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EDITORIAL

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Aerospace heritage: Footprints of human civilization on and beyond Earth

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Aerospace heritage (ASH) began in the early 20th century with pioneers like the Wright brothers and their 1903 flight, followed by rapid advancements in aviation during World War I and the growth of commercial aviation. The space age began in 1957 with Sputnik 1, followed by milestones such as Yuri Gagarin's 1961 orbit and the Apollo 11 moon landing in 1969. ASH includes valuable artifacts and sites related to space exploration, such as early satellites, lunar landings, Mars rovers, and space probes. These assets not only represent technological breakthroughs but also embody humanity's ambitions for aerospace exploration. In this Editorial, we explore the concept of ASH, categorize its various types, highlight the importance of preservation, examine challenges in protecting it, and discuss the future of safeguarding these legacies.

DEFINITION AND TYPES OF ASH

ASH can be comprehensively defined as any tangible or intangible item or site of historical, cultural, or scientific significance associated with Earth observation, space exploration, and related activities.[1] In this Editorial, we classify ASH into several distinct categories (Figure 1):

Earth's orbital artifacts. These artifacts include satellites, space stations, and spacecraft that remain in Earth's orbit. Notable examples are the Landsat Satellites, the Hubble Space Telescope, and China's Tiangong Space Station (TSS).

Figure 1. Categories of aerospace heritage (ASH) and their characteristics.

Lunar and deep space probes. This category covers probes and spacecraft sent to explore distant planets, moons, and other celestial bodies. Prominent examples include the Chang'e probes, the Mars Reconnaissance Orbiter, and the Voyager and Pioneer missions.

Landing sites and artifacts. These are objects left on the Moon and Mars by human exploration missions. Examples include the Apollo modules, Viking landers, Yutu rovers, scientific instruments, flags, and personal items left by astronauts.

Launch sites and ground facilities. This includes infrastructure on Earth that supports aviation and space missions, such as launch pads, mission control centers, tracking stations, and landing sites. Examples are the Baikonur Cosmodrome (former Soviet Union), Edwards Air Force Base (USA), and Siziwang Banner landing site (China).

Intangible heritage. This encompasses the knowledge, traditions, and narratives associated with Earth observation and space exploration. It includes scientific data (especially historical photographs and remote sens-

ing images), mission logs, and oral histories.

SIGNIFICANCE OF ASH

ASH encompasses heritage linked to the realization of human ambitions in aviation and space, aerospace flight and exploration, as well as human cultural heritage that persists both on and beyond the Earth's surface.[2] The notion of preserving these precious heritage assets gained traction around the beginning of the 21st century as the space era matured and the historical importance of these endeavors became increasingly apparent. The preservation of ASH is essential for several reasons:

Historical significance. ASH artifacts represent milestones of human ingenuity, exploration, and achievement. They serve as tangible records of our journey into the skies and space, reflecting the advancements that have shaped our understanding of the universe.

Cultural value. ASH holds profound cultural importance, symbolizing the collective dreams and aspirations of humanity. It stands as a testament to our quest for knowledge, the spirit of exploration, and the desire to transcend our earthly limitations.

Educational importance. Preserved ASH serves as a powerful educational resource, inspiring future generations of scientists, engineers, and explorers. It provides tangible connections to past achievements, stimulating interest in science, technology, and innovation.

Scientific research. Artifacts and sites from past missions offer valuable scientific insights. For instance, analyzing the effects of long-term exposure to the space environment on materials can inform the design of future spacecraft and missions.[3]

International cooperation. Safeguarding ASH promotes international collaboration and mutual understanding. It underscores the shared human endeavor in Earth observation and space exploration. It fosters cooperative efforts to preserve these legacies, benefiting all of humanity.

CURRENT SITUATION AND CHALLENGES IN ASH

Recent years have seen significant progress in efforts to study ASH. Organizations such as the United Nations Office for Outer Space Affairs (UNOOSA) and the International Council on Monuments and Sites (ICOMOS) have acknowledged the importance of preserving ASH. Additionally, nations with active space programs, such as China and the United States, have taken steps to protect their space artifacts and landing sites. In 2019, NASA launched the Lunar Gateway Heritage Initiative to preserve the historical artifacts left on the Moon by the Apollo missions. In 2024, China unveiled a long-term roadmap to guide its space science programs up to 2050, including missions to implement the manned lunar exploration project and protect lunar heritage. Despite these efforts, several challenges persist in the field of ASH.

Legal and regulatory frameworks. The current international space law, primarily governed by the Outer Space Treaty of 1967, does not include specific provisions for ASH. This absence creates ambiguities and challenges in implementing and enforcing sustainable management measures effectively.

Orbital debris and space traffic. The increasing volume of space debris presents a major risk to orbital artifacts. Collisions with debris can result in significant damage or destruction of heritage artifacts, thereby gradually leading to the loss of integrity and authenticity of the ASH.

Environmental degradation. The severe conditions of space, such as radiation, micrometeoroids, and extreme temperature fluctuations, can cause degradation of artifacts over time.[1] Addressing and mitigating these effects presents a complex challenge.

Accessibility issues. Many ASH sites are difficult to access, complicating efforts to document and preserve them. Artifacts on the Moon or Mars, for instance, necessitate expensive and technologically advanced missions for study and protection.

Resource allocation. Studying and preserving ASH demands significant financial and technical resources. Balancing these needs with the priorities of ongoing and future space exploration remains a persistent challenge for space agencies and organizations.

TRENDS AND PROSPECTS OF ASH

With the increasing global awareness regarding the ASH, it is imperative to enhance the identification, investigation, protection, preservation, and sustainable management of humanity's tangible and intangible ASH on Earth, in orbit, and in outer space. The future of ASH study holds promising potential in several key areas, as outlined below.

International cooperation and partnership. Studying ASH on a global scale necessitates international collaborations and partnerships.[4] Collaborative efforts, including joint missions, publicly available databases, and shared protocols, are becoming more prevalent. Initiatives such as the ICOMOS International Scientific Committee on Aerospace Heritage (https://iscah.icomos.org/) and national registers of historic places are vital in identifying and safeguarding ASH sites of universal value.

Education and cultural tourism. The management and utilization of ASH for educational purposes is expanding, with museums, educational institutions, and online platforms offering curated exhibits, interactive displays, and educational programs. These initiatives aim to engage diverse audiences, fostering a deeper appreciation for the history and impact of space exploration. As commercial space travel becomes more feasible, ASH sites could become destinations for tourism, providing financial support for preservation efforts and offering unique cultural experiences to the public.

Enhanced preservation techniques. Ongoing research into the effects of the space environment on materials is leading to improved preservation methods, which can help mitigate degradation and extend the lifespan of ASH artifacts. Particularly, advances in digital techniques are opening new possibilities for documenting and disseminating ASH. Virtual reality (VR) and augmented reality (AR) offer immersive experiences, allowing individuals to explore historic spacecraft and aviation artifacts remotely, thereby increasing public engagement and awareness.[5]

Sustainable space exploration. Integrating ASH study into the planning and execution of space missions ensures that tangible and intangible properties are respected and protected. This approach promotes sustainable and responsible practices in space exploration. Additionally, advances in space technology, such as autonomous robots and advanced imaging systems, enable detailed assessments of artifact conditions and monitor environmental impacts, thereby facilitating the long-term preservation of ASH.

Global policy frameworks. Efforts to update and expand international space law and norms to include heritage protection and utilization are underway.[3] These legal frameworks aim to establish clearer guidelines and responsibilities for the sustainable management of ASH. The development of comprehensive international policies and agreements focused on ASH will provide a unified approach to research efforts. These frameworks will facilitate cooperation and ensure the longevity of ASH for future generations.

CONCLUSION

ASH encapsulates the legacy of humanity's ventures into the skies and outer space. From the earliest aviation innovations to the monumental achievements in space exploration, ASH not only signifies technological progress but also embodies human ingenuity, courage, and ambition. The study of these sites and artifacts is essential for maintaining a connection to our past, inspiring future generations, and advancing scientific knowledge. Despite the challenges, ongoing efforts and emerging trends provide optimism for the protection, management, and utilization of ASH. By safeguarding and leveraging ASH on an international scale, we ensure that the traces of human civilization, both on and beyond Earth, persist to enrich our understanding of the cosmos and our place within it.

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DECLARATION OF INTERESTS

The authors declare no competing interests.