U.S. Spacesuit Knowledge Capture – Expanding Our Future

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NASA is going to the Moon. And it will don a new spacesuit when it reaches its destination. NASA is partnering with industry to build the spacesuit and supporting systems (i.e., surface mobility tools) that astronauts will use on the Moon, starting with Artemis III. The Johnson Space Center's (JSC) Extravehicular Activity and Human Surface Mobility Program (EHP) is managing this effort, and the U.S. Spacesuit Knowledge Capture (SKC) Program is expanding its scope to help. For 15 years, the SKC Program has collected, archived, and disseminated decades of spacesuit-related knowledge, as appropriate, to help NASA scientists, technicians, and engineers support space exploration. The SKC Program captures its knowledge by hosting and recording subject-matter expert (SME) lectures, interviews, and workshops. It also collects retired SMEs' reports, drawings, and schematics containing legacy spacesuit knowledge. To build a technically capable spacesuit essential for future lunar exploration, spacesuit professionals borrowed much of their knowledge from legacy Extravehicular Activity (EVA) spacesuits. Most of the SKC Program's captured knowledge has focused on legacy and current spacesuits. To support EHP, the SKC Program is expanding its knowledge capture focus beyond the spacesuit and will seek to collect knowledge from other pertinent topics (e.g., Lunar Terrain Vehicle and EVA tools). In 2007, the SKC Program began as an independent source, without funding. As demand for capturing essential spacesuit knowledge increased, consequently, the SKC Program's funding increased. Expansion of the SKC Program was evident in 2019, when it seized the opportunity to capture the Exploration Extravehicular Mobility Unit (xEMU) buildup at JSC. In 2021, its collaboration with the xEMU Technical Community of Practice facilitated training and knowledge sharing with the xEMU team. In 2022, the SKC Program began supporting EHP. This paper describes the SKC Program's expansive evolution, plans to support EHP, and more.

Nomenclature

AEMU	=	Advanced Extravehicular Mobility Unit
BS	=	Bachelor of Science
CoP	=	Community of Practice
COVID-19	=	coronavirus disease 2019
CTSD	=	Crew and Thermal Systems Division
DAA	=	Document Availability Authorization
EA	=	Engineering Directorate

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EC5 = Space Suit and Crew Survival Systems Branch
EHP = Extravehicular Activity and Human Surface Mobility Program
EMU = Extravehicular Mobility Unit
EVA = extravehicular activity
FY = Fiscal Year
HITL = Human-in-the-Loop
HSM = Human Surface Mobility
HX = heat exchanger
ISS = International Space Station
JSC = Johnson Space Center
K-CAP = knowledge capture
LTV = Lunar Terrain Vehicle
NBL = Neutral Buoyancy Laboratory
NESC = NASA Engineering and Safety Center
PGS = Pressure Garment Subsystem
PLSS = Portable Life Support System
SEMP = Systems Engineering Management Plan
SIPI = Southwestern Indian Polytechnic Institute
SKC = U.S. Spacesuit Knowledge Capture
SME = subject-matter expert
STEM = science, technology, engineering, and math
STI = Scientific and Technical Information
STS = Shuttle Transportation System
SWME = Spacesuit Water Membrane Evaporator
TVAC = Thermal Vacuum
xEMU = Exploration Extravehicular Mobility Unit
xEVA = exploration extravehicular activity
xEVAS = exploration extravehicular activity (xEVA) services
xPLSS = Exploration Portable Life Support System

I. Introduction

WE are the U.S. Spacesuit Knowledge Capture (SKC) and Strategic Communications Program, and we are helping NASA go to the Moon to stay. For ease of reference, the SKC and Strategic Communications Program will be referred to as the SKC Program. After over 50 years, NASA will return to the Moon, starting with Artemis III, where it will land the first woman and first person of color to prepare for a sustained presence.[1] The Artemis vehicle will transport the astronauts to the Moon. When they reach their lunar destination, they will don the Exploration Extravehicular Activity (xEVA) System spacesuit, NASA's next-generation spacesuit, which will mobilize astronauts to explore safely outside the vehicle.[2]

As part of the mission to reach and have a sustained presence on the Moon, NASA is combining legacy extravehicular activity (EVA) spacesuit knowledge with new knowledge and partnering with industry to build the xEVA System spacesuit and supporting systems (e.g., EVA tools). Documentation of lessons learned is crucial to build onto knowledge for the future. Since 2007, the SKC Program (logo shown in Figure 1) has collected and preserved pertinent spacesuit-related knowledge reaching as far back as Mercury to guard against future knowledge loss and help support space-related missions, such as Artemis. The SKC Program is a unique, educational tool for NASA's technical personnel to augment their work.

Figure 1. U.S. Spacesuit Knowledge Capture Program logo. *(Image by NASA)*

In 2022, the Extravehicular Activity and Human Surface Mobility Program (EHP) (logo shown in Figure 2) augmented the SKC Program's budget to expand its knowledge capture to align with EHP's mission. This expansion led to the SKC Program augmenting its scope to include

Figure 2. Extravehicular Activity and Human Surface Mobility Program logo.
(Image by NASA)

strategic communications. As a result, the SKC Program expanded its knowledge capture focus beyond the spacesuit and collects knowledge from other pertinent topics (e.g., Lunar Terrain Vehicle (LTV) and EVA tools). The LTV will use extreme environment technologies to mitigate moon dust and navigate across the lunar terrain and around the Moon's dark shadows and expand human reach on the Moon.[3] The crew will also operate the vehicle remotely and have it scout and perform science. As NASA develops requirements and operational concepts for the LTV, it is establishing goals.

Since the 1970s, astronauts have relied on the Extravehicular Mobility Unit (EMU) for spacewalks (i.e., EVAs). Astronauts have also donned the EMU to perform EVAs necessary to maintain the International Space Station (ISS).[4] Until a new ISS spacesuit is available, the EMU will continue to be used for spacewalks outside the ISS. An xEVA services (xEVAS) vendor will provide the next-generation spacesuit to be used on the ISS.[5]

For industry to build the xEVA System spacesuit and supporting systems, NASA created the xEVAS contract. In 2022, NASA awarded the xEVAS to two vendors to provide spacesuits for ISS spacewalks and Artemis moonwalks.[6] Services include certified contractor-provided spacesuits, tools and equipment, vehicle interfaces, and support to training and real-time operations.[2] NASA Johnson Space Center's (JSC) EHP is managing this effort, and the SKC Program is expanding its scope to help. Spacesuits will be built by the NASA expert-defined technical and safety standards, and the chosen companies agreed to meet these key agency requirements.[5] The SKC Program is poised to share its captured knowledge with NASA's partners to help meet these requirements.

Lara Kearney, EHP manager, expressed NASA's involvement in the xEVAS contract: "NASA is proud to partner with commercial industry on this historic mission that will kickstart the United States building a lasting presence on the surface of the Moon. What we learn on Artemis III and future missions on and around the Moon will pave the way for missions to Mars. Spacesuits enable us to literally take that next step."[7] Astronauts will take that next step while donning the xEVA System spacesuit – the spacesuit designed for more diverse sizes than the existing spacesuit. It will also allow for more mobility, increase performance and hardware efficiency, and offer more protection from radiation.[8] The SKC Program captures the knowledge used to build EHP products and archives it in a well-organized library that the space community can access and borrow to enable humans to explore farther into space than ever before. This paper describes some of the details involved.

II. Evolution

Past lessons learned inform the present. When applied properly, these lessons help ensure a successful future. Undocumented knowledge is lost when it is no longer used. As NASA employees and contractors vacate their jobs, unless their knowledge is documented, it is lost. An August 2013 article published by *The Washington Post* forecast the federal attrition surge that occurred during that time.[9] A few days earlier, *The Post* published an article calculating that every second, 46 days of experience was being lost within the federal government.[10] Figure 3 shows the drastic drop in JSC employees from Fiscal Year (FY) 2012 through FY 2016, the FY 2017 employment uptick, and another drastic employment plunge in FY 2022. Figure 3 excludes contractors.

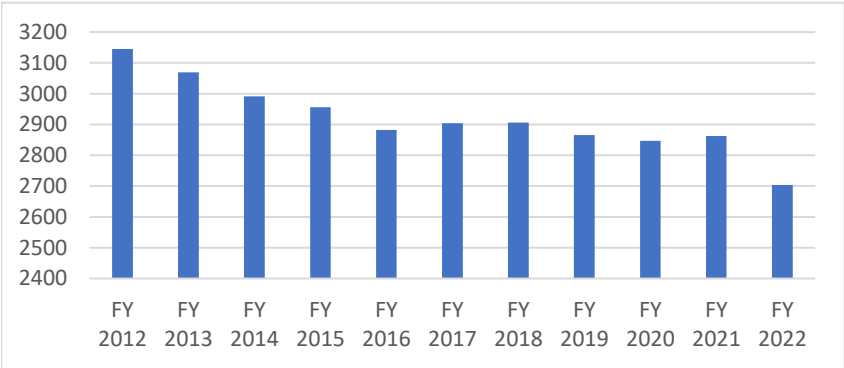

Figure 3. Number of JSC employees during FY 2012 through FY 2022.[11]

Even when attrition at JSC slows, employees continue to vacate their jobs, annually. This motivated the SKC Program to continue developing effective strategies to collect and archive historical and current space-related information from subject-matter experts (SMEs). SMEs' knowledge and experiences are shared to heighten awareness and broaden capabilities for future space exploration. Knowledge capture that is approved for public distribution is publicly accessible.

To retain the SMEs' unique and valuable knowledge acquired during their years of service, the SKC Program is designed to capture their knowledge base before they retire. For retirees, this is one of their last contributions to their workplace; it is part of their legacy. The program accepts SMEs' (retired and currently employed) donated files and artifacts that are relevant to the space community. It has also collaborated extensively with NASA employees and contractors who retired decades before the SKC Program existed. SMEs' knowledge is usually captured through videos, which the program deemed to be the most impactful, efficient, cost-effective medium to use. Videos capture not only the SME-conveyed lessons, they also capture the emotions that SMEs often reveal during pivotal events. The emotions captured express the importance of the lessons and the serious consequences, if not applied.

A. Infancy

In 2007, because the SKC Program recognized knowledge gaps that resulted in missed opportunities, it was created as a grassroots effort to identify, collate, and preserve valuable spacesuit-related knowledge and make it accessible to its customers who would apply it to support NASA's space-related missions.[12] The program's desire was to help educate NASA's spacesuit community. Its function also met the intent of the 2008 JSC Policy Directive that encouraged JSC organizations to promote knowledge transfer, collaborative sharing, and required learning for successful missions.[13]

In the SKC Program's infancy, it existed with only the SKC Program manager maintaining it, without funding, and delivered and recorded lectures and workshops by SMEs, some of whom had over 50 years of experience in their field. As the program's reputation grew, its funding and resources expanded to meet its customers' needs.

B. Formative Years – SKC Program Expansion

During 2014, the SKC Program began to focus on capturing knowledge specific to components within the Advanced Extravehicular Mobility Unit (AEMU (later known as the Exploration Extravehicular Mobility Unit (xEMU)). This approach was intertwined with hosting traditional events with SMEs to gain historical knowledge and foster discussions around lessons learned. As the AEMU project continued through its development, it was critical that the engineers be acutely knowledgeable of their hardware and the hardware with which they had to interface. As a result, the SKC Program concentrated on knowledge capture events that would provide these engineers with technical knowledge from SMEs knowledgeable of former or like systems.[14]

C. Later Years – Internal Knowledge Sharing Emphasis

Beginning in 2019, the SKC Program's scope and role expanded significantly when it seized the unique opportunity to capture and preserve the xEMU buildup at JSC. As NASA leveraged its 60 years of experience, this was its first opportunity to capture a real-time spacesuit buildup. With this new opportunity, the SKC Program's staff grew from the SKC Program manager and administrator to include a producer, public-relations coordinator, and a spacesuit multimedia developer (intern), as it began coordinating the electronic recordings of the new spacesuit's buildup. To capture the xEMU buildup, field video production was used, taking photography and videography equipment to where the knowledge was being developed (e.g., laboratories and testing facilities). The focus was on sharing knowledge with early career engineers, professionals new to human spaceflight, and the xEMU community. The SKC Program also teamed with the xEMU Community of Practice (CoP) to facilitate knowledge sharing. This arrangement provided an environment where the knowledge was easily and routinely captured, recorded, and shared. During the xEMU buildup, SKC Program focused its knowledge sharing internally because of the technical information's sensitivity.

D. Recent Year – External Strategic Communication Emphasis

The SKC Program continues to be a conduit to share knowledge within the space community, and its primary process remains constant: capture, curate, and disseminate. With the program's vast experience capturing and curating knowledge, it has learned how to evolve and adjust to meet its customers' goals. As the SKC Program's scope expands, it adapts to meet these goals.

At the beginning of 2022, the SKC Program experienced another significant opportunity when it began supporting EHP from a strategic communication perspective. On June 1, 2022, NASA JSC Director Vanessa Wyche announced the winners of the xEVAS contract. EHP began setting an unprecedented course forward as it partnered with industry for EVA services through the xEVAS contract. This is a unique endeavor for NASA and industry to build new spacesuits, tools and equipment, vehicle interfaces, and support to training and real-time operations.[2] The xEVAS winning firms will now help NASA embark on the incredible journey back to the Moon and beyond.

With the changes in EHP, the SKC Program, along with its strategic communication element, expanded to support EHP. Now, the emphasis is on external communication, and continued focus is on knowledge capture and preserving

lessons learned from SMEs in EVA (e.g., spacesuits, pressure garment systems, portable life support systems (PLSS), and associated avionics) and Human Surface Mobility (HSM) capability (e.g., LTV and pressurized rover), along with archiving for historical and learning purposes. It also includes the knowledge capture administrative and media services associated with capturing images and technical content related to EVA, spacesuits, and other HSM technology. This means expanding the SKC Program's product line beyond spacesuits to include a transportation vehicle for the lunar crew (i.e., LTV) and EVA tools.

The SKC Program, with the added strategic communication element, is providing full production of videos and editing. Various mechanisms are being used to obtain the information to prepare the content and make it a rich compilation of knowledge. These mechanisms may include, but are not limited to, photoshoots of pertinent hardware and laboratories, video recordings of test operations and hardware assembly, and interviews.

The SKC Program accommodated this new opportunity by restructuring and expanding its team to provide the necessary capability to facilitate EHP to accomplish its goals. The skill set includes a manager, administrator, and producer, as in previous years. Expansion of the team includes the transition of the public-relations coordinator to a strategic communications & multimedia coordinator and the addition of a video editor. The team continues to retain the spacesuit multimedia developer (intern).

With this unique skill-focused team, which has over 100 combined years of experience, the SKC Program has become increasingly sought after to capture and share space-related knowledge. In addition to the program's experience, a project engineer manages it out of the Space Suit and Crew Survival Systems Branch (EC5). This unique location of service allows the team to be embedded within the lines of how the work is performed. This allows for ease of communication from senior management who prescribes the work, to the technicians and engineers who perform it. Mechanisms to achieve the support of EHP's mission are discussed in Section V. As the SKC Program's reputation expanded, its demand, staff, and unique skills increased to support EHP, as described below:

1) Collaborates and coordinates with personnel across the NASA agency to record and archive events permanently
2) Edits photos and videos, such as facilities, components, spacesuit systems and subsystems, HSM systems, and associated test environments; reviews and edits final products for potential public release; supports onsite photo and video shoots, as needed; and collaborates with the director to achieve the final product
3) Participates and potentially leads recording and editing productions and assists in a quality review of event content; participates in video field productions in onsite laboratories
4) Develops strategic plans for event implementation, provides multimedia coordination, ensures all parties and resources are coordinated for each event, coordinates with photographers, videographers, and venue personnel as needed, leads planning where multiple skills are needed to execute the event
5) Coordinates implementation of complex events internally and externally, consults with production assets to develop media products, directs set creation and media production for events
6) Forms a communication and educational foundation that facilitates the knowledge transfer across the EVA and surface mobility community

Throughout the SKC Program's existence, and now with its new strategic communication element, it continuously increases its robustness to identify, capture, curate, and disseminate valuable space-related knowledge and has progressed to be a proven fleet leader.

III. Successes and Challenges

Since the SKC Program's inception, it has been flexible, resourceful, worked around constraints, and modified the focus of its lessons, as needed, to help educate its audience to support NASA's missions. Initially, the SKC Program operated without funding. By 2010, the interest in the program's existence grew, along with the demand for it to capture essential spacesuit-related knowledge from several spacesuit experts who were retiring during that time. As a result, the program received funding to hire a part-time administrator. This addition to the program became one of the most vital assets to its survival.

Over the last 15 years, except for several months, the SKC Program's funding remained steady. From 2010 to 2013, the EVA Office provided programmatic funding to sustain the SKC Program. The SKC Program was idle during late 2013 and early 2014 when funding lapsed because of budget cuts. In 2014, the NASA Engineering and Safety Center (NESC) technical fellow Hank Rotter recognized the SKC Program's importance and inactivity and provided sustaining funds to restart the program. In the spring of 2018, Mr. Rotter collaborated with EVA Office Manager Chris Hansen to transition the SKC Program funding back to the EVA Office. The EVA Office agreed to provide funding with a knowledge capture emphasis on the xEMU buildup. EHP was formed in 2022.[15] Thereafter, EHP has provided resources to sustain the SKC Program, along with Strategic Communications.

The SKC Program has persevered through its challenges to successfully capture knowledge. Table 1 reflects this achievement. Currently, the program has captured 212 recorded products. The public can access 96 of them. Six recordings contain sensitive information that NASA employees and contractors can access only through request and with the SKC Program manager's consent. The program is reviewing and editing 24 products before submitting them into the Document Availability Authorization (DAA) system. The DAA system is NASA's process to review products for export control release. There are 61 xEMU modules, which relate to the xEMU buildup. All modules have been edited, processed, and distributed internally or uploaded to NASA's Imagery Online where they are accessible to the xEMU team. Fourteen spacesuit spotlights have been recorded and will be edited and accessible to NASA employees and contractors. Table 1 separates these 212 recordings (total products, modules, and spacesuit spotlights) into seven categories. Section IV B of this paper further describes spacesuit spotlights.

Table 1. SKC Products

Categories of Products	Number of Products
Publicly available	96*
Preparing to submit into the DAA	24‡
Restricted access	8*
Sensitive	6‡
In DAA process	3*
xEMU modules	61‡‡
Spacesuit Spotlights	14**
Total number of products	**212**

*107 products have been submitted into DAA system
‡30 products have not been submitted into DAA system
‡‡61 xEMU modules not distributed (not planned for public or agency release)
**14 Spacesuit Spotlights not distributed (planned for NASA internal use only)
Note: The NESC Academy is processing 12 events that have been DAA-approved but are not yet accessible on the NESC Academy website.

Throughout the SKC Program's existence, it has met many trials. Three of its greatest challenges have involved processing its captured information through export control, securing video and photography services, and navigating through the implications of the coronavirus disease 2019 (COVID-19), as described below:

1) The NASA export control process is used to determine what information is released to the public and what is restricted. This process can be arduous. To adhere to the export control process, the SKC Program scrutinizes every product it plans to release to ensure the information is sanitized before it is submitted through the approval process. Over the last several years, the export control process has evolved through several data systems. However, through the SKC Program's extensive use of the different data systems and complete process, it has adapted well to the export control workflow.
2) When the SKC Program began, videography and photography services were not funded. The program collaborated with other entities to share their resources, on a non-interference basis, to record SKC Program events. This caused the program to operate at a slow pace for recording events. Photography services were never funded. Starting in 2020, the ISS Program provided photography and videography services for the SKC Program. At that time, the SKC Program was substantially capturing the xEMU buildup for the EVA Office and the ISS Program. The ISS Program funding ends at the end of September 2023.
3) In 2020, COVID-19 introduced new challenges. The SKC Program's commitment to capture the xEMU buildup aligned with the onset of the COVID-19 pandemic. To schedule photo and video shoots within the timeframe of the xEMU buildup, the SKC Program adhered to the added safety requirements that JSC established to protect from COVID-19. Soon before the pandemic occurred, the NASA Agency launched a new teleconferencing tool. During the pandemic, this tool became an unexpected asset vital to performing work. This tool allowed employees to remain spatially distanced while collaborating with each other. Although COVID-19 introduced new challenges, the teleconferencing tool led to providing an extensive, economical, effective, and secure means to record and share real-time events. This type of teleconferencing outlasted the pandemic and proves to be a valuable resource to this day. Previously published International Conference on Environmental Systems papers reveal more detail regarding the program's challenges and comprehensive history through 2021.[12,14,16-25]

The SKC Program is a small team with concentrated skills that allow versatility and adaptability. These qualities, along with the trust and support from multiple NASA programs, led the SKC Program to gain robustness to overcome its greatest challenges and reach its current success. Without the program's supporters and collaboration with SMEs, it would cease to exist.

IV. Special Projects

Since the SKC Program's inception, it has captured, curated, and disseminated spacesuit knowledge, as appropriate, as a resource for the spacesuit community to further human space exploration. As its reputation in knowledge capture proficiency expanded, its scope increased to perform special projects. Examples of the wide variety of special knowledge capture projects include capturing the xEMU buildup, the spacesuit spotlight series, along with an online space conference – a new endeavor. The SKC Program also contributes to other valuable projects that include scanning and archiving spacesuit-related documents, including images, donated by current and retired JSC employees; updating a database that summarizes these documents; and curating archived space-related artifacts that support NASA's human exploration mission. To have a central location for users to access space-related knowledge, the SKC Program will create a consolidated electronic library. The following subsections describe these projects in more detail.

A. Exploration Extravehicular Mobility Unit

Beginning in 2019, the SKC Program accepted the unique responsibility to document the xEMU buildup. NASA personnel grew, as well as the demand for the SKC Program, and the need for spacesuit professionals to gain knowledge quickly was revealed. These developments slightly shifted the reasons to capture and share knowledge.

To capture the xEMU buildup, the SKC Program coordinated with xEMU engineers and other xEMU contributors to schedule recorded xEMU modules that contain in-depth presentations with intricate knowledge of over 90 individual xEMU components. The program also coordinated with media services to enter laboratories where the new spacesuit was being tested and built. Adhering to added safety requirements that NASA JSC established to protect from the COVID-19 pandemic allowed access to these facilities.[26] For certain knowledge capture events, the SKC Program continues to use classrooms, but sharing knowledge through videography captured entering laboratories and testing facilities can provide a higher level of visual and comprehensive detail.

To record the xEMU buildup, the SKC Program guided videographers through laboratories and testing facilities to capture what classrooms cannot. Having the SKC Program embedded in spacesuits and EVA tools, with a certain level of understanding of how to build a spacesuit and how it applies to EHP's overall mission, is vital to the SKC Program's success. The program uses its understanding of the subject and multimedia production skills to help guide the videographers through the capture, resulting in a quality product. With access into laboratories and testing facilities and the convenience of videoconferencing, the SKC Program now specializes in capturing intricate knowledge from the xEMU component owners who build the hardware.

With the use of online knowledge sharing, the SKC Program also discovered a significant increase in real-time attendance. Classrooms can accommodate only a fraction of what videoconferencing software can. Although classroom events can offer benefits, such as more personalized learning and more interaction among peers, the number of online attendances is often at least twice that of classroom events. Speakers have the convenience of presenting from their personal workspace. Viewers have the ease of watching events in their individual workspace, without taking extra time to transition to the meeting place. As the SKC Program's remote real-time events through videoconferencing gave more viewers an opportunity to attend, the program's existence was amplified.

As each component of the xEMU was tested and integrated into the spacesuit, the SKC Program chronicled these moments using high-speed video production and photography that included time-lapsed images. These are archived on JSC's Imagery Online. Only the xEMU community and authorized EVA community members have access to the xEMU's sensitive information.

In 2021, to help share the SKC Program's pertinent knowledge with those who were part of the xEMU buildup, it seized an opportunity that would help ensure that those who need this knowledge realize it exists. The program collaborated with the xEMU Technical CoP, which was a community for training, knowledge sharing, and asking questions to which peers and SMEs might have answers. The SKC Program recorded and edited the CoP's pertinent content. Participants included early career engineers, professionals who are new to human spaceflight, and experienced xEMU community members. The CoP invited the xEMU team (approximately 500 personnel) to routinely meet and collaborate with peers, share resources and in-depth xEMU-related knowledge, and ask questions. Collaboratively, for 2 years, the SKC Program and CoP held and recorded over 40 modules that focused on xEMU components and related topics, which are stored on the SKC Program library.[24] There was an average of 95 attendees per module. Although the xEMU community has access to the archived recorded modules, there is no mechanism to track the number of views in the SKC Program library.

B. Spacesuit Spotlights

Since the SKC Program's inception, it has produced over 200 events delivered by more than 110 SMEs. Although the SKC Program library has a plethora of recorded technical space-related knowledge, little was known about the SME, who is a major vehicle to knowledge sharing.

In 2022, to allow and encourage viewers to become better acquainted with and pay homage to those who contribute to the design, build, and maintenance of spacesuits, the SKC Program launched its spacesuit spotlight series. In this series, the SKC Program interviews the spacesuit experts, technicians, engineers, and interns and delves beneath the surface to reveal more about the person behind the spacesuit. These interviews are conducted in an intimate, online setting with only the interviewer and interviewee present and are recorded using videoconferencing software. These 10- to 30-minute interviews capture the insights of individual contributors, along with the impacts they have made to the spacesuit industry. Although the discussion might appear casual at times, usually revealing the interviewee's educational background, job description, and circumstances that led him or her to NASA, most interviews expose much more. As the interviewee answers questions asked by a member of the SKC Program, the contributor's story begins to deepen, often revealing responses that are unique to the contributor. This series captures the sometimes-emotional description of some of the contributors' favorite spacesuit memories and why the spacesuit is important to them. This, along with the sometimes-complex path that the contributors took to arrive at NASA and the unusual, fascinating jobs they often have might otherwise be undocumented, until they share them in a spacesuit spotlight. Two of the spacesuit spotlights highlighted below are examples of unique revelations captured to inspire viewers.

1. William Lynch Spotlighted

Systems engineer William (Bill) Lynch (Figure 4) is a 35-year aerospace veteran. During his spacesuit spotlight, he described his professional background, what led him to NASA, why he has a passion for the spacesuit, and several fascinating memories of it.

Figure 4. William (Bill) Lynch. *(Images by NASA)*

Mr. Lynch earned his Bachelor of Science (BS) in aerospace technology at Bowling Green State University in Ohio. Later, he studied mechanical and civil engineering at the University of Central Florida. After college, Mr. Lynch worked for industry in Ohio making airplane landing gear for various types of aircraft, including B-1 bombers and Boeing 747s. It was not until Mr. Lynch decided to move to a warmer climate that he considered working for NASA. In 1988, he began working on solid rocket booster processing at the Kennedy Space Center. There, he was also selected to be a project engineer working with booster stacking, alignment, and retrieval, which included being a recovery diver on retrieval boats after each rocket launch.

Later, Mr. Lynch transferred to JSC, where he worked with the spacesuit. He recognized the spacesuit as momentous: "a milestone for NASA." He revealed his passion to work with it and his desire to meet the challenges necessary for future crewed missions to reach the Moon and Mars: "It's that execution of a plan to continue pursuing space exploration."

With decades of spacesuit experience, Mr. Lynch shared a few of his favorite memories. During the launch of Shuttle Transportation System (STS)-126, he was within 2 miles of the launchpad while he stood on a fire-escape ladder on the side of a building called the Rotation, Processing, and Surge Facility. He described that moment: "Watching the Shuttle lift off the pad is the absolute, most impressive display of power anyone could ever witness." Another fascinating memory was when he performed booster retrieval: "Jumping into 3,000 feet of water with absolutely clear blue seas, in the middle of winter, when it's rough seas, and the booster is pitching about, it's also another first that is not easily forgotten."

Mr. Lynch shared a memory that focused on his early years at JSC, when he joined a small team that performed EVA development testing. They helped coordinate tests in the Thermal Vacuum (TVAC) Chamber and on a processionary-bearing floor or 1-G environments. Many of these tests were performed at the Neutral Buoyancy Laboratory (NBL). With Mr. Lynch's diving background, he had opportunities to work with teams to build hardware in the NBL: "Being able to dive at that world-class facility, a one-of-a-kind anywhere, and over the years, watch the Space Station be assembled in the water, I couldn't ask for more."

Mr. Lynch admitted to having many unique and fascinating experiences and shared a few of them during this interview. He had a few opportunities to be a spacesuit subject and wear the spacesuit in the NBL. However, his most

compelling or striking memory might be the loss of Space Shuttle Columbia: "It's not one that people truly want to recall as their best memory, but what it did was it drove a motivated workforce to do better."

Mr. Lynch also shared key advice for those beginning their career: "Learn as much as you can. Accept that this is a daily challenge. Find what is hard to do, when it is done, you will look back and say 'Wow, that was hard and I'm really glad it's over, but look at what I've done.'" "It will never be just you – it will be you and a team…but you will still take pride in that which you have accomplished." For those who are reaching the latter part of their career, Mr. Lynch emphasized the importance of sharing knowledge: "The most important is what you can teach the folks that are just coming up, because if you do it, then as they come up, they will pay it forward and do it for the next group. It's a means of contributing."

As a project engineer and manager at JSC, Mr. Lynch has worked with EVA development testing, EVA tools, James Webb Space Telescope Chamber A Facility modifications, and Exploration Portable Life Support System (xPLSS) heat exchangers. He was also the EVA Hardware Systems and Robotics section manager. Currently, Mr. Lynch is an xPLSS systems engineer and former xEMU component owner of the PLSS Spacesuit Water Membrane Evaporator ((SWME)-HX440) and spacesuit heat exchangers (HX-540/Mini-Membrane Evaporator). He currently works with heat exchangers on the xEVA System spacesuit.

2. Kristine Davis Spotlighted

Kristine Davis (Figure 5) earned her BS in mechanical engineering from Kansas State University. Although she grew up on a farm in a small Kansas town that was hundreds of miles away from JSC, a nearby museum had a strong impact on her career decision. When she was a child, Ms. Davis' parents often took her to the Cosmosphere in Hutchinson, Kansas, which is one of the largest space museums in the United States. It was ripe with information about science, technology, engineering, and math (STEM) and NASA occupations. Its mockup of Dr. Robert Goddard's laboratory filled with experiments piqued Ms. Davis' desire to pursue a career in space. During middle school, she participated in the museum's camps, through which she visited JSC. It was then that she decided to embark on a path that would lead her to work with NASA, particularly JSC. This led her to pursue an engineering degree.

Figure 5. Kristine Davis.
(Images by NASA)

After Mr. Davis graduated from high school, in a class of 24 students, she attended Kansas State University and applied for internships in aerospace. Her first two were with United Launch Alliance, a company that launched the Atlas and Delta rockets, which carry many NASA and U.S. Army satellites. Next, Ms. Davis worked with the NASA Pathways Internship Program at JSC. Her first rotation was with Flight Operations in the Ethos group. Her second, third, and fourth rotations were with the Pressure Garment Subsystem (PGS) in EC5. In the spring of 2016, NASA JSC hired Ms. Davis as a full-time employee, where she is currently the xEMU PGS hardware manager.

Currently, there are 14 spacesuit spotlights archived. This series is for new or experienced NASA employees and contractors to view, pique their interest, and be inspired by the effort, courage, and creativity necessary to contribute to the spacesuit. This series can also motivate a viewer to be part of the space community and seek opportunities that they never realized existed. Because these spacesuit spotlights may reveal sensitive information, they are accessible only to NASA employees and contractors, including interns.

C. Exploring the Moon Conference

To expand communication of space-related knowledge with NASA's human space exploration contributors and supporters, the SKC Program is collaborating with space and communications experts to deliver the first Exploring the Moon Conference, which is planned to occur twice a year. Web-based and social media platforms will be used to educate, engage, and inspire academia, industry partners, and space enthusiasts about the future of NASA's journey to the Moon. This publicly accessible conference will debut virtually in the summer of 2023, with a forum like that of a newsroom and podcast. It will contain a combination of real-time moderators and panelists, complemented by multiple 5- to 20-minute pre-produced videos focused on spacesuits, the LTV, pressurized rovers, and Artemis geology tools. The public will have an opportunity to experience what is involved in astronaut training for the Artemis missions and engage via the real-time chat. The knowledge shared during this conference will be continually evolving, relevant, and accessible to the public.

This conference is more evidence of how the SKC Program has evolved and remained flexible to meet the needs of its growing customers and audience. It continues to share its export-control-approved knowledge with the public, and now, the program educates new employees who support EHP, and is preparing to share this knowledge with vendors.

D. Donated Historical Documents

Currently, the SKC Program has scanned over 2500 documents donated by SMEs. These contain information from Project Mercury, Apollo, and Gemini; advanced life support system development; and the EVA systems of the Space Shuttle and ISS Programs. Reports, memorandums, drawings, and configurations are among these documents. The SKC Program will make the knowledge within these documents accessible to NASA employees and contractors to learn and apply knowledge within them for future space exploration.

E. Apollo EMU Human-in-the-Loop Thermal Vacuum Chamber Testing Images

In 2022, the SKC Program cataloged 623 glass projector slides featuring Apollo EMU Human-in-the-Loop (HITL) TVAC testing images. This action was a response to a request to properly archive Apollo EMU HITL TVAC testing images into JSC's Imagery Online. As a result, NASA employees and contractors will have access to these images to prepare for the xEMU TVAC testing. With the program's achievements, knowledge that was shelved with limited user access can now be available to the space community to use and advance human space exploration.

F. Curation of Historical Spacesuit Hardware

JSC's Crew and Thermal Systems Division (CTSD) recognizes the importance of spacesuit hardware preservation. To determine if all EC5 historical spacesuit hardware is properly identified and tracked, a project that the SKC Program performed in 2020 was resurrected in 2022. The program was assigned the initiative to identify and archive surplus hardware that resides within CTSD. To accomplish this, the SKC Program identified laboratory leads who are the custodians of historical spacesuit equipment and assigned them to identify the hardware and its location. The inventory is routinely updated as hardware is no longer used or needed.

G. Consolidated Library

As part of the SKC Program's support for EHP, it will create, develop, and maintain knowledge in a consolidated electronic library. The goal is to capture and develop internal and external multimedia and communications events and products and maintain a visual resource library for internal customers and the public. This will help inform, educate, and inspire knowledge-seeking audiences. The consolidated library will expand the existing U.S. Spacesuit Knowledge Capture Program Library (see Section V. G.) to include other areas, such as the LTV and geology tools. Creating a consolidated library, the SKC Program will continue with its successes, build on its legacy, and evolve to serve EHP.

V. Knowledge Capture and Sharing Mechanisms

With the SKC Program's extensive knowledge-capture experience, it has become proficient at gathering, curating, and sharing relevant knowledge. The program's archived knowledge spans from basic to intricate. This knowledge is curated, stored in a well-organized library, and accessible to the space community to help pave the way for future space exploration missions. Currently, the SKC Program has held over 200 valuable lessons-learned events that have been attended by more than 9,000 real-time participants. Its knowledge capture and sharing mechanisms that contributed to its current success are revealed in the following subsections.

A. Collaborators

Within a few years of the SKC Program's existence, its collaborators grew to include the Flight Operations Directorate (formerly known as Mission Operations Directorate Training Academy), JSC History Office, JSC Engineering Academy, NASA Scientific and Technical Information (STI) Program, and the Smithsonian. Eventually, approved-for-public-release SKC Program events were accessible on the NASA STI Program's YouTube, the Engineering Directorate (EA) Engineering Academy, the JSC History Office, and the SKC domains. This knowledge was especially important to share with NASA's tax-paying U.S. citizens who support NASA missions. As the SKC Program's recognition and demand to capture essential spacesuit-related knowledge expanded, consequently, its mechanisms used to capture, organize, and share its valuable lessons learned changed, as needed.

Beginning in 2014, the NESC Academy recognized the SKC Program's value and agreed to fund it and archive its events on its website. The NESC Academy gives the NASA community access to critical knowledge to aid

professional development and support NASA's mission.[27] It continues to archive the SKC Program's events and provides an ideal forum for the program's workshops, interviews, vignettes, and lectures. These events involve spacesuits and exploration lessons learned, design, and failure analysis; and many are publicly accessible at this URL: https://nescacademy.nasa.gov/catalogs/cfd4cdc970c046358afc1c2e5f72a0554d. The SKC Program recognizes its privileged opportunity to participate in the NESC Academy.

In 2015, the Southwestern Indian Polytechnic Institute (SIPI) in Albuquerque, New Mexico won a grant that resulted in the SKC Program engaging with the college, as well as with students from SIPI's partner high schools, to deliver knowledge capture (K-CAP) lessons. These schools educate primarily Native American and minority students. Between 2015 and 2017, the program delivered to these students eight K-CAP lessons containing STEM education. Because SIPI is over 900 miles away from the SKC Program's speakers, the SKC Program used the Digital Learning Network and NESC Academy's interactive conferencing services to conduct these events remotely. Interactive conferencing services also gave students the ability to ask pertinent questions to the speaker and obtain answers instantly.

B. Classroom Lectures, Interviews, and Workshops

The SKC Program's original way to capture knowledge involved hosting and recording classroom lectures, interviews, and workshops and collecting retired SMEs' reports, drawings, and schematics that contained legacy spacesuit knowledge. Until recently, most of the program's focus has been on legacy and current spacesuits, their associated technologies, and peripheral topics that enhance an engineer's performance to develop spacesuits.

C. Vignettes

In 2016, vignettes became part of the SKC Program's agenda to share past lessons primarily through story. The program has created 12 vignettes. Although their content is less technical than traditional SKC Program events (e.g., workshops and lectures), their value is in the application of lessons learned from experiences of past NASA technical experts.

D. Videoconferencing

Spatial restrictions caused by the COVID-19 pandemic significantly shifted how the SKC Program physically captured knowledge. Until 2020, the SKC Program collected its video-recorded historical spacesuit-related knowledge inside classrooms and studios, but the COVID-19 pandemic forced NASA to communicate using a different approach. Before COVID-19, well-established, online tools to record presentations were nonexistent. As the information technology industry supplied a secured means to record remotely through videoconferencing, it reduced the need to mobilize videography equipment and reserve a physical location and videographers. The pandemic also shifted the SKC Program's mindset. Although the program retains quality products, videoconferencing offers lower-quality recording than videographers create. During the pandemic, the SKC Program realized it was more important to capture the knowledge than to focus on the quality of the video. Now, the SKC Program uses videoconferencing regularly, as appropriate.

E. Virtual Tours

In 2021, the xEVA Office Strategic Planning and Communication manager requested the SKC Program to support processing 38, 2-minute videos that contained virtual tours of JSC government facilities. These videos could be valuable to industry and other government agencies interested in NASA facilities like these to meet the challenges involved in sending astronauts to the Moon.

Figure 6. Fully integrated xEMU. *(Image by NASA)*

F. Technical Community of Practice

In 2021, the SKC Program expanded its knowledge sharing by collaborating with the xEMU Technical CoP, which facilitated training and knowledge sharing with the xEMU team. Participants included newly hired or transferred engineers, new-to-human-spaceflight professionals, and experienced xEMU community members. CoP forums involved interactive knowledge capture designed to encourage peers and SMEs to gather and share their in-depth knowledge pertaining to the xEMU. In the summer of 2022, the xEMU buildup was fully integrated and completed (Figure 6). With the high attendance rate at CoP-held forums, it was apparent that those who were a part of the xEMU buildup needed the pertinent technical knowledge. The CoP became a vital component of sharing knowledge to ensure that those who needed it received it.

G. Library

Capturing and archiving valuable space-related knowledge and making it easily searchable and ascertainable to its users is vital, and it continues to be part of the SKC Program's primary objectives. As the program's knowledge collection grew extensively, it created the U.S. Spacesuit Knowledge Capture Program Library (Figure 7) to collate and store its conglomeration, giving access to spacesuit technicians and engineers within NASA to accurately inform, inspire, and maximize learning possibilities. The SKC Program Library contains a voluminous collection of organized valuable spacesuit-related knowledge, as well as ancillary information to maximize learning possibilities within the space community. Currently, this comprehensive collection holds over 200 recorded events, including 61 xEMU recorded modules, as well as numerous videos and photographs that chronical the xEMU buildup. To protect the xEMU's sensitivity, this knowledge is accessible only to the xEMU community and authorized EVA community within NASA. NASA export-control-approved SKC Program events are publicly accessible at this URL: https://nescacademy.nasa.gov/catalogs/cfd4cdc970c046358afc1c2e5f72a0554d.

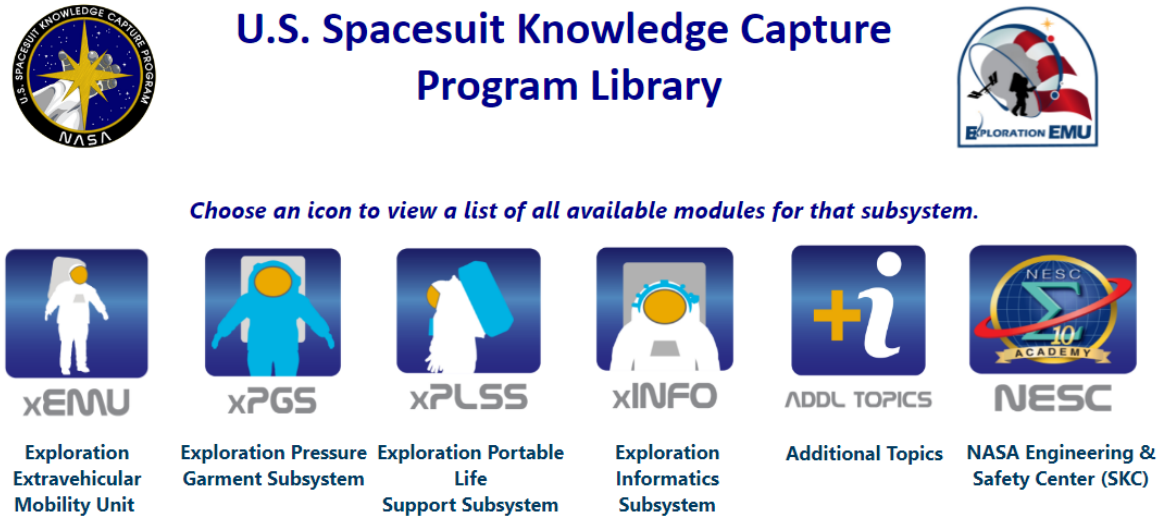

Figure 7. U.S. Spacesuit Knowledge Capture Program Library. *(Image provided by NASA)*

The U.S. Spacesuit Knowledge Capture Program Library is being revised to include EVA tools. A compilation of the SKC Program's 196 events, from inception through FY 2022 is cataloged in the SKC Program's U.S. Spacesuit Knowledge Capture Series Catalog CTSD–SS–3487 Revision D.[28] It documents the SKC Program events' location, synopses, event availability, and video length, along with each speaker's biography. Because the catalog contains sensitive information, NASA credentials are required to access it.

VI. Knowledge Capture Impact

For NASA's missions to be successful, part of JSC's policy is to promote required knowledge transfer, collaborative sharing, and learning.[29] The SKC Program adheres to this policy and encourages the sharing of its captured knowledge to the widest extent possible. Archiving its export-control-approved recordings on the NESC Academy's website helps the program meet this goal. NASA employees and contractors, as well as the public, can subscribe to NESC Academy emails (URL: https://nescacademy.nasa.gov/subscribe), which advertise real-time webcast that the NESC Academy broadcasts, as well as a monthly newsletter.

To gauge the effectiveness of the SKC Program's shared knowledge, it distributes a survey for its audience to rate each event. In 2018, as proof of the SKC Program's positive effects, some of the technical staff and members of academia who attended the program's events completed a unique survey and offered feedback on the benefits resulting from the program's captured and shared knowledge. A young engineer commented that shared experiences relevant to Apollo and EMU development, certification, testing, and operations have been highly valuable to the project planning and development of the advanced xEMU. One surveyor felt strongly about the SKC Program's value as it shares the corporate knowledge of spacesuit development and past lessons learned. This surveyor believes that the technical community will use the information shared as the building blocks for future spacesuits, as this knowledge becomes paramount in human exploration of deep space. Another surveyor stressed the importance of being able to ask questions and get answers from the presenter who enhances the listener's memory for the lesson learned.[21]

With a reputation for the SKC Program's expertise in capturing knowledge, it is achieving positive recognition from various JSC organizations with ongoing feedback and requests to support multiple special events. In 2021, EA CTSD released a document titled "Systems Engineering Management Plan (SEMP) for the Exploration Extravehicular Mobility Unit (xEMU) Project," which describes the technical approaches to organize people, products, and processes to meet the xEMU requirements maturation and design definition, and design for sustainment strategy within cost, schedule, and other applicable constraints.[30] In this document, EA recognizes the SKC Program's roll to capture, curate, and share knowledge.[30] This document was shared with the EVA community.

Recognition of the SKC Program's effectiveness has also been revealed in its event evaluations completed by its audience. To measure the program's impact and assess where improvements are needed, it uses surveys at the close of each event. An example of the program's positive impact resulted after Joe Nowetner's January 10, 2023, "Lessons Learned from the EMU Fire." CTSD's deputy division chief commented: "This was the most valuable 90-minute meeting that I have been to in my first year as deputy division chief."

The program is becoming an increased asset to JSC organizations. The SKC Program has supported various JSC events and projects, using its unique capabilities to help:

1) NASA's Day of Remembrance – share valuable lessons learned
2) JSC's Health & Safety Day – share an annual lessons learned for human exploration health and safety
3) Historical artifact inventory – ensure historical spacesuit hardware is properly identified and tracked
4) Disseminate – share knowledge to a broad audience

To continue being a knowledge resource, the SKC Program evolves to expand communication of its knowledge. Its expansion and evolution to meet the challenges necessary to accomplish NASA's mission are articulated in Section V. To have a sustainable presence on the Moon, NASA will build on documented past knowledge and develop more advanced technology to take humans further into space than ever before.

VII. Conclusion

NASA is on the cusp of new space explorations. Building on past and current knowledge will take NASA beyond its past achievements, and the SKC Program is an important entity in this process, equipped with the tools to meet its goals. As the SKC Program supports EHP to communicate the knowledge of NASA's human space travel, EHP is supporting the SKC Program through funding and providing resources needed for the program to thrive and succeed. As a result, the SKC Program continues to seek ways to expand its scope and share pertinent space-related knowledge with those who can learn and apply it to help NASA push the boundary of space exploration.

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