Chapter 5
The Space Shuttle *Discovery*, Its Scientific Legacy in a Museum Context

Hanna M. Szczepanowska

Abstract This chapter is written from the perspective of a conservation scientist who works on early satellites, solar panels, thermal protection systems and heat shields from the Apollo and Space Shuttle missions in the context of museum exhibits. The author looks at the Space Shuttle orbiters as technologically advanced systems which, when their missions were completed, entered museums as part of humanity's scientific and cultural heritage.

Introduction

The operation of complex, integrated space systems requires revolutionary thinking both in their development and management. Space exploration, whether human or robotic, is the grandest and most technically challenging expression of human imagination and ingenuity.

Theodore von Karman said: "Scientists study the world as it is; engineers create the world that has never been" (after Griffin 2008). However, analysis of engineering creations and the prediction of their behavior under various environmental and operational conditions require science. The synergy of both produces unprecedented results. Spacecraft, upon ending their operation begin a new phase while on exhibit in the science museums, educating the public about the space exploration. Some of them, reaching their 50 anniversary of creation, form a new collection of space-archeology artifacts. How these artifacts can be presented in a museum setting to fully experience their performance in the space environment and harsh atmospheric re-entry? A proposed concept of showcasing the space heritage artifacts integrates both humanistic and engineering approach.

The *Discovery*, one of the Space Shuttle Fleet Orbiters, completed its last 133rd mission on March 9, 2011. One month later, it retired to its new permanent location

---

H.M. Szczepanowska (✉)
MCI Smithsonian Institution, Suitland, MD 20746, USA
e-mail: hszczepanowska1@gmail.com

© Springer International Publishing Switzerland 2015

B.L. O'Leary and P.J. Capelotti (eds.), *Archaeology and Heritage of the Human Movement into Space*, Space and Society, DOI 10.1007/978-3-319-07866-3_5

at the National Air and Space Museum, Udvar Hazy Center, in Chantilly VA (NASA 2012). This unique spacecraft that traveled to the Low Earth Orbit (LEO) and returned to Earth embodies engineering achievements measured by the importance of its science missions and design of the spacecraft. To the public, the space shuttle delivered results as the program promised; routine launches of cargo and people into orbit, returning to Earth for refurbishing and launching again for a new mission. Although it seemed routine, the vehicle, its maintenance and the missions all were highly complex.

The focus of this discussion is on the technological legacy exemplified by the thermal protective system (TPS) of the space shuttle orbiter which posed one of the main challenges in ensuring the shuttles' safe return to Earth. These technological advancements are highlighted in the context of TPS predecessors, ablative systems of Apollo, Gemini, and Mercury which by now have gained the status of space archaeology objects. How that technology can be experienced by and conveyed to the museum visitors during their short contact with an artifact on exhibit is proposed in a new framework of visitors' interactions with these artifacts.

The Space Shuttle Program, an Overview

The phrase 'space shuttle' refers to the program of Space Transportation System (STS) which begun its operation in 1981 with the first STS flight of *Columbia*, on April 12. The first flight in 1981 commenced the three decades lasting operation of the space shuttle program. The 133th and final launch was on March 9, 2011, from the Kennedy Space Center.

All five orbiters of the fleet, *Columbia, Challenger, Endeavour, Discovery* and *Atlantis* were flown. A test orbiter, *Enterprise*, was built for the purpose of testing approach and landing and did not have capability to fly into orbit; it lacked engines, heat shields and any equipment required for orbital flights. After completion of tests it became part of the collection at the National Air and Space Museum (NASM) exhibited since 1985 at the new branch of NASM, the Steven F. Udvar-Hazy Center in Chantilly, VA. On April 17 of 2012 it was replaced by *Discovery* once the Space Shuttle Program was no longer in operation (Fig. 5.1).

Similarly, all remaining orbiters continue their educational role in various science museums and centers across the United States. The *Enterprise* was transferred to the Intrepid Sea-Air-Space Museum in New York City shortly after leaving the Udvar-Hazy Center in 2012. *Atlantis* is on display at the Kennedy Space Center Visitor Complex in Florida. The *Endeavour* became part of the exhibit at the California Science Center in Los Angeles, CA.

Two shuttles, *Challenger* and *Columbia*, were lost in missions in 1986 and 2003 respectively. In 1991, the orbiter *Endeavour* was built as replacement of *Challenger*. The Space Shuttle vehicles delivered payloads to orbit, re-entered the atmosphere and captured large payloads on their return back to Earth. STS orbiters were the first space vehicles to travel multiple times to LEO and back to Earth.

One of the most notable functions of the STS was participation in the construction and later the servicing of the International Space Station. Other missions

Fig. 5.1 *Enterprise* and *Discovery* facing each other on the grounds of NASM's Udvar-Hazy Center, April 17, 2012 (image 2012, H.Szczepanowska 2012)

included collaboration with the European Space Agency and their Spacelab program, supporting numerous scientific experiments that were carried out in space.

The design of the orbiters, their deployment strategies as well as the multifaceted purpose of the shuttle program evolved after many years of changing objectives, adjustments to congressional budgetary cuts, and the desire to incorporate many functions meeting military, scientific and commercial needs. The complex political climate shaping the shuttle program development is the subject of space historians' study. This chapter is focused on the artifact, the orbiter exhibited in a museum, what it represents in that context, how its technological advancements can relate to its predecessors and how that can be traced in its design and, finally, how to present the artifact and its missions to museum visitors often overwhelmed by the sheer size of an artifact that measures 122 × 78 ft and weighs 171,000 lb.

The Space Shuttle, General Design Requirements

The main objectives of the space shuttle vehicles—to travel to space on various missions and return to Earth—shaped the spacecraft design. Furthermore, the design had to accommodate military requirements for high capacity payload deployment. The unique design of STS orbiters' side doors facilitated deployment of large satellites such as the Hubble Space Telescope.

To meet the requirements at reentry to the Earth atmospheric a new thermal system had to withstand high temperatures and impacts experienced during reentry. The invention of reusable thermal protection systems, 'heat shields' that would not ablate and could be reused to adequately protect each part of the space vehicle exposed to ranges of fluctuating temperatures was one of the greatest challenges.

Each space shuttle included three main assemblies, an orbiter vehicle (OV), a pair of recoverable solid rocket boosters (SRB), and an expandable external tank (ET) with liquid hydrogen and liquid oxygen. All of these components were stacked together. The shuttle had a two-stage ascent and was lifted by its two SRBs reinforced by three main engines fueled by liquid hydrogen and oxygen from the external tank. Two minutes after liftoff the pair of SRBs was separated by frangible nuts that held them in place until that moment. SRBs fell by parachute into the ocean to be recovered for refurbishing and reuse.

Two orbital maneuvering systems (OMS) engines facilitated both jettisoning and, later, the orbiters' drop out of orbit and re-entry to the atmosphere. The launch was vertical, similar to a conventional rocket launch. Once the space mission was completed the orbiter fired its OMS to re-enter the atmosphere to achieve the necessary hypersonic speed (N.B.: In aerodynamics such speed is associated with Mach 5 or above; hypersonic speeds are greater than the speed of sound).

The other great challenge, next to the development of reusable heat shield, was to design a vehicle with aerodynamic stability at various speeds from subsonic and supersonic at points from atmosphere reentry to controlled gliding on landing. The aerodynamic shape was a compromise between the demands of radically different speeds and air pressures during re-entry, hypersonic flight and subsonic atmospheric flight. Large wings were included to accommodate gliding of the shuttle at the end of its descent.

Such space vehicles conceptually existed two decades prior to the Apollo program. The concept of a reusable winged spacecraft and suborbital bomber was developed in the 1940s although it materialized later (Day 2003). Many attempts of designing a reusable and multifunctional spacecraft followed, some of them even overcame technical challenges of reentry using heat shields that did not ablate such as the X-20 Dyna-Soar, however the project canceled before flight trials could begin (NASA 2008a, b).

Maxim Faget, who oversaw the space shuttle design, was also involved in designing space vehicles of Mercury, Gemini and Apollo, so similarities of the early engineering solutions can be traced in the STS orbiters. The legacy of the engineering solutions from the Apollo era is exemplified in the thermal protective systems.

The Historic Context of Thermal Protective Systems

Atmospheric reentry is the movement of human-made or natural objects as they enter the atmosphere of a planet from outer space, in case of earth, from an altitude above Karman Line (100 km; 62.1 miles) (Donegan 2009: 83–90; see also

Darrin this volume). The Thermal Protective System (TPS) is critical for the successful reentry of the space vehicle to the Earth atmosphere; it shields the cargo and human crew inside the vehicle. The space vehicle reentering the atmosphere experiences surface pressure, convective, catalytic and radiative heat, shear heating, vibration, turbulence, just to name a few simultaneously occurring impacts upon the spacecraft. The heated surface interacts with the gas boundary layer. In that environment the composite materials undergo chemical and physical changes (Dymitrienko 1999).

Re-entry parameters dictated the choice of materials which, in order to sustain the impacts of reentry forces, had to possess slow thermal conductivity and large enthalpy. Different thermal management techniques are applied to different flight vehicles. In case of vehicles reentering the Earth atmosphere two different TPS systems were employed in managing the aerodynamic heat and impact of reentry, ablative and reusable systems.

The first manned space vehicles of Apollo era, Gemini and Mercury, used ablative shields; the space shuttle used reusable systems [N.B. The first Mercury spacecraft used a blunt body design and a heat sink; the later version used blunt body design and an ablative material (Swenson et al. 1966)]. Some of the processes used in the development of TPS systems lead to innovative solutions, such as reinforced carbon–carbon (RCC) and reusable silica-base tiles later used on the space shuttle orbiters.

The first ablators were phenolic resin plastics, modeled into desired shape. Nylon cloth was impregnated with the phenolic resin and underwent pyrolysis, a process utilized in the production of STS's RCC. Some of the materials which were considered in the early development of thermal protection systems included: beryllium oxide, ceramics, oak, wet oak, graphite, plastic laminates, and glass cloth saturated in thermosetting resin. A selection of short fibers, randomly oriented in a 'soup' of resin, molded into desired shape was promising. The refractory fibers used in the early experiments included oxides, mostly silica oxide, to hold the charred resin. Another fiber, graphite, was attractive material because its strength and thermal conductivity increase with increasing temperature (Sutton 1982: 3–11). This extensive research in the 1960s lead to even greater technological advancements of TPS in later years.

Two examples of heat shields from the manned space vehicles were selected to exemplify the different technologies used in the historic thermal protective systems, one from Mercury 7 (flown 1962) and the other from the Gemini Capsule (flown 1966). They provide a historic context for the TPS utilized on the Space Shuttle orbiter, bridging the early developments with new technological advancements. Phenolic resin used in the historic ablators had the highest-temperature capability, and as it cross linked it reduced to a char with some structural integrity, especially if refractory fibers were holding it together (cross linking occurs when resin is heated under pressure). Development of pyrolytic graphite in the process of testing ablatives attracted considerable interest at that time. This form of graphite is made by placing a high-temperature form in an atmosphere of gaseous hydrocarbons. The hot surface pyrolyzed, the gas molecules which impinged

Fig. 5.2 Mercury 7, 1962, cross-section through the ablated upper part of the heat shield, illustrates layers of the fiberglass cloth laminate saturated with phenolic resin (NASM 1968-0263-002; image 2008 H. Szczepanowska)

upon it, left the carbon on the surface. This technology was known then as Reinforced Pyrolyzed Plastic (RPP). RPP was used on the door of the capsules and the navigation equipment. The process was revisited later leading to the fabrication of RCC on the space shuttle orbiters. The Mercury heat shield material was cloth-like, fiberglass-reinforced resin (Fig. 5.2). It exemplifies one of the methods of manufacturing high-performance composites which involved the resin-impregnation of bundled filaments to form a continuous tape or fabric. This material was subsequently plied in layers and then subjected to pressure and heat, which yielded a consolidated composite structure for subsequent assembly or manufacturing steps.

The Gemini heat shield utilized honey-comb structure filled with ablative material (Fig. 5.3). Avco invented a method of structurally fastening a low-density polymer to the substructure of metallic honeycomb. The depth of each cell was considerably greater than its width, so that the ablation material adhered to the honeycomb when exposed to shear which ensured that the ablation material did not fall out (Dolan 1965). The same principle of ablative shield was used on Apollo vehicles and is discussed elsewhere (Szczepanowska and Mathia 2011).

The ablative technologies, historically successful in protecting the cargo upon reentry to the Earth atmosphere, could not be employed on the space shuttle; ablative materials could not be reused. However, as pointed out earlier, some of the technological concepts from early materials' tests were developed further and utilized on the orbiters' TPS.

shield, illus-
1968-0263-

'n then as
e capsules
to the fab-
ld material
ne of the
l the resin-
This mate-
and heat,
sembly or

vith abla-
ly fasten-
omb. The
the abla-
h ensured
principle
elsewhere

argo upon
ıttle; abla-
ıme of the
er and uti-

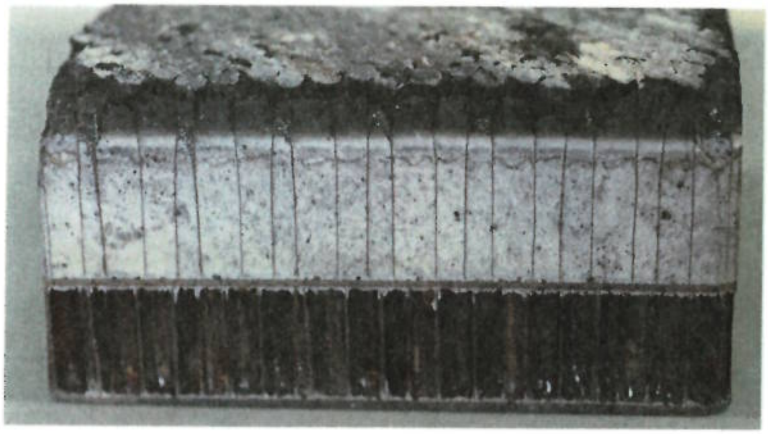


Fig. 5.3 Gemini, 1966, cross-section of a heat shield showing a fiber-glass honeycomb core filled with an elastomeric ablator, Dow-Corning DC-352 (NASM 1968-0580, image 2008, H. Szczepanowska)

The STS Orbiters' Thermal Protective System

The space shuttle orbiter was the first space vehicle designed to be used multiple times; its thermal protection system had to be reused for 100 missions. A heavy thermal protection system such as ablative heat shields that disintegrated during re-entry would not work. The space shuttle, which is much larger than the early single-use spacecraft, needed a system that was lightweight in addition to being reusable.

Among several TPS systems used on the orbiters, two were selected to exemplify one of the most interesting technological advancements, Reinforced Carbon–Carbon (RCC) and High-temperature Reusable Surface Insulation (HRSI) ceramic tile. Both are discussed in the context of the multitude of TPS materials used on the orbiters.

The space shuttle orbiters were exposed to a range of temperatures in different locations of the spacecraft at the time of re-entry to the atmosphere. The external surface reached extreme temperatures up to 3,000 °F (Jenkins 1993). Exposure to temperature depended directly on the orbiter's position upon re-entering the atmosphere. In most cases the orbiter flew nose first and upside down. Firing the RCS thruster pitched the orbiter into nose-first position with the underside exposed to the most extreme heat. Moving at 17,000 mph (28,000 km/h), all the phenomena occurring at that speed, upon contact with air, produced heat reaching 3,000 °F (1,650 °C).

The structural temperatures were required to stay below 350 °F for re-use purposes. To keep the temperatures at that level (down to 350 °F), the re-usable surface insulation tiles were applied to the areas that experienced the highest temperature, the windward surfaces. Reusable blankets were used primarily on other leeward surfaces. Reinforced carbon–carbon (RCC) was applied on the

Fig. 5.4 Reinforced carbon–carbon (RCC) shield applied on the leading edges and nose of the shuttle orbiter (courtesy of Dr. Nathan Jacobs, NASA Glenn Research Center)

leading edges and the nose cap, where temperatures were greater than 2,300 °F (Fig. 5.4). Furthermore, high-temperature coatings of SiC-based were used on the Space Shuttle Orbiter leading edges protecting the surface up to 3,000 °F (Alvaro and Snapp 2011). In addition to embracing the challenges of engineering reusable materials, the attachments to the various components of the vehicle, tank, insulation or sub-structure of TPS, posed additional technical difficulties. These materials operated at a wide range of temperatures, expanding and contracting at different magnitudes.

Other thermal protective materials of the orbiter included black, high temperature, reusable surface insulation tiles (HRSI), which insulted upper and forward fuselage windows. White Nomex blankets were used on the upper payload bay doors, portions of the upper wing and mid/aft fuselage. White tiles, low-temperature reusable surface insulation tiles (LRSI) were applied on the remaining areas, forward, mid-, and aft fuselage, vertical tail, upper wing and OMS/RCS pods, where temperature did not reach 1,200 °F (NSTS 1988).

Reinforce Carbon–Carbon

RCC development can be traced to the Apollo era, more precisely, to research and development of Reinforced Pyrolyzed Plastic (RPP). The idea of pyrolyzing a polymer to carbon thus led to RCC (12/10/2013, Personal communication with Dr. Nathan Jacobson, Research Physicist, NASA Glenn Research Center, Cleveland, OH who conveyed this information from David Wright at Lockheed). Fabrication of RCC began with pyrolized (or graphitizing) rayon cloth impregnated with phenolic resin. The cloth layers which formed a laminate were cured in an autoclave. The rayon fibers were pyrolyzed to become carbon fibers.

The two-step pyrolizes involved, first, the conversion of resin to carbon and, next, treatment with furfural alcohol. The carbon-cloth was repeatedly infiltrated with a carbon precursor to form a carbon matrix. Each infiltration step was designated RCC-0, RCC-1, RCC-2, etc. That produced the carbon fibers in a carbon matrix, hence the name carbon/carbon, i.e. carbon fibers in a carbon matrix.

To ensure reusability of RCC, the outer layer is converted to silicon-carbide, protecting the surface against oxidation. Once converted, the top layer is whitish-gray color, with cracks caused by differential thermal expansion throughout the curing and oxidation processes. The operating temperature of RCC ranged from –250 to 3,000 °F. The final product, having a relatively high thermal conductivity with respect to other thermal protection system components, promoted the internal cross-radiation from the hot stagnation region at the apex to cooler areas of the component. This cross-radiation reduced the temperatures near the apex (NASA 2008a).

The reinforced carbon–carbon (RCC) was used on the nose cap and an area immediately aft of the nose cap on the underside and on the leading edge of the wings. RCC protected the areas where temperature exceeded 2,300 °F. The leading edges of each of the orbiters' wings had 22 RCC panels. The molded components were approximately 0.25–0.5-in. thick.

During fabrication, the RCC panels were covered with a silicon carbide coating; a final coating of glass served as sealant. Early RCC did not use a glass protection system. The idea of protecting RCC with a glass developed after the first few STS flights and was a major step forward (personal communication with Dr. N. Jacobson, NASA Glenn). Although the RCC panels were strong and capable of withstanding extreme temperatures, they were thermally conductive, which required to use insulating blankets and tiles behind the RCC panels to protect the internal structures of the orbiter.

High Temperature Reusable Surface Insulation Tiles

Several different types of reusable tiles were used on the STS orbiters. Among them were Advanced Flexible Reusable Insulation (AFRSI), Flexible Reusable Surface Insulation (FRSI) and several types of ceramic tiles. The two main categories of ceramic tiles included High-temperature Reusable Surface Insulation (HRSI) and Low-temperature Reusable Surface Insulation (LRSI), differentiated by color coating, pigmented with materials that would respond to different ranges of temperature.

HRSI, found on the lower surface of the orbiter were coated with black borosilicate glass, while LRSI tiles were coated white (Alvaro and Snapp 2011). The white coating contained silica and alumina and better reflected the heat of the Sun while on–orbit. They were used for areas exposed to lower temperatures, ranging from 600 to 1,200 °F. The white tiles were usually larger and thinner, 8 in. long on each side and from less than a 1/2 in. thick up to 1 in. in thickness. Waterproofing polymer was applied as the final coating on all tiles.

HRSI, once made of the ceramic tiles, were of different thickness, depending on the temperature that the surface was exposed to; thicker at the forward areas of the orbiter and thinner toward the aft end. Except for closeout areas, the HRSI tiles were nominally 6- by 6-in. squares.

Black, reusable tile exemplify another technologically advanced material of which conceptual and empirical roots can be traced back to the mid-1950s. From a broad range of material used in the early research from 1957, silica was selected as the primary component by 1961. The final component of the basic shuttle material emerged in 1968 as LI-900 (Lockheed Insulation/9 lbs per cubic foot). It is a low-density and high-strength rigid fiber ceramic tile, meeting the main objectives, to protect against high temperatures, of light weight and reusable.

The reusable surface insulation ceramic tiles were used on the entire fleet of shuttle orbiters. The earlier orbiters used 34,000 tiles, later only 26,000, replacing the areas of exposure to moderate re-entry temperatures with flexible insulting blankets.

High purity amorphous silica fibers derived from sand and were the main component of bulk of these ceramic tiles. The fibers of 2–4 micron in diameter are approximately 1/16th in. long suspended in water slurry were cast, forming soft, porous blocks; colloidal silica binder was added to hold them together. Dried and sintered at 2,300 °F, the blocks were cut to precise dimensions. Each tile was unique to fit the curvature of surface on the orbiter. Machined tiles were covered with coatings, baked-on in ovens. The black coating of borosilicate glass covered the tiles that experienced the highest temperatures at re-entry, up to 23,000 °F (that is why they are referred to as high-temperature tiles). Not surprisingly, after atmospheric re-entry, this coating shows only minor changes of its surface texture and roughness (Szczepanowska and Renegar, 2014).

An uncoated HRSI tile held in the hand feels like very light foam, less dense than Styrofoam, and the delicate, friable material must be handled with extreme care to prevent damage. The ceramic coating, forming a thin, hard shell encapsulates the friable fibers on all sides except the side where the tile is attached to the orbiter's surface (Fig. 5.5). Even a coated tile feels very light, lighter than a same-sized block of Styrofoam.

Exhibit

The STS Orbiters represent the class of space artifacts embodying multitude of technological challenges, not least those encountered in engineering solutions to atmospheric reentry. The thermal protective systems discussed earlier exemplify one aspect only, innovative systems and materials designed for multiple re-entry to the Earth atmosphere, thus serving as a model applicable to analysis of space

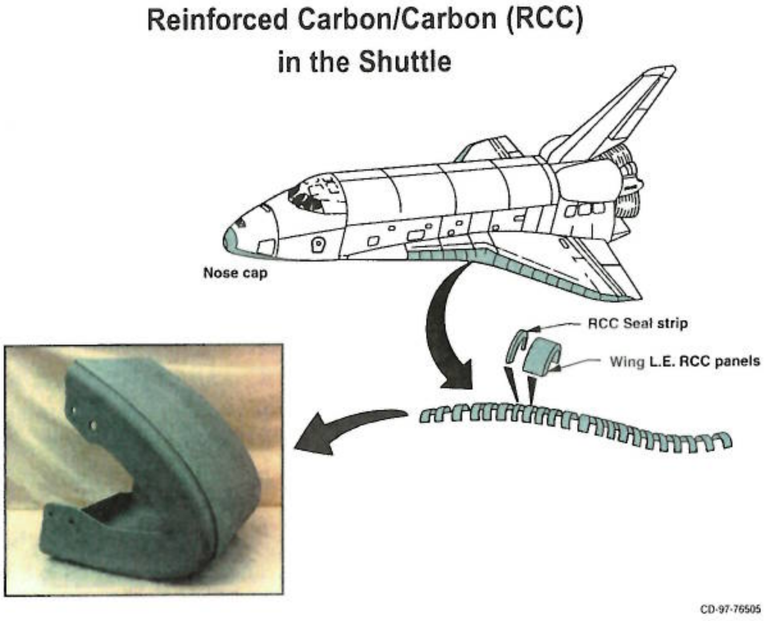


Fig. 5.5 Detail of HRSI tile reveals in the chip areas structure under the black coating, RTV adhesive and remnants of an insulation pad to which it was attached.(Image H. Szczepanowska 2008)

collections in general. The primary consideration for a museum curator is how to exhibit those artifacts so they would effectively enable the museum visitors a glimpse into challenges of space exploration.

The technological-scientific artifacts, to which space vehicles belong, are not merely symbols and icons, presented in a narrative of space historians; they were functional, operational, evolving and dynamic structures. That dynamism must be conveyed to the public in an exciting way, aiming to bring closer the experience of space exploration.

A discussion on this subject—among historians entrusted with care for space artifacts in museums—lead to a meeting entitled "Artefacts" in 1996. One of the objectives was to develop a model for effective use of scientific collections in historical studies (Collins and Millard 2005). Although many essays were published after the "Artefacts" meeting, and thought it was clear that an appreciation of the objects as conveyors of the technology grew over the years, the exhibits did not seem to change very much. They remained static and dense sediment of human agency, culture and technology.

Without doubt, word-based information is essential in conveying concepts of knowledge embodied in artifacts, which that is particularly important when exhibiting space artifacts. Many scientific definitions and concepts originated in specific disciplines, thus the need for clearly defining terms and developing word-base communication is even more essential.

However, to fully appreciate an artifact especially one involved in space exploration, calls for a full-sensory experience, engaging olfactory sensations of charring and melting of heat shields, acoustic impressions of supersonic speed, and the many other imaginable effects of reentry impact. This framework of presenting space artifacts expands the traditional means of exhibits and reaches out into the epistemological concept of inquiring information, through non-verbal means.

Epistemic culture occupied with conveying knowledge distinguishes between settings of generating such knowledge and stressing its contextual aspects. Such a concept is particularly appropriate to experiencing space objects and the science which they represent, in order to understand how knowledge is created and how it can be perceived through these scientific objects.

Cultural values and ideas, a subject of historical and anthropological studies, serve as a word-base background for tailoring definitions necessary to communicate scientific terminology and concepts. Furthermore, it is nearly inescapable to include the political background of space exploration, which provides another layer of word-based interpretation for artifacts from that era. That, enriched with an understanding of the technology which enabled the objects to function, formulates a base for designing a full-sensory experience for experiencing the space objects on exhibit.

Conclusions

Space artifacts exemplify particularly rich, intriguing, and fascinating, multi-layered complex technological systems. The tracing of the technological innovations encapsulated in an aerospace artifact was illustrated utilizing examples of thermal protective systems to elucidate some aspects of complexities involved in designing space vehicles and innovative materials suited for space missions.

Details of TPS technology developed for STS orbiters that traveled multiple times through the earth atmosphere, characterization of some of many materials used in TPS and analysis of their behavior in varied environments, provide examples of the nearly limitless possibilities that accompany the presentation of a complex artifact in a museum setting. The core of this model is to streamline the concept of complex technology embodied in themes and subjects represented by space artifacts.

The space shuttle orbiters exemplify multitude of technological advancements of engineering and material science. The multifaceted objectives of their mission and the international collaborations provide a full spectrum of possibilities encapsulated in the artifact itself should inspire and engage the exhibition of space technologies. Today's technology offers a multitude of interactive solutions, which, when coupled with the scientific approach of monitoring the receptions and responses of museum visitors, would provide a platform for quantitative and qualitative analysis of the success of such exhibits. This new framework should invigorate and bring much closer some aspects of the space exploration adventure while educating the audience about complex technological systems.

Referen

Alvaro, R. (
2011-73
Collins, M.
Ltd, Sci
Day, A. D.
Commis
reentry/
Dolan, C. M
under c
March 1
Donegan, M
O'Leary
CRC Pr
Dymitrienk
mechan
Griffin, M.
Griffin,
Jenkins, D.
beginni
NASA. (20
nasa.go
NASA. (20
DC: NA
NASA. (200
Space C
TPS-08.
NSTS. (198
nasa.go
Sutton, G.
tive. Ev
19(1): 3
Swenson, L
project
Szczepanow
reentry
1319. d
Szczepanow
of HRS
MS&T
Proceed

References

Alvaro, R. C., & Snapp, C. G. (2011). *Orbiter thermal protective system lesson learned.* AIAA 2011-7308, AIAA Space 2011 Conference and Exposition, Long Beach, CA.

Collins, M., & Millard, D. (Eds.). (2005). *Showcasing space.* Cromwell Press, NMSI Trading Ltd, Science Museum.

Day, A. D. (2003). *Early reentry vehicles: Blunt bodies and ablatives.* US Centennial of Flight Commission, 1903–2003. http://www.centennialofflight.net/essay/Evolution_of_Technology/reentry/Tech19.htm

Dolan, C. M. (1965). *Study for development of elastomeric thermal shield materials.* Prepared under contract No. NAS 1-3251 by General Electric Company, Philadelphia PA for NASA, March 1965. NASA CR-186.

Donegan, M. (2009). Space basics: Getting to and staying in space. In A. G. Darrin & B. L. O'Leary (Eds.), *Handbook of space engineering, archaeology and heritage.* Boca Raton: CRC Press, Taylor and Francis Group.

Dymitrienko, Y. I. (1999). *Thermodynamics of composites under high temperatures. Series: Solid mechanics and its applications* (Vol. 65). Dordrecht: Kluwer Academic Publisher.

Griffin, M. (2008). *Leadership in space: Selected speeches of NASA administrator Michael Griffin,* May 2005–October 2008. NASA SP-2008-564.

Jenkins, D. J. (1993). *The history of developing the national space transportation system: The beginning through STS-50.* Marceline, MO: Walsworth Publishing Company.

NASA. (2012). Media Advisory. M12-062, April 9, 2012. Accessed January 3, 2014. http://www.nasa.gov/home/hqnews/2012/apr/HQ_M12-_SCA_Discovery_Flight_DC.html

NASA. (2008a). *NASA: The first 50 years.* An aerospace America special report. Washington, DC: NASA.

NASA. (2008b). Orbiter thermal protection systems. NASA Facts-FS-2008-02-042-KSC. FL: Kennedy Space Center. Accessed January 3, 2014. http://www.nasa.gov/centers/kennedy/pdf/167473main_TPS-08.pdf

NSTS. (1988). *NSTS 1988 news reference manual.* Accessed January 3, 2014. http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/sts_sys.html#sts-rcc

Sutton, G. W. (1982). *The initial development of ablation heat protection: An historic perspective.* Everett, MA.: Avco-Everett Research Laboratory, Inc. (AIAA 50th Anniversary 1981: *19*(1): 3–11).

Swenson, L. S., Jr., Grimwood, J. M., & Alexander, C. C. (1966). *This new ocean: A history of project mercury.* NASA SP-4201, Washington, DC.

Szczepanowska, H., & Mathia, T. G. (2011). Space heritage: The apollo heat shield; atmospheric reentry imprint on materials' surface. *Materials Research Society Symposium Proceedings, 1319.* doi:10.1557/opl.2011.780.

Szczepanowska, H., & Renegar, Th. (2014, in press). Space Exploration Heritage; Characterization of HRSI Ceramic Titles in the Space Shuttle Program using Surface Metrology Techniques. MS&T 14, October 2014, Pittsburgh PA. *Materials Science & Technology 2014, Collected Proceedings.*

Beth Laura O'Leary · P.J. Capelotti
Editors

Archaeology and Heritage of the Human Movement into Space

Springer

Editors
Beth Laura O'Leary
Department of Anthropology
New Mexico State University
Las Cruces, NM
USA

P.J. Capelotti
Division of Social Sciences
Abington College
Penn State University
Abington, PA
USA

ISSN 2199-3882
ISBN 978-3-319-07865-6
DOI 10.1007/978-3-319-07866-3

ISSN 2199-3890 (electronic)
ISBN 978-3-319-07866-3 (eBook)

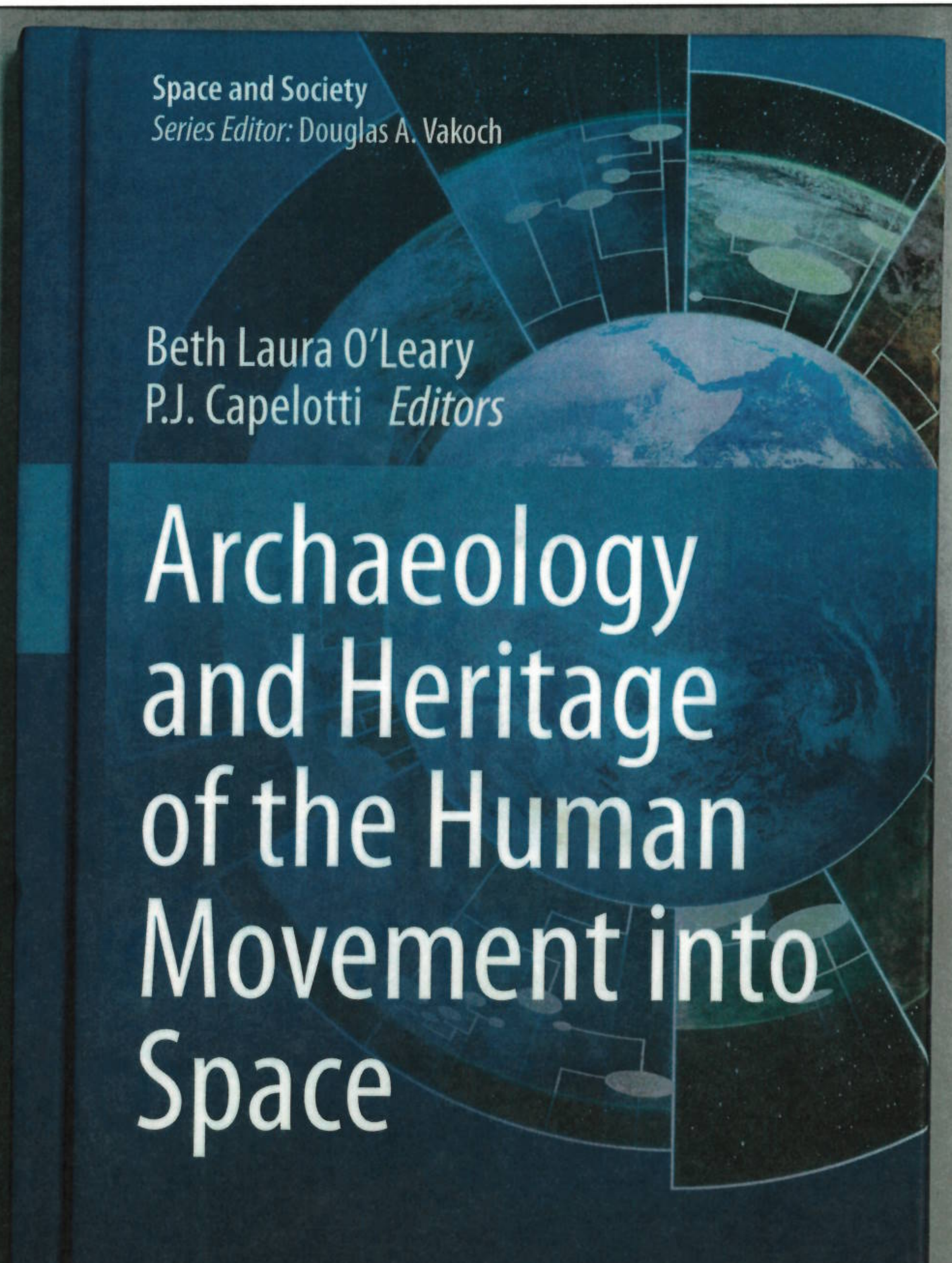
Library of Congress Control Number: 2014946396

Springer Cham Heidelberg New York Dordrecht London

© Springer International Publishing Switzerland 2015
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)



Space and Society
Series Editor: Douglas A. Vakoch

Beth Laura O'Leary
P.J. Capelotti *Editors*

Archaeology and Heritage of the Human Movement into Space

Springer

Space and Society

Beth Laura O'Leary · P.J. Capelotti *Editors*

Archaeology and Heritage of the Human Movement into Space

This volume addresses the creation, documentation, preservation, and study of the archaeology of lunar, planetary, and interstellar exploration. It defines the attributes of common human technological expressions within national and, increasingly, private exploration efforts, and explore the archaeology of both fixed and mobile artifacts in the solar system and the wider galaxy.

This book presents the research of the foremost scholars in the field of space archaeology and heritage, a recent discipline of the field of Space Archaeology and Heritage. It provides the emerging archaeological perspective on the history of the human exploration of space. Since humans have been creating a vast archaeological preserve in space and on other celestial bodies. This assemblage of heritage objects and sites attest to the human presence off the Earth and the study of these material remains are best investigated by archaeologists and historic preservationists. As space exploration has reached the half century mark, it is the appropriate time to reflect on the major events and technological development of this particular unique 20th century arena of human history.

The authors encapsulate various ways of looking at the archaeology of both fixed and mobile human artifacts in the solar system. As missions continue into space, and as private ventures gear up for public and tourist visits to space and to the Moon and even Mars, it is the appropriate time to address questions about the meaning and significance of this material culture.

Humanities

ISBN 978-3-319-07865-6

9 783319 078656

▸ springer.com