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3D Digital Documentation of Historic Launch Complex Structures at CCAFS: A Workflow Methodology for DOD Cultural Resources

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3D Digital Documentation of Historic Launch Complex Structures at CCAFS: A Workflow Methodology for DOD Cultural Resources

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Project Overview
At the request of the 45th Space Wing of the United States Air Force, Cape Canaveral Air Force Station (CCAFS), this documentation was undertaken to provide baseline terrestrial laser scanning (TLS) survey and spatial recordation for six historic launch complexes. Select structures were chosen for 3D laser scan survey, and these data were brought together with aerial Light Detection and Ranging (LiDAR) and Geographic Information Systems (GIS) applications in a digital platform for landscape and structure consideration. The project was performed in combination with Global Positioning Systems (GPS), videography, and imaging documentation, with the 3D terrestrial laser scanning providing the referent data for the derived 3D Computer Assisted Drawing (CAD) products and archival as-is conditional reference. All work were conducted in accordance with the National Historic Preservation Act of 1966 (PL 89-665) as amended and the Archaeological and Historic Preservation Act of 1974 (PL 93-291) and were performed and directed by a Register of Professional Archaeologists (RPA) certified archaeologist. In addition, all work meets the guidelines as set forth in the Historic Preservation Compliance Review Program of the Florida Department of State, Division of Historical Resources.

This project utilized a combination of spatial documentation tools including terrestrial laser scanning (TLS) and photogrammetric and imaging techniques, to document and record as-is and as-built conditions of several structures within six historic launch complexes and additional feature (building) locales (Figure 1). The present survey utilized best available documentation survey techniques in an effort to digitally archive and preserve the sites and terrains, and to provide an accurate record for visualization, replication, management, and archival needs. At the landscape level, aerial LiDAR models were combined with areas of terrestrial laser scanning survey, and can allow for the examination of issues and to provide precise means of assessing loss and developing mitigation and stabilization strategies (Abby 2014). Aerial and Terrestrial Laser Scanning (LiDAR) data collection and interpretation has been described as one of the most significant innovations for the field of archaeology and for landscape analysis (Opitz 2013).

Global Positioning Systems (GPS) and Geographic Information Science (GIScience) was utilized to record locations and features of interest in the immediate surrounding environ. Data collected in the 3D survey were used to produce accurate sectional details, models, and drawings of selected structures and complexes, and were used to depict and record terrain conditions associated with the resource. Using data collected on site (TLS, GPS, photographs and notes, in combination with aerial LiDAR and aerial imagery), relevant 3D CAD models, profiles, and perspectives depicting existing conditions were also prepared. These CAD drawings, as well as GIS cartographic and 3D products included location maps, terrain and elevation models, and profile and sectional analyses for each site. Sectional details were compared to as designed drawings that were available. Historic American Building Survey (HABS) and Historic American Engineering Records (HAER) level CAD measured drawings and products were available on a number of these structures, and comparisons were made to the actual site configurations and layouts as well as to structural analyses and details whenever possible. The TLS data collected by this survey stands as a lasting digital archive of these structures in their current condition, and provide valuable information concerning monitoring and condition assessment, relationship with natural systems and landscape documentation, and other management and historic preservation documentation needs.

Aerial LiDAR data was acquired and processed to provide detailed terrain maps for all landscape areas, providing a topographical understanding of the historic and modern setting. Additionally, GPS survey and GPS photography were used to field truth and verify areas of interest and to provide overall site plan map details and conditional assessment information.
Figure 1. Documented historic structures and facilities for the Cape Canaveral TLS Survey.
A GIS geodatabase and derived GIS products (FGDC compliant metadata and data quality standards used), provide spatial understanding for resources that are presently located within the project area. A GPS photo report was also produced as a PDF document, showing conditions and features with coordinate and viewshed information and is provided as an added value product. The TLS data, used to produce sectional information, are also provided in a 3D PDF format, allowing for manipulation and visualization of the 3D structural and terrain features. All 3D data collected are provided in archival formats using the ASTM E57 standard for 3D imaging data exchange, which is a vendor neutral data format. Models provided are in ubiquitous .stl and .obj formats that are viewable and sharable in numerous free and neutral software. This report overviews the 3D documentation project and provides representative product examples and materials developed. A data external drive is provided in addendum to this report, containing all GPS, GIS, Geodatabase, imagery and TLS survey data and models produced. A variety of data formats are provided and will be discussed in later sections. These formats allow for freely available software applications and viewing of collected information, and serve as a management, visualization, and archival record foundation for the complexes and facilities documented.

Survey Methods
The Cape Canaveral 3D Digital Documentation Project utilized a new approach to bringing multiple types of data together, including 3D, 2D, GIS, and imaging formats, providing an important tool for archival documentation, management and decision-making. The survey began with a bringing together of remotely sensed (aerial LiDAR and aerial imagery) data with ground-based survey data such as TLS and GPS survey data and collected photographic attribute information using standard, panoramic, scanner spherical, and GPS imagery types. Special effort at 3D archival level documentation and full 3D modeling were performed for selected facilities and structures at each of the six complexes and other selected locales. Each area, along with methods used and results will be overviewed in this report, along with section discussions on each of the methods used.

Terrestrial Laser Scanning Survey
A 3D laser scanning survey was performed, including full spherical photographic and standard (external from the scanner) photographic documentation, as well as utilization of aerial LiDAR survey data. Three dimensional laser scanning surveys can offer a method of rapidly and accurately producing highly representative and precise 3D details of complex terrains and architectural structures. Accurate portrayal and understanding of spatial locations of resources is important from both a management perspective and from a research and public interpretive perspective. The resultant survey was used to create 3D plan view, profile and sectional analyses, which were provided for detailed CAD and 3D renderings, orthographic projections, and 3D models. 3D data collected in the survey were used to create a digital archive of current “as-is” conditions, as well as to provide information for the “as-built” understanding of the site for 3D CAD architectural plans. The TLS data were also exported for use in GIS applications.

Accurate spatial mapping can be used to develop slope and erosional representations, and coastal change assessments, and allow delineation for regions of concern for management, having the added value of providing valuable information for both natural and cultural resource management. These models can also help to provide a precise means of assessing loss and to develop mitigation and stabilization strategies for natural and cultural features (Abby 2014). Models were produced using a combination of aerial laser scanning (ALS) or LiDAR, terrestrial laser scanning (TLS), and ground truth verification with GPS. The AIST at the University of South Florida are integrating ALS with TLS and other techniques to examine large scale landscape areas, with rapid and highly accurate assessments of elevation and surface details possible. The GIS exports entailed bringing the TLS data together with the ALS data to provide a more comprehensive
overview of the complexes and facilities. ALS data alone would not have provided enough detail features on specific structures, but does provide context and landscape terrain details that were brought together with specific TLS target areas (Figure 2). In this way, areas of documentation interest and target can be captured with the highest level of detail and brought together in modeling and GIS platforms with associated structures and features to provide landscape settings and conditions across a large area. Correct assessments of not only locations, but capturing details allowing for a change detection analysis at these sites can insure preservation into the future. The AIST’s work to develop accurate digital elevation models (DEMs) derived from ALS, GPS, and TLS applications, should be utilized as a means of assessing condition more accurately and monitoring changes and stabilization needs at the locations where work was performed.

These types of surveys have proven successful for the analysis and conservation of historic objects, structures, and environments (Murphy et al. 2013). Polygonal mesh 3D models were produced, allowing for digital sharing, archiving, and for new techniques such as 3D printing to be performed. These data can be used to create interpretive and tangible items, including full landscape and structure scaled models or even the potential for full-sized architectural detail and object replicas (Leronesa 2010). Complete 3D models were derived from the 3D laser scanning survey data. These data are useful for engineering records and to establish an architectural archive for the feature. Digital terrain models can be shared in fully viewable 3D formats and provide data for future computer interactive apps and interpretative development.

Our TLS survey utilized a several phase-based FARO Focus 3D laser scanners (120 and 330 models), that were chosen for reasons of portability and size as well as robustness and accuracy in spatial metrology and representative documentation needs for the project. Additionally, the 330 model combined distance (up to 330 meters) with low data noise and high accuracy at +/- 2mm. The on-board imaging capabilities of this instrument as well as the virtualization workflow with post-processed data were also important factors of instrument choice. Software registration utilized targeting schema performed in our laser scanning survey, and options for limited visibility of targets in some instances, as well as complex or sometimes symmetrical geometric positioning and distribution of targets were planned out ahead of the survey. For example, targeting for scan point cloud registration can prove difficult in straight line confined and largely symmetric locations, which are challenging for constrained matching and registration of point clouds and surfaces in the post-processing of data (Bellekens et al. 2014). Shafts, tunnel features, and circular shaped structures all pose these types of challenges for TLS survey methods. Subsidence and deformation studies utilizing these data for monitoring and analytic potentials are planned for, and data were collected to be representative as well as serve as a foundational archive for planned return targeted scanning documentation in the future. Sectional analysis and research into the stability and conditional aspects are also possible with a high degree of accuracy and representativeness using the TLS data (Gu and Xie 2013). The TLS data also enable accurate calculation of volumetric and metrology details, with findings important from a structural assessment perspective as well as from an interpretive perspective in regards to the construction methods and historical engineering.

GPS, GIS and Cartography

The 3D documentation survey is inclusive not only of the TLS survey data collected, but is brought together with other forms of spatial and legacy data in a GIS geodatabase platform. The project geodatabase includes all of the collected GPS (sub-decimeter data) and GPS photographs, as well as the LiDAR 3D products. Cartographic products made in the GIS include a site level DEM, digital surface models (DSM), contour maps and terrain models, and 3D GIS and web GIS models. Feature locations, attribute information and the
Figure 2. GIS Modeling workflow entails combined ALS data with TLS derived models. The image above shows point distribution from ALS with the TLS derived models, with finalized models derived from both data sets also shown (middle and below), showing contextual details that come from the combination of information.
condition details were recorded using GPS across the site, and these data are contained as part of the project geodatabase files.

GPS field data collection for this project provided spatial control for survey precision and accuracy, location and attribute information for database development and for use with interpretive and interactive tools, and provided data for use in georeferencing legacy and previous survey maps that were utilized to view, understand and portray the historic landscape. The USF AIST webpage hosts a project page for the Cape Canaveral 3D Documentation Project, and this web URL contains most of the GIS cartographic products utilizing the GPS data collected, as well as an online version of the interactive map (Figure 3). (see: http://aist.usf.edu/projects/capecanaveral.aspx and http://aist.usf.edu/flexviewer2/Cape_Canaveral/).

Additionally, a story mapping project was completed for several of the launch complex features and the documentation project, as part of a student project initiative for the USF Museum Visualization course. In this project, graduate students worked with undergrads to develop online interpretative concepts for Cape Canaveral, using data from our survey. Curriculum and course design involved content about Cape Canaveral, using the project as a means of learning about digital heritage preservation and heritage tourism concepts (Figure 4). The mapping project is archived as part of an initiative by the USF library and AIST, and can be viewed at: http://aist.usf.edu/CCAFS/index.html.

Sectional and CAD Analyses
Sections and orthographic image details from the scan data allowed for CAD, GIS products (especially when combined with LiDAR data and GPS information), and sectional elevation analyses. 3D imaging can be evaluated by sections, and can be compared against as-designed and historic or legacy information (Figure 5). Using the GIS structure, several cartographic products have been created, including site plans and sectional analyses. Data slices and orthoimage point cloud renderings also provide architectural and engineering details and analysis information that can be measured precisely and visualized in a number of ways. Both slices and orthoimages are scaled and contain spatial information that allows for the import into CAD based software, affording highly accurate drawings to be made that portray profiles, elevations, site plans, and other important architectural details (Figure 6). From these slices and data sections, we have provided information for architectural analyses and the production of as-built archival 3D CAD models and detail records. Scan data exports such as tomographic slicing, orthophoto scaled images, and direct CAD import methods are allowing historic documentation records to reflect more accurately, precisely, and representatively the as-built and conditional aspects of landscape and structural features, as compared to more subjective and laborious traditional methods of measurement. When these data are combined with other tools of documentation, including traditional phototography and CAD drawings from these data, a full and complete level of detail are captured, increasing the abilities for assessment, interpretation, and archival preservation.
Figure 3. The interactive map web portal (above), allows users to view 3D, CAD, photos, and terrain information for all areas surveyed. This “living document” can be expanded and added to as more data or survey information is collected.
Figure 4. The Story Mapping of Cape Canaveral involved students learning and using web-based GIS tools along with data and information relating to digital preservation, museum interpretative and heritage tourism concepts. The project overviews the course assignment and efforts, and showcases information in a GIS interactive web site about several of the launch complexes that were surveyed. The site includes present day conditions, historical images and maps, and 3D models and interpretative designs.
Figure 5. TLS survey data from Facility 49800 is compared against legacy as-design drawings. In this manor, 3D software tools are used to evaluate current conditions against previous or historic conditions, or as in this case, design evaluation against reality.
Figure 6. Slices made from the TLS survey data for the Launch Complex 14 Blockhouse. These slices are made at select positions and can reveal elevation and floorplans, structural aspects, plan view and site plan spatial data and configuration and even relate subterranean and above ground features if surveyed.
Survey Locations
Area 55 (BR3031)

TLS survey was conducted at Area 55, with the locale scheduled for demolition following successful completion of our documentation. This area, inclusive of all exteriors of structures and surrounding landscape features, were documented with TLS survey methods. The TLS survey consisted of 39 scans, with 36 ground-based and three from elevated positions (Figure 7).

Figure 7. Area 55 TLS survey positions and data capture. Green locations are ground based positions of laser scanner and red/orange indicates elevated scanner locations.
Area 55 is directly related to the Cold War, and several facilities were associated with military research and development of aids to navigation, radar, and national defense. Area 55 was used to support the launch operations at LC-17. These support operations included operating first as a tracking facility for the Thor missile program and later included the use as a processing area for Delta II components. From the 1950s through the 1970s, Area 55 served as a research and development facility for radar and as a tracking station for the Atlas ICBM and the manned space program beginning with Project Mercury and continuing to the Apollo program (Figure 8). In 1980, Area 55 became a support facility for the Delta II missile program, serving as a shipping, receiving, and equipment cleaning area for Delta II components. The facility continued to be used in this capacity until 2010, when it was abandoned in place (for a complete history, see: Penders 2012b). Figures 9 and 10 shows the building names and locations within the complex, and provides a contextual understanding for the site layout as it was in 2012, as well as relationships with land classification areas. In 2015, Area 55 was demolished in 2015, with the 2014 TLS survey combined with the historical and legacy documentation performed, including the 2012 NRHP eligibility determination report, representing the final documentation archive.

Figure 8. Area 55 (BR3031 Resource Group) historic image from May 1976.
Figure 9. TLS survey area, showing the site as it appeared with 2012 aerial as base map. Building locations and names are shown using the CCAFS GIS building data layer information.
Figure 10. Land Use mapping showing building and natural community and use information.
As part of the TLS survey, all complex building exteriors were documented using methods previously described, including sub-decimeter GPS, GPS photography, standard imaging, along with the TLS survey. Additionally, all features and noted areas of attribute were spatially recorded and imaged, and these data were brought together in a GIS geodatabase inclusive of aerial LiDAR for complete terrain and building area mapping. Specific TLS projects were conducted at BR3018 (aka Facility 1305P-MOD III Radar Antenna Pad); BR3026 (aka Facility 56605 -Rate Antenna Pad); and BR3021 (aka Facility 56608 – Wave Guide Access Structure). Also laser scanned were BR2029 (aka Facility 56632 - the Delta Labs and Lab Annex), and BR3030 (aka Facility 56636 - the Delta 2nd Stage Checkout Building). All of the buildings and facilities were captured in the TLS survey (BR3017-BR3031), with emphasis placed on the aforementioned structures. Figure 11 below, shows a plan view slice through the scan data of all areas captured with the TLS survey. Photographic images as well as laser scanned perspectives of these buildings are also shown in Figures 12-20.

TLS and ALS data combined, also allowed for consideration of the entirety of the location complex. The aerial LiDAR data were used to develop a digital elevation model of the site, and these data were then further processed to reveal more distinctive ground surface features as well as vegetation and natural community relationships. Digital surface modeling and elevation modeling (Figure 21) were combined with targeted areas of 3D modeling to create GIS layouts in 2D and 3D showing the entirety of the complex (Figures 22-24). Specific buildings in Area 55 were further modeled to create more detailed models in 3D. Laser scan data was selected for these structures and exported to examine as sectional slices and modeled further to create 3D CAD renderings for the Administrative Buildings and the Delta Laboratories (Figures 25-32).

Data collected for all buildings and areas documented in the Area 55 area include GPS location information, aerial LiDAR digital surface modeling, TLS data used to make 3D and CAD models, and photographic and GPS photo images for all structures. These data sets and all derived products, such as videos, building sectional analyses and images, and complete geodatabase and GIS information, are shown in examples as figures to the report, but have also been provided on external hard drive data copies to the CCAFS. Online and mapping representation for Area 55 features and spatial details includes geodatabase access through GIS online access, and Google Earth visualization programs.
Figure 12. BR 3018 (Facility 1305P), view to southeast. This building is part of the Area 55 laboratory facility.

Figure 13. BR 3029 (Facility 56632), Delta Labs, view to the NE.
Figure 14. Facility 56638, Delta Lab Annex.

Figure 15. Elevations showing portions of the Area 55 Delta Lab and Annex that were documented in the TLS survey.
Figure 16. Photo showing elevation view to the north (above) and laser scanned image of elevation (below) for BR3030 (Facility 56636), the Delta 2nd Stage Checkout Building.
Figure 17. BR3019 (Facility 56605), Rate Antenna Pad, view to southeast, along with 56618, High Test Leak Facility and the BR3021 (Facility 56608) ramp.

Figure 18. BB3021 (Facility 56608), view to the northwest.
Figure 19. Plan view (above) and elevation from laser scan data showing the Rate Antenna Pad, the High Pressure Leak Test Facility (56618) and the ramp (56608) features that were captured as part of the Area 55 TLS survey.
Figure 20. Elevation photograph (above) showing BR3022 (Facility 56620) to the south, and scaled ortho-images from laser scan data showing elevations from the 3D model results from surveying of the structure.
Figure 21. Digital Elevation Model created from aerial LiDAR data at Area 55 was used to visualize landscape features and to map and consider the built environment in relation to natural land use communities. The LiDAR data depicts more accurately the locations of structures than does the previous mapping delineations such as the georeferenced building data layer map shown.
Figure 22. Digital Surface Model for Area 55, showing height above ground and surface detailed features.
Figure 23. Example of laser scanned modeling locations within the Area 55 complex.
Figure 24. Example of laser scanned modeling locations within the Area 55 complex.
Figure 25. Example of the Area 55 Building 3D Survey Laser Scan Data that was used to create CAD renders in 3D for the Delta Laboratories and Annex Buildings.

Figure 26. Area 55 Administrative Building 3D Survey CAD Rendering showing plan view.
Figure 27. Area 55 Administrative Building 3D Survey CAD Rendering showing elevations.

Figure 28. Area 55 Administrative Building 3D Survey CAD Rendering showing three-dimensional perspectives.
Figure 29. Area 55 Laboratory Building 3D Survey CAD Rendering showing plan view.

Figure 30. Area 55 Laboratory Building 3D Survey CAD Rendering showing elevations.
Figure 31. Area 55 Laboratory Building 3D Survey CAD Rendering showing elevations.

Figure 32. Area 55 Laboratory Building 3D Survey CAD Rendering showing three-dimensional perspectives.
Building 49800 (BR2480)

Listed with the FMSF as BR2480, Building 49800 at CCAFS is a unique structure, with a design developed by the American Machine Company. The company was contracted to develop a launch shelter for the Goose/Bull Goose missile program. This building was actually a prototype launch shelter, and historical research indicates that it is the only existing structure of its kind (Penders 2012a). The building has the look of a Quonset hut, with its riveted corrugated metal panel construction and semicircular cross sectional appearance. The design consisted originally of a divided space, with three “cells” on the interior. These cell areas have three roll up access doors in the rear and originally had a large door on the front side, similar to historic depictions (Figure 33). The front side of the building could open up and the smaller back doors could roll up providing access to the missiles in the cells and also enabling exhaust escape (see: Penders 2012a). This design enabled low cost and rapid assembly techniques that could be mobile, and were intended for easy ground support and concealment. Historic images of Goose missile launches from the structure at CCAFS, show these designed functions of the building (Figure 34). In 1959, Building 49800 was moved from its original location at LC-21/22, when that launch complex was being modified for the Mace missile program (Figure 35). The new location was at the Industrial Area at CCAFS. In 1963, 49800 was modified, with the larger opening replaced with smaller roll-up doors on the building’s south elevation (Penders 2012a). The current conditional assessment listed with the FMSF is deteriorated.

Figure 33. 1958 newspaper article about the building typology.
Figure 34. Goose missile launch at Facility 49800.
Figure 35. Current location of BR2480 (Building 49800) at CCAFS. The building was moved to this locale in 1959.
TLS survey was conducted at Building 49800, inclusive of the facility interior and exterior. Because the building is relocated from its original position, terrain capture was limited to the current building footprint area. The TLS survey consisted of 15 ground based scans. Figure 36 depicts the locations of the scan set up positions and shows the primary range of area captured in the survey.

Figure 36. Laser scan data from the TLS survey, showing area and positions for scanner setup at Building 49800 at CCAFS.
As part of the TLS survey, the entirety of the building interior and exterior was documented using methods previously described, including sub-decimeter GPS, GPS photography, and standard imaging, along with the TLS survey. Additionally, all features and noted areas of attribute were spatially recorded and imaged, and these data were brought together in a GIS geodatabase inclusive of aerial LiDAR for complete terrain and building area mapping. Figure 37 shows a plan view slice through the scan data of the structure.

![Plan view tomographic slice through Building 49800 revealing dimensional aspect and floorplan structural features.](image)

These tomographic slices through the data captured, allow for viewing of structural aspects of the building and provide floorplan and ability to export to CAD for accurate measured drawings with the TLS survey. Laser scanned perspectives of this building are also shown in Figures 38 and 39. Details from the current survey can be easily compared against historic as-designed and as-built measured drawings, with modifications, change detection, and analysis of as-built vs. as-designed aspects considered. Building 49800 for example, had measured drawings from June 1958 available for consideration and comparison (Figure 40 and see Figure 5).

TLS and ALS data combined, allowed for consideration of the entirety of the location and position in the developed GIS geodatabase. This geodatabase contains 2D and 3D information and positional and attribute details, allowing for effective management and spatial location details to be maintained. The aerial LiDAR data were used to develop digital surface modeling (Figure 41) and were combined with targeted areas of 3D modeling to create GIS layouts in 2D and 3D showing the entirety of the complex. Data collected for Building 49800 include GPS location information, aerial LiDAR to produce digital surface modeling, TLS data used to make 3D and CAD models (Figures 42-46), and photographic and GPS photo images for all structures. These data sets and all derived products, such as videos, building sectional analyses and images, and complete geodatabase and GIS information, are shown in examples as figures to the report, but have also been provided on external hard drive data copies to the CCAFS. Online and mapping representation for Building 49800 includes geodatabase access through GIS online, and Google Earth visualization programs.
Figure 38. 1958 cross-section drawing (above) compared with laser scan point cloud details from survey (center and below), with differences found in the designed doors and the as-built and current condition.
Figure 39. Plan view and elevation data and sectional details of Building 49800 derived from the laser scan data.
Figure 40. Scaled and measureable depictions revealing sectional components of Building 49800 are able to be analyzed and visualized using the TLS data, and compared to 1958 measured drawings (above). These laser scan data are accurate to +/-2mm, and are used to create the most precise measured drawings and feature analyses currently possible.
Figure 41. Digital Surface Model (DSM) for the Industrial Park area at CCAFS shows the Building 49800 footprint and geolocation along with surrounding terrain and building features. Inset images show the 3D models from different elevation perspectives.
Figure 42. Examples of the 3D CAD and 3D modeling process using TLS data from our survey.
Figure 43. 3D models from the TLS data are used for depiction of the structure’s elevation details, and are used in GIS and other interpretative visualization and for analytic applications.
Figure 44. Site map in the plan view showing the roof and footprint of the structure derived from TLS survey.

Figure 45. 3D CAD side elevation views of Building 49800.
Figure 46. 3D CAD perspectives of Building 49800.
Launch Complex 1 & 2 (Resource Group BR2248)

The terrestrial laser scanning survey was conducted at Launch Complex 1 & 2, inclusive of exteriors of structures and surrounding landscape features and terrain that were documented with TLS methods previously discussed. The TLS at this Launch Complex consisted of 11 scans total, three of which were elevated and eight of which were ground-based scan positions. Scan areas include the BR2249 (Blockhouse 1&2/Blockhouse 4140), BR2252 (Launch Complex 1 & 2 Transformer Building, Facility 4120), and BR2250 and BR2251 (Launch Pads 1 and 2 areas) (Figure 47). Additionally, TLS and LiDAR data were processed to delineate the nearby BR2253 (Snark Pad for LC 23/24) location. These areas are all contributing resources to the Launch Complex 1 & 2 Resource Group as recorded with the FMSF (Penders 2008a).

Figure 47. Survey scan positions recorded in the vicinity of BR2249 (Blockhouse 1&2, Facility 4140) and BR2252 (LC 1&2 Transformer Building, Facility 4120) at Cape Canaveral.

In mid-1950, work began to construct the first permanent access road and launch sites on Cape Canaveral Air Force Station. The first area developed for launch operations became known as Launch Pads 1, 2, 3 and 4. Blockhouse 1&2 was constructed in the early 1950s (between 1951 and 1953) for use with the Snark winged missile program. The blockhouse had four-inch thick tempered laminated glass, and the image was received through the glass and reflected downward and inward to observers using a pair of mirrors and another tempered glass window. An observation deck was constructed above the blockhouse. The Air Force's Snark missile was a surface-to-surface pilotless bomber with a range of over 5,000 miles. It was the first and only long-range intercontinental winged missile. Ninety-seven downrange flights were launched from Complexes 1 and 2 between August 29, 1951 and December 5, 1960 (Air Force Space and Missile Museum 2015; Hinder 2003a) (Figure 48).

Launch Complex 1 and 2 at CCAFS played an important role in the missile research and development program, which provided the United States with an operational conventional and nuclear missile force for defense in the arms race (Hinder 2003a). The site was utilized throughout the 1950s through 1961 for the Snark and Matador winged cruise missile programs. Technologically advanced in its era, the complex was later modified to function as a heliport facility that supported Mercury manned launches, and subsequently played a role as part of a Tethered Aerostat Radar System (Hinder 2003a). The site today is abandoned, and lies in close proximity to Launch Complex 3 & 4 and the Bomarc launching building area (Figures 49 and 50).
Figure 48. 1952 images showing the construction of the Launch Complex 1 & 2 Blockhouse at Cape Canaveral. Photos Courtesy 45th Space Wing History Office, Patrick Air Force Base.
Figure 49. 2014 image of BR2249 (Launch Complex 1 & 2 Blockhouse).
Figure 50. Aerial view of the facilities at FMSF Resource Group BR2248 (Launch Complex 1 & 2), and showing the proximity to the LC 3 & 4 buildings and pads. Building names on map originate from the CCAFS GIS building data layer.
Several surveys to determine eligibility for National Historic Landmark status have been conducted at Launch Complexes 1 & 2, with conflicting results. At least one survey found the site to be eligible (1984), while two others indicated that the site was not eligible for the status listing, including a survey conducted by the National Park Service in the 1990s. Additionally, a Historic American Engineering Record (HAER) survey was conducted at the locales in 2003. In 2008, the 45th Space Wing Environmental Planning and Conservation Office, submitted all materials and their concurrence with significance and eligibility status for Launch Complex 1 & 2, to the State Historic Preservation Office (SHPO). In this 2008 memorandum, it is noted that the site was associated with Werner Von Braun and the last two Bumper-WAC missiles ever flown. These missiles represented the first and second launches from Cape Canaveral’s fledgling missile testing grounds. A marriage of the German V-2 ballistic missile and the U.S. Army WAC Corporal Research rocket, the Bumper-WAC was designed, and can be trace it’s lineage to the creation of the WAC Corporal, the first sounding rocket developed in the United States in 1944 (Sutherland 2008). For these reasons, as well as the history relational to the early winged missile programs and the missile research and development program that provided the United States with an operational nuclear missile force for defense in the arms race, the site is of historic value and is eligible to the National Register of Historic Places (Hinder 2003a; Sutherland 2008).

As part of the TLS survey, all complex building exteriors were documented using methods previously described, including sub-decimeter GPS, GPS photography, standard imaging, along with the TLS survey. Additionally, all features and noted areas of attribute were spatially recorded and imaged, and these data were brought together in a GIS geodatabase inclusive of aerial LiDAR for complete terrain and building area mapping. Specific TLS projects were conducted to capture the Blockhouse 1 & 2 and pads 1 & 2 area. Data from the TLS survey were brought together with aerial LiDAR to reveal the entirety of the complex terrain and structural details (Figure 51). These data are far more accurate than previous methods used in mapping and measured drawings, as noted when viewing the georeferenced HAER map in relation to the LiDAR data (Figure 52). Penders (2008a) survey of the area notes a previously unrecorded site (8 BR 2253) consisting of a concrete pad that was possibly relational to Launch Pad 23/24, that may have served as a functioning Snark launch area. This pad is more fully seen in the present LiDAR survey of the area, and can be fully delineated and viewed (Figure 53).

The aerial and terrestrial LiDAR data were used to develop a digital elevation model of the site (Figure 54), and these data were then further processed to reveal more distinctive ground surface features as well as vegetation and natural community relationships. The Blockhouse at LC 1 & 2 and associated structures were further modeled in 3D utilizing the TLS data. Laser scan data was selected for these structures and exported to examine as sectional slices and ortho-photo, measurable elevations (Figure 55). These scan data were then modeled further to create 3D CAD renderings (Figures 56-58).

Data collected for all buildings and areas documented at the Launch Complex 1 & 2 area include GPS location information, aerial LiDAR digital surface modeling, TLS data used to make 3D and CAD models, and photographic and GPS photo images for all structures and features. These data sets and all derived products, such as videos, building sectional analyses and images, and complete geodatabase and GIS information, are shown in examples here, but have also been provided on external hard drive data copies to the CCAFS. Online and mapping representation for structures and features, as well as spatial details including geodatabase access through GIS online, and Google Earth visualization programs have been created from our survey data.
Figure 51. Aerial LiDAR combined with ground based laser scanning was used to produce a Digital Surface Model (DSM) for the area of Launch Complex 1-4, inclusive of buildings, pads, terrain features, and natural systems.
Figure 52. HAER overview map georeferenced to the LiDAR DSM map showing spatial inaccuracies and the ability to see features previously not well-delineated.
Figure 53. Aerial LiDAR and TLS survey data used to create a digital surface model (DSM) of area near Blockhouse 1 & 2, reveals the rectangular delineation of the recorded 8BR2253 location, thought to be Launch Pad 23/24 and associated with historic Snark missile launches.
Figure 54. DSM view of the TLS and Aerial LiDAR data showing models derived from the laser scanning survey in relation to their elevation position shown. BR2249 and BR2252 were captured with higher resolution, with the BR2250 and BR2251 Launch Pads also captured as terrain models.
Figure 55. Point cloud data is shown from the TLS Survey of BR2249 Launch Complex 1 & 2, allowing for sectional and plan view details of the blockhouse and associated structures and features to be considered as CAD measured drawings and 3D renderings.
Figure 56. 3D CAD model creation using laser scanning data from the TLS survey, showing structural details captured at the BR2249 Blockhouse 1 & 2 facility.
Figure 57. Plan view (above) and side view (below) measured drawings in 3D CAD were produced for the Launch Complex 1 & 2 blockhouse.
Figure 58. Side view and perspective view 3D CAD renderings were derived from the TLS survey data information collected at Launch Complex 1 & 2 blockhouse area.
Launch Complex 3 & 4 (Historical District BR2234)

Launch Complex 3 and 4 consists of a total of nine cultural resource contributing elements to the Historic District. These are BR2235-BR42, and BR2259 (Penders 2008b). These sites consist of two concrete rectangular launch pads with one Blockhouse. There are also several buildings of importance with historic storage and launch functions. These structures include BR2240 (the Radar Maintenance Building aka Bomarc Launching Building, Facility No. 2841); associated structures including BR2241 (the POL Building/Compressor and Cooling Building); BR2239 (the Small Engine Repair Building, Facility 2805); BR2242 (High Pressure Air)(Figure 59). Laser scanning in this complex included all of the aforementioned areas and associated structures and pads. Terrain and other landscape features are also captured through the combination of aerial and terrestrial LiDAR for the site, inclusive of the tethered balloon facility and ground support station area for the “Fat Albert” tethered balloon system dating to 1971 and ineligible for NRHP inclusion. Additional features of interest, including a revetment, a suspected location for an original blockhouse, and a relocated launch pad were also documented using the methods previously discussed, including TLS, GPS, GPS photographs, standard photography, and aerial LiDAR.

Four previous studies were done on Launch Complex 3 & 4. These include a 1990s National Historic Landmark (NHL) study conducted by the National Park Service (NPS) which determined the launch complex was ineligible for listing on the National Register; a 1984 study by Resource Analysts, Inc. which found the site to be eligible for the NRHP; a 1993 study by US Army Corp of Engineers Construction Engineering Research Laboratories (USACOE-CERL) which found the complex was ineligible for the NRHP; and a 2003 Historic American Engineering Record (HAER) study (Sutherland 2008). Additionally, the area was demonstrated as a Historic District and listed with the FMSF as such (Penders 2008b).

Launch Complex 3 & 4 was the site of some of the first US missile launches. The 2003 HAER centered on the later configuration of the facility. It should be noted this site was associated with Werner Von Braun and the last two Bumper-Wac missiles ever flown. These missiles represented the first and second launches from Cape Canaveral's fledgling missile testing grounds. The Bumper-Wac design can be traced back to the creation of the Wac Corporal in 1944. It was a combining of the German V-2 ballistic missile and the U.S. Army Wac Corporal Research rocket (Sutherland 2008). The Launch Complex at 3 & 4 saw 125 missile launches between 1950 and 1960, and played an important vital role in the missile research and development program. Launches between 1950 and 1953 included the Bumper, Matador, Bomarc, Lark, X-17, Polaris FTV, and Redstone missile programs. Although simple compared to subsequent launch complexes, Launch Complex 3 and 4 was actually technologically advanced at the time of its construction, including underground tunnel systems connecting launch pads to the blockhouse that held hydraulic control lines, carbon dioxide (CO₂) lines, potable and firefighting water lines, a sprinkler system, and transformer and CO₂ storage rooms. The facilities at Launch Complex 3 and 4 were later modified for use as medical support for the Mercury Project and use as the Tethered Aerostat Radar System (Hinder 2003a).

Blockhouse 3 & 4 (BR2236, Facility 4100)

The TLS survey of the Blockhouse 3 & 4 vicinity consisted of 11 total scan positions, nine of which were ground-based and two which were taken at raised elevations (Figure 60). The survey focus was on Blockhouse 3 & 4, with aerial LiDAR, GPS and aerial imagery also processed to visualize terrain and related features, including the full terrain and pad areas. TLS survey was also conducted at the Bomarc building and here, related structures, pads, and features were also captured with the ground-based laser scanning as well as were processed with the aerial LiDAR data. GPS photos were taken at all feature locales, and ground GPS
Figure 59. Digital Surface Model derived from aerial and terrestrial LiDAR data and shown in relation to previous HAER sketch mapping of structures in the LC 3&4 area. Noted differences can be seen in building scale and location in previous survey.
Figure 6o. TLS survey setup locations at Blockhouse 3 & 4 vicinity. Circular areas indicate scanner setup locations, with the full area shown above.
verification of processed LiDAR data was also performed. Aerial LiDAR was processed to reveal slight terrain variation and features (Figure 61). At the Bomarc facility area (includes Bomarc, Pol building, Storage Building, Pad 3, Pad 4, High Pressure Air Building and Facility), a total of 36 scans, 30 ground-based and six from elevated positions, were taken (Figure 62).

The Blockhouse at Launch Complex 3 & 4 (BR2236) is in close proximity to the pads used for missile launches. The building, constructed in 1951, was made from reinforced concrete, and has a domed reinforced concrete roof, that is partially inset in the ground on a concrete foundation (Figure 63). In 1961, the complex was modified and reassigned to serve the Mercury program as part of a medical station area. The building is today vacant, and has been in this state since around 1967 (Hinder 2003a) (Figure 64).

Three dimensional data, captured in the TLS survey of the Launch Complex 3 & 4 area, shows all of the extant exterior features of the blockhouse. Entry into the structure was not permitted as part of this project. Our current 3D survey data allows as-built elevation conditions existing today to be compared with as-designed elevation drawings of the structure made in 1958 (Figures 65 and 66). The TLS survey data incorporates information from the surrounding terrain and berm areas that are integral to the structure. Additionally, the 3D data can be viewed in plan view, with removal of the roof and dome feature to reveal interior footprint configuration of the structure (Figures 67 and 68). These types of visualizations are not possible using conventional survey techniques.

![Figure 61. Hillshade of the DSM showing terrestrial and aerial LiDAR terrain for the Launch Complex 3 & 4 area. The hillshade allows for computerized illumination of the surface value calculations to better visualize terrain features. The model is shown with previously mapped areas and building identifiers. Note that the new 3D terrain data provides much more specific and accurate area delineations, including pads, roads, and structural details.](image-url)
Figure 62. TLS survey locations in BR2240, the Bomarc building area, showing ground-based positions in blue and raised positions in green and red (highest elevations).

Figure 63. 1951 historic image of Blockhouse at Launch Complex 3 & 4.
Figure 64. Blockhouse at Launch Complex 3 & 4, southeast views (2005 and 2014).
Figure 65. Side views and elevation of BR2236 Blockhouse 3 & 4 as seen from point cloud ortho-images (colorized and without color shown) from the TLS survey.
Figure 66. 1958 elevation drawings from Blockhouse 3 & 4 allow for analysis and comparison to as-built and current conditions.
Figure 67. Point cloud plan view image showing laser scanning data from BR2366, Blockhouse 3 & 4 structure, revealing the building footprint in its entirety.
Figure 68. Point cloud tomographic slice at ground level showing the footprint of BR2236, Blockhouse 3 & 4 as surveyed with TLS. These slices are all measurable and able to be brought into CAD software for use in creation of measured drawings.

Utilizing the 3D data acquired from the TLS survey, the blockhouse at Launch Complex 3 & 4 was modeled to show the structure's extant exterior features. These models of the structure are utilized in the 3D GIS to show the structure in relation to the overall landscape as visualized with aerial LiDAR digital surface modeling (Figure 69). 3D CAD modeling, showing plan view, side elevations and perspective views were also made for the structure (Figures 70-73). These CAD models are useful for dimensional and as-built design understanding.

Noted Features Viewed from LiDAR Data

Several features of note were recorded both on the ground and remotely using aerial LiDAR and imagery data in a GIS. One such feature is a three-sided, rectangular-shaped area relational to a noted depression location as seen in ground verification. This area is associated with a meta-revetment that is located near Launch Pad 4 and across from the Bomarc building (Figures 74 and 75). Revetments were utilized as an early means of blast protection from launches, and today attest to some of the early unsophisticated approaches to technology at the CCAFS. The aerial LiDAR remote sensing allows for examination of the size and extent of the feature and consideration of its location and relationships with nearby launch remains.

Another feature of note is an area of successional vegetation disturbance and ground elevation difference nearby and to the east of the blockhouse at Launch Complex 3 & 4, and NW of launch pad 3. This general area is known to have had an earlier blockhouse that was more temporarily constructed for use with Bumper missile launches (Penders personal communication May 2015). Historical images of this site show it to be a tent facility with a sandbag revetment reinforcement (Figure 76). LiDAR data reveals a probable locale that matches the historical details, including size and shape likely for the feature as noted in historic images (Figures 77 and 78). Further ground verification and subsurface testing using the LiDAR targets would be needed to more precisely locate any structural remains (Figure 79).
Figure 69. Digital Surface Model of the Launch Complex 3 & 4 area, with inset showing the 3D modeling of the Blockhouse at 3 & 4 that is derived from the TLS survey information.
Figure 70. Plan view of Launch Complex 3 & 4 blockhouse in 3D CAD model.

Figure 71. Side view elevation in 3D CAD of the blockhouse at Launch Complex 3 & 4.
Figure 72. Side and perspective views in 3D CAD of the blockhouse at Launch Complex 3&4.
Figure 73. Additional 3D CAD perspective views of the blockhouse at Launch Complex 3&4.

Figure 74. Image showing the depression feature that is an earthen revetment location near Launch Complex 3 & 4. These revetments were often used as early measures for blast protection from launch locations at CCAFS.
Figure 75. Location of revetment as seen from DSM of LiDAR data. Site is across from the Bomarc building location and in vicinity of Launch Pad 4.
Figure 76. Historic image showing the original blockhouse at Launch Complex 3 & 4. The tent feature was found within a sandbagged reinforced feature and was to the NW of what is today Launch Pad 3 at the facility.
Figure 77. Historic image showing present day location of Blockhouse 3 & 4 with berm and roof of original Bumper blockhouse location seen to the northwest of the present location.

Figure 78. Historic image showing plan view layout of Bumper blockhouse location in relation to launch pad.
Figure 79. Aerial and terrestrial LiDAR data, used to create a DSM for the Launch Complex site at 3 & 4, shows indication of a signature that is a possible location for the historic blockhouse location (shown in red rectangle). This locale shows vegetation successional changes indicative of ground disturbance from structural remains, and is of the general size and dimension as the known historical reference information.

Bomarc Building (BR2240, Facility 2841)

The Air Force first launched the Bomarc missile from Complex 4 on September 10, 1952. The defensive winged missile was designed to intercept and destroy enemy aircraft. The following year, the Army began testing the Redstone at Cape Canaveral in 1953, the first launch occurring on August 20 at Complex 4. This was the first ballistic missile launch at Cape Canaveral. The building was uniquely constructed to launch the Bomarc missile with a roof that could split right and left down the middle, allowing the missile to be raised prior to a quick launch (Figure 80). The building was used for Bomarc launches into 1959, but because the facility was too expensive to replicate as a means of launching Bomarc missiles, the building was altered by the National Aeronautics and Space Administration (NASA) and served as the Delta Spin Balance Facility for the Delta program, and would become the Delta Storage facility after 1967. The building was transferred back to the Air Force in 1976, and was utilized again in the Tethered Aerostat Radar System program from 1983 through 1989 (Figure 81). Following the end of that program, the building was used for the rocket restoration project of the Air Force Space and Missile Museum (Hinder 2003a). Remnants of rocket parts and control panels continue to be stored at the facility today (Figure 82).
Figure 80. Bomarc B launch, showing the separation in the building roof design to accommodate the takeoff.

Figure 81. BR2240, the Bomarc Building, view to NE.
Utilizing the 3D data acquired from the TLS survey in combination with aerial LiDAR, the Bomarc Building, related structures and pads can be visualized (Figure 83). Models in CAD and 3D were created for the Bomarc building, and 3D plan view and building slices and images were produced for these structures (Figures 84 – 86). The Bomarc Building was scanned on the interior and exterior, while the related structures were documented on the exterior inclusive of terrain features. Figures 85 and 86 show a slice through these structural footprints and shows an elevation slice detail for the Bomarc structure. The building was modeled in 3D CAD to show the structure’s extant features. 3D CAD modeling, showing plan view, side elevations and perspective views were also made for the structure. These CAD models are useful for dimensional and as-built design understanding (Figures 87-92).
Figure 83. Digital Surface Model derived from aerial and terrestrial LiDAR, showing the Blockhouse at 3&4, the Bomarc building, and the relational Storage and Pol buildings and pad areas and structures. Insets show the Bomarc building 3D models in perspective.
Figure 84. Terrestrial laser scan data displayed as ortho-images showing elevation details from BR2240, the Bomarc building.
Figure 85. Plan view section slice of TLS data, showing structural footprints of features captured in the TLS survey of the Bomarc building area (shown from right to left are BR2240 - the Bomarc Building, BR2241 - the POL Building/Compressor and Cooling Building, BR2239 - the Small Engine Repair Building, and BR2242 - the High Pressure Air Facility).
Figure 86. Tomographic slice through the point cloud data from the TLS survey showing south elevation of BR2240, the Bomarc Building.
Figure 87. TLS data is utilized to derive 3D CAD renderings of the Bomarc building and nearby related features.
Figure 88. Plan view of the Bomarc building area shown in 3D CAD modeling.

Figure 89. Side view elevations of BR2240 the Bomarc building and BR2241, as a 3D CAD model.
Figure 90. Side view elevations of the Bomarc building and the Compressor and Cooling Building, shown as 3D CAD model.

Figure 91. Perspective view of the Bomarc building as seen in the 3D CAD model.
Figure 92. Additional perspective view 3D CAD models of the Bomarc building area.
Launch Complex 9 & 10

Constructed between 1953 and 1957, Launch Complex 9 and 10 at Cape Canaveral Air Force Station was designed to support the Air Force's Navaho winged intercontinental missile program (Figures 93 and 94). Although the Navaho program was cancelled soon after completion of the complex, test flights continued until November 1958. The complex was deactivated in 1959, but with its close proximity to Launch Complex 31 and 32, most of the facilities were reused for the Minuteman missile program (Hinder 2003b).

Launch Complex 9 and 10 were the subject of two previous studies. In 1993 the US Army Corp of Engineers conducted a survey and in 2003 a HABS/HAER investigation was undertaken. The conclusions of these studies, as well as that of the CCAFS 45th Space Wing recommendation, was that the complex area as a whole was not eligible for listing on the NRHP, but that two structures within the complex area are of significance and are NRHP eligible (Sutherland 2007), and one is likely eligible based on style of construction and engineering. Of noted importance within the complex are the launch platform (BR2183, Facility 17780W) and the Navaho Blockhouse 9 & 10 (BR2185, Facility 17767). The blockhouse represents the evolution of launch vehicle facility construction, and was used in the Navaho missile program.

The TLS survey at LC 9 & 10 included concentration on the eligible and potentially NRHP eligible structures, as well as overall documentation of the terrain features utilizing the TLS and aerial LiDAR in a GIS. Structures BR2183 (17780W- the LC 9 Launch Platform) and BR2185 (17767- the Navaho Blockhouse/aka/Blockhouse 9 & 10) were fully documented using 3D laser scanning methods as well as GPS, GPS imaging and standard photography techniques. These models were brought together with digital surface models derived from airborne LiDAR data, to provide a more holistic presentation of the built environment (Figures 95-97).

Launch Complex 9, (BR2183, Facility 17780W)

Centered on the Pad, is a two-story, reinforced concrete pedestal that had a fold-away erector gantry that was used to launch the missile. The gantry, known as the "Taj Mahal" by the engineers, would raise the missile to the pedestal's top deck in preparation for a launch and provided access to the missile when in place (Figure 98). The site was abandoned in place after 1971, and its unique, one-of-a-kind architecture is representative of Cold War missile technology at CCAFS (Hinder 2003b). Today, the site appears much as it did in historic images, except for the folding erector gantry (Figures 99-101).

The TLS survey at BR2183 Facility 17780W included a total of 20 scan location positions, eight of which were elevated and 12 that were ground-based (Figures 102). From these positions, the entirety of the structure was documented along with related terrain and launch pad features. These scan data, once registered and processed as a point cloud, are used to visualize structural details in elevation, plan view, and slices showing structural detail (Figures 103 and 104). These data are additionally used in the development of 3D and 3D CAD models (Figures 105 and 106).
Figure 93. Aerial image showing the Launch Complex 9 & 10 location and proximity to the LC 31 & 32 area.
Figure 94. Land Use map for the area, showing building footprints and name designations.
Figure 95. Digital Surface Model derived from aerial LiDAR data, shows terrain and landscape features at the LC 9/10 area.
Figure 96. Aerial LiDAR DSM used to show landscape relation to the 3D models produced for the LC9 Launch Platform (BR2183).
Figure 97. Aerial LiDAR DSM used to show landscape relation to the 3D models produced for BR2185, the LC 9 & 10 Blockhouse.
Figure 98. 1957 image of a Navaho XSM-64 on the launch stand (facility 17780W) and showing the folding gantry.

Figure 99. June 1957 launch of a Navaho XSM-64 missile from the BR2183 Facility (17780W) at Launch Complex 9. Pre-launch shelter in background.
Figure 100. Launch Platform at Complex 9, BR2183 (Facility 17780W), NE view.

Figure 101. North elevation of BR2183 Facility 17780W at LC 9.
Figure 102. Point cloud map showing laser scanning survey positions. Blue indicates ground-based, with green positions intermediary and red positions more elevated. The entirety of the 17780W structure, pad and terrain were captured using these methods.
Figure 103. Ortho-images showing slices made to laser scan data from Facility 17780W at LC 9 to reveal elevation and plan view perspectives.
Figure 104. Ortho images showing the point cloud as a measureable elevation and ortho slice model for Facility 17780W.
Figure 105. Utilizing the TLS survey data for development of 3D CAD model for Facility 17780W.
Figure 106. 3D CAD modeling from TLS data for BR2183, Facility 17780W.
Blockhouse 9/10 (BR2185, Facility 17766, aka the Navaho Blockhouse)

BR2185, the Blockhouse at Launch Complex 9 & 10 (Facility 17766) was used to support Navaho, Jason, and Alpha Draco missile launches. The building is a one-story construction that is partially in the ground on a 6” concrete slab foundation set on sand fill that is lined with a waterproof membrane (Hinder 2003b). The building is made from reinforced concrete and has a concrete barrel-shaped roof. The facility was utilized as a launch control center. Following an explosion of the pad pedestal during the third launch from the facility in 1957, renovations that centered on reinforcing the structure occurred. The southwest and southeast walls were reinforced, and a retaining wall extension to the roofline was built around the southeast wall. Additionally, a mounded earth insulating wall was added and covered with shotcrete cast in place concrete (Figure 107). Today, there are evidenced batten impressions left in the revetment wall feature at the site (Figures 108 and 109). Extra vision ports were installed on the southeast wall to provide a view of Launch Pad 10, and additional mirrors were added above to provide increased visibility overall (Hinder 2003b). The site today is abandoned, with noted issues including invasive exotic plant and vegetation intrusion from subsequent years (and with ongoing need for maintenance) that has impacted structural fabrics and mortars. Cracking and crazing of fabric areas are in particular, noted on the revetment wall feature that has suffered from vegetation concerns in previous years (Figure 110).

Figure 107. 1959 historic image of Blockhouse 9/10 at (Facility 17766 – The Navaho Blockhouse) LC 9 & 10. An earthen berm is shown here in front of the revetment structure during the McDonnell “Draco” guided missile testing.
Figure 108. Current (2013) view to the north of BR2185 LC 9 & 10 Blockhouse showing concrete revetment and mirrors.

Figure 109. Current (2013) view of the site. Examination of the revetment surface reveals batten impressions.

Figure 110. Photograph of BR2185 Facility 17766 taken in 2007, showing vegetation intrusion on fabric of revetment wall and growth occurring inside and Brazilian Pepper and other plants and grasses on the roof of the structure.
TLS survey for BR2185, the Navaho Blockhouse 9 & 10 (Facility 17766), included nine scan locations with three positions elevated and six ground-based scan positions (Figure 111). The entirety of the extant building and revetment wall from the exterior were surveyed. GPS, GPS images and standard photography was also utilized to record structure details. Point cloud registration and colorized laser scan models were created from data gathered in the field, allowing for viewing of the locale from plan view, elevation, tomographic slices and other perspectives (Figures 112-114). These 3D laser scan data were utilized to create 3D CAD models of the structure (Figures 115-117). Additionally, video flythrough animations, GPS and online GIS applications, Google Earth models, and interactive maps and 3D PDFs of the CAD models were also provided as part of the deliverables for the overall project. These point cloud data are accurate to the as-built current conditions +/- 2mm, and provide a contextual reference for the landscape setting for the site that can be visualized, shared, and examined into the future.

Figure 111. TLS survey map showing positions of the laser scanning setup locations at BR2185. The green positions are ground-based, while the orange and red are more elevated instrument locations.
Figure 112. Colorized point cloud views of BR2185, Blockhouse 9/10 (Facility 17766), showing plan view and elevation perspectives. These ortho-images are utilized in CAD and retain their spatial correctness and scale.
Figure 113. Slice sections showing BR2185, Facility 17766 in a plan view perspective (above) and through the center of the point cloud to reveal the building elevation (below).
Figure 114. 3D point cloud data with color texture showing the wall elevation on BR2185, Facility 17766. Batten markings, fabric details and cracking of surface and exfoliated areas are all evidenced in these measurable views.
Figure 115. Plan view of Launch Complex 9 & 10 Blockhouse (Facility 1776).

Figure 116. Elevation side views of Facility 1776.
Figure 117. Perspective views of the blockhouse at Launch Complex 9 & 10, Facility 17766.
Launched Complex 14 (BR2209, FMSF Historical District and National Historical Landmark)

Declared a National Historic Landmark in 1984, Launch Complex 14 is the location of the famous efforts to send a man into space with the manned Atlas Mercury missions. These operations included the Friendship 7 Mission, with John Glenn becoming the first American person to successfully complete a manned orbital flight, circling the earth three times on February 20, 1962. Other famous missions included Scott Carpenter, Walter Schirra, and Gordon Cooper’s orbital flights (Figure 118).

![Figure 118. Memorial (BR2221) and commemorative signage area at Launch Complex 14.](image)

Launch Complex 14 was built between 1956 and 1957, and was designed to support the Atlas missile program, the United States’ first operational ICBM missile. There were modifications made to the complex between 1959 and 1960 for the Mercury missions. Following the Mercury manned orbital flights, the complex was again altered to accommodate the Atlas-Agena program and the unmanned Gemini Target Vehicle program, with astronauts using the facility to practice docking sequences used in the Gemini program lunar landing efforts, and unmanned launches for this effort. The facility was abandoned in place in 1973, after being deactivated in 1967 (Hinder 2003c).

The complex consists of a ramp and launch stand and a blockhouse control facility. Storage areas, blast walls and a flume and skimming station are also located within the complex (Figure 119). These areas are clearly delineated using aerial LiDAR to examine elevation and surface details (Figure 120). Public and memorial interpretive areas are featured, including several plaques, kiosks and a Friendship 7 monument (Figure 121). The monument (BR2221) is made from stainless steel and is the astronomical symbol for the planet Mercury and contains the number “7” for the seven astronauts. The memorial also contains a time capsule that is to be opened in the year 2464 (Penders 2008c). The TLS survey at Launch Complex 14 involved targeting several areas of interest for laser scanning survey efforts. These areas included memorials, blast walls, ramp, flume, blockhouse and the pad and launch stand areas. The complex was also documented utilizing GPS for spatial control as well as GPS imagery and standard photography. The terrestrial LiDAR data were merged with aerial LiDAR to provide a holistic 3D interpretation of the entirety of the complex terrain (Figure 122). Comparison of data to previous mapping at the site shows detail and accuracy improvements, and areas of more defined documentation (Figure 123).
Figure 119. Aerial image showing configuration of structures and features at the Launch Complex 14 area.
Figure 120. Aerial LiDAR, processed to examine elevation differences, shows feature areas and is useful for defining structures, canals and other important system functions at the site.
Figure 121. Examples of memorials at the Launch Complex 14 area include a dedication on the ramp portion of the site (left) and several commemorative markers near the Friendship 7 Memorial. Gus Grissom and Wally Schirra (Bottom left) are pictured at the Mercury Monument in 1964, and President Kennedy with John Glenn (bottom), visiting the complex in 1962. This Presidential visit was one of several times Kennedy came to the Cape. Kennedy’s priority set for the nation was to send a man to the moon.
Figure 122. Digital Surface Modeling (DSM) for Launch Complex 14 allows for an accurate depiction and 3D understanding of built environment as well as natural systems features such as water bodies and vegetation differences.
Figure 123. Georeferenced HAER survey map from earlier documentation shows the accuracy and improvements of mapping utilizing the aerial and terrestrial LiDAR. Natural vegetation data and features are clearly distinguishable, as are area and spatial delineation for features and structures. Many of the structural footprints shown in black that were previously documented are located incorrectly.

Blockhouse at Launch Complex 14 (BR2216, Facility 10905)

One area that was targeted for higher resolution terrestrial survey in the Launch Complex 14 location was the Blockhouse 14 structure and surrounding environs. A total of 38 scans were taken at the blockhouse structure, with ground-based, interior below grade, and elevated scans acquired from both the interior and exterior portions of the facility (five elevated positions and six below grade interior scans were taken and combined with various scan positions from in and around the structure) (Figure 124). These data can be viewed in 3D, or in 2D tour mode, allowing viewers to virtually visit the area documented (see: http://youtu.be/WZa4QbgGXBI) (Figure 125). Sectional analyses of scan data (Figures 126-128) are also useful in comparing to the as-built drawings made of the structure by Maurice H. Connell & Associates, Inc. in 1963, and Pan American World Airways, Inc. in 1964, at the close of the Mercury Program (Figure 129). All laser scan data were processed as colorized point clouds that provide measurable detail to +/- 2mm for the whole of the structure area, and allow elevation renders, sectional analyses and 3D CAD depictions to be created for the facility (Figures 130-133).
Figure 124. Plan view map of scanner positions from the TLS survey. Data was captured from interior and exterior and includes below surface interior features of the Blockhouse structure.

Figure 125. The TLS survey data can be viewed in a tour mode platform (Webshare®), allowing visualization from one scan area of a structure to the next. Shown is the interior of Blockhouse 14 with the inset image enabled to click to the next view that is shown.
Figure 126. Elevations of Blockhouse 14, derived from the TLS survey data. Note that the lower image shows the structure with “see-through” viewing enabled. In this way, interior features recorded are able to be shown with the exterior of the building in sectional analysis. Areas including the dome, escape tunnel and hatch, air intake and exhaust enclosures and blast door are all documented, as are the control room, ready room and nearby communications and cable building locale.
Figure 127. Elevation perspectives of the Blockhouse 14 are shown with cut away portions to reveal interior features and examine building design aspects.
Figure 128. Examples of plan view and sectional elevation analysis from point cloud TLS data at Blockhouse 14.
Figure 129. 1964 as-built drawings show sectional and elevation details that can be used to compare and contrast against the recorded TLS survey data. These drawings provide important detail about configuration and condition in the historical lineage of the building. These drawings were made from measurements and field assessment, with scale and attribute information recorded. In the second phase of this project, we will use these historical drawings in a forensic study of the building morphology and condition.
Figure 130. Examples of 3D CAD model development for the Blockhouse at Launch Complex 14.
Figure 131. Plan view 3D CAD Model for Blockhouse 14 at CCAFS.

Figure 132. Side view elevation 3D CAD models of Blockhouse 14.
LC 14 LOX Storage Area and Blast Wall (BR2214)

The Liquid Oxygen (LOX) Storage area and Blast Wall feature at LC14 is found to the west of the ramp and launch stand. This fuel storage area consisted of a LOX tank, a LOX Sub-cooler, and storage for gaseous nitrogen (GN2) bottles/tanks. The storage area was situated on a concrete slab foundation. A reinforced concrete blast wall with earthen fill on the east side, borders the fuel storage area, and acted as a separation between the storage area and the nearby Launch Stand and Ramp area (Hinder 2003c). A total of eight terrestrial scans were taken in and around this area of the complex, with the entirety of the wall and slab area documented (Figure 134). These data were also merged with aerial LiDAR to provide a more detailed terrain understanding, and are also useful in the documentation and contextual analysis for the overall structure. The berm as well as storage and slab areas were documented using TLS methods (Figure 135). GPS point and line feature data collection and GPS images as well as standard photography were also used to document this locale.
**Figure 134.** Plan view showing laser scanning set-up locations for survey work conducted near the LOX Storage Area and Blast Wall at LC14.

**Figure 135.** View from the Webshare® software interface, showing the east side of the blast wall that was captured in the TLS survey positioning.
Launch Complex 14 Launch Pad Area (BR2210, BR2211, BR2212, BR2213, 2214 and 2215)

Another area of laser scanning concentration at Launch Complex 14 was the launch pad at LC 14, which includes the pad, launch stand, ramp, paint storage building, storage area and blast wall, flume and skimming basin, and propellant condition facility building areas. In this area of the complex, a total of 34 scan positions were collected, with seven elevated locations included (Figure 136). The colorized point cloud from the survey includes high levels of detail especially relational to areas of conservation and conditional assessment concern including areas on the ramp and launch stand (Figure 137).

The ramp and launch stand were constructed in 1957, and was approximately 432’ long and could be visually divided into twelve bays, with the northernmost bay being the stand, which in 1976 was partially razed due to excessive corrosion and deterioration (Hinder 2003c:4). Also gone are the service structure and umbilical mast used in launches. The ramp and stand area are of continuing conditional assessment concern (Figures 138-140). The stand portion of the ramp has considerable rust and metal loss, and the structural components are in danger of collapse or loss from continuing sea and salt exposure or from storm wind or surge damage. In these areas, elevation and sectional representations utilizing the laser scan point cloud data have yielded information concerning the as-is condition and as-built details. These slices and sections can be used to derive feature information and exact metrological analyses, allowing for strategies for conservation and restoration of features as needed (Figures 141 and 142). 3D CAD products allow for digital rendering of the as-designed and built structural details (Figures 143-147), and these scan data have also been utilized to produce fly-through visualization in formats that can be readily shared and viewed (see: https://sketchfab.com/models/2519bf3faa948689800f37f5dddaaf37; https://youtu.be/o3ODOTb8dBs).

Figure 136. Plan view map showing scan positions in the TLS survey of the Launch Complex 14 ramp, stand, pad and surrounding environs. The red, orange and green locations represent elevated positions, and the blue are ground-based scan locations.
Figure 137. Point cloud from TLS data, showing extent of ramp and stand (BR2210) from plan view. Includes BR2212, BR2213 and BR2214, as well as the memorial at end of ramp. The Flume and Skimming Basin (BR2215) extend beyond and aerial LiDAR is used to bring together the larger landscape features including this and the Rail and Parking areas (BR2220).
Figure 138. Ramp at Launch Complex 14.

Figure 139. SE end of ramp at Launch Complex 14.
Figure 140. Stand at end of ramp at Launch Complex 14.
Figure 141. TLS elevation ortho-image sections showing ramp and stand and related area portion of Launch Complex 14.
Figure 142. Ortho-images and sectional details can be used in the analysis of conditions at the facility, and can provide important details relating to measurement, settings and contextual details. Areas of bowing deformation, spalling and corroding can be studied and reviewed using these data.
Figure 143. 3D modeling of the launch ramp and stand area can look at the as-designed and as-built information and prove useful for understanding functional aspects and providing visualization tools.
Figure 144. 3D CAD modeling derived from laser scanning survey data.
Figure 145. 3D CAD plan view of the Launch Complex 14 ramp and stand area.

Figure 146. 3D CAD modeling of the launch stand and ramp area, showing elevation details.
Figure 147. 3D CAD perspective views of the launch stand and ramp areas.
Launch Complex 21/22 (BR2022 District)

Launch Complex 21/22 of the Cape Canaveral Air Force Station (CCAFS) was constructed in multiple phases between 1957 and 1960, and is associated with the Bull Goose and Mace American missile programs (Enscore et al. 2008c:36). Between both of these missile programs, 64 total launches were completed at the Complex, with the final one launching in July of 1963 (Figure 148). The Complex was abandoned the following year (Enscore et al. 2008c:36-42).

In 1993, an inventory and historical significance evaluation for the CCAFS was completed, and at that time the Complex’s remaining structures were together determined to be eligible for listing on the National Register of Historic Places (NRHP) (Enscore et al. 2008c:iv). A formal NRHP nomination was however, not made. The significance of the complex relates to the association with early missile development testing for the U.S. military. The Complex was recorded with the Florida Master Site File (FMSF) as a District Resource Group by Thomas Penders, Cultural Resource Manager for the 45th Space Wing. The new resource group was assigned the FMSF number 8BR2022 (Penders 2006). Five structural facilities were identified as contributing to the District Resource Group and these buildings also were recorded individually with the FMSF as Historic Structures (8BR1981-8BR1985).

In 2008, a Historic American Engineering Record (HAER) survey of the Complex was completed by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). This survey represents the most comprehensive and complete description and assessment of the Complex to date, providing a thorough description of the structural elements including an inventory and summary of those structures that existed when the Complex was active, as well as those that were extant at the time of the HAER survey (Enscore et al. 2008c). Figure 149 shows the location of structures discussed in the HAER survey document in relation to the terrain features recorded in the present survey.

Major features at the complex include the a launch building structure (BR1981), a revetment bunker area (BR1985), a Blockhouse (BR1983-Bldg. 5951) that now serves as the Coast Guard Ordinance Supply facility building, and other storage and utility structures and a cable communication trench (Figure 150). TLS survey at LC 21 included the documentation with laser scanning of the Launch Building 21, revetment, two storage buildings and a utility room area, and the communication trench that allowed for monitoring launch status from the blockhouse. This trench area runs between the blockhouse and underground utility room (see: Enscore et al. 2008c for complete descriptions of these facilities).

A total of 54 scans (23 elevated and 31 ground scans) were taken at this complex location, with an additional six scan positions taken at the Coast Guard ORD facility, formerly the Blockhouse (BR1983- Building 5951) (Figures 151 and 152). Additional documentation strategies for the complex included the use of aerial LiDAR and TLS data brought together to create a digital surface model (Figure 153) for the entire area. Ground truth verification of features utilizing sub-decimeter GPS was performed, and GPS images and positions, as well as standard photography were also utilized in the area documentation.
Figure 148. Aerial image with building location information from the CCAFS GIS building data layer shown for the Launch Complex 21 area.
Figure 149. Digital Elevation Model showing terrestrial and aerial LiDAR survey data in relation to the georeferenced HAER photograph map for LC 21. Noted inaccuracies in locations and extents from the HAER mapping are evident in this overlay.
Figure 150. Aerial photograph showing BR2022 LC 21/22 District, with BR1985 revetment area to the north, and the BR1983 Blockhouse/Coast Guard ORD facility shown adjacent to the west.
Figure 151. Plan view showing the TLS survey positions in and around the LC 21 area and revetment feature (n=54, with seven positions covering the revetment area). Red and orange positions shown are elevated scanner positions.

Figure 152. Plan view showing the TLS survey positions (n=6) for the Coast Guard ORD facility (Bldg. 5951), which was the Blockhouse for LC21. Green positions shown are ground based and the red location is an elevated position set-up.
A Digital Surface Model (DSM) was created from aerial and terrestrial LiDAR for the LC 21 area, and is shown in relation to the CCAFS building data information. These data are useful for examining large scale areas and provide highly accurate depiction of building footprints, terrain and landscape information.
Launch Complex 21: the Launch Building (BR1981- Building 5912 and the Control House Building 5959) along with the Revetment (BR1985)

The most recent addition to the site complex under the third phase of construction was the launch building (c. 1960). The architecture of this structure is unique, with an irregular design with side-by-side launching bays designed for Mace missiles, complete with missile track platforms (Figures 154-156). The building features two large exhaust ducts located to the rear of the building, one of which is bent at 90 degrees, designed to keep the launch debris on the site. The control house is a rectangular structure, constructed prior to the launch building and located immediately adjacent to the west corner of the launch building (Figure 157). For a complete description of the building and its historical use see: Ensore et al. (2008:59-63).

Laser scanning of the Launch Building and Control House structures were conducted on the interior and exterior of the Launch Building, and on the exterior of the Control House, with documentation performed to +/-2mm in accuracy. Documentation included standard photography, spherical color imagery collected with the laser scanning, GPS position photography and GPS decimeter level positional data collection. As previously mentioned, these data were brought together in a GIS with aerial LiDAR to produce DEM, DSM, contour, and terrain models (Figure 158). Deliverables produced from this documentation include point cloud images and visualizations, Goggle Earth visualizations, GIS geodatabase and mapping products, tomographic slices and building ortho-images showing sectional and elevation details with the point cloud (Figures 159-162), as well as 3D CAD TLS derived models and as-built CAD products (Figures 163-170).

Another unique construction feature at LC21 is an equally proportioned V-shaped revetment wall that was built to serve as a protection measure for power and communication features at Complex. Constructed of concreted earthen fill with cement-filled sand bags on the exterior, this structure integrity can be impacted by vegetation growth, such as Brazilian Pepper which can cause damage and loss of the structural fabric (Figure 171). Point cloud and tomographic slices and ortho-photos can assist with the analysis of condition for this feature and the TLS data has been captured to record the revetment and its environs in total (Figures 172 and 173).

Blockhouse Building 5150 (BR1983)

The blockhouse structure for LC 21 is an architecturally unassuming square construction, located to the northwest of the launch building. The facility is currently being utilized as a US Coast Guard Ordinance Supply building. The exterior of this structure was documented with laser scanning, with six scan positions around the perimeter and roof areas (Figures 174 and 175). The roof is flat and the entire building is constructed of reinforced concrete, with specialized flood lighting and security fencing. The HAER building survey conducted in 2008 provides details as to construction and additional feature notes (Ensore et al. 2008).
Figure 154. Interior of Launch Complex 21 (Building 5912). Exhaust duct opening (above) and a missile track to the launching bay (below) are shown.
Figure 155. July 1960 was the first Mace B Hard site (underground) launch from pad 22. Note lighthouse in background.

Figure 156. Mace B launch at LC 21/22 in December of 1962.
Figure 157. Adjacent to the Launch Building 5912 is the Control House Building 5959, here shown in relation to exhaust duct from the exterior of Building 5912.
Figure 158. DSM derived from LiDAR and showing view locations of 3D models produced from TLS data.
Figure 159. Launch Complex 21 point cloud slice, revealing floor plan in a site plan view perspective of the Launch Building 5912 (BR1981) and the adjacent Control Building 5959. Also captured in this view is the BR1984 Storage Building seen to the lower left of the image.

Figure 160. Section showing tomographic slice of TLS data through the east elevation of Launch Complex 21/22 Buildings 5912 and 5959. “See-through” slicing reveals interior aspects to the structure.
Figure 161. Section showing slice of TLS data revealing interior from south elevation view of Building 5912.

Figure 162. Planar tomographic section slice of TLS data revealing interior structural details of the LC 21 Launch Building 5912 and the Control House Building 5959.
Figure 163. 3D models from TLS data showing conjectural Mace launch, demonstrating the building function as well as depicting structural aspects of the facility.
Figure 164. 3D models from TLS data, showing building layout and configuration, including spatial locations of associated buildings and features such as the revetment and communications trench.
Figure 165. 3D CAD plan view for Launch Complex 21 District (BR2022).

Figure 166. 3D CAD elevations
Figure 167. 3D CAD perspective views

Figure 168. 3D CAD perspective views of LC 21 Launch Building (BR1981) and building 5959. The unique flame exhaust tubes are depicted.
Figure 169. Perspective view showing revetment positioning at BR2022.

Figure 170. Perspective view in 3D CAD showing overall launch facility.
Figure 171. Revetment feature at Launch Complex 21 with communication trench shown in front (above). Brazilian Pepper and vegetation growth can impact structural fabric integrity, as shown in these images from 2005 (photos courtesy Thomas Penders, 45th Space Wing).
Figure 172. Tomographic slice data from the TLS survey of the revetment area (BR1985) of LC 21 (position of the slice is shown in above image from the scan point cloud), is used to reveal details as to configuration, integrity and condition, and other structural details such as dimension and volume.
Figure 173. Plan view ortho-image of the revetment from the TLS point cloud, and used to extract exterior wall slice to reveal measured footprint of the feature (scales show = 3 ft.). Note conditional problems along the north wall (bottom right) highlighted in the box graphic.
Figure 174. Point cloud data in elevation showing BR1983-Building 5951 that functioned as the Blockhouse for LC21/22, and is today the Ordinance Supply Building for the US Coast Guard.

Figure 175. Webshare® image showing laser scanning project area at the BR1983 - Building 5951 area.
Launch Complex 31 & 32

Launch Complex 31/32 of the Cape Canaveral Air Force Station (CCAFS) was constructed between July 1959 and November 1960 at a location that previously had been a part of Launch Complex 9/10 (Enscore et al. 2008d:34-35)(Figure 176). The Complex is characterized by two nearly identical sets of facilities that include unique “beehive” shaped blockhouses, designed using reinforced concrete covered with an exterior shell consisting of cement filled hardened fabric sandbags (Figures 177 and 178). The twin configuration was due to the emphasis on the Minuteman program as part of the US response to the Cuban Missile Crisis. The facilities were duplicated to insure no down time from potential damage or loss of function (Enscore et al. 2008d: 35)Two sets of facilities were required to insure no testing time would be lost due to potential launch facility damage. These two storied dome structures were, according to the design specifications, built at 29.2 ft. as a reinforced concrete dome. The thick concrete dome shell is covered with rip-rap sand-cement bags, giving a ‘beehive’ appearance to the structures. The structures sit on a continuous, large, reinforced concrete footing pad (Enscore 2008d: 63-64). There are also launch pads and silos, and optical alignment buildings for each blockhouse. Additionally, there are equipment rooms, and other support facilities found within the Launch Complex. Together these structures were primarily designed for testing two different missile systems—the Minuteman (Minuteman I, II, III) and the Pershing 1-A (Figure 179), although the launch pads of the Complex also were used for various mobile missile testing activities (Enscore et al. 2008d: 34). Minuteman missile testing was conducted at the Complex from 1961 to 1970, and the Pershing 1-A test launches were completed in 1973 (Enscore 2008d: 38). The Complex was deactivated following the Pershing 1-A launches. In February, 1987, debris recovered from the 1986 Challenger Space Shuttle tragedy were interred in the Complex’s silos.

An inventory and historical significance evaluation for the CCAFS was completed in 1993, and at that time the Complex’s remaining structures were together determined to be eligible for listing on the National Register of Historic Places (NRHP) (Enscore et al. 2008d:iv). A Historic American Engineering Record (HAER) survey of the Complex was completed in 2010 by the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). The HAER report represents a comprehensive and complete description and assessment, providing a thorough description of structural elements including an inventory and summary of those structures that existed when the Complex was active as well as those that still remained at the time of the HAER survey (Enscore et al. 2008d). Subsequent to this HAER survey, the two “beehive” block houses were recorded in an early effort with terrestrial laser scanning. In 2008, AIST researchers Collins and Doering along with CCAFS 45th Space Wing Cultural Resources Manager Thomas Penders, and then USF graduate student Bart McLeod, used an early commercially available scanning system to record the surface geometry of the beehive structures (Figure 180). This documentation provided dimensionally-accurate point cloud data that is able to now be used as a benchmark to compare currently collected measurement data against. In 2010, Penders recorded the buildings as historic structures with the Florida Master Site File (FMSF). Blockhouse 31 and 32 were assigned the FMSF number 8BR2517 and 8BR2816. Overall conditional assessment of these structures shows advancing deterioration (Penders 2010), with the inside facility access problematic due to asbestos concerns. Metal corrosion and impacts from vegetation distressing the structural fabric are of primary concern at both blockhouse buildings.
Figure 176. Land Use Map showing building locations for the Launch Complex 9/10 and 31/32 areas.
Figure 177. Construction of LC 31/32 at the Cape in 1959, showing the building’s reinforcing rods (image courtesy USAF, 45th Space Wing).

Figure 178. Overall view showing both “beehive” dome-shaped blockhouses and gantry launch structure at LC 31/32 in 1960 (image courtesy of USAF, 45th Space Wing).
Figure 179. Historic Minuteman missile launch from LC 31/32.
Figure 180. Using a scissor lift (above) to take elevated scanner positions, the team from AIST utilized an early version of a commercially available laser scanner to document the LC 31/32 Blockhouses in 2008, and produce dimensionally accurate 3D survey results (below).
Blockhouse 31 (BR2517, Facility 17702)

An area of targeted high resolution survey with TLS was conducted at the LC 31/32 Blockhouse 31 area. This location was laser scanned using a total of 10 positional set-up locations. Seven locations were ground based scans and three positions were documented from elevated positions (Figure 181). Unlike the 2008 survey, a scissor lift was not utilized, as the laser scanner we were utilizing had a better distance and range capture, and less noise error. Laser scanning allowed the capture of a large area of terrain around the blockhouse, useful not only for 3D modeling and CAD production, but for integration with aerial LiDAR in a GIS to make a highly detailed digital surface and terrain models (Figure 182). Additionally, GPS point and line data were collected with sub-decimeter level accuracy, allowing ground verification of LiDAR as well as positional details and attributes to be recorded. Imagery, including standard photography, spherical images (panoramic 360 degree images from the laser scanner), and GPS positional data images were recorded. Notes and data concerning conditional details, such as corrosion areas, deformation, spalling and fabric integrity loss on the structure, and areas of invasive exotic impacts were also recorded (Figure 183). Results from the 2014 TLS survey of the LC 31 Blockhouse include sectional analytics that are allowing for monitoring and understanding of structural integrity and deformational changes (Figure 184). These conditions relate to areas of metal corrosion and loss, especially on the stairs and cableway transitions to the rear of the Blockhouse, as well as the electrical conduit system areas (Figure 185). TLS data were utilized to create 3D CAD renders of the structure (Figures 186-190).

Also of interest for the beehive blockhouse structures, is a comparison of the TLS survey data against the as-designed data that are available from the construction drawings. These buildings were to be constructed identically, and so the laser scanning information can be used to examine the forensics of the structure against these construction designs. Using 3D software, historical CAD data can be brought together in the same planar perspective and scale as the TLS data, and can be viewed and compared for areas of change or differences in design from as-built (designed) to as-is conditions (Figure 191).

Blockhouse 32 (BR2516, Facility 17703)

The “beehive” shaped blockhouse at LC32 was additionally targeted for TLS survey in 2014. A total of 11 scanner positions were captured from ground and raised elevation locations (four raised elevations and seven ground tripod based positions). These locations allowed for complete coverage of the architectural elements from exterior positions (Figure 192). Interior to the structure data capture was not feasible due to hazards posed from asbestos and unsafe conditions, as well as other access concerns. Sub-decimeter level GPS was utilized to map in associated features and attribute details, and GPS photography allowed for conditional information to be included with geolocation details. Standard and spherical, panoramic imagery was also captured to assist with providing documentation of the landscape and built environment. Aerial LiDAR was also brought together with the TLS and other data to provide a more holistic recording of geolocation and spatial attributes of the Launch Complex area (Figure 193). Structural details such as the steel stairway and camera decks, periscope mounts, plumbing vents and toilet exhaust pipes, chamfered concrete wing walls and blast-resistant entry doors, upper-level blast door, and electrical conduit sleeves and pull boxes that were documented in photos for the 2008 HAER survey, were all captured in the present TLS, photographic and geolocation efforts. These data show in detail terrain aspects, including re-use areas such as those for modifications to the site made in the 1980s, when the 45th Space Wing Mobile Combat Communications Group conducted training activities at the Complex 31/32 site. For example, a bivouac temporary camp area, complete with concrete tent pads was constructed at this time, and is clearly
Figure 181. Plan view map of LC 31 Blockhouse showing the scanning potion set-up locations for the TLS survey in 2014 (above) and the Webshare® panoramic laser scan images (below) that allow for detail feature examination including measurements and movement through the scan project showing each position (inset window shows the next position).
Figure 182. DSM derived from aerial LiDAR showing the inset 3D model from TLS survey.
Figure 183. Conditions at LC 31/32 include corrosive loss to metals, asbestos concerns for the interior (above images), and exterior fabric and surface degradation concerns from weathering and vegetation growth as well as potential damage from vegetation removal (below image from 2005 showing Brazilian Pepper growth on the fabric of the structure).
Figure 184. Blockhouse 31 TLS data allows for sectional analysis and monitoring (above) and provides spatial and conditional details that can be brought together with aerial LiDAR and other GIS data (below).
Figure 185. Areas of corrosion and metal loss and of conditional concern on Blockhouse 31 include the stair and electrical conduit areas (above and below) as well as the cableway transition area (below). Vegetation growing within the fabric structure of the sandbags is also of potential conditional impact and areas were captured with the TLS survey.
Figure 186. Example of TLS data for LC 31 (above) and derived model (below) for 3D CAD work.
Figure 187. 3D CAD elevations, perspectives, and detail views for LC 31.

Figure 188. Orthographic views for LC 31. Drawings are derived from TLS data. Doors and stairs have been digitally “restored” for models, however, the TLS survey point cloud data shows current conditions in their “as-is” state. Note that electrical junction box and periscope features were not digitally added back to this model, which was meant to focus on the fabric and wall features.
Figure 189. Isometric views in 3D CAD, eliminating the distortion of shape as seen with certain perspective views in 3D. Model is focusing on the structural fabric details.

Figure 190. Detail views in 3D CAD, showing structural fabric details, with door and stair digitally added for location specifics.
Figure 191. Previous “as-designed” CAD details can be spatially considered and scaled to allow for examination of the as-is condition compared to these previous data.
Figure 192. Laser scan positions shown in the plan view (above) and with data shown clipped to the Blockhouse 32 feature (below).
Figure 193. Digital Surface Model derived from aerial LiDAR, showing LC 9, 10, 31, and 32 areas with the HAER map georeferenced for comparison.
delineated in our documentation (Figures 194 and 195). Also evident is the rail system, utilized to move missiles around to make them less of an obvious target potential, and for mobile launching from a rail car as part of a mobile Minuteman system (Enscore et al. 2008:45, 78 and 142). The railroad spur and car bumper features can clearly be delineated using the LiDAR terrain information, seen to the north of Blockhouse 32 (Figure 196).

Web-based GIS products depicting various data visualization tools in relation to one another can offer valuable insight into landscape variables. For example, as part of a student project in a USF course in heritage technologies, an interactive GIS slider tool allows users to view LiDAR data in relation to aerial imagery for the LC 31/32 area (Figure 197). A virtual tour was also produced for LC31/32 as part of a Museum Visualization course at USF in spring 2015. This tour is in an online GIS format, complete with historic photos, viewable 3D models, and modern images and technical maps and drawings (Figure 198). The virtual tour platform allows for sharing and engagement for heritage tourism and education, and is an added value benefit that comes from the collaboration with the university and federal partners. The full tour can be viewed online at http://aist.usf.edu/CCAFS/index.html. The project also included students producing an exhibit space showing digital heritage tourism potentials for Cape Canaveral. The exhibit was part of an event at the USF library Digital Media Commons area, and students produced augmented reality applications, visualizations in 3D, and 3D prints of several structures that were laser scanned (Figure 199).

3D CAD renderings were made for Blockhouse 32 utilizing the data acquired from the TLS survey (Figures 200 and 201). These data were used to produce models that show the building in elevation, perspective, and plan view, with emphasis placed on the building fabric and structure. Point cloud data are used to visualize the entirety of the structure, and were also used to produce tomographic slice details that assist with the forensic understanding of the construction (Figure 202). These forensic comparisons were also performed with using earlier 2008 scan data that was captured at LC31/32, and were also done comparing one building against the other (Figures 203-205). The morphologic comparison of buildings shows that there are slight variances in the walls and structural aspects despite the utilization of the same as-built design (Figure 206). Change detection utilizing TLS data as well as aerial LiDAR is an area of continuing interest for monitoring, assessing transformation processes, and in the management of cultural and natural sites (Zeibak and Filin 2008; van Gaalen et al. 2011).
Figure 194. Spherical imagery from the laser scanner taken from a raised elevation position on the Blockhouse 32 camera pad, shows the steel staircase corrosion and breakage, as well as provides a view to the cableway and cement tent pads on the ground below.

Figure 195. Aerial LiDAR hillshade map shows the location of 20 tent pad features near the Blockhouse 32 location. These pads were utilized as temporary camp sites during training exercises in the 1980s.
Figure 196. Aerial LiDAR data for the LC31/32 Complex (shown in relation to the georeferenced HAER map) clearly delineates features such as the rail spur and bumper to the north of Blockhouse 32.

Figure 197. A web-based GIS slider interactive tool allows users to compare historical imagery from 2007 and 2012, or compare aerial imagery to aerial LiDAR elevation data for the LC 31/32 area. See: http://arcg.is/1T4cejW.
Launch Complex 31-32

Launch Complex 31-32 was built in 1959 with LC-32 for the U.S. Air Force to conduct test launches of the first USA-30 Minuteman missiles (2). LC-31 consisted of a blockhouse, static launch pad and missile site (2). The hemispherical blockhouse is 210 yards from the static pad and 300 yards from the site (2). This architectural configuration was due to the high priority of the Minuteman program as part of the nation’s response to the Cuban Missile Crisis (2). Two sets of facilities were required to ensure no testing time would be lost due to potential launch facility damage (2).

The Air Force launched three Minuteman missiles between February 1, 1960 and September 23, 1969 (2). This missile was designed around the concept of instantaneous response to enemy attack (2). It was lighter, smaller, simpler and less expensive than the Atlas and Titan (2). These missiles eventually became the backbone of the nation’s strategic, land-based, nuclear missile force (2).

The service tower has since been removed and site filled in, although recovered debris from the space shuttle disaster Challenger were buried in the site (2).

Figure 198. Views from the online virtual tour web site developed as part of a student group project for a USF Museums course in spring 2015, led by graduate student Richard McKenzie. The web site contains information about three areas that were documented at Cape Canaveral by USF, Launch Complexes 14, 31/32 and 34 (see: http://aist.usf.edu/CCAFS/index.html).
Figure 199. USF students showcase Cape Canaveral in 3D digital exhibit at the USF library. 3D Printing, interactive maps, augmented reality applications and videos were part of the display design. For more about the exhibit, see: https://www.youtube.com/watch?v=NLoTWYE0geA.
Figure 200. 3D CAD renderings utilizing the TLS data, were made for each structure documented in our survey. These models provide baseline information and assist in the monitoring and structural detail archival development.
Figure 201. TLS data (above in see-through mode) and 3D model of blockhouse 32 at LC31/32 (below).
Figure 202. Tomography slices are a method of producing a three-dimensional image of the internal structures of a solid object. When performed using TLS data for LC 31 (above) and LC 32 (below) blockhouses, cross-sectional comparisons can be made and show slight differences in morphology and condition.
Figure 203. Morphologic analyses were conducted for Blockhouses at LC 31 compared to LC32 using TLS data.

Figure 204. Orthographic views showing morphologic comparison of Blockhouses at LC 31 and LC 32 blockhouses.
Figure 205. Elevation views with morphologic comparison of Blockhouses at LC 31 and 32.

Figure 206. Showing the morphological difference between the LC31 and LC32 Blockhouses, with LC32 data shown projected over the LC31 model. The nearest to green colors indicate almost no difference, and the farthest from green are the most extreme differences.
Launch Complex 31/32 Silos

The silo areas at 31 and 32 are significant to our nation’s history as being the final resting site for the Space Shuttle Challenger recovered debris. These silos were documented in higher resolution detail using TLS survey (Figure 207). A total of three ground-based tripod scans were acquired at each silo area, to document the features in their entirety. Spherical imagery, standard photography, and GPS and GPS imagery were also collected during the documentation of the areas. These data were brought together with aerial LiDAR for the landscape record, but the silo data were also processed individually. Following a long search and recovery operation, numerous vehicle fragments from the Challenger disaster were recovered in the Atlantic and on the land near the shuttle launch location at Cape Canaveral. The complex silos at 31/32 were selected as the internment location for the debris, with the material transferred to the site in February 1987 (Figure 208). The Challenger debris was placed in the silos for permanent long-term storage, with the openings sealed with massive concrete caps (Figure 209). The debris included large sections of fuselage, one wing, the craft’s tail and more than 100 crates of components. The Challenger’s crew cabin was also recovered and placed in the silos (Orlando Sentinel January 5, 1987).

Figure 207. TLS survey at the silo at LC32.
Figure 208. Webshare® point cloud data for the silo areas at LC 31/32 (31 above and 32 below), showing the silos and surrounding terrain documented with 3D laser scanning in the TLS survey. A total of three ground-based tripod scans were taken at each locale.
Figure 209. Debris from the Space Shuttle Challenger being interred at the LC31/32 silo location in 1987 (Photos courtesy 45th Space Wing, Cape Canaveral, Florida).
Using the 3D data and geolocation information collected, along with historical video and image footage, opportunities for digital heritage tourism and interpretation on and off site exist. One such technique of onsite information might include augmented reality (AR) and mobile applications that work using geolocation information. Using video and imagery of the story of the national tragedy and the internment in the silos, interpretation can be provided through the use of mobile devices like smartphones and tablets, triggered by a GPS location. This concept of digital heritage interactive tools was presented by students in the USF Museum Visualization course, who developed AR applications that work by recognizing visual or geolocation targets (Figure 210). These types of visualizations and apps can also be used on site to provide interactive experiences with a physical space (Figure 211). AR and mobile heritage tourism tools are being utilized globally and could play a role in the future of site and web portal tourism and virtual visitation for Cape Canaveral (Kounavis et al. 2012).

Figure 210. USF students demonstrate how signage can be used to trigger information and apps on mobile phone and tablet devices using AR strategies for heritage interpretation.
Figure 211. Utilization of an AR application on a mobile device such as a tablet or smart phone, enables information such as videos, 3D models and other documentation to be associated with a physical location.
Launch Complex 34 Memorial (Launch Stand Pedestal BR2292)

Launch Complex 34 of the Cape Canaveral Air Force Station (Figure 212) was constructed between June 1959 and February 1961, and is associated with the tragic Apollo 1 and Saturn 1B missile test flights and two Apollo program launches including the tragic Apollo 1 launch rehearsal fire and the successful Apollo 7 mission. In November of 1971, the Complex was deactivated following the construction of Launch Complex 39, and two years later it was abandoned (Hinder 2003d:19-20). In April 1984, the Complex was included as part of a National Historic Landmark District designation for multiple Launch Complex facilities located on the CCAFS (National Park Service and United States Air Force 1983).

To date, the most comprehensive and complete description and assessment of Launch Complex 34 stems from a Historic American Engineering Record (HAER) survey in 2003 by Archaeological Consultants, Inc. (ACI) (Hinder 2003d). The HAER survey report provides a complete physical description of the Complex’s structural elements and is largely based on a review of multiple historic materials including the As-Built Drawings of the Complex completed in 1959 and 1968 (Hinder 2003d:2). Additionally, the HAER report provides important descriptions of the alterations to the Complex that occurred following its abandonment in the early 1970s (Hinder 2003:19-29). In 2007, an additional HAER report was completed by ACI for the Complex’s Engineering Support Building due to NASA plans to demolish the structure (Slovinac 2007). The Complex was recorded with the Florida Master Site File as a resource group by Thomas Penders (2008d), Cultural Resource Manager for the 45th Space Wing at Cape Canaveral. The resource was assigned the FMSF number 8BR2279. Twenty one of the LC 34 structures were listed as contributing and were also recorded individually with the FMSF as historic structures (8BR2280-8BR2300).

The launch stand at LC 34 (BR2292) was the site of a tragic Apollo 1 cabin fire during a rehearsal test launch on January 27, 1967. Three astronauts, Virgil I. "Gus" Grissom, Edward H. White II, and Roger B. Chaffee, were all killed in the inferno (Figure 213). The early Apollo Command Module was found to have a number of flaws and design issues that required extensive reworking for the manned missions (Figure 214) (Smithsonian National Air and Space Museum 2015). The tragedy resonated with the American public and the world, showing the inherent dangers of space exploration (Figure 215). The site was found by the State Historic Preservation Officer (SHPO) to be eligible for listing on the National Register of Historic Places in 2009 (Florida Master Site File 2009). The site is part of a National Historic Landmark listing, and numerous visitors and family members of the astronauts visit the complex as a memorial to the lives and to the deaths of these early space explorers (Figure 216).

The squared-shaped pedestal, which sits on a circular launch pad (Figure 217), was documented with TLS survey in conjunction with GPS control, GPS imagery, spherical imagery, and standard photography. The pedestal is 42 ft. on each side of the square, and measures 27 ft. high with a circular blast hole in the center that allowed engine exhaust to pass through to the flame deflectors (Figures 218 and 219). It is constructed from reinforced concrete formed over steel and support columns (Hinder 2008d: 4). Today, the site is in ruinous condition after being abandoned in place in 1971 (Penders 2008e).

TLS survey was undertaken to document the current conditions and structural details of the pedestal and surrounding environs. These data are planned to be brought together in a more complete understanding of the area in a later phase of this project, but here were done to record details and conditions of this important structure and memorial. A total of five ground-based tripod positions were acquired for the current effort (Figure 220). The measurements differ slightly, with the width actually being 41.56 feet per side at the top and 42.14 ft. at the base width. TLS data collection was combined with spherical imagery, standard photography, GPS imagery and GPS sub-decimeter level geolocation information for the pad area. Aerial
Figure 212. Aerial image showing structures located at LC 34, including the central pad and pedestal features.
Figure 213. Apollo I Astronauts Grissom, White, and Chaffee in front of their Apollo/Saturn IB space vehicle on the launch pad. This photo was taken just 10 days before the tragedy that would end their lives (image courtesy of USAF, 45th Space Wing).

Figure 214. Interior image of capsule following the flash fire that claimed the lives of the three astronauts aboard on January 27, 1967 (image courtesy NASA).
Figure 215. Post card sharing news of tragedy in American history, issued on the day of the event (image courtesy NASA).

Figure 216. Commemorative plaque from the LC 34 memorial site, considered hallowed ground for the Apollo I tragedy.
Figure 217. The Launch Pad (BR2290), Pedestal (BR2292) and Flame Deflectors (BR2293) are shown in landscape aerial view. Photo courtesy of the 45th Space Wing, Cape Canaveral, Florida.
Figure 218. The Launch Pedestal (Stand) at LC 34, shown with the flame deflectors in the background.

Figure 219. The central blast hole allowed for the exhaust to pass through to the nearby flame deflectors.
LiDAR data processed in the GIS provide a contextual understanding of the elevation features at the location and can be visualized in relation to previous mapping for the HAER survey study (Figure 221). The LiDAR data allow for delineation of features and structures across LC34 (Figure 222), and for a closer analyses of the Launch Pad and stand area (Figure 223). The TLS data for the pedestal and surrounding area captured can be used to assess and visualize current condition and as-built design features, as well as provide an accurate and representative visual record. Surface quality characteristics, such as color variation, intensity, and reflectivity can also be examined (Figure 224). These spectral values can help in the understanding of material typological differences and areas of variation such as where rust and corrosion or other surface irregularities may be occurring (Costantino and Angelini 2013; Pesci and Teza 2008) (Figure 225).

Deliverables derived from the TLS, geospatial and imaging survey of the area include video point cloud and model fly-through and visualizations (see for example: https://youtu.be/tuzUmDF6Dg8 ); GIS interactive mapping for the project, inclusive of the LC 34 environs (http://aist.usf.edu/flexviewer2/Cape_Canaveral/ ); customized Google Earth and GIS geodatabase products provided to the Cultural Resource section of the 45th Space Wing at CCAFS; and Webshare® virtual scan project walk-through data that allow for digital recreation of the scan project and viewing of all spherical and measurable XYZ data acquired. 3D models for the launch pedestal were also provided (Figures 226 and 227). An interactive GIS tool has also been created that allows examination of the aerial imagery from 2007 in comparison to 2012, and allows comparison against a Height Above Ground (HAG) processed Digital Elevation Model (DEM) derived from aerial LiDAR. This tool is very useful at LC 34 overall for the understanding of vegetative change through time, especially relational to Brazilian Pepper encroachment and emergence. This tool is accessible online at: http://arcg.is/1T4ddQW .
Figure 221. Historic American Engineering Record (HAER) survey map shown georeferenced to the digital elevation model produced from aerial LiDAR for LC 34.
Figure 222. Digital Surface Model from aerial LiDAR processed for LC 34 landscape. Building names from the Cape Canaveral building GIS data are shown.
Figure 223. Digital Surface Model for the Launch Pedestal Stand and Launch Pad location area with inset showing the 3D model produced from the TLS data for the pedestal structure.
Figure 224. Point cloud data allow the visualization of structural details and elements from numerous perspectives.
Figure 225. Reflectivity (below) and color RGB values (above) can be examined to help in structural analyses and material assessment characteristics.
Figure 226. 3D models produced from TLS survey data show the Launch Pedestal from all perspectives. High resolution color images of details such as the commemorative plaque (below) allow for color texture mapping to the 3D geometry and provide a highly realistic representation of the site.
Figure 227. 3D CAD models were produced showing the Launch Pedestal at LC34 from all elevations and perspectives, with the ability to add and remove color textures to examine design details.
Conclusions

Overall, the 3D models, cartographic products, 3D tomographic slices, and CAD renderings derived from the TLS survey proved useful in the analysis of ‘as built’ archival documentation for the areas of historic launch complexes at the CCAFS. These data are useful for the digital preservation, replication, CAD and sectional analysis, and for future interpretative development options, such as web based heritage tourism, Augmented Reality and mobile device applications, and on site museum, kiosk and wayside interpretative development.

Cartographic products, including digital geodatabases, provide an accurate assessment of the features, structures, and surrounding terrains. Accurate portrayal and understanding of spatial locations of resources is important from both a management perspective and from a compliance and public interpretive perspective. Having a true understanding for locations and associations of features on the landscape help to lessen the potential for conflicts, and allows for the greater protection and preservation of properties (Entwistle et al. 2009).

At the landscape level, aerial LiDAR models were combined with areas of terrestrial laser scanning survey, and can allow for the examination of issues and to provide precise means of assessing loss and developing mitigation and stabilization strategies (Abby 2014). The Digital Elevation Models (DEM) and Digital Surface Models (DSM) were produced using a combination of aerial laser scanning (ALS) or LiDAR, terrestrial laser scanning (TLS), and ground truth verification with GPS. ALS data collection and interpretation has been described as one of the most significant innovations for the field of archaeology and for landscape analysis (Opitz 2013). The AIST at the University of South Florida are integrating ALS with TLS and other techniques to examine large scale landscape areas, with rapid and highly accurate assessments of elevation and surface details possible. At the historic launch complexes and related structures at the CCAFS, these data provide a way to visualize and to digitally document these NRHP, NHL, and eligible sites, using efficient, exact, and highly representative approaches. These data will serve as a foundational step in the longer range planning, management, archive development, and monitoring programs at the CCAFS, and offer a model for how base historic structure management can be conducted.
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