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KENNEDY SPACE CENTER – APOLLO TO MULTI-USER SPACEPORT

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ABSTRACT

NASA Kennedy Space Center (KSC) was established as the gateway to exploring beyond earth. Since the establishment of KSC in December 1963, the Center has been critical in the execution of the United States of America's bold mission to send astronauts beyond the grasp of the terra firma. On May 25, 1961, a few weeks after a Soviet cosmonaut became the first person to fly in space, President John F. Kennedy laid out the ambitious goal "of landing a man on the moon and returning him safely to the Earth" by the end of the decade. The resultant Apollo program was massive endeavor, driven by the Cold War Space Race, and supported with a robust budget. The Apollo program consisted of 18 launches from newly developed infrastructure, including 12 manned missions and six lunar landings, ending with Apollo 17 that launched on December 7, 1972. Continuing to use this infrastructure, the Skylab program launched four missions. During the Skylab program, KSC infrastructure was redesigned to meet the needs of the Space Shuttle program, which launched its first vehicle (STS-1) on April 12, 1981. The Space Shuttle required significant modifications to the Apollo launch pads and assembly facilities, as well as new infrastructure, such as Orbiter and Payload Processing Facilities, as well as the Shuttle Landing Facility. The Space Shuttle was a workhorse that supported many satellite deployments, but was key for the construction and maintenance of the International Space Station, which required additional facilities at KSC to support processing of the flight hardware. After reaching the new Millennium, United States policymakers searched for new ways to reduce the cost of space exploration. The Constellation Program was initiated in 2005 with a goal of providing a crewed lunar landing with a much smaller budget. The very successful Space Shuttle made its last launch on July 8, 2011, after 135 missions. In the subsequent years, KSC continues to evolve, and this paper will address past and future efforts of the transformation of the KSC Apollo and Space Shuttle heritage infrastructure into a more versatile, multi-user spaceport. The paper will also discuss the US Congressional and NASA initiatives for developing and supporting multiple commercial partners, while simultaneously supporting NASA's human exploration initiative, consisting of Space Launch System (SLS), Orion spacecraft and associated ground launch systems. In addition, the paper explains the approach with examples for NASA KSC to leverage new technologies and innovative capabilities developed to reduce the cost to individual users.

1. INTRODUCTION

NASA Kennedy Space Center (KSC) was established as the gateway to exploring beyond earth. Since the establishment of KSC in December 1963, the Center has been critical in the execution of the United States of America's bold mission to send astronauts beyond the grasp of the terra firma. On May 25, 1961, a few weeks after a Soviet cosmonaut became the first person to fly in space, President John F. Kennedy laid out the ambitious goal "of landing a man on the moon and returning him safely to the Earth" by the end of the decade. The resultant Apollo program was massive endeavor, driven by the Cold War Space Race, and supported with a robust budget. The Apollo program consisted of 18 launches from newly developed infrastructure, including 12 manned missions and six lunar landings, ending with Apollo 17 that launched on December 7, 1972. Continuing to use this infrastructure, the Skylab program launched four missions. During the Skylab program, KSC infrastructure was redesigned to meet the needs of the Space Shuttle program, which launched its first vehicle (STS-1) on April 12, 1981. The Space Shuttle required significant modifications to the Apollo launch pads and assembly facilities, as well as new infrastructure, such as Orbiter and Payload Processing Facilities, as well as the Shuttle Landing Facility. The Space Shuttle was a workhorse that supported many satellite deployments, but was key for the construction and maintenance of the International Space Station, which required additional facilities at KSC to support processing of the flight hardware. After reaching the new Millennium, United States policymakers searched for new ways to reduce the cost of space exploration. The Constellation Program was initiated in 2005 with a goal of providing a crewed lunar landing with a much smaller budget. The very successful Space Shuttle made its last launch on July 8, 2011, after 135 missions.

2. KSC MASTER PLAN 2012-2032 [1]

In 2012, Robert Cabana, the NASA Kennedy Space Center Director, rolled out a 20-year vision for the evolution of KSC in the post-Space Shuttle age, where NASA would continue reaching for the stars, while nurturing nascent commercial space-faring ventures. The KSC Master Plan outlined the philosophy as well as the road map for becoming a multi-user spaceport.

> *The Master Plan's central focus remains in support of NASA achieving its programmatic mission objectives but additionally it is also designed to maximize the provision of excess capabilities and assets in support of non-NASA access to space. This transformation to a multiuser spaceport will allow NASA to subsidize costs of expensive infrastructure and facilities and still maintain the country's ability to push the boundaries of our understanding of the universe.*

To execute such an effort, the document outlined how to transform KSC, from focusing primarily on NASA programs (and collaborations) such as the Space Shuttle and International Space Station, to become a multi-user spaceport, working with commercial industry to be able to collaborate use of common needs, and to efficiently utilize resources, both highly trained people and space-mission-specific facilities, for which the Space Coast of Florida has been so aptly named.

Since NASA established a presence on the east coast of Florida, adjacent to Cape Canaveral Air Force Station (CCAFS), it has been managing the launches of NASA's manned space flight missions, such as Project Mercury, Project Gemini, Apollo, Skylab and the Space Shuttle, as well as robotic missions. The KSC Master Plan details what KSC capabilities and resources exist (Core Competencies), followed by the plan to transition to multi-user access.

KSC Core Competencies

Building upon over 50 years of experience, the 2012 Master Plan methodically attacks the challenge of thoroughly defining its' path for a successful transition to being a multi-user spaceport. To lay the necessary groundwork, KSC outlined the launch support capabilities, which includes matching payloads with appropriate launch vehicles, supporting development activities, processing launch vehicles, spacecraft and payloads, performing operations such as launch, landing and recovery, and providing program sustainment support. In addition, KSC has significant experience with the design, development, operation, and sustainment of flight systems, ground systems, and supporting infrastructure, and the activities necessary to bring advanced flight systems and transformational technologies to advance exploration and space systems to operational levels.

Planning Strategy

The vision for the KSC transformation is to become an economically sustainable multi-user spaceport. To achieve this vision, the Plan's Core Strategies integrate NASA capabilities and resources with emerging non-NASA opportunities, and utilizes development factors, future land use, and right-sizing initiatives to support the success of NASA missions, and the growth and success of non-NASA space initiatives.

Development Factors

The development approach seeks to balance the operational needs of a spaceport with the protection of the Merritt Island National Wildlife Refuge and the Canaveral National Seashore, working closely with the United States Fish & Wildlife Service and the National Park Service, respectively. Currently, about 5% of the 141,829 acre land area is used to support operations. Preserving critical wildlife habitats and wetlands, as well as excluding areas at risk from sea level rise, opens up another 5% of area suitable for development and use for spaceport needs (Fig. 1). With a lot of the very low-lying land, new development needs to avoid regions identified as being within a 500-year flood plain, or the land and facilities need to be hardened to withstand a 500-year flood event.

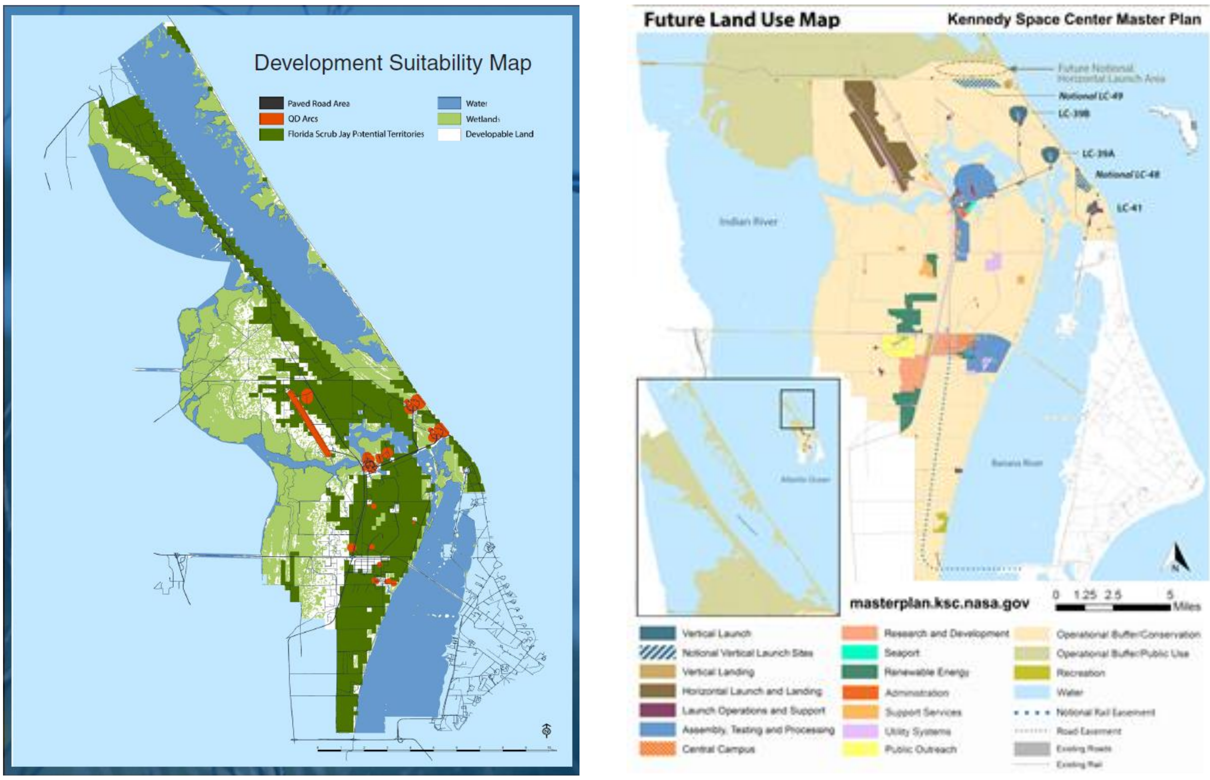

Fig. 1: KSC Development Suitability and Future Land Use Maps

Future Land Use

The Planning Strategy further clarifies the development factors to expand upon KSC's current capabilities and infrastructure to promote clustering of facilities such that compatible capabilities are grouped together, while hazardous and non-hazardous operations will be appropriately separated. Such a clustering plan will encourage synergy among users, improve the efficiency of spaceport operations, provide safety for the workforce, improve security considerations for all operations and hardware, and maximize the preservation of critical habitats.

Asset Strategy

To best execute the development of the infrastructure and launch operation facilities will require a different approach to allocation and management of the spaceport assets. The transition to a multi-user spaceport will require a reduction of aging NASA-funded facilities and infrastructure, reducing the NASA operational footprint to be optimally sized to accomplish NASA program objectives while supporting the growth and relative independence of non-NASA operations. Future NASA assets will need to be evolvable to meet the needs of the current missions, as well as be able to evolve to support future missions. To do so, development will need to minimize unique program-specific capabilities.

The KSC multi-user spaceport of the future will be composed of co-located NASA, Non-NASA, and multi-use facilities, funded through a mix of federal, state, and commercial funds, all used for the benefit of the spaceport.

In addition, KSC has outlined a strategy for improving the sustainability of the spaceport [2], with emission reduction targets, implementation of renewable energy, reduction of energy intensity, use of green buildings, and the use of energy-efficient processes throughout.

Emerging Opportunities

When the 2012-2032 KSC Master Plan was drafted, the commercial space programs were in their infancy, and planning was based upon available data at that time. KSC planned to position itself to capture this developing market, such that those efforts would benefit from the depth of experience of the KSC area workforce, as well as the infrastructure and capabilities of the center. Business analyses were completed to assess the emerging opportunities in the overall global space market, and based on that data, the key market strategies to aid in KSC's success in the commercial space flight market were identified, which would leverage the highly skilled human capital in the region, expand upon the available Ground Support Operations for the spaceport, and partner with economic development organizations, to name a few.

The commercial space flight market was considered an emerging, complex market, with many unknowns. However, KSC strengths position the center very competitively in this market, being able to provide great benefits to carry this market forward, and upward.

3. KSC TRANSFORMATION INTO MULTI-USER SPACEPORT

In the subsequent years following the retirement of the Space Shuttle, KSC continues to evolve, transforming the KSC Apollo and Space Shuttle heritage infrastructure into a more versatile, multi-user spaceport.

The launch center formally opened July 1, 1962, when NASA established it as a field center named the Launch Operations Center. Throughout the decades, and NASA's massive programs, the large property on the northern end of Merritt Island in Florida has been and still is carefully managed, as described above, to provide an uninhabited buffer zone between launch pads and processing centers and the cities of Titusville on the western side of the Indian River, CCAFS on the east, and suburbs of Merritt Island south of the space center.

Apollo to Space Shuttle [3]

The initial transformation of KSC took place following the end of the Saturn and Skylab programs, in preparation for the Space Shuttle in the 1970's. The specialized facilities that were critical in readying Apollo spacecraft and Saturn V rockets for missions were modified, and processes adapted so they could continue to be used by NASA's highly trained workforce. Whereas each Apollo spacecraft and Saturn V rocket was built brand-new and used for one mission, NASA pursued reusability as a hallmark for the Space Shuttle, and pushed toward a goal of making spaceflight routine.

Although NASA had a new spacecraft and mission, the budget environment was far more austere than it had been during Apollo. Engineers set out to use whatever Apollo-generation structures they could for Space Shuttle processing. Nearly all of Kennedy's Apollo-era structures would continue in NASA service for three more decades as they were adapted to process and launch the Space Shuttle and its payloads. The Operations and Checkout (O&C) Building's high bay was used to process payloads horizontally, and the Vehicle Assembly Building (VAB) was used to stack the solid rocket boosters and external tank before placing a shuttle orbiter in launch position atop the Mobile

Launcher Platform (MLP), where the Saturn service towers were removed, and reutilized at the Launch Pads for the Fixed Service Structure (FSS). The Launch Control Center (LCC) retained its role as an overseeing location for all the processing and launch operations, as engineers watched over consoles modified for Space Shuttle.

The launch pads were heavily modified to host Space Shuttles. Instead of taking the service tower with the Saturn V out to the launch pad, the Space Shuttles were rolled to the pad on platforms that had very little structure. Each launch pad was outfitted with a pair of service structures: the FSS that stayed in place on the side of the Space Shuttle in launch position, and the Rotating Service Structure (RSS). The RSS included a clean room that would roll into place over the orbiter's cargo bay so payloads could be slid into the cargo bay without being exposed to the elements of the ocean-side launch pads, as well as providing access for loading time-critical payloads.

The processing needs for Space Shuttle were substantially different from those for Apollo because the spacecraft were reusable and the payloads were generally larger than a completed Apollo command and service module. Those needs predicated a new generation of specialized facilities that were built for the Space Shuttle program. Three Orbiter Processing Facilities (OPFs), were built on the west side of the VAB. A dedicated complex for solid rocket booster refurbishment was built to receive and process the boosters and parachutes recovered at sea, with additional storage and processing facilities closer to the VAB.

The Shuttle Landing Facility (SLF) is a three mile-long, 300-foot-wide runway, built in the swampy areas west of the VAB. The surrounding lands were dredged to build up the 500 acres of the SLF, and cement was poured to create the landing surface. Though built from 1974 to 1976, the SLF remains one of the largest runways in the world. The SLF is operated as a full airport with an air traffic control tower and support buildings on-site, including a fire station, and a 50,000-square-foot hangar built in 2000.

Separate facilities for handling the vertical payloads of the Space Shuttle, and for hazardous fueling operations were also built. Later, the 457,000-square-foot Space Station Processing Facility (SSPF), was constructed to ready components of the International Space Station (ISS) for launch aboard the Space Shuttles. Engineers and technicians would also use the SSPF to pack cargo for ISS missions. At its height of processing, the 46,000-square-foot high bay of the SSPF was loaded with station components in various levels of preparation for launch, from our international partners.

<u>Shuttle to Multi-User</u>

The retirement of the Space Shuttle provided a catalyst that is unique in NASA history and very rare in federal property and asset management: A specialized field center established for a well-defined mission conducted by a single customer would no longer serve that single customer and would instead focus on broader uses of its facilities by a range of customers with needs different from each other. The transformation also put NASA in a position in many cases of acting as a supplier of services instead of a customer.

It is generally accepted that turning around a large organization or major company akin to the size of Kennedy takes about seven years. Using that scale, Kennedy is about complete of its transformation period that began in 2010 and picked up steam in 2011 when NASA retired the Space Shuttle fleet.

The most dramatic element of the transition came in the months leading up to the last flight of the Space Shuttle and for about a year following the last flight, as the orbiters were readied for disposition to museums across the country. It was during this time that Kennedy released the vast majority of the contractor workforce that processed, launched and recovered the shuttles, and reassigned or allowed the retirements of the civil service employees attached to the Space Shuttle program. Kennedy's workforce dropped from about 14,700 to 8,000 [4] in this time frame. The number has remained steady since the Space Shuttle were retired, indicating that the current workforce is appropriately sized for the current needs of the center, however, the new programs could provide a need for an additional 2000 people, even with more efficient processes and technological advancements. [5]

More than 40 buildings at KSC were used at one point to launch, process and recover the Space Shuttle. A large part of the transformation at KSC focused on finding new uses and partners for the specialized buildings, and deconstructing those that were either too old to be maintained economically, or without a foreseeable use by NASA's future missions or with commercial partners.

The retirement of the space shuttles also reduced the amount of funding Kennedy received from NASA. Shuttle funding accounted for a considerable amount of Kennedy's annual budget, so much of the transformation since then has been funded through Kennedy's center maintenance and operations budget. One of the first objectives of the transformation was to catalog and prioritize the modernization of Kennedy's facilities such as the VAB and launch pads. The infrastructure had not been upgraded in up to 50 years in some cases. Miles of cables, wiring and plumbing in the VAB were pulled out and replaced for the first time since the structure was completed in 1967. Copper cables leading from the Launch Control Center to the launch complexes at 39A and B were also removed and replaced with state-of-the art fiber-optic cables that can carry at least 100 times more data in less than half the space. Other facilities, such as the O&C building's high bay, were refurbished with funding from partners, such as Space Florida, which is now being used by Lockheed Martin for assembling and processing NASA's Orion spacecraft.

Overall, the modernization program has made Kennedy's facilities far more attractive to commercial partners who expect to work in an environment equal to modern offices, research labs and facilities.

The VAB has additional upgrades to accommodate the SLS rocket, NASA’s launch vehicle for future missions to the moon and beyond (Fig. 2). The high bay to be used for processing the new rocket had to be modified from working on the 184 foot tall Space Shuttle stack to the 321 to 384 foot tall SLS rocket. This involved removing 7 massive access platforms and installing 10 new platforms, each weighing up to 325,000 lbs (147,000 kg), and each being the size of a small house.

Fig. 2: Evolution of the Saturn/Shuttle Vehicle Assembly Building

The Space Shuttle Mobile Launcher Platform also was modified from an essentially empty deck to include a launch tower for the SLS rocket, similar to the old Saturn service tower (Fig. 3). The tower includes 7 umbilical arms that connect to the rocket and provide fuel, oxidizer, ground power, and all of the other services needed to prepare and monitor the rocket for launch.

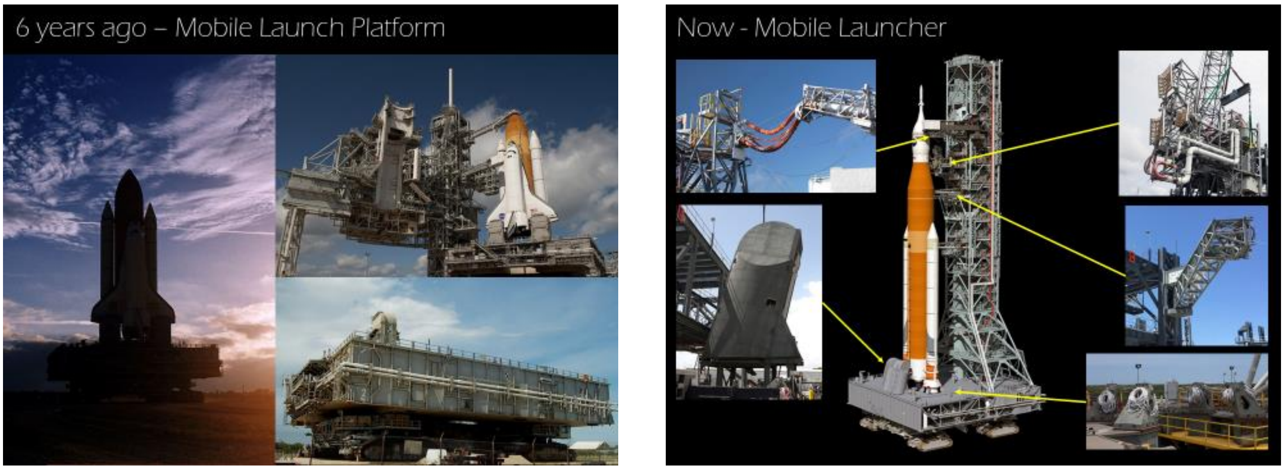

Fig. 3: Evolution of the Saturn/Shuttle Mobile Launcher

Other facilities were upgraded for more multi-user purposes, such as Launch Pad 39B (Fig. 4), which now embodies the "clean pad" concept such that the user brings their own launch pad structure and connects to the insfrastructure, which includes all the necessary launch support commodities, such as fuel, oxidizer, power, and water. The LCC is also being upgraded for multi-users to monitor launch operations, as well as hardware testing in other KSC facilities (Fig. 5).

Fig. 4: Launch Pad 39B Clean Pad Concept for Multi-User Capabilities

Fig. 5: LCC Upgrades to Support Multi-User Launch Operations

Partnerships

NASA determined during the development of its' Master Plan that the facilities and workforce at Kennedy would be in high demand from the private and public sectors in America. As soon as the proverbial door was opened to industry's ideas for Kennedy, inquiries started, and are continuing to come in. KSC has acted on numerous proposals that have resulted in partnerships with industry, academia, and federal and local agencies. Kennedy's Center Planning and Development organization, which focuses on agreement development for the center, currently has 98 active partnership agreements, 43 additional ones are being developed while 22 others are under assessment; the number of active agreements have increased throughout the years. Working with organizations such as Space Florida, the space industry organization for the State of Florida, has facilitated such activities.

Facilities Leased to Partners

With so many proposals spanning many types of partnering opportunities, such as Launch Systems, Spacecraft and Payloads, Capabilities and Testing, and Emerging Markets [6], the landscape at KSC has changed much in the past 6 years, most noticeably with the facility usage across the now-recognized multi-user spaceport (Fig. 6).

Fig. 6: Post-Shuttle KSC Facility Reutilization with Commercial Partners

Orbiter Processing Facilities 1 and 2:

The Air Force partnered with Kennedy for two of the Orbiter Processing Facilities (OPF 1 and 2) that had served as the Space Shuttle hangars. The armed service is processing its X-37B spacecraft in the hangar bays of the OPFs and use other Kennedy facilities in the operational aspects of the spacecraft, such as landing at the SLF, with future launches from either KSC or CCAFS.

Shuttle Landing Facility:

Space Florida has partnered with Kennedy to lease, maintain and operate the SLF. The three-mile-long runway, its associated buildings and capabilities have been in demand for years, and this partnership serves that demand in ways NASA is not set up to accomplish effectively itself. The SLF is already home to Starfighters Aerospace [7], a company that offers sub-orbital flight training, as well as the ability to perform aerospace flight testing services from basic research to systems evaluation, and the ability to launch small satellites on suborbital missions using F-104 supersonic jets. Many companies that plan to use winged spacecraft for missions ranging from satellite launches to carrying tourists into space on short missions have expressed interest in the SLF.

Orbiter Processing Facility 3 and Space Shuttle Main Engine Processing Facility:

The Boeing Company, working with Space Florida, leased the third Space Shuttle hangar, OPF 3, along with the Space Shuttle Main Engine Processing Facility, for the assembly and processing of the CST-100 spacecraft (Fig. 7) being developed with NASA's Commercial Crew Program (CCP). The CST-100 program processes and operates the spacecraft that is one of the two selected to carry astronauts to the International Space Station.

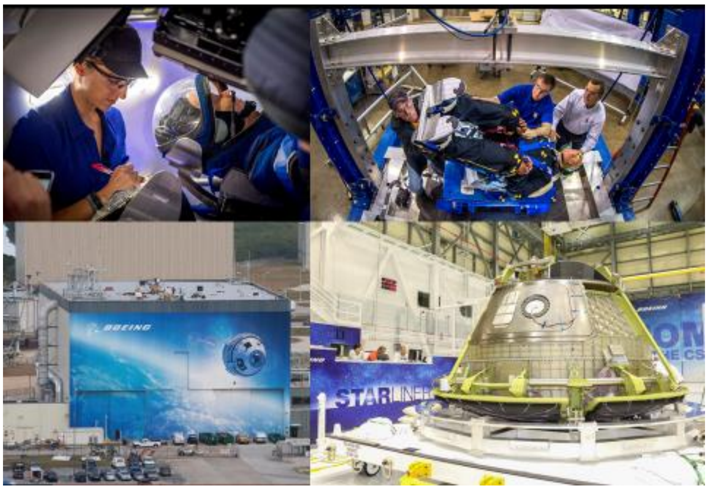

Fig. 7: Boeing CST-100 Starliner Operations at the Former Shuttle OPF

Launch Complex 39A

SpaceX, formally known as Space Exploration Technologies, leased Launch Complex 39A as the east coast launch site for the Falcon Heavy and the sole launch site for the Crew Dragon, a spacecraft developed with NASA's Commercial Crew Program to carry astronauts and cargo to the International Space Station (Fig. 8). The company has been modifying LC-39A, adding a horizontal integration facility, upgrading the FSS, adding a launch platform, and removed the RSS to serve the Falcon Heavy and Crew Dragon. The complex area also has sizeable propellant tanks and lines required of large boosters, but is getting upgraded for the specific needs of SpaceX.

Fig. 8: SpaceX at Launch Complex 39A

Operations and Checkout Building High Bay:

Lockheed Martin, working with Space Florida, leased the high bay at the O&C Building for the processing and assembly of the Orion spacecraft (Fig. 9), NASA's next craft designed to take astronauts into deep space on missions to asteroids and eventually Mars. Space Florida paid to modernize the facility from its time as a servicing area for Apollo spacecraft to make it more attractive for commercial companies.

Fig. 9: O&C High Bay for Lockheed Martin Orion Processing and Assembly

Space Life Sciences Laboratory and Exploration Park

The Space Life Sciences Laboratory (SLSL) and Exploration Park are showcase emblems of Kennedy's utility in research and development outside the realm of launch and processing. Again working closely with Space Florida, Kennedy has dedicated a parcel of land on the southwest portion of the center for use as a research campus anchored by the SLSL and expected to house new buildings specified for commercial or university use. Kennedy adjusted the fence-line of the center so that those working at the SLSL and Exploration Park would not have the same strict security conditions applied to them as they are on other parts of the center.

Blue Origin

Coordinated with Space Florida, Blue Origin is constructing a 750,000 square-foot rocket manufacturing and refurbishment facility (Fig. 10) for its reusable, heavy-lift orbital rocket, New Glenn at Exploration Park, a 299-acre facility on NASA's Merritt Island property outside the gated perimeter of KSC. The company plans to launch New Glenn from CCAFS SLC-36, offering suborbital flights for tourists, as well as a platform for scientists to conduct microgravity experiments. [8]

Fig. 10: Blue Origin New Glenn Facility (Concept, Credit: Blue Origin)

OneWeb Satellites

Coordinated with the State of Florida and Space Florida, OneWeb Satellites is constructing a high-volume satellite manufacturing facility at Exploration Park outside the gated perimeter of KSC. The company, which is a joint venture between OneWeb and Airbus Defence and Space, plans to have the facility capable of producing over 15 satellites per week, to support the 900 low-Earth orbit satellite constellation to offer high-speed internet with global coverage. [9]

Laboratories

Because Kennedy's laboratories remain essential elements for research into launching and ground support equipment for NASA's missions, partnering agreements are being limited to buying time and expertise from NASA's workforce at the labs in order to perform research and testing to a company's needs. Aerodynamic tests, materials evaluation and many other scientific studies can be performed in Kennedy's settings and numerous proposals have been submitted for different studies that would find the labs useful.

KSC Programs that Enable/Support the Multi-User Spaceport

Kennedy has made enormous strides in the past six years and is already accomplishing goals and partnerships that some considered impossible. There remain many more partnership possibilities for the center that indicate a continuing demand from industry for sites with the KSC's assets. In the meantime, Kennedy continues to take steps to advance the speed of partnership development to show private industry that the center is open for business and welcoming of their ideas.

The Commercial Crew Program (CCP) is working with SpaceX and Boeing to develop the capability to take American astronauts to the ISS, expanding the options to ferry crew since the retirement of the Space Shuttle has resulted in only the Soyuz capsules being the certified vehicle.

Exploration Ground Systems (EGS) is the program that manages the SLS ground systems mission, which provides the oversight for the KSC facility upgrades, launch vehicle and spacecraft assembly, processing, and launch.

The ISS program supports the crew, hardware and science aboard the orbiting station.

The Launch Services Program (LSP) supports NASA from a higher level, matching payloads with launch vehicles, typically for CCAFS launches (Fig. 11).

Fig. 11: KSC Launch Services Support Activity

4. U.S. CONGRESSIONAL AND NASA INITIATIVES

There are several U.S. Congressional and NASA initiatives for developing and supporting multiple commercial partners, as well as NASA's human exploration initiative, consisting of Space Launch System (SLS), Orion spacecraft and associated ground launch systems.

21st Century Launch Complex

After the retirement of the Space Shuttle Program, the White House and Congress enacted an initiative to modernize the KSC and CCAFS, transforming them to provide the capabilities this Nation's 21st century space programs would need. The effort was intended to augment NASA's current and future operations to achieve safe, increased operational efficiency and reduced launch costs for all customers (industry, NASA, national security, etc.).

The goal of the enhanced complex was to facilitate multiple launches of different vehicle types from different companies carrying both humans and cargo to space in a cost-effective and timely manner. Other important projects include enhancements to the range, payload processing capabilities and environmental clean-up activities.

Deep Space Gateway [10]

The ISS is considered Phase 0, the foundation, for NASA's strategy for deep space exploration, scientific research, economic growth, and global diplomacy (partnerships). As such, the ISS has been bringing the nations of the world together to discover, develop, and advance solutions for a better life both here on Earth and in space.

The next step, considered the first phase (Fig. 12), will bring forth opportunities for exploration near the moon, use current technologies and allowing mankind to gain experience with extended operations farther from Earth than previously completed. These missions enable NASA to develop new techniques and apply innovative approaches to solving problems in preparation for longer-duration missions far from Earth.

In addition to demonstrating the safe operation of the integrated SLS rocket and Orion spacecraft, the agency is also looking to build a crew tended spaceport in lunar orbit within the first few missions that would serve as a gateway to deep space and the lunar surface. This deep space gateway would have a power bus, a small habitat to extend crew time, docking capability, and an airlock, and be serviced by logistics modules to enable research. The propulsion system on the gateway mainly will use high power electric propulsion for station keeping and the ability to transfer among a family of orbits in the lunar vicinity. The three primary elements of the gateway, the power and propulsion bus, the habitat module, and a small logistics module(s), would take advantage of the cargo capacity of SLS and crewed deep space capability of Orion. An airlock can further augment the capabilities of the gateway and can fly on a subsequent exploration mission, Building the deep space gateway will allow engineers to develop new skills and test new technologies that have evolved since the assembly of the International Space Station. The gateway will be developed, serviced, and utilized in collaboration with commercial and international partners.

"I envision different partners, both international and commercial, contributing to the gateway and using it in a variety of ways with a system that can move to different orbits to enable a variety of missions," said William Gerstenmaier, associate administrator for Human Exploration and Operations at NASA Headquarters in Washington. "The gateway could move to support robotic or partner missions to the surface of the moon, or to a high lunar orbit to support missions departing from the gateway to other destinations in the solar system."

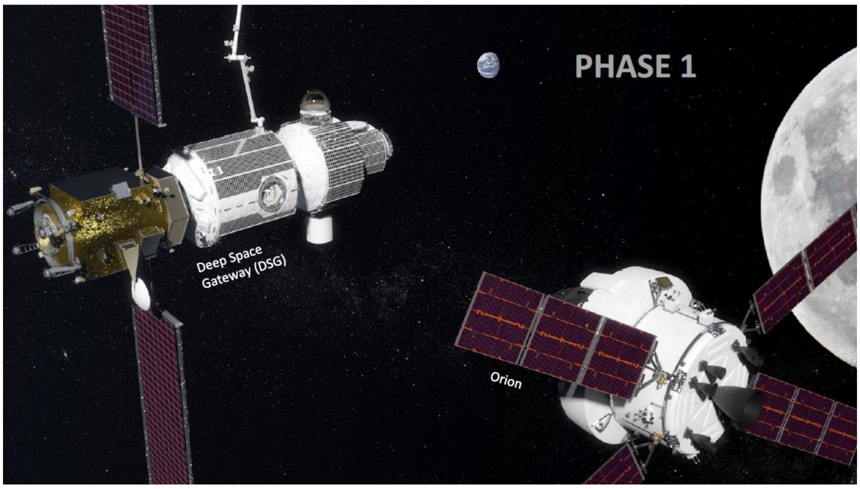

Fig. 12: Deep Space Gateway Concept

Deep Space Transport

The second phase of missions will confirm that the agency's capabilities built for humans can perform long duration missions beyond the moon (Fig. 13). For those destinations farther into the solar system, including Mars, NASA envisions a deep space transport spacecraft. This spacecraft would be a reusable vehicle that uses electric and chemical propulsion and would be specifically designed for crewed missions to destinations such as Mars. The transport would take crew out to their destination, return them back to the gateway, where it can be serviced and sent out again. The transport would take full advantage of the large volumes and mass that can be launched by the SLS rocket, as well as advanced exploration technologies being developed now and demonstrated on the ground and aboard the International Space Station.

This second phase will culminate at the end of the 2020s with a one year crewed mission aboard the transport in the lunar vicinity to validate the readiness of the system to travel beyond the Earth-moon system to Mars and other destinations, and build confidence that long-duration, distant human missions can be safely conducted with independence from Earth. Through the efforts to build this deep space infrastructure, this phase will enable explorers to identify and pioneer innovative solutions to technical and human challenges discovered or engineered in deep space.

To achieve the agency's goal to extend humanity's presence in the solar system will require the best research, technologies and capabilities from international partners and the private sector. NASA will look to partners for potential contributions of spaceflight hardware and the delivery of supplemental resources. The gateway and transport could potentially support mission after mission as a hub of activity in deep space near the moon, representing multiple countries and agencies with partners from both government and private industry. NASA is open to new ideas of both a technical and programmatic nature suggestions as we develop, mature and implement this plan.

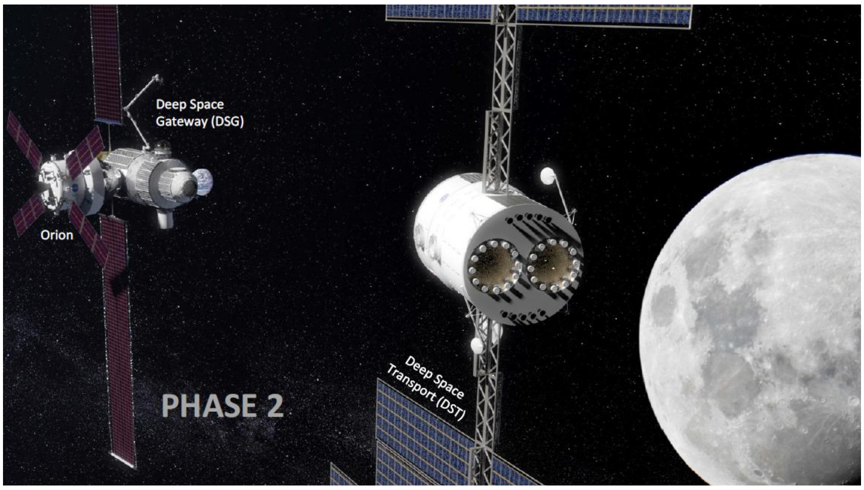

Fig. 13: Deep Space Transport Concept

5. COST-SAVING TECHNOLOGIES, CAPABILITIES, AND PROCESSES

NASA was created to do two things when it was established in 1958 (and updated in 2010):

1) Build the technological base of our country through the machine shops, manufacturing, laboratories, test facilities, and universities, and
2) Push the technologies to the marketplace to help with Item 1.

We did that well throughout the following 59 years, and now is the time to embrace the future, accept commercial access to space at all levels, and get on with the work of exploration of the larger universe, a better understanding of Spaceship Earth, for sustaining our country and the good of all people.

Thus, to meet these goals and expectations for a state-of-the-art Multi-User Spaceport, NASA cannot stand still with respect to embracing emergent technologies, as well as developing technologies and processes that *enable* the future.

There are many ways that technology development are viewed. One perspective of the evolution of technology is a graphical representation known as a Hype Cycle (Fig. 14), an extension of Amara's Law [11], which states:

> *We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run.*

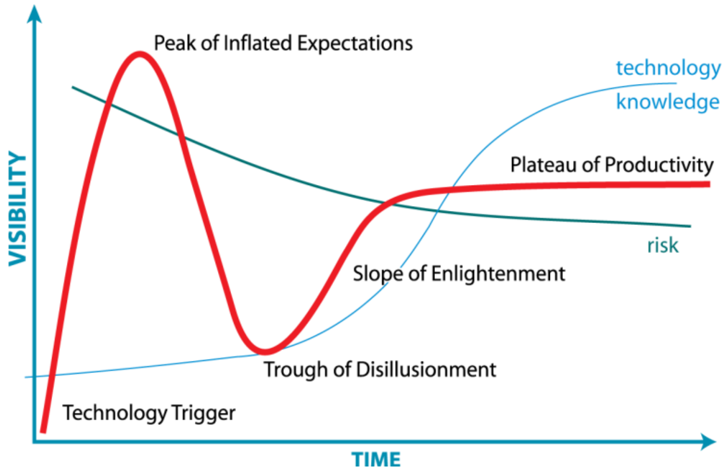

Fig. 14: Hype Cycle for Emerging Technologies

This view recognizes that immature technologies and processes tend to have high expectations, but until the concepts and technology have been proven, can they lead to significant impacts. While this perspective is not as deterministic as the Technology Readiness Level (TRL) characterization for technology maturity, it does provide a useful insight into when it might be most timely to assess the feasibility of technology that has been proven, but not permeated throughout society.

As such, Kennedy Space Center established an organizational directorate, Exploration Research and Technology Programs, for the management and implementation of technical, cost, and schedule requirements for KSC research and technology programs and projects. Working closely with the other programs and projects at KSC, there is a focus to take items that have potential uses for NASA's specific goals and needs, and support further efforts to develop and embrace the capabilities. KSC looks at such technologies as falling into three focus categories (some may fall into several of these categories); efficiency, safety and sustainability.

The KSC Research and Development (R&D) team works with other government agencies, universities and industry partners, both domestic and international for all organizations, to evaluate and evolve ideas and concepts within the technology focus areas for space launch and exploration, as well as all the enabling spin-off technologies. The R&D Team work closely with people in industry and companies of all kinds to help come up with the *right* problem to solve, and support the activities to bring these solutions to fruition through *Research, Industry, and Training*.

As to be expected, KSC has deep expertise with cryogenic materials, including thermal insulators, thermal control systems, and thermal protection systems, but there is also strong subject expertise within the associated material sciences and the operational handling of cryogenics, high pressure gases, and hazardous materials. Examples of technology that are early in their development cycle include the use of microbes for safely handling hazardous material spills, and developing capabilities to reduce cryogenic commodity boil-off. The first example of hazardous waste eating bacteria can play a critical role in contained environments, such as space craft, space stations and extra-terrestrial facilities, where neutralizing hazardous spills quickly and safely are critical. The second technology will allow for less loss of precious cryogenic fuels and oxidizers where those resources may be limited. Both of these technologies would be beneficial to the needs of spaceport users, as well as the greater industrial world.

Other technologies have already found their way into commercial industry, but have not been incorporated into the NASA processes and designs. With the development of the new, multi-user spaceport, incorporating Artificial Intelligence (AI) to monitor communication channel traffic using Natural Language Processing with probabilistic semantics will allow for a lean workforce to be able to monitor activities spread across the spaceport, launch site, or test area, and direct the attention of the Control Room staff to appropriate discussions, whether they be related to safety or technical issues, for example. To facilitate operations processing, the use of augmented reality headsets and voice control can be used to provide hands-free access to data such as work steps, where the computer can provide a view of the necessary information, and help the worker progress through the operation more efficiently. KSC also has implemented using a suite of sensors for Hazardous Gas Leak Detection, a key sub-system for its own programs, and very useful for other users of the processing and operational facilities at KSC.

Another set of technologies are those that NASA has evolved beyond the Commercial-Off-The-Shelf (COTS) capabilities that are of value-added to customers of the spaceport. One such example would be system and design visualization tools which start with COTS products, but add a layer of process improvement tools and capabilities that take relevant information from very complex component or sub-system models, and enable the use of an integrated model for a myriad of applications such as the integration of the hardware, or simulations. These simulations can be used to develop processes for complex operations, as well as validate that designed equipment will support those complex operations, reducing the need for expensive, complex mock-ups and pathfinders.

6. SUMMARY

On July 21st, 2011, Space Shuttle Atlantis landed for its final mission at the Kennedy Space Center Shuttle Landing Facility, marking the end of an era. While this was the end of a 30+ year program, NASA had already laid out plans for America's future as a cornerstone for global access beyond the reaches of the Earth's gravity. Following those plans laid out, as detailed within this paper, KSC has been evolving into a multi-user spaceport. This is an unprecedented accomplishment for a dedicated government facility to open up its gates for supporting partnerships with commercial and international partners to be able to co-locate and take advantage of the highly skilled local workforce, as well as sharing common infrastructure needs for reaching to those heights.

7. REFERENCES

[1] *KSC-PLN-8810.1, Kennedy Space Center Master Plan 2012-2032.* Kennedy Space Center, FL: National Aeronautics and Space Administration, 2012.

[2] *KSC-PLN-8553, Kennedy Space Center Sustainability Plan 2013-2015.* Kennedy Space Center, FL: National Aeronautics and Space Administration, 2013.

[3] Colleredo, Scott T., *Kennedy Space Center Transformed and Transforming*, Space Traffic Management Conference, 2014.

[4] NP-2016-01-032-KSC, *Kennedy Space Center Annual Report FY2015*, Kennedy Space Center, FL, National Aeronautics and Space Administration, 2016.

[5] Santana, Marco, *Kennedy Space Center resurgence led by Bob Cabana's vision*, The Orlando Sentinel, 08/21/2017.

[6] https://kscpartnerships.ksc.nasa.gov/

[7] https://www.starfighters.net/

[8] Cofield, Calla, *Blue Origin's Giant Rocket Facility is Taking Shape in Florida*, Space.com, 12/08/2016.

[9] *OneWeb Satellites Breaks Ground On The World's First State-Of-The-Art High-Volume Satellite Manufacturing Facility*, http://oneweb.world/press-releases/2017/oneweb-satellites-breaks-ground-on-the-worlds-first-state-of-the-art-high-volume-satellite-manufacturing-facility, 03/16/17.

[10] Hambleton, Kathryn, https://www.nasa.gov/feature/deep-space-gateway-to-open-opportunities-for-distant-destinations, 08/04/2017.

[11] Phillips, Jeffrey, *Over- and Under- estimating Innovation*, Innovate on Purpose (Blog), 07/23/2013.