning of correct movement patterns [13]. These suits have resulted in accelerating as well as enhancing the effects of the rehabilitation process. The solutions used in the ADELI suit have lived to see many similar developments around the world, such as THERASUIT or SPIDERSUIT.

Adaptations were also made to HAP-type flight suits, which were given the trade name ATLANT. Their construction is similar to the WUK suit based on a winch pull suit design [9]. This suit (Fig. 4), due to its design, allows only very limited movements or exercises. These limitations are due to the structure of the suit itself, as the winch-type structure used is inflated pneumatically and this results in limited mobility in the limb joints. In addition, the authors of the ATLANT suit used a head position regulator hooked up to the suit to prevent the head from drooping. This system significantly limits the flexion of the trunk or limbs, creating a kind of frame, which has a significant impact on the on the applicability of physiotherapy techniques for patients with neurological deficits. The main field of application according to the originators of the ATLANT suit is the therapy of patients with cerebral palsy [8].

Fig. 4. ATLANT rehabilitation suit [4].

Another problem associated with the use of suits of this type is the physiological response of the body to increased pressure, which results in increased blood pressure and increased heart rate [1,2]. This problem is not addressed in the process of using the ATLANT rehabilitation suit.

ADAPTATION OF WUK-90 FOR REHABILITATION PURPOSES

The WUK-90 is a High Altitude Pressure Suit, which was developed for aviation by Lucjan Golec, PhD, at the Military Institute of Aviation Medicine [16]. Its task is to brace the body and prevent or reduce the movement of blood between the pilot's head and the rest of the body. At the same time, the suit is intended to provide protection for the pilot's body from the atmospheric pressure drop factor in the event of sudden cabin decompression or if the pilot leaves the cabin at high altitudes. Large changes in the pressure range carry the risk of lung tissue expansion or even rupture, so there is a need for external chest compression to balance intrapulmonary pressure [15]. Second, at even higher altitudes – around 18-19,000 m (60–62,000 ft.) the risk of boiling body fluids is present. At a pressure of about 47 mmHg water, and thus body fluids begin to boil at human body temperature, which would quickly lead to tissue destruction [10]. The design of WUK suits allows for an increase in G-force tolerance of about 1.5-2 G.

Approval was obtained from the Ministry of Defence and the Air Force Command for the use of WUK-90 suits for research and rehabilitation purposes. They were made available by the 23rd Tactical Air Base. In addition, research approval No. 13/2015 has been received from the Bioethics Committee on Human Research at the Military Institute of Aviation Medicine on "The use of WUK High Altitude Pressure Suits in the therapy of patients with neurological deficits" as well as the subsequent extension No. 11/2021 "The use of WUK High Altitude Pressure Suits and NEURES suits in the therapy of patients with neurological deficits and psychiatric disorders."

The main task within the framework of the undertaken research was to adapt the WUK-90 suits for the purposes of the undertaken research and to prepare them for conducting therapy given the different scope of application of the WUK suits in the normal way as well as the specifics of working with neurological patients. It consisted in adapting the pneumatic system in such a way that kinesitherapy could be conducted while keeping the structural system of the system intact (Fig. 5).

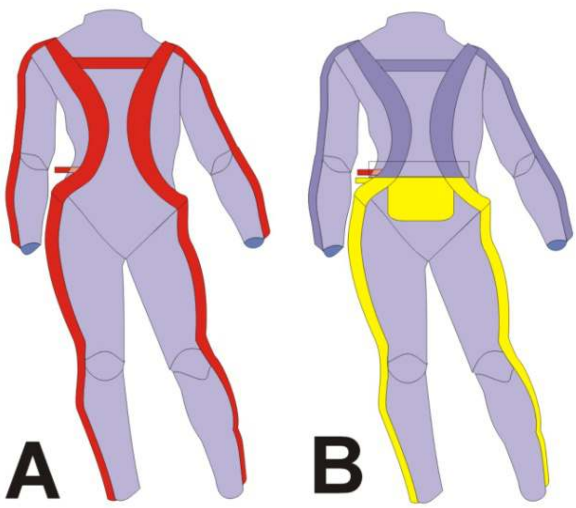

Fig. 5. Pneumatic system of the WUK-90 suit (A – altitude circuit, B – G-force circuit).

The adapted suit features ¼-inch valves that allowed pressure to be applied to the suit. Closing valves were used to ensure the tightness of the system. This made it possible to disconnect the suit from the external power supply and perform exercises without a permanent connection to the pneumatic system limiting the patient's mobility (Fig. 6).

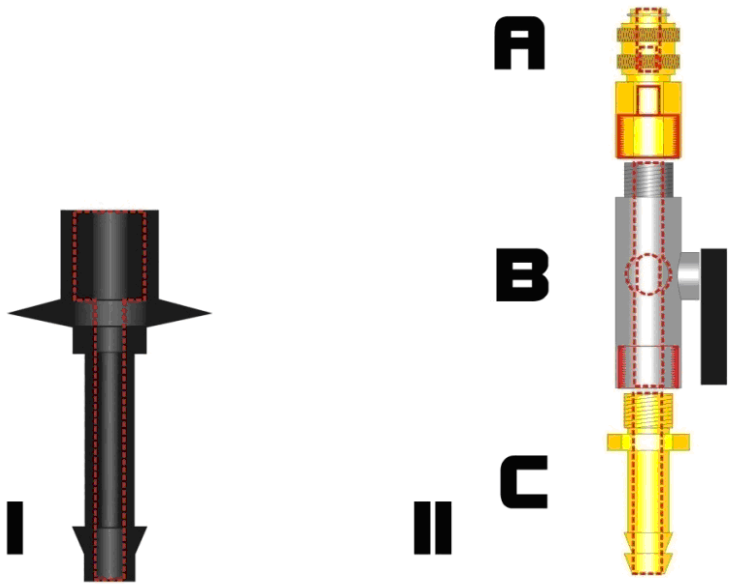

Fig. 6. Replacement of pressure connectors in the WUK-90 suit (I – the system used in the WUK-90 suit, II – the system used in the R-WUK suit, A – quick connector ¼", B – shut-off valve ¼", C – plug ¼").

The WUK-90 suit has a lacing system designed for individual adjustment by the pilot. It allows for a one-time, yet long-lasting suit adjustment (provided there is no change in weight), performed by the technician. Individual fitting takes about 2-3 hours each time, which, given the rehabilitation process, is too long a time and would prevent or at least significantly limit the use of the WUK-90 suit in conducting research. The time deficits involved in conducting rehabilitation have necessitated changes allowing the suit to be quickly fitted to the patient, as well as to be subsequently untied. To this end, single-segment sections were converted into multi-segment sections and, for easier lacing, they were divided by colour (Fig. 7). In addition, the lacing was finished with an adjuster. These changes made it possible to reduce the suit fitting time to 5 minutes. After the modifications, the WUK-90 suit was named R-WUK, abbreviated from the Polish name “Rehabilitacyjny Wysokościowy Ubiór Kompensacyjny” *(Rehabilitation High Altitude Pressure Suit)*.

Fig. 7. R-WUK suit lacing (multi-segment section with colour division).

A separate issue was to design a pressure supply that would allow easy filling of the suit's pneumatic system. For this purpose, a compressor with a pressure gauge has been developed, powered by 230V as well as a 12V battery (Fig. 8).

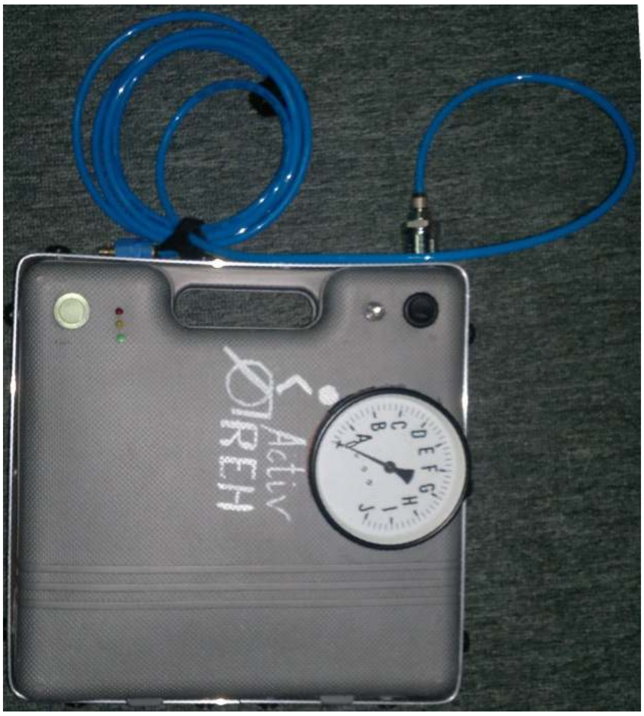

Fig. 8. The compressor for filling the R-WUK suit.

Hoping to obtain information on the pressures that the suit exerts on the pilot's body at specific values of pressure in the pneumatic system, an inquiry was made to the Air Pol Legionowo Company being the manufacturer of these pressure suits. It turned out that this manufacturer had never conducted such research. Since the issue of exerted pressure is crucial to the safety of using WUK-90 suits in rehabilitation, it was decided to conduct empirical studies on healthy patients while conducting other research.

A two-wire arm cuff with an attached mercury manometer and a "bulb" was used to conduct the study. The gauge's measuring range was from 0 to 300 mmHg. The cuff was placed in the front of the WUK on the forearm between the lacing of the suit and the pressure hoses.

The study involved 17 subjects, on whom the pressure exerted by the suit on the patient was measured. The experiment was conducted while studying the safety of the suits on control patients [1]. The test consisted of inflating the cuff to a level of 15 mmHg and then applying pressure to the main circuit. The cuff reading was given in 10 mmHg increments starting at a value of 20 mmHg. Higher readings than 0.9 KPa in the pneumatic system exceeded the research value of interest due to the scope of aviation use.

The manufacturer's technical documentation indicates that the maximum pressure in the pneumatic system must not exceed 1.98 KPa [6]. However, when WUK-90 suits are used in combat conditions, this value rarely exceeds 0.9 KPa. An important factor is the temperature range of application of WUK-90 suits, which is from -50^{o}C to +50^{o}C. This factor is strange to say the least because the manufacturer states the altitude range of use of the suits from 0 to 40,000 meters, but temperatures in this altitude range vary from -70^{o}C to +60^{o}C [12]. This parameter for R-WUK suits has been narrowed down to the ambient temperature of the therapeutic procedures performed, which take place at temperatures of min. +18^{o}C to +30^{o}C. These assumptions indicate a significant reduction in the critical values of the use of R-WUK suits, which in the case of new designs will not require sophisticated technological solutions. It is important to determine the service life, i.e. the maximum operating time of the suit at 3 years or 200 hours, which in the case of R-WUK suits is irrelevant, since failure of the pneumatic system causes only interruption of session [6] and does not endanger the patient in any way.

An additional limitation of the use of the WUK-90 and therefore R-WUK adaptive version of the suits is their size, the main element of which is the patient's height and BMI. For pilots, it is possible to use special sizes, i.e. tailor-made suits (for a specific pilot). R-WUK rehabilitation suits are designed for patients with standard BMI, and their height sizes range from 160 to 185 cm. In the case of normal human development, it eliminates patients under 13 years of age and patients over 185 cm tall [7].

CONCLUSION

The designs of the suits, which originated in aviation or aerospace, make it possible to adapt them for the purpose of conducting therapy with patients who have various deficits resulting from neurological, orthopaedic or psychiatric disorders. The parameters resulting from the design of the WUK-90 suits, as well as the adapted version of the R-WUK, are details that affect the conduct of therapeutic activities, reducing the time to prepare the equipment for operation and improving ergonomics. Elements that limit the motion range or changes in physiological parameters of the body that endanger the patient must be taken into account and incorporated into the design of the new suit, which will fulfil the specifics of conducting physical therapy of neurological patients or patients with mental disorders. Research work with the R-WUK suit made it possible to carry out studies to determine the methodology of working with the patient, to delineate operating parameters, to develop safety rules, to specify the level of risks and, in particular, contraindications to therapy [1,2]. At the same time, research on the R-WUK suit has made it possible to delineate the area of major disease entities for which suit therapy can be effective or will produce the desired therapeutic effects.

AUTHORS' DECLARATION

Study Design: Maciej Abakumow, Krzysztof Kowalczuk. **Data Collection:** Maciej Abakumow. **Statistical Analysis:** Maciej Abakumow, Krzysztof Kowalczuk. **Manuscript preparation:** Krzysztof Kowalczuk, Maciej Abakumow. The Authors declare that there is no conflict of interest.

REFERENCES

1. Abakumow M, Kowalczuk K. Safety of use of high altitude protection suits for kinesitherapy – preliminary report. Pol J Aviat Med Bioeng Psychol. 2019; 25(1): 50-54. doi: 10.13174/pjambp.07.12.2020.05.
2. Abakumow M, Zielińska P, Kowalczuk K. Safety of the use of high-altitude protection suits in patients with neurological disorders in kinesitherapy. Pol J Aviat Med Bioeng Psychol. 2019; 25(4):13-20. doi: 10.13174/pjambp.07.09.2022.02.
3. Available from: BARTMED Gallery [online 20/01/2022]. Access: http://bartmed.eu/gallery/.

4. Available from: Kombinezony neurorehabilitacyjne Atlant w Ośrodku AMICUS [online 10/01/2022]. Access: http://osrodekamicus.pl/kombinezony-neurorehabilitacyjne-atlant/.
5. Available from: Одеться в космос. Что космонавты носят на МКС [online 18/01/2022]. Access: https://nplus1.ru/material/2021/06/03/what-they-wear-in-space.
6. Available from: Wysokościowy ubiór kompensacyjny WUK-90 [online 15/01/2022]. Access: https://www.air-pol.com.pl/oferta/ubior/ubior-wuk-90/?doing_wp_cron=1639873730.8251709938049316406250. 26/12/2021.
7. Hopman MT, Oeseburg B, Binkhorst RA. The effect of an anti-G suit on cardiovascular responses to exercise in persons with paraplegia. Med. Sci. Sports Exerc. 1992; 24(9):984-90.
8. Исанова ВА. Новые инновационные технологии медико-социальной реабилитации в условиях многоаспектных реабилитационных учреждений. Казань: МСЗ РТ, 2007. - 27 с.
9. Исанова ВА. Мобильность, жизненно-важная функция в реабилитации детей с детским церебральным параличом. Казанского государственного медицинского университета 06.11.12.
10. Lim YC, Teo SG, Poh KK. ST-segment changes with exercise stress. Singapore Med J. 2016; 57(7): 347-353. doi: 10.11622/smedj.2016116.
11. Małachowska-Sobieska M, Demczuk-Włodarczyk E, Wronecki K, Skolimowski T, Kwiatkowski R, Skolimowska B, Staniszewski Ł. “Dunag 02” dynamic orthosis. Fizjoterapia, 2013; 21(1): 45-61.
12. 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, Washington 1971.
13. Nowotny J, Czupryna K, Domagalska M. Aktualne podejście do rehabilitacji dzieci z mózgowym porażeniem dziecięcym. Neurologia Dziecięca, 2009; 18(35): 53-60.
14. Rood G. A brief history of flying clothing. Journal of Aeronautical History. Paper No. 2014/01.
15. Różdżyńska-Świątkowska A, Kułaga Z, Grajda A, Gurzkowska B, Góźdź M, Wojtyło M, Świąder A, Litwin M. et al. Wartości referencyjne wysokości, masy ciała i wskaźnika masy ciała dla oceny wzrastania i stanu odżywienia dzieci i młodzieży w wieku 3-18 lat. Standardy Medyczne. 2013; 1: 11-21.
16. Szcześniak B. Wojskowy Instytut Medycyny Lotniczej. Wyd. MON 1988.

17. Szefostwo Służby Hydrometeorologicznej Sił Zbrojnych RP. Meteorologia dla pilotów - poradnik. Warszawa 2011.
18. Terelak J. Człowiek w Kosmosie: Bariery adaptacyjne z perspektywy astronautycznej. Studia Philosophiae Christianae. 2016; 52(3): 111-128.

.