

Skylab Legacy

Arnauld Nicogossian, MD, FACP, FACPM, FASMA, FAAS

ABSTRACT

Skylab was the first United States orbital station.¹ The Skylab program used the remaining Apollo hardware to study human endurance and ability to live and work in space for progressively increasing time. The three missions of 28-, 56- and 84-days duration benchmarked biomedical responses to microgravity and closed environments, logistics, on orbit systems maintenance and repair, solar physics, and Earth observations. During the final mission, the crew was able to study the comet, Kohoutek. The launch of the station resulted in considerable damage to the solar panels and micro-meteoroid shield, requiring a complex in space crew repairs. Using Skylab related terms PubMed, Web of Science and Google Scholar were queried for refereed publications, and personal experience contributed additional input to this paper.

Over 1,700 biomedical and physical sciences and review publications were identified. Twenty met the inclusion criteria. These consisted of refereed articles, books, NASA technical reports and conference papers. Only peer reviewed publications received a robust evidence rating.

Skylab program produced a wealth of fundamental biomedical and human factors knowledge paving the way for the International Space Station and future planetary crewed missions. Skylab operational, engineering, and scientific accomplishments paved the way for telemedicine, automated biomedical measurement system accelerating the development of hospital intensive care units on Earth, understanding the life cycle of our star, and fostering student participation in space experiments. The delays in the Space Shuttle development necessary for continuing use and servicing of Skylab contributed to its orbital decay and destruction during re-entry into the Earth atmosphere. After 50 years, Skylab biomedical and engineering findings remain as the benchmark for all subsequent investigations of space crew health, performance, and hab-

¹ Some of the materials included in this paper were presented in the keynote address at the APUS/PSO annual SESA Conference, September 21-22, 2023. Washington, D.C.

itability. The supporting experimental hardware launched a new era of medical care and telemedicine on Earth and in space. The International Space Station, the longest flying human habitat in LEO would be impossible without the experience from *Skylab*, and *Soviet/Russian Orbital Stations*.

Keywords: Skylab, LEO, biomedical, human factors, space, crew health

Disclaimer

Some of the materials presented in this paper are personal impressions and unpublished observations of the author, who served as a researcher and flight surgeon for the Skylab Program.

Skylab Legacy

RESUMEN

Skylab fue la primera estación orbital de Estados Unidos. El programa Skylab utilizó el hardware restante de Apollo para estudiar la resistencia humana y la capacidad de vivir y trabajar en el espacio durante un tiempo cada vez mayor. Las tres misiones de 28, 56 y 84 días de duración compararon las respuestas biomédicas a la microgravedad y entornos cerrados, la logística, el mantenimiento y reparación de sistemas en órbita, la física solar y las observaciones de la Tierra. Durante la misión final, la tripulación pudo estudiar el cometa Kohoutek. El lanzamiento de la estación provocó daños considerables en los paneles solares y en el escudo contra micrometeoritos, lo que requirió complejas reparaciones por parte de la tripulación espacial. Utilizando términos relacionados con Skylab, se consultaron PubMed, Web of Science y Google Scholar para publicaciones arbitradas, y la experiencia personal contribuyó con aportes adicionales a este artículo.

Se identificaron más de 1.700 publicaciones de revisión y ciencias biomédicas y físicas. Veinte cumplieron los criterios de inclusión. Estos consistían en artículos arbitrados, libros, informes técnicos de la NASA y ponencias de conferencias. Sólo las publicaciones revisadas por pares recibieron una calificación de evidencia sólida.

El programa Skylab produjo una gran cantidad de conocimientos biomédicos y de factores humanos fundamentales que allanaron

el camino para la Estación Espacial Internacional y futuras misiones planetarias tripuladas. Los logros operativos, de ingeniería y científicos de Skylab allanaron el camino para la telemedicina, un sistema automatizado de medición biomédica que aceleró el desarrollo de unidades de cuidados intensivos hospitalarios en la Tierra, comprendió el ciclo de vida de nuestra estrella y fomentó la participación de los estudiantes en experimentos espaciales. Los retrasos en el desarrollo del transbordador espacial necesarios para continuar el uso y mantenimiento del Skylab contribuyeron a su desintegración orbital y destrucción durante el reingreso a la atmósfera terrestre. Después de 50 años, los hallazgos biomédicos y de ingeniería de Skylab siguen siendo el punto de referencia para todas las investigaciones posteriores sobre la salud, el rendimiento y la habitabilidad de la tripulación espacial. El hardware experimental de apoyo inició una nueva era de atención médica y telemedicina en la Tierra y el espacio. La Estación Espacial Internacional, el hábitat humano de vuelo más largo en LEO, sería imposible sin la experiencia de Skylab y las estaciones orbitales soviéticas/rusas.

Palabras clave: Skylab, LEO, biomédico, factores humanos, espacio, salud de la tripulación

天空实验室遗产

摘要

天空实验室(Skylab)是美国第一个轨道站。天空实验室计划使用了剩余的阿波罗硬件来研究人类在逐渐增加的时间里在太空中生活和工作的耐力及能力。为期28天、56天和84天的三次太空探索任务对“微重力和封闭环境、后勤、轨道系统维护和修理、太阳物理学和地球观测”的生物医学响应进行了基准测试。在最后一次任务中，机组人员能够研究科胡特克彗星。空间站的发射对太阳能电池板和微流星体防护罩造成了相当大的损坏，需要太空人员进行复杂的维修。使用Skylab相关术语，在PubMed、Web of Science和Google Scholar中查询参考出版物，并使用个人经历为本文贡献了额外的参考。

确定了1,700多篇生物医学和物理科学及述评出版物。其中二十篇符合研究标准，包括参考论文、书籍、美国宇航局技术报告和会议论文。只有经过同行评审的出版物获得了稳健的证据评级。

天空实验室计划产生了丰富的基础生物学和人类因素知识，为国际空间站和未来的行星载人任务铺平了道路。天空实验室在操作、工程和科学方面的成就为远程医疗和自动化生物学测量系统铺平了道路，加速了地球上医院重症监护室的发展，理解了恒星的生命周期，并促进了学生参与太空实验。继续使用和维护天空实验室一事需要航天飞机的开发，而开发延误导致了其在重返地球大气层期间的轨道衰变和破坏。50年后，天空实验室的生物学及工程研究结果仍然是所有后续太空宇航员健康、表现和宜居性调查的基准。配套的实验硬件开启了地球和太空医疗保健及远程医疗的新时代。如果没有天空实验室和苏联/俄罗斯轨道站的经验，国际空间站（近地轨道上持续时间最久的人类飞行栖息地）的建立是不可能的。

关键词：天空实验室，低地轨道，生物学，人类因素，太空，机组人员健康

Introduction and Historical Perspectives

Planning for the United States orbital space stations began as early as 1963 (Compton & Benson, 1983). The Apollo program was designed to demonstrate USA technological leadership during the “Cold War,” following the USSR successes in rocketry, space communications and human space flight (Scott & Leonov, 2006, Siddiqi, 2000). NASA Skylab was deployed in 1973 following the explosion of the N 1 lunar heavy lift vehicles at Baikonur (Ladier, 2018) and the Salyut 1 orbital station tragic death of the three cosmonauts (Vallerani, 1988). NASA primary objectives for Skylab three progressively longer duration missions:

1. Conduct biomedical studies to establish human ability to live and

work in space for extended periods, and

2. Expand the knowledge of the Sun and Earth in preparation for future advanced space missions.

Methods

Using Skylab related terms PubMed, Web of Science and Google Scholar were queried for refereed publication relevant to the Skylab program. The author’s personal experience provided an additional input to this paper.

Results

Over 1,700 biomedical and physical sciences and review publications were identified. Twenty publications with relevance to the Skylab program met the inclusion criteria. These publications

consisted of refereed articles, books, NASA technical reports and conference papers. Peer reviewed publications strength of evidence was judged as robust.

Discussion

1. Preparing for the first U.S. space station

Plans envisioned three successive Skylab missions exposing crews to increased duration space flight. To understand the operational constraints and evaluate the ability of the crew interface hardware to function properly for a minimum of three years on orbit, NASA conducted a simulation called the Skylab Medical Experiment Altitude Test (SMEAT). Three astronauts lived and worked for 56 days in a simulated ground-based Skylab environment inside a specially outfitted hypobaric test chamber at the NASA facility in Houston (Johnston & Dietlein, 1922). This simulation and experiment rehearsal proved to be a resounding success, with lessons learned incorporated into the three Skylab missions. In addition, the data collected during SMEAT served as a baseline against which future space data was compared (Johnston & Dietlein, 1922; Nicogossian, Doarn, & Hu, 2016).

2. Skylab Space Station Design

The Skylab space station was 1/5th the size of the International Space Station and smaller than the Soviet/Russia MIR orbital complex. Skylab served as a space habitat, a physical fitness facility and an orbital laboratory. It was divided into five components stacked verti-

cally: the workshop, airlock, docking adapter, solar observatory, command, and service module. The Apollo command and service modules served as the logistics vehicle, berthed at the forward end of the of the complex, which housed research hardware and served as a docking port. The solar observatory was mounted on a structure above the docking adapter. The interior of the workshop consisted of two major sections: an upper compartment, with two airlocks, for large-scale experiments; and a lower compartment containing areas for food preparation and consumption, sleeping, waste management, and an experiment work area doubling as a physical fitness facility.

The Skylab habitable volume had food and waste-management systems, outfitted with collecting, measuring, and processing urine and feces in separate bags, and frozen for post-flight analysis. Trash was discarded through an airlock into a holding tank. A collapsible shower, a water dispenser and a vacuum cleaner were included. Skylab contained a significant medical capability, and the crew was linked to the ground for consultation with flight surgeons for managing medical issues during flight.

3. Skylab Damages and Repair

The first Skylab crew launch was delayed until May 25, 1973, due to the damage of the orbital workshop. During Skylab's ascent a thermal [meteoroid](#) shield was damaged, resulting in the loss of one of the solar power arrays, with structural damage preventing the full deployment of the second solar panel. The external

protective aluminum micrometeoroid and radiation shield. Launch thrusters generated vibrations damaged and tore these protective structures.

The first three-man crew used an improvised “parasol” sunshade, and later placing an overlying sun shield to prevent damages from overheating of the habitat. Skylab reinforced the intrinsic value of the human operator in space (Nicogossian et al., 2016). For real time decision and intervention. An intravehicular activity was required next to deploy a parasol, specially built by NASA and brought by the crew, providing the needed protection to the orbital workshop. For the first four days, the crew lived in the Apollo Command Module, until the workshop cooled off. The life support system was also activated to remove potentially toxic material byproducts from potential interior systems and panels off gassing due to elevated habitat temperatures (Johnston & Dietlein, 1977).

4. Skylab reentry

Delays in the Space Shuttle program and increased solar activity accelerated Skylab’s orbital decay. The station reentered and disintegrated in the Earth’s atmosphere over the Indian Ocean and Western Australia in July 1979. Skylab debris left a ninety miles footprint in a sparsely populated region of Western Australia. There were no fatalities, injuries, or property damage (Gorman, 2011).

5. Biomedical Results from Skylab

Skylab provided a wealth of biomedical data concerning the health and physio-

logical responses of humans performing work activities. Medical experiments and using countermeasures during long-term space missions. Skylab data were particularly useful in differentiating self-limiting physiological changes from those that continued throughout exposure to space flight. This information has since guided ground-based and flight research to characterize human responses to the stresses of space flight (Figure 1).

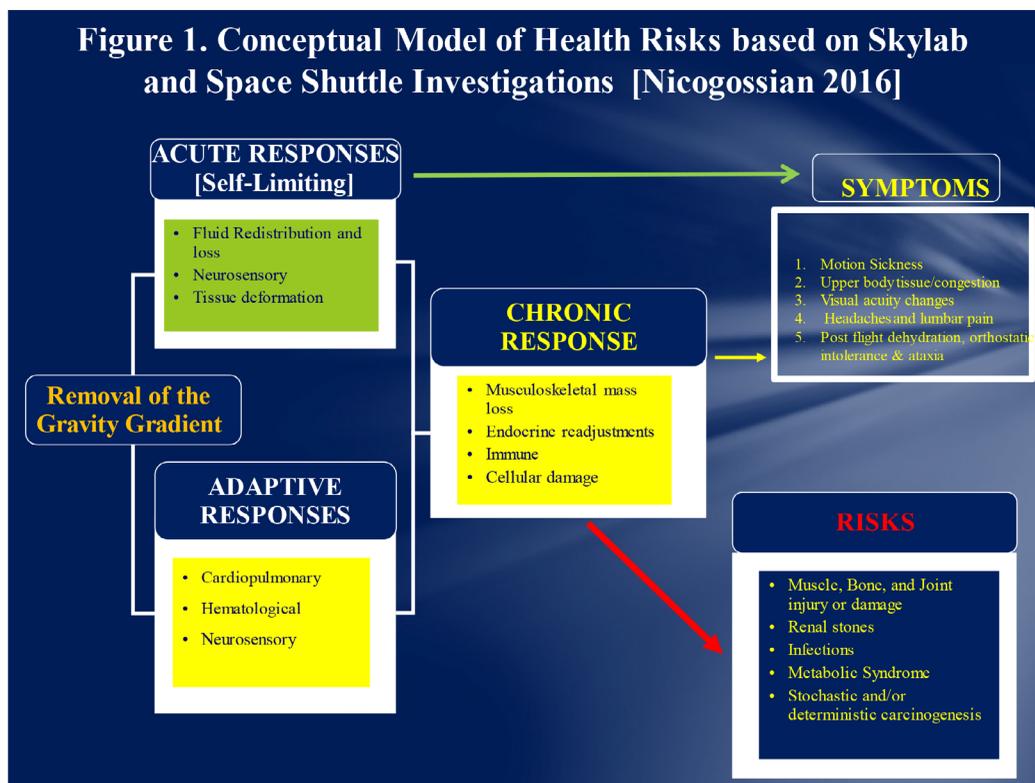
6. Astronomy and Physical Sciences

The dividends from Apollo and Skylab were substantial. Observations of the Solar coronal activity over a year period provided a better understanding of the sunspots, mass ejections and coronal activity (Eddy, 1979). Comet Kohoutek provided valuable information on the nucleus composition (Delsemme, 1982), Earth observations contributed the use of human observations and photography from space to document temporal surface changes (Parker, 1977). Lastly material sciences research laid the foundations for future commercial processing and in space manufacturing using microgravity as an experimental tool (Neuman et al., 1980).

7. Legacy

The dividends from Apollo and Skylab were substantial. The biomedical experiments demonstrated the need for a treadmill to maintain crew physical fitness. A passive foldable treadmill was flown with the last Skylab mission and demonstrated marked improvement in crew physical fitness (More et al., 2010).

Figure 1. Conceptual Model of Health Risks based on Skylab and Space Shuttle Investigations [Nicogossian 2016]



Underestimating caloric intake in larger habitats than the cramped quarters of Apollo required additional food supplements to be stowed with the last Skylab mission (Altman & Talbot, 1987).

The health and medical fields were enriched by the technology development and transfer, including sensor miniaturization, automation and data computation coupled with telemetry (Nicogossian et al., 2001) and revolutionized medical practice. Skylab also inspired future U.S./USSR collaboration in space when Skylab 2 crew visited the meeting of President Richard Nixon and Chairman Leonid Brezhnev during the two countries détente summit in 1972. Skylab laid the foundations for the Apollo Soyuz Test Project (ASTP) the first internal space mission

(Nicogossian & Campbell 2023). All crews were able to exit their spacecraft, with minimal assistance, using the inflated anti-g suits. A special platform with chairs was designed to dock with the Apollo space crafts, hoisted on to the hangar decks of the aircraft carriers (personal observations).

Conclusions

Skylab space station was occupied for 171 days and 13 hours, completing more than two hundred and fifty scientific and technical observations and experiments, including students experiments (Henry, 1973). The Skylab program produced a wealth of fundamental knowledge paving the way for the International Space Station

and future planetary crewed missions. Skylab proved that a three-month stay on orbit with the use of well-designed countermeasures protects the crews after the return to Earth, requiring a short readaptation period to a gravitational field.

Skylab operational, engineering, and scientific accomplishments contributed to innovations in health care delivery by fostering telemedicine, use of automated biomedical measurement systems, accelerating the development of hospital intensive care units on Earth (Nicogossian et al., 2001; Doarn et al., 1998), and fostering student participa-

tion in space experiments.

The delays in the Space Shuttle development necessary for continuing use and servicing of Skylab contributed to its orbital decay and destruction during reentry into the Earth atmosphere depriving U.S. for access to an orbital laboratory for almost a quarter of a century. Space stations as commercial entities, habitats, and logistic nodes around other planets to be settled remain an important part of the human space infrastructure despite political and economic controversies (Launius, 2008).

Limitations and bias

Nine experienced and “healthy” Caucasian male military pilots took part in the Skylab program. Each crewmember preflight biomedical measurements served as his control for inflight and post mission data analysis. All crews participated in the medical experiments with nine subjects available for 28, six for 56, and only three for 84 days exposures to the LEO environment. Thus, the sample size limits the statistical power of the results. Caution should be exercised when extrapolating the information to the general population and current individuals involved in commercial space missions.

References

Altman, P. L., & Talbot, J. M. (1987). Nutrition and metabolism in spaceflight. *The Journal of Nutrition*, 117(3), 421–427.

Compton, W. D., & Benson, C. D. (1983). *Living and working in space: a history of Skylab* (Vol. 4208). Scientific and Technical Information Branch, National Aeronautics and Space Administration.

Delsemme, A. H. (1982). Chemical composition of cometary nuclei. In *Comets* (pp. 85–130). Univ. of Arizona Press, Tucson.

Doarn, C. R., Nicogossian, A. E., & Merrell, R. C. (1998). Applications of telemed-

icine in the United States space program. *Telemedicine Journal*, 4(1), 19–30.

Eddy, J. A. (1979). *A new sun: The solar results from SKYLAB* (Vol. 402). National Aeronautics and Space Administration, Scientific and Technical Information Branch.

Floyd, Henry B., “The Skylab Student Project.” (1973). The Space Congress® Proceedings. 3. <https://commons.erau.edu/space-congress-proceedings/proceedings-1973-10th/session-1/3> (accessed December 2023).

Gorman, A. (2011). The sky is falling: How Skylab became an Australian icon. *Journal of Australian Studies*, 35(4), 529–546.

Johnston, R. S., & Dietlein, L. F. (Eds.). (1977). *Biomedical results from Skylab* (Vol. 377). Scientific and Technical Information Office, National Aeronautics and Space Administration.

Johnston, R. S., Stonesifer, J. C., & Hawkins, W. R. (1975). Development of Skylab medical equipment and flight preparations. *Acta Astronautica*, 2(1-2), 69–84.

Lardier, C. (2018). The soviet manned lunar program N1-L3. *Acta Astronautica*, 142, 184–192.

Launius, R. D. (2008). Space stations for the United States: An idea whose time has come—and gone? *Acta Astronautica*, 62(10-11), 539–555.

Moore, A. D., Lee, S. M., Stenger, M. B., & Platts, S. H. (2010). Cardiovascular exercise in the U.S. space program: past, present, and future. *Acta Astronautica*, 66(7-8), 974–988.

Naumann, R. J., & Herring, H. W. (1980). *Materials processing in space: early experiments* (Vol. 443). Scientific and Technical Information Branch, National Aeronautics and Space Administration.

Nicogossian, A., & Campbell, M. R. (2023). The Legacy of the Apollo-Soyuz Test Project. *Aerospace medicine and human performance*, 94(8), 651–653.

Nicogossian, A. E., Doarn, C. R., & Hu, Y. (2016). Evolution of human capabilities and space medicine. *Space Physiology and Medicine: From Evidence to Practice*, 3-57.

Nicogossian, A. E., Pober, D. F., & Roy, S. A. (2001). Evolution of telemedicine in the space program and earth applications. *Telemedicine Journal and E-health*, 7(1),

1–15.

Packer, D. M., & Packer, I. G. (1977). Exploring the earth's atmosphere by photography from Skylab. *Applied Optics*, 16(4), 983–992.

Scott, D., & Leonov, A. (2006). *Two sides of the moon: Our story of the cold war space race*. Macmillan.

Siddiqi, A. A. (2000). *Challenge to Apollo: The Soviet Union and the space race, 1945–1974* (Vol. 1). U.S. National Aeronautics & Space Administration.

Vallerani, E. (1988). The space station. *Interdisciplinary Science Reviews*, 13(2), 156–165.