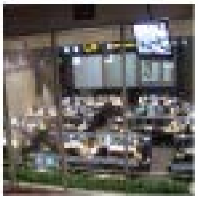
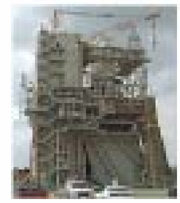
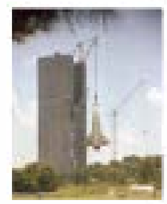


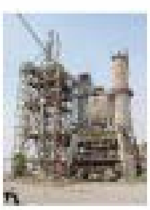


NASA-WIDE SURVEY AND EVALUATION OF HISTORIC FACILITIES IN THE CONTEXT OF THE U.S. SPACE SHUTTLE PROGRAM: ROLL-UP REPORT



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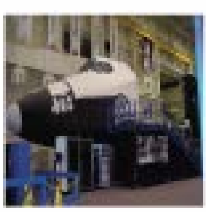



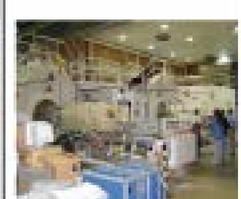

NASA-WIDE SURVEY AND EVALUATION OF HISTORIC FACILITIES IN THE CONTEXT OF THE U.S. SPACE SHUTTLE PROGRAM: ROLL-UP REPORT

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"The first great era of space is over. The second is about to begin. It will come into its own with the Shuttle, the heart of our new space transportation system. The Shuttle program has been a very large effort. More than 5,000 companies and nearly 50,000 Americans all across the country have worked in designing, manufacturing, and testing the Shuttle. I congratulate the scientists, engineers, skilled workers, and others that have contributed directly to this success."

President Jimmy Carter, March 24, 1979, in recognition of the arrival of *Columbia* at the Kennedy Space Center

EXECUTIVE SUMMARY

The National Aeronautics and Space Administration (NASA) has undertaken a historical survey and evaluation of NASA-owned facilities and properties (real property assets) to determine their eligibility for listing in the National Register of Historic Places (NRHP) in the context of the U.S. Space Shuttle Program (SSP) (ca. 1969-2010), which has been slated for retirement in the year 2010. In February of 2006, a Shuttle Transition Historic Preservation Working Group (HPWG) was formed which included the Historic Preservation Officers (HPOs) for all NASA Centers. This group, tasked with implementation of the historic facilities survey, coordinated their efforts with the Shuttle Transition Environmental Support Team. The HPWG drafted a set of standard criteria for the evaluation of Shuttle program-related properties at all NASA Centers.

This report, prepared for NASA Headquarters in Washington, D.C., was conducted in compliance with Section 110 of the National Historic Preservation Act (NHPA) of 1966 (Public Law 89-665), as amended; the National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190); Executive Order (EO) 11593: Protection and Enhancement of the Cultural Environment; EO 13287; Preserve America; and other relevant legislation.

A total of 335 facilities at 13 NASA Centers and component facilities were identified and evaluated as part of this study. The surveyed locations include: Joseph S. Ames Research Center (ARC), Canoga Park Facility, Hugh L. Dryden Flight Research Center (DFRC), John H. Glenn Research Center (GRC), Lyndon B. Johnson Space Center (JSC), John F. Kennedy Space Center (KSC), Langley Research Center (LaRC), George C. Marshall Space Flight Center (MSFC), Michoud Assembly Facility (MAF), Air Force Plant (AFP) 42, Site 1 North, Palmdale, Santa Susana Field Laboratory (SSFL), John C. Stennis Space Center (SSC), and White Sands Test Facility (WSTF). Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and the Wallops Flight Facility (WFF) have assets that support the SSP, but which are not dedicated to the program. However, no formal eligibility surveys were conducted as part of this study.

As a result of field survey and evaluation, 70 NASA-owned historic properties that are listed, determined eligible, or considered eligible for individual listing in the NRHP were identified. All are exceptionally significance in the context of the SSP. Of these 70 individually eligible properties, 24 were previously listed or determined eligible for listing in the NRHP, including seven that are designated National Historic Landmarks (NHLs): the Structural Dynamic Test Facility and the Multi-purpose High Bay Facility and Neutral Buoyancy Simulator (NBS) at MSFC; the Propulsion Test Stands A1, A2, B1 and B2 at SSC; and the Mission Control Center (MCC) at JSC. Forty-six NASA assets were assessed as newly eligible for listing in the NRHP in the context of the SSP.

Approximately two-thirds of the historic properties were originally constructed in the 1960s for the Apollo Program, and subsequently modified for the SSP. The distribution of the 70 historic properties is as follows: KSC - 26, MSFC - 13, JSC - 11, SSC - 4, MAF

- 4, ARC - 2, GRC - 2, Palmdale - 2, SSFL - 2, DFRC - 1, LaRC - 1, WSTF - 1, and the Canoga Park Facility - 1.

The 70 NASA-wide historic properties fall within all 12 property types defined for this study. Due to the multiple category classifications of 24 historic properties, the 70 assets represent a total of 98 property type affiliations. The most commonly occurring property type is Type 7: Engineering and Administrative Facilities. A total of 26 facilities are classified within this group, of which almost half are located at the MSFC. In descending order of frequency, the other most common property type affiliations are Type 1: Resources Associated with Transportation (N=17); Type 2: Vehicle Processing Facilities (N=12); Type 3: Launch Operation Facilities (N=10); Type 10: Resources Associated with the Training of Astronauts (N=10); Type 11: Resources Associated with Space Flight Recovery (N=7); and Type 9: Manufacturing and Assembly Facilities (N=6).

The SSP survey focused on the NRHP eligibility of individual buildings, structures, and sites. Given this study's focus on only a single NASA program and its related assets, potential historic districts were considered in a preliminary manner, but not defined and evaluated. The one exception is KSC, where historic districts had previously been defined. Also, this NASA-wide survey did not include the approximately one million line items of personal property associated with the SSP which are managed and dispositioned in accordance with federal personal property regulations. Many of these assets will be transferred to the new space exploration program, Constellation. Personal property that is excessed by NASA is screened to identify flown assets. These are the historic artifacts that may have display value at our NASA Centers or as part of the national collection.

The 70 exceptionally important historic properties include a variety of buildings and structures. While the National Park Service (NPS) requires that entire buildings, not parts of buildings, be evaluated as per the NRHP eligibility criteria, in many cases, the significant assets derive their importance from specialized facilities or equipment within only a portion of the building. This factor has important implications for future resource management under Section 106 of the NHPA. Center-specific reports were reviewed and approved by Center management and NASA Headquarters. The HPOs have submitted final Center reports to the respective SHPOs. The study findings will be used to support Section 106 consultation for undertakings that are anticipated to support NASA's Transition to the new space program, Constellation. Except for their possible enhancement, this study does not affect the existing NHL and NRHP status of previously evaluated historic properties.

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LIST OF ACRONYMS AND ABBREVIATIONS

ABMA	Army Ballistic Missile Agency
ACCESS	Assembly Concept for Construction of Erectable Space Structures
ACHP	Advisory Council on Historic Preservation
ACI	Archaeological Consultants, Inc.
AETF	Advanced Engine Test Facility
AFB	Air Force Base
AFDCS	Aft Flight Deck Crew Station
AFP	Air Force Plant
AFRSI	Advanced Flexible Reusable Surface Insulation
ALDF	Aircraft Landing Dynamics Facility
ALT	Approach and Landing Tests
APU	Auxiliary Power Unit
ARC	Ames Research Center
ARF	Assembly and Refurbishment Facility
ARMSEF	Atmospheric Reentry Materials and Structures Evaluation Facility
CAIB	Columbia Accident Investigation Board
CCAFS	Cape Canaveral Air Force Station
CCT	Crew Compartment Trainer
CDDT	Countdown Demonstration Test
CEV	Crew Exploration Vehicle
CRM	Cultural Resource Management
CTV	Crew Transportation Vehicle
DFRC	Dryden Flight Research Center
DoD	Department of Defense
DSN	Deep Space Network
EA	Environmental Assessment
EASE	Experimental Assembly of Structure in Extravehicular Activity
ECLSS	Environmental Control and Life Support System
EMD	Environmental Management Division
EMU	Extravehicular Mobility Unit
EO	Executive Order
ESA	European Space Agency
EST	Eastern Standard Time
ESTL	Electronics Systems Test Laboratory
ET	External Tank
ETA	Environmental Test Area
ETTV	External Tank Television
EVA	Extravehicular Activity
F	Fahrenheit
FFT	Full Fuselage Trainer
FPO	Federal Preservation Officer
FRCI	Fibrous Refractory Composite Insulation
FRSI	Felt Reusable Surface Insulation
FSS	Fixed Service Structure
FY	Fiscal Year
GALCIT	Guggenheim Aeronautical Laboratory of the California Institute of Technology
GAO	General Accounting Office

LIST OF ACRONYMS AND ABBREVIATIONS

GAS	Get Away Specials
GH2	Gaseous Hydrogen
GN2	Gaseous Nitrogen
GHe	Gaseous Helium
GOCO	Government-owned, Contractor-operated
GRC	Glenn Research Center
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HOSC	Huntsville Operations Support Center
HPO	Historic Preservation Officer
HPWG	Historic Preservation Working Group
HRSI	High Temperature Reusable Surface Insulation
HSL	Hardware Simulation Laboratory
HST	Hubble Space Telescope
ILRV	Integral Launch and Reentry Vehicle
ISS	International Space Station
ISTB	Integrated Subsystem Test Bed
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LC	Launch Complex
LCC	Launch Control Center
LDEF	Long Duration Exposure Facility
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
LRSI	Low Temperature Reusable Surface Insulation
LUT	Launch Umbilical Tower
MAF	Michoud Assembly Facility
MCC	Mission Control Center
MDD	Mate-Demate Device
MEDS	Multifunction Electronic Display Subsystem
MER	Mission Evaluation Room
MFR	Manipulator Foot Restraint
MILA	Merritt Island Launch Annex
ML	Metallurgy Laboratory
MLP	Mobile Launcher Platform
MMSE	Multi-use Mission Support Equipment
MMU	Manned Maneuvering Unit
MOL	Manned Orbiting Laboratory
MOW	Mission Operations Wing
MPTA	Main Propulsion Test Article
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MTF	Mississippi Test Facility
MTO	Mississippi Test Operation
MVGVT	Mated Vertical Ground Vibration Test

LIST OF ACRONYMS AND ABBREVIATIONS

MW	Megawatt
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NBL	Neutral Buoyancy Laboratory
NBS	Neutral Buoyancy Simulator
NCSHPO	National Conference of State Historic Preservation Officers
NDC	NASA Data Center
NEPA	National Environmental Policy Act
NFL	Nevada Field Laboratory
NHL	National Historic Landmark
NHPA	National Historic Preservation Act
NMI	NASA Management Instruction
NPR	NASA Procedural Requirements
NPS	National Park Service
NRHP	National Register of Historic Places
NSTL	National Space Technology Laboratory
O&C	Operations and Checkout
OD	Operational Downlink
ODS	Orbiter Docking System
OLF	Orbiter Lifting Frame
OMB	Office of Management and Budget
OMDP	Orbiter Maintenance Down Period
OMM	Orbiter Major Modifications
OMS	Orbital Maneuvering System
OPF	Orbiter Processing Facility
OV	Orbiter Vehicle
PA	Programmatic Agreement
PBS	Plum Brooke Station
PCR	Payload Changeout Room
PEIS	Programmatic Environmental Impact Statement
PFC	Preliminary Flight Certification
PGHM	Payload Ground Handling Mechanism
PLSS	Portable Life Support System
PWR	Pratt & Whitney Rocketdyne, Inc.
R&D	Research and Development
RCC	Reinforced Carbon-Carbon
RCS	Reaction Control System
RFP	Request for Proposal
RMS	Remote Manipulator System
RPSF	Rotation Processing Surge Facility
RSI	Reusable Surface Insulation
RSRM	Redesigned Solid Rocket Motor; Reusable Solid Rocket Motor
RSS	Rotating Service Structure
RTF	Return to Flight
SAIC	Science Applications International Corporation
SAIL	Shuttle Avionics Integration Laboratory

LIST OF ACRONYMS AND ABBREVIATIONS

SCA	Shuttle Carrier Aircraft
SEM	Space Experiment Module
SESC	Shuttle Engineering Support Center
SESL	Space Environment Simulation Lab
SESTL	Space Environment Simulator and Testing Lab
SHPO	State Historic Preservation Officer
SIP	Strain Isolator Pad
SLC	Space Launch Complex
SLF	Shuttle Landing Facility
SLP	Spacelab Pallet
SLWT	Super Lightweight Tank
SMS	Shuttle Motion Simulator
SOFI	Spray-On Foam Insulation
SPF	Space Power Facility
SRB	Solid Rocket Booster
SRM	Solid Rocket Motor
SSC	Stennis Space Center
SSFL	Santa Susana Field Laboratory
SSME	Space Shuttle Main Engine
SSMEPF	Space Shuttle Main Engine Processing Facility
SSP	Space Shuttle Program
SSPPO	Shuttle Small Payloads Project Office
STA	Shuttle Training Aircraft; Structural Test Article
STG	Space Task Group
STS	Space Transportation System; Shuttle Test Station
SVMF	Space Vehicle Mockup Facility
SWT	Supersonic Wind Tunnel
TAL	Transoceanic Abort Landing
TDRS	Tracking and Data Relay Satellite
TDRSS	TDRS System
TF	Test Facility
TPS	Thermal Protection System
TPSF	Thermal Protection System Facility
TPTA	Transient Pressure Test Article
TS	Test Stand
TSM	Tail Service Mast
TUFI	Toughened Uni-piece Fibrous Insulation
UHF	Ultrahigh Frequency
USA	United Space Alliance
USBI	United Space Boosters
VAB	Vehicle Assembly Building
VLS	Vandenberg Launch Site
VMS	Vertical Motion Simulator
WETF	Weightless Environment Training Facility
WFF	Wallops Flight Facility
WSMR	White Sands Missile Range
WSSH	White Sands Space Harbor
WSTF	White Sands Test Facility

1.0 INTRODUCTION

1.1 Background

In response to President George W. Bush's announcement in January 2004 that the Space Shuttle Program (SSP) would end in 2010, the National Aeronautics and Space Administration (NASA) has undertaken a historical survey and evaluation of NASA-owned facilities and properties (real property assets) which have supported the SSP to determine their eligibility for listing in the National Register of Historic Places (NRHP). Such facilities may include, but are not necessarily limited to, those used for research, development, design, testing, fabrication, and operations. The evaluation of facilities within the context of the SSP, ca. 1969-2010, proceeds, in part, from the 1984 Man in Space Theme Study completed by the National Park Service (NPS) (Butowsky 1984). Like the previous theme study, the NASA agency-wide survey attempted to identify the resources which best exemplify the goals and operations of the U.S. Space Shuttle Program.

The SSP survey focused on the NRHP eligibility of individual buildings, structures, and sites. Given this study's focus on only a single NASA program and its related assets, potential historic districts were considered in a preliminary manner, but not defined and evaluated. The one exception is the Kennedy Space Center (KSC), where historic districts had previously been defined. The NASA-wide survey did not include the approximately one million line items of personal property associated with the SSP which are managed and dispositioned in accordance with federal personal property regulations. Many of these assets will be transferred to the new space exploration program, Constellation. Personal property that is excessed by NASA is screened to identify flown assets. These are the historic artifacts that may have display value at our NASA Centers or as part of the national collection. The study did include, however, certain types of resources which are considered "personal property" under federal regulations. These resources (e.g., Pacific Scientific furnace, orbiter vehicles, retrieval ships, crawler transporters) are typically large; most are mobile and, with a few exceptions, are associated with one geographical location.

In February of 2006, a Shuttle Transition Historic Preservation Working Group (HPWG) was formed which included the Historic Preservation Officers (HPOs) for all NASA Centers. This group, tasked with implementation of the historic facilities survey, coordinated their efforts with the Shuttle Transition Environmental Support Team. As an initial step, the HPWG drafted a set of standard criteria for the evaluation of Shuttle program-related properties at all NASA Centers. These criteria were reviewed by the NPS and approved by NASA Headquarters in May of 2006. The agency-wide historic eligibility survey of assets which have supported or contributed to the Space Shuttle Program was approved in June of 2006, and funded by the Environmental Management Division (EMD), Office of Infrastructure & Administration, Headquarters, in July 2006.

Between July 2006 and January 2007, historic facilities surveys were conducted at 13 NASA Centers and component facilities by four cultural resource management (CRM) contractors on behalf of NASA, in compliance with Section 110 of the National Historic Preservation Act (NHPA) of 1966 (Public Law 89-665), as amended; the National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190); Executive Order (EO) 11593: Protection and Enhancement of the Cultural Environment; EO 13287, Preserve America; and other relevant legislation. The Center-specific historic contexts and survey results were presented in a series of draft reports which were reviewed and approved by Center management and NASA Headquarters. The HPOs have submitted final Center reports to the respective State Historic Preservation Officers (SHPOs) in accordance with Section 110 of the NHPA. The results were also included in two NEPA documents: the Constellation Programmatic Environmental Impact Statement (PEIS) issued in January 2008 and the Shuttle Transition Environmental Assessment (EA) scheduled to be issued in June 2008.

This agency-wide roll-up report presents a synthesis of findings for the 13 NASA Centers and component facilities; summaries for Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and Wallops Flight Facility (WFF), which were not formally surveyed as part of this study, also are included. The scope of this study is the NRHP eligibility of NASA-owned facilities and properties in the context of the SSP only. Except for their possible enhancement, this study does not affect the existing NHL and NRHP status of previously evaluated historic properties. The agency-wide SSP survey supports NASA's regulatory obligations to inventory resources in accordance with Section 110 of the NHPA, and also is intended to provide information needed to support any subsequent Section 106 consultation for undertakings that are anticipated to support NASA's Transition to the new space program, Constellation.

1.2 Objectives and Study Methods

The objective of this study was to identify the facilities at the 13 NASA Centers and component facilities in the context of the U.S. Space Shuttle Program, ca. 1969-2010, and to evaluate their significance as per the criteria of eligibility for listing in the NRHP. Specific work elements included research and historic context development, field survey and assessment of facilities, and preparation of draft and final reports. To standardize the methodology used, a uniform set of protocols, evaluation criteria and reporting format were developed by the HPWG.

The historic facilities field surveys, including archival research, were conducted between July 2006 and January 2007 by four CRM contractors: Archaeological Consultants, Inc. (ACI); Page & Turnbull, Inc.; Science Applications International Corporation (SAIC); and TRC. Typically, field surveys and facilities assessments focused on a list of potentially significant facilities and properties associated with the SSP that was prepared by a team and reviewed by the HPO in consultation with the CRM contractor. Field survey included guided facility tours and interviews. Questions were designed to elicit information regarding the historic and current functions of individual facilities relative to the SSP. For the purpose of continuity, a standard list of questions was used, which included the following:

- What is the original or primary function of the facility?
- How has or does the facility support the SSP?
- What, if any, modifications have been made to the facility to support the changing functions?
- If the facility no longer supports the SSP, when was the facility used to support the SSP (dates) and how (describe use)?
- What are the dates of construction and names of the builder/architect/engineer?
- What specific functions occur here, and what is the internal organization of the facility which supports these?
- What is unique or significant about this facility in the context of the SSP?

In addition, field survey included the gathering of descriptive information such as building construction materials and distinguishing structural features. Digital photographs were taken of exterior elevations and selected interior elements. Facility-specific research included the examination of historic photographs, facility handbooks, real property records, as-built drawings, floor plans, and published and unpublished materials.

1.3 The NRHP Requirements

1.3.1 National Register Criteria for Evaluation

The significance of a cultural resource is evaluated in terms of the eligibility criteria for listing in the NRHP. The National Register Criteria for Evaluation, as described in 36 CFR Part 60.4, are as follows:

The quality of significance in American history, architecture, archeology, engineering and culture is present in districts, sites, buildings, structures and objects that possess integrity of location, design, setting, materials, workmanship, feeling and association and:

A. That are associated with events that have made a significant contribution to the broad patterns of history; or

B. That are associated with the lives of persons significant in our past; or

C. That embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components may lack individual distinction; or

D. That have yielded, or may be likely to yield information important in prehistory or history.

The significance of historic buildings, structures, objects and districts is usually evaluated under Criterion A (association with historic events); Criterion B (association with important persons); or Criterion C (distinctive design or distinguishing characteristics as a whole). Often, more than one criterion will apply to historic resources.

1.3.2 Criteria Considerations

Some types of cultural resources are not typically considered eligible for the NRHP. These resources are religious properties (A), moved properties (B), birthplaces and graves (C), cemeteries (D), reconstructed properties (E), commemorative properties (F), and properties that have achieved significance within the past 50 years (G). As a result, a resource may meet one or more NRHP criteria and still not be eligible unless special requirements are met. These requirements are called Criteria Considerations and are labeled A-G. Of relevance to the Space Shuttle Program study are Criteria Considerations B and G, as follows:

- ***Criteria Consideration B*** **(**Moved Properties) – Some historic resources of significance in the context of the Space Shuttle Program may meet Criteria Consideration B since they were designed to be moved. Thus, it is not required that they, or their integral components, be at their original location in order to retain integrity. These resources are generally significant for their engineering or are significant for their association with events or persons integral to the Space Shuttle Program. However, objects removed from their original setting and that are now located within a museum are typically excluded from NRHP-listing as the change in setting and location diminishes the resources' historic integrity (NPS 1998:36).

- ***Criteria Consideration G*** **(**Properties that have Achieved Significance within the Past 50 Years) – The entire Space Shuttle Program is less than 50 years old. Therefore, Criteria Consideration G cannot be a discriminator for determining eligibility. Some of the resources identified as part of the program will likely be determined to possess exceptional significance in the context of the Space Shuttle Program. Thus, all of these properties should also be considered to meet Criteria Consideration G.

1.3.3 Integrity

To be considered eligible for listing in the NRHP, a property must retain enough integrity to convey its historical significance. The NRHP recognizes seven aspects or qualities that, in various combinations, define integrity: location, setting, materials, design, workmanship, feeling, and association. These are defined as follows (NPS 1995: 44-45):

- *Location is the place where the historic property was constructed or the place where the historic event occurred.*

- *Design is the combination of elements that create the form, plan, space, structure, and style of a property.*
- *Setting is the physical environment of a historic property.*
- *Materials are the physical elements that were combined or deposited during a particular period of time and in a particular pattern or configuration to form a historic property.*
- *Workmanship is the physical evidence of the crafts of a particular culture or people during any given period in history or prehistory.*
- *Feeling is a property's expression of the aesthetic or historic sense of a particular period of time.*
- *Association is the direct link between an important historic event or person and a historic property.*

Many original Apollo-era facilities underwent major modification to support the SSP. As per the guidance provided by the Advisory Council on Historic Preservation (ACHP), as a general rule, in the case of highly technical and scientific facilities, "there should be continuity in function, and thus, in integrity of design and materials, and there may always be integrity of association" (ACHP 1991:33). Where properties have undergone change through time, they must retain "the essential physical features that enable it to convey its historic integrity. The essential physical features are those that define both *why* a property is significant and *when* it was significant" (NPS 1997:46).

1.4 SSP Survey Significance Requirements

For the purpose of this agency-wide survey, in order to qualify for listing in the NRHP, resources must meet the following general registration requirements:

- Real or personal property owned or controlled by NASA;
- Constructed, modified or used for the Space Shuttle Program between the years 1969 and 2010 (or the actual end of the Space Shuttle Program);
- Classified as a structure, building, site, object, or district;
- Eligible under one or more of the four NRHP Criteria (A, B, C, and D); and
- Meets appropriate Criteria Considerations, if applicable

All properties considered eligible for listing under **Criterion A** (Events)

- Must be of significance in reflecting the important events associated with the Space Shuttle Program during the period of significance (1969-2010); or,
- Must be distinguished as a place where nationally significant program-level events occurred regarding the origins, operation and/or termination of the Space Shuttle Program; or

Properties eligible under **Criterion B** (Significant Persons)

- Must be associated with a person whose individual significance to the goals, missions, development and design of the Space Shuttle Program can be identified and documented; or
- Must be distinguished as a place where persons of significance to the Space Shuttle Program worked or trained; or
- Best represent the important achievements or the cumulative importance of prominent persons; or
- Have consequential association with a person who gained national prominence relative to the Space Shuttle Program during the period of significance.

Properties eligible under **Criterion C** (Design/Construction)

- Were uniquely designed and constructed or modified to support the pre-launch testing, processing, launch and retrieval of the Space Shuttle and its associated payloads; or
- Reflect the historical mission of the Space Shuttle in terms of its unique design features without which the program would not have operated; or
- Reflect the distinctive progression of engineering and adaptive reuse from the Apollo-era to the Space Shuttle-era.

Criterion D (Information Value) is primarily used for archeological sites. In accordance with the protocols established for this study, this criterion is considered inappropriate to use as a discriminator, and therefore, was not used as part of the Space Shuttle facilities evaluation.

1.5 National Register Historic Districts

The agency-wide survey focused on the identification of assets which individually meet the criteria of eligibility for listing in the NRHP. While potential historic districts at several Centers (e.g., Johnson Space Center [JSC], Marshall Space Flight Center [MSFC], and Stennis Space Center [SSC]) were considered, they were not identified and evaluated, given this study's examination of only a single NASA program. The exception was the KSC, where a previous survey of Apollo Program historic facilities included the preparation of a Multiple Property nomination. Therefore, the findings of the KSC SSP historic facilities survey were added to this nomination under the newly defined historic context. In general, a Multiple Property nomination, which groups related significant properties, facilitates the evaluation of individual properties by comparing them with resources that share similar physical characteristics and historical associations. In addition, the Multiple Property nomination is a flexible document permitting additional contexts and resources to be added as they become eligible.

1.6 Property Types

Twelve property types, and the associated NRHP eligibility criteria, were used in the evaluation of all NASA-owned and controlled facilities at all NASA Centers and component facilities. These type categories were vetted by the SHPOs prior to their use in the survey. The 12 property types are: Resources Associated with Transportation, Vehicle Processing Facilities, Launch Operation Facilities, Mission Control Facilities, News Broadcast Facilities, Communication Facilities, Engineering and Administrative Facilities, Space Flight Vehicle (or Space Shuttle), Manufacturing and Assembly Facilities, Resources Associated with the Training of Astronauts, Resources Associated with Space Flight Recovery, and Resources Associated with Processing Payloads. Use of these categories serves to narrow the list of eligible properties to those that have true significance in the overall context of the SSP. While some of the facilities were previously listed or determined NRHP-eligible in the context of the Apollo Program or other programs, the application of these eligibility criteria on the SSP-related properties in no way affects their previous designations.

Type 1: Resources Associated with Transportation

A variety of transportation resources were constructed and/or modified to support mission and launch operations in support of the SSP. These resources include runways and landing facilities, Crawlerways, Mobile Launcher Platforms (MLPs), and Mate-Demate Devices (MDD). Special-use vehicles such as Crawler Transporters, 747 Shuttle Carrier Aircraft (SCA), the External Tank (ET) barge, and solid rocket booster (SRB) retrieval ships, also are part of the transportation network. In order to qualify for NRHP listing, transportation resources must meet one or more of the following criteria:

- Have been used for the transportation of unique objects, structures, or significant persons associated with Space Shuttle missions;
- Have been an essential component to the Space Shuttle missions, such that the program could not function without it;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed for the transportation of the Space Shuttle or its payloads;
- Have a direct historical association with the Space Shuttle (including the orbiter, ET and SRB, or a significant person associated with the Space Shuttle Program;
- Must be examples of one of the identified subtypes: road-related resources, water-related resources, rail-related resources, and air-related resources.

Type 2: Vehicle Processing Facilities

Vehicle Processing Facilities include those resources which are vital to the preparation of the launch vehicle for its mission. NASA vehicle processing facilities administer such operations as assembly, testing, checkout, refurbishment, and protective storage for launch vehicles and spacecrafts. Those processing facilities which are eligible for the NRHP were essential in support of the Space Shuttle Program and include but are not limited to the Shuttle Orbiter Final Assembly Facility, the Vehicle Assembly Building

(VAB), the Vertical Assembly Building, and the Orbiter Processing Facility (OPF). To be considered significant, the resources must have been essential to the successful completion of Space Shuttle missions. Vehicle processing facilities were specifically designed for processing the launch vehicle and, therefore, played a major role in nationally significant events related to space exploration. In order to qualify for listing, resources must:

- Have been an essential component to the processing of the Space Shuttle;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed or modified for the processing of the Space Shuttle for launch;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 3: Launch Operation Facilities

Launch Operation Facilities support all activities which occur after the launch vehicle has been processed up to the point of launch. These facilities provide a base and support structure for the transport and launching of the vehicle, service the launch vehicle at the launch pad, control pre-launch and launch operations, and launch the vehicle. These facilities include but are not limited to the launch pads, Launch Control Center (LCC), MLPs, the Rotating Service Structure (RSS), and the Fixed Service Structure (FSS). Such facilities function as the primary resources integral to the launch of the Space Shuttle. In order to qualify for listing, resources must:

- Possess engineering importance and have facilitated nationally significant events associated with space travel;
- Have been integral in pre-launch and launch preparation or the launching of the Space Shuttle;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed for the Space Shuttle;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 4: Mission Control Facilities

Mission Control Facilities support the design, development, planning, training and flight control operations for Space Shuttle flights. These facilities provide the infrastructure that allow the planning, training and flight operations processes necessary to support the Space Shuttle from the inception of requirements through the flight execution process. In order to qualify for listing, resources must have:

- Developed integrated flight crew and flight control plans, procedures, and training;
- Established simulators and flight control ground instrumentation;
- Configured orbiter flight software;

- Contributed to the development and integration of spacecraft and payload support system;
- Provided on-board portable computer hardware and software for the Space Shuttle.

Type 5: News Broadcast Facilities

Press facilities provide a primary site for news media activities at NASA-owned facilities. These broadcasting facilities were essential for relating to the American public news of the Space Shuttle Program to the nation and the world. In order to qualify for listing, resources must:

- Have been an integral facility in the dissemination of information about the Space Shuttle missions to the public;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed to broadcast information;
- Be associated with a significant person associated with the broadcast of Space Shuttle events.

Type 6: Communication Facilities

Communication Facilities in support of the Space Shuttle Program provide a vital site for instrumentation to receive, monitor, process, display and/or record information from the space vehicle during test, launch, and/or flight. Significant Communication Facilities were designed specifically to house computers and computer-related technology vital to the Space Shuttle mission. In order to qualify for listing, resources must:

- Have been integral to the mission of the Space Shuttle;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed for the Space Shuttle missions;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 7: Engineering and Administrative Facilities

Engineering and Administrative Facilities include those resources which are essential to the administrative, scientific, and engineering work of the Space Shuttle Program. Engineering and Administrative Facilities administer such operations as research and development, testing, fiscal matters, procurement, planning, central management, and facilities engineering and construction, as well as providing offices for associated contractors and laboratories for engineers and scientists. These facilities which qualify for listing under the Space Shuttle context must:

- Be places, such as test facilities, that are directly associated with activities of significance which were associated with the development, component testing, implementation and termination of the Space Shuttle Program or missions;

- Be places where persons who made lasting achievements to the Space Shuttle Program worked or convened;
- Should clearly embody the distinctive characteristics of a type or method of construction.

Type 8: Space Flight Vehicle (or Space Shuttle)

This property type includes resources that comprise and/or facilitate the Space Flight Vehicle or Space Shuttle. These include, but are not limited to, the orbiter, SRB, and ET as well as mockups of these components that were used for flight tests or other important development activities. In order to qualify for listing, resources must:

- Have been an integral component of the Space Shuttle stack in its completed form, ready for space flight;
- Have been essential to the Space Shuttle missions and should clearly embody the distinctive aspect of reusability which reflects the goals of the Space Shuttle Program;
- Have been developed and used as test components used in preparation or evaluation for flight or flight tests;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 9: Manufacturing and Assembly Facilities

This property type includes facilities where major flight components were manufactured or assembled. These would include the manufacturing plants where the major components of the Space Shuttle vehicle were fabricated and assembled. In order to qualify, these facilities must:

- Have been an essential component to the manufacturing or assembling of the Space Shuttle;
- Have been constructed or modified to house this manufacturing or assembly facility exclusively;
- Embody a design that is unique to the Space Shuttle requirements;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 10: **Resources Associated with the Training of Astronauts**

This property type includes resources constructed or modified for the purpose of astronaut training and preparation for Space Shuttle missions. These facilities may include but are not limited to: processing facilities, neutral buoyancy tanks, flight simulators and training aircraft. In order to qualify for listing, resources must:

- Have been designed and constructed, or modified, for the unique purpose of astronaut training and be directly associated with preparing astronauts for the completion of a Space Shuttle mission;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed for aeronautical training;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 11: Resources Associated with Space Flight Recovery

This property type includes resources that facilitate the recovery of the Space Flight Vehicle or Space Shuttle and its significant components after its return to Earth. These include, but are not limited to, runways, the MDDs, and the SRB retrieval ships (*Liberty Star* and *Freedom Star*). These resources are essential to the recovery and subsequent reuse of the Space Shuttle and are therefore a significant resource to the program as a whole. In order to qualify for listing, resources must:

- Have been integral to the recovery of the Space Shuttle and/or its significant components;
- Clearly embody the distinctive characteristics of a type or method of construction specifically designed for the recovery of the Space Shuttle;
- Have a direct historical association with the Space Shuttle, or a significant person associated with the Space Shuttle Program.

Type 12: Resources Associated with Processing Payloads

This property type is limited to facilities where fully assembled payloads are readied for insertion in the Space Shuttle orbiter. In order to qualify for listing, these resources must have been used in the processing of payloads for the Space Shuttle. Eligibility is restricted to resources which:

- Represent outstanding achievements in technological, aeronautical or scientific research which would otherwise not have been attainable without the use of the Space Shuttle;
- Clearly embody the distinctive characteristics of a type or method of construction, and which reflect the distinctive aspect of reusability unique to the goals of the Space Shuttle Program;
- Have a direct historical association with the Space Shuttle, or a significant person associated with scientific and/or technological advancements of national significance made as part of the Space Shuttle Program.

1.7 Acknowledgements

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2.0 THE U.S. SPACE SHUTTLE PROGRAM

2.1 Prologue

A "new era for the U.S. Space Program" began on February 13, 1969 when President Richard Nixon established the Space Task Group (STG). The purpose of this committee was to conduct a study to recommend a future course for the U.S. Space Program. Three years later, on January 5, 1972, the Space Shuttle Program was initiated in a speech delivered by President Nixon. During this speech, Nixon outlined the end of the Apollo era and the future of a reusable space flight vehicle providing "routine access to space." By commencing work at this time, Nixon added, "we can have the Shuttle in manned flight by 1978, and operational a short time after that" (Lindroos 2000). The STG presented three choices of long-range space plans. All included an Earth–orbiting space station, a space shuttle, and a manned Mars expedition (NASA, *Report of the Space Task Group* 1969).

Although none of the original programs presented was eventually selected, NASA implemented a program, shaped by the politics and economic realities of its time, that served as a first step toward any future plans for implementing a space station (Jenkins 2001:99). Following a decade of research and development, and more than twenty years of operational flights, including the tragic losses of *Challenger, Columbia*, and their crews, the end of the Space Shuttle Program was announced in a speech delivered by President George W. Bush in January 2004. Although plans for space exploration will advance, the technology of the Space Shuttle and its associated facilities will change or end by 2010.

2.2 Early Visions and Concepts

The idea of a reusable space vehicle can be traced back to 1929 when Austrian aeronautical pioneer Dr. Eugen Sänger conceptualized the development of a spacecraft capable of flying into low earth orbit and returning to earth. While never built, Sänger's concept vehicle, the Silverbird, continued to serve as inspiration for future work, including his 1963 proposal for a two-stage vehicle that would be launched into low-Earth orbit through the use of a large aircraft booster (Jenkins 2001:1; Williamson 1999:161).

Shortly after World War II, the Dornberger Project, carried out by Bell Aircraft Company, developed a two-stage piggy-back orbiter/booster concept (Baker 1973a:202). In the 1950s, rocket scientist Dr. Werner von Braun contributed to the concept of large re-usable boosters. In a series of articles which appeared in Colliers magazine in 1952, he proposed a fully reusable space shuttle, along with a space station, as part of a manned mission to Mars.

The conceptual origins of NASA's Space Shuttle began in the mid-1950s, when the Department of Defense (DoD) began to explore the feasibility of a reusable launch vehicle in space. The primary use of the vehicle was for military operations including piloted reconnaissance, anti-satellite interception, and weapons delivery (Williamson 1999:162). A wide variety of concepts were explored and the X-20 Dyna-Soar (Dynamic Soaring) was chosen. In November 1958, NASA joined with the Air Force on the Dyna-Soar project, which envisioned a "delta-winged glider that would take one pilot to orbit, carry out a mission, and glide back to a runway landing" boosted into orbit atop a Titan II or III (Williamson 1999:162). However, given limited available funds and the competing priorities of other programs, the Dyna-Soar program was cancelled in December 1963 (Williamson 1999:162).

In 1965, the Air Force and NASA established an ad hoc subpanel to determine the status of the technology that was needed to support the development of a Reusable Launch Vehicle. Included in their 1966 report were a variety of design and launch concepts using fully and partially reusable systems (Williamson 1999:164).

George Mueller, the head of the Office of Manned Space Flight at NASA Headquarters, believed that following Apollo, a large space station, supported by low-cost, reliable launch vehicles, was the next logical program for NASA (Jenkins 2001:77). Testifying before the Senate Space Committee on February 28, 1968, he stressed the importance of a new approach to space logistics. Later that year, in an August speech before the British Interplanetary Society, Mueller stated:

> *Essential to the continuous operation of the space shuttle will be the capability to resupply expendables as well as to change and/or augment crews and laboratory equipment . . . Our studies show that using today's hardware, the resupply cost for a year equals the original cost of the space station. . . Therefore, there is a real requirement for an efficient earth-to-orbit transportation system - an economical space shuttle . . . The shuttle ideally would be able to operate in a mode similar to that of large commercial air transports and be compatible with the environment at major airports. . .* (Jenkins 2001:78).

In 1968, NASA convened the Space Shuttle Task Group and, through the Manned Spacecraft Center (MSC) (later named Johnson Space Center [JSC]) and the MSFC, the group issued a request for proposals for an Integral Launch and Reentry Vehicle (ILRV) system. As initially conceptualized, the Space Shuttle, designed to be completely reusable, would be part rocket, part orbiting spacecraft, and part airplane. Supported by a fleet of five vehicles, each designed for a maximum of 100 reuses, the primary use of this low-cost space transportation system was to provide logistical support of the Space Station. The reusable nature was expected to reduce payload costs.

2.3 Feasibility and Definition Studies

On January 31, 1969, NASA awarded contracts for design concept studies of the ILRV to four industrial contractors, General Dynamics/Convair, Lockheed, McDonnell Douglas, and North American Rockwell (Ezell 1988:Table 2-57; Jenkins 2001:79; Williamson 1999:164). These Phase A feasibility studies were to terminate in September 1969, at which time NASA would synthesize the results (Baker 1973a:202). Impacting the scheduled completion date was NASA's decision to study the two-stage fully reusable spacecraft concept. Accordingly, the ILRV contracts were reoriented, and the feasibility studies emphasizing the fully reusable concept were concluded on November 1. NASA evaluated the results over the next three months.

NASA issued a Request for Proposal (RFP) for Phase B definition studies on February 18, 1970, and subsequently selected North American Rockwell's Space Division and McDonnell Douglas to proceed with studies to define the two-stage, fully reusable, fly-back shuttle (Baker 1973a:203). At the outset of Phase B studies, the booster portion of the shuttle initially developed by Rockwell was a manned, powered, fly-back vehicle. Propulsion systems for the baseline design included 12 main engines, 22 altitude control thrusters, and four thrust air-breathing engines. The flight deck was designed to hold a two-man flight crew (Baker 1973a:209-210).

As a result of pressures within NASA, further Phase A awards to fund alternative approaches to shuttle design were made to Grumman/Boeing, Lockheed, and Chrysler. Work by the Grumman/Boeing team had an influence on Rockwell and McDonnell Douglas, resulting in major program changes. A two and one-half year period of change and modification followed, driven largely by the politics and economics of annual budgeting. While NASA's intended goal for the "Space Transportation System" was to provide a low cost capability "for delivering payloads of men, equipment, supplies, and other spacecraft to and from space . . ." (Jenkins 2001:99), the ultimate goal was to develop a permanent manned space station. However, to secure program approval, NASA had to meet its commitment to the Office of Management and Budget (OMB) to make access to space more economical. One key strategy was getting support from the DoD to use the system (Jenkins 2001:99). Among the Air Force requirements for the Shuttle were that it was powerful enough to accommodate large payloads such as classified satellites, and the ability to fly often and on short notice (Harland 2004:5). Ultimately, in an effort to overcome Congressional opposition to the Shuttle Program, and to reduce costs in the face of continued Federal budget cuts, NASA chose a partially rather than a fully reusable shuttle design, with the support of the Air Force.

As a result, a radically transformed shuttle design configuration emerged, much unlike the vehicle conceived at the outset of Phase B. Further studies in Phase B showed that savings could result if both the oxygen and hydrogen tanks of the orbiter were carried as external appendages, thus permitting a reduction in the size of the orbiter. The partially reusable design with external propellant tank and a delta-wing orbiter was about half the manufacture cost of a fully reusable vehicle. It also enhanced the aerodynamics of the shuttle orbiter and increased its safety. More than 29 different shuttle designs were analyzed in 1971 before the final design was chosen in 1972 (Williamson 1999:167, 172). In addition to the adoption of an external propellant, NASA selected a parallel burn solid rocket motor configuration for the shuttle (Baker 1973a:344, 350).

Concurrent with the shuttle design studies, a search for a launch and recovery site for the shuttle was conducted. By 1970, NASA received over 100 unsolicited bids from across the U.S., and choosing a launch site had become a political issue. To facilitate the selection process, the Ralph M. Parsons Company in Los Angeles was awarded a $380,000 contract to review potential locations. Also, a 14-member Space Shuttle Facilities Group was established to select the final site. After nearly a year of study, on April 14, 1972, NASA announced KSC in Florida and Vandenberg Air Force Base (AFB) in California as the two launching sites (Ezell 1998). Numerous variables, such as booster recovery, launch azimuth limitations, latitude and altitude effects on launch, and impact on present and future programs were taken into account by NASA. The fact that NASA had already invested over $1 billion in launch facilities at KSC made it a logical choice. KSC would be used for easterly launches, accounting for most missions; Vandenberg would be used for polar launches, accounting for most Air Force missions. Like KSC, where existing facilities could be modified and reused, the Vandenberg Launch Site (VLS) already housed a launch and landing site, Space Launch Complex Six (SLC-6), built for the Manned Orbiting Laboratory (MOL) Program which was cancelled in 1969 (Jenkins 2001:155).

2.4 Center Responsibilities and Contractor Awards

NASA gave responsibility for developing the orbiter and overall management of the SSP to the MSC in Houston, based on the Center's experience with the orbiter. MSFC was responsible for development of the Space Shuttle Main Engine (SSME), SRBs, the ET, and for all propulsion-related tasks. Engineering design support continued at MSC, MSFC and NASA Langley (Jenkins 2001:122), and engine tests were to be performed at NASA's Mississippi National Space Technology Laboratories (NSTL, later named Stennis Space Center [SSC]) and at the Air Force's Rocket Propulsion Laboratory in California, the Santa Susana Field Laboratory (SSFL). KSC, responsible for designing the launch and recovery facilities, was to develop methods for shuttle assembly, checkout, and launch operations (Ezell 1988:Table 2-57; Williamson 1999:172-174).

On January 5, 1972, President Richard Nixon instructed NASA to proceed with the design and building of a partially reusable space shuttle consisting of a reusable orbiter, three reusable main engines, two reusable SRBs, and one non-reusable external liquid fuel tank. NASA's administrators vowed that the shuttle would fly at least 50 times a year, making space travel economical and safe.

In March 1972 NASA issued an RFP for development of a space shuttle. Technical proposals were due by May 12, 1972, with cost proposals due one week later. In its instructions, NASA noted that:

> *The primary objective of the Space Shuttle Program is to provide a new space transportation capability that will (a) reduce substantially the cost of space operations, and (b) provide a capability designed to support a wide range of scientific, defense and commercial uses.*

Proposals were submitted by four major aerospace corporations, all of which had participated in the definition studies. The U.S. Air Force, a prospective major user of the Space Shuttle, participated in the contractor selection process. The Space Division of North American Rockwell Corporation of Downey, California was selected by NASA as the prime contractor responsible for design, development and production of the orbiter vehicle and for integration of all elements of the Space Shuttle system. The contract was valued at $2.6 billion over a period of six years.

On July 12, 1972, MSFC announced that Rocketdyne had been selected to design and manufacture 35 SSMEs (Ezell 1988:Table 2-57). This contract award was contested by Pratt & Whitney, who requested an investigation by the General Accounting Office (GAO). NASA’s contract to Rocketdyne was held pending the investigation. In March 1972, the GAO determined that NASA chose Rocketdyne fairly, and gave NASA permission to proceed with the contract.

Other contract awards followed. In August 1973, the Martin Marietta Corporation was selected to design, develop, and test the ET, with tank assembly taking place at NASA’s Michoud Assembly Facility (MAF) near New Orleans, Louisiana. Also in 1973, a contract covering SRB development was awarded to Thiokol Chemical Company (now ATK Thiokol Propulsion) of Utah.

Originally, a seven year development period was planned, resulting in full operational activities beginning in mid-1979. However, the shuttle development program formally took nine years. In a seeming prediction of future events, David Baker noted, in 1971, that “. . . it is likely that shuttle development will stretch considerably beyond the predicted schedule. It can be expected that the integration of shuttle development with relatively static NASA budgets will spread the initial date of operations out to the 1981-83 period at least” (Baker 1971:454).

The $246 billion 1973 fiscal year (FY) budget sent to Congress by President Nixon included $3.379 billion for NASA, or roughly 1.3% of the total budget. This request included $200 million for Space Shuttle development. At this time, the total development costs were expected to be roughly $5.5 billion with an operational system in place by the end of the decade. Thirty to forty launches per year were assumed. While specific funding for the shuttle did not begin until 1974, by 1973 NASA already had moved from the planning and study stage to design and production (Dethloff 1998:289).

2.5 Shuttle Development and Testing

Initially, between 1973 and 1977, several discrete system designs were adopted, tested, modified or deleted. The SSME principal components, including the thrust chamber, turbopumps, propellant injectors, and nozzle, were fabricated by Rocketdyne, who also conducted the first preburner test at the SSFL in California in August 1973. The Integrated Subsystem Test Bed (ISTB) test facility at the NSTL (now SSC) was used for the first full-up ignition test in May 1975, with the full thrust chamber ignition test conducted in June 1975 (Biggs 1992). ET component testing started in 1974, and tests on the SRB components began in 1976. Wind tunnel tests on integrated shuttle components were started by 1977.

2.5.1 The Space Shuttle Main Engines

In mid-July 1971, NASA announced that the Rocketdyne Division of North American Rockwell had been selected to develop and manufacture the SSME. Prior to this, North American Rockwell won Phase A (1969) and Phase B (1970) shuttle developmental contracts, administered through the MSC in Houston (today's JSC) (Bromberg 1999:77-88; Dethloff 1993:222-225). North American Rockwell/Rocketdyne's Phase B tests of a Space Shuttle engine took place at the company's Nevada Field Laboratory (NFL) near Reno during late 1970 and early 1971. A prototype SSME thrust chamber (partial engine) fired successfully in early 1971 at the NFL, giving North American Rockwell/ Rocketdyne the critical edge toward award of the later manufacturing contract for the engine (Heppenheimer 2002a:102, 132).

In early 1972, NASA awarded the Rocketdyne Division of North American Rockwell a 90-day letter contract to initiate work on the development and production of the SSME. Canoga Park, California was the designated manufacturing location for the engine. The contract called for delivery of the first flight engines by 1977 (*Marshall Star* 19 April 1972:2). NASA provided $15.4 million in additional monies to Rocketdyne for modifying the Coca Area test stands at the SSFL for the SSME, as well as lesser funding for facilities changes needed at Canoga Park (*Marshall Star* 25 October 1972:2). The SSFL would accommodate static firings of SSME turbopumps, combustion devices, and combined SSME components.

In early 1973, the MSFC, responsible for the development of the SSME, provided Rocketdyne with specifications for the SSME. The MSFC, working with Rocketdyne, designed each SSME for 55 flights and "an accumulative run time of 7.5 hours before overhaul" (*Marshall Star* 11 October 1978:3-4). During the development and testing of the engine, the MSFC conducted quarterly SSME reviews. The Center also established an SSME Hardware Simulation Laboratory (HSL) in late 1974 (*Marshall Star* 9 October 1974:1-2).

The SSMEs manufactured at Rocketdyne's plant in Canoga Park were tested at both the SSFL in California and the NSTL near Bay St. Louis, Mississippi. The MSFC planned static firings of the SSME on the A-1 and A-2 test stands at the NSTL, with components testing for the developmental SSME at the SSFL. Collectively, these facilities evaluated the performance of every engine, engine components, and complete propulsion systems.

The first hot firing of the SSME test program occurred in April 1974 with the successful run of a preburner assembly at the SSFL (*Marshall Star* 24 April 1975:2). The test, run on the Coca I stand, lasted for a total of 3.5 seconds. This initial program test predated by one year the start of engine level tests of the ISTB at the NSTL, initiated in May 1975. Manufacture of the ISTB, the alternate name for SSME 0001, was completed at Rocketdyne's Canoga Park facility in March 1975 (*Marshall Star* 26 March 1975:1 and 4). Generally, a month elapsed between a component test at the SSFL and the counterpart ISTB run at the NSTF (Heppenheimer 2002b:137).

Photo 2.1. Preparations for SSME components test on Coca I (Test Stand A-3) at Santa Susana (NASA Area II), 20 December 1974.
(Source: Boeing, Rocketdyne Historic Photograph Collection, SSFL)

In July 1976, the first flight configuration nozzle for the SSME was proof tested by Rocketdyne at its facilities in Canoga Park. More tests were to follow to verify design and manufacturing techniques. These tests were planned to occur at the SSFL and at the NSTL (*Marshall Star* 21 July 1976:1). SSME 0002, fitted with a flight-configuration nozzle, was fired successfully on Test Stand A-2 at the NSTL in March 1977 (*Marshall Star* 30 March 1977:1).

The first simultaneous test of three SSMEs in the Orbiter Boattail simulator (also known as the Main Propulsion Test Article [MPTA]), a mocked up aft section of the orbiter, was conducted at the NSTL on April 21, 1978 (*Marshall Star* 24 May 1978:1; *Marshall Star* 2 August 1978:1 and 3; Weitze October 2004:15-29). The test, which lasted 1.90 seconds, "heralded a series of eighteen MPTA tests, six of which lasted the entire 520 seconds, which is the time required for the Shuttle to enter Earth's orbit. The final test of the system occurred on January 17, 1981 and lasted 629 seconds, the longest conducted on the MPTA and the first full duration static firing using the flight-type nozzle" (SSC 2006:23). The MPTA test series concluded with a combined test time of 3,775 seconds (SSC 2007:23).

NASA's overall objective was to boost the accumulated firing time to meet their goal of 80,000 seconds, which was viewed as a necessary testing milestone prior to the first flight of the Orbiter *Columbia*. To achieve this goal, NASA contracted with Bechtel to modify the Coca I test stand at the SSFL, renaming the facility Test Stand A-3. Modifications were carried out in October and November 1978. Rocketdyne added personnel and ran the Coca I (A-3) test stand "around the clock, with a two-shift firing crew and a third shift for maintenance" (Heppenheimer 2002b:164). In general, SSFL's A-3 stand supplemented the sea level testing at the NSTL's A-1 stand, and was "crucial in identifying problems related to the initial designs of the high-pressure turbopumps, powerhead, valves, and nozzles" (Jue n.d.). The major SSME components, including turbopumps, combustion devices, preburners, main injectors, main combustion chambers, and short nozzles, were tested individually, at operational levels. The initial firing on November 7, 1978 was conducted to check out the test stand as well as the rebuilt SSME 0201. The 0201 engine, originally designed as 0001, had previously completed 67 tests on Test Stand A-1 and 15 altitude tests on A-2 at the NSTL (*Marshall Star* 25 October 1978:3; *Marshall Star* 15 November 1978:4). Thirty-five consecutive firings, all at the scheduled duration, were made at SSFL during 1979 and 1980, in a prelude to certification of individual engines for flight. As the result of an aggressive test schedule at both SSFL and NSTL, the first 100,000 seconds of development test time was reached in five years and seven months following the start of the SSME test program in 1974 (Jue n.d.).

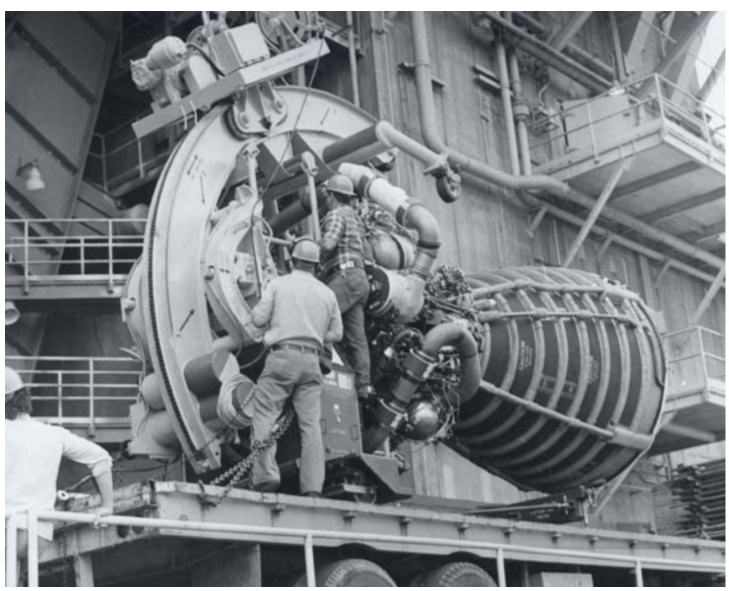

Photo 2.2. SSME hoisted into the A-2 test stand at Stennis Space Center (then, NSTL) before undergoing test firing, January 1, 1979.
(Source: NASA-HQ-GRIN; GPN-2000-000546)

In April 1979, Rocketdyne personnel ran acceptance tests on the third SSME for the *Columbia*. Tests included checkout of electrical and mechanical systems, followed by three static firings at the NSTL. After completion of the tests, NASA would ship the SSME to the KSC for fitting into the *Columbia*. At this junction, NASA planned to launch the *Columbia* in late 1979 (*Marshall Star* 4 April 1979:1).

The cumulative test firings at SSFL and the NSTL (SSC), measured in seconds, led to the certification of the SSMEs for operation prior to the first manned orbital flight of the *Columbia*. Beginning in 1974, and currently backed by almost one million seconds of hot fire experience, continuous improvements have been made to the SSME, the world's first reusable liquid booster engine designed for human space flight.

2.5.2 The Orbiter *Enterprise*

On September 17, 1976, the full-scale Orbiter Vehicle (OV) prototype *Enterprise* (OV-101) was completed. Designed for test purposes only and never intended for space flight, structural assembly of this orbiter had started more than two years earlier in June 1974 at Air Force Plant (AFP) 42 in Palmdale, California. Major components, including the fuselage parts and wings, were fabricated by Rockwell's Space Division and its subcontractors. The forward and aft fuselages were built at Rockwell's plant in Downey, California; the mid-fuselage was manufactured by Convair in San Diego; the wings were built by Grumman; and the vertical fin came from Fairchild Republic (Heppenheimer 2002b:29). Other subcontractors engaged in the production and testing of key components included Aerojet's work on the Orbital Maneuvering System (OMS); the small thrusters built by Marquardt, and the Auxiliary Power Unit (APU) fabricated by Sunstrand.

The completed orbiter was originally slated to be named *Constitution* in honor of the Bicentennial. However, as the result of a massive letter campaign initiated by Richard Hoagland, a science advisor at CBS News and devoted Star Trek fan, OV-101 underwent a last-minute name change when President Gerald Ford was persuaded to name the orbiter after the famous television program starship. Thus, on September 8, 1976, OV-101 was officially designated *Enterprise.* Roll-out of the *Enterprise* on September 17 was attended by thousands, including Star Trek actors Leonard Nimoy, George Takei, and DeForest Kelly (Heppenheimer 2002b:100-101).

Although the *Enterprise* was an aluminum shell prototype incapable of space flight, it reflected the overall design of the orbiter. As such, it served successfully in 1977 as the test article during the Approach and Landing Tests (ALT) aimed at checking out both the mating with the Boeing 747 SCA for ferry operations, as well as the orbiter's unpowered landing capabilities.

2.5.3 Shuttle Carrier Aircraft

In 1973, NASA considered both the C-5A cargo aircraft and the Boeing 747 as potential vehicles to carry and ferry the orbiter cross country. In August and October of this year, contracts were awarded to Lockheed and Boeing, respectively, to conduct preliminary feasibility studies to evaluate whether the orbiter could separate clearly from the back of the carrier aircraft. Test results demonstrated that the 747 had several advantages over the C-5A. Compared with the C-5A, the 747 was shown to be safer and to have a longer estimated range capable of a nonstop transcontinental flight without the need for refueling. Additionally, the 747 could use shorter runways, and had a longer structural life.

Following the request of authorization to use the 747 by Christopher Kraft, director of NASA's JSC, purchase of a Boeing 747 was approved in June 1974 by the NASA Space Shuttle Program Office. NASA paid $15.6 million for a used Boeing 747-123, which was given the new registration number N905A (Heppenheimer 2003b:94). This was a commercial aircraft that was not built specifically for the SSP. Between August and December 1976, the aircraft was physically modified for use as a SCA at Boeing's production facilities near Everett, Washington. Structural modifications to increase stability and safety included strengthening of the fuselage to support the weight of the orbiter, new fittings to support the orbiter atop the fuselage, and new controls and displays for the cockpit. Improvements also were made to the Pratt and Whitney JT-9D engines to provide more power. In January 1977, the modified aircraft was flown to Edwards AFB for use with the *Enterprise*.

2.5.4 Approach and Landing Tests Program: 1977

Initial flight tests of an aircraft resembling the orbiter were conducted concurrent with the assembly of the *Enterprise*. These early tests, conducted in 1975, made use of the X-24B, a lifting body.
Between February and October 1977, a series of phased approach and landing tests (ALT) was conducted at NASA DFRC using the Orbiter *Enterprise* mated with the 747 SCA. The first phase of the ALT program, conducted on February 15, 1977, entailed three high speed taxi tests at Runway 04/22, the main concrete runway at Edwards AFB. The purpose of these tests was to "assess directional stability and control, elevator effectiveness during rotation prior to takeoff, airplane response in pitch, thrust reverser effectiveness, use of the 747's brakes, and airframe buffet" (Heppenheimer 2002b:106). The tests were a success and demonstrated the flightworthiness of the aircraft-orbiter combination.

The following "captive-inert" phase of testing, conducted in February and March, served to qualify the 747 SCA for use in ferry operations. Six flights were planned at increasing speeds for the purpose of evaluating the flying and handling characteristics of the mated configuration, including such qualities as buffeting and flutter, airspeed calibration, and stability. This phase of the test series was controlled on the scene at the DFRC. Given the success of the first three flights, Deke Slayton, manager of the ALT program, decided to cancel the final (sixth) flight. The goal of the last two test flights was to conduct the maneuvers of an air launch.

Next, three "captive-active" tests were performed on June 18, June 28, and July 26, 1977. These tests marked the first time that the MCC at JSC controlled a shuttle in flight. During these tests, the orbiter was piloted and powered up while attached to the SCA to check how the *Enterprise* would perform in the air. The third captive-active test deployed the shuttle landing gear for the first time.

The final phase of testing marked the first free flight of the orbiter. Five test free flights were conducted between August 12 and October 26, 1977. These were controlled by astronauts Joseph Engle, Charles Fullerton, Fred Haise, and Richard Truly. (Haise was a veteran of the Apollo Program. Truly became the director of NASA's SSP in 1986, and served as NASA's administrator from 1989 to 1992.) The third free flight on September 23 used the microwave landing system at Edwards AFB for the first time. The final flight landed on the 10,000-foot concrete runway at Edwards AFB rather than a dry lake bed, as used before. The first three free tests were flown with the tail cone (fairing) on the orbiter; the fourth and fifth free flights were made with the cone off. Overall, the ALT program was successful in providing both operational experience as well as "benchmarking data for the flight simulators that were the working tools of day-to-day astronaut training" (Heppenheimer 2002b:121). In addition, the test results illustrated where significant redesign of the orbiter was needed.

Photo 2.3. *Enterprise* and SCA during the second free flight of the ALT program, September 13, 1977.
(Source: NASA JSC, S77-28137)

2.5.5 Mated Vertical Ground Vibration Tests: 1978-1979

Following completion of the ALT flights, *Enterprise* was flown to MSFC for a series of Mated Vertical Ground Vibration Tests (MVGVT) to determine the structural integrity of the Shuttle vehicle. The test program, initiated in May 1978 and completed in February 1979, simulated the period of flight just prior to SRB separation (Dunar and Waring 1999:314). The MVGVT series "used a set of exciters and sensors placed on the skin of the mated elements to create and monitor vibrations and resonances to those that would later be encountered during powered ascent" (Jenkins 2001:213). In 1977, prior to the start of the test program, the *Pathfinder*, a 75-ton Shuttle orbiter weight simulator, was built at the MSFC to validate the facilities being used for the MVGVT series. This steel structure, which approximated the dimensions of the *Enterprise,* was used to practice lifting and handling the orbiter. It was also used to fit check the roads and facilities that were used during the MVGVT (Jenkins 2001:215).

Photo 2.4. Orbiter *Enterprise* on strongback, outside Building 4550 at MSFC, 1978. (Source: NASA Marshall Space Flight Center, MSFC-7889025)

The earliest tests used the ET test article mated to the *Enterprise*. The liquid oxygen (LOX) tank contained deionized water and the liquid hydrogen (LH2) tank was pressurized but empty. The combined orbiter-ET was suspended by a combination of air bags and cables attached to the top of the Structural Dynamic Test Facility (Building 4550) located at MSFC. This configuration was used to simulate the high altitude portion of ascent after SRB separation. In August 1978, additional modifications were made to Building 4550 to support a second series of vibration tests. The test configuration added a set of SRBs containing inert propellant to simulate lift-off conditions. "This marked the first time that a complete set of dimensionally correct elements of the Space Shuttle had been assembled together" (Jenkins 2001:213). The test series in the lift-off configuration was completed on September 15, 1978, and in the burn-out configuration on December 5.

The final series of vibration tests, initiated in January 1979, used a configuration similar to the second series, except that the SRBs were empty.

At the conclusion of the test series, and contrary to original plans, *Enterprise* was not refitted as a flight orbiter. Rather, NASA decided that the less costly alternative was to use structural test article, STA-099, then under construction at Palmdale. Rebuilt for operational service, STA-099 thus became OV-099, the *Challenger* flight vehicle.

2.6 Orbital Test Flights: 1981-1982

The first orbiter intended for space flight, *Columbia* (OV-102), arrived at NASA KSC from Palmdale in March 1979. Originally scheduled to lift off in late 1979, the launch date was delayed by problems with both the SSME components as well as the thermal protection system (TPS). Upon its arrival at KSC, the orbiter was missing thousands of tiles, its main engines, APUs, on-board computers, and fuel cells. About six months of assembly work needed to be done. As the result of changed requirements for increased tile strength ("densification"), for 20 months technicians at KSC worked three shifts per day, six days per week installing, testing, removing and reinstalling approximately 30,000 tiles. *Columbia* spent 610 days in the OPF, another 35 days in the VAB and 105 days on Pad 39A before finally lifting off on April 12, 1981.

In early November 1980, the work on the TPS was completed, the ET was mated to the SRBs, and the three SSMEs were installed. The Orbiter *Columbia* was mated to the ET and SRBs in the VAB on November 26, and powered up on December 4. Preparations for rollout and ordnance installation were begun on December 19, and ten days later, *Columbia* was transported aboard the MLP from the VAB to Pad A of Launch Complex 39.

In preparation for the first launch of *Columbia*, NASA KSC, with the support of MSFC, ran a series of Space Shuttle systems tests and procedures between December 1980 and April 1981. These included the following:

In December:
- Shuttle Integrated Test (S0008)

In January:
- Shuttle Launch Pad Validation Test (S0009)
- Shuttle Plug Out Test (S0010)
- Auto Load and Detank Test

In February:
- SRB Instrument Electronic Assembly Tests
- Simulated Wet Countdown Demonstration Test (CDDT) (S0014)
- Flight Readiness Firing of all three SSMEs
- Mission Verification Tests

In March:

- Shuttle Systems Test (S0005)
- Dry CDDT. This two-day dry test launch was the first major prelaunch simulation.

In April:

- Dual External Tank Propellant Load and Drain Test (S0036)

Columbia launched at 7:00 a.m. Eastern Standard Time (EST) on April 12, 1981. STS-1, the first orbital test flight and first Space Shuttle Program mission, was commanded by John W. Young and piloted by Robert L. Crippen. The *Columbia* landed at 10:20 a.m. PST on April 14 at Runway 23 at Edwards AFB after its historic mission, which lasted two days, six hours, 20 minutes, and 53 seconds. This launch demonstrated *Columbia's* ability to fly into orbit, conduct on-orbit operations, and return safely (Jenkins 2001:268). However, 16 tiles were lost during the flight, and 148 were damaged. Tile damage was blamed on an overpressure wave created by the ignition of the SRBs. "Subsequent modifications to the launch pad water sound suppression system eliminated this problem in future flights" (Lethbridge 1998).

Photo 2.5. The April 12, 1981 launch of STS-1.
(Source: NASA Headquarters, GPN-2000-000650)

Columbia flew three additional test flights in 1981 and 1982 (Table 2.1), all with a crew of two. The Orbital Test Flight Program ended in July 1982 with 95% of its objectives completed. After the end of the fourth mission, President Ronald Reagan declared that with the next flight the Shuttle would be "fully operational."

Table 2.1. Orbital Test Flights.

Flight	Launch	Landing	Duration	Notes
STS-1	April 12, 1981	April 14, 1981	54 hr 20 min	16 tiles lost and 148 damaged
STS-2	Nov. 12, 1981	Nov. 14, 1981	54 hr 13 min	First test of Remote Manipulator System
STS-3	March 22, 1982	March 30, 1982	192 hr 4 min	Landed at White Sands because the Edwards AFB landing site was flooded due to heavy rains
STS-4	June 27, 1982	July 4, 1982	169 hr 9 min	First concrete runway landing

2.7 Astronaut Selection

In July 1976, NASA issued a call for Space Shuttle astronauts. In accordance with the needs of the SSP, the candidates were divided into two groups, shuttle pilots and mission specialists, each with different requirements. Pilots, at the minimum, needed a bachelor's degree from an accredited institution in engineering, physical science or mathematics, 1,000 hours of first pilot time, and pass a NASA Class 1 space flight physical. Any advanced degrees, equivalent experience, 2,000+ hours of flying time, high performance jet or flight test experience, and a height between 64 and 76 inches was desired. Mission specialists had similar requirements, except that a degree in biological sciences was accepted; they did not need flying time; and they had to pass a Class 2 space flight physical. Their desirable height was between 60 and 76 inches (*Roundup* 16 July 1976:1). Women and minority candidates were encouraged to apply. In January 1978, the first class of Shuttle astronauts, and eighth group overall, was selected. It consisted of 21 military officers and 14 civilians from which came 15 pilots and 20 mission specialists, including six women and four minorities (*Roundup* 20 January 1978:1). From this class, Sally Ride became the first American woman in space (1983); Guion Bluford became the first African-American in space (1983); and Kathryn Sullivan became the first woman to conduct a spacewalk (1984).

2.8 Operational Flights: 1982+

STS-5, which began with the lift-off of *Columbia* from Pad 39A on November 11, 1982, marked the first operational flight of the Space Shuttle Program. The mission, which was crewed by a team of four and lasted 122 hours and 14 minutes, ended on November 16 with a landing at Edwards AFB.

Challenger (OV-099) was added to the Shuttle fleet in 1982 and made its first flight (STS-6) in April 1983. *Discovery* (OV-103) and *Atlantis* (OV-104) were delivered to KSC in November 1983 and April 1985, respectively. *Discovery* made its maiden flight (STS-41-D) on August 30, 1984; the first space flight of *Atlantis* (STS-51-J) took place on October 3, 1985. Between 1982 and 1985, *Columbia*, *Challenger*, *Discovery* and *Atlantis* collectively averaged four to five launches per year. Despite the 1970s projections of a maximum of 60 launches per year, in reality, the nine flights in 1985 were a milestone for the SSP. All of these early launches, from 1982 through 1985, were made from Pad 39A; all but six missions ended with landings at Edwards AFB.

The missions flown between 1982 and early 1986 were marked by several milestones (see Appendix B) and accomplishments. Beginning with STS-9 in 1983, the Shuttle flew a number of science missions with the Spacelab module; carried the first woman astronaut, Sally Ride (STS-7); and took U.S. Senator Jake Garn (STS-51-D) and Representative Bill Nelson (STS-61-C) into space. In 1984, the Solar Max satellite was retrieved, repaired, and reorbited. In the same year two malfunctioning commercial communication satellites were retrieved in orbit and brought back to Earth; in 1985, another satellite was fixed in orbit (Rumerman and Garber 2000:2).

2.8.1 The *Challenger* Accident and Aftermath

On January 28, the 25th launch of the Space Transportation System (STS) program (STS-51-L), and the first Shuttle launch from Pad 39B, ended in disaster. Seventy-three seconds after launch, the *Challenger* was destroyed, and the crew of seven astronauts (Francis R. Scobee, Michael J. Smith, Ellison S. Onizuka, Judith A. Resnick, Ronald E. McNair, Sharon Christa McAuliffe, and George B. Jarvis) all perished.

Following this tragedy, the SSP was suspended for approximately two and one-half years, and President Ronald Reagan formed a 13-member commission to investigate the cause of the accident. The Presidential Commission on the Space Shuttle Challenger Accident, popularly known as the Rogers Commission after its chairman, William P. Rogers, was tasked with reviewing the images (video, film and still photography), telemetry data, and debris evidence. As a result, the Commission concluded:

> *The consensus of the Commission and participating investigative agencies is that the loss of the Space Shuttle Challenger was caused by a failure in the joint between the two lower segments of the right Solid Rocket Motor. The specific failure was the destruction of the seals that are intended to prevent hot gases from leaking through the joint during the propellant burn of the rocket motor. The evidence assembled by the Commission indicates that no other element of the Space Shuttle system contributed to this failure* (Jenkins 2001:279).

In addition to identifying the cause of the *Challenger* accident, the Rogers Commission report, issued on June 6, 1986, included a review of the Space Shuttle Program. The report concluded "that the drive to declare the Shuttle operational had put enormous pressures on the system and stretched its resources to the limit" (CAIB 2003:25). In addition to mechanical failure, the Commission noted a number of NASA management failures that contributed to the catastrophe. Nine basic recommendations were made. As a result, among the tangible actions taken were extensive redesign of the SRBs; upgrading of the Space Shuttle tires, brakes, and nose wheel steering mechanisms; the addition of a drag chute to help reduce speed upon landing; the addition of a crew escape system; and the requirement for astronauts to wear pressurized flight safety suits during launch and landing operations. Other changes involved reorganization and decentralization of the Space Shuttle Program. Experienced astronauts were placed in key NASA management positions, all documented waivers to existing flight safety criteria were revoked and forbidden, and a policy of open reviews was implemented (Lethbridge 2001:4). In addition, NASA adopted a Space Shuttle flight schedule with a reduced average number of launches, and discontinued the long-term practice of launching commercial and military payloads (Lethbridge 2001:5).

In January 1987, the recovered remains of the Space Shuttle *Challenger* were sealed in two Minutemen missile silos and adjacent underground equipment rooms at Launch Complex 31/32 at Cape Canaveral Air Force Station (CCAFS).

In July 1987, NASA awarded a contract to Rockwell for construction of OV-105, *Endeavour,* to replace *Challenger*. To build the new orbiter, Rockwell used structural spares previously constructed between 1983 and 1987 under contract with NASA. These spares included an aft fuselage, crew compartment, forward reaction control system, lower and upper forward fuselage, mid-fuselage, wings (elevons), payload bay doors, vertical stabilizer, body flap, and one set of orbital maneuvering system/reaction control system pods. Assembly of OV-105 was completed in July 1990, and the orbiter was delivered to KSC in May 1991. *Endeavour* made its first flight (STS-49) on May 7, 1992.

Photo 2.6. *Endeavour* (OV-105) roll-out at Palmdale, California, May 6, 1991.
(Source: NASA, Johnson Space Center, S91-36157)

In the aftermath of the *Challenger* accident, and following the recommendation of the Rogers Commission for organizational change, NASA moved the management of the SSP from JSC to NASA Headquarters, with the aim of preventing communication deficiencies (CAIB 2003:101). In addition, an exhaustive investigation by a Senate subcommittee resulted in the cancellation of NASA's plans to activate the VLS in California, leaving the U.S. without a manned polar launch capability. The subcommittee outlined potential technical and structural problems at the VLS, which would further delay a West Coast shuttle launch until mid-1989 (United States Senate Subcommittee on Military Construction June 1986). Prior to this time, during late 1984 and early 1985, the site was used for a series of flight verification tests using *Enterprise*. *Discovery* was to fly the first mission from VLS in 1986 and be permanently based there, but all launch preparations were suspended before this occurred (Jenkins 2001:217). The facilities were ordered mothballed in 1988, and the Space Shuttle Program at VLS was officially terminated in December 1989.

2.8.2 Return to Flight: 1988 to 2002

The launch of *Discovery* (STS-26) from KSC Pad 39B on September 29, 1988 marked a Return to Flight after a 32-month hiatus in manned spaceflight following the *Challenger* accident. STS-26 carried a crew of five and a replacement for NASA's Tracking and Data Relay Satellite (Williamson 1999:186). The problem in the design of the SRBs that had caused the loss of *Challenger* had been found and corrected. Many other critical flight systems had been re-examined and recertified. "Since 1988, NASA has kept the rate of Shuttle flights relatively low (five to seven per year) and improved its on-time launch performance, suggesting that such a rate provides a good balance between safety and costs" (Williamson 1999:188). Between September 29, 1988 and November 23, 2002, a total of 87 launches were made from the KSC, averaging six launches per year. The years following the STS-26 flight "were among the most productive in the Shuttle's history, as a long backlog of payloads finally made it to the launch pad" (Reichhardt 2002:65). Roughly 79% of the missions during the first decade of the Shuttle Program (1981-1991) terminated with landings at Edwards AFB in California. During the next decade (1992-2002), this preference was reversed, with most landings taking place at KSC.

Compared with the original figure of $10.45 million in 1972 "when the Shuttle existed only on paper" (Heppenheimer 2002b:386), in 1996 the cost per Shuttle flight was estimated at $550 million.

2.8.3 Missions and Payloads

A total of 123 Space Shuttle missions were launched from the KSC between April 1981 and May 2008 (Tables 2.2 and 2.3). From April 1981 until the *Challenger* accident in 1986, between two and nine missions were flown yearly, with an average of four to five per year (Table 2.2). The milestone year was 1985, when nine flights were successfully completed. With the 1988 Return to Flight, the average increased to six missions yearly, until the *Columbia* accident in 2003. The years between 1992 and 1997 were the most productive, with seven or eight yearly missions. *Discovery* was the first orbiter to complete 20 missions, accomplished with STS-63, which launched on February 3, 1995. To date (July 2008), *Discovery* has flown a total of 35 missions, six more than *Atlantis* and 14 more than *Endeavour* (Table 2.2).

Between 1981 and 1991, 79% of the 44 successful missions ended with a landing at Edwards AFB. No landings were made at KSC between April 1985 (STS-23) and November 1990 (STS-38). However, by 1995, KSC had become the preferred landing site; between May 1996 and September 2000, all 23 Shuttle missions ended with a landing at KSC. Of the total 50 missions flown since the beginning of 1995, all but seven have landed at KSC (Table 2.3). On March 22, 1982, the Orbiter *Columbia* (STS-3) was the only Shuttle to land at White Sands Missile Range in New Mexico, necessitated due to flooding of the Edwards AFB runway as the result of heavy rains.

Table 2.2. Tabulation of Space Shuttle Missions, 1981 through June 2008.

Year	OV-102 *Columbia*	OV-99 *Challenger*	OV-103 *Discovery*	OV-104 *Atlantis*	OV-105 *Endeavour*	Yearly Total
1981	2					2
1982	3					3
1983	1	3				4
1984		3	2			5
1985		3	4	2		9
1986	1	1[a]				2
1987						0
1988			1[b]	1		2
1989	1		2	2		5
1990	2		2	2		6
1991	1		2	3		6
1992	2		2	2	2	8
1993	2		2		3	7
1994	2		2	1	2	7
1995	1		2	2	2	7
1996	3			2	2	7
1997	3		2	3		8
1998	1		2		2	5
1999	1		2			3
2000			1	2	2	5
2001			2	2	2	6
2002	1			2	2	5
2003	1[c]					1
2004						0
2005			1[d]			1
2006			2	1		3
2007			1	1	1	3
2008			1	1	1	3
Totals	28	10	35	29	21	123

a *Challenger* (STS-33) broke up 1 minute and 13 seconds after launch, January 28, 1986
b Return to Flight, *Discovery* (STS-26), September 29, 1988
c *Columbia* destroyed during reentry, February 1, 2003.
d Return to Flight, *Discovery* (STS-114), July 26, 2005

Table 2.3. Space Shuttle Mission Launch and Landing Data, 1981 through June 2008.

Seq. No.	Mission No.	Orbiter - Flight No.	Launch Date	Launch Site		Landing Site	Landing Date
				Pad A	Pad B		
1	STS-1	*Columbia* - 1	12 Apr 1981	X		EAFB, 23	14 Apr 1981
2	STS-2	*Columbia* - 2	12 Nov 1981	X		EAFB, 23	14 Nov 1981
3	STS-3	*Columbia* - 3	22 Mar 1982	X		WSMR, 17	30 Mar 1982
4	STS-4	*Columbia* - 4	27 Jun 1982	X		EAFB, 22	04 Jul 1982
5	STS-5	*Columbia* - 5	11 Nov 1982	X		EAFB, 22	16 Nov 1982
6	STS-6	*Challenger* - 1	04 Apr 1983	X		EAFB, 22	09 Apr 1983
7	STS-7	*Challenger* - 2	18 Jun 1983	X		EAFB, 15	24 Jun 1983
8	STS-8	*Challenger* - 3	30 Aug 1983	X		EAFB, 22	05 Sep 1983
9	STS-9	*Columbia* - 6	28 Nov 1983	X		EAFB, 17L	08 Dec 1983
10	STS-41-B	*Challenger* - 4	03 Feb 1984	X		KSC, 15	11 Feb 1984
11	STS-41-C	*Challenger* - 5	06 Apr 1984	X		EAFB, 17L	13 Apr 1984
12	STS-41-D	*Discovery* - 1	30 Aug 1984	X		EAFB, 17L	05 Sep 1984
13	STS-41-G	*Challenger* - 6	05 Oct 1984	X		KSC, 33	13 Oct 1984
14	STS-51-A	*Discovery* - 2	08 Nov 1984	X		KSC, 15	16 Nov 1984
15	STS-51-C	*Discovery* - 3	24 Jan 1985	X		KSC, 15	27 Jan 1985
16	STS-51-D	*Discovery* - 4	12 Apr 1985	X		KSC, 33	19 Apr 1985
17	STS-51-B	*Challenger* - 7	29 Apr 1985	X		EAFB, 17L	06 May 1985
18	STS-51-G	*Discovery* - 5	17 Jun 1985	X		EAFB, 23	24 Jun 1985
19	STS-51-F	*Challenger* - 8	29 Jul 1985	X		EAFB, 23	06 Aug 1985
20	STS-51-I	*Discovery* - 6	27 Aug 1985	X		EAFB, 23	03 Sep 1985
21	STS-51-J	*Atlantis* - 1	03 Oct 1985	X		EAFB, 23	07 Oct 1985
22	STS-61-A	*Challenger* - 9	30 Oct 1985	X		EAFB, 17L	06 Nov 1985
23	STS-61-B	*Atlantis*- 2	26 Nov 1985	X		EAFB, 22	03 Dec 1985
24	STS-61-C	*Columbia* - 7	12 Jan 1986	X		EAFB, 22	18 Jan 1986
25	STS-51-L	*Challenger* - 10	28 Jan 1986		X		
26	STS-26	*Discovery* - 7	29 Sep 1988		X	EAFB, 17L	03 Oct 1988
27	STS-27	*Atlantis* - 3	02 Dec 1988		X	EAFB, 17L	06 Dec 1988
28	STS-29	*Discovery* - 8	13 Mar 1989		X	EAFB, 22	18 Mar 1989
29	STS-30	*Atlantis* - 4	04 May 1989		X	EAFB, 22	08 May 1989
30	STS-28	*Columbia* - 8	08 Aug 1989		X	EAFB, 17L	13 Aug 1989
31	STS-34	*Atlantis* - 5	18 Oct 1989		X	EAFB, 23L	23 Oct 1989
32	STS-33	*Discovery* - 9	22 Nov 1989		X	EAFB, 04	27 Nov 1989
33	STS-32	*Columbia* - 9	09 Jan 1990	X		EAFB, 22	20 Jan 1990
34	STS-36	*Atlantis* - 6	28 Feb 1990	X		EAFB, 23L	04 Mar 1990
35	STS-31	*Discovery* - 10	24 Apr 1990		X	EAFB, 22	29 Apr 1990
36	STS-41	*Discovery* - 11	06 Oct 1990		X	EAFB, 22	10 Oct 1990
37	STS-38	*Atlantis* - 7	15 Nov 1990	X		KSC, 33	20 Nov 1990
38	STS-35	*Columbia* - 10	02 Dec 1990		X	EAFB, 22	10 Dec 1990
39	STS-37	*Atlantis* - 8	05 Apr 1991		X	EAFB, 33	11 Apr 1991
40	STS-39	*Discovery* - 12	28 Apr 1991	X		KSC, 15	06 May 1991
41	STS-40	*Columbia* - 11	05 Jun 1991		X	EAFB, 22	14 Jun 1991
42	STS-43	*Atlantis* - 9	02 Aug 1991	X		KSC, 15	11 Aug 1991
43	STS-48	*Discovery* - 13	12 Sep 1991	X		EAFB, 22	18 Sep 1991
44	STS-44	*Atlantis* - 10	24 Nov 1991	X		EAFB, 05R	01 Dec 1991
45	STS-42	*Discovery* - 14	22 Jan 1992	X		EAFB, 22	30 Jan 1992
46	STS-45	*Atlantis* - 11	24 Mar 1992	X		KSC, 33	02 Apr 1992
47	STS-49	*Endeavour* - 1	07 May 1992		X	EAFB, 22	16 May 1992
48	STS-50	*Columbia* - 12	25 Jun 1992	X		KSC, 33	09 Jul 1992
49	STS-46	*Atlantis* - 12	31 Jul 1992		X	KSC, 33	08 Aug 1992
50	STS-47	*Endeavour* - 2	12 Sep 1992		X	KSC, 33	20 Sep 1992
51	STS-52	*Columbia* - 13	22 Oct 1992		X	KSC, 33	01 Nov 1992
52	STS-53	*Discovery* - 15	02 Dec 1992	X		EAFB, 22	09 Dec 1992
53	STS-54	*Endeavour* - 3	13 Jan 1993		X	KSC, 33	19 Jan 1993
54	STS-56	*Discovery* - 16	08 Apr 1993		X	KSC, 33	17 Apr 1993
55	STS-55	*Columbia* - 14	26 Apr 1993	X		EAFB, 22	06 May 1993
56	STS-57	*Endeavour* - 4	21 Jun 1993		X	KSC, 33	01 Jul 1995

Seq. No.	Mission No.	Orbiter - Flight No.	Launch Date	Launch Site Pad A	Launch Site Pad B	Landing Site	Landing Date
57	STS-51	*Discovery* - 17	12 Sep 1993		X	KSC, 15	22 Sep 1993
58	STS-58	*Columbia* - 15	18 Oct 1993		X	EAFB, 22	01 Nov 1993
59	STS-61	*Endeavour* - 5	02 Dec 1993		X	KSC, 33	13 Dec 1993
60	STS-60	*Discovery* - 18	03 Feb 1994	X		KSC, 15	11 Feb 1994
61	STS-62	*Columbia* - 16	04 Mar 1994		X	KSC, 33	18 Mar 1994
62	STS-59	*Endeavour* - 6	09 Apr 1994	X		EAFB, 22	20 Apr 1994
63	STS-65	*Columbia* - 17	08 Jul 1994	X		KSC, 33	23 Jul 1994
64	STS-64	*Discovery* - 19	09 Sep 1994		X	EAFB, 04	20 Sep 1994
65	STS-68	*Endeavour* - 7	30 Sep 1994	X		EAFB, 22	11 Oct 1994
66	STS-66	*Atlantis* - 13	03 Nov 1994		X	EAFB, 22	14 Nov 1994
67	STS-63	*Discovery* - 20	03 Feb 1995		X	KSC, 15	11 Feb 1995
68	STS-67	*Endeavour* - 8	02 Mar 1995	X		EAFB, 22	18 Mar 1995
69	STS-71	*Atlantis* - 14	27 Jun 1995	X		KSC, 15	07 Jul 1995
70	STS-70	Discovery - 21	13 Jul 1995		X	KSC, 33	22 Jul 1995
71	STS-69	*Endeavour* - 9	07 Sep 1995	X		KSC, 33	18 Sep 1995
72	STS-73	*Columbia* - 18	20 Oct 1995		X	KSC, 33	05 Nov 1995
73	STS-74	*Atlantis* - 15	12 Nov 1995	X		KSC, 33	20 Nov 1995
74	STS-72	*Endeavour* - 10	10 Jan 1996		X	KSC, 15	20 Jan 1996
75	STS-75	*Columbia* - 19	22 Feb 1996		X	KSC, 33	09 Mar 1996
76	STS-76	*Atlantis* - 16	22 Mar 1996		X	EAFB, 22	31 Mar 1996
77	STS-77	*Endeavour* - 11	19 May 1996		X	KSC, 33	29 May 1996
78	STS-78	*Columbia* - 20	20 Jun 1996		X	KSC, 33	07 Jul 1996
79	STS-79	*Atlantis* - 17	16 Sep 1996	X		KSC, 15	26 Sep 1996
80	STS-80	*Columbia* - 21	19 Nov 1996		X	KSC, 33	07 Dec 1996
81	STS-81	*Atlantis* - 18	12 Jan 1997		X	KSC, 33	22 Jan 1997
82	STS-82	*Discovery* - 22	11 Feb 1997	X		KSC, 15	21 Feb 1997
83	STS-83	*Columbia* - 22	04 Apr 1997	X		KSC, 33	08 Apr 1997
84	STS-84	*Atlantis* - 19	15 May 1997	X		KSC, 33	24 May 1997
85	STS-94	*Columbia* - 23	01 Jul 1997	X		KSC, 33	17 Jul 1997
86	STS-85	*Discovery* - 23	07 Aug 1997	X		KSC, 33	19 Aug 1997
87	STS-86	*Atlantis* - 20	25 Sep 1997	X		KSC, 15	6 Oct 1997
88	STS-87	*Columbia* - 24	19 Nov 1997		X	KSC, 33	05 Dec 1997
89	STS-89	*Endeavour* - 12	22 Jan 1998	X		KSC, 15	31 Jan 1998
90	STS-90	*Columbia* - 25	17 Apr 1998		X	KSC, 33	03 May 1998
91	STS-91	*Discovery* - 24	02 Jun 1998	X		KSC, 15	12 Jun 1998
92	STS-95	*Discovery* - 25	29 Oct 1998		X	KSC, 33	07 Nov 1998
93	STS-88	*Endeavour* - 13	04 Dec 1998	X		KSC, 15	15 Dec 1998
94	STS-96	*Discovery* - 26	27 May 1999		X	KSC, 15	06 Jun 1999
95	STS-93	*Columbia* - 26	23 Jul 1999		X	KSC, 33	27 Jul 1999
96	STS-103	*Discovery* - 27	19 Dec 1999		X	KSC, 33	27 Dec 1999
97	STS-99	*Endeavour* - 14	11 Feb 2000	X		KSC, 33	22 Feb 2000
98	STS-101	*Atlantis* - 21	19 May 2000	X		KSC, 15	29 May 2000
99	STS-106	*Atlantis* - 22	08 Sep 2000		X	KSC, 15	20 Sep 2000
100	STS-92	*Discovery* - 28	11 Oct 2000	X		EAFB, 22	24 Oct 2000
101	STS-97	*Endeavour* - 15	30 Nov 2000		X	KSC, 15	11 Dec 2000
102	STS-98	*Atlantis* - 23	07 Feb 2001	X		EAFB, 22	20 Feb 2001
103	STS-102	*Discovery* - 29	08 Mar 2001		X	KSC, 15	21 Mar 2001
104	STS-100	*Endeavour* - 16	19 Apr 2001	X		EAFB, 22	1 May 2001
105	STS-104	*Atlantis* - 24	12 Jul 2001		X	KSC, 15	24 Jul 2001
106	STS-105	*Discovery* - 30	10 Aug 2001	X		KSC, 15	22 Aug 2001
107	STS-108	*Endeavour* - 17	05 Dec 2001		X	KSC, 15	17 Dec 2001
108	STS-109	*Columbia* - 27	01 Mar 2002	X		KSC, 33	12 Mar 2002
109	STS-110	*Atlantis* – 25	08 Apr 2002		X	KSC, 33	19 Apr 2002
110	STS-111	*Endeavour* - 18	05 Jun 2002	X		EAFB, 22	19 Jun 2002
111	STS-112	*Atlantis* - 26	07 Oct 2002		X	KSC, 33	18 Oct 2002
112	STS-113	*Endeavour* - 19	23 Nov 2002	X		KSC, 33	07 Dec 2002
113	STS-107	*Columbia* - 28	16 Jan 2003	X			

Seq. No.	Mission No.	Orbiter - Flight No.	Launch Date	Launch Site		Landing Site	Landing Date
				Pad A	Pad B		
114	STS-114	*Discovery* - 31	26 Jul 2005		X	EAFB, 22	09 Aug 2005
115	STS-121	*Discovery* - 32	4 Jul 2006		X	KSC, 15	17 Jul 2006
116	STS-115	*Atlantis* - 27	9 Sep 2006		X	KSC, 33	21 Sep 2006
117	STS-116	*Discovery* - 33	9 Dec 2006		X	KSC, 15	22 Dec 2006
118	STS-117	*Atlantis* - 28	8 June 2007	X		EAFB, 22	22 June 2007
119	STS-118	*Endeavour* - 20	8 Aug 2007	X		KSC, 15	21 Aug 2007
120	STS-120	*Discovery* - 34	23 Oct 2007	X		KSC, 33	7 Nov 2007
121	STS-122	*Atlantis* - 29	7 Feb 2007	X		KSC, 15	20 Feb 2008
122	STS-123	*Endeavour* - 21	11 Mar 2008	X		KSC, 15	26 Mar 2008
123	STS-124	*Discovery* - 35	31 May 2008	X		KSC, 15	14 June 2008

Over the past two decades, the SSP has launched a number of planetary and astronomy missions including the Hubble Space Telescope (HST), the Galileo probe to Jupiter, Magellan to Venus, and the Upper Atmospheric Research Satellite. Several dedicated DoD missions were flown, as well as a series of Spacelab research missions (1983-1998) carrying dozens of international experiments in disciplines ranging from materials science to plant biology.

Starting with STS-1 and continuing through STS-9, shuttle missions were numbered sequentially. Beginning with the 10th flight, a new system was introduced. The first digit designated the last digit of the fiscal year (FY, which starts on October 1) in which the mission was scheduled to launch. The second digit designated the launch site, with “1” for KSC and “2” for Vandenberg. Next, an alphabetical designation indicated the sequential position of the launch. For example, STS-41B was the second launch of FY 1984 from KSC. After the *Challenger* accident (STS-51L), the new numbering system was abandoned, and NASA returned to a sequential numbering system. This change coincided with the termination of Vandenberg as a launch site. Since STS-51L had been the 25th launch of the SSP, the designated return to flight on September 29, 1988 was numbered STS-26. As illustrated in Table 2.3, sometimes flights are launched out of sequence. This is mainly due to scheduling impacts such as bad weather and technical problems.

2.8.3.1 *Spacelab*

On September 24, 1973, the European Space Agency (ESA) and NASA signed a Memorandum of Understanding, agreeing to design and develop Spacelab. The decision to develop Spacelab “resulted almost entirely from West Germany’s strong desire to get involved in manned space flight, and its willingness to finance 52 percent of Spacelab’s costs” (Jenkins 2001:101). Spacelab was a manned, reusable, microgravity laboratory flown into space in the rear of the Space Shuttle cargo bay. It was developed on a modular basis allowing assembly in a dozen arrangements depending on the specific mission requirements (NASA 1988).

MSFC was responsible for Spacelab development and missions, as well as payload control during missions. Actual construction of the Spacelab pressurized modules was started by ERNO-VFW Fokker in 1974. The first lab, LM1, was donated to NASA in exchange for flight opportunities for European astronauts. Later, NASA purchased LM2, the second lab. The first Spacelab mission, carried aboard *Columbia* (STS-9), began on November 28, 1983 and concluded December 8, 1983. Called "science around the world and around the clock," the mission accomplishments included growing the first protein crystals in space, scanning the chemical makeup of the atmosphere, measuring radiation from the sun, and experimenting with the behavior of fluids (NASA 1999).

In contrast to the first Spacelab mission, which focused on demonstrating its usefulness in all scientific disciplines, the following two Spacelab missions were dedicated to specific disciplines. Spacelab 3, launched in March 1985, carried an array of materials science experiments and atmospheric instruments; Spacelab 2, flown in July 1985, carried instruments to study the sun, stars, and cosmic rays. A total of five Spacelab missions were flown between 1983 and 1985. Following a hiatus in the aftermath of the *Challenger* disaster, the next Spacelab mission was not launched until 1990. In this year, STS-35 carried ASTRO-1, an ultraviolet telescope.

In total, 28 Space Shuttle missions carried Spacelab hardware before the program was decommissioned in 1998 (NASA 1999). In addition to astronomical, atmospheric, microgravity, and life sciences missions, Spacelab was also used as a supply carrier to the HST (Dismukes 2002) and the Soviet space station *Mir*. STS-90, launched in April 1998 aboard *Columbia*, was the last mission to carry a Spacelab module. Known as Neurolab, it carried life-science experiments that sought to study the behavior of nervous systems in zero-gravity (Heppenheimer 2002b:48). In 1998, the Spacelab program was retired since the experiments conducted on it could now be performed on the International Space Station (ISS).

2.8.3.2 *Hubble Space Telescope*

The HST was first deployed on STS-31 during the 10th flight of the Orbiter *Discovery,* which launched on April 24, 1990. Astronauts revisited Hubble three years after launch to correct a defect in its optics. To date, four missions, STS-61 (December 1993), STS-82 (February 1997), STS-103 (December 1999), and STS-109 (March 2002), have serviced the HST. The fifth and final servicing mission is currently scheduled for October 2008. The goals of this mission are to install new instruments, replace degraded systems, and bring inactive instruments back to life.

2.8.3.3 *The Shuttle-Mir Program: 1995-1998*

In 1995, a joint U.S./Russian Shuttle-*Mir* Program was initiated as a precursor to construction of the ISS. *Mir* was launched in February 1986 and remained in orbit until March 2001 (Reichhardt 2002:85). The first approach and flyaround of *Mir* took place on February 3, 1995 (STS-63); the first *Mir* docking was in June 1995 (STS-71). During the three-year Shuttle-*Mir* Program (June 27, 1995 to June 2, 1998) the Space Shuttle docked with *Mir* nine times. All but the last two of these docking missions used the Orbiter *Atlantis*. In 1995, Dr. Norman Thagard was the first American to live aboard the Russian space station. Over the next three years, six more U.S. astronauts served tours on *Mir*. The Shuttle served as a means of transporting supplies, equipment and water to the space station in addition to performing a variety of other mission tasks, many of which involved earth science experiments. It returned to Earth experiment results and unneeded equipment. The Shuttle-*Mir* program served to acclimate the astronauts to living and working in space. Many of the activities carried out were types they would perform on the ISS (Rumerman and Garber 2000:3).

2.8.3.4 *International Space Station: 1999+*

The first component of the ISS, the Zarya Control Module, was launched on November 20, 1998 atop a Russian rocket. The following month, *Endeavour* (STS-88) delivered the Unity Node and the crew mated it with Zarya. As noted by Williamson (1999:191), this event marked, "at long last the start of the Shuttle's use for which it was primarily designed – transport to and from a permanently inhabited orbital space station." The 26th flight of the Orbiter *Discovery* (STS-96), launched on May 27, 1999, was the first mission to dock with the ISS. Since that time, most Space Shuttle missions have supported the continued assembly of the space station. As currently planned, ISS assembly missions will continue through the life of the Space Shuttle Program.

2.8.4 The *Columbia* Accident and Aftermath: 2003-Present

By 2003, Shuttle flights almost had become routine. On January 16, 2003, at 10:39 AM EST, *Columbia* (STS-107) was launched from Pad 39A. It carried a crew of seven, including the first Israeli astronaut. The landing was set for February 1 following a 16-day mission. Sixteen minutes prior to its scheduled touchdown at KSC, the spacecraft was lost during reentry over eastern Texas and all members of the crew (Commander Rick Husband; Pilot William McCool; Mission specialists Dave Brown, Kalpana Chawla, Mike Anderson, and Laurel Clark; and Israeli payload specialist Ilan Ramon) perished.

The Space Shuttle Program again was faced with explaining what had gone horribly wrong. Following the loss of *Columbia*, a seven month investigation ensued, including a four month search to recover debris. The Columbia Accident Investigation Board (CAIB) determined that both technical and management conditions accounted for the loss of the orbiter and crew. According to the CAIB Report, the physical cause of the accident was a breach in the thermal protection system on the leading edge of the left wing, caused by a piece of insulating foam, which separated from the ramp section of the ET after launch and struck the wing in the vicinity of Reinforced Carbon-Carbon (RCC) panel number 8. During reentry, this breach "allowed superheated air to penetrate through the leading edge insulation and progressively melt the aluminum structure of the left wing, resulting in a weakening of the structure until increasing aerodynamic forces caused loss of control, failure of the wing, and break-up of the Orbiter" (CAIB 2003:9).

NASA spent more than two years researching and implementing safety improvements for the orbiters, SRBs and ET. Upgrades to the SRBs and ET, for example, included redesign of valves, fillers, and seals in the steering system. Also, a new friction-stir welding technique produced stronger and more durable welds throughout the ET (Veris 2001).

Planned for installation in all Shuttles by 2002, a new "glass cockpit," technically called the Multifunction Electronic Display Subsystem (MEDS) was designed to reduce the pilot's workload in an emergency situation (Veris 2001).

Following a two-year hiatus, the 31st launch of the Orbiter *Discovery* (STS-114) on July 26, 2005 marked the first Return to Flight since the loss of *Columbia*. This 14-day mission resupplied the ISS. After four delays due to bad weather and a failed power cell and fuel sensor, *Atlantis* (STS-115) launched from Pad 39B on September 9, 2006. The goal of this mission was to deliver and install the largest payload ever, a 17.5- ton truss of solar arrays for the ISS. NASA's plan is to launch several more missions to complete the ISS by 2010. Assembling the station will be the last achievement of America's Space Shuttle Program. NASA's targeted dates for the final 10 missions of the SSP are provided in Table 2.4 (from NASA, "Future Missions - Launch Schedule.").

Table 2.4. Future Space Shuttle Missions Launch Schedule, 2008-2010.

Mission Number	Orbiter Vehicle	Targeted Launch Date
STS-125	*Atlantis*	October 8+, 2008
STS-126	*Endeavour*	November 10+, 2008
STS-119	*Discovery*	February 12+, 2009
STS-127	*Endeavour*	May 15+, 2009
STS-128	*Atlantis*	July 30+, 2009
STS-129	*Discovery*	October 15+, 2009
STS-130	*Endeavour*	December 10+, 2009
STS-131	*Atlantis*	February 11+, 2010
STS-132	*Discovery*	April 8+, 2010
STS-133	*Endeavour*	May 31+, 2010

On January 14, 2004, President George W. Bush outlined a new space exploration initiative in a speech given at NASA Headquarters.

> *Today I announce a new plan to explore space and extend a human presence across our solar system . . . Our first goal is to complete the International Space Station by 2010 . . . The Shuttle's chief purpose over the next several years will be to help finish assembly of the International Space Station. In 2010, the Space Shuttle – after nearly 30 years of duty – will be retired from service. . . Our second goal is to develop and test a new spacecraft, the Crew Exploration Vehicle, by 2008, and to conduct the first manned mission no later than 2014. . . Our third goal is to return to the Moon by 2020, as the launching point for missions beyond . . .*
> (The White House 2004).

Following the President's speech, NASA released *The Vision for Space Exploration*, which outlined the Agency's approach to the new direction in space exploration (NASA 2004). In 2006, NASA announced the start of the Constellation Program, which included development of the Crew Exploration Vehicle (CEV) and a launch vehicle to place the CEV into space. As part of this initiative, NASA will continue to use the Space Shuttle to complete assembly of the ISS. The Shuttle will not be upgraded to serve beyond 2010 and, after completing the ISS, the Space Shuttle Program will be retired. The next generation of human-rated spacecraft, the CEV, named *Orion*, will transport humans to low Earth orbit for missions to support the ISS, and will also be the vehicle used to carry a crew to lunar orbit. The Constellation Program will develop the new class of exploration vehicles to launch both crew and cargo and associated infrastructure in exploring the Moon, Mars, and beyond.

3.0 THE SHUTTLE TRANSPORTATION SYSTEM

The Space Transportation System, commonly called the Space Shuttle, was designed for missions to Earth orbit. The Shuttle is the first winged U.S. spacecraft capable of launching crew vertically into orbit and landing horizontally upon return to Earth. The Shuttle consists of three major components: the reusable orbiter vehicle, which holds the crew and payloads; a pair of reusable SRBs which provide initial ascent thrust for the vehicle; and the large expendable ET, which holds the fuel for the main engines (Photo 3.1). The orbiter has a large payload bay and three main engines, and an OMS with two smaller engines.

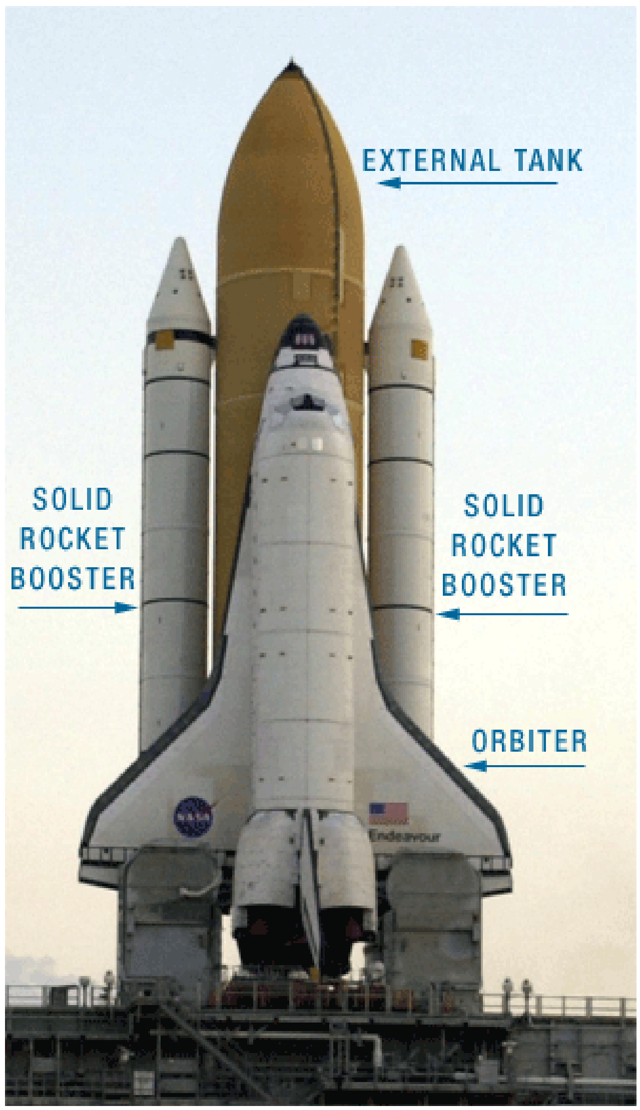

Photo 3.1. The Space Shuttle system. (Source: NASA)

3.1 Orbiter Vehicles and Prototypes

3.1.1 Introduction

Structural assembly of the orbiter prototype *Enterprise* (OV-101) was started on June 21, 1974 and completed on September 17, 1976. Between 1974 and 1991, all five operational orbiters of the Space Shuttle fleet were assembled in Building 150 at AFP 42, Site 1 North in Palmdale, California. The fifth operational orbiter, *Endeavour,* which replaced the *Challenger*, was built with structural spares made by various contractors during construction of *Discovery* (OV-103) and *Atlantis* (OV-104). Upon completion, each orbiter was rolled out of the assembly hangar and, with one exception, was transported overland to Edwards AFB for flight to the KSC. The last orbiter added to the fleet, *Endeavour* (OV-105), was ferry-flighted directly from Palmdale to the KSC in May 1991. This operation was made possible by the newly erected Orbiter Lifting Frame (OLF) mate-demate device at Palmdale. The dates of structural assembly start and completion, rollout from Palmdale, overland transport from Palmdale to Edwards AFB, and delivery to the KSC for each orbiter (adapted from Jenkins 2001:242) are provided in Table 3.1.

Table 3.1. Space Shuttle Program orbiter milestones.

Milestone	STA-099	OV-099	OV-101	OV-102	OV-103	OV-104	OV-105
Start structural assembly	11-21-75	1-28-79	6-21-74	6-4-74	6-28-76	3-3-80	2-15-82
Complete final assembly	2-10-78	10-23-81	3-12-75	4-23-78	8-12-83	4-10-84	7-6-90
Palmdale rollout	2-14-78	6-30-82	9-17-76	3-8-79	10-16-83	3-6-85	4-25-91
Overland transport: Palmdale to EAFB	n/a	7-1-82	1-31-77	3-12-79	11-5-83	4-3-85	n/a
Delivery to KSC	n/a	7-5-82	4-10-79	3-25-79	11-9-83	4-9-85	5-7-91

About 250 major subcontractors supplied all the individual components, parts and systems of the Space Shuttle orbiter to the Palmdale assembly facility. Approximately two million parts, as well as about 237 miles of wire, were used to build each orbiter. At the peak of production, 1800 people worked around the clock in Building 150 at Palmdale during two back-to-back shifts. The orbiter production line at Palmdale saw minimal activity between January 1986 and October 1988, following final assembly of *Atlantis* in April 1985, and was shut down after completion of *Endeavour* in 1990. However, beginning in the summer of 1991, Building 150 was reactivated to perform Orbiter Major Modifications (OMM) of the fleet vehicles.

Until 2002, all major mid-life overhauls of the orbiters, including both Orbiter Maintenance Down Period (OMDP) and OMM activities, were accomplished at Palmdale. The SSP requires an OMM every eight flights for each orbiter, or approximately every three years. Work includes component changes, routine and special inspections, modifications, deferred work, and correcting "stumble ons." During an OMM, the orbiters are disassembled down to the airframe for intensive inspection. Of the 10 OMMs performed in the history of the SSP, eight were performed at the Palmdale facility, and two at the KSC. The duration of each OMM has varied from 5.7 months to 19.5 months. The 1997-1998 OMM of *Atlantis* (OV-104), which included the first installation of the MEDS "glass cockpit," was "the most extensive orbiter modification and maintenance project in the program's history, which included 443 structural inspections and 363 modifications" (Levine 1998:4). The last OMM at Palmdale, for OV-102, was performed during a 517-day period between September 26, 1999 and February 23, 2001. Starting with OV-103 in September 2002, NASA relocated the orbiter overhaul and upgrade activities from Palmdale to the KSC. A schedule of orbiter major modifications is presented in Table 3.2.

Table 3.2. Schedule of orbiter major modifications.

Orbiter Vehicle	OMM Start Date	OMM End Date	Duration (in months)
OV-102	25 January 1984	11 September 1984	18
OV-102	15 August 1991	7 February 1992	5.7
OV-103*	17 February 1992	1 August 1992	7
OV-104	19 October 1992	27 May 1994	19.5
OV-102	13 October 1994	10 April 1995	6
OV-103	29 September 1995	24 June 1996	9
OV-105	30 July 1997	21 September 1998	10.2
OV-104	30 July 1996	24 March 1997	8
OV-102	26 September 1999	23 February 2001	17
OV-103*	1 September 2002	1 April 2004	19

*Performed at KSC

3.1.2 Test Articles and Orbiter Prototypes

With the exception of the three extant orbiters and a few large and unique assets, the evaluation of NASA personal property was not within the scope of this study. However, at the request of the NPS, a look at some of the major orbiter antecedents, including test articles and prototypes, is included in this report. Each NASA orbiter designation is composed of a prefix and a suffix separated by a dash. The prefix for operational shuttles is OV, for Orbiter Vehicle. The suffix is composed of two parts: the series and the vehicle number. The numbering is sequential, with the series beginning with a 0 for a non-flight ready orbiter and 1 for a flight-ready orbiter. "STA" is used to designate a structural test article. As noted below, a few structural test articles are associated with OV numbers.

OV-095: The Shuttle Avionics Integration Laboratory (SAIL), located in Building 16 at the JCS, was also known as the Shuttle Test Station (STS) OFT Test Article. Assigning this laboratory an orbital vehicle number (STS OV-095) did not follow the OV naming protocol. It is believed that it was assigned by an IBM programmer to meet a SAIL software requirement. OV-095 has unofficially been referred to as a "bird without a skin." Rather than the SAIL facility proper, the "bird without a skin" more aptly describes the "Big Rig" within the SAIL. The "Big Rig" is a full-scale mockup of the orbiter minus the wings and landing gear, the latter of which is simulated. It contains all of the equipment and wiring (exposed), usually flight certified, found on the orbiter (Photo 3.2). The "Big Rig" was developed at JSC in 1974 to provide integration and verification of Space Shuttle hardware and software for flight. The "Big Rig" has numerous interfaces with external laboratories, including the Inertial Measurement Laboratory, the Electronic Systems Test Laboratory, the Software Production Facility, the Orbiter Data Record Center, the KSC Launch Processing System Checkout, Control, and Monitor System, the Guidance Integration Test and Facility, the Payload Operations Control Center, and the MCC. The SAIL is scheduled to support the SSP till the end of the program.

Photo 3.2. "Big Rig" orbiter forward bay in Building 16 at the JSC, looking north. (Source: Archaeological Consultants, Inc., 2006)

STA-096: Research revealed no records of an OV-096 non-flight ready orbiter. A mock-up of the orbiter was built at NASA's Downey Plant, California. However, this was not part of the OV nomenclature. A Boeing Shuttle manager believes STA-096 was an Environmental Control and Life Support System (ECLSS) test article that was cancelled prior to delivery. The NASA History Office has no record of STA-096, and its current state and disposition are unknown.

STA-097: This structural test article is listed in NASA records as a Vibro Acoustic (Mid Fuselage) Test Article. However, like STA-096, the NASA History Office has no record of STA-097, and its current state and disposition are unknown.

STA-098: The MPTA was constructed by Rockwell and used to test the SSMEs "in a realistic structural environment" (Jenkins 2001:225). The MPTA is named OV-098 in some NASA records. However, since it was a test article and does not fit the OV nomenclature for a non-flight ready orbiter, the reference to the MPTA as OV-098 appears to be incorrect and unofficial. It may have been reassigned as OV-098 when it was rebuilt into the Shuttle-C mockup during the 1990s. The test article is more commonly referenced in documents as MPTA-098. The MPTA "consisted of an aft-fuselage, a truss arrangement which simulated the mid-fuselage, and a complete thrust structure including all main propulsion system plumbing and electrical systems" (Jenkins 2001:225). It was mated with an ET (MPTA-ET) and three prototype SSMEs, and used between April 21, 1978 and the end of 1979 for propellant loading and static firing tests. It was last used on January 17, 1981 for static firing of flight nozzles. This final test was the longest duration (629 seconds) and the first full duration static firing using the flight-type nozzle on the three main engines (rather than the snub nozzle). The MPTA is currently in storage at the SSC in Mississippi.

OV-098: There are many references to the Pathfinder Orbiter Weight Simulator as OV-098. Though it was never formally numbered by NASA, the OV-098 designation was assigned unofficially and retroactively. The Pathfinder was built at MSFC in 1977. This steel structure is approximately the same size, shape, and weight as an actual orbiter, and was used as a stand-in for *Enterprise* (OV-101). It was first used at MSFC in order to fit-check the roads and facilities that were used during the MVGVT program, and also used to test the hoisting system that was used to lift the *Enterprise.* In April 1978, the Pathfinder was shipped by barge to KSC and was used, until early 1979, to check out the MDD, OPF, and VAB work platforms. For example, fit-checks were performed in the OPF High Bay 1 to ensure that the work platforms were positioned correctly and would not hit the orbiter when used (Jenkins 2001:215). In addition, the Pathfinder was used to train ground crew in post-landing procedures at the KSC Shuttle Landing Facility (SLF). Following these operations, in late 1979, Pathfinder was returned to MSFC for storage. Years later, it was modified by Teledyne-Brown Engineering to more closely replicate an orbiter (Jenkins 2001:215). Subsequent to its display at the Great Space Shuttle Exposition in Tokyo, Japan between June 1983 and August 1984, it was transferred to the Smithsonian's National Air and Space Museum (NASM). It is currently on display at the U.S. Space & Rocket Center in Huntsville, Alabama, where it is mounted on the MPTA-ET, along with a pair of inert SRBs (whose nose segments and aft skirts were removed in 1999 and replaced by a set of mockups).

Photo 3.3. Pathfinder Simulator is hoisted into MSFC Dynamic Test Stand, 1977.
(Source: NASA MSFC, NIX No.: MSFC-7885689)

STA-099: *Challenger* was originally intended to be used as a high-fidelity structural test article, and was named STA-099 as a non-flight ready orbiter. It was later rebuilt as a flight-capable orbiter. On July 26, 1972, NASA awarded a contract to Rockwell for production of STA-099. Structural assembly was started on November 21, 1975, and final assembly was completed on February 10, 1978. Subsequently, Rockwell delivered STA-099 to the Lockheed Company at Palmdale, where the test article underwent a year-long test program, concluded on October 4, 1979. Testing took place in a specially-built 430-ton steel rig, known as a reaction frame. The rig contained 256 hydraulic jacks which operated, under the control of a computer, to distribute loads across 836 application points. STA-099 was subjected to various simulated stress levels that duplicated the launch, ascent, on-orbit, reentry, and landing phases of flight (Jenkins 2001:241; *Marshall Star* 17 October 1979:1 and 4). Three one-million pound-force hydraulic cylinders were used to simulate the thrust from the SSMEs, and heating and cooling simulations were also conducted using gaseous nitrogen to simulate the cold of space and heating blankets to simulate ascent and reentry heating. Thermal loads were applied directly to the metal structure (Jenkins 2001:241). "In a separate test, the fuselage was given loads that simulated the impact of the nose landing gear on a runway" (Heppenheimer 2002b:252-256).

After testing was completed, STA-099 was returned to Rockwell on November 7, 1979 for conversion into OV-099. The conversion process involved a major disassembly of the vehicle. The payload bay doors, elevons, body flap, vertical stabilizer, upper forward fuselage, and entire aft fuselage were removed and returned to their original vendors for modification (Jenkins 2001:242).

OV-100: NASA's vehicle number for the orbiters is sequentially assigned within the series, beginning with 1. Therefore, OV-100 was never used (as it would read "Orbiter Vehicle Series 1 Vehicle 0").

OV-101: OV-101, *Enterprise*, was originally intended to be rebuilt into a flight-capable orbiter. However, NASA found it cheaper to rebuild STA-099 instead, and OV-101 remained a test article. During 1975-1976, Rockwell International assembled OV-101 at its Palmdale plant. The spacecraft's main components had been in fabrication by other manufacturers subcontracted to Rockwell International since June 19, 1974 (*Marshall Star* 8 September 1976:1 and 4). The first orbiter hardware to arrive in Palmdale was the mid-fuselage (payload bay), shipped from the Convair plant in San Diego in March 1975 (*X-Press* 28 March 1975:2). Next were the orbiter wings, in May. Fabricated in Grumman's facilities on Long Island, New York, the wings were transported on a container ship through the Panama Canal to Long Beach, California, where Grumman trucked them overland to Palmdale (*X-Press* 23 May 1975:2). Rockwell shipped the orbiter crew module, alternately known as the floating cabin, from Downey to Palmdale in December. The crew module fit inside the lower half of the forward fuselage. Rockwell mated the orbiter's forward, mid- (Convair), and aft fuselages with the spacecraft's wings (Grumman) and vertical tail (Fairchild) by the end of 1975. Rockwell next moved its Apollo checkout equipment from Downey to Palmdale for adaptation to the shuttle orbiter (*Marshall Star* 3 December 1975:4; Heppenheimer 2002b:98). In

May 1976, Rockwell personnel installed a fiberglass nose cap on OV-101, for use in the upcoming ALT program.

As a test article, the OV-101 featured numerous substitute components as placeholders for the equipment found in vehicles built for actual space flight (*Marshall Star* 19 May 1976:7). Late in the summer of 1976, Rockwell mounted three dummy SSMEs in the orbiter's boattail (the rearmost section of the spacecraft), fabricated by its Rocketdyne Division at AFP 56 in Canoga Park (*Marshall Star* 8 September 1976:1 and 4). In the weeks before rollout of the orbiter, Rockwell oversaw a horizontal ground vibration test at Palmdale to verify structural dynamics data for a full-sized orbiter. Tests in the early 1970s at NASA LaRC had used 1/8th-scale models to study the anticipated longitudinal oscillation frequencies, known as "pogo." A second round of model tests, at 1/4th scale, had been a joint effort of the JSC and Rockwell in 1975 (Heppenheimer 2002b: 100, 251-252).

Photo 3.4. *Enterprise* en route overland between Palmdale and Dryden, 1977.
(Source: NASA Dryden, ECN 6679)

On January 31, 1977, Rockwell moved OV-101, the *Enterprise*, from Palmdale to the DFRC at Edwards AFB. Transport of the orbiter test vehicle, which weighed 150,000 pounds, proceeded at about three miles per hour (*Marshall Star* 26 January 1977:1 and 4). During February-October 1977, the DFRC conducted the ALT program using the *Enterprise* test vehicle, as described in Section 2.5.4.

Following the ALT tests at the DFRC, the *Enterprise* was used for vibration tests at the MSFC. Subsequently, the *Enterprise* was moved to the KSC where, between May through July 1979, it was used to verify the correct locations of maintenance platforms, and to check crew escape procedures (Jenkins 2001:216). Later that year, the *Enterprise* was flown to California, and moved overland to Palmdale, where selected parts, including most of the cockpit instrumentation and consoles, the control sticks, and most of the avionics, were removed and refurbished in October 1979, for use on later orbiters.

In October 1982, the DFRC conducted vibration tests on the *Enterprise* in its shuttle hangar (*X-Press* 1 October 1982:2 and 4), and in early 1984 during inflight refueling tests, the Center attached samples of tiles, Felt Reusable Surface Insulation (FRSI), and Advanced Flexible Reusable Surface Insulation (AFRSI) to the *Enterprise*, to further evaluate these protective materials (*X-Press* 3 February 1984:3-4). Also during the 1980s, the *Enterprise* was ferried to France for the Paris Air Show (May and June 1983); was displayed at the World's Fair in New Orleans (1984); visited Germany, Italy, England and Canada; was put on display at the KSC (September 1985); and was used in a series of flight verification vehicle tests at the VLS.

In November 1985, the *Enterprise* was officially transferred (on loan) to the Smithsonian's NASM. After retirement to the Smithsonian, the *Enterprise* continued to be used for various tests, and for the loan of its parts. For example, in the aftermath of the *Challenger* accident, it was used in tests of the shuttle orbiter arresting system, and of crew bail-out concepts, both conducted at Dulles International Airport. During the 1990s, various parts were removed and subsequently reinstalled. These included the main landing gear (borrowed in April 1990; partially reinstalled in June 1997); the door from the starboard wing (removed in July 1993; reinstalled in March 1994); the nose gear (removed in June 1997); the simulated TPS tiles from the right side of the forward fuselage, as well as a splice plate and the thermal control system blankets under it (removed April-May 1999); and eight samples of Kapton wiring (permanently removed in October 1999) (Jenkins 2001:221).

Since 2003, following completion of the new exhibit space, the *Enterprise* has been on permanent display at the NASM's Steven F. Udvar-Hazy Center at Dulles International Airport in Virginia.

3.1.3 NASA's Space Shuttle Orbiter Fleet

Of the five operational orbiters that flew in space (OV-099, -102, -103, -104, and -105), three are extant (OV-103, -104, and -105). In addition, OV-106 is the administrative name given to the set of structural components manufactured to replace those used in the construction of *Endeavour* (OV-105). However, the contract for these was cancelled shortly afterwards, and they were never completed. A description of the five Space Shuttle orbiters follows.

3.1.3.1 *Columbia (OV-102)*

Columbia was the first orbiter built for operational use. It was named after the Boston-based sloop captained by American Robert Gray, who led the vessel and its crew on the first American circumnavigation of the globe. Assembly of the Orbiter *Columbia* was initiated in Palmdale on June 4, 1974, and completed on April 23, 1978. It was rolled out of the hangar on March 8, 1979. Rockwell transported the *Columbia* to the DFRC at Edwards with more than 7,000 of its thermal protection tiles not yet installed. Rockwell employees had filled in the tile gaps with "temporary versions [of the tiles] made of

Styrofoam," to lessen aerodynamic drag during the *Columbia*'s ferrying from Edwards to KSC (Heppenheimer 2002b:235). *Columbia* was delivered to the KSC on March 25, 1979. With an empty weight of 158,289 pounds at rollout, and 178,000 pounds with the main engines installed, *Columbia* was the heaviest of NASA's orbiters.

The launch of *Columbia* on April 12, 1981 (STS-1) marked the first time that a Space Shuttle flew into Earth orbit. *Columbia* flew a total of 28 missions before it was destroyed during re-entry over eastern Texas on February 1, 2003 at the end of mission STS-107. Achievements and "firsts" for *Columbia* included the successful completion of the Orbital Test Flight Program (STS-1 through STS-4); the maiden flight for Spacelab (STS-9); the first ESA astronaut (Dr. Ulf Merbold) (STS-9); recovery of the Long Duration Exposure Facility (LDEF) satellite from orbit (STS-32); the first manned Spacelab mission totally dedicated to human medical research (STS-40); the first Japanese Space Agency, as well as first Japanese woman (Chiaki Mukai) to fly in space (STS-65); and deployment of the X-ray Observatory (STS-93).

In 1991, following completion of mission STS-40, *Columbia* was transported to Palmdale where it underwent approximately 50 modifications, including the addition of carbon brakes, drag chute, improved nose wheel steering, removal of development flight instrumentation and an enhancement of its TPS. After completing its 17th mission, in October 1994, *Columbia* underwent its first OMDP in Palmdale. During a six-month period, approximately 90 modifications and upgrades were made, including upgrades to the main landing gear thermal barrier, the tire pressure monitoring system and radiator drive circuitry (NASA KSC 1994). After nine more flights, and following STS-93 in July 1999, *Columbia's* second OMDP began in September 1999, which included installation of the "glass cockpit." OV-102 launched two more times, before its destruction during reentry in 2003. Compared with its configuration in 1981, the *Columbia* that lifted off in January 2003 retained more than 44% of its tiles and 41 of the 44 wing leading edge RCC panels as original equipment (CAIB 2003:25).

3.1.3.2 *Challenger (OV-099)*

Challenger was the second orbiter built for operational use. It was named after the British Naval research vessel HMS Challenger which sailed the Atlantic and Pacific oceans during the 1870s. The orbiter *Challenger* originated as a test article (STA-099) for the SSP, as described in Section 3.1.2.

Conversion of STA-099 to OV-099 was initiated in Palmdale on January 28, 1979, and completed on October 21, 1981; the orbiter was delivered to the KSC in early July 1982. For the *Challenger*, Rockwell had reduced the orbiter weight; improved its TPS; and removed an ejection-seat area integral to the *Columbia*, retrofitting the latter as cabin space for mission specialists (*X-Press* 2 July 1982:2). NASA first launched the *Challenger* for the sixth mission (STS-6) on April 4, 1983. *Challenger* flew nine successful missions from 1983 through 1985 before it was destroyed one minute and 13 seconds after the launch of STS-51L on January 28, 1986.

During its brief service, the *Challenger* was associated with a number of "firsts," including the first spacewalk of the SSP (STS-6); the deployment of the first satellite in the Tracking and Data Relay Satellite (TDRS) System (STS-6); the launch of the first American woman (Sally Ride) (STS-7); the first to launch and land at night (STS-8); the first Space Shuttle landing at KSC (STS-41-B); and the first German-dedicated Spacelab mission (STS-61-A)

3.1.3.3 *Discovery (OV-103)*

The Orbiter *Discovery* was the third orbiter built for operational use, following the *Columbia* and the *Challenger*. It was named after one of two ships the British explorer James Cook used in the 1770s for the exploration of the South Pacific, which led to the discovery of the Hawaiian Islands. Assembly of the Orbiter *Discovery* was initiated in Palmdale on August 27, 1979; it was rolled out of the hangar on October 16, 1983. From Palmdale, it was transported overland to Edwards AFB, mated to the SCA and flown to the KSC, where it arrived on November 9, 1983. *Discovery* made its maiden flight, STS-16, from August 30 to September 5, 1984.

Photo 3.5. *Discovery* during rollout ceremony at AFB Plant 42, Palmdale, 1984.
(Source: NASA Lyndon B. Johnson Space Center, S84-30898)

Since that time, *Discovery* has flown a total of 35 missions to space, and became the first orbiter to complete 20 missions with STS-63 in 1995. It is associated with a number of "firsts," including the first on-orbit satellite retrieval (STS-19, 1984); the first dedicated DoD payload (STS-20, 1985); the first use of carbon brakes on landing (STS-31R, 1990); the first Russian cosmonaut to fly on a U.S. Space Shuttle (STS-60, 1994); the first female shuttle pilot (Eileen Collins); as well as the first approach and fly-around of *Mir* (STS-63, 1995); the first time both SSME Block I and II were used (STS-70, 1995 and STS-95, 1998, respectively); first use of the JSC's new MCC (STS-70, 1995); the first flight to dock with the ISS (STS-96, 1999); and the first extravehicular activity (EVA) on flight that demonstrated techniques for repairing TPS materials in orbit (STS-121, 2006). Other accomplishments made by *Discovery* include deployment of the HST (STS-31R, 1990), and serving as the vehicle which returned John Glenn to space (STS-95, 1998).

In 1992, *Discovery* underwent a checkout and modification period (OMDP-1) at the KSC. During this time, 78 modifications were made, including the installation of a drag chute. In addition, minor corrosion was repaired, and the TPS was inspected and refurbished. In 1995-1996, *Discovery* underwent another checkout and modification period (OMDP-2) in Palmdale, which included 96 modifications and 87 deferred maintenance items. During this time, the new Orbiter Docking System (ODS) was installed to support ISS operations; the TPS was inspected and repaired; upgraded hardware for the payload bay flood lighting was installed; and some of the star-tracker shutters were replaced. In 2002, *Discovery* became the first orbiter to undergo an OMM period at the KSC. This included hardware and software upgrades and safety modifications for the second Return to Flight, following the *Columbia* accident.

3.1.3.4 *Atlantis (OV-104)*

The Orbiter *Atlantis* was the fourth orbiter built for operational use, following the *Columbia, Challenger,* and *Discovery*. It was named after the primary vessel for the Woods Hole Oceanographic Institute in Massachusetts, which was the first U.S. vessel to be used for oceanographic research. Assembly of the Orbiter *Atlantis* was initiated in Palmdale on March 30, 1980; it was rolled out of the hangar on March 6, 1985. From Palmdale, it was transported overland to Edwards AFB, mated to the SCA and flown to the KSC, where it arrived on April 9, 1985. *Atlantis* made its maiden flight, STS-28, from October 3 to October 7, 1985. Since that time, *Atlantis* has flown a total of 29 missions to space, marking the completion of its 20th mission with STS-86 in 1997. *Atlantis* is associated with a number of "firsts," including the support of the first construction of structures in orbit (STS-31, 1985); the first landing at the KSC since STS-23 in 1985 (STS-38, 1990); the first Return to Flight spacewalk (STS-37, 1991); the first docking operation with *Mir*, as well as the first mission to land with a different crew than the one at launch (STS-71, 1995); the first joint U.S./Russian EVA (STS-86, 1997); and the first flight with the new MEDS cockpit (STS-101, 2000). Other accomplishments of *Atlantis* include deployment of the Magellan and Galileo space probes, as well as the Gamma Ray Observatory.

Between 1992 and 1994, *Atlantis* underwent a checkout and modification period (OMDP-1) in Palmdale, during which time 331 modifications were made. These included the installation of a drag chute, preparations for the *Mir* ODS (which would be installed at KSC), and structural and electrical provisions for the Long Duration Orbiter pallet, which was never completed. In addition, the orbiter was outfitted with improved nose-wheel steering and the original APUs were swapped with improved models. In 1997-1998, *Atlantis* underwent OMDP-2 in Palmdale which entailed 96 modifications and 87 deferred maintenance items. During this period, the ODS which supports ISS operations was installed, the FRSI was replaced with AFRSI as a weight-saving measure, and the first MEDS 'glass cockpit' was installed.

Photo 3.6. Launch of Space Shuttle *Atlantis*, 1989.
(Source: NASA John F. Kennedy Space Center, KSC-89PC-1049)

3.1.3.5 *Endeavour (OV-105)*

The Orbiter *Endeavour* was the fifth orbiter built for operational use, and served as the replacement for the *Challenger*. It was named after the ship British explorer James Cook used when he discovered New Zealand and Australia, and in which he successfully navigated the Great Barrier Reef. *Endeavour* was the first spacecraft named through a national competition of elementary and secondary school students. To build the new orbiter, Rockwell used structural spares previously constructed between 1983 and 1987 under contract with NASA. These spares included an aft fuselage, crew compartment, forward reaction control system, lower and upper forward fuselage, mid-fuselage, wings (elevons), payload bay doors, vertical stabilizer, body flap, and one set of orbital maneuvering system/reaction control system pods. Construction and assembly was started on September 28, 1987 and completed in July 1990; *Endeavour* was rolled out of the Palmdale hangar on April 25, 1991. It is the only orbiter to have been ferried directly from Palmdale to the KSC, where it was delivered on May 7, 1991. *Endeavour* made its maiden flight, STS-49, from May 7 to May 16, 1992, and has since flown a total of 21 missions.

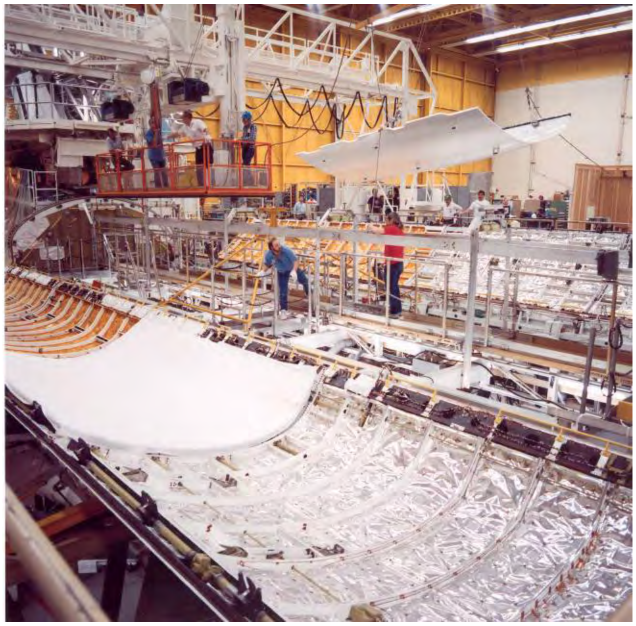

Photo 3.7. *Endeavour* in Orbiter Bay 1 during construction, looking northeast, 1991.
(Source: NASA Lyndon B. Johnson Space Center, S91-34626)

Endeavour is associated with a number of "firsts," including the first use of a braking parachute, the first three-astronaut EVA, and the first mission to feature four EVAs (STS-49, 1992); the first operational use of a drag chute (STS-47, 1992); the first flight of the Spacehab module (STS-57, 1993); the first HST servicing mission (STS-61, 1993); the first flight with toughened uni-piece fibrous insulation (TUFI) tiles (STS-59, 1994); and the first deployment and retrieval of two satellites on the same mission (STS-69, 1995). In addition, *Endeavour* marked two milestones on STS-47 in 1992 as the first orbiter to fly both a Japanese astronaut as well as the first married couple.

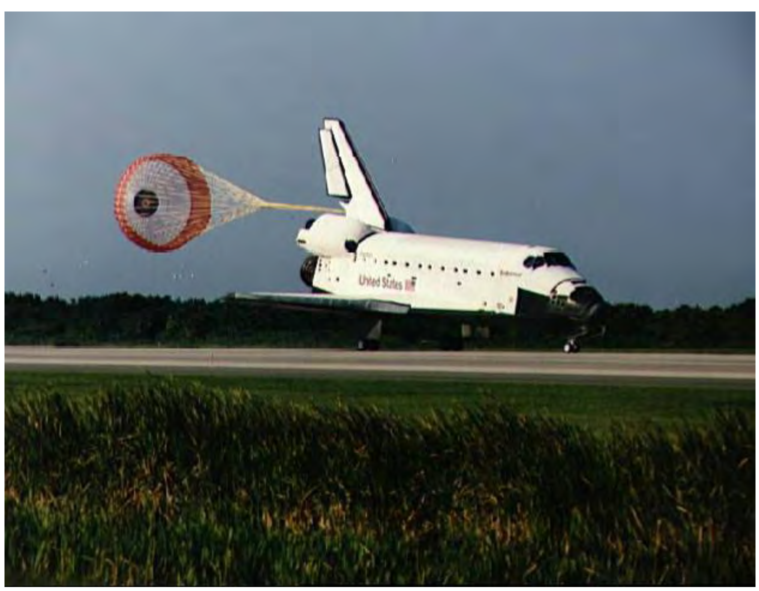

Photo 3.8. Landing of *Endeavour* at Kennedy Space Center, Florida, 1992.
(Source: NASA Lyndon B. Johnson Space Center, STS057(S)082)

In 1996-1997, *Endeavour* underwent a checkout and modification period (OMDP-1) which was partially conducted at the Rockwell plant in Palmdale and partially at the KSC. During this time, 63 modifications were made at Palmdale, 33 at the KSC, and 10 were shared between the two facilities. The modifications included the installation of an external airlock and ODS in bay 3, but made provisions for it to be placed in bay 2 when necessary. In addition, the AFRSI blankets on the mid-fuselage, aft-fuselage, payload bay doors, and upper wings were replaced by FRSI blankets, which are thinner and lighter. Also, doublers were added to several wing spars to eliminate load restrictions. Between 2003 and 2007, *Endeavour* underwent a second checkout and modification period (OMDP-2) at the KSC which entailed 124 modifications, including Return to Flight safety measures and the new glass cockpit.

3.2 Solid Rocket Boosters

Two solid-propellant boosters provide the main thrust to lift the Space Shuttle up to an altitude of about 150,000 feet (24 nautical miles). The SRBs are "the largest solid-propellant rocket motors ever flown, and the first to be man-rated" (Jenkins 2001:425). Each SRB measures approximately 150 feet in length and 12 feet in diameter, and is comprised of nine major elements, including four solid rocket motor (SRM) segments, a nose cap, a frustum, forward and aft skirts, and a nozzle. Loaded with about 1.1 million pounds of propellant, each SRB, mounted on either side of the ET, weighs approximately 1.3 million pounds at launch. The twin SRBs are loaded with a propellant mixture comprised of the oxidizer ammonium pechlorate (ca. 70% by weight) and aluminum powder fuel (16%). The SRBs provide 71.4% of the thrust at lift-off and during the first stage ascent. Following expenditure of the fuel supply, occurring about two minutes after launch, the SRBs are jettisoned and fall into the Atlantic Ocean. They are then retrieved, refurbished, and reused. The motor segments, igniter, and nozzle are shipped back to Thiokol in Utah for refurbishment and reloading with propellant.

With the exception of the SRMs, the SRBs were designed by the MSFC. NASA chose the Chemical Systems Division of United Technology Corporation in 1975 to supply the SRB separation motors, and McDonnell Douglas to provide SRB structures (aft skirts, rings, struts, frustums, nose caps). In 1976, MSFC selected United Space Boosters (USBI) as the booster (non-motor parts) assembly contractor at KSC; Martin Marietta was selected the same year to produce the SRB decelerator (parachute) system, with Pioneer Parachute Company as subcontractor. USBI later took over as prime contractor for the SRBs. In 1999, USBI became part of United Space Alliance (USA), and their functions were absorbed. The SRMs are manufactured by the Thiokol Chemical Company at their plant in Brigham City, Utah. NASA selected Thiokol in 1973, and originally awarded a six-year contract to design, develop, and test the SRM.

Prior to the launch of STS-1 in 1981, the SRB fired only seven times, four for development and three as qualification for flight. The cumulative run time was less than 1000 seconds (Heppenheimer 2002b:183). The first demonstration motor, DM-1, a prototype of a complete SRM, was first fired in Utah on July 18, 1977 by Thiokol. DM-2, assembled and filled in 1977, was fired in January 1978. As a response to a number of problems indicated by these early tests, engineering changes were made to the SRM. Drop tests for parachute development ran parallel to the DM-1 and DM-2 testing in 1977 and 1978. DM-1 and DM-2 also were used for structural and vibration tests at MSFC. The development series ended with the firing of DM-4 in February 1979. Three qualification firings, which tested the SRM in its flight configuration, were conducted in 1980 (Heppenheimer 2002b:189).

Completed SRM units are transported by rail car to the KSC, where they are assembled in the VAB. Thiokol shipped the first flight motors to KSC in late August and early November 1980.

In the aftermath of the *Challenger* accident, it took 32 months to redesign and requalify the SRB (CAIB 2003:100). A number of changes were made to the SRBs, including modifications to the SRM field joint metal parts, redesign of the internal case insulation and seals, and the addition of a weather protection system (Jenkins 2001:426). The post-*Challenger* SRMs were originally known as Redesigned Solid Rocket Motors (RSRM); by 1995 they had been renamed Reusable Solid Rocket Motors (still RSRM).

3.3 External Tank

The ET, the largest element of the Space Shuttle and the only major component that is not reused, measures approximately 154 feet in length and 27 feet in diameter. It is comprised of three main parts: a LOX tank, located in the forward position; an aft-positioned LH2 tank; and an intertank, which connects the two propellant tanks, houses instrumentation and processing equipment, and provides the attachment structure for the SRBs. The hydrogen tank is approximately twice as large as the oxygen tank. The skin of the ET is covered with spray-on foam insulation (SOFI). The ET feeds 535,000 gallons of LOX and LH2 propellants to the three SSMEs during the first 8.5 minutes of launch. The launched Shuttle jettisons the ET at an altitude of about 70 miles. The ET disintegrates in the atmosphere over the ocean as it falls back to Earth.

The ETs are manufactured and assembled by the Lockheed Martin Space Systems Company at NASA's MAF near New Orleans. It takes about 20 to 22 months to build a tank. The first ET was assembled at MAF in 1976. In July 1977, fabrications for the first flight ET began, and in November of that year, the intertank structural test program was completed. The first flight ET (ET-1) was delivered to the KSC in July 1979.

Today's Super Lightweight External Tank (SLWT) represents the third generation in the evolutionary development of the ET, and reflects successive efforts to lighten the weight in order to carry heavier payloads. The original ET, manufactured of aluminum alloy 2219, weighed 76,000 pounds. Originally coated in white latex paint, after the first two launches, NASA stopped painting the tank, resulting in a 600-pound weight reduction. The first unpainted, rust-colored ET was launched in March 1982 with STS-3 (Cleveland 2007:16). The second generation Lightweight Tank weighed 10,000 pounds less than the original. It was first flown on STS-6 in April 1983 (Cleveland 2007:19). The latest generation, the SLWT, weighs 7,500 pounds less than the Lightweight Tank. The first

SLWT (ET-96) was used on mission STS-91 in June 1998. Primarily made of an aluminum-lithium alloy (Alloy 2195), the SLWT features a new orthogonal waffle grid design to improve strength and stability. Prior to the STS-91 mission, between February and September 1996, a special Aluminum Lithium Test Article was used in a series of tests at MSFC. The testing program included a certification series followed by capability tests. The test article, which replicated the design enhancements, measured 40 feet long and 27 feet in diameter.

A total of 135 ETs have been manufactured at MAF (Cleveland 2007), averaging about eight per year. NASA's latest contract extension (to September 2008) with Lockheed Martin, signed in 2002, called for production of 35 SLWTs at a rate of six per year. In addition to the individual ET assigned to each space shuttle mission, through STS-133 targeted for May 2010, ET-138 was manufactured as a spare tank "for a launch on need, or rescue, mission for STS-133" (NASA MSFC 2008).

The components of the ET are manufactured in Building 103 at the MAF. The process begins with three concurrent manufacturing and assembly tracks – one for the LOX tank, one for the intertank, and one for the LH2 tank. Next, the LOX tank and intertank are combined in Cell J of Building 114. Finally, the LH2 tank and the LOX tank/intertank are assembled into the finished ET in Cell A of Building 110 (Lockheed Martin 2006a:13 in Cleveland 2007). Pressure testing of the oxygen and hydrogen tanks occurs in Building 110 and Structure 451. Cleaning and spraying of the ET components is conducted in Buildings 110, 114, and 131. Ablator is applied to elements of the ET in Building 318. Final approval and purchase of the ET by NASA takes place in Building 420 (Cleveland 2007:19).

3.4 Space Shuttle Main Engines

The SSME is a reusable, staged combustion LOX/LH2 engine. Three SSMEs, in conjunction with the SRBs, provide the thrust to launch the Space Shuttle vehicle. Each SSME measures approximately 14 feet in length and 7.5 feet in width at the mouth of the nozzle, and weighs 6,700 pounds. The designed life of each SSME is 7.5 hours of accumulative run time before overhaul, or 55 starts (*Marshall Star* 11 October 1978:3-4). The main engines operate for 8.5 minutes after launch. After the SRBs are jettisoned, the SSMEs provide a maximum thrust of more than 1.2 million pounds, which accelerates the Shuttle to reach orbit in just six minutes. As the Shuttle accelerates, the SSMEs burn 500,000 gallons of LH2 and LOX propellant provided by the ET. The propellant mixture is comprised of six parts LOX to one part LH2, by weight, to produce a sea level thrust of 375,000 pounds and a vacuum thrust of 470,000 pounds. The engines can be throttled over a thrust range of 65-109 percent, and they are gimbaled to provide pitch, yaw and roll during the ascent.

In July 1971, NASA selected the Rocketdyne Division of North American Rockwell to develop and manufacture the SSME, and in early 1972 awarded a 90-day letter contract to initiate work on SSME development and production (*Marshall Star* 23 August 1972:1-2). Rocketdyne's Canoga Park facility was the designated manufacturing location for the engine, with completed-engine system development testing to be conducted at the Mississippi Test Facility (MTF) near New Orleans (today's SSC). The contract called for delivery of the first flight engines by 1977 (*Marshall Star* 19 April 1972:2). NASA provided $15.4 million in additional monies to Rocketdyne for modifying the Coca Area test stands at the SSFL to accommodate static firings of SSME turbopumps, combustion devices, and combined SSME components; lesser funding also was provided for facilities changes needed at Canoga Park (*Marshall Star* 25 October 1972:2).

The start of the formal design process was delayed 10 months due to a protest lodged by a competitor (Biggs 1992). Not until early 1973 did the MSFC (the designated NASA center responsible for the development of the shuttle's SSME, SRB and ET) provide Rocketdyne with specifications for the SSME. In September 1974, the Shuttle Projects Office at the MSFC assigned James L. Splawn as the NASA resident manager of the SSME Resident Office at Rocketdyne in Canoga Park. He would head an on-site group of 23 MSFC employees at Canoga Park (*Marshall Star* 28 November 1976:1 and 3). During the development and testing of the engine, the MSFC conducted quarterly SSME reviews. The center also established an SSME HSL in late 1974 (*Marshall Star* 9 October 1974:1-2). Rocketdyne personnel from Canoga Park participated in computer flight simulations of the SSME at the MSFC, beginning in 1975 and running into 1981 (*Marshall Star* 8 April 1981:7).

The first SSME engine, a test article alternately known as the ISTB, was completed by Rocketdyne a month early, in March 1975. It was shipped to the NSTL (a follow-on name for the MTF) for static firing (*Marshall Star* 26 March 1975:1 and 4). SSME 0002, fitted with a flight-configuration nozzle, was fired successfully at the NSTL, in March 1977. More than 150 engine firings have been conducted by Rocketdyne at the NSTL since initiation of the test program in May 1975 (*Marshall Star* 30 March 1977:1). Rocketdyne conducted the first major static test firing of three SSMEs in a flight configuration, installed in the MPTA, at the NSTL, in May 1978. The first series of tests using the MPTA concluded in August (*Marshall Star* 2 August 1978:1 and 3). Acceptance testing of the third SSME for the shuttle *Columbia* was conducted at the NSTL in April 1979. Tests included checkout of electrical and mechanical systems, followed by three static firings at the NSTL. After completion of the tests, NASA would ship the SSME to the KSC for fitting into the *Columbia*. At this junction, NASA planned to launch the *Columbia* in late 1979 (*Marshall Star* 4 April 1979:1). Following various setbacks which impacted the launch schedule, the successful pre-launch Flight Readiness Firing of *Columbia*'s three SSMEs in February 1981 brought NASA closer to lift off of the Space Shuttle (*Marshall Star* 25 February 1981:1 and 4).

In 1983, NASA began undertaking major improvements to the SSME. One primary enhancement was a more powerful engine control computer. The second major modification was the redesigned Block I engine, upgraded with a new high-pressure oxygen turbopump made by Pratt & Whitney of West Palm Beach, Florida (NASA MSFC 2005). The new turbopump included new bearing elements made of a ceramic material which greatly improved the wear performance and fatigue life of the turbopump bearings. Other improvements manifested in the Block I engine included a two-duct powerhead, which "improved the distribution of the fuel flow and reduced the pressure and temperature in the engine," and a single-coil heat exchanger, "which eliminated welds and increased reliability" (NASA MSFC 2005). The Block I SSME was an interim upgraded SSME developed and fabricated at Canoga Park. Testing on the new Block I configuration SSME was completed at SSC on May 26, 1995. The Block I engine was first flown on *Discovery* (STS-70) in 1995. *Endeavour* was the first Space Shuttle to fly three Block I SSMEs on STS-77, May 19, 1996. The succeeding Block IIA engine, first flown on *Discovery* in 1998 (STS-95), was distinguished by the addition of a large throat main combustion chamber. The enlargement improved engine reliability by reducing pressure and temperature in the chamber and throughout the engine. The latest modification, the Block II engine, adds new hydrogen turbopumps. "The new design uses a unique casting process to eliminate welds and eliminates the need for special airfoil coatings" (NASA MSFC 2005). The first Block II engine flew on STS-104 in July 2001; the first flight incorporating three Block II engines was STS-110 in April 2002.

On October 5, 2004, SSC shipped the last of *Discovery's* three main engines to KSC for NASA's return to flight mission following the *Columbia* accident. STS-114 launched on July 26, 2005. These three SSMEs were tested and proven flight-worthy at SSC (NASA SSC 2007).

The Space Shuttle Main Engine Processing Facility (SSMEPF) was completed in June 1998 as an addition to the OPF-3 at the KSC. It was designed specifically for processing the SSMEs in support of SSP flight operations. The specifications for the facility were developed by representatives from Pratt & Whitney Rocketdyne (PWR)-SSME, NASA Design Engineering, and USA. The facility provides the capabilities for post-flight inspections and maintenance and functional check-out of all engine systems prior to installation in the orbiter. Before completion of this facility, these operations were conducted in the VAB at the KSC. Engines arrive at the SSMEPF either from the OPF, after removal from the orbiter, or from SSC following testing. Beginning in February 2002, both SSME assembly and flight inspection were performed at KSC. Historically, SSMEs were built and assembled at Rocketdyne's Canoga Park facility in California, with flight inspections performed at KSC. These functions are now consolidated in the SSMEPF. Engine 2058, the first to be fully assembled in the SSMEPF, was flown on mission STS-115 as part of the Orbiter *Atlantis.*

3.5 Thermal Protection System

A variety of TPS materials are used to protect the orbiter vehicle, mostly from the extreme heat of reentry. Among the TPS materials applied externally to the structural skin of the orbiter are RCC, high temperature reusable surface insulation tiles (HRSI), fibrous refractory composite insulation (FRCI), low-temperature reusable surface insulation (LRSI), AFRSI, and FRSI, as well as strain isolator pads (SIPs) and gap fillers.

While the earliest orbiters used as many as 34,000 tiles, the last addition to the orbiter fleet, *Endeavour*, is protected by approximately 26,000 tiles. A notable evolutionary trend is the replacement of some tiles by flexible insulation blankets. In general, the type and placement of TPS materials on the orbiter are related to temperature. RCC is used to protect areas subjected to extreme temperatures (more than 2300 degrees Fahrenheit [F]), such as the wing leading edges, the nose cap, and the area around the forward orbiter/ET structural attachment. The black HRSI tiles, which protect against temperatures less than 2300 degrees F, cover the upper forward fuselage, the underside of the vehicle where RCC is not used, portions of the OMS/reaction control system (RCS) pods, and the upper body flap surface, among other areas. White LRSI tiles are placed in selected areas of the forward, mid-, and aft fuselages, vertical and upper wings, and parts of the OMS/RCS pods. The LRSI tiles protect areas where temperatures are less than 1200 degrees F. AFRSI, a quilted fabric insulation, replaced the majority of LRSI tiles on *Discovery* and *Atlantis*. After its seventh flight, *Columbia* was modified to replace most of the LRSI tiles with AFRSI. White FRSI blankets, made of coated Nomex material, are used to protect areas where temperatures are below 700 degrees F, including the upper payload doors, portions of the mid- and aft fuselage sides, portions of the upper wing surface, and a portion of the OMS/RCS pods. AFRSI blankets and FRSI are bonded directly to the orbiter by silicon adhesive. SIPs are thermal isolators made of Nomex felt material which are bonded to the tiles; the SIP and tile assembly is bonded to the orbiter. Gap fillers ("filler bars"), also made of Nomex, are placed in the bottom of the gap between tiles. FRCI, made with Nextel, an aluminum-borosilicate fiber, was developed by NASA ARC. It has been used to replace HRSI 22-pound-per-cubic foot tiles to provide improved strength, durability, resistance to coating cracking, and weight reduction (NASA 1988).

The *Columbia* was the first shuttle to be sheathed in thermal tiles. For the *Enterprise*, Rockwell had substituted Styrofoam replacements, as was acceptable for the spacecraft's role as a test vehicle. Rockwell International had awarded Lockheed the subcontract for producing most of the shuttle's TPS. Ceramic reusable surface insulation was originally developed by the Lockheed Missile and Space Company, and tiles for the Space Shuttle were originally made at Lockheed's Sunnyvale, California plant in 1976, with the first shipment of HRSI in early 1977. In the mid-1980s, Rockwell took over the manufacture of TPS materials in Palmdale, California.

Reentry created very large heat loads, and aerodynamic forces that could lead to a spacecraft's breakup (as indeed did happen in February 2003 with the *Columbia*). NASA first experimented with ablative heat shields for the Mercury, Gemini, and Apollo programs, but by 1970—for the future shuttle—the agency sought a type of heat shield that was reusable. One of the alternate reusable heat shields under consideration was known as reusable surface insulation (RSI). RSI, in turn, led directly to the development of thermal ceramic tiles. Lockheed's research center in Palo Alto, California, had undertaken research and development (R&D) for this type of thermal protection shield, beginning in the early 1960s. By 1970-1971, Lockheed had a functioning pilot plant to manufacture silica RSI tiles. Experimentation for improved tile materials continued, and in late 1972 NASA ran a series of tests at several of its centers. At the MSC (now JSC) in

Houston, Lockheed RSI tiles were the only ones that survived the final series of thermal-acoustic tests (Bromberg 1999:100).

The final tiles had two different coatings, as well as size and thickness dimensions, dependent on which area of the shuttle they were to cover. NASA testing and evaluation of the tiles continued through the 1970s, especially at the ARC at Moffett Field, California. NASA encountered major challenges in the tile adhesive process. The tiles were fragile and required an intermediate, flexible layer next to the skin of the shuttle. A SIP, made of DuPont Nomex nylon felt, served this purpose. Rockwell individually bonded the tiles to SIP. Workmen glued them to the shuttle in arrays, with small gaps set between the tiles. At their Palmdale plant, Rockwell workers painted the exterior of the shuttle with a green epoxy corrosion inhibiter at the start of the tile application process. Rockwell also used a blueprint-like guide printed on Mylar to assist in tile layout.

The thermal protection tiles of the shuttle required extensive post-mission reworking after each shuttle flight. NASA personnel at the KSC "removed, reshaped (to conform to the contours of the spacecraft), and rebounded" the tiles of the *Columbia* in preparation for each successive mission during 1981-1982 (Hallion and Gorn 2003:260). Beginning in late 1982, the DFRC conducted tests of FRSI and of alternate thermal protection materials for the shuttle (Hallion and Gorn 2003:260-261; *X-Press* 17 September 1982:2; *X-Press* 15 October 1982:2). At Palmdale, NASA added Building 154, for work on protective tile adhesives, gap fillers, thermal barriers, and foam, during 1983-1984 (Boeing 2006). Rockwell fabricated FRSI here, producing this specialty insulation in varied thicknesses.

Supplementing the existing tile assembly and manufacturing capabilities at Lockheed's Sunnyvale plant and at Rockwell International's Palmdale plant was the KSC's Thermal Protection System Facility (TPSF), completed in 1988. The first tiles made at KSC were produced in the OPF High Bay 2. Subsequently, the manufacture and repair of the Space Shuttle's tiles, gap fillers, and insulation blankets, as well as coatings and adhesives were moved to the TSPF. Each unique tile undergoes a process which takes it from raw materials through finished product; the gap fillers and blankets are assembled from pre-made fabrics. Following their manufacture, TPS products are delivered to the OPS for installation on the orbiter. The first tiles produced at the KSC flew on *Columbia* in January 1990.

Qualifying a new TPS material requires extensive testing. Critical to the testing process are NASA's arc jet facilities at ARC and JSC, which simulate flight entry conditions. NASA ARC has also played a leading role in the development and testing of plugs, patches, pastes, and other materials used to repair damage to the shuttle's TPS while in orbit.

3.6 Launch, Landing, and Recovery: General Process Flow

Of the three major components of the Space Shuttle, only the ET is not recovered and reused. Historically, the ET arrived by barge from the MAF near New Orleans to the KSC. Since June 1998, the NASA barge *Pegasus* is towed between the MAF and the KSC by the SRB retrieval ships *Liberty Star* and *Freedom Star.* Berthed at the KSC, *Pegasus* is currently the only barge used to transport the ETs. The SRM units arrive by rail from Utah; the SSMEs are delivered by truck from SSC in Mississippi to the SSMEPF in the OPF-3 Annex. From there, the engines go to the OPF for installation.

Processing the orbiter vehicle for launch takes place in one of the OPF high bays, and begins with the orbiter's return from its previous mission. Processing takes an average of three to six months. Subsequently, the vehicle is towed into the VAB transfer aisle. High Bays 1 and 3 of the VAB are where integration and stacking of the complete Shuttle vehicle occurs in a vertical position on the MLP, to facilitate mating with the SRB/ET stack atop the MLP. The Space Shuttle and MLP are then rolled out to the pad on the Crawler. Shuttle countdown and launch are orchestrated from the KSC.

A typical Space Shuttle launch countdown begins approximately 72 hours prior to launch, at T-43 hours and counting. For the next 16 hours, final checkouts are conducted, software is loaded, and the middeck and flight deck platforms are removed. Around T-28 hours, preparations begin for loading the orbiter's fuel cell power reaction and storage distribution systems. At T-27 hours and holding, a four-hour hold commences while the launch pad is cleared of all non-essential personnel. When the countdown begins again, the cryogenic reactants are loaded into the orbiter's fuel cell storage tanks. Another hold begins at T-19 hours and holding, when the orbiter's midbody umbilical unit is demated, which usually lasts about four hours. When the countdown begins again, at T-19 hours and counting, final preparations are made for loading the fuel for the main engines, filling the water tank for the sound suppression system, and closing out the tail service masts on the MLP.

At T-11 hours and holding, the rotating service structure is removed and the orbiter's communications systems are activated. This hold sequence typically lasts 12 to 13 hours. Once countdown resumes, the orbiter's fuel cells are activated, and non-essential personnel are cleared from the blast area. At T-6 hours and holding, typically a two-hour hold, the launch team verifies that there are no violations of the launch commit criteria, and all personnel are cleared from the launch pad. In addition, fueling procedures for the external tank begin, and continue through the T-6 and counting stage. At T-3 hours and holding, the final inspection team proceeds to the launch pad for a detailed analysis of the Space Shuttle vehicle, and the closeout crew begins to configure the crew module for countdown and launch. After this two hour hold, at T-3 and counting, the astronauts arrive at the launch pad and begin their entry into the orbiter. Additional air-to-ground voice checks are conducted between the LCC and MCC at the JSC in Houston. The orbiter crew hatch is closed and checked for leaks before the closeout crew retreats to the fallback area.

Beginning at T-20 minutes and holding, the Shuttle Test Director conducts the final briefings for the launch team and preflight alignments of the inertial measurement unit are completed. After this 10-minute hold, the countdown begins again at T-20 minutes and counting. During this period, the orbiter's onboard computers and backup flight system are switched to launch configuration, and the thermal conditioning for the fuel cells begin. The final built-in hold occurs at T-9 minutes and counting, when the Launch Director, the Shuttle Test Director and the Mission Management Team confirm a go/no go for launch. This hold varies in length depending on the mission. Final countdown begins at T-9 minutes and counting. At this time, the automatic ground launch sequencer is started, and final tests and preparations for launch are completed. Once the SRBs ignite at liftoff, or T-0, mission responsibility is transferred to the MCC at JSC. The MCC also oversees the landing.

Following launch, and after about two minutes into the flight, the two SRBs burn out and jettison. A series of parachutes slow their fall into the Atlantic Ocean, where they are recovered by the *Liberty Star* and *Freedom Star* (Photo 3.9) which tow them back to CCAFS in and around Hangar AF. Here, at the SRB Disassembly Facility, special equipment lifts the SRBs from the water. They are then washed and disassembled into the four main segments and aft and forward skirt assemblies. After cleaning, the main casings are placed on railroad cars for shipment by train to the manufacturer in Utah, where they are reloaded with propellant. The new and reloaded SRB segments are received at the Rotation, Processing and Surge Facility (RPSF) located just north of the VAB. Inspection, rotation, and aft booster buildup occur here. Refurbishment and subassembly of inert SRB hardware takes place at the SRB Assembly and Refurbishment Facility (ARF) located south of the VAB at the KSC. Completed aft skirt assemblies from the SRB ARF are integrated with the booster aft segments at the RPSF's Rotation/Processing Building. The two nearby Surge Buildings are used to store the SRB segments until they are moved to the VAB for integration. The retrieval ships also retrieve the parachutes from the ocean, hauling them in on large reels. The reels are then taken to the Parachute Refurbishment Facility at KSC, where the parachutes are unspooled, washed, dried, and stored in canisters for eventual reuse.

Following mission completion, the orbiter makes an unpowered landing at the SLF, or Edwards AFB if inclement weather or other circumstances prevent landing at KSC. In the case of an Edwards AFB landing, the orbiter is returned via a ferry flight atop the SCA. In the early years of the SSP, Edwards AFB was the preferred landing site because of more stable weather conditions as well as a choice of concrete and dry lake beds. However, KSC became the primary landing site because it saved processing time to prepare for the next mission. The first landing at KSC was mission 41-B on February 11, 1984. Of all the Shuttle missions from 1981 to 2006, more than 60 percent have landed at KSC (see Table 2.3). At KSC, the MDD detaches and lifts the orbiter from the SCA. Astronauts are transported to the Operations and Checkout (O&C) Building for medical examination and debriefing. The orbiter is then safed and towed to the OPF within hours of its arrival. Here, it undergoes postflight servicing and checkout, as well as vehicle modifications needed for future flight requirements or to enhance vehicle performance and correct deficiencies.

Photo 3.9. Retrieval ship *Freedom Star* towing SRB.
(Source: NASA John F. Kennedy Space Center, 05PD-1788)

4.0 SURVEY RESULTS FOR ALL NASA CENTERS

4.1 Overview

Between July 2006 and January 2007, historical surveys were conducted at 13 NASA Centers and component facilities (Figure 4.1):

- Joseph S. Ames Research Center
- Canoga Park Facility
- Hugh L. Dryden Flight Research Center
- John H. Glenn Research Center (including Plum Brook Station)
- Lyndon B. Johnson Space Center (including Ellington Field)
- John F. Kennedy Space Center
- Langley Research Center
- George C. Marshall Space Flight Center
- Michoud Assembly Facility
- Air Force Plant (AFP) 42, Site 1 North, Palmdale
- Santa Susana Field Laboratory
- John C. Stennis Space Center
- White Sands Test Facility (including White Sands Space Harbor)

Detailed results of these studies are contained in a series of reports prepared on behalf of each Center (ACI 2007a, 2007b, 2007c, 2007d; ACI and Weitze Research 2007a, 2007b, 2007c, 2007d, 2007e; Cleveland 2007; Page & Turnbull, Inc. 2007; SAIC 2006; SSC 2007). Section 4.2 provides a description of each Center and component facility vis a vis their respective SSP mission, and a summary of survey findings.

In addition, the assets at Goddard Space Flight Center, the Jet Propulsion Laboratory, and Wallops Flight Facility (Figure 4.1) were considered, but not surveyed. All three have assets that support the SSP, but which are not dedicated to the program. Descriptions of these field centers, and their respective contributions to the SSP, are summarized in Section 4.3.

ARC, DFRC, LaRC, GRC, and WFF originated as facilities of the National Advisory Committee for Aeronautics (NACA), which became the nucleus of NASA in October 1958. GSFC, KSC, MSFC, and JPL began their associations with NASA as transfers from the U.S. military space program (Wells et al. 1976).

While many of the 70 significant buildings and structures were designed, constructed, and modified over a long period of time, the "Year" column in Tables 4.1 through 4.13 indicates the date of original building completion; if applicable, major modifications for the SSP, or the completion of major additions containing significant features (e.g., NBS) are provided after this date.

NASA Center Locations

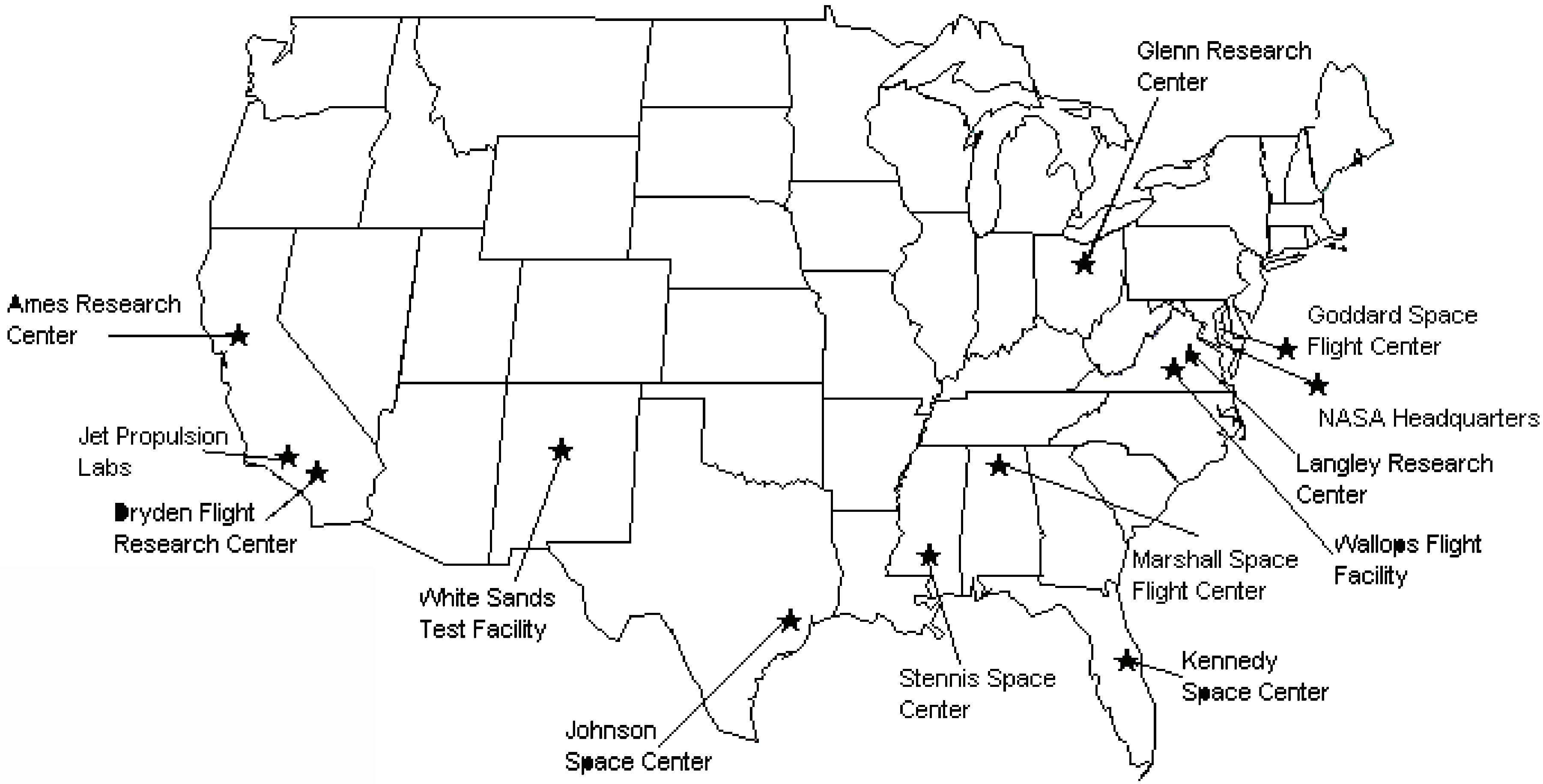

Figure 4.1. Location of NASA Centers (www.nasaexplores.com/extras/maps/center_map.html). The locations of the Michoud Assembly Facility near New Orleans, Louisiana and the Santa Susana Field Laboratory and Canoga Park Facility, both in the greater Los Angeles area, are not depicted.

4.2 Summary of Survey Findings

4.2.1 Joseph S. Ames Research Center (ARC)

NASA ARC at Moffett Field in Santa Clara County, California (Photo 4.1), which encompasses approximately 2000 acres, has played a critical role in the SSP in the areas of wind tunnel testing, thermal protection systems, piloted landing simulation, and computational fluid dynamics. In the decades preceding the SSP, fundamental studies in lifting body concepts, trajectory analyses, and thermal protection materials were made. ARC began operations in 1949 as the Moffett Field Laboratory, NACA's second laboratory for research in aircraft structures. In 1944, the facility was named "Ames Aeronautical Laboratory" in honor of Dr. Joseph S. Ames, a leading aerodynamicist, former president of Johns Hopkins University, and one of the first NACA members. On October 1, 1958, the laboratory became part of NASA and was renamed Ames Research Center (Wells et al. 1976).

Photo 4.1. Aerial view of Ames Research Center, Mountain View, California.
(Source: NASA, GRIN No.: GPN-2000-001759)

Following consideration of all properties at ARC, a preliminary list of 11 facilities was compiled by a team consisting of the Center HPO, Mr. Keith Venter, the Facilities Planning Group, the Ames History Office, Code Q-Office of the Director of Safety, Environmental and Mission Assurance, and the support service contractor ISSi's CRM Division. The 11 properties, including ten buildings and one object (Table 4.1), were surveyed between August and October 2006 by Page & Turnbull, Inc., San Francisco, California (Page & Turnbull 2007). As a result, two facilities, the Arc Jet Laboratory (N-238) and the Flight and Guidance Simulation Laboratory (N-243) were evaluated as NRHP-eligible in the context of the SSP. Building N-238, which contains the 60-megawatt (MW) Interaction Heating Facility (the only portion of the building that is directly associated with the SSP), was considered significant under NRHP Criterion A (Events) for the research and development of the Space Shuttle's thermal protection system. Building N-243 was evaluated as significant under Criterion A for the Vertical Motion Simulator (VMS), which contributed to the training of the astronauts for the SSP.

Table 4.1. List of Assets at NASA ARC Surveyed for SSP Significance.

Facility No.	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
N-238	Arc Jet Laboratory	1964	Eligible	Building
N-243	Flight and Guidance Simulation Laboratory	1967	Eligible	Building
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
	36% Scale Orbiter Model	1975	Not eligible	Object
N-221	40-By 80-Foot Wind Tunnel	1944	Not eligible	Building
N-227A to D	Unitary Plan Wind Tunnels	1955	Not eligible	Building
N-229	Experimental Fluid Dynamics Facility	1961	Not eligible	Building
N-237	Hypervelocity Free Flight Facility	1964	Not eligible	Building
N-240	Airborne Missions and Applied Life Sciences Experiments	1965	Not eligible	Building
N-240A	Life Sciences Flight Experiments	1982	Not eligible	Building
N-244	Space Projects Facility	1967	Not eligible	Building
N-258	NASA Advanced Supercomputing Facility	1986	Not eligible	Building

4.2.2 Canoga Park Facility

The Canoga Park Facility, located at 6633 Canoga Avenue in Canoga Park, Los Angeles County, California (Photo 4.2), is owned and operated by PWR, a United Technologies Company. Within Building 001 of this facility, NASA owns several pieces of equipment, including furnaces and welding machines, currently used in support of the NASA SSME Supply Contract (No. NAS8-01140), managed by NASA's MSFC.

Photo 4.2. The PWR Canoga Park Facility
(Source: PWR 18 July 2006:14)

The historic facilities field survey at Canoga Park was performed on September 20, 2006 by ACI, Sarasota, Florida; archival research was conducted by ACI subconsultant Dr. Karen Weitze, Weitze Research, Stockton, California between November 2006 and January 2007. The evaluation of NASA-owned assets at PWR's Canoga Park Facility focused on five large pieces of equipment located within Building 001 (Table 4.2) which were identified by the MSFC's HPO, Ralph Allen, to have possible associations with the SSP. As a result of research and field survey, one structure, the Pacific Scientific Furnace, was considered eligible for listing in the NRHP for its significant historical associations with the SSP under Criterion A, as well as under Criterion C for its design and engineering. Every SSME flown on the Space Shuttle was brazed in this furnace.

Table 4.2. List of Assets at the Canoga Park Facility Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
n/a	Pacific Scientific Furnace	1966	Eligible	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
n/a	Electron Beam (EB) Welding Machine (EB-5)	1978	Not eligible	Structure
n/a	General Electric (GE) Furnace	1959	Not eligible	Structure
n/a	Inertia Welding Machine	1991	Not eligible	Object
n/a	Tornetic (Special) Drill Machine	ca. 1974	Not eligible	Object

4.2.3 Hugh L. Dryden Flight Research Center (DFRC)

The DFRC (Photo 4.3), located on Edwards AFB in Edwards, Kern County, California, is NASA's premier flight research and test facility. DFRC originated in 1946 as the "NACA Muroc Flight Test Unit," and was subsequently redesignated as the "High Speed Flight Research Station" in 1949, then the "High Speed Flight Station" in 1954. It became part of NASA with the agency founding in October 1958, and on January 8, 1976 was given its current name in honor of Dr. Dryden, an aeronautical research pioneer and first NASA Deputy Administrator (Wells et al. 1976). The Center is comprised of 77 buildings as well as mobile and temporary structures. The buildings which support the SSP operations are clustered at the northern end of the DFRC.

Photo 4.3. Aerial view of NASA Dryden Flight Research Center.
(Source: NASA Dryden, ECOI 264-52)

Many significant contributions to the SSP have been made at the DFRC. In the 1980s and 1990s, the Center conducted tests relating to heat resistant tiles, tested a new drag chute for the Shuttle orbiter, and performed tire and landing tests over a period of two years which ultimately resulted in the repaving of the runways at the KSC. In addition to more than two decades of Shuttle-related flight research, the DFRC is distinguished by its key role in two exceptionally significant historical events. The Shuttle's ALT program, conducted at the DFRC in 1977, demonstrated the Shuttle orbiter's flight and landing abilities, and verified that the Shuttle orbiter mated with the 747 SCA could fly safely. The DFRC also served as the primary Shuttle landing site during the first decade of operational flights. In the 1980s, Dryden managed 80% of all Shuttle landings; between 1981 and 1996, 60% of all missions ended at Edwards AFB (Hallion and Gorn 2003:264). Since the 1990s, Dryden has served as NASA's alternate Shuttle landing site.

The historic facilities field survey was performed on September 18, 2006 by ACI; on-site archival research was conducted during the week of November 13 by Dr. Karen Weitze.

Under the direction of DFRC's HPO, Dan Morgan, a detailed field survey and evaluation was performed on the five extant assets (Table 4.3) determined by Morgan to have potentially significant associations with the SSP. As a result of research and field survey, the Shuttle MDD was considered eligible under Criteria A and C. Under Criterion A, the MDD is exceptionally significant for its association with early test programs conducted at DFRC, which paved the way for all future Space Shuttle missions, and for its operational use following Shuttle landings on the runways of Rogers Dry Lakebed and on the primary runway at Edwards AFB. The Dryden MDD is considered eligible under Criterion C for its specialized engineering and design to accommodate the mating and demating of the Shuttle orbiter and the SCA. The Dryden MDD, distinguished as NASA's first mating-demating tower built exclusively for the SSP, was also designed to incorporate several unique features required for the early Space Shuttle testing programs, unlike its counterpart at the KSC in Florida.

Table 4.3. List of Assets at NASA DFRC Surveyed for SSP Significance.

Facility No.	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
4860	Shuttle Mate-Demate Device (MDD)	1976	Eligible	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
4833	Shuttle Hangar	1976	Not eligible	Building
4845	Shuttle Support Office	1999	Not eligible	Building
4863	Shuttle Support Administration	1999	Not eligible	Building
4864	Orbital Turn Around Building	1999	Not eligible	Building

4.2.4 John H. Glenn Research Center (GRC)

The GRC consists of two sites in Ohio, the Lewis Field (Photo 4.4) in Cuyahoga County, near Cleveland, and Plum Brook Station (PBS), located near Sandusky in Erie County. Lewis Field, which encompasses almost 365 acres of land, mostly within the City of Brook Park, supports NASA's research, technology, and development programs in the areas of aero-propulsion, space flight systems, space propulsion, space science applications, and space power. PBS, operated as a satellite facility of GRC, encompasses approximately 6454 acres of land. GRC originated in 1942 as a NACA flight propulsion laboratory, named the "Aircraft Engine Research Laboratory." In 1948, NACA renamed it "Lewis Flight Propulsion Laboratory" in honor of Dr. George W. Lewis, a leading aeronautical engineer and NACA's Director of Aeronautical Research (1919-1947). It was redesignated "Lewis Research Center" upon the formation of NASA on October 1, 1958 (Wells et al. 1976), and officially became the "John H. Glenn Research Center at Lewis Field" on March 1, 1999. The new name honors both Dr. Lewis and John H. Glenn, astronaut and U.S. Senator from Ohio.

NASA has used the GRC's wind tunnels to test Shuttle parts for their safety and performance in flight conditions, and pioneering work here paved the way for today's SSME. NASA GRC also helped develop improved fuel cells for the SSP. Technologies developed at GRC are applied to projects that support the Space Shuttle and the ISS. The GRC was responsible for the initial design of the Space Station power system, and continues to support the launch and operations of the power system for the ISS.

Photo 4.4. Aerial view of the Glenn Research Center at Lewis Field, Cuyahoga County, Ohio. (Source: NASA, GRIN No. GPN-2000-002008)

The historic facilities field survey and archival research were performed during the week of August 15-19, 2006 by ACI. The evaluation of NASA GRC facilities focused on eight properties (Table 4.4) which were determined by the Center HPO, Leslie Main, to have supported the SSP. As a result of research and field survey, both the 8 by 6-foot Supersonic Wind Tunnel (SWT) and the Abe Silverstein (10 by 10-foot) SWT best exemplify the vital contributions made to the SSP by the engineers, scientists and technicians at NASA GRC. Both are considered eligible for listing in the NRHP under Criteria A and C, and both exhibit excellent integrity. The latter was previously determined NRHP-eligible.

Table 4.4. List of Assets at NASA GRC Surveyed for SSP Significance.

Facility No.	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
39, 46, 53, 54, 55, 56, 57, 59, 61, 138	8 by 6-foot SWT	1949	Eligible	Structures and Buildings
85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 113, 114	Abe Silverstein (10 by 10-foot) SWT	1955	Eligible	Structures and Buildings
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
100, 202, 205, 206	Rocket Engine Test Facility (RETF)	1955-57	NHL listed Oct. 3, 1985. Designation withdrawn April 4, 2005. No longer extant	Buildings (demolished)
5, 23, 37, 38	Engine Research Building (ERB)	1942-47	Not eligible	4 Buildings
35	Research Combustion Lab (RCL)	1945	Not eligible	Building
301	Electric Propulsion Lab (EPL)	1958	Not eligible	Building
3211, 3231, 3232, 3233, 3251, 3252, 3253, 3261	Spacecraft Propulsion Research Facility (B2) (at PBS)	1968	NHL and NRHP-listed, but not applicable within the Space Shuttle context	8 Buildings
1411, 1431, 1432, 1433, 1441, 1451, 1452, 1453, 1454, 1461, 1491, 8336, 9858	Space Power Facility (SPF) (at PBS)	1969	Not eligible	13 Buildings

4.2.5 Lyndon B. Johnson Space Center (JSC)

NASA JSC (Photo 4.5) encompasses approximately 1620 acres adjacent to Clear Lake City in Harris County, Texas, about 25 miles southeast of Houston. Originating as the Manned Spacecraft Center (MSC), on February 17, 1973, the MSC became the Johnson Space Center, named in memory of former President and U.S. Senator Lyndon B. Johnson. Today's JSC includes 1000 acres donated to NASA by Rice University in late 1961, and 620 acres purchased by NASA. Facilities construction was begun in April 1962, and the Center opened for business in February 1964, following the transfer of personnel from multiple temporary work sites. Among the approximate 140 buildings at the JSC, many of the specialized facilities are devoted to spacecraft systems and materials research and development, as well as for astronaut training. The JSC is NASA's original lead Center for the SSP. Its key responsibilities include the design, development and testing of spacecraft and associated systems for manned flight; the selection and training of astronauts; and the planning and controlling of manned missions. JSC is the site of the Mission Control Center (MCC), which directs all Space Shuttle missions, and is also the home base for the Nation's astronauts.

Photo 4.5. Aerial view of the Johnson Space Center, Harris County, Texas. (Source: NASA, GRIN No.: GPN-2000-001112.jpg)

The nearby Ellington Field, originally built in 1917, maintains aircraft for astronaut training. Since 1984, Ellington Field has been owned by the City of Houston. Of the NASA-owned facilities at the air field, only one or two are dedicated to the SSP.

The historic facilities survey of JSC was conducted by ACI between October 30 and November 3, 2006. The evaluation focused on 30 potentially significant properties (Table

4.5) identified by the JSC HPO, Perri Fox. As a result of research and field survey, 11 assets, including eight buildings and the three extant Space Shuttle orbiters, were considered to individually meet the criteria of eligibility for listing in the NRHP. Among these, the MCC (Building 30) is a designated NHL. The other 10 assets were newly identified as NRHP-eligible. In general, most of the NRHP-eligible historic properties are large, multi-functional facilities, where, in most cases, the building derives its exceptional significance from specialized facilities located within a portion of the overall building.

Table 4.5. List of Assets at NASA JSC, including Ellington Field, Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
5	Jake Garn Mission Simulator and Training Facility	1965	Eligible	Building
7	Crew Systems Laboratory	1964	Eligible	Building
9	Systems Integration Facility	1966	Eligible	Building
16	Avionics Systems Laboratory (SAIL)	1964	Eligible	Building
30	Mission Control Center	1964	Eligible (Designated NHL)	Building
44	Communications and Tracking Development Lab	1966	Eligible	Building
222	Atmospheric Reentry Materials and Structures Evaluation Facility	1966	Eligible	Building
920N	Sonny Carter Training Facility/ Neutral Buoyancy Laboratory	1993/ 1996	Eligible	Building
OV-103	*Discovery*	1983	Eligible	Structure
OV-104	*Atlantis*	1985	Eligible	Structure
OV-105	*Endeavour*	1990	Eligible	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
29	Long Duration Evaluation Facility	1964	Not eligible	Building
32	Space Environment Simulation Lab (SESL)	1964	(Designated NHL)	Building
33	Space Environment Effects Lab	1966	Not eligible	Building
35	Mission Simulation Development Facility	1968	Not eligible	Building
49	Vibration and Acoustic Test Facility	1965	Not eligible	Building
222A	Rectifier Building	1966	Not eligible	Building
222aa	Arc Power Supply	1966	Not eligible	Building
222B	Boiler Building No. 1	1966	Not eligible	Building
350	Energy Systems Support Laboratory	1964	Not eligible	Building
351	Power Systems Test Facility	1964	Not eligible	Building
351A	Thermal Equipment Storage Building	1970	Not eligible	Building
352/352A	Pyrotechnics Test Facility	1964	Not eligible	Building
352A	Pyrotechnics Test Cells	1964	Not eligible	Structure
354	Cryogenics Test Facility	1964	Not eligible	Building
356A	Fluid Systems Test Building	1964	Not eligible	Building
EF 135	Maintenance Hangar	1943	Not eligible	Building
EF 990	Maintenance Hangar	1956	Not eligible	Building
N905NA	Shuttle Carrier Aircraft	1974*	Not eligible	Structure
N911NA	Shuttle Carrier Aircraft	1989*	Not eligible	Structure

* Date acquired by NASA

4.2.6 John F. Kennedy Space Center (KSC)

The KSC in Brevard County, Florida is NASA's primary Center for launch and landing operations, and is the liftoff site for all Space Shuttle missions. It is responsible for the planning and direction of space vehicle assembly; preflight preparation of the space vehicles and their cargo; the test and checkout of launch vehicles; coordination of tracking and data acquisition; countdown and launch operations; landing operations; and the refurbishment of the Shuttle for future missions. The KSC also performs the checkout, assembly and launch of the component parts of the ISS. NASA maintains operational control over approximately 4463 acres of the KSC. The major facilities are located within the Industrial Area, the Launch Complex (LC) 39 Area, the VAB Area, and the SLF Area. The Industrial Area was developed to support administrative/technical functions, and also provides for areas in which hazardous payload processing operations could be performed. The LC 39 and VAB Areas (Photo 4.6) were developed primarily to support launch vehicle operations and related launch processing activities. The SLF Area supports landing operations.

Photo 4.6. Aerial view of the LC 39 and VAB Areas, KSC, Florida.
(Source: NASA, GRIN No.: GPN-2000-000855)

The historic facilities survey at KSC was conducted during the week of July 25-28, 2006 and May 9, 2007 by ACI. The evaluation included 112 properties, which were determined, preliminarily, by then KSC HPO, Mr. Mario Busacca, to have supported the SSP. As a result of research and field survey, 26 assets (Table 4.6) were considered to individually meet the criteria of eligibility for listing in the NRHP, including six NRHP-listed historic properties: the VAB, LCC, Crawlerway, two Crawler Transporters, and the

Press Site: Clock and Flag Pole. These were identified in a 1997 historic facilities survey of KSC (ACI 1998), which resulted in the preparation of a NRHP Multiple Property Nomination. Eight individually eligible historic properties, two historic districts (LC 39: Pad A Historic District and the LC 39: Pad B Historic District), and 34 contributing resources within the two districts were identified in this earlier study as significant in the context of the Apollo Program. The nomination was signed by the Florida SHPO in August 1998. The SSP-related historic facilities survey of KSC supplements this previous study.

In addition to the six NRHP-listed historic properties, 20 assets were newly assessed as individually NRHP-eligible. These include LC 39: Pad A, LC 39: Pad B, the SLF Runway, the Landing Aids Control Building, the MDD, the OPF (High Bays 1 and 2), the OPF High Bay 3 (OPF-3), the Thermal Protection System Facility, the Rotation/Processing Building, the SRB Manufacturing Building, the Parachute Refurbishment Facility, the Canister Rotation Facility, the Hypergol Module Processing North, two Payload Canisters, the two Retrieval Ships *Freedom Star* and *Liberty Star*, and the three MLPs.

To provide continuity with the previous survey of KSC historic facilities and the existing Multiple Property Nomination, the KSC study included the identification of historic districts. As a result, the previously listed LC 39: Pad A Historic District and the LC 39: Pad B Historic District, originally listed for their exceptional significance in the context of the Apollo Program, were reassessed within the context of the SSP. Each district contains 21 contributing resources of which one is individually eligible and 20 are contributing but not individually eligible. In addition, four new historic districts were identified. The SLF Area Historic District contains three properties which are all both individually eligible and contributing; the Orbiter Processing Historic District includes three properties which are both individually eligible and contributing; the SRB Disassembly and Refurbishment Complex Historic District contains no individually eligible properties but nine contributing resources; and the Hypergolic Maintenance and Checkout Area Historic District contains one individually eligible property and one contributing resource.

The historic facilities which are contributing to these historic districts, but not individually eligible, are included in Table 4.6 as “Not eligible.” These are denoted by an asterisk to indicate their eligibility as contributing resources.

In conclusion, of the total 112 assets identified and evaluated at the KSC, 76 are NRHP-listed or eligible properties, including 26 individually listed or eligible properties and 50 which are contributing to a historic district, but which are not considered individually eligible. Of the 76 significant assets, 36 were previously determined NRHP-eligible, and 40 were newly evaluated. Thirty-six assets are evaluated as ineligible for listing in the NRHP, either individually or as part of a historic district.

Table 4.6. List of Assets at NASA KSC Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
	INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT			
K6-848	Vehicle Assembly Building (VAB)	1966/1976	Eligible (Listed)	Building
K6-900	Launch Control Center (LCC)	1966	Eligible (Listed)	Building
UK-008	Crawlerway	1965	Eligible (Listed)	Structure
	Crawler Transporters (2)	**1965/1979**	Eligible (Listed)	Structure
	Press Site: Clock and Flagpole	**1969**	Eligible (Listed)	Structure
J8-1708	Launch Complex 39: Pad A	1965/1979	Eligible	Structure
J7-337	Launch Complex 39: Pad B	1968/1985	Eligible	Structure
M7-657	Parachute Refurbishment Facility	1964	Eligible	Building
M7-777	Canister Rotation Facility	1993	Eligible	Building
	Payload Canisters (2)	1978	Eligible	Structure
	Retrieval Ship *Liberty Star*	1980-81	Eligible	Structure
	Retrieval Ship *Freedom Star*	1980-81	Eligible	Structure
	Mobile Launcher Platforms (3)	1968/1976-1983	Eligible	Structure
K6-494	**Rotation/Processing Building**	**1984**	Eligible	Building
L6-247	SRB ARF Manufacturing Building	**1986**	Eligible	Building
	Shuttle Runway	1976	Eligible	Structure
J6-2313	Landing Aids Control Building	1976	Eligible	Building
J6-2262	Mate-Demate Device	**1978**	Eligible	Structure
K6-894	Orbiter Processing Facility	1977	Eligible	Building
K6-696	Orbiter Processing Facility High Bay 3 (includes the SSME Processing Facility)	1987/1991	Eligible	Building
K6-794	Thermal Protection System Facility	**1988**	Eligible	Building
M7-961	Hypergol Module Processing (North)	1964	Eligible	Building
	NOT INDIVIDUALLY ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT			
M6-399	Headquarters Building	1965	Not eligible (Listed)	Building
M7-355	**Operations and Checkout (O&C) Building**	**1964**	Not eligible (Listed)	Building
J5-1197	SLF Air Traffic Control Tower	2003	Not eligible	Structure
J6-2465	Flight Vehicle Support Building	2002	Not eligible	Building
K6-015	Convoy Vehicle Enclosure (T-Shelter)	2001	Not eligible	Structure
K6-1547	Logistics Facility	1986	Not eligible	Building
J8-1462	High Pressure GH2 Facility	1968	Not eligible*	Structure
J8-1502	LOX Facility	1966	Not eligible*	Structure
J8-1503	Operations Support Building A-1	1966	Not eligible*	Building
J8-1512	Camera Pad A No. 1	1966	Not eligible*	Structure
J8-1513	LH2 Facility	1966	Not eligible*	Structure
J8-1553	Electrical Equipment Building No. 2	1965	Not eligible*	Building
J8-1554	Camera Pad No. 6	1965	Not eligible*	Structure
J8-1563	Electrical Equipment Building No. 1	1965	Not eligible*	Building
J8-1564	Foam Building	1965	Not eligible	Building
J8-1565	Pump House	1964	Not eligible	Building
J8-1610	Water Tank	1980	Not eligible*	Structure

Facility No.	Name	Date		NRHP Resource Type
J8-1611	Flare Stack	1985	Not eligible*	Structure
J8-1614	Operations Support Building A-2	1966	Not eligible*	Building
J8-1659	Compressed Air Building	1965	Not eligible	Building
J8-1703	Slidewire Termination Facility	1965	Not eligible*	Structure
J8-1707	Water Chiller Building	1968	Not eligible*	Building
J8-1714	Camera Pad A No.2	1965	Not eligible*	Structure
J8-1753	Remote Air Intake Building	**1965**	Not eligible	Building
J8-1811	Electrical Equipment Building No. 3	**1979**	Not eligible*	Building
J8-1856	Electrical Equipment Building No. 4	**1979**	Not eligible*	Building
J8-1858	Azimuth Alignment Station	**1965**	Not eligible	Structure
J8-1862	Hypergol Oxidizer Facility	**1979**	Not eligible*	Structure
J8-1906	Hypergol Fuel Facility	**1979**	Not eligible*	Structure
J8-1956	Camera Pad A No. 4	**1965**	Not eligible*	Structure
J8-1961	Camera Pad A No. 3	**1965**	Not eligible*	Structure
J7-132	Operations Support Building B-1	**1967**	Not eligible*	Building
J7-140	High Pressure GN2 Facility	**1967**	Not eligible*	Structure
J7-182	LOX Facility	**1967**	Not eligible*	Structure
J7-183	Camera Pad B No. 6	**1968**	Not eligible*	Structure
J7-191	Camera Pad B No. 1	**1968**	Not eligible*	Structure
J7-192	LH2 Facility	**1967**	Not eligible*	Structure
J7-231	Electrical Equipment Building No. 2	**1967**	Not eligible*	Building
J7-240	Flarestack	**1985**	Not eligible*	Structure
J7-241	Electrical Equipment Building No. 1	**1967**	Not eligible*	Building
J7-242	Foam Building	**1968**	Not eligible	Building
J7-243	Operations Support Building B-2	**1967**	Not eligible*	Building
J7-288	Water Tank	**1981**	Not eligible*	Structure
J7-331	Slidewire Termination Facility	**1967**	Not eligible*	Structure
J7-338	Compressed Air Building	**1967**	Not eligible	Building
J7-342	Camera Pad B No.2	**1967**	Not eligible*	Structure
J7-385	Water Chiller Building	**1968**	Not eligible*	Building
J7-432	Remote Air Intake Building	**1967**	Not eligible	Building
J7-490	Hypergol Oxidizer Facility	**1981**	Not eligible*	Building
J7-491	Electrical Equipment Building No. 3	**1981**	Not eligible*	Building
J7-534	Hypergol Fuel Facility	**1981**	Not eligible*	Structure
J7-535	Electrical Equipment Building No. 4	**1981**	Not eligible	Building
J7-537	Azimuth Alignment Station	**1967**	Not eligible	Building
J7-584	Camera Pad B No. 4	**1968**	Not eligible	Structure
J7-589	Camera Pad B No. 3	**1968**	Not eligible	Structure
K6-495	Support Building	1984	Not eligible	Building
K6-497	Surge Building #1	1984	Not eligible	Building
K6-345	Surge Building #2	1984	Not eligible	Building
L6-147	Chiller Building	1986	Not eligible	Building
L6-146	Engineering and Administration Building	1986	Not eligible	Building
L6-248	Service Building	1986	Not eligible	Building
L6-295	Hazardous Waste Staging Building	1992	Not eligible	Building

Facility No.	Name	Date		NRHP Resource Type
L6-297	Storage Building	1988	Not eligible	Building
L7-251	Aft Skirt Test Building	1986	Not eligible	Building
1728	Hangar N	1958	Not eligible	Building
M7-1061	Hypergol Support Building	1964	Not eligible*	Building
M7-1011	HMCA GSE Support Building	1988	Not eligible	Building
M5-1494	MILA Operations Building	1966	Not eligible	Building
M7-505A	Launch Equipment Test Facility	1976	Not eligible	Structure
M7-505	Payload Support Building	1964	Not eligible	Building
M7-1469	Vertical Processing Facility	1964	Not eligible	Building
66250	Hangar AF	**1962**	Not eligible*	Building
66251	High Pressure Gas Facility	**1963**	Not eligible*	Building
66240	High Pressure Wash Facility	**1979**	Not eligible*	Building
66242	First Wash Building	**1979**	Not eligible*	Building
66244	SRB Recovery Slip	**1979**	Not eligible*	Structure
66310	SRB Paint Building	**1984**	Not eligible*	Building
66320	Robot Wash Building	**1987**	Not eligible*	Building
66249	Thrust Vector Control Deservicing Building	**1985**	Not eligible*	Building
66340	Multi-Media Blast Facility	**1992**	Not eligible*	Building
	Crew Transportation Vehicle (CTV)		Not eligible	Structure
	Astrovan		Not eligible	Structure
	Payload Canister Transporters (2)	**2000**	Not eligible	Structure
	Solid Rocket Motor Transporter		Not eligible	Structure
	Orbiter Transporter		Not eligible	Structure

* denotes eligibility as a contributing resource, but not individually eligible.

4.2.7 Langley Research Center (LaRC)

NASA LaRC (Photo 4.7) is one of NASA's three original major research laboratories, and the lead NASA Center for research in airframe systems and atmospheric sciences. It occupies 808 acres in Hampton, Virginia. LaRC began as NACA's first field station in 1917. In 1920, it was named "Langley Memorial Aeronautical Laboratory" in honor of Dr. Samuel P. Langley, the third Secretary of the Smithsonian Institution (Wells et al. 1976). It was the only NACA laboratory until 1940. On October 1, 1958, it became a NASA installation and was renamed "Langley Research Center." The majority of the LaRC's approximate 220 buildings are located in the West Area, to the west of Langley AFB. Research performed at the Center in the 1950s and 1960s helped aircraft break the sound barrier and played a major role in helping Americans reach the moon. In the 1970s, research focused on aircraft design to cut emissions and noise, and on testing Space Shuttle concepts (SAIC 2006:7). LaRC supports NASA's SSP with atmospheric research and technology testing and development. The Center is notable for its computer-enhanced wind tunnels and laboratories, research aircraft and spacecraft, and flight simulators, which have made vital contributions in the areas of aerospace systems concepts and analysis; aerodynamics; aerothermodynamics and acoustics; structures and materials; airborne systems; atmospheric sciences; and systems engineering.

Photo 4.7. Aerial view of Langley Research Center, Virginia. (Source: NASA LaRC at http://www.aero-space.nasa.gov/research_centers/images/langley.jpg)

LaRC's HPO, Mr. Rodney Harris, in consultation with LaRC's Wind Tunnel Manager and other knowledgeable Center personnel, developed a preliminary list of LaRC facilities that may have contributed to the SSP. LaRC also solicited information from the entire LaRC community, reached via a LaRC Public Affairs Office email request. Based on the input of more than 25 employees, the LaRC HPO and the Head of the Center Operations Directorate determined that 14 facilities (Table 4.7) should be surveyed to determine their level of contribution to the SSP. The 14 facilities were investigated in the fall of 2006 by SAIC. As a result, the Aircraft Landing Dynamics Facility (ALDF), a complex of buildings, structures and equipment, was evaluated as NRHP-eligible in the context of the SSP (SAIC 2006). The ALDF, eligible under NRHP Criterion C (Design/Construction), was used in the 1980s and 1990s to test shuttle tire performance, for tire-failure wheel tests, and to test the effects of runway modifications. It is the only facility that could provide the specific braking and landing tests required for the Space Shuttle development program. It is still in active use.

Table 4.7. List of Assets at NASA LaRC Surveyed for SSP Significance.

Facility No(s).	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
1257, 1257N, 1257S, 1258, 1258A, 1261, 1262	Aircraft Landing Dynamics Facility (ALDF)	1956/ 1985 upgrade	Eligible	5 buildings, 2 structures
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
582	Low Turbulence Pressure Tunnel Complex	1941	Not eligible	Structure
640	8-Foot Transonic Pressure Tunnel	1953	Not eligible	Structure
644	12-Foot Low Speed Tunnel	1940	Not eligible	Structure
645	Vertical Spin Tunnel	1948	Not eligible	Structure
648	Transonic Dynamics Tunnel	1958	Not eligible	Structure
1146	16-Foot Transonic Tunnel	1941	Not eligible	Structure
1212B	7x10 Foot Tunnel	1945	Not eligible	Structure
1212C	14 x 22 Foot Tunnel	1970	Not eligible	Structure
1236	National Transonic Facility	1983	Not eligible	Structure
1251	Unitary Plan Wind Tunnel	1950	Not eligible	Structure
1265	8-Foot High Temperature Tunnel	1960	Not eligible	Structure
1297	Lunar Lander Facility (Gantry)	1965	Not eligible	Structure
1247D, 1251A, 1275, 1247B	Langley Aerothermodynamics Laboratory	1950s	Not eligible	Structure

4.2.8 George C. Marshall Space Flight Center (MSFC)

NASA's MSFC encompasses approximately 1841 acres located within the U.S. Army's Redstone Arsenal in Huntsville, Madison County, Alabama. It originated as the U.S. Army Ordnance Guided Missile Center in April 1950, and began operations in July 1960 as a NASA field center with the formal transfer of personnel and facilities from the Army Ballistic Missile Agency (ABMA). MSFC is named after General Marshall, the Army Chief of Staff during World War II, Secretary of State, author of the Marshall Plan, and Nobel Peace Prize winner (Wells et al. 1976). Today, the MSFC has 238 real property assets, valued at $467.2 million. Of these, 13 assets have been mothballed or abandoned. Seventy-two buildings and structures were built during the 1940s and 1950s, 102 during the 1960s and 1970s, 41 between 1980 and the end of the 1990s, and 14 since 2000. Large administration buildings occupy the northern end of MSFC; test facilities are clustered at the southern end in the 4500 and 4600 areas. Most of the major test facilities, including the Saturn V Dynamic Test Stand (Building 4550; now the Structural Dynamic Test Facility) and the S-IC Stage Static Test Stand (Building 4670; now the Advanced Engine Test Facility), were constructed in the 1960s.

MSFC manages the key propulsion hardware and technologies of the Space Shuttle. The Center is responsible for the three major elements of the Space Shuttle: the main engines (SSMEs), SRBs, and ET.

Photo 4.8. Shuttle Orbiter *Enterprise* transported via road at the Marshall Space Flight Center, 1978, looking northwest.
(Source: NASA MSFC, MSFC-75-SA-4105-2C)

The historic facilities survey of MSFC was conducted by ACI and Weitze Research during the week of October 16-20, 2006. A total of 38 assets identified by the MSFC HPO, Ralph Allen, as potentially significant in the context of the SSP (Table 4.8) were the focus of field survey. In addition, three NASA barges, *Poseidon*, *Pearl River*, and *Pegasus*, not currently located at the MSFC, were assessed on the basis of research. As a result, of the total 41 resources evaluated, 13, including seven buildings and six structures, are considered individually eligible for listing in the NRHP. Two of these, Buildings 4550 and 4705, are previously designated NHLs, and seven buildings (4583, 4612, 4619, 4670, 4674, 4707, and 4732) were previously determined NRHP-eligible. Four of the 13 eligible assets, Buildings 4436, 4540, and 4663, as well as the NASA barge *Poseidon*, were newly evaluated as significant.

Table 4.8. List of Assets at NASA MSFC Surveyed for SSP Significance.

Facility No.	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
4436	SSME – HSL Block II Facility	1962	Eligible	Building
4540	Acoustic Model Engine Test Facility (TF 116)	1964	Eligible	Structure
4550	Structural Dynamic Test Facility	1964	Eligible* (Designated NHL)	Structure
4583	Test and Data Recording Facility (TS 115)	1957/1964	Eligible*	Structure
4612	Materials and Processes Laboratory	1959	Eligible*	Building
4619	Structures, Dynamics and Thermal Vacuum Laboratory	1959	Eligible*	Building
4663	Huntsville Operations Support Center (HOSC)/NASA Data Center (NDC)	1959/1968	Eligible	Building
4670	Advanced Engine Test Facility	1965	Eligible*	Structure
4674	Control Facility	1964	Eligible*	Building
4705	Multi-Purpose High Bay Facility and NBS	1955	Eligible* (Designated NHL)	Building
4707	National Center for Advanced Manufacturing	1956	Eligible*	Building
4732	14" Trisonic Wind Tunnel in Building 4732	1943/1957	Eligible*	Structure
n/a	NASA Barge *Poseidon*	1945/1965	Eligible	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
4200	Office Building	1963	Not eligible*	Building
4201	Office Building	1964	Not eligible*	Building
4202	Office Building	1964	Not eligible*	Building
4475	Power Systems Lab	1964	Not eligible	Building
4476	Marshall Avionics Systems Testbed	1963	Not eligible*	Building
4515	Transient Pressure Test Facility	1987	Not eligible	Structure
4520	Solid Propulsion Test Facility	1989	Not eligible	Structure
4522	Test Facility 500 (TF 500)	1966	Not eligible	Structure
4524	Test Stand Support Building	1987	Not eligible	Building
4530	Test Facility 300 (TF 300)	1964	Not eligible	Structure
4539	Test Stand Support Building	1964	Not eligible	Building
4541	Test Stand Control Building	1964	Not eligible	Building
4542	Test Support Building	1992	Not eligible	Structure
4530	Test Facility 300 (TF 300)	1964	Not eligible	Structure
4539	Test Stand Support Building	1964	Not eligible	Building
4541	Test Stand Control Building	1964	Not eligible	Building
4542	Test Support Building	1992	Not eligible	Structure

Facility No.	Name	Date		NRHP Resource Type
4551	Structural Dynamic Support Facility	1964	Not eligible*	Building
4553	Test Facility Terminal Building	1965	Not eligible	Building
4554	Hot Gas Test Facility	1962	Not eligible*	Building
4561	Test Control and Service Building	1961	Not eligible	Building
4564	TPTA Refurbishment Facility	1987	Not eligible	Building
4570	Advanced Propulsion Research Facility	1956	Not eligible*	Building
4572	Propulsion and Structural Test Facility	1953	Not eligible* (Designated NHL)	Building
4628	Hydrogen Test Facility	1964	Not eligible	Building
4650	Shop and Calibration Laboratory	1958	Not eligible	Building
4656	Hydraulic Equipment Development Facility	1965	Not eligible	Building
4711	Developmental Processes Laboratory	1943	Not eligible	Building
4760	Surface Treatment Facility	1960	Not eligible	Building
4777	Engine Dynamic Fluid Flow Facility	1985	Not eligible	Building
n/a	NASA Barge *Pearl River*	1945/1965	Not eligible	Structure
n/a	NASA Barge *Pegasus*	1997-1999	Not eligible	Structure

*Previously determined NRHP-eligible under non-SSP context.

4.2.9 Michoud Assembly Facility (MAF)

The 835-acre NASA MAF (Photo 4.9), located near New Orleans, Louisiana, originated in the 1940s as the Higgins Corporation Aircraft Assembly Plant. In 1961, NASA took over operations here for the design and assembly of large space vehicles, including the first stage of the Saturn booster for the Apollo Program. In 1973, MAF was selected as the site for the manufacture and final assembly of the Space Shuttle's ET because of its manufacturing capabilities and its deep-water access. Components of the tank production that take place at the MAF include systems engineering, engineering design, manufacturing, fabrication, assembly and testing, laboratory analysis, and total automatic checkout and computer data reduction (Cleveland 2007:6). The ET is produced by Lockheed Martin Space Systems Company.

Photo 4.9. Aerial view of the Michoud Assembly Facility, Louisiana.
(Source: NASA, GRIN No.: GPN-2000-000046)

On November 13-17, 2006, TRC, Atlanta, Georgia assessed eight resources (Table 4.9) at the MAF identified by the HPO, Mr. Francis Celino, as associated with NASA's SSP. As a result, four assets, including one structure, the Pneumatic Test Facility (451), and three buildings, the Vertical Assembly Building (110), the High Bay Addition (114), and the Control Building for the Pneumatic Test Facility (452), were evaluated as eligible for the NRHP, all under Criteria A and C. Building 110 was previously determined eligible due to its association with the Apollo Program. All are significant for their major role in the manufacture and assembly of the ET.

Table 4.9. List of Assets at NASA MAF Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
110	Vertical Assembly Building	1963	Eligible*	Building
114	High Bay Addition	1982	Eligible	Building
451	Pneumatic Test Facility	1976	Eligible	Structure
452	Control Building	1976	Eligible	Building
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
103	Manufacturing Building (68 major tools only)	1943	Not eligible	Objects
131	Spray Facility	1980	Not eligible	Building
318	Component Ablator Facility	1985	Not eligible	Building
420	Acceptance and Prep Building	1964	Not eligible*	Building

*Previously determined NRHP-eligible under non-SSP context.

4.2.10 Air Force Plant (AFP) 42, Site 1 North, Palmdale

AFP 42 is located within the incorporated boundary of Palmdale, approximately 50 miles north of the City of Los Angeles, in the northern area of Los Angeles County, California. The 5800-acre government-owned, contractor-operated (GOCO) facility consists of eight separate production sites sharing a common runway complex (Photo 4.10). Site 1 North contains 19 buildings and the Orbiter Lifting Frame (OLF). Of these, 10 buildings (151C, 153, 154, 163, 164, 165, 171, 172, 173, and 198) and the OLF are NASA-owned. Five properties are owned by the Air Force, including Building 150 and the attached Building 192; these are leased by NASA from the Air Force. The other four buildings are real property assets of The Boeing Company.

Photo 4.10. Aerial view of AFP 42, Palmdale, California.
(Source: Boeing 2006)

Palmdale is the birthplace of the SSP's fleet, including the prototype orbiter *Enterprise* and the five orbiters built for operational flight: *Columbia*, *Challenger*, *Discovery*, *Atlantis* and *Endeavour*. Until 2002, it served as the primary site for major mid-life overhauls and modifications to the orbiter fleet.

The historic facilities field survey was performed on September 19, 2006 by ACI; archival research was conducted in January 2007 by Dr. Karen Weitze. The evaluation of NASA JSC assets at Air Force Plant (AFP) 42, Site 1 North in Palmdale focused on five properties (Table 4.10), including four buildings and one structure, which were determined, preliminarily, by the JSC HPO, Perri Fox, to have possible associations with the SSP. As a result of research and field survey, two assets were considered to meet the criteria of eligibility for listing in the NRHP. Building 150, "birthplace of the Space Shuttle fleet," was previously determined eligible for listing in the NRHP. It continues its exceptional significance in the context of the SSP under Criterion A as the site where the first full-scale test vehicle (*Enterprise*) and all five operational orbiters (*Columbia*, *Challenger*, *Discovery*, *Atlantis,* and *Endeavour*) were assembled, upgraded and maintained, from 1973 through 2001. Building 150 is also considered eligible under Criterion C in the area of Engineering for its adaptation in 1973-1974 as the only Shuttle orbiter assembly hangar in the United States. The OLF is considered eligible for listing in the NRHP under Criteria A and C. Under Criterion A, the OLF is NASA's only extant demountable mate-demate device. It was used to mate the newly assembled fifth and last orbiter of the Space Shuttle fleet, *Endeavour,* for transport directly from its manufacturing site at Palmdale to the KSC for its maiden flight. The OLF has also supported major modifications to four of the five operational orbiters. The OLF is eligible under Criterion C for its specialized engineering and design to accommodate the mating and demating process of the Shuttle orbiter and the SCA.

Table 4.10. List of Assets at AFP 42, Site 1 North, Palmdale Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
	Orbiter Lifting Frame (OLF)	1990-91 (at (Palmdale)	Eligible	Structure
150	Shuttle Orbiter Final Assembly Building	1958/1975	Eligible*	Building
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
153	Thermal Protection Building	1978	Not eligible	Building
154	Blanket Fab/Bond Shop	1983-84	Not eligible	Building
192	ACE Building for Approach and Landing	1974	Not eligible	Building

*Previously determined NRHP-eligible under non-SSP context.

4.2.11 Santa Susana Field Laboratory (SSFL)

The SSFL is located in the Simi Hills area of Ventura County, California, approximately 30 miles northwest of downtown Los Angeles, and a short distance northwest of Canoga Park. The 2668-acre site is divided into four administrative areas, I, II, III and IV, as well as undeveloped buffer zones to the northwest and south (Figure 4.2). Approximately 41.7-acres of Area I, formerly AFP 64, was transferred to NASA in August 1978; the 409.5-acre Area II, former AFP 57, was transferred to NASA in November 1973. An additional 671 acres in Area I, as well as Areas III and IV, are owned by The Boeing Company. Historically, the MSFC SSME Project Office has been the custodian of NASA SSFL real and personal property. The SSME Project no longer uses the NASA SSFL capabilities or assets.

Photo 4.11. Coca Test Area, May 1974.
(Source: Boeing, Rocketdyne Historic Photo Collection, SSFL, Photo No. 41)

The historic facilities field survey at the SSFL was performed on September 20-21, 2006 by ACI; archival research was conducted by Dr. Karen Weitze during November 2006 and January 2007. The evaluation included an initial review and limited reconnaissance of the NASA-owned buildings and structures located within Area II of the SSFL. Among these properties, the field survey focused only on the 29 buildings, structures, and sites located within the Coca Area (Table 4.11) which were determined, preliminarily, by MSFC HPO, Mr. Ralph Allen, in cooperation with PWR personnel, to have possible associations with the Space Shuttle Program. As a result of research and field survey, both the Coca I Test Stand (A-3) (Building 733) and the associated Coca Control Center

Santa Susana Field Laboratory (SSFL)

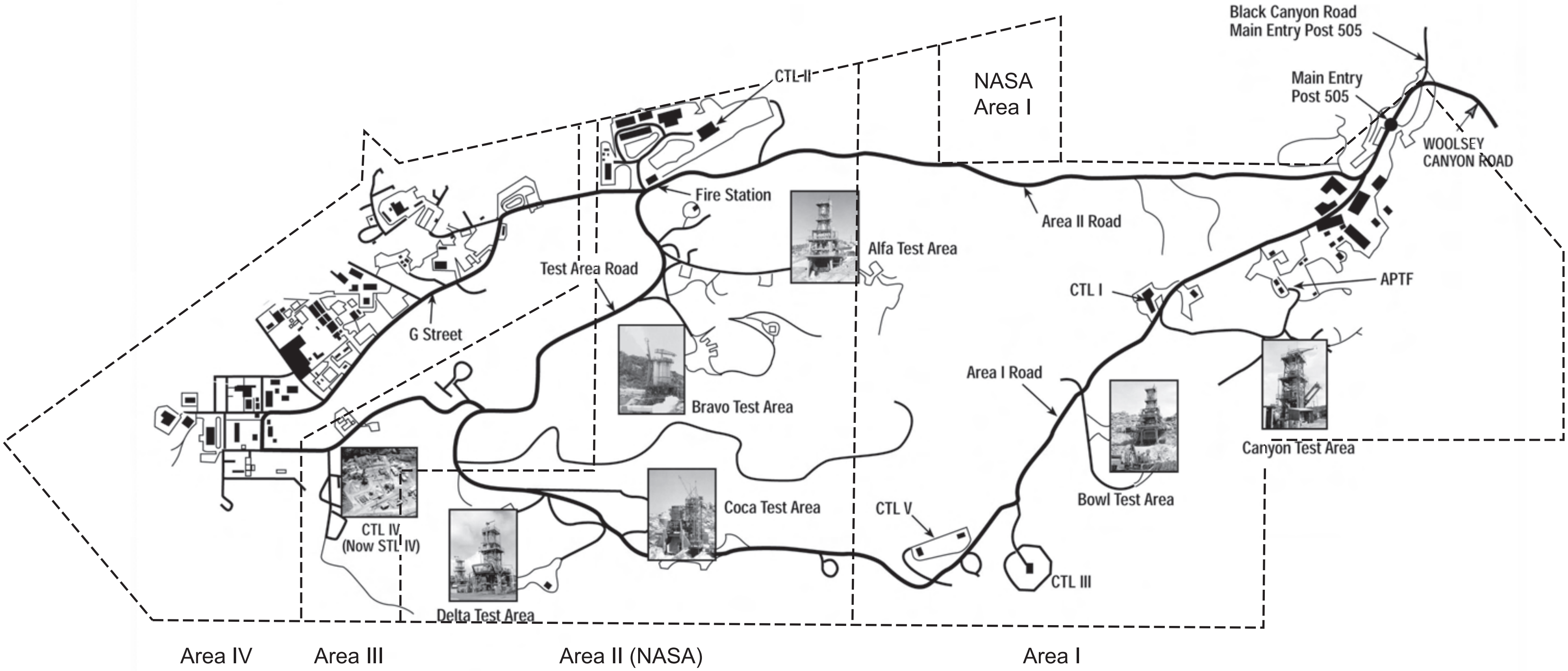

Figure 4.2. Location of the test and other areas within the Santa Susana Field Laboratory (Courtesy of Boeing Corporation).

(Building 218) were considered eligible for listing in the NRHP under Criterion A for their exceptionally important role in the development and testing of the SSME, and under Criterion C for their specialized engineering and design.

Table 4.11. List of Assets at SSFL Surveyed for SSP Significance.

Facility No.	**Name**	**Date**		**NRHP Resource Type**
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
733	Coca I Test Stand (A-3)	1956/1964/ 1978	Eligible	Structure
218	Coca Control Center	1956	Eligible	Building
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
219	Coca Terminal House	1959	Not eligible	Building
220	Coca RNTF Storage (ruins)	1956	Not eligible	Site
222	Coca Pretest Shop	1956	Not eligible	Building
234	Coca Upper Pretest (ruins)	1964	Not eligible	Site
235	Electrical Control Station (LOX)	1964	Not eligible	Building
236	Electrical Control Station (LH2)	1964	Not eligible	Building
237	Compressor Station – Control Center	1964	Not eligible	Building
239	Compressor Station – Main Building	1967	Not eligible	Building
240	Hydraulic Pumphouse	1975	Not eligible	Building
241	Deflector Water Pumphouse	1975	Not eligible	Building
451	Roof Shelter	1967	Not eligible	Structure
520	High Pressure Vessel Vault	1975	Not eligible	Structure
614	Coca IV Pillbox	1965	Not eligible	Building
734	Coca II Test Stand	1956	Not eligible	Structure
787	Coca IV Test Stand	1964	Not eligible	Structure
2A	Observation Bunker	1964	Not eligible	Building
2B	Observation Bunker	1956	Not eligible	Building
2F	Bulkhead Test Facility (ruins)	1964	Not eligible	Site
V180	LOX Vessel #1	1964	Not eligible	Structure
V100	LH2 Vessel #1	1963	Not eligible	Structure
V99	GH2 Vessel	1964	Not eligible	Structure
n/a	GN2/GHe Bottle Bank	1956	Not eligible	Structure
n/a	LOX Vessel #2	Unknown	Not eligible	Structure
n/a	LOX Vessel #3	Unknown	Not eligible	Structure
n/a	LH2 Vessel #2	Unknown	Not eligible	Structure
n/a	Cable Tunnel	1964	Not eligible	Structure
n/a	Spillway	1964	Not eligible	Site

4.2.12 John C. Stennis Space Center (SSC)

The SSC encompasses 125,327 acres in Bay St. Louis, Hancock County, Mississippi. It was established in 1961 as a national rocket test site, and named "Mississippi Test Operations" (MTO). Saturn launch vehicle stages were tested here, under the direction of the MSFC. In 1965, MTO was redesignated the Mississippi Test Facility (MTF); on June 14, 1974, it was renamed "National Space Technology Laboratories" (NSTL), and became a permanent NASA field installation reporting directly to NASA Headquarters (Wells et al. 1976). This NASA facility acquired its present name on May 20, 1988, by Executive Order of President Ronald Reagan. SSC provides the facilities, equipment and technical support necessary to develop and flight certify the SSMEs. Selected in March 1971 as the site for NASA's sea-level testing of the SSMEs, the first static-fire SSME test was conducted in 1975. Since that time, every SSME which has been flown on a Space Shuttle mission has been tested at the SSC. America's largest rocket test complex, on December 30, 1991, NASA designated SSC as the Center for Excellence for large propulsion system testing. The final SSME test on the A-1 Test Stand at SSC was conducted on September 29, 2006.

Photo 4.12. Aerial view of the Stennis Space Center's Propulsion Test Complex. (Source: NASA, GRIN No.: GPN-2000-00556)

The SSC HPO, Marco J. Giardino, consulted with the SSC Facility Manager to develop a comprehensive list of all facilities used by the SSP. As a result, 48 facilities were identified, and subsequently revised to 44. These facilities (Table 4.12) were surveyed in November and December 2006 by the HPO and contractor survey team. As a result, the four major components of the Rocket Propulsion Test Complex, Test Stands A-1, A-2, B-1, and B-2 were considered NRHP eligible under Criteria A and C. All were previously designated as NHLs because of their contribution to the Apollo Program. Every SSME that has flown in space was certified at this test complex.

Table 4.12. List of Assets at NASA SSC Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
4120	A-1 Test Stand	1966	Eligible* (NHL)	Structure
4122	A-2 Test Stand	1965	Eligible* (NHL)	Structure
4210	B-1 Test Stand	1966	Eligible* (NHL)	Structure
4220	B-2 Test Stand	1965	Eligible* (NHL)	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
2110	Shared Resources Laboratory	1967	Not eligible	Building
2311	Lock Water Supply Pump Station	1965	Not eligible	Structure
2312	Water Well and Pump House No. 2	1966	Not eligible	Building
2317	Lock and Bascule Bridge	1965	Not eligible	Structure
3202	Propulsion Engine Assembly Building	1966	Not eligible	Building
3208	SSME Logistic Annex	1986	Not eligible	Building
3220	Scale Building	1967	Not eligible	Building
3304	Air Compressor Shelter	1988	Not eligible	Structure
3305	Central Compressor Building	1966	Not eligible	Building
3306	Hydrogen Compressor Building	1966	Not eligible	Building
3309	Liquid Nitrogen Tank	1967	Not eligible	Structure
3310	Gaseous Helium Tank Center	1967	Not eligible	Structure
3311	Gaseous Helium Tank East	1967	Not eligible	Structure
3312	Water Well and Pump House	1965	Not eligible	Building
3320	Hydrogen Flare Stack	1965	Not eligible	Structure
3406	LOX Storage Building	1992	Not eligible	Structure
3407	Liquid Hydrogen Control Center	1967	Not eligible	Building
3414	LOX Storage Transfer Facility	1971	Not eligible	Structure
3415	Hydrogen Transfer Facility	1971	Not eligible	Structure
4103	A-Complex Inert Gas Storage Area	1967	Not eligible	Structure
4110	A- Complex Test Control Center	1966	Not eligible	Building
4125	Bunker A-1	1966	Not eligible	Building
4126	Bunker A-2	1967	Not eligible	Building
4202	B Complex Guard House	1968	Not eligible	Building
4225	Observation Bunker B-1	1966	Not eligible	Building
4226	Observation Bunker B-2	1966	Not eligible	Building
4230	Orbiter Test Stand Instrumentation Tower Ctr	1965	Not eligible	Building
4231	Orbiter Test Stand Instrumentation Tower E	1965	Not eligible	Building
4240	Orbiter Test Stand Instrumentation Tower W	1965	Not eligible	Building
4301	Test Complex Office Building	1967	Not eligible	Building
4302	Test Complex Shop	1981	Not eligible	Building
4312	B Complex Potable Water Pump House	1965	Not eligible	Building
4325	Industrial Water Reservoir	1967	Not eligible	Structure
4400	High Pressure Industrial Water Emergency Power and Heating Plant	1966	Not eligible	Building
4995	Data Storage Facility	1966	Not eligible	Building
8101	Radiographic Facility	1997	Not eligible	Building
8110	Measurement Standards and Calibration Lab	1967	Not eligible	Building
8301	Test Support Office Building	1990	Not eligible	Building
8304	Propulsion Test Electrical Shop	1991	Not eligible	Building
8305	Test Operations Support Building	1988	Not eligible	Building

*Previously determined NRHP-eligible under non-SSP context.

4.2.13 White Sands Test Facility (WSTF)

The WSTF (Photo 4.13), which originated as the Apollo Spacecraft Propulsion Development Facility, was opened on-site in June 1964. This new Center was built near Las Cruces, New Mexico, on a 55,680-acre tract donated to NASA by the U.S. Army's White Sands Missile range (WSMR). Facilities construction, supervised by the U.S. Army Corps of Engineers, was begun in spring 1963. In September 1964, the WSTF fired its first engine, a 22,000-lb-thrust engine for the Apollo Service Module. Many of the specialized facilities are devoted to specific orbiter propulsion systems components, as well as materials research and development. The White Sands Space Harbor (WSSH), which is located on the WSMR northeast of the WSTF, was established by NASA in 1976.

Photo 4.13. Aerial view of the White Sands Test Facility in New Mexico.
(Source: NASA at http://history.nasa.gov/SP-4312/ch2.htm)

The WSTF is a component facility of the JSC. It has three primary missions: to test and evaluate spacecraft materials, components, and propulsion systems; to perform depot-level refurbishment of selected engine components; and to provide space shuttle crew training. The WSSH serves as the primary location for shuttle pilot and commander flight training.

The survey and evaluation of the WSTF was conducted during the week of November 13-16, 2006 by ACI. The investigation focused on 14 assets identified by the JSC HPO, Perri Fox, and WSTF HPO, Timothy Davis, as potentially significant in the context of the SSP. These 14 assets (Table 4.13) include six buildings and eight structures. As a result of evaluation, the three runways (17/35, 23/05, and 20/02) within the SLF at WSSH were evaluated as NRHP-eligible under Criteria A and C.

Table 4.13. List of Assets at NASA WSTF, including WSSH, Surveyed for SSP Significance.

Facility No.	Name	Date		NRHP Resource Type
INDIVIDUALLY NRHP ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
WSSH	Shuttle Landing Facility at White Sands Space Harbor	Late 1940s-1986	Eligible	Structure
NOT ELIGIBLE UNDER SPACE SHUTTLE PROGRAM CONTEXT				
200	Laboratory Building (CTF)	1963	Not eligible	Building
203	Laboratory Building (SESTL & ML)	1965	Not eligible	Building
250	GOX Hi Flow Test Facility	1982	Not eligible	Building
270	270 Area Test Building	1990	Not eligible	Building
272	Hypervelocity Impact Facility	1991	Not eligible	Building
TS 301	Engine Test Stand	1964	Not eligible	Structure
TS 303	Engine Test Stand	1995	Not eligible	Structure
TS 328	Engine Test Stand	1964	Not eligible	Structure
TS 401	Engine Test Stand	1965	Not eligible	Structure
TS 403	Engine Test Stand	1965	Not eligible	Structure
TS 405	Engine Test Stand	1987	Not eligible	Structure
TS 406	Engine Test Stand	2006	Not eligible	Structure
800	Material Test Facility	1976	Not eligible	Building

4.3 Non-surveyed NASA Sites

No formal eligibility surveys were conducted at Goddard Space Flight Center (GSFC), the Jet Propulsion Laboratory (JPL), and the Wallops Flight Facility (WFF). All have assets that support the SSP, but which are not dedicated to the program. Brief descriptions of the assets which support the SSP are provided in Sections 4.3.1, 4.3.2, and 4.3.3.

4.3.1 Goddard Space Flight Center (GSFC)

The GSFC is located in Greenbelt, Maryland. Originating in 1959 as the "Beltsville Space Center," it was renamed "Goddard Space Flight Center" in honor of Dr. Robert H. Goddard, the "father of modern rocketry" (Wells et al. 1976). The primary support of this facility in regard to the SSP is payloads, which is conducted in buildings not dedicated to the program.

The MILA (Merritt Island Launch Annex) Spaceflight Tracking and Data Network Station at KSC in Florida is owned and operated by GSFC. It was originally established at KSC in 1966 by GSFC as part of a 17 tracking station network in support of the Apollo Program. These stations were phased out with the creation of the TDRS constellation. MILA serves as the primary voice, data and telemetry communications link between the

Space Shuttle and the ground during the first 7- 1/2 minutes of launch. MILA is also used during shuttle landing at KSC and provides communications beginning 13 minutes before touchdown. In addition, MILA assists KSC, JSC, JPL, and GSFC "in making sure that communication systems on orbiters, space station elements, scientific spacecraft and other payloads receive and transmit information correctly through their antennas before launch" (NASA Facts FS-2005-03-009-KSC). Two 10-foot-diameter steerable TDRS ground antennas (Photo 4.14) at MILA serve as a communications interface between spacecraft undergoing testing at KSC payload processing facilities and the payload operations control centers at JSC, JPL, or GSFC.

Photo 4.14. MILA TDRS Antenna.
(Source: Archaeological Consultants, Inc., July 2006)

MILA encompasses a 16 building complex at KSC, of which Building M5-1494 (Photo 4.15) is the center of operations. It was originally built in 1966, with multiple additions made in the late 1960s or early 1970s. It was first used to support the Apollo Program, and was reconfigured for the SSP. MILA was evaluated by ACI as part of the KSC survey, and found to not meet the criteria of eligibility for listing in the NRHP in the context of the SSP.

Photo 4.15. MILA (Building M5-1494) at the KSC, east elevation.
(Source: Archaeological Consultants, Inc., July 2006)

4.3.2 Jet Propulsion Laboratory (JPL)

The JPL (Photo 4.16) is located at the California Institute of Technology (Cal Tech) in Pasadena, Los Angeles County, California, and is operated for NASA under contract with Cal Tech. The JPL originated in 1936 as the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT); experimental work with liquid-propellant rocket engines was conducted here. The facility was reorganized in 1944 under the name "Jet Propulsion Laboratory," and supported research and development for the U.S. Army. In December 1958, the functions and facilities of the JPL were transferred from the Army to NASA. "Operating in government-owned facilities, JPL remained a laboratory of Cal Tech under contract to NASA" (Wells et al. 1976). From the beginning of its association with NASA in 1958, the JPL has served as the primary NASA Center for the unmanned exploration of the planets.

Photo 4.16. Aerial view of the JPL, Pasadena, California.
(Source: NASA, GRIN No.: GPN-2000-001980)

The Space Flight Operations Facility (Building 230; Photo 4.17) at JPL is where spacecraft tracking and scientific data are received and processed from JPL's Deep Space Network (DSN). It is the focal point of the DSN. The facility is significant because it is the hub of the vast communications network through which NASA controls its unmanned spacecraft flying in deep space. Commands that control spacecraft flying millions of miles from the Earth are sent from the Network Control Center in the Space Flight Operations Facility. Scientific and engineering information generated by unmanned spacecraft is transmitted to the Space Flight Operations Facility.

Photo 4.17. JPL's Space Flight Operations Facility.
(Source: NASA at http://grin.hq.nasa.gov/ABSTRACTS/GPN-2003-0064.html)

The Space Flight Operations Facility was used in a limited role as voice support during Space Shuttle landings until approximately 1994. No other information is currently available that identified other Space Shuttle operations associated with the Space Flight Operations Facility. While the facility plays no exceptionally significant role in the context of the SSP, the Space Flight Operations Facility "represents the role and achievement of JPL in the American effort to explore the moon, planets, and solar system" (Butowsky 1984). It was listed as a NHL on October 3, 1985.

4.3.3 Wallops Flight Facility (WFF)

The WFF in Wallops Island, Virginia (Photo 4.18) was established in May 1945 as the "Auxiliary Flight Research Center," a NACA test-launching facility for its Langley laboratory (Wells et al. 1976). In May 1959, "Wallops Station" became an independent NASA field installation. It was named for the 17th century surveyor, John Wallops. On April 26, 1974, Wallops Station was renamed "Wallops Flight Center," and served as the only rocket flight-test range owned and operated by NASA (Wells et al. 1976). Today, the facility supports launch communication of a variety of NASA and DoD projects, including on-orbit support for the SSP. Services provided include air-to-ground voice, command, and telemetry and tracking services. The Wallops Ground Network also provides scheduling coordination for shuttle support. The following information has been provided by Shari Silbert, NASA WFF.

Photo 4.18. Aerial view of Wallops Flight Facility, Virginia.
(Source: NASA, GRIN No.: GPN-2000-001326)

The Ground Network and Research Range equipment that supports the Shuttle Program includes:

- **Tracking Radars (RIR-706, RIR-716 & RIR-778C)** - Shuttle Certified Radars are utilized to provide tracking for Shuttle launches. Radars also provide support for every viewable Shuttle pass above 5 degrees elevation providing tracking data for orbit determination. Radar's are required for all rendezvous missions with the ISS.

- **Telemetry 9-Meter System transitioning to 11-Meter System**
    - Operational Downlink (OD) telemetry support both GSTDN and TDRSS mode for launch and on-orbit
    - Command Throughput
    - S-Band Voice
    - Shuttle Main Engine (SME) telemetry downloads
    - External Tank Television (ETTV) during launch
- **Telemetry 7-Meter S-Band** - back-up downlink telemetry
- **UHF A/G Canoga Antenna System -** UHF uplink and downlink voice support for launch and on-orbit

All four of these tracking radars and antenna systems are equipment, not real property, and as such do not have real property numbers or identification. They each have concrete foundation pads and can be unbolted and moved fairly easily if needed. Each system is still in use today for tracking various projects.

The Shuttle Small Payloads Project Office (SSPPO) was involved with design, development, and integration, of a group of small payload carrier systems for the Space Shuttle. The office supported Shuttle payloads since the early 1980s and included Hitchhiker, Get Away Specials (GAS), Space Experiment Module (SEM) payloads supplied by NASA, other US government agencies, or educational organizations. Management and implementation of the GAS and SEM programs was transferred to the WFF in 1998.

An integration lab was established at Wallops Island that was used to test, integrate, and prepare payloads for shipment to the KSC. The WFF office also managed an integration area at KSC used for final payload preparation prior to turning over to the orbiter installation team. WFF was involved with these activities from the late 1990s until the programs were directed for closure in 2004. All ground support hardware and flight carrier system hardware was transferred to WFF from a warehouse in Beltsville, Maryland and from the KSC integration lab. Since 2004, hardware has been transferred to other organizations, sent to surplus, or remains in storage at WFF.

5.0 NASA-WIDE SIGNIFICANT HISTORIC PROPERTIES

5.1 Overview of Survey Results

Field survey and evaluation of 335 SSP-related assets located at 13 NASA Centers and component facilities resulted in the identification of 70 (20.9%) assets assessed as individually eligible for listing in the NRHP solely in the context of the SSP. Summary statements of significance for these facilities and properties are provided in Appendix B. Of the 70 significant assets, 24 were previously listed or determined eligible for inclusion in the NRHP under other historic contexts, and 46 (13.7%) were assessed as newly eligible in the context of the SSP (Table 5.1). It should be stressed that NASA owns other properties which are listed or determined eligible for listing in the NRHP. However, because they lack association with the SSP, they were not included as part of this study. Also, the counts for KSC in Table 5.1 are exclusive of assets which are contributing to a historic district, but not individually eligible.

Table 5.1. Previously and Newly Eligible Assets for all NASA Centers.

NASA Center	Total Assets Surveyed	Total NRHP Eligible	Previously Listed/Eligible	Newly Eligible
ARC	11	2	0	2
Canoga Park	5	1	0	1
DFRC	6	1	0	1
GRC	8	2	1	1
JSC	30	11	1	10
KSC	112	26	8	18
LaRC	14	1	0	1
MAF	8	4	1	3
MSFC	41	13	8	5
Palmdale	5	2	1	1
SSC	44	4	4	0
SSFL	37	2	0	2
WSFC/WSSH	14	1	0	1
TOTALS	335	70	24	46

Seven of the 24 previously listed or determined eligible historic properties are designated NHLs:

- Structural Dynamic Test Facility at MSFC
- Multi-Purpose High Bay Facility and Neutral Buoyancy Simulator at MSFC
- Propulsion Test Stand A1 at SSC
- Propulsion Test Stand A2 at SSC
- Propulsion Test Stand B1 at SSC
- Propulsion Test Stand B2 at SSC
- Mission Control Center at JSC

5.2 Distribution by Property Type

As described in Chapter 2, 12 property types were identified for this study:

- Type 1: Resources Associated with Transportation
- Type 2: Vehicle Processing Facilities
- Type 3: Launch Operation Facilities
- Type 4: Mission Control Facilities
- Type 5: News Broadcast Facilities
- Type 6: Communications Facilities
- Type 7: Engineering and Administrative Facilities
- Type 8: Space Flight Vehicle (Space Shuttle)
- Type 9: Manufacturing and Assembly Facilities
- Type 10: Resources Associated with the Training of Astronauts
- Type 11: Resources Associated with Space Flight Recovery
- Type 12: Resources Associated with Processing Payloads

Twenty-four of the historic properties are classified into more that one property type. As a result, the 70 individually NRHP-listed or eligible historic properties represent a total of 98 property type affiliations (Tables 5.2 and 5.3). Twenty-one assets are classified into two property types, two have three property type affiliations, and one is classified into four property groups.

The most commonly occurring property type is Type 7: Engineering and Administrative Facilities (Table 5.2). A total of 26 facilities are classified within this group, of which almost half are located at the MSFC. In descending order of frequency, the other most common property type affiliations are Type 1: Resources Associated with Transportation (N=17); Type 2: Vehicle Processing Facilities (N=12); Type 3: Launch Operation Facilities (N=10); Type 10: Resources Associated with the Training of Astronauts (N=10); Type 11: Resources Associated with Space Flight Recovery (N=7); and Type 9: Manufacturing and Assembly Facilities (N=6). The remaining property types (4, 5, 6, 8, and 12) have less than four affiliations each.

The following section contains summary evaluations of the 70 NRHP-listed and eligible historic properties, arranged by property type. In the cases where NASA assets have multiple affiliations, the historic property is described under its primary functional type.

Table 5.2. Summary Distribution of Property Types by NASA Center.

	Assets Surveyed	NRHP Listed/ Eligible	Property Type													Total
				1	2	3	4	5	6	7	8	9	10	11	12	
ARC	11	2								1			1			2
Canoga Park	5	1										1				1
DFRC	6	1		1										1		2
GRC	8	2								2						2
JSC*	30	11					1		2	4	3		5			16
KSC	112	26		13	7	9		1	1					5	3	43
LaRC	14	1			1					1						1
MSFC	41	13								11	4					14
MAF	8	4			4											4
Palmdale	5	2	1		1			1				1 1				4
SSFL	37	2								2						2
SSC	44	4	1						1	4						4
WSTF**	14	1		1									1	1		3
Totals	335	70			12	10	1	1	4	26	3	6	8	7	3	98

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* Includes Ellington Field
** Includes White Sands Space Harbor (WSSH)

Table 5.3. NRHP-listed and eligible historic properties by property type.

NASA CENTER	FACILITY NO.	FACILITY NAME	APPLICABLE PROPERTY TYPE*											
			1	2	3	4	5	6	7	8	9	10	11	12
ARC	N238	Arc Jet Laboratory							X					
ARC	N243	Flight & Guidance Sim Lab/VMS										X		
CANOGA PARK	N/A	Pacific Scientific Furnace									X			
DFRC	4860	Mate-Demate Device	X										X	
GRC	85-94, 113-114	Abe Silverstein 10 by 10 SWT							X					
GRC	39, 46, 53-57, 59, 61, 138	8 by 6 SWT							X					
JSC	5	Jake Garn Mission Simulator and Training Facility										X		
JSC	7	Crew Systems Laboratory												
JSC	9	Systems Integration Facility										X		
JSC	16	Avionics Systems Laboratory						X	X		X			
JSC	30	Mission Control Center (MCC)			X	X		X				X		
JSC	44	Communications and Tracking Development Lab						X	X					
JSC	222	Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF)							X					
JSC	920N	Sonny Carter Training Facility/ NBL										X		
JSC	OV-103	*Discovery*								X				
JSC	OV-104	*Atlantis*								X				
JSC	OV-105	*Endeavour*								X				
KSC	K6-848	Vehicle Assembly Building (VAB)		X										
KSC	K6-900	Launch Control Center (LCC)			X			X						
KSC	N/A	Crawler Transporter (#1)	X		X									
KSC	N/A	Crawler Transporter (#2)	X		X									
KSC	N/A	Crawlerway	X		X									
KSC	N/A	Press Site: Clock and Flag Pole					X							
KSC	J8-1708	LC 39: Pad A			X									
KSC	J7-0337	LC 39: Pad B			X									
KSC		Shuttle Landing Facility (Runway)	X										X	
KSC	J6-2313	Landing Aids Control Building	X										X	

NASA CENTER	FACILITY NO.	FACILITY NAME	APPLICABLE PROPERTY TYPE*											
			1	2	3	4	5	6	7	8	9	10	11	12
KSC	J6-2262	Mate-Demate Device	X										X	
KSC	K6-894	Orbiter Processing Facility (OPF)		X										
KSC	K6-696	Orbiter Processing Facility High Bay 3 (OPF-3)												
KSC	K6-794	Thermal Protection System Facility									X			
KSC	K6-494	Rotation/Processing Building	X	X						X				
KSC	L6-247	SRB ARF Manufacturing Building		X							X			
KSC	M7-961	Hypergol Module Processing (North)		X										
KSC	M7-657	Parachute Refurbishment Facility									X			
KSC	M7-777	Canister Rotation Facility		X										X
KSC	N/A	Payload Canister (#1)	X											X
KSC	N/A	Payload Canister (#2)	X											X
KSC	N/A	Retrieval Ship *Liberty Star*	X										X	
KSC	N/A	Retrieval Ship *Freedom Star*	X										X	
KSC	N/A	Mobile Launcher Platform (MLP) (#1)	X		X									
KSC	N/A	MLP (#2)	X		X									
KSC	N/A	MLP (#3)	X		X									
LaRC	1257, 1257N/S, 1258, 1258A, 1261, 1262	Aircraft Landing Dynamics Facility (ALDF)							X					
MSFC	4436	SSME – HSL Block II Facility							X					
MSFC	4540	Acoustic Model Engine Test Facility 116 (TF 116)							X					
MSFC	4550	Structural Dynamic Test Facility							X					
MSFC	4583	Test and Data Recording Facility							X					
MSFC	4612	Materials and Processes Laboratory							X					
MSFC	4619	Structures, Dynamics and Thermal Vacuum Lab							X					
MSFC	4663	HOSC/NDC						X						
MSFC	4670	Advanced Engine Test Facility							X					
MSFC	4674	Control Facility							X					
MSFC	4705	Multi-Purpose High Bay Facility and NBS												
MSFC	4707	National Center for Advanced Manufacturing							X					
MSFC	4732	Office and Wind Tunnel Facility (14" Trisonic Wind Tunnel only)						X	X		X			
MSFC	N/A	NASA Barge *Poseidon*	X											

NASA CENTER	FACILITY No.	FACILITY NAME	APPLICABLE PROPERTY TYPE*											
			1	2	3	4	5	6	7	8	9	10	11	12
MAF	110	Vertical Assembly Building		X										
MAF	114	High Bay Addition		X										
MAF	451	Pneumatic Test Facility		X										
MAF	452	Control Building (for 451)		X										
PALM-DALE	150	Shuttle Orbiter Final Assembly Building		X							X			
PALM-DALE	N/A	Orbiter Lifting Frame (OLF)	X					X						
SSFL	218	Coca Control Center (for 733)							X					
SSFL	733	Coca I Test Stand (A-3)							X					
SSC	4120	Propulsion Test Stand A-1							X					
SSC	4122	Propulsion Test Stand A-2							X					
SSC	4210	Propulsion Test Stand B-1							X					
SSC	4220	Propulsion Test Stand B-2							X					
WSSH	N/A	Shuttle Landing Facility (SLF) Runways 17/35, 23/05, and 22/02	X									X	X	
TOTALS			***17***	***12***	***10***	***1***	***1***	***4***	***26***	***3***	***6***	***8***	***7***	***3***

Property Types:
1 Resources Associated with Transportation
2 Vehicle Processing Facilities
3 Launch Operation Facilities
4 Mission Control Facilities
5 News Broadcast Facilities
6 Communications Facilities
7 Engineering and Administrative Facilities
8 Space Flight Vehicle (Space Shuttle)
9 Manufacturing and Assembly Facilities
10 Resources Associated with the Training of Astronauts
11 Resources Associated with Space Flight Recovery
12 Resources Associated with Processing Payloads

5.3 Description of Significant Historic Properties by Property Type

5.3.1 Type 1: Resources Associated with Transportation

A total of 17 NASA-owned historic properties are classified as Type 1 resources:

- SLF Runway at KSC
- SLF Runways at WSSH
- OLF at Palmdale
- MDD at DFRC
- MDD at KSC
- Three MLPs at KSC
- Two Crawler Transporters at KSC
- Two Payload Canisters at KSC
- NASA Barge *Poseidon* (a MSFC asset located at SSC)
- Retrieval ship *Liberty Star* at KSC
- Retrieval ship *Freedom Star* at KSC
- Landing Aids Control Building at KSC
- Crawlerway at KSC

Of these 17 assets, 13 are located at the KSC. The other four transportation-related assets are located at DFRC, SSC, Palmdale, or WSSH. Property Type 1 subsumes a variety of air, land, and water-related buildings, structures and objects such as landing facilities (runways) at KSC and WSSH; mate-demate devices at KSC, DFRC and Palmdale; specialized equipment and vehicle transporters; plus two ships and a barge. Among the multiple resources, the two Payload Canisters, two retrieval ships, and three MLPs, all at KSC, were designed and built to the same specifications (within their group), are identical or near identical in configuration, and are functionally interchangeable. On the other hand, neither the SLF runways at KSC and WSSH, nor the two MDDs and OLF, are identical.

Air-related resources: Subtype Runways

- SLF Runway at KSC
- SLF Runways at WSSH

KSC SLF Runway, looking north.
(Source: Archaeological Consultants, Inc., 2006)

The KSC SLF Runway

- Built in 1976 to support the SSP
- NASA's preferred shuttle landing site, since 1984
- The return from landing site following landing at Edwards AFB
- Site where all five orbiters originally arrived from the assembly plant in Palmdale
- Used as a practice facility by Shuttle astronauts
- Eligible under Criterion A as the primary landing site for the SSP, and under Criterion C for its design and construction. It is one of the largest runways in the world.

White Sands Space Harbor, Runway 23/05, looking southwest.
(Source: White Sands Test Facility, wstf0606e04460)

The SLF Runways at WSSH

- The three runways, built or modified between the late 1940s and 1986, replicate the shuttle landing runways at KSC (Runway 17/35), Edwards AFB (Runway 23/05), and the Transoceanic Abort Landing (TAL) sites (Runway 20/02).
- Runway 17/35 was originally constructed in the late 1940s, and modified for the SSP in 1976. Runway 23/05 was built in 1978 and Runway 20/02 dates to 1986.
- Serves as a contingency landing site for the Shuttle orbiter
- Provides 70-80% of the Shuttle pilot's Shuttle Training Aircraft (STA) training
- Eligible under Criterion A as the only facility in the history of the SSP used on a contingency basis when *Columbia* (STS-3) could not land at Edwards AFB. Also significant as the primary training location for Shuttle pilots and commanders. Under Criterion C, the runways are eligible for their design and construction.

Air-related resources: Subtype Mate/Demate Devices (MDD)

- OLF at Palmdale
- MDD at DFRC
- MDD at KSC

Four MDDs were configured by NASA to support the attachment and detachment of the Shuttle orbiter and SCA. The OLF in Palmdale complements permanent MDDs erected at DFRC and at KSC. It was originally designed to be quickly disassembled, moved, and reassembled at a contingency landing site. NASA also constructed a mobile, derrick-and-crane MDD at the MSFC in Huntsville, Alabama (1976), reusing a stiff-legged derrick from an early 1960s engine test stand. Used at MSFC from 1976 through 1979, NASA subsequently disassembled the improvised mobile MDD in Huntsville and transported its derrick to the WSMR in New Mexico to support the third Shuttle landing in 1982. The mobile MDD, no longer extant, was the precursor to the OLF. The KSC, and its architectural-engineering contractor Connell Associates of Miami, were responsible for the DFRC, KSC, and MSFC/WSMR MDDs of the 1970s. The JSC developed the underlying concept for the OLF.

The MDDs at DFRC and KSC were both designed by Connell Associates. While nearly identical in appearance, the MDD at DFRC is more complex than its counterpart at the KSC, mainly due to some unique personnel safety features required as part of the ALT program. These features include an access/egress route for SCAPE-suited personnel, two personnel hoists, a compressed air system, emergency showers and eye-face wash features, wash down stations, and a deluge system to protect personnel in the event of a hypergol spill or ground-level fire. The DFRC MDD is also distinguished by a personnel elevator located to the west of the south tower, and a ladder with safety cage in the north tower, for access to the 100-foot level.

 Orbiter Lifting Frame, looking northwest. (Source: Archaeological Consultants, Inc., 2006)	**The Orbiter Lifting Frame at Palmdale** • Originally built at Vandenberg; reassembled at Palmdale in late 1990/ early 1991 • First used to mate *Endeavour* to the SCA for transport to the KSC • Used between 1991-2001 to mate-demate the orbiters for transport between KSC and Palmdale for major overhaul and maintenance • Eligible under NRHP Criteria A and C as the SSP's only demountable MDD, and for its operational use in the maintenance, overhaul, and upgrading of the orbiters *Columbia*, *Discovery*, *Atlantis* and *Endeavour* during the 1990s. Under Criterion C, notable for its unique design and engineering as a lightweight demountable device.

Mate-Demate Device at DFRC, east elevation.
(Source: Archaeological Consultants, Inc., 2006)

The MDD at Dryden

- Completed in 1976 as NASA's first MDD built exclusively for the SSP
- Supported the ALT program in 1977
- Used following Shuttle landings on the runways of Rogers Dry Lakebed and Edwards AFB
- Eligible under NRHP Criteria A and C for its association with the early test programs at DFRC, for its continued operational use, and for its special design and engineering. This MDD incorporates several unique features required for the early shuttle testing program.

Mate-Demate Device at KSC, south and west elevations.
(Source: Archaeological Consultants, Inc., 2006)

The MDD at KSC

- Completed in 1978
- Used to mate-demate the *Enterprise* and all five operational orbiters upon their original delivery to KSC; for end of mission returns from Edwards AFB; and for ferry flights between KSC and Palmdale for maintenance and modifications.
- Eligible under NRHP Criterion A as one of two permanent MDDs built specifically to enable the attachment and detachment of the Shuttle orbiter and SCA
- Eligible under NRHP Criterion C for the distinctive characteristics of its design and method of construction

Land-related resources: Subtype Transporters

- Three MLPs at KSC
- Two Crawler Transporters at KSC
- Two Payload Canisters at KSC

These large and mobile personal property assets, all at KSC, are used to transport the shuttle and its payload to the launch pad. While the MLPs and Crawler Transporters were originally constructed in the 1960s to support the Apollo Program and subsequently modified for the SSP, the two Payload Canisters were built specially for the SSP in 1978.

Mobile Launcher Platform.
(Source: Archaeological Consultants, Inc., 2006)

Three MLPs at KSC

- Originally built between 1963 and 1968 for the Apollo Program; converted for the SSP between 1976 and 1983.
- Eligible under Criterion A for their unique function in supporting the build-up of the Space Shuttle vehicle in the VAB and its transport to the launch pad
- Eligible under Criterion C in the area of Engineering for their specialized design and modifications to support the SSP

Crawler Transporter.
(Source: Archaeological Consultants, Inc., 1996)

Two Crawler Transporters at KSC

- Built by the Marion (Ohio) Power Shovel Company in 1965-1967 in support of the Apollo Program; modified in 1978-1979 for the SSP.
- Since the beginning of the SSP, used to move the fully-assembled Space Shuttle vehicle, mounted on the MLP, from the VAB to the launch pad
- Listed in the NRHP in 2000
- Eligible under Criteria A and C for their vital role in moving the Space Shuttle in preparation for launch, as well as for their engineering. In 1997, the Crawler Transporters were designated National Historic Mechanical Engineering Landmarks.

Payload Canister on Canister Transporter in the Space Shuttle Processing Facility.
(Source: Archaeological Consultants, Inc., 2006)

Two Payload Canisters at KSC

- Built in 1978 for the SSP
- Large, environmentally-controlled containers used to transport fully-integrated shuttle payloads from the processing/assembly facilities at KSC to the launch pad
- Matches the capacity of the orbiter's payload bay
- Eligible under Criteria A and C for their unique payload transport capabilities as well as design and construction

Water-related resources:

- NASA barge *Poseidon*
- Retrieval ship *Liberty Star*
- Retrieval ship *Freedom Star*

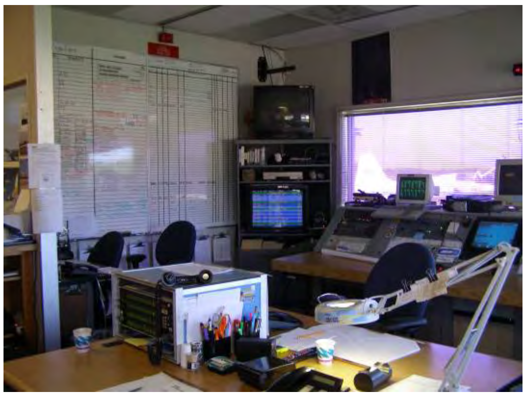
These large and mobile personal property assets are used to transport the ET and SRBs. While the barge *Poseidon* was modified from its original design to support the SSP, the two retrieval ships were built specially for the SSP.

<table>
<tr><td>
NASA Barge Poseidon carrying External Tank.
(Source: Taylor, November 25, 2003)</td><td>NASA barge Poseidon
Originally built in 1945 as a Navy supply barge; converted in 1965 for NASA
From the mid-1970s until 1999, used to transport the ET from MAF to KSC
Eligible under NRHP Criterion A. It transported the first ET flown on a Space Shuttle mission and continued to provide service to the on-going operations of the SSP until 1999. It is the only remaining covered barge still in NASA ownership.
Eligible under Criterion C. It was specially designed and modified to protect the ETs during transport, and has the largest cargo hangar of any NASA barge.</td></tr>
<tr><td>
Looking east at Retrieval ships Liberty Star and Freedom Star.
(Source: Archaeological Consultants, Inc., 2007)</td><td>Retrieval ships Liberty Star and Freedom Star
Built in 1980 and 1981 at the Atlantic Marine Shipyard, Ft. George Island, Florida
Used to recover expended SRBs and their components (including parachutes) after splashdown. The ships tow the SRBs to the dock at the disassembly complex at CCAFS
Since 1998, the ships support towing of NASA's ET barge Pearl River from MAF to KSC
Eligible under Criterion A for their vital role in the recovery of the SRBs, facilitating the reuse of this major Shuttle component</td></tr>
</table>

Other resources associated with transportation:

- Landing Aids Control Building at KSC
- Crawlerway at KSC

Both of the assets in the "Other" category support shuttle operations at the KSC. The Landing Aids Control Building at the SLF was built specially for the SSP, while the Crawlerway dates to the Apollo era.

 Landing Aids Control Building, control room looking southwest. (Source: Archaeological Consultants, Inc., 2006)	**Landing Aids Control Building (Facility J6-2313) at KSC** • Built between 1975-1976 for the SSP • Houses the equipment and personnel who operate the KSC SLF • Eligible under Criterion A as the control center for flight operations which support the landing of the Shuttle orbiter, and for managing the transport of the orbiter on the SCA when it lands at another NASA Center or needs to travel to another site for rehabilitation.
 Space Shuttle *Atlantis* en route to VAB via the Crawlerway, 2001. (Source: NASA John F. Kennedy Space Center, KSC-01PP-0140)	**Crawlerway at KSC** • Built between 1963 and 1965 to support the Apollo Program • Provides the roadway for transport of the Space Shuttle vehicle from the VAB to the launch pad • NRHP listed in 2000 • Eligible under Criteria A and C. The Crawlerway has a unique dual-lane surface capable of supporting the weight of the launch vehicle, MLP, and Crawler Transporter as they move from the VAB to the launch pad.

5.3.2 Type 2: Vehicle Processing Facilities

A total of 12 NASA-owned historic properties are classified as Type 2 resources:

- Shuttle Orbiter Final Assembly Facility at Palmdale
- Vehicle Assembly Building at KSC
- Orbiter Processing Facility (OPF), High Bays 1 and 2 at KSC
- OPF High Bay 3 at KSC
- SRB ARF Manufacturing Building at KSC
- Rotation/Processing Building at KSC
- Canister Rotation Facility at KSC
- Hypergol Module Processing (North) at KSC
- Vertical Assembly Building at MAF
- High Bay Addition at MAF
- Pneumatic Test Facility at MAF
- Control Building at MAF

Of these 12 assets, seven are located at the KSC, four at MAF, and one at Palmdale. All were specifically designed for processing the Shuttle vehicle and its major components, including the orbiter, ET, SRB, and SSME. Collectively, they support a variety of pre-launch and post-landing processing operations, including assembly, testing, checkout, refurbishment, and storage. All 12 historic properties are eligible under NRHP Criterion A for their exceptionally significant associations with the SSP; some are also distinguished by their design and construction, and thus, are eligible under Criterion C.

Four of the 12 Type 2 assets have multiple type affiliations. The Shuttle Orbiter Final Assembly Facility at Palmdale is also assigned to Types 7 and 9; the SRB ARF Manufacturing Building, as well as the OPF High Bay 3, are also Type 9: Manufacturing and Assembly Facilities; and the Canister Rotation Facility is also classified as a Type 12: Resource Associated with Processing Payloads.

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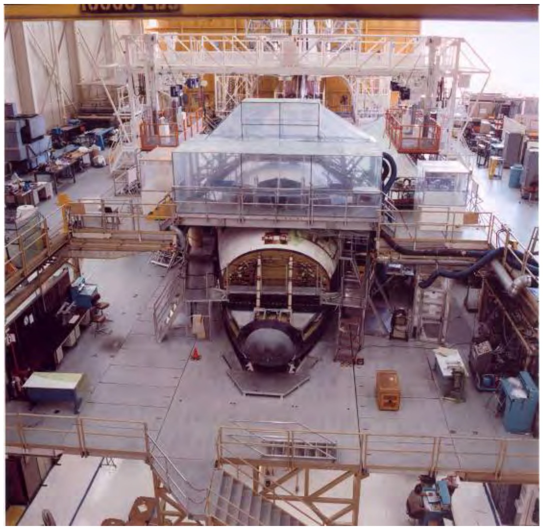

Columbia in Orbiter Bay 2 of Building 150 during modifications, looking north, 1991.
(Source: NASA Lyndon B. Johnson Space Center, S91-53142)
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<td>
Shuttle Orbiter Final Assembly Facility (Building 150) at Palmdale

Built in 1958 by the Air Force; acquired by NASA on a lease basis beginning in 1973
Modified between 1973 and 1975 for Space Shuttle orbiter assembly, integration, test and checkout
OMMs were accomplished here through 2001
Determined NRHP eligible by the California SHPO
Eligible under NRHP Criterion A as the birthplace of the Space Shuttle’s full-scale test vehicle (Enterprise) and the five operational orbiters
Eligible under Criterion C for its adaptation as the only Space Shuttle orbiter assembly hangar in the United States

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Vehicle Assembly Building, south elevation.
(Source: Archaeological Consultants, Inc., 2007)
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Vehicle Assembly Building (VAB) (Facility K6-848) at KSC

Built in 1964 for the Apollo Program; reconfigured in 1976 to support the SSP
NRHP listed in 2000
Supports the integration and stacking of the complete Space Shuttle vehicle on the MLP
Eligible under Criteria A and C. Uniquely designed to support the build up of the Space Shuttle vehicle. One of the world’s largest buildings, by volume, it is also distinguished by its design and engineering.

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Orbiter Processing Facility High Bay 1 interior, looking southwest.
(Source: Archaeological Consultants, Inc., 2006)

Orbiter Processing Facility (OPF) (Facility K6-894) at KSC

- Built in 1977 for the SSP
- Designed exclusively to prepare the Shuttle orbiter for flight
- High Bays 1 and 2 are currently dedicated to the processing of *Atlantis* and *Endeavour*, respectively
- Eligible under NRHP Criterion A as one of two NASA facilities built exclusively to support pre-flight and post-landing processing of the Shuttle orbiter. Each of the five orbiters was processed for its first operational flight in this facility.
- Eligible under Criterion C. The design embodies the specific requirements of the SSP. Internal components, such as work platforms, were specially designed around the shape of the orbiter.

Orbiter Processing Facility High Bay 3, south and west elevations.
(Source: Archaeological Consultants, Inc., 2006)

OPF High Bay 3 (Facility K6-696) at KSC

- Originally built in 1987, and converted to an OPF between 1989 and 1991.
- Expanded KSC's capabilities for pre-flight and post-landing orbiter processing.
- Currently dedicated to processing *Discovery.*
- The Space Shuttle Main Engine Processing Facility (SSMEPF), added in 1996-1998, consolidates both SSME assembly and flight inspection.
- Eligible under NRHP Criteria A and C, as noted for the OPF.

 SRB ARF Manufacturing Building, north and west elevations. (Source: Archaeological Consultants, Inc., 2006)	**SRB Assembly and Refurbishment Facility (ARF) Manufacturing Building (Facility L6-247) at KSC** • Built in 1986 for the SSP as part of the SRB ARF complex • Inert or non-propellant SRB elements, including the forward and aft skirts, frustums, and nose caps are fabricated, refurbished and assembled here • Eligible under NRHP Criterion A. Manufacture, processing and assembly of the SRB non-motor components are vital in preparing the Space Shuttle launch vehicle for flight.
 Rotation/Processing Building, north work area. (Source: Archaeological Consultants, Inc., 2006)	**Rotation/Processing Building (Facility K6-494) at KSC** • Built in 1984 to support the SSP as part of the Rotation, Processing and Surge Facility complex • SRB segments are inspected and rotated here, following their arrival from the Thiokol plant in Utah • Eligible under NRHP Criterion A. Rotation of the SRB segments is an operation vital to the preparation of the launch vehicle for its mission.

Canister Rotation Facility, south and east elevations.
(Source: Archaeological Consultants, Inc., 2007)

Canister Rotation Facility (Facility M7-777) at KSC

- Constructed in 1993 for the SSP
- Specifically designed to accommodate payload canister rotation
- Eligible under NRHP Criteria A and C. Designed and built exclusively to provide for the horizontal and vertical rotation of the payload canister in support of the SSP. This building made possible a more efficient performance of this operation, previously conducted in the VAB.

Hypergol Module Processing (North), south elevation.
(Source: Archaeological Consultants, Inc., 2006)

Hypergol Module Processing (North) (Facility M7-961) at KSC

- Originally built in 1964 for the Apollo Program; extensively modified in the late 1970s for the SSP
- Used for the checkout, refurbishment and revalidation of the hypergolic fuel modules of the OMS, the RCS, and the APU
- Eligible under NRHP Criterion A. It is a one-of-a-kind facility critical to the successive launch of the Space Shuttle vehicle.

Vertical Assembly Building, north and west sides, looking southeast.
(Source: Cleveland 2007: Figure 27, page 35)

Vertical Assembly Building (Building 110) at MAF

- Constructed in 1963 for the Apollo Program; modified to support the SSP.
- Components of the ET are washed, primed, sprayed with SOFI, assembled, pressure treated, and inspected here.
- Eligible under NRHP Criteria A and C. Every ET for every Space Shuttle mission ever flown has been processed in this building. Under Criterion C, it is note-worthy for its design and construction, particularly the size of uninterrupted interior space.

High Bay Addition, south side, looking north.
(Source: Cleveland 2007: Figure 43, page 48)

High Bay Addition (Building 114) at MAF

- Constructed in 1982 for the SSP
- The liquid oxygen tank and intertank components of the ET are machined, primed, sprayed with SOFI, and assembled here
- Eligible under NRHP Criteria A and C. Every oxygen tank and intertank for every Space Shuttle mission flown since 1982 has been processed in this building Under Criterion C, the five cells are significant for their design and construction.

Pneumatic Test Facility, south and east sides, looking northwest.
(Source: Cleveland 2007: Figure 79, page 79)

Pneumatic Test Facility (Structure 451) and Control Building (Building 452) at MAF

- Both built in 1976 for the SSP
- Structure 451 is used to pressure test the ET's liquid hydrogen tank component
- Building 452 administers and monitors the tests that occur in Structure 451
- Both are eligible under NRHP Criteria A and C. Every hydrogen tank for every Space Shuttle mission ever flown has been tested here. Under Criterion C, the testing apparatus within Structure 451 is the only test unit of its size in the U.S. The blast-proof construction of Building 452 is also significant.

5.3.3 Type 3: Launch Operation Facilities

Ten historic properties are classified as launch operations facilities:

- Launch Control Center at KSC
- LC 39: Pad A at KSC
- LC 39: Pad B at KSC
- Mission Control Center at JSC
- Two Crawler Transporters at KSC
- Crawlerway at KSC
- Three MLPs at KSC

All but one of the 10 assets, the MCC at JSC, is located at the KSC. All play a vital role in the SSP, from the control of prelaunch operations to the launch of the Space Shuttle vehicle. All are eligible under NRHP Criterion A for their exceptionally significant associations with the SSP; some are also distinguished by their design and construction, and thus, are eligible under Criterion C. Of the 10 assets affiliated with this property type, only Launch Complex (LC) 39 Pad A and Pad B are classified solely as a Type 3 property. The two Crawler Transporters, the Crawlerway, and the three MLPs are also classified as Resources Associated with Transportation (Type 1), and are described in Section 5.3.1. The LCC is also classified as a Communication Facilities (Type 6), while the MCC is affiliated with Property Type 4 (Mission Control Facilities), Type 6 (Communication Facilities), and Type 10 (Resources Associated with the Training of Astronauts), in addition to Type 3. The MCC is foremost a Type 4: Mission Control Facility, and thus, is described in Section 5.3.4.

Launch Control Center, looking south.
(Source: Archaeological Consultants, Inc., 1996)

Launch Control Center (Facility K6-900) at KSC

- Built in 1966 to support the Apollo. Program; no structural changes made for the SSP
- Listed in the NRHP in 2000
- Controls the checkout processes during preparation for launch, as well as the initial Space Shuttle launch sequence
- Eligible under NRHP Criteria A for the vital operations performed here, integral to the prelaunch preparation and launch of the shuttle
- Eligible under Criterion C (Architecture) for its design and construction

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Aerial view of Space Shuttle Discovery at LC 39A, 2000.
(Source: NASA John F. Kennedy Space Center,
KSC-00PP-1297)
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LC 39 Pad A (Facility J8-1708) at KSC

Originally built between 1963 and 1965 for the Apollo Program; modified for the SSP between 1976 and 1979.
Listed in the NRHP in 2000 as a contributing resource within the LC 39: Pad A Historic District
Served as the first active launch pad for the SSP
Launched the first 23 Shuttle missions between 1981 and 1986
Individually eligible under NRHP Criteria A and C (Engineering) as one of two NASA properties specifically designed and constructed to launch the Space Shuttle vehicle

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STS-112, Space Shuttle Atlantis, surrounded by RSS,
at LC 39B, 2002.
(Source: NASA John F. Kennedy Space Center,
KSC-02PD-1371)
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<td>
LC 39 Pad B (Facility J7-337) at KSC

Originally built between 1964 and 1968 for the Apollo Program; modified for the SSP between 1978 and 1985.
Listed in the NRHP in 2000 as a contributing resource within the LC 39: Pad A Historic District
First used to launch Challenger on January 28, 1986, which ended in disaster approximately one minute after launch
Became NASA's primary launch facility in 1988 with the September 29 launch of Discovery (STS-26)
Individually eligible under NRHP Criteria A and C (Engineering) as one of two NASA properties specifically designed and constructed to launch the Space Shuttle vehicle

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5.3.4 Type 4: Mission Control Facilities

The Mission Control Center (MCC) at JSC is the sole NASA facility classified as Type 4.

Mission Control Center, White Flight Control Room, looking west.
(Source: Archaeological Consultants, Inc., 2006)

Mission Control Center (Building 30) at JSC

- Built between 1963 and 1964 to support the Apollo Program; numerous additions and modifications made between 1982-2004
- Designated a NHL as part of the Man in Space theme study
- Housed the control room for the ALT program during the early development phase, and also was used to monitor simulations for Orbital Test Flight missions
- Eligible under NRHP Criteria A and C. Derives its exceptional significance from Wings M and S which include both Apollo-era and SSP flight control rooms.
- Eligible under Criterion A as the support center critical to full control of Space Shuttle missions, from liftoff to landing
- Eligible under Criterion C for its design which reflects the key function as a spacecraft mission control center. Also reflects the progression of engineering and adaptive reuse from the Apollo-era to the SSP.

5.3.5 Type 5: News Broadcast Facilities

The Press Site: Clock and Flag Pole at KSC is the only NASA facility classified as Type 5.

Press Site: Clock and Flag Pole.
(Source: Archaeological Consultants, Inc., 2007)

Press Site: Clock and Flag Pole at KSC

- Constructed ca. 1969 during the Apollo Program.
- Featured in every broadcast of a launch, the flagpole flies the U.S. flag during countdown and liftoff; the clock was specially made to mark the time to liftoff.
- Listed in the NRHP in 2000.
- Eligible under NRHP Criterion A. Historically associated with Space Shuttle launches in the minds of people worldwide, the clock and flag pole framed the vehicle during televised broadcasts of the launch sequence. Also serves as an integral facility in the dissemination of information to the public about Space Shuttle missions.

5.3.6 Type 6: Communication Facilities

Four historic properties are classified as communication facilities:

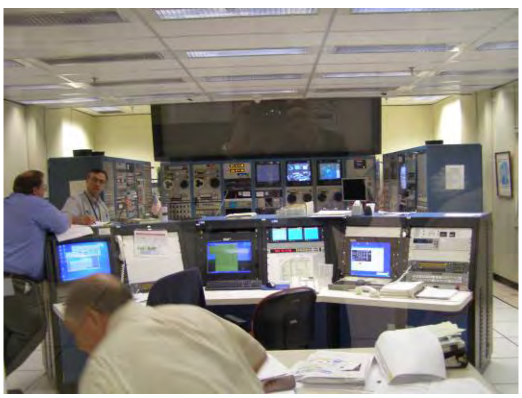
- Huntsville Operations Support Center/NASA Data Center (HOSC/NDC) at MSFC
- Communication and Tracking Development Laboratory at JSC
- Mission Control Center at JSC
- Launch Control Center at KSC

Of these four facilities, two are located at JSC, one at MSFC, and one at KSC. The HOSC/NDC in Building 4663 at the MSFC is the only property classified solely as a Communication Facility (Type 6). The LCC at KSC is also a Launch Operations Facility (Type 3), as described in Section 5.3.3; the MCC at JSC, with multiple affiliations (Types 3, 4, 6, and 10), is described in Section 5.3.4; and the Communications and Tracking Development Laboratory at JSC is also classified as an Engineering and Administration Facility (Type 7). The latter is described below, along with the HOSC/NDC. All four properties are eligible under NRHP Criterion A for their exceptionally significant associations with the SSP; some are also eligible under Criterion C for their distinguished design and construction.

HOSC during STS-78 mission, 1996.
(Source: NASA Marshall Space Flight Center, MSFC-9610972)

HOSC in Building 4663 at MSFC

- Building 4663 was constructed in 1959; the HOSC was added in 1968
- The Shuttle Engineering Support Center (SESC) in the HOSC is used every six weeks for simulations of the Shuttle countdown. Certification runs for contingencies are performed by all the engineers responsible for the major elements of the STS, including the SRBs, SSMEs, and ET.
- Eligible under NRHP Criterion A. Since 1980, this computer command center has played a key role in support of major launch preparation tests run at KSC, and for assisting in problem-solving throughout the SSP.



Test control center in Building 44, looking south.
(Source: Archaeological Consultants, Inc., 2006)

Communications and Tracking Development Laboratory (Building 44) at JSC

- Built between 1965 and 1966 in support of the Apollo Program
- Contains the Electronics Systems Test Laboratory (ESTL), a one-of-a-kind NASA facility used for system verification testing of Shuttle communication systems. Also used for the investigation and resolution of communication anomalies, as well as to create communication systems scenarios.
- Eligible under NRHP Criterion A for the vital role in testing the Space Shuttle communication systems and interfaces, plus for real-time communications trouble-shooting
- Eligible under Criterion C for housing equipment uniquely designed and engineered to perform its specialized functions in support of the SSP

5.3.7 Type 7: Engineering and Administrative Facilities

Twenty-six assets are classified as Type 7 resources. The Engineering and Administrative Facilities group includes test stands and associated control centers, wind tunnels, arc jet facilities, and R&D facilities.

- Propulsion Test Stand A-1 at SSC
- Propulsion Test Stand A-2 at SSC
- Propulsion Test Stand B-1 at SSC
- Propulsion Test Stand B-2 at SSC
- Coca I Test Stand at SSFL
- Coca Control Center at SSFL
- Acoustic Model Engine Test Facility (TF 116) at MSFC
- Structural Dynamic Test Facility at MSFC
- Test and Data Recording Facility (TF 115) at MSFC
- Advanced Engine Test Facility at MSFC
- Control Facility at MSFC
- Materials and Processes Laboratory at MSFC
- Structures, Dynamics and Thermal Vacuum Laboratory at MSFC
- National Center for Advanced Manufacturing at MSFC
- Arc Jet Laboratory at ARC
- Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF) at JSC
- 14-inch Trisonic Wind Tunnel at MSFC
- Abe Silverstein (10 by 10) Supersonic Wind Tunnel (SWT) at GRC
- 8 by 6 SWT at GRC
- Aircraft Landing Dynamics Facility (ALDF) at LaRC
- SSME Hardware Simulation Laboratory (HSL) Block II Facility at MSFC
- Crew Systems Laboratory at JSC
- Avionics Systems Laboratory at JSC
- Multi-Purpose High Bay Facility and Neutral Buoyancy Simulator (NBS) at MSFC
- Shuttle Orbiter Final Assembly Building at Palmdale
- Communications and Tracking Development Laboratory at JSC

Eleven of the 26 assets are located at MSFC, four each are at JSC and SSC, two each are located at GRC and SSFL, and one each is at ARC, LaRC, and Palmdale. All are eligible under NRHP Criterion A for their exceptionally significant associations with the SSP; some are also distinguished by their design and construction, and thus, are eligible under Criterion C in the area of Engineering.

Four of the 26 historic properties are affiliated with more than one property type. Those whose primary function is as Engineering and Administrative Facility are described below. Properties with a secondary Type 7 affiliation include the Shuttle Orbiter Final Assembly Building (150) at Palmdale, described as a Type 2: Vehicle Processing Facility in Section 5.3.2; the Communications and the Tracking Development Laboratory at JSC, described as a Type 6: Communication Facility in Section 5.3.6; and the Multi-Purpose High Bay Facility and NBS at MSFC, described in Section 5.3.10 as a Type 10: Resources Associated with the Training of Astronauts.

Subtype: Test Stands

A total of nine test stands located at SSC, MSFC, and SSFL, and two associated control centers at MSFC and SSFL, comprise this subgroup:

- Propulsion Test Stand A-1 at SSC
- Propulsion Test Stand A-2 at SSC
- Propulsion Test Stand B-1 at SSC
- Propulsion Test Stand B-2 at SSC
- Coca I Test Stand at SSFL
- Coca Control Center at SSFL
- Acoustic Model Engine Test Facility (TF 116) at MSFC
- Structural Dynamic Test Facility at MSFC
- Test and Data Recording Facility (TF 115) at MSFC
- Advanced Engine Test Facility at MSFC
- Control Facility at MSFC

The test stands and support buildings, originally constructed in the 1950s and 1960s, were structurally modified to support testing of the SSME, SRB, ET, and various shuttle systems. They are all eligible for listing in the NRHP under Criteria A and C. Five of the historic properties are designated NHLs; three were previously determined NRHP-eligible.

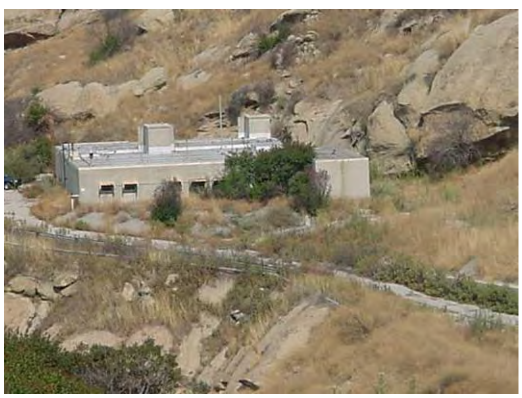
A-1 Test Stand Configured for SSME Testing.
(Source: Stennis Space Center 2007:32)

B-1 (left) and B-2 (right) Positions Configured for SSME Testing.
(Source: Stennis Space Center 2007:32)

Propulsion Test Stands A-1 (Building 4120), A-2 (Building 4122), B-1 (Building 4210) and B-2 (Building 4220) at SSC

- All were built in 1965 and 1966 to support flight certification of the Saturn V (Apollo). Test hardware at each stand has been modified to support the SSP.
- All are designated NHLs
- All accommodate full-scale, liquid propellant rocket engine and systems testing
- A-1, A-2, and B-2 are single position test stands; B-1 is a dual-position stand
- Test stands A-2 and B-1 can simulate altitude conditions encountered by the SSME during ascent
- B-2, the largest test stand of its type in the country, can accommodate the static firing of all three SSMEs at one time. It was used during the test firing of the MPTA on April 21, 1978.
- The four test stands are eligible under NRHP Criterion A. They are the only structures in the world that can support the type and level of testing required by the SSME. Every SSME that has flown in space was certified at the SSC Rocket Propulsion Test Complex.
- All are also eligible under NRHP Criterion C for their unique capabilities, configuration and method of construction

The Coca I (A-3) Test Stand, looking north.
(Source: Norman Betz, The Boeing Company, September 2006)



Coca Control Center, east elevation.
(Source: Norman Betz, The Boeing Company, September 2006)

Coca I Test Stand (A-3) (Building 733) and Coca Control Center (Building 218) at SSFL

- The Coca I Test Stand was built in 1956-1957, and modified in 1963-1964 (Saturn/Apollo) and 1973-1975 and 1978 (SSP)
- Engine component testing on A-3 in 1974 marked the beginning of the SSME test program
- Supported tests for SSME components (1974-1978), static firings of single SSMEs (1978-1988), and SSME turbopump acceptance tests (1978-1988)
- Eligible under NRHP Criteria A and C for the crucial role it played in the certification of the main engines for the first flight of *Columbia.* Also significant for its specialized engineering and design.

- The Coca Control Center, built in 1956, supported SSME component and complete engine testing between 1974 and 1988
- The Control Center is eligible under Criteria A and C for the vital role it played in controlling and monitoring the test firings at Coca I. Under Criterion C, it is an excellent example of blockhouse design and engineering.

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<td>
Acoustic Model Engine Test Facility, aerial view, 1976.
(Source: NASA MSFC - 777250)</td>
<td>Acoustic Model Engine Test Facility (TF 116) (Building 4540) at MSFC

• Built in 1964 to support the Apollo Program; used since 1974 for the SSP.
• Associated with very early and continuous acoustic model testing for the initial development of the Shuttle, from 1974 to 1981
• Eligible under NRHP Criteria A and C for the instrumental role it played in the development of propulsion systems for the Space Shuttle, and for its design and engineering</td>
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<td>
Structural Dynamic Test Facility; Enterprise being lifted by crane, 1978.
(Source: NASA MSFC - 7890776)</td>
<td>Structural Dynamic Test Facility (Building 4550) at MSFC

• Built in 1964; modified in 1975 for the SSP
• Designated a NHL as part of the Man in Space theme study
• Associated with the MVGVT (May 1978-February 1979) which verified that the Shuttle could withstand the vibrating forces encountered during powered flight
• Eligible under NRHP Criteria A and C for its unique capability to dynamically test the Space Shuttle, and for its design and engineering which allowed for vibration testing of an assembled launch vehicle.</td>
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Test Cell 115 at Building 4583.
(Source: Archaeological Consultants, Inc., 2006)

Test and Data Recording Facility (TF 115) (Building 4583) at MSFC

- Originally built in 1957, with TF 115 added in 1964
- Previously determined NRHP-eligible under non-SSP context.
- Associated with scale model tests to improve the SRB following the *Challenger* accident in 1986
- Eligible under NRHP Criteria A and C for its key role leading to improvements in the SRBs, and for its design and engineering to support tests of an improved SRB launch deflector

AETF, west elevation.
(Source: Archaeological Consultants, Inc., 2006)

Control Facility (Building 4674), west elevation.
(Source: Archaeological Consultants, Inc., 2006)

Advanced Engine Test Facility (AETF) (Building 4670) and Control Facility (Building 4674) at MSFC

- Originally built in 1965 for Apollo Program; modified in 1974 and 1986 for SSP.
- Previously determined NRHP-eligible under non-SSP context
- Used to test ETs and SSMEs between 1976 and 1999
- Eligible under NRHP Criterion A for its key role in testing the liquid hydrogen tank of the ET during the SSP development phase. It is also distinguished for its role in full-scale testing of advanced technologies for the SSME in the 1990s.
- Eligible under Criterion C in the area of Engineering for its design and construction

- The Control Facility was built in 1964
- Previously determined NRHP-eligible under non-SSP context
- It is eligible under Criteria A and C for its support of important tests for the ET (1974-1980) and SSME (1986-1990s). It is also noteworthy for its blockhouse design and construction.

Subtype: R&D Facilities

Three historic properties at MSFC are exceptionally significant in the context of the SSP as premier R&D facilities. These include:

- Materials and Processes Laboratory
- Structures, Dynamics and Thermal Vacuum Laboratory
- National Center for Advanced Manufacturing

Materials and Processes Laboratory, west elevation.
(Source: Archaeological Consultants, Inc., 2006)

Materials and Processes Laboratory (Building 4612) at MSFC

- Originally built in 1959; 1965 addition
- Previously determined NRHP-eligible under non-SSP context
- Premier testing facility for materials science and analysis in support of the SSP
- Eligible under NRHP Criterion A. Research here has contributed significantly to the development and improvement of materials which constitute the major components of the Space Shuttle vehicle. Also played a key role in Return to Flight after the *Challenger* and *Columbia* accidents.

Load Test Annex in Building 4619.
(Source: Archaeological Consultants, Inc., 2006)

Structures, Dynamics and Thermal Vacuum Laboratory (Building 4619) at MSFC

- Originally built in 1959, with additions in 1962 and 1964
- Previously determined NRHP-eligible under non-SSP context
- Eligible under NRHP Criterion A as a premier testing facility for the major components of the Space Shuttle vehicle. Since 1972, it has played a key role in the validation of the SRB, ET, and SSME which qualified the Shuttle for flight.
- Eligible under NRHP Criterion C for the design and construction of its specialized equipment, including vacuum chambers and one of the world's three Gilmore machines

National Center for Advanced Manufacturing, east and north elevations.
(Source: Archaeological Consultants, Inc., 2006)

National Center for Advanced Manufacturing (Building 4707) at MSFC

- Originally built in 1956, with a 1962 south addition
- Previously determined NRHP-eligible under non-SSP context
- Eligible under NRHP Criteria A as a premier R&D facility responsible for the development of many key materials for the Space Shuttle, including the composite nose cone for the ET, SOFI, and a super lightweight ET
- Eligible under Criterion C for its design and engineering

Subtype: Arc Jet Facilities

Two arc jet facilities, located at ARC and JSC, are of exceptional significance in the context of the SSP. These include:

- Arc Jet Laboratory at ARC
- ARMSEF at JSC

Arc Jet Laboratory, north façade.
(Source: Page & Turnbull, Inc. 2007: Page IV-37)

Arc Jet Laboratory (N-238) at ARC

- Constructed in 1964
- The 60-MW Interaction Heating Facility was added in 1974 for the SSP
- Used for shuttle panel and leading edge TPS tests
- Conducted more arc jet testing for Shuttle TPS than all the other arc jets in the U.S.
- Eligible under Criterion A for the advancement of the Shuttle TPS. Enabled the development of reusable TPS in use on the Space Shuttle orbiters.
- Eligible under Criterion C. The 60-MW heating facility is an important engineering achievement since it was capable of producing heat three times hotter and on larger models than any other arc jet.

Arc Jet in ARMSEF, looking northeast.
(Source: Archaeological Consultants, Inc., 2006)

Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF) (Building 222) at JSC

- Built between 1965 and 1966; upgraded with a 10-MW arc heater in 1972 to support the SSP. Equipment upgrades in 1989-1990.
- Used to test TPS materials, including sections of RCC, tile systems, and wing leading edge segment models
- Eligible under NRHP Criterion A as one of only two NASA-owned arc jet facilities capable of testing all types of Shuttle TPS. Has contributed significantly to improvements in TPS technology.
- Eligible under Criterion C in the area of Engineering for its unique design and construction to produce sustained high temperatures to simulate the conditions associated with entry into the Earth's atmosphere.

Subtype: Wind Tunnels

Three wind tunnels, located at GRC and MSFC, were evaluated as of exceptional significance in the context of the SSP:

- 14” Trisonic Wind Tunnel at MSFC
- Abe Silverstein 10 by 10 SWT at GRC
- 8 by 6 SWT at GRC

Overall view of 14x14 Trisonic Wind Tunnel, 1988.
(Source: NASA Marshall Space Flight Center, MSFC-8891417)

14-inch Trisonic Wind Tunnel (in the Office and Wind Tunnel Facility, Building 4732) at MSFC

- Building 4732 was constructed in 1943; the 14-inch trisonic wind tunnel dates to 1957.
- Previously determined NRHP-eligible under non-SSP context
- Used to test models of the orbiter, SSME, ET, and SRB
- Eligible under NRHP Criteria A and C. Under Criterion A, it is significant for its association with a variety of Shuttle tests using percent-scale models. Tests were underway by early 1976, and continued during the early development period from 1976 to 1981. It allowed NASA to test concepts relatively cheaply.
- Under Criterion C, it is distinguished by its design and engineering. The small wind tunnel has been a workhorse at MSFC, due, in part, to the high quality of its design.

An engineer checks a scale model of the transportation system before testing in NASA Glenn's 10 by 10-foot wind tunnel in 1975.
(Source: NASA Glenn Research Center, 1975-02610)

Abe Silverstein 10 by 10 SWT at GRC

- Built in 1955
- One of only two dual-cycle wind tunnels owned by NASA
- Was used throughout the 1970s and 1980s for aerodynamic tests on the SRBs; aerodynamic pressure data and base heating studies on the complete Shuttle launch configuration; air speed and angle-of-attack data on the orbiter; and engine-out loads studies.
- Eligible under NRHP Criteria A and C
- Under Criteria A, it provides simulation of high speed atmospheric flight used to verify the design and performance of Space Shuttle systems. It also played a vital role in Shuttle component design improvements and innovations during post-*Challenger* and *Columbia* Return to Flight.
- Under Criterion C, the 10 by 10 SWT is distinguished for its design and engineering

1983 Test in the 8 by 6-foot SWT.
(Source: NASA Glenn Research Center, 1983-6425)

8 by 6 SWT at GRC

- Originally constructed in 1946-1949, with additions made in 1950, 1957 and 1968
- One of the first wind tunnels specially designed and built for propulsion testing
- Currently, the only transonic propulsion wind tunnel owned by NASA, and one of two NASA-owned wind tunnels capable of either aerodynamic or propulsion cycle testing
- Eligible under NRHP Criteria A and C, as noted for the 10 by 10 SWF

Other Type 7 Historic Properties

Four assets are classified as “Other” Engineering and Administrative Facilities. These exceptionally significant R&D facilities, located at LaRC, MSFC, and JSC, include:

- ALDF at LaRC
- SSME HSL Block II Facility at MSFC
- Crew Systems Laboratory at JSC
- Avionics Systems Laboratory at JSC

 ALDF Carriage on the Test Track, 2004. (Source: Science Applications International Corporation 2006:61)	**Aircraft Landing Dynamics Facility (ALDF) at LaRC** • Originally constructed in 1956; major upgrade in 1985 and renaming to ALDF • A multi-component facility comprised of seven structures, buildings and objects • Used in the 1980s and early 1990s to test Shuttle tire performance, tire-failure wheel tests, and the effects of runway modifications • Eligible under NRHP Criteria A and C. It is the only facility in the world that could provide Space Shuttle braking and landing tests required for the Space Shuttle development program. Also distinguished by its design and construction.
 SSME HSL, interior, 1999. (Source: NASA Marshall Space Flight Center, MSFC-9904407)	**SSME HSL Block II Facility (Building 4436) at MSFC** • Building 4436 was originally constructed in 1962; converted to HSL in 1985 to support the SSP. • Eligible under Criterion A as a unique facility responsible for hardware and software design and development, real time launch support, and quality assurance of the computer software that controls the main engines for all Space Shuttle flights

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Integrated Life Support Test Facility in Building 7.
(Source: Archaeological Consultants, Inc., 2006)
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Crew Systems Laboratory (Building 7) at JSC

Built between 1962 and 1964 to support the Apollo Program; additions made between 1967 and 1995.
Wing E high bay (Environmental Test Area [ETA]) was constructed specifically for the SSP
The ETA supports performance testing of spacesuit and backpack systems
Eligible under Criterion A as the performance testing site for primary life support equipment critical to the health and safety of the Space Shuttle mission crew. Also plays a key role in maintaining the habitability of the orbiter environment.
Eligible under Criterion C in the area of Engineering for its specialized equipment such as vacuum chambers, which simulate the extreme environment of space

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“Big Rig” orbiter forward bay in Building 16,
looking north.
(Source: Archaeological Consultants, Inc., 2006)
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**Avionics Systems Laboratory
(Building 16) at JSC**

Built between 1962 and 1964; additions made in 1965 and between 1975 and 1993.
In 1974, the SAIL was developed in Wing N to provide integration and verification of Space Shuttle hardware and software for flight. It has been modified to match the configuration of each orbiter.
Eligible under NRHP Criterion A for the SAIL facility, which played a vital role in testing and hardware and software certification, for the first flight of each orbiter.
Eligible under Criterion C for its special design and construction to test and evaluate Space Shuttle avionics systems, including a full-scale replica of the orbiter’s payload bay.

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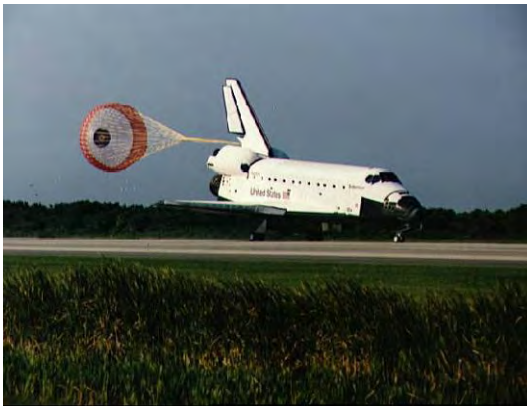
5.3.8 Type 8: Space Flight Vehicle (or Space Shuttle)

The three extant Space Shuttle orbiter vehicles, *Discovery*, *Atlantis* and *Endeavour* comprise the Type 8 property group.

 *Discovery* during rollout ceremony at Palmdale, 1984. (Source: NASA Lyndon B. Johnson Space Center, S84-30898)	***Discovery* (OV-103)** • Constructed between 1979 and 1983 as NASA's third orbiter built for operational use • First flight was STS-16 in 1984 • Oldest of the remaining orbiters, with 33 missions through 2006 • First orbiter to complete 20 missions, with STS-63 in 1995 • Served as the Return to Flight vehicle after both the *Challenger* and *Columbia* accidents • Eligible under NRHP Criteria A and C as one of three remaining orbiter vehicles of the SSP, and as an exceptional work of design and engineering. Its various components are specially designed for the environment of space.
 Launch of Space Shuttle *Atlantis*, 1989. (Source: NASA John F. Kennedy Space Center, KSC-89PC-1049)	***Atlantis* (OV-104)** • Constructed between 1980 and 1985 as NASA's fourth orbiter built for operational use • First flight was STS-28 in 1985 • Completed 28 missions (as of June 2007) • First orbiter to fly with the new MEDS "glass cockpit" (STS-101 in 2000) • Eligible under NRHP Criteria A and C as one of three remaining orbiter vehicles of the SSP, and as an exceptional work of design and engineering. Its various components are specially designed for the environment of space.

 Landing of *Endeavour* at Kennedy Space Center, Florida, 1992. (Source: NASA Lyndon B. Johnson Space Center, STS057(S)082)	***Endeavour* (OV-105)** • Completed in 1990 as NASA's fifth orbiter built for operational use • First flight was STS-49 in 1992 • As of June 2007, has flown 19 missions • Carried the Spacehab module on its first mission, completed the first HST servicing mission, and was the first orbiter to fly with TUFI tiles • Eligible under NRHP Criteria A and C as one of three remaining orbiter vehicles of the SSP, and as an exceptional work of design and engineering. Its various components are specially designed for the environment of space.

5.3.9 Type 9: Manufacturing and Assembly Facilities

Six historic properties are classified as Type 9: Manufacturing and Assembly Facilities:

- Thermal Protection System Facility at KSC
- Parachute Refurbishment Facility at KSC
- Pacific Scientific Furnace at Canoga Park
- OPF High Bay 3 at KSC
- SRB ARF Manufacturing Building at KSC
- Shuttle Orbiter Final Assembly Building at Palmdale

Four properties are located at KSC, and one each is located at the Canoga Park Facility and Palmdale. All six Type 9 assets are eligible under NRHP Criterion A as significant places where major Space Shuttle flight components, including the SRBs, SSMEs, and TPS materials, were manufactured or assembled; some are also eligible under Criterion C for their design and construction. The Shuttle Orbiter Final Assembly Building, also classified as Types 2 and 7, is described in Section 5.3.2. The OPF High Bay 3 and SRB ARF Manufacturing Building also are both described in Section 5.3.2 as Type 2: Vehicle Processing Facilities. The three facilities, whose primary function is as a Manufacturing and Assembly Facility, are described as follows.

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<td>
Thermal Protection System Facility, south and east elevations.
(Source: Archaeological Consultants, Inc., 2006)</td>
<td>Thermal Protection System Facility (Facility K6-794) at KSC
Built in 1988
Used for the manufacture and repair of the Space Shuttle’s thermal protection and thermal control systems, including tiles, gap fillers and insulation blankets, as well as coatings and adhesives
Eligible under NRHP Criterion A as one of only two NASA-owned assets constructed exclusively to house the manufacture and repair of the Space Shuttle’s thermal protection and thermal control systems, essential to the success of the SSP</td>
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Parachute Refurbishment Facility, work area.
(Source: Archaeological Consultants, Inc., 2006)

Parachute Refurbishment Facility (Facility M7-657) at KSC

- Constructed in 1964; modified between 1978 and 1979 for the SSP
- Since 1979, used to receive, clean, refurbish, pack and store the pilot, drogue and main parachutes. Pilot parachutes and replacements for parachute/drogue chute deployment bay assemblies are also made.
- Eligible under NRHP Criterion A. The main, drogue and pilot parachutes are essential components of the Space Shuttle SRBs, essential for space flight recovery and component reuse.

Pacific Scientific Furnace, with control room to right, 2006.
(Source: Pratt & Whitney Rocketdyne, Canoga Park, CA, 06-PWR-00599-021D)

Pacific Scientific Furnace at the Canoga Park Facility

- Purchased by NASA in 1966, the furnace is located inside Building 001 owned by PWR
- Originally used for the Apollo Program
- Used to braze the SSMEs
- Eligible under NRHP Criterion A for its exceptionally significant role in the manufacturing process for every main engine which powers the Shuttle vehicle
- Eligible under Criterion C for its specialized engineering and design which makes possible the brazing of major SSME components. It is further distinguished as the largest furnace of its type in the world.

5.3.10 Type 10: Resources Associated with the Training of Astronauts

Eight historic properties are classified as Type 10 resources:

- Jake Garn Mission Simulator and Training Facility at JSC
- Systems Integration Facility at JSC
- Sonny Carter Training Facility/NBL at JSC
- Multi-Purpose High Bay Facility and NBS at MSFC
- Flight and Guidance Simulation Laboratory at ARC
- Crew Systems Laboratory at JSC
- Mission Control Center at JSC
- SLF Runways at WSSH

Five properties are located at JSC, and one each is located at ARC, MSFC, and WSTF. All are eligible under NRHP Criterion A as astronaut training sites in support of the SSP, and under Criterion C for their design and engineering. Four of the historic properties are classified solely as Type 10 resources: the Flight and Guidance Simulation Laboratory (Building N-243) at ARC; the Jake Garn Mission Simulator and Training Facility (Building 5) at JSC; the Systems Integration Facility (Building 9) at JSC; and the Sonny Carter Training Facility/NBL (Building 920-N) at JSC. The other four assets have multiple property type affiliations. Both the Multi-Purpose High Bay and NBS (Building 4705) at MSFC and the Crew Systems Lab (Building 7) at JSC are also classified as Type 7: Engineering and Administrative Facilities. The latter is described in Section 5.3.7. The MCC (Building 30) at JSC, also classified as Types 3, 4 and 6, is described in Section 5.3.4 for its primary affiliation as a Mission Control Facility; the SLF at WSSH, also classified as Types 1 and 11, is described in Section 5.3.1 under its primary classification, a Resource Associated with Transportation (Type 1). The five facilities, whose primary function is as an astronaut training facility, are described as follows.

Motion-based Simulator in Building 5,
looking northwest.
(Source: Archaeological Consultants, Inc., 2006)

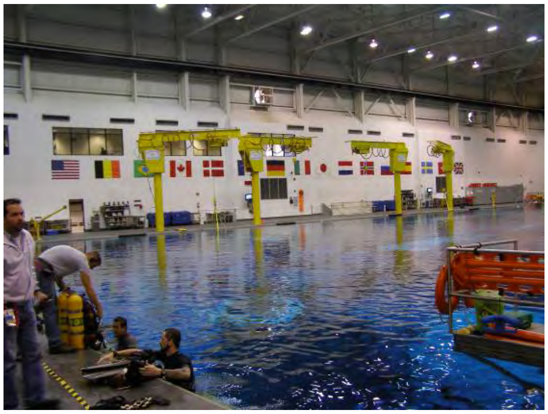
Jake Garn Mission Simulator and Training Facility (Building 5) at JSC

- Built between 1964 and 1965; additions made in 1992 and 1993
- Mockups housed here are used to train astronauts in vehicle operations, including launch, landing, payload and ISS operations, as well as rendezvous activities
- The Motion-based Simulator was first used as a training tool during the ALT program in 1977. In 1978, it was modified to become the motion-based portion of the Shuttle Motion Simulator (SMS).
- Eligible under NRHP Criterion A as a premier NASA facility for preparing astronauts for Space Shuttle missions, including launch and landing situations, and critical on-orbit operations.
- Eligible under Criterion C. The simulators, which provide realistic sensory feedback to the astronauts, were uniquely designed to replicate the Shuttle vehicle and its launch, orbit, and landing environments.

Crew Compartment Trainer I in Building 9N,
looking southwest.
(Source: Archaeological Consultants, Inc., 2006)

Systems Integration Facility (Building 9) at JSC

- Built between 1965 and 1967; additions made in 1975, 1988 and 1992.
- Wing N houses the Space Vehicle Mockup Facility (SVMF) which contains three large Space Shuttle mockups, each built at full scale, and each of which is multi-functional in support of astronaut training and certification, flight control training, and engineering evaluation.
- Eligible under NRHP Criteria A and C. Building 9 derives its exceptional significance from the SVMF which contains unique tools which provide astronauts with more "real" training experiences not found anywhere else. Astronaut testing has resulted in important improvements to the orbiter vehicle design.



NBL Pool in Building 920N, looking northwest.
(Source: Archaeological Consultants, Inc. 2006)

Sonny Carter Training Facility/NBL (Building 920N) at JSC

- Building 920N was constructed between 1992 and 1993; the NBL within it was built between 1995 and 1996.
- The NBL allows for the simultaneous performance of multiple training activities in a simulated space environment. It contains full-scale working models of both the orbiter and ISS components in the pool and high bay areas.
- Used to train astronauts for EVAs and real-time problem solving during missions
- Building 920N derives its exceptional significance from the NBL pool and high bay located in Wing N
- Under NRHP Criterion A, the abilities perfected here by the astronauts are critical to the success of space missions involving spacewalks, and are fundamental to the construction of the ISS
- Under Criterion C, the NBL is the world's largest indoor pool, and a one-of-a-kind facility designed to simulate the environment of space

NBS Facility in Building 4705, exterior of NBS tank.
(Source: Archaeological Consultants, Inc., 2006)

Multi-Purpose High Bay Facility and NBS (Building 4705) at MSFC

- Building 4705 dates to 1952; the NBS was constructed in the high bay in 1968. It closed for use in 1997.
- Designated a NHL as part of the Man in Space theme study
- Used in the late 1970s to prepare Shuttle astronauts for assembling large structures in space
- In the 1980s and 1990s, it was used to conduct test flight simulations and to practice assembly techniques
- Eligible under NRHP Criterion A as an early SSP facility for astronaut EVA training which paved the way for the first structures built in space
- Under Criterion C, the NBS was uniquely designed to simulate the space environment. It marks the beginning of the evolutionary line leading to the WETF and the NBL at the JSC.


Flight and Guidance Simulation Laboratory, east façade.
(Source: Page & Turnbull, Inc. 2007:VI-59)

Flight and Guidance Simulation Laboratory (Building N-243) at ARC

- Built between 1965 and 1967 for the Apollo Program
- Derives its significance from the VMS, constructed by 1979
- Since 1980, the VMS has provided training to prepare Shuttle commanders and pilots with a wide array of possible landing failures.
- Eligible under NRHP Criterion A for its contributions to the training of SSP astronauts. The VMS is the world's largest motion-base simulator, and the sole training simulator for landing and rollout of the Shuttle orbiter. It is the only NASA facility that can simulate final descent and landing of the orbiter. Almost every pilot astronaut involved in the SSP has trained on the VMS.

5.3.11 Type 11: Resources Associated with Space Flight Recovery

Seven historic properties are classified as Type 11 resources:

- MDD at DFRC
- SLF Runways at WSSH
- SLF Runway at KSC
- Landing Aids Control Building at KSC
- MDD at KSC
- Retrieval ship *Liberty Star* at KSC
- Retrieval ship *Freedom Star* at KSC

All are eligible under NRHP Criterion A as exceptionally significant facilities that facilitated the recovery and reuse of the spacecraft and its major components after their return to Earth. Some are also distinguished by their design and construction, and thus, are eligible under Criterion C. Five properties are located at KSC, and one each is located at DFRC and WSSH. All seven historic properties are also classified as Type 1: Resources Associated with Transportation, and are described and illustrated in Section 5.3.1.

5.3.12 Type 12: Resources Associated with Processing Payloads

Three properties at KSC, the Canister Rotation Facility and the two Payload Canisters, are classified as Type 12 resources. The two Payload Canisters are described and illustrated in Section 5.3.1 as Type 1: Resources Associated with Transportation; the Canister Rotation Facility is described and depicted in Section 5.3.2 as a Type 2: Vehicle Processing Facility.

6.0 CONCLUSIONS AND MANAGEMENT RECOMMENDATIONS

6.1 Overview of Significant Historic Properties

As a result of NASA's agency-wide survey and assessment of SSP-related historic facilities, 70 assets were identified which individually meet the NRHP criteria of eligibility. This number includes 19 personal property assets (the three orbiters, two retrieval ships, two payload canisters, two SLF runways, two Crawler Transporters, three MLPs, the barge *Poseidon*, the Pacific Scientific Furnace, the OLF, the Crawlerway, and the Clock and Flag Pole). All surveyed real and personal property assets are NASA-owned. The WSSH SLF runways are located on property leased by NASA from the U.S. Army, and the OLF and Shuttle Orbiter Final Assembly Building are on property leased from the U.S. Air Force at AFP 42 in Palmdale. The Pacific Scientific Furnace is housed in PWR's Canoga Park Facility.

Collectively, these buildings, structures, and objects embody the historical developments of the U.S. Space Shuttle Program, from the early period of development through the near final years of operation. Many of the historic properties were originally built to support the Apollo Program, and were modified and adaptively reused for the SSP. Others were specially built as new facilities to meet the unique needs of the SSP.

6.1.1 Chronology of Infrastructure Development

The 70 exceptionally important SSP-related historic properties were first constructed between 1943 and 1996. Fourteen were originally built prior to 1960, and 34 were constructed in the 1960s, largely in support of Saturn/Apollo. The other 22 historic properties were designed and built exclusively for the SSP during the 1970s, 1980s, and 1990s.

The oldest facilities used in support of the SSP predate the birth of NASA. The historic properties built before 1960 include Runway 17/35 at WSSH (late 1940s); the 8 by 6 SWT (1949) and the 10 by 10 SWT (1955) at GRC; the ALDF (1956) at LaRC; the Coca I Test Stand and associated Coca Control Center (both 1956) at SSFL; Building 150 at Palmdale (1958); and seven facilities at MSFC, including the Office and Wind Tunnel Facility (1943), as well as the late 1950s Materials and Processes Laboratory; Structures, Dynamics and Thermal Vacuum Laboratory; HOSC/NDC; Multi-Purpose High Bay Facility and NBS; and the National Center for Advanced Manufacturing. To varying degrees, all were modified to support operations for the SSP. Similarly, with few exceptions, facilities constructed during the 1960s, including large rocket engine test stands and Apollo-era launch facilities, were adapted for use in support of the SSP during the 1970s and 1980s. Modifications included large building additions, as well as upgrades to equipment, without alteration to the physical structure. A chronology of selected facility modifications, additions and upgrades is provided in Table 6.1

Table 6.1. Timeline of selected NASA agency-wide building modifications.

Year	Modification
1972	• 10 MW arc jet added to ARMSEF (Building 222) at JSC • Modifications to Building 4619 (Structures, Dynamics and Thermal Vacuum Laboratory) at MSFC
1973	• Begin modifications to Coca I test stand at SSFL • Begin modifications to Building 150 (Shuttle Orbiter Final Assembly Building) at Palmdale (1975 completion) • Modifications to Building 4540 (TF 116) at MSFC
1974	• SAIL developed in Wing N of Building 16 (Avionics Systems Laboratory) at JSC • 60 MW arc jet added in Building N-238 at ARC • Modifications to Building 4670 (AETF) at MSFC to support ET structural verification testing
1975	• Building 4550 (Structural Dynamic Test Facility) at MSFC modified for the MVGVT • Crew Compartment Trainer I (CCT I) added to Building 9 (Systems Integration Facility) at JSC
1976	• Reconfiguration of the VAB at KSC begins • Beginning of modifications to the three MLPs at KSC, including removal of launch umbilical towers (LUTs) and addition of tail service masts (TSMs) • Modification to Runway 17/35 at WSSH • Beginning of major modifications to LC 39 Pad A at KSC (completed in 1979) • Internal modifications to Building M7-961 (Hypergol Module Processing (North)) at KSC • Motion-based Simulator added in Building 5 (Jake Garn Mission Simulator and Training Facility) at JSC
1978	• Beginning of major modifications to LC 39 Pad B at KSC (completed in 1985) • Beginning of major additions and modifications to convert Building M7-657 at KSC into the Parachute Refurbishment Facility (completed in 1979)
1979	• Shuttle EMU/Airlock/Life Support Test Facility added in Building 7 (Crew Systems Laboratory) at JSC
1980	• Opening of the Vertical Motion Simulator (VMS) in Building N-243 at ARC to test designs of the Shuttle cockpit and to support Shuttle pilot training • Full Fuselage Trainer (FFT) added to Building 9 (Systems Integration Facility) at JSC
1985	• Building 4436 at MSFC converted into the SSME HSL • Major upgrades to the Landing Loads Track at LaRC to create the ALDF
1986	• Addition of a third static fire position to the B-1 test stand at SSC • Modifications to Building 4670 (AETF) at MSFC to support SSME testing
1987	• Modifications to Test Cell 103 of Building 4583 (TS 115) at MSFC to support scale-model tests of the SRB • Mission Operations Wing (MOW) of the MCC (Building 30) at JSC added
1989	• Building K6-696 at KSC converted into the OPF-3 (completed in 1991)
1992	• Wing S (including the White Flight Control Room) of the MCC (Building 30) at JSC added • Wing 5 South and High Bay added to Building 5 (Jake Garn Mission Simulator and Training Facility) at JSC (completed in 1993)
1993	• CCT II added to Building 9 (Systems Integration Facility) at JSC
1996	• NBL added to Building 920N at JSC • SSMEPF added to the OPF-3 at KSC (completed in 1998)
2004	• Mission Evaluation Room (MER) in MCC (Building 30) at JSC added

Of the 70 significant NASA-wide historic properties, approximately one-third were built exclusively for the SSP. Included in this group are the three MDDs, the two SLFs, the two SRB retrieval ships, the two payload canisters, the two orbiter processing facilities, and the three extant orbiter vehicles. Thirteen of the new constructions are located at the KSC. A chronology of new construction (using the date of completion) is provided in Table 6.2.

Table 6.2. Timeline of selected SSP-related new facility construction.

Year	Facility
1976	• MDD at DFRC • Shuttle Runway and Building J6-2313 (Landing Aids Control Building) at KSC • Buildings 451 and 452 (Pneumatic Test Facility and Control Building) at MAF
1977	• Building K6-894 (OPF) at KSC
1978	• Two Payload Canisters at KSC • Runway 23/05 at WSSH • MDD at KSC
1980	• Retrieval ship *Liberty Star*
1981	• Retrieval ship *Freedom Star*
1982	• Building 114 (High Bay Addition) at MAF
1983	• Orbiter *Discovery*
1984	• Building K6-494 (Rotation/Processing Building) at KSC
1985	• Orbiter *Atlantis*
1986	• Building L6-247 (SRB ARF Manufacturing Facility) at KSC • Runway 20/02 (TAL) at WSSH
1987	• Building K6-696 (OPF-3) at KSC
1988	• Building K6-794 (Thermal Protection System Facility) at KSC
1990	• Orbiter *Endeavour*
1991	• OLF at Palmdale
1993	• Building 920N (Sonny Carter Training Facility) at JSC • Building M7-777 (Canister Rotation Facility) at KSC
1996	• NBL in Building 920N at JSC

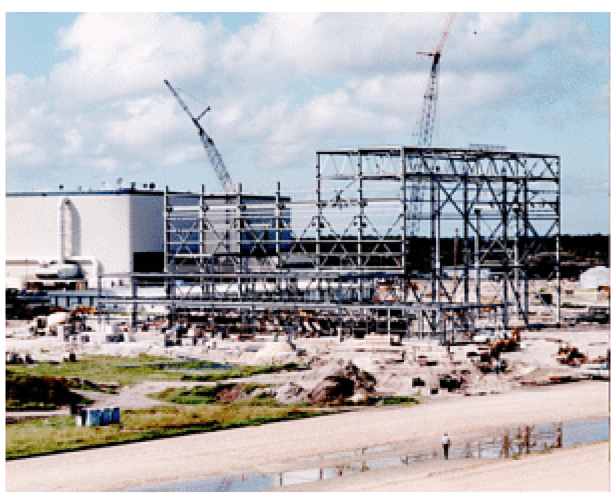


Photo 6.1. Construction of the Shuttle Orbiter Modification and Refurbishment Facility (later OPF-3), September 25, 1986.
(Source: NASA KSC, ID No. KSC-86PC-0302)

6.1.2 Evolutionary Developments

Evolutionary advancements in technology are showcased in a number of NASA-owned historic properties, including arc jet facilities, wind tunnels, and test stands. Equipment upgrades and structural modifications to existing facilities served to integrate improved technologies to meet the needs of NASA's new SSP. In other cases, new facilities were constructed which embodied the cumulative progression of ideas and innovations since the beginning of the U.S. Space Program. Major modifications to the launch pads at KSC's LC 39 illustrate the adaptive reuse process; the succession of water training facilities developed at the MSFC and JSC reflect the overall evolutionary changes in new facility constructions.

Launch Complex 39: Beginning in 1976, major modifications were made to facilities and properties at KSC in preparation for the first Space Shuttle launch. At LC 39 Pad A, modifications were started in 1976 and completed in mid-1978; work progressed at Pad B between 1978 and 1985. With the exception of the six fixed pedestals which support the MLP, all of the structures on the hardstands of each pad were removed or relocated. Fuel, oxidizer, high-pressure gas, electrical, and other service lines were rerouted. New hypergolic fuel and oxidizer support areas were constructed at the southwest and southeast corners, respectively, of the pads; the unneeded Saturn fuel support area was removed, a new FSS was erected using the original Apollo-era LUT, a RSS was added with a Payload Changeout Room (PCR) and Payload Ground Handling Mechanism (PGHM), and the Saturn flame deflectors were replaced. A sound suppression water system was installed on the pads to reduce the acoustical levels within the orbiter's payload and thus, to protect it and its payloads from damage. The sound suppression system includes a 300,000 gallon capacity water tank. A related system, the Overpressure Suppression System, was installed to reduce the pressure pulse at SRB ignition.

Photo 6.2. Aerial view of Apollo 11 spacecraft on Pad A, LC 39, KSC, July 1, 1969. (Source: NASA, Johnson Space Center, ID No. S69-38660)

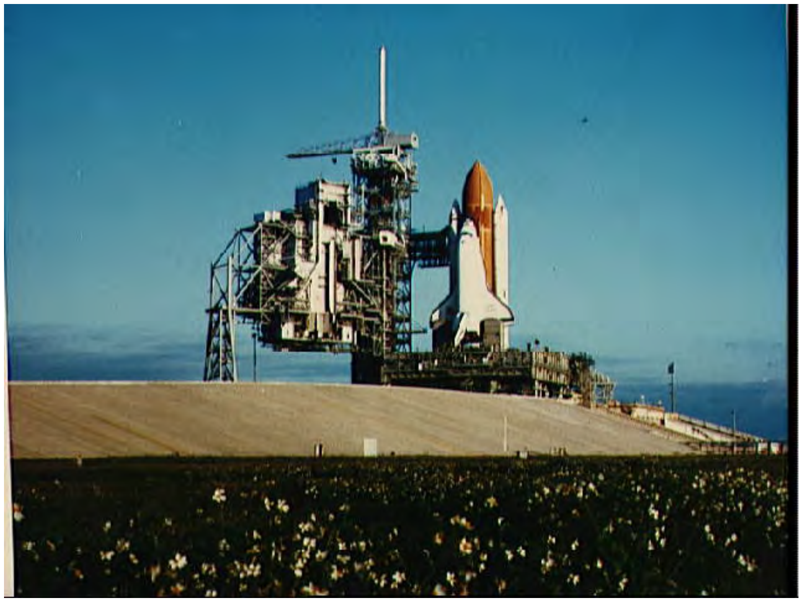


Photo 6.3. *Discovery* arrives at Pad A for STS 51-C, January 24, 1985.
(Source: NASA, Johnson Space Center, ID No. S85-25985)

Water Training Facilities: The history of development of water training facilities at both the MSFC and JSC illustrates a succession of new facility construction, beginning in the pre-SSP period. The first facility used for neutral buoyancy training, in 1965, was an existing tank at MSFC (Hickam 1993). Made from sheet metal, the small 8-feet diameter by 8-feet deep tank was used during early attempts to approximate zero-gravity working conditions (Hickam 1993:47). Operations at the MSFC's NBS began in 1968. The earliest use of this facility was in the design of Skylab. In the late 1970s, the NBS was used to prepare Shuttle astronauts for assembling large structures in space. Following a reorganization of NASA in the late 1970s, and the opening of the Weightless Environmental Training Facility (WETF) in 1980 within Building 29 at the JSC, the center for astronaut EVA training shifted from MSFC to the JSC. The WETF itself represented an evolutionary leap in the line of facilities at the JSC, which started in 1966 with the Water Immersion Facility (WIF) in Building 5. Both the NBS and WIF were deep tanks (Photos 6.4 and 6.5); the WETF (Photo 6.6), as well as the NBL which followed, were large pools.

Despite the addition of the WETF, the MSFC's NBS continued to be used. In the 1980s, it was the only NASA facility large enough to hold a mockup of both the HST and the Shuttle cargo bay (Hickam 1993:53). In 1985, following the perfection of techniques in the NBS, NASA astronauts constructed EASE (Experimental Assembly of Structures in Extravehicular Activity) and ACCESS (Assembly Concept for Construction of Erectable Space Structures), the first structures built in space. Throughout the 1980s and 1990s, the NBS was used to conduct test flight simulations, as well as to practice assembly and handling techniques. A full-scale mockup of the HST was used in both 1979 and 1981 to determine the methods needed to service the actual spacecraft. In 1993, a new and improved Remote Manipulator System (RMS-II), an underwater version of the Shuttle Orbiter RMS, replaced the old RMS components in the NBS.

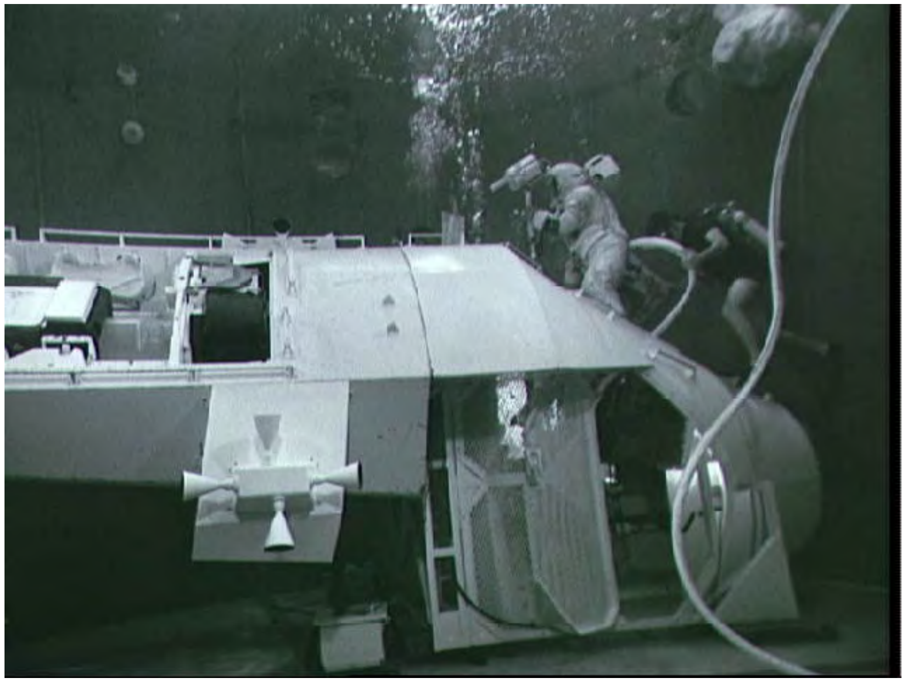


Photo 6.4. EVA simulation in the water facility tank in Building 5, December 1, 1971. (Source: NASA, Johnson Space Center, ID No. S71-58148)

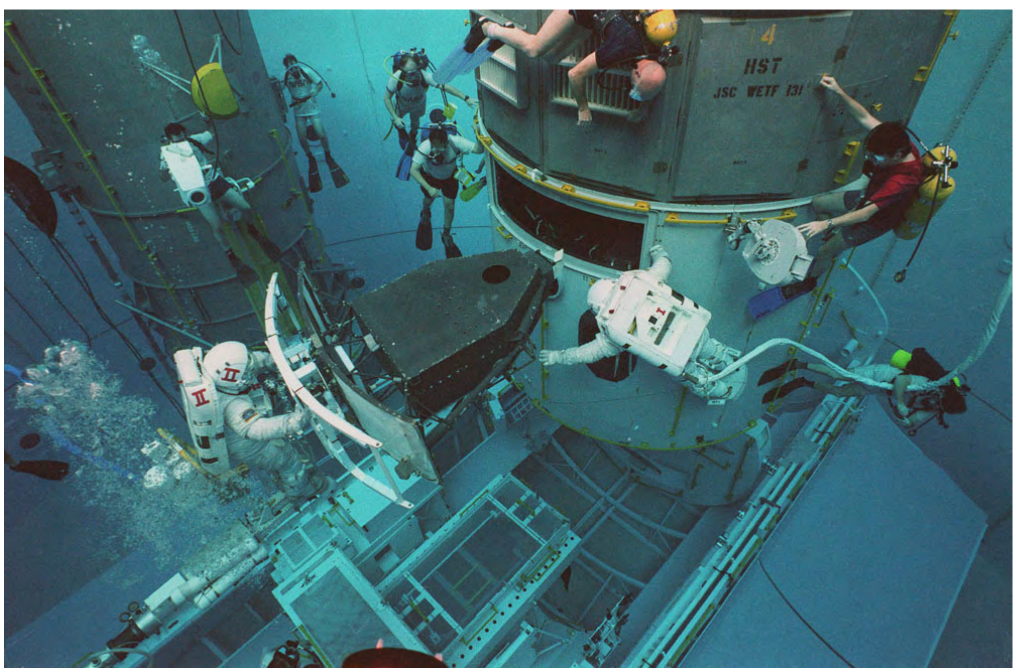


Photo 6.5. Hubble Space Telescope training in the NBS, 1992. (Source: NASA Marshall Space Flight Center, MSFC-9263351)

Photo 6.6. Water egress training at the WETF Building 29 pool, December 1, 1991. (Source: NASA, Johnson Space Center, ID No. S91-52074)

NASA officially closed the NBS for use on July 1, 1997. It was functionally replaced by the new NBL at the JSC. The following year, some equipment needed at the NBL was removed from the NBS. The transferred artifacts included the Spacelab Pallet (SLP) Mock-up, the Shuttle Payload Bay Mock-up, the Manipulator Foot Restraint (MFR) Mock-up, the Aft Flight Deck Crew Station (AFDCS), the RMS simulator, and the Extravehicular Mobility Unit (EMU) components and support equipment (Allen 2001). Subsequently, the SLP mockup, the AFDCS, and the RMS simulator were returned to MSFC; the SLP mockup, MFR, and EMU were retained by JSC. The NBS is currently in mothballed status.

The NBL was designed to allow for the simultaneous performance of multiple training activities in a simulated space environment. The pool contains full-scale working models of both the Space Shuttle orbiter and ISS components, including robotic arms. The abilities perfected here are critical to the success of space missions involving EVAs, including those required to assemble the ISS and to service and maintain the HST. The NBL is also used for real-time problem-solving during active missions to work out solutions for the in-orbit crew. The NBL contains the world's largest indoor pool which was specially designed and built to simulate the environment of space. This one-of-a kind, world class facility reflects the zenith in the four decade evolutionary progression of weightless training facility design, construction and use.

6.2 Significant Facilities and the Space Shuttle Story

The "historicity" of the Space Shuttle Program, including key themes, is reflected in its tangible elements – NASA's historic buildings and structures located across the nation. Collectively, these tell the story of the SSP from the early period of **development and testing** to its past and present **operational phase.** Among the key themes are those relating to the early testing of Space Shuttle components and systems; research and development efforts leading to the creation and improvements of parts and materials, from TPS tiles to life support systems; construction, assembly, and integration of the Space Transportation System; and astronaut training, among others. NASA's historic properties which illustrate some of the major achievements in testing, R&D, and astronaut training are noted in Sections 6.2.1, 6.2.2, and 6.2.3, respectively.

6.2.1 Test Facilities

Many NASA Centers played a key role in shuttle components and systems testing during both the developmental and operational phases of the SSP. Wind tunnels, arc jets, vacuum chambers, test stands, and other NASA facilities and equipment were used to design, improve, and validate the Space Transportation System. NASA's wind tunnels were used for development tests of the orbiter, SSMEs, ET, and SRBs, using percent-scale models, and were fundamental to understanding the aerodynamics of the orbiter/SCA ferry configuration. A variety of candidate TPS materials for the shuttle orbiter were evaluated in NASA's arc jet facilities at the ARC and JSC. Every SSME flown in space was tested at the SSC propulsion test stand complex.

Among the numerous agency-wide test facilities, five historic properties located within the East and West Test Areas of the MSFC, for example, made exceptional contributions to the SSP through the testing of major Space Shuttle components, including the ET, SRBs, and SSMEs. These historic properties include the Acoustic Model Engine Test Facility (TF 116) (Building 4540), the Structural Dynamic Test Facility (4550), the Test and Data Recording Facility (4583), the Advanced Engine Test Facility (4670), and the Control Facility (4674). Among the primary testing programs conducted at these facilities were various structural tests on SRB assemblies; acoustic model testing (1974-1980) at TF 116, which was instrumental to the development of the Space Shuttle propulsion system; the MVGVT series of 1978-1979 at Building 4550, used to verify that the Shuttle could withstand the forces encountered during powered flight; and structural verification testing of the LH2 tank of the ET (1974-1980) at Building 4670 during the buildup to the first Space Shuttle launch in April 1981.

TF 116, for example, was in active use between 1974 and 1981 during the developmental period of the SSP. Using 6.4-percent scale models prepared at the MSFC, the first tests used to gather acoustical data vital to program design and development activities were conducted here on September 4, 1974 (Wright 2001:15). The following year, acoustic tests of a 6.4-percent scale model of the Space Shuttle, including the SSMEs and SRMs, as well as a scaled down version of the Shuttle launch pad at the KSC, allowed MSFC engineers to study the effects of sound waves on the Shuttle vehicle and the launch pad.

The data derived from these tests contributed directly to launch pad design concepts. Between 1974 and July 1976, 150 test firings were conducted at TF 116. Between July and November 1976, a second phase of testing was initiated using a 6.4-percent model of the launch pad at Vandenberg along with the same scale model of the Shuttle. A total of 24 test firings were conducted, and these data were planned to be used in redesigning the launch pad at Vandenberg as an alternate Space Shuttle launch site. During tests conducted in April 1979 as part of the acoustic test program, Tomahawk missile motors were used to substitute for SRBs. A new series of tests for an uprated Space Shuttle configuration, conducted in December 1979, included strap-on rocket motors to augment the thrust of the SRBs. These tests featured 6.4-percent scale models simulating the launch pads at the KSC and Vandenberg. In July 1981, firing tests attempted to reproduce the stress loads detected on the *Columbia* during its April launch with a view towards finding a method for reducing those loads.

In addition to components and systems testing during the ca. 1974-1981 developmental phase of the SSP, the 32 month stand-down period following the *Challenger* accident of January 1986 was a time of significant testing activities and advancements. In accordance with the Rogers Commission recommendations, one focus of the Return to Flight work was the redesign and recertification of a Redesigned Solid Rocket Motor (RSRM). In response, MSFC engineers performed tests for the SRB joint and seal to evaluate design changes under all relevant environmental and loading conditions. During the post-*Challenger* period, other test programs at MSFC included the full scale testing of the SSME, plus tests of the thermal protection system for the SRB and ET, SRM O-rings, and SSME injectors, bearings and seals. In the 1990s, the Advanced Engine Test Facility (Building 4670) played a key role in the full-scale testing of advanced technologies for the SSME. Also at this time, Building 4670 was used to test other hardware, including the Space Shuttle liquid hydrogen pressure valve. The Control Facility, or “blockhouse,” (Building 4674), controlled the testing at Building 4760, including important tests for the SSME (1986-1990s).

6.2.2 Research and Development (R&D)

Several historic properties at both the JSC and the MSFC exemplify NASA’s R&D accomplishments in support of the SSP. These include four facilities at the JSC which have supported the SSP since the 1970s: the Crew Systems Laboratory (Building 7), the Avionics System Laboratory (Building 16), the Communications and Tracking Development Laboratory (Building 44) and the ARMSEF (Building 222). First used in the early developmental phase of the program, these facilities contain unique equipment, such as simulators and thermal vacuum chambers, which continue to provide performance testing of primary life support system equipment, Space Shuttle avionics systems, and spacecraft flight-equivalent communications systems and their interfaces. Equipment vital to the success of all Shuttle missions, including spacesuits and backpacks, as well as software and spaceflight hardware, are performance tested, validated, and certified in these facilities.

Research and development at the JSC generally falls into four categories: materials testing, electrical systems testing, life systems testing, and life sciences testing. In the area of materials testing, a variety of Shuttle components, including the OMS pods, the TPS systems, and the active thermal control systems are tested in JSC facilities. Thermal tests at the ARMSEF verify the heat collection and rejection properties of various TPS components. Such tests analyze the various temperature control techniques, as well as their operational limits and life spans. This facility also aided in the Return to Flight efforts after the *Columbia* accident, including damage assessments of the RCC and the HRSI.

Facilities at the JSC involved in electrical systems testing include the SAIL in Building 16 and the ESTL in Building 44 (known as the Electronic Systems Compatibility Facility until 1980). These facilities conduct testing on the Shuttle's hardware and software to determine if they are interfacing properly. The orbiter's wiring and electronics are also tested to confirm procedures and to locate any anomalies within the systems. In addition, these facilities test the communication systems of the orbiter, and their ability to connect with relay satellites and ground stations. Any modifications or upgrades were tested within these buildings prior to being installed on the orbiter. These facilities also perform contingency simulations and conduct post-flight anomaly resolutions.

The JSC has unique facilities used to develop and test the orbiter's life support systems, including spacesuits and backpacks. Since at least 1979, the Crew Systems Laboratory (Building 7) has supported performance testing of spacesuit backpack systems, including the Manned Maneuvering Unit (MMU) and the EMU, designed to provide astronauts the ability to move around and work in space. Other JSC facilities are used to test the Portable Life Support System (PLSS) backpack, unique to the SSP, or to develop the food that astronauts eat while in space.

At the MSFC, the Material and Processes Laboratory (4612), the Structures, Dynamics and Thermal Vacuum Laboratory (4619), the Multi-Purpose High Bay Facility and NBS (4705), and the National Center for Advanced Manufacturing (4707) are premier facilities for materials science and analysis focused on the materials which comprise the major components of the Space Shuttle, including the SSMEs, SRBs, and ET. Research conducted here has contributed significantly to the design, development and improvement of new materials, including a composite nose cone for the ET, SOFI for the ET, and a super lightweight external tank. During the early developmental phase of the SSP, these facilities played a key role in qualifying the major Shuttle vehicle components for flight. They are also significantly associated with NASA's Return to Flight efforts in the aftermath of the *Challenger* and *Columbia* accidents. The facilities embody unique design elements and equipment, including two of the world's three Gilmore machines which were used for testing programs in support of the SSP.

The Structures, Dynamics and Thermal Vacuum Laboratory (Building 4619), for example, played a key role in the validation of major vehicle components which qualified the Shuttle for flight. Space Shuttle components testing at Building 4619 started in early 1973 with testing of a simulated 77-percent model of an SRB. The Fabrication Division of the Test Laboratory manufactured and assembled SRB components for a full-scale mockup of the propulsion system. MSFC personnel installed the SRB mockup in Building 4619 to serve as an engineering and tooling aid. The Fabrication Division also prepared an all-aluminum 1/15th-scale model of the Space Shuttle used for antenna testing. By the end of 1974, Test Lab personnel had completed three significant tests for the SSME, including the first ignition of a 40,000 pound thrust engine pre-burner. In March 1977, the first major test articles for the Shuttle's ET were installed in Building 4619 in a huge steel truss test fixture for structural testing. This work complemented tests run in 1977-1978 using the intertank and a LOX tank mounted in Building 4550. Between 1977 and 1979, a series of vibration and structural tests were conducted in the high bay using the LOX intertank test article of the Shuttle ET. These tests were followed by structural tests of the SRB in September 1979, and vibration tests on a modified SSME nozzle in October 1980.

6.2.3 Astronaut Training Facilities

Three historic properties at NASA JSC are premier facilities dedicated to astronaut training: the Jake Garn Mission Simulator and Training Facility (Building 5), the Systems Integration Facility (Building 9), and the NBL at the Sonny Carter Training Facility (Building 920N). Collectively, these have provided continuous support to the SSP from the early developmental phase in the 1970s to today. Buildings 5 and 9, for example, were used as training aides for the test pilots during the ALT Program.

The three historic properties include a variety of unique training facilities and equipment, such as full-scale mockups and computerized simulators, which replicate components and systems of the Space Shuttle orbiter vehicle and its effective environments. For example, full-scale mockups of the orbiter flight deck provide astronauts with more "high fidelity" training experiences not found anywhere else. A variety of simulators provide realistic sensory feedback to the astronauts; and the world's largest indoor pool, the NBL in Building 920N, replicates the environmental conditions of space. In these facilities the astronauts work through flight plans, including failure scenarios, and practice the activities they will engage in while in space. These hands-on learning experiences are critical to the success of Space Shuttle missions, including launch and landing situations, and on-orbit operations. These facilities are in active use today, providing training for on-going Shuttle mission operations, including assembly of the ISS.

In addition to these JSC facilities, the VMS in Building N-243 at ARC, which can simulate final descent and landing of the orbiter, is used for shuttle pilot astronaut training. The VMS provides the opportunity to practice landing scenarios or critical maneuvers involving the orbiter, as well as provides worst-case scenarios for pilots, such as blown tires, crosswinds, or failed auxiliary power units. It continues to be used twice a year to study landing and rollout of the orbiter (Page & Turnbull, Inc. 2007).

6.3 National Historic Landmarks

In 1984, the Man in Space NHL Theme Study (Phases I and II) was completed by the NPS (Butowsky 1984). The Theme Study considered the Space Program in an integrated fashion, and attempted "to identify, inasmuch as is possible, the surviving resources of those that were necessary to accomplish the goals of landing a man on the moon and exploring the earth, planets and solar system" (Butowsky 1984). The selected resources represented the best and most important surviving examples of the technological resources that were necessary to support the American space program (Gemini through Space Shuttle Program). Resources were related to four general subthemes: 1) Technical Foundations before 1958; 2) The Effort to Land a Man on the Moon; 3) The Exploration of the Planets and Solar System; and 4) The Role of Scientific and Communications Satellites.

Twenty-four NASA historic properties were evaluated as nationally significant in the context of the manned spacecraft program of the U.S., and subsequently designated as NHLs in October 1985. Of these, seven were identified in the current nationwide study as of exceptional significance in the context of the SSP:

- MCC at JSC
- Structural Dynamic Test Facility (Building 4550) at MSFC
- NBS (in Building 4705) at MSFC
- A-1, A-2, B-1 and B-2 Test Stands (Propulsion Test Stand Complex) at SSC

Compared with historic properties that meet the eligibility criteria for listing in the NRHP, NHLs are those recognized by the Secretary of the Interior as nationally significant properties which "help us to understand the history of the Nation and illustrate the nationwide impact of events or persons associated with the property, its architectural type or style, or information potential. A nationally significant property is of exceptional value in representing or illustrating an important theme in the history of the Nation" (NPS n.d.). Before a property can be designated as a NHL, it must be evaluated by the NPS's National Historic Landmark Survey, reviewed by the National Park System Advisory Board, and recommended by the Secretary of the Interior.

While all NHLs are included in the NRHP, the criteria for Landmark designation are different from the eligibility criteria for listing in the NRHP. The criteria used to select NHLs are as follows:

> *The quality of national significance is ascribed to districts, sites, buildings, structures, and objects that possess exceptional value or quality in illustrating or interpreting the heritage of the United States in history, architecture, archeology, technology and culture; and that possess a high degree of integrity of location, design, setting, materials, workmanship, feeling and association, and :*

(1) That are associated with events that have made a significant contribution to, and are identified with, or that outstandingly represents, the broad national patterns of United States history and from which an understanding and appreciation of those patterns may be gained; or

(2) That are associated importantly with the lives of persons nationally significant in the history of the United States; or

(3) That represent some great idea or ideal of the American people; or

(4) That embody the distinguishing characteristic of an architectural type specimen exceptionally valuable for the study of a period, style or method of construction, or that represent a significant, distinctive and exceptional entity whose components may lack individual distinction; or

(5) That are composed of integral parts of the environment not sufficiently significant by reason of historical association or artistic merit to warrant individual recognition but collectively compose an entity of exceptional historical or artistic significance, or outstandingly commemorate or illustrate a way of life or culture; or

(6) That have yielded or may be likely to yield information of major scientific importance by revealing new cultures, or by shedding light upon periods of occupation over large areas of the United States. Such sites are those which have yielded, or which may reasonably be expected to yield, data affecting theories, concepts and ideas to a major degree.

For properties that have achieved significance within the past 50 years, such properties will qualify as NHLs if they of "*extraordinary national importance*."

All 70 historic properties identified in the SSP study are considered significant at the national level, and all have reached significance within the past 50 years; they all qualify for the NRHP because of their "*exceptional*" importance to the SSP. Among these 70 NRHP-listed, determined eligible, and eligible properties are some (in addition to the seven previously designated NHLs) which potentially may be considered of *extraordinary* national importance, and which best represent the historical and engineering values of the SSP on the national level (e.g., the three extant orbiter vehicles, the VAB). While the evaluation of potential NHLs was beyond the scope of this agency-wide survey and evaluation of SSP-related facilities, the new survey data may provide useful information for a future update of the NPS's Man in Space Theme Study.

6.4 A Programmatic Approach to Historic Property Management

"A great deal of latitude is afforded in the modification of such highly technical and scientific facilities to accommodate NASA's ongoing mission" (ACHP 1991).

As the U.S. Space Program continues to unfold, the transition from the SSP to the Constellation Program will require the modification of existing facilities to support new program activities. Major construction of new buildings is not anticipated at any NASA Center. Decisions regarding which facilities will provide the infrastructure in support of the Constellation Program are currently being decided. Whether selected for adaptive reuse and modification, or excessed at the end of the SSP, NASA undertakings involving the 70 NRHP-listed or eligible properties identified as part of this study (in addition to the historic properties at the KSC which are contributing resources to NRHP-listed and eligible historic districts), as well as historic properties listed or determined eligible under previous NASA programs, will require review and consultation under Section 106 of the NHPA.

In 1991, a Programmatic Agreement (PA) was executed among NASA, the National Council of State Historic Preservation Officers (NCSHPO) and the Advisory Council on Historic Preservation (Council) for the management of NASA's NHLs resulting from the Man in Space Theme Study. The PA (Appendix C) provides guidance for NASA managers regarding the treatment of these landmark properties. This agreement was promulgated pursuant to the regulations (36 CFR Part 800) implementing Sections 106 and 110(f) of the NHPA, as amended, in order to take into account the effect of ongoing NASA programs and specific undertakings on 20 of NASA's NHLs (as of February 24, 1989). Stipulation I specified the actions which would require consultation with the appropriate SHPO, and, as necessary, the Council, as well as mitigation measures (Stipulation I.A); actions that required the development and implementation of mitigation measures, but no consultation (Stipulation I.B); and actions whereby NASA could proceed without consultation or the implementation of mitigation measures (Stipulation I.C). The consultation process is described in Stipulation II of the PA, and two mitigation measures, recordation and salvage, are defined in Stipulation III. The final part of the agreement (Stipulation IV) includes administrative stipulations, such as provisions for continuing coordination, and the termination of the agreement. This PA is currently used by the NASA Centers to meet their Section 106 responsibilities.

Since the execution of this agreement more than 17 years ago, the number of historic properties under NASA's jurisdiction has grown with the addition of designated NHLs and dozens of facilities which are listed or determined eligible for listing in the NRHP. In addition, since 1989, NASA policy changes (e.g., the replacement of NASA Management Instruction [NMI] 4310.4 with NASA Procedural Requirement [NPR] 43100.1), and the increased roster of generally accepted mitigation measures, as encouraged by the NPS and Council, suggest the need for a new agency-wide programmatic agreement.

In consideration of the number and complexity of potential NASA undertakings engendered by the retirement of the SSP and transition to Constellation, a new PA should be procedural in approach, establishing a streamlined and rationalized process through which NASA will meet its compliance responsibilities for different categories of projects. It is recommended that the new PA broaden its scope to include not only designated NHLs, but all NRHP-listed and determined eligible properties. Further, the agreement document should establish categorical exclusions and standard treatments and programs for the mitigation of adverse effects, as well as standard administrative stipulations for dispute resolution, amendments, and termination.

The Shuttle Transition HPWG has considered an agency-wide programmatic agreement. However, in view of the varying degree in which Centers anticipate they will support the new Constellation Program, the HPWG currently encourages more Center-specific PAs be executed to support the management of the expanded inventory of historic resources.

6.4.1 Classification of Undertakings

Consistent with the intent of Stipulation I of the original PA, two broad categories of undertakings are proposed for the new PAs: undertakings requiring Section 106 consultation, and undertakings which are categorically excluded from Section 106 review. The latter category is defined as undertakings presumed to have minimal potential to cause effects on historic properties, and therefore, which will not require public notification or consultation with the Council, NCSHPO, or individual SHPOs. Such undertakings will be reviewed for Section 106 purposes within NASA without further review by the Council, NCSHPO, or SHPO. Table 6.4 provides a provisional list of example undertakings defined for each of the two categories.

Table 6.3. Classification of NASA Undertakings Relative to Section 106 Review.

Undertakings Requiring Section 106 Consultation	
Action	***Conditions/Examples***
Demolition and dismantlement	Physical destruction of, or damage to, all or part of the historic property
Alterations	Includes, but is not limited to, the replacement of building materials with non-compatible materials, additions to historic properties, removal or excessing of significant elements/equipment, significant changes to floor plans, and partial demolition
New construction	Applicable if the new construction is within or proximate to the boundaries of the historic property where such construction creates a visually intrusive element, or is of non-compatible design and placement
Repair/maintenance	If such actions result in a change in the existing structural integrity, operational function, or visual integrity of the historic property
Neglect/abandonment-in-place	If maintenance is reduced or withdrawn from a historic property, resulting in deterioration
Transfer, sale or lease	To another agency or non-federal entity
Moving/Relocation	Removal of the historic property from its historic setting
Changes in function, purpose, or use of a facility	Structural alterations or the introduction of new elements which result in the loss of continuity in historic function, and the loss of features that define why and when the property was significant
Undertakings Categorically Excluded from Section 106 Review	
Removal or replacement of existing equipment or facility components	Applicable only where the equipment or component itself is not a feature which contributes to the significance of the historic property
General maintenance, repair, or direct in-kind replacement	Includes, but not limited to, painting; siding; roofing; door, ceiling, wall, window, floor covering repair/replacement; elevator repair; filter and light replacement; and repairs to existing equipment. Includes in-kind emergency repairs to maintain structural integrity. Replacement in-kind should match the configuration, material, size, detail, and

	construction of the historic fabric. Cleaning and replacing in-kind must comply with the *Secretary of the Interior's Standards for Rehabilitation*
Retrofitting	May include siting, installation, maintenance, repair, removal or replacement of communications and computer systems, including public address systems, facsimile systems, microwave/radio systems, fiber-optic cables, and phone systems. Not applicable if the historic property is significant in the area of communications. In such cases, consultation will be required
Changes to fire detection/ suppression systems	Includes routine upgrades and modifications to fire alarm systems, smoke detectors, and sprinkler systems
Changes to interior and exterior lighting systems	Includes replacement of or modification to lighting systems that do not alter or detract from the qualities that contribute to the significance of the historic property
Changes to electrical systems	Includes installation, maintenance, repair, removal, or replacement of plant and building electrical systems (e.g., building conduit, wiring and lighting, emergency lighting, etc.)
Changes to water systems	Includes siting, installation, maintenance, repair, removal, and operation of plant water systems including, but not limited to: water wells, cooling water systems, potable water systems, storm sewers, waste water treatment systems, plant drainage, and plumbing
Energy conservation measures	Includes installation, replacement and modifications to the heating, ventilation, and air conditioning (HVAC) control systems and conversions to alternative fuels (provided that these elements do not detract from the qualities that make the historic property eligible)
Health and safety activities	Includes clean-up, encapsulation, and removal/disposal of asbestos-containing materials and lead paint from buildings and structures
New construction of non-permanent facilities	Applicable where the construction process is reversible and does not physically alter significant historic properties. Includes fencing and sheds
Temporary parking or placement	Includes mobile homes, tents, and portable structures on extant parking lots or launch pads where the original surface remains essentially the same
Road maintenance	Includes paving extant roads or parking lots with asphalt or concrete or placing marl or shell on dirt roads or lots; small-scale road, sidewalk, and parking lot repair; and minor relocation of access roads
Landscaping	Includes mowing and trimming of grass, shrubs, or trees; routine vegetation and erosion control activities; maintenance, repair or installation of fencing or signs

6.4.2 Identification of Character-defining Elements

In accordance with NPS requirements, "Parts of buildings, such as interiors, facades, or wings, are not eligible independent of the rest of the existing building. The whole building must be considered, and its significant features must be identified" (NPS 1995:4). The 70 exceptionally significant historic properties identified at the 13 NASA Centers and component facilities include several large, multi-functional buildings where additions and modifications are common. For many of these, the building derives its exceptional significance under Criterion A and/or C from specialized facilities and/or equipment located within only a portion of the overall building; the remaining areas of the building have no significant historical associations. Thus, the respective NRHP-listed or eligible building is a "shell" distinguished neither by its architecture, design or engineering. Identifying and understanding the character-defining elements or features of these historic properties is a fundamental consideration when determining the effects of a proposed undertaking. As a result of the agency-wide historic facilities survey, efforts were made by the contractors to identify these character-defining elements or features within the historic properties, as identified in Table 6.4.

Table 6.4. Significant Features Identified within NASA's Historic Properties.

Center	Building No.	Significant Area(s)/Elements
ARC	N-238	60 MW Interaction Heating Facility
ARC	N-243	Vertical Motion Simulator
JSC	5	North wing, Room 117D; South wing, Room 1150
JSC	7	North wing high bay, Room 1000
JSC	9	North wing SVMF, Room 1191
JSC	16	Wing N – SAIL, Rooms 1004A, 1008, 1010, 1012, 1016, 1040, and 2005; South wing, Rooms 147 and 147A
JSC	30	Wing M, Rooms 313, 316, 330, 331, 332, 332A, 332B; Wing S, Rooms 2306 and 2300
JSC	44	Rooms 119, 120, 121, 122, 123, 124, 126, 127, 143, 143A, 143B, 144, 144C, 152, 154, and 156
JSC	222	Arc Jet Test Complex, Rooms 116, 117, 120, 120A, and 10N
JSC	920N	NBL in North wing, Rooms 1300, 2300, 3350, 3353, 3355 and 3357)
MSFC	4663	HOSC/NDC - nine rooms on the second floor: A264, A280, A280B, A281, A282, A283, A284, A285, and A286)
MSFC	4705	Multi-purpose High Bay Facility and NBS
MSFC	4732	14" Trisonic Wind Tunnel
MAF	114	Test cells only
MAF	451	Testing apparatus only
Palmdale	150	Work platforms and related equipment

6.4.3 Mitigation Options

Where preservation (including maintenance and interpretation) of a historic facility is not feasible, one or more mitigation measures may be appropriate, depending upon the applicable NRHP criteria of eligibility (Criterion A, B, and/or C). While all 70 of NASA's SSP-related historic properties have exceptionally significant associations with historical events (Criterion A), some are also distinguished by their engineering or architecture, as well as specialized features and equipment. These are important considerations in the selection of mitigation measures. Some of the suggested mitigation measures, such as an oral history program, are already in place at some NASA Centers. Standard treatments may include, but not be limited to, the following:

Documentation: A standard treatment for most historic properties which will be adversely affected by NASA undertakings is documentation of the "end stage" condition of the historic property to Historic American Building Survey/Historic American Engineering Record (HABS/HAER) standards, in accordance with the *Secretary of the Interior's Standards for Architectural and Engineering Documentation* (Federal Register, 48 FR 190:44730-44734, September 29, 1983). The kind and amount of documentation should be appropriate to the nature and significance of the building or structure being documented. Determination of the level of documentation should be made in consultation with the NPS. In general, documentation efforts should focus on the character-defining elements (e.g., innovative structural and mechanical systems; noteworthy architectural features; specialized equipment; etc.). In accordance with the selected level of documentation, a combination of measured drawings depicting existing and historic conditions; reproduction of as-built drawings and site plans; black and white archival photographs with large-format negatives of exterior and interior views; photographs of selected existing drawings or historic views, where available; and/or a historic narrative, may be required. An original documentation package will be provided to the Secretary of the Interior for incorporation into the National Historic Architectural and Engineering Records in the Library of Congress; archival or non-archival copies should also be provided to the appropriate SHPO as well as the NASA History Office and Center-specific archives.

Salvage and Preservation of Significant Artifacts: The 1989 PA stipulated that NASA will apply its agreement with the Smithsonian Institution (NASA Management Instruction [NMI] 4310.4) to determine appropriate retention and curation activities with respect to significant artifacts. NMI 4310.4 was replaced with NPR 4310.1 which provides procedures and guidance for the identification, reporting, transfer, and disposal of NASA artifacts of great historical and educational or other value. It includes (as Appendix A) the "Agreement Between the National Aeronautics and Space Administration and the Smithsonian Institution Concerning the Transfer and Management of NASA Historical Artifacts, May 28, 1998." Salvage of architectural or scientific/engineering elements from NRHP-listed or eligible properties, should not be carried out without prior documentation, as described above. In cases of facility demolition, dismantlement, or removal of significant elements, NASA may apply its agreement with the Smithsonian Institution to determine appropriate retention and curation activities with respect to significant artifacts.

On-site Public Interpretation: Objects which embody historicity vis a vis the SSP, such as tools, instruments, scale models, spacesuits, etc., can be identified, collected, preserved, interpreted and made available for on-site public display. Other forms of public interpretation may include web-based information, including virtual tours and 3-D views of unique facilities; videos and audiotapes; publications including brochures, pamphlets, and books; and markers and kiosks.

Creation of an archival record: This mitigation option includes, but is not limited to, the location and archiving of as-built drawings and site plans, historic photographs, video and movie footage, test schedules and related data from selected scientific tests or research programs that relate to the SSP.

Oral histories: The systematic collection of oral histories from long-term NASA employees and contractors who designed, tested, built, assembled, controlled and flew the Space Shuttle will serve to capture the stories of the SSP. Oral histories provide an important source of information regarding worker life and social history not available in publications. Such stories can be popularized and made available to the public.

Off-site mitigation: In keeping with the provisions of the National Aeronautics and Space Act of 1958, which charges NASA with the development of public education and outreach programs, NASA may direct its mitigation efforts to provide support for research and written popular and technical histories and other accounts; support for the existing offices of Agency historians and archivists to further the increased dissemination of historical documentation and official agency histories already available but little known outside of NASA; and to encourage increased private and public participation in an effort to preserve the tangible elements of America's manned space program.

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APPENDIX A: Space Shuttle Program Milestones

Space Shuttle Program Milestones

YEAR	EVENT
1969	• President Nixon's Space Task Group endorses concept of a reusable space shuttle • Contracts for design concept studies of the Integral Launch and Reentry Vehicle (ILRV) are awarded to General Dynamics/Convair, Lockheed, McDonnell Douglas, and North American Rockwell
1970	• Space Shuttle concept is formally designated the "Space Transportation System" • Contracts for Phase B studies on the Space Shuttle Main Engine (SSME) are awarded to Aerojet-General Corp., Rocketdyne Division of Rockwell Division of North America, and Pratt & Whitney Aircraft • NASA selects McDonnell Douglas and North American Rockwell for definition and preliminary design studies for a reusable Space Shuttle
1971	• President Nixon announces that NASA will begin the Space Transportation System (STS) program • Mississippi Test Facility (now Stennis Space Center) selected as site for sea-level testing of the SSME
1972	• President Nixon formally endorses plans for the Space Shuttle • NASA Administrator Dr. James Fletcher announces that the Space Shuttle will be powered by recoverable, reusable solid rocket motors in a parallel burn configuration • Space Division of North American Rockwell Corp. is selected by NASA as prime contractor for design, development and production of the orbiter vehicles and for integration of all elements of the Space Shuttle system • NASA signs contract with Rocketdyne for the design, development and testing of the SSME • NASA announces that the Kennedy Space Center (KSC) and Vandenberg Air Force Base will be the two Shuttle launch sites.
1973	• Rocketdyne conducts the first preburner test for the developmental SSME at Santa Susana Field Laboratory (SSFL), California • NASA signs contract with Martin Marietta Corporation for the design, development and testing of the External Tank (ET) • NASA signs contract with the Thiokol Chemical Corporation for the design, development and testing of the solid rocket motor
1974	• Structural assembly of the Orbiter *Enterprise* (OV-101) starts in Palmdale, California • NASA announces that Edwards AFB will be used as the landing site for the first several Shuttle missions.
1975	• Martin Marietta Aerospace awards subcontract to Avco for the manufacture of the ET intertank • Rocketdyne completes the first SSME; first full thrust-chamber ignition test at the National Space Technology Laboratory (NSTL, now Stennis Space Center)
1976	• Assembly of the first ET is underway at the Michoud Assembly Facility (MAF) in Louisiana • Structural assembly of the *Enterprise* (OV-101) is completed • Structural assembly of the Orbiter *Columbia* (OV-102) starts • The first 747 is modified for use as a Shuttle Carrier Aircraft (SCA) at Boeing facilities in Washington • United Space Booster, Inc. of Sunnyvale, California is selected as the solid rocket booster (SRB) assembly contractor

YEAR	EVENT
1977	• SRB testing begins at Marshall Space Flight Center (MSFC), and development tests of a solid rocket motor are first performed in Utah • Wind tunnel tests on integrated Shuttle components begin • Phased Approach and Landing Tests (ALT) are conducted at NASA Dryden using the Orbiter *Enterprise* mated with the SCA. • First development test firing of a solid rocket motor (Development Motor-1) performed in Utah • The first completed ET rolls off the assembly line at MAF
1978	• *Enterprise* and a complete ET arrive at MSFC for vertical ground vibration tests • First major test of the Shuttle's main propulsion system at MSFC • Flight test program with the *Enterprise* (OV-101) is completed • Assembly of the Orbiter *Columbia* (OV-102) is completed
1979	• Orbiter *Columbia* arrives at KSC for two years of assembly and modification work • First complete assembly of the Shuttle configuration (*Enterprise*) in the KSC VAB • Assembly of *Challenger* (OV-099) starts • First series of tests preliminary to flight certification of the SSME is completed • First flight ET is delivered to KSC from MAF
1980	• SSME flight certification tests are completed • *Columbia* (STS-1) arrives at Pad 39A in preparation for first Space Shuttle Program test flight • Structural assembly of the Orbiters *Discovery* (OV-103) and *Atlantis* (OV-104) starts
1981	• First Flight Readiness Firing (FRF) of STS-1 main engines • April 12 launch of *Columbia* marks the first orbital test flight by a winged spacecraft
1982	• STS-3 lands at White Sands due to flooding of Edwards AFB landing site • STS-5 launch marks the first operational Shuttle flight and the first flight with a four-person crew • First flight of mission specialist astronauts (STS-5) • Orbiter *Challenger* (OV-099) is completed • *Columbia* (STS-4) makes first landing on a concrete runway at Edwards AFB • Assembly of *Endeavour* (OV-105) starts
1983	• First flight of *Challenger* (STS-6) • First Shuttle-based extra-vehicular activity (EVA) (STS-6) • Assembly of Orbiters *Discovery* (OV-103) and *Atlantis* (OV-104) is completed • First five-person (STS-7) and six-person (STS-9) crews • First flight by an American woman astronaut, Sally Ride (STS-7) • First flight by an African-American astronaut, Guion "Guy" Bluford (STS-8) • First night launch and first night landing (STS-8) • First Spacelab mission (STS-9)
1984	• First use of the Manned Maneuvering Unit (MMU) (STS-41-B) • First flight of *Discovery* (STS-41-D) • First seven-person crew (STS-41-G) • First Shuttle landing at KSC is made by *Challenger* (STS-41-B) • First flight to include a non-astronaut crewman, Charles D. Walker (STS-41-D) • First on-orbit satellite retrieval (STS-19)

YEAR	EVENT
1985	• First flight of *Atlantis* (STS-51-J) • Most (nine) Shuttle flights in a single year • First Shuttle flight dedicated to the Department of Defense (DoD) (STS-51-C) • First member of Congress, Senator Jake Garn, to fly in space (STS-51-D) • First "abort to orbit" of the Space Shuttle Program (STS-51-F) • First crosswind landing (STS-51-B) • First eight-person crew (STS-61-A) • First Shuttle mission (STS-61-A) managed by a foreign country (West Germany)
1986	• January 28 *Challenger* accident (STS-51-L) marks the first in-flight accident involving a Space Shuttle • First Shuttle launch from LC 39B (STS-51-L) • Rogers Commission established to identify the cause of the *Challenger* accident. Presents report to the President in June.
1987	• Remains of the *Challenger* are sealed underground at Cape Canaveral Air Force Station. • NASA awards contract to Rockwell for construction of OV-105 (*Endeavour*) to replace *Challenger*
1988	• Return to Flight by *Discovery* (STS-26) • Vandenberg Launch Site (VLS) is placed in mothball status
1989	• Space Shuttle Program at VLS is officially terminated • First (Magellan, STS-30) and second (Galileo, STS-34) launches of planetary spacecraft
1990	• Hubble Space Telescope (HST) deployment (STS-31) • Last classified military Shuttle flight (STS-38)
1991	• First spacewalk by U.S. astronauts since 1985 (STS-37) • First unclassified defense-related mission (STS-39) • First mission dedicated entirely to understanding the physiological effects of space flight (STS-40) • First scheduled landing at KSC since January 1986 (STS-43)
1992	• First flight of *Endeavour* (STS-49), which included four spacewalks, the most, to date, on a single mission • First landing with new synthetic tread tires (STS-50) • First operational use of drag chute • Fiftieth flight of the Space Shuttle Program (STS-47) • Last Shuttle flight carrying a DoD payload (STS-53)
1993	• First flight of Spacehab (STS-57) • First nighttime landing at KSC (STS-51) • First servicing of the HST (STS-61)
1994	• MSFC begins development of new super lightweight ET • First flight of a Russian cosmonaut on the Space Shuttle (STS-60) • First flight of improved thermal protection tile, Toughened Uni-Piece Fibrous Insulation (TUFI) (STS-59)
1995	• First docking with *Mir*, and first time an American lives aboard the Russian space station (STS-71) • *Discovery* (STS-63) is the first orbiter to complete 20 missions • First use of the new Mission Control Center at Johnson Space Center (JSC) for *Discovery* mission STS-70 • First flight of the new Block I SSME (STS-70) • Second docking with *Mir* (STS-74)

YEAR	EVENT
1996	• STS-75 marks the seventy-fifth Shuttle flight • First U.S. and world human spaceflight record set by astronaut Shannon Lucid (STS-79) • Third (STS-76) and fourth (STS-76) docking with *Mir*
1997	• Fifth (STS-81), sixth (STS-84), and seventh (STS-86) docking with *Mir* • Second HST servicing mission (STS-82) • First joint US-Russian spacewalk during a Shuttle mission (STS-86)
1998	• Eighth (STS-89) and ninth (STS-91) docking with *Mir* • First U.S. built component of the International Space Station (ISS) is delivered by the Shuttle (STS-88) • STS-91 marks the debut of the new aluminum lithium super lightweight ET • STS-95 marks John Glenn's return to flight after 36 years • First flight of the SSME Block II (STS-95)
1999	• First woman Shuttle commander, Eileen Collins (STS-93) • First Shuttle docking with the ISS (STS-96) • Third HST servicing mission (STS-103)
2000	• The 100th flight of the Space Shuttle Program (STS-92) • Inaugural flight of *Atlantis'* new Multifunction Electronic Display Subsystem (MEDS), also known as the "glass cockpit" (STS-92)
2001	• On March 5, for the first time two Shuttle orbiters were ferried simultaneously – *Atlantis* returning from Edwards AFB and *Columbia* returning from Palmdale after modifications.
2002	• Fourth HST servicing mission (STS-109)
2003	• February 1 *Columbia* disaster (STS-107) marks the first reentry accident involving a Space Shuttle. Spacecraft destroyed 16 minutes before scheduled landing • Columbia Accident Investigation Board (CAIB) is formed to determine both technical and root causes accounting for the loss of *Columbia.*
2004	• President George W. Bush announces that after assembly of the ISS is completed, the Space Shuttle Program will be retired in 2010.
2005	• July 26 Return to Flight with the 31st launch of the Orbiter *Discovery* (STS-114) • First on-orbit repair of the Shuttle heat shield (STS-114)
2006	• STS-115 delivers the largest payload to date for installation in the ISS • NASA announces plans to conduct a HST servicing mission

(Sources: Ezell 1988; Green 2006; Jenkins 2002; Rumerman and Garber 2000; and Wright 2001)

APPENDIX B:
Summary of NASA-wide Significant Historic Properties

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
AMES RESEARCH CENTER (ARC), CA				
N-238	Arc Jet Laboratory	The 60-MW Interaction Heating Facility, added to Building N-238 in 1974, is used for tests of the Shuttle's TPS. It has enabled the development of reusable TPS for the orbiters. It is an important engineering achievement, capable of producing heating three times hotter and on larger models than any other NASA arc jet.	No	Yes
N-243	Flight and Guidance Simulation Laboratory/Vertical Motion Simulator (VMS)	Building N-243 derives its significance from the VMS, which has provided training to prepare Shuttle astronauts with an array of possible landing failures. It is the world's largest motion-based simulator. It is the only NASA facility that can simulate final descent and landing of the orbiter, and has been used by almost every pilot astronaut involved in the SSP.	No	Yes
CANOGA PARK, CA.				
n/a (located inside Building 001)	Pacific Scientific Furnace	Used to braze every Space Shuttle Main Engine (SSME) built for the SSP, the Pacific Scientific Furnace has played an exceptionally significant role in the SSP. It is also distinguished as the largest furnace of its type in the world.	No	Yes
DRYDEN FLIGHT RESEARCH CENTER (DFRC), CA.				
4860	Mate-Demate Device	Completed in 1976, this is NASA's first MDD built exclusively for the SSP. It is significant for its support of the ALT program in 1977, and for its continued operational use following landings at Edwards AFB. Unlike the MDD at the KSC, the DFRC structure incorporates several unique personnel safety features. It is distinguished by its specialized design and engineering.	No	Yes
GLENN RESEARCH CENTER (GRC), OH				
85-94, 113-114	Abe Silverstein 10 by 10 foot Supersonic Wind Tunnel (SWT)	Opened in 1955 as one of only two dual-cycle wind tunnels owned by NASA. It provides simulation of high speed atmospheric flight used to verify the design and performance of Space Shuttle systems. It also played a vital role in Shuttle component design improvements and innovations during the post-*Challenger* and *Columbia* Return to Flight. It is also distinguished for its design and engineering.	Yes	No
39, 46, 53-57, 59, 61, 138	8 by 6 foot SWT	Opened in 1949, it is one of the first wind tunnels specially designed and built for propulsion testing. It is currently the only transonic propulsion wind tunnel owned by NASA, and one of two NASA-owned wind tunnels capable of either aerodynamic or propulsion cycle testing. It is also distinguished for its design and engineering.	No	Yes
JOHNSON SPACE CENTER (JSC), TX				
OV-103	*Discovery*	The third orbiter built for operational use, it is the oldest extant vehicle of the Space Shuttle fleet. It was the first orbiter to complete 20 missions, and has the distinction of being the Return to Flight vehicle after both the *Challenger* and *Columbia* accidents. It is also significant as an exceptional feat of engineering.	No	Yes
OV-104	*Atlantis*	The fourth orbiter built for operational use, it is significant as one of three remaining orbiting vehicles of the SSP. It is also significant as an exceptional feat of engineering.	No	Yes

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
OV-105	*Endeavour*	The fifth orbiter built for operational use, it is significant as one of three remaining orbiting vehicles of the SSP It is associated with a number of "firsts." It carried the Spacehab module on its first mission, completed the first HST servicing mission, and was the first orbiter to fly with TUFI tiles. *Endeavour* is also significant as an exceptional feat of engineering.	No	Yes
30	Mission Control Center (MCC)	The MCC, a designated NHL, is exceptionally significant as the support center critical to full control of Space Shuttle missions. It also supports the control of simulated flight missions used during training. Its unique design features reflect its historic mission of manned spaceflight control, as well as the distinctive progression of engineering and adaptive reuse from the Apollo era.	Yes	No
5	Jake Garn Mission Simulator and Training Facility	Building 5 is a premier NASA facility for preparing astronauts for Space Shuttle missions. It derives its exceptional significance from the training simulators which were uniquely designed to replicate the Shuttle vehicle and its launch, orbit, and landing environments.	No	Yes
9	Systems Integration Facility	Building 9 derives its exceptional significance from the Space Vehicle Mockup Facility (SVMF) in Wing N. The mockups contained here are unique tools which provide astronaut training, and contribute significantly to astronaut-tested design improvements to the Shuttle orbiter vehicle.	No	Yes
920N	Sonny Carter Training Facility and Neutral Buoyancy Laboratory (NBL)	Building 940N derives its exceptional significance from the NBL, a unique training facility used to prepare astronauts for missions involving spacewalks. Maintenance and assembly operations learned and practiced here are critical to mission success, and fundamental to the construction of the International Space Station. This one-of-a-kind facility contains the world's largest indoor pool which was specially designed and built to simulate the environment of space.	No	Yes
7	Crew Systems Laboratory	The Crew Systems Laboratory derives its exceptional importance from the Environmental Test Area in Wing E., a performance testing site for primary life support equipment, including spacesuits and backpacks, which are critical to the health and safety of the Shuttle mission crew. It also plays a key role in maintaining the orbiter proper as a habitable environment. The vacuum chambers which simulate the space environment provide valuable engineering data on the long-term performance of Shuttle spacesuits and other equipment needed for long duration missions.	No	Yes
16	Avionics Systems Laboratory (SAIL)	The significance of Building 16 is embodied in the Shuttle Avionics Integration Laboratory (SAIL) located within Wing N. This facility is distinguished for providing the highest fidelity Shuttle simulations for all flight phases. It played a key role in the testing and hardware and software certification for the first flight of each orbiter, and is a unique facility which continues to provide software verification and new flight hardware integration and verification in support of the SSP. It contains one-of-a-kind test articles and simulators.	No	Yes

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
44	Communications and Tracking Development Lab	This is a unique NASA facility used for system performance verification testing of Space Shuttle communications systems, including interfaces with satellites and ground stations. It plays a key role in the investigation and resolution of flight and post-flight communications anomalies. It has the unique capability to help plan missions and to create communications systems scenarios used for contingencies.	No	Yes
222	Atmospheric Reentry Materials and Structures Evaluation Facility (ARMSEF)	The ARMSEF is one of only two NASA-owned arc jet facilities with the capability to test and verify the thermal performance of every type of TPS material used on the Shuttle. It has contributed significantly to improve-ments in TPS technology, and played a key role in NASA's Return to Flight efforts in the aftermath of the *Columbia* accident. The arc jet facility was uniquely designed and constructed to produce sustained high temperatures needed to conduct TPS performance evaluations.	No	Yes
		KENNEDY SPACE CENTER (KSC), FL		
K6-0848	Vehicle Assembly Building (VAB)	The NRHP-listed VAB, one of the world's largest buildings by volume, is a unique facility which supports the integration and stacking of the complete Space Shuttle vehicle on the Mobile Launcher Platform (MLP). It is also distinguished by its design and engineering.	Yes	No
K6-0900	Launch Control Center (LCC)	The NRHP-listed LCC performs the vital operations integral to the prelaunch preparation and launch of the Space Shuttle. It is also distinguished by its architectural design.	Yes	No
UK-0008	Crawlerway	The NRHP-listed Crawlerway is a unique dual-lane surface capable of supporting the weight of the Shuttle vehicle, the MLP, and the Crawler Transporter as they move from the VAB to the launch pad. It has provided continuous service to the nation's space program since the 1960s.	Yes	No
n/a	Crawler Transporters (2)	The two NRHP-listed Crawler Transporters are unique vehicles used to transport the Space Shuttle vehicle, mounted on the MLP, to the launch pad. They have provided continuous service to the nation's manned space program since the 1960s. The Crawler Transporters are designated National Historic Mechanical Engineering Landmarks.	Yes	No
n/a	Press Site: Clock and Flagpole	The NRHP-listed Press Site: Clock and Flag Pole are historically associated with Space Shuttle launches in the minds of people worldwide, as they framed the vehicle during televised broadcasts. The site is an integral facility in the dissemination of information to the public about the Shuttle missions.	Yes	No
J8-1708	Launch Complex 39: Pad A	This site is of exceptional significance as one of only two facilities used to launch the Space Shuttle vehicle. It is distinguished as the site for the launch of the first 23 Shuttle missions between 1981 and 1986. It is also significant for its design and engineering.	Yes	No
J7-0337	Launch Complex 39: Pad B	This site is of exceptional significance as one of only two facilities used to launch the Space Shuttle vehicle. In the aftermath of the *Challenger* accident, it became the primary launch site at KSC. It is also significant for its design and engineering.	Yes	No

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
M7-657	Parachute Refurbishment Facility	This manufacturing and assembly facility is used to fabricate and repair a variety of parachute types (main, drogue, and pilot), and keeps the parachute flight sets in excellent working condition. Essential components of the SRBs, the parachutes deploy sequentially to slow the fall of the SRBs, thus facilitating space flight recovery efforts and subsequent reuse of the SRBs.	No	Yes
M7-777	Canister Rotation Facility (CRF)	The CRF was designed and built exclusively to provide for the horizontal and vertical rotation of the Payload Canister in support of the SSP. It made possible a more efficient performance of this operation, previously conducted in the VAB.	No	Yes
n/a	Payload Canisters (2)	The two Payload Canisters are environmentally-controlled cargo containers used to transport fully-integrated Shuttle payloads from various processing or assembly facilities to the launch pad. They were uniquely designed and constructed to match the orbiter cargo bay, and embody the distinctive method of for the transportation of payloads in support of the SSP.	No	Yes
n/a	Retrieval Ships *Liberty Star* and *Freedom Star*	The two retrieval vessels were designed and constructed specifically for the task of SRB recovery, thus facilitating space flight recovery efforts and subsequent reuse of the SRBs, an essential component of the Space Shuttle vehicle. Also, since 1998 have been used to transport ETs from the MAF to KSC.	No	Yes
n/a	Mobile Launcher Platforms (3) (MLP)	The three MLPs are of exceptional importance for their unique function in supporting build-up of the Shuttle vehicle in the VAB and its transport to the launch pad. They are also distinguished by their design and engineering.	No	Yes
n/a	Shuttle Landing Facility (SLF) Runway	The SLF Runway was built in 1976 for the SSP. Since 1981, it is NASA's primary landing site for the SSP. It is also significant as a practice facility for the astronauts. One of the world's longest runways, it is distinguished by its design and construction.	No	Yes
J6-2313	Landing Aids Control Building (LACB)	As the control center for flight operations which support the landing of the Shuttle orbiter, this facility is an exceptionally significant component in the SSP. It plays a key role in the Orbiter's safe return to Earth.	No	Yes
J6-2262	Mate-Demate Device (MDD)	The KSC MDD is one of only three extant devices used to attach and detach the Shuttle orbiter and the SCA. It was used to detach the *Enterprise* and all five operational orbiters upon their delivery from the assembly plant in Palmdale, and is also used for ferry flights between KSC and Palmdale for maintenance and modifications. It is also distinguished by its design and construction.	No	Yes
K6-894	Orbiter Processing Facility (OPF)	The OPF is one of two structures at KSC built exclusively for Shuttle orbiter pre-flight and post-landing processing. Each orbiter was processed for its first operational flight in this facility. The structural components of the OPF, including work platforms, were specifically designed and engineered to be compatible with the orbiter's access points.	No	Yes

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
K6-696	Orbiter Processing Facility High Bay 3 (OPF-3)	The OPF-3 is one of two structures at KSC built exclusively for Shuttle orbiter pre-flight and post-landing processing. The structural components of this building, including work platforms, were specifically designed and engineered to be compatible with the orbiter's access points. The Space Shuttle Main Engine Processing Facility (SSMEPF) within this building is also distinguished as a one-of-a-kind facility designed specifically for the SSME.	No	Yes
K6-794	Thermal Protection System Facility (TPSF)	The TPSF is significant as one of only two NASA-owned assets constructed exclusively to house the manufacture and repair of the Shuttle's thermal protection and thermal control systems, essential to the success of the SSP.	No	Yes
K6-494	Rotation/Processing Building	The Rotation/Processing Building was specifically designed for the purpose of rotating the SRB segments, an operation vital to the preparation of the launch vehicle for its mission	No	Yes
L6-247	SRB Assembly and Refurbishment (ARF) Manufacturing Building	As a manufacturing, processing, and assembly facility for SRB non-motor components, the Manufacturing Building plays a vital role in preparing the Shuttle vehicle for flight.	No	Yes
M7-961	Hypergol Module Processing (North)	This one-of-a-kind facility is used for the checkout, refurbishment and revalidation of the hypergolic fuel modules of the orbital maneuvering system (OMS) pods, with the incorporated reaction control system (RCS).	No	Yes
LANGLEY RESEARCH CENTER (LaRC), VA.				
1257, 1257N/S, 1258, 1258A, 1261, 1262	Aircraft Landing Dynamics Facility (Track, Carriage Arresting System, Command Center, Propulsion Center, Calibration Building, Main Support Building)	This facility was used since 1985 to test Shuttle tire performance, tire failure wheel tests, and the effects of runway modifications. It is the only facility in the world that could provide Space Shuttle braking and landing tests required for the Shuttle development program. It is also distinguished by its design and construction.	No	Yes
MARSHALL SPACE FLIGHT CENTER (MSFC), AL				
4436	SSME Hardware Simulation Laboratory (HSL) Block II Facility	Unique facility responsible for both hardware and software design and development, real time launch support, and quality assurance of the computer software that controls the main engines for all Space Shuttle flights.	No	Yes
4540	Test Facility 116	Test Facility 116 derives its primary importance for its role in the development of propulsion systems for the Space Shuttle. It is uniquely designed and engineered to support acoustic model testing for the Shuttle.	No	Yes
4550	Structural Dynamic Test Facility	Built in 1964 and modified in 1975 to support the SSP, this NHL is distinguished by its unique capability to dynamically test the Space Shuttle. It is historically associated with the Mated Vertical Ground Vibration Test (MVGVT) program of 1978-79 which served to verify that the Shuttle could withstand the forces encountered during powered flight. It is also distinguished by its unique design and engineering.	Yes	No
4583	Test and Data Recording Facility (TF 115)	This facility is significantly associated with scale model tests to improve the SRB following the Challenger accident of January 1986. It is also significant for its design modifications made to support tests of an improved SRB launch deflector.	Yes	No

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
4612	Materials and Processes Laboratory	Building 4612 is a premier facility for materials science and analysis in support of the SSP. Since the mid-1990s, it has played a critical role in the development and improvement of materials which constitute the main components of the Shuttle vehicle, including the SSME, ET and SRBs. Research here also played a key role in NASA's Return to Flight efforts in the aftermath of the *Challenger* and *Columbia* accidents.	Yes	No
4619	Structures, Dynamics and Thermal Vacuum Laboratory	Since 1972, Building 4619 has played a key role in the validation of major vehicle components which qualified the Shuttle for flight. It also played a key role NASA's Return to Flight efforts in the aftermath of the *Challenger* and *Columbia* accidents. The facility embodies unique design elements and equipment, including one of the world's three Gilmore machines.	Yes	No
4663	Huntsville Operations Support Center (HOSC)/NASA Data Center (NDC)	Since 1980, the HOSC computer command center has supported major launch preparation tests run at KSC and assists in problem-solving during operational launches throughout the SSP.	No	Yes
4670	Advanced Engine Test Facility (AETF)	Constructed in 1964, Building 4670 was first modified in the mid-1970s for the structural verification testing of the ET, and later adapted in the mid-1980s to support the 1990s full-scale testing of advanced technologies for the SSME. It is one of two large test stands at MSFC adapted to support Shuttle testing. It is also a major engineering achievement, and was designated a National Historic Mechanical Engineering Landmark.	Yes	No
4674	Control Facility	This building is functionally associated with Building 4670 (AETF) which played a key role in the testing of major Shuttle components. It is also distinguished as an excellent example of major blockhouse design and engineering.	Yes	No
4705	Multi-purpose High Bay Facility and Neutral Buoyancy Simulator (NBS)	The NBS, a designated NHL, was uniquely designed to simulate the weightless space environment. It is significantly associated with the development and refinement of hardware and assembly techniques which paved the way for the first structures built in space. It continues to have application in today's construction of the ISS.	Yes	No
4707	National Center for Advanced Manufacturing	Building 4707 is significant as a premier research and development facility responsible for the development of key materials which support Shuttle missions, including the composite nose cone for the ET, spray-on foam insulation (SOFI), and a super lightweight ET. It is also significant for its design and engineering.	Yes	No
4732	Office and Wind Tunnel Facility (14-inch Trisonic Wind Tunnel)	The 14-inch Trisonic Wind Tunnel in Building 4732 is significant for its association with important developmental tests of the orbiter, SSMEs, ET, and SRBs using percent-scale models. Use of this tunnel allowed NASA to test concepts cheaply. It is also distinguished by its design and engineering.	Yes	No
n/a	NASA Barge *Poseidon*	Specifically designed to transport large space vehicle hardware, *Poseidon* is the only remaining covered barge still in NASA ownership. It is distinguished as the NASA barge used to transport the first ET flown on a Shuttle orbital	No	Yes

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
		mission. It continued to contribute significantly to the SSP by transporting the ET, the only non-reusable major Shuttle component, during river and open sea journeys.		
MICHOUD ASSEMBLY FACILITY (MAF), LA				
110	Vertical Assembly Building (VAB)	Since the beginning of the SSP, Building 110 is where the components of the Shuttle's ET are washed, primed, sprayed with SOFI, assembled, pressure treated, and inspected. Every ET for every Space Shuttle mission ever flown has been processed in this building. It is also significant for its design and construction.	Yes	No
114	High Bay Addition	Built in 1982 for the SSP, this assembly facility is where the liquid oxygen tank and intertank components of the ET are machined, primed, sprayed with SOFI, and assembled. Every oxygen tank and intertank for every Space Shuttle mission ever flown has been rocessed in this building. The five cells inside the building also are significant for their design and construction.	No	Yes
451	Pneumatic Test Facility	Constructed in 1976 for the SSP, Structure 451 is a pressure test facility for the ET's liquid hydrogen tank component. It is responsible for the pneumatic pressure and leak testing of the hydrogen tank component of the ET, and has processed every hydrogen tank for every Space Shuttle mission ever flown. The testing apparatus within Building 451 is significant for its design and construction, and is the only test unit of its size in the U.S.	No	Yes
452	Control Building	Building 452 is the control center for the testing that occurs in Structure 451. It has served the SSP since its beginnings by administering and monitoring the hydrogen tank testing process. The hydrogen tank is an element of the ET, a major component of the Space Shuttle. It is also significant for its blast-proof design and construction.	No	Yes
PALMDALE, CA.				
150	Shuttle Orbiter Final Assembly Building	Building 150 is the site where the first full-scale test vehicle (*Enterprise*) and all five operational orbiters were assembled, upgraded and maintained, from 1973 through 2001. It is the only orbiter assembly hangar in the U.S.	Yes	No
	Orbiter Lifting Frame (OLF)	The OLF is NASA's only extant demountable mate-demate device. It was used to mate the *Endeavour*, the last orbiter of the Shuttle fleet, from its manufacturing site to the KSC for its maiden voyage. It also supported major modifications to four of the operational orbiters. It is distinguished by its specialized design and engineering.	No	Yes
SANTA SUSANA FIELD LABORATORY (SSFL), CA.				
733	Coca I Test Stand	The Coca I test stand is where NASA's SSME component testing program was first started in April 1974. It is associated with the early development testing of the SSME components and complete engine, critical to the design and of and subsequent improvements to the Shuttle propulsion system. It played a key role leading to the certification of the main engines for the first flight of *Columbia,* and is also significant for its specialized design and engineering.	No	Yes

FACILITY NO.	NAME	SIGNIFICANCE TO SSP	EXISTING ELIGIBILITY	NEWLY ELIGIBLE
218	Coca Control Center	Used to control and monitor the test firings of the Coca I stand, it played a key role leading to the certification of the SSME.	No	Yes
STENNIS SPACE CENTER (SSC), LA.				
4120	Propulsion Test Stand A-1 Complex	All designated NHLs, Test Stands A-1, A-2, B-1, and B-2 are exceptionally significant for their role in the pre-launch testing and verification of every Space Shuttle Main Engine (SSME) flown in space. They represent the only structures in the world that could support the type and level of testing required by the SSME. The test stands were uniquely designed and built such that the SSP could not have operated without their contribution	Yes	No
4122	Propulsion Test Stand A-2 Complex		Yes	No
4210	Propulsion Test Stand B-1		Yes	No
4220	Propulsion Test Stand B-2		Yes	No
WHITE SANDS SPACE HARBOR (WSSH), NM				
n/a	Shuttle Landing Facility (SLF) Runways (17/35, 23/05, and 22/02)	Built or modified between the late 1940s and 1986, the three runways replicate those at KSC (Runway 17/35), Edwards AFB (Runway 23/05), and the TAL sites (Runway 20/02). The runways represent the only facility in the history of the SSP used on a contingency basis, when STS-3 could not land at Edwards AFB due to adverse weather conditions. The runways are also significant as the primary training location for Shuttle pilots and commanders.	No	Yes

APPENDIX C:
NASA's Programmatic Agreement for NHLs

**PROGRAMMATIC AGREEMENT
AMONG THE
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
THE NATIONAL CONFERENCE OF STATE HISTORIC PRESERVATION OFFICERS,
AND THE
ADVISORY COUNCIL ON HISTORIC PRESERVATION**

WHEREAS, the National Aeronautics and Space Administration (NASA) undertakes research, development, space mission operations, and management use of its facilities which have been designated as National Historic Landmarks (Landmarks) (Attachment 1); and

WHEREAS, such facilities require frequent modification over the life of agency missions to adapt them to meet the requirements of ongoing NASA programs; and

WHEREAS, NASA has determined that such modifications may have an effect on those Landmarks, and has consulted with the National Conference of State Historic Preservation Officers (NCSHPO) and the Advisory Council on Historic Preservation (Council) pursuant to the regulations (36 CFR Part 800) implementing Sections 106 and 110(f) of the National Historic Preservation Act, as amended (16 U.S.C. 470f and 470h-2(f)); and

WHEREAS, the Department of the Interior, National Park Service (NPS) was invited and participated in the consultation;

NOW, THEREFORE, NASA, the NCSHPO, and the Council agree that the programs shall be implemented in accordance with the following stipulations in order to take into account the effect of the programs and specific undertakings on the Landmarks.

<u>Stipulations</u>

NASA will ensure that the following measures are carried out.

I. Categories of Activities

A. When the proposed undertaking involves any of the following activities, NASA shall consult with the appropriate SHPO and, as necessary, the Council in accordance with Stip. II:

1. Demolition, dismantling, or relocation of original engineering structures, or of buildings housing facilities;
2. Removal or excessing of significant elements of the Landmarks specifically named on the National Register nomination forms;
3. New construction not compatible with major portions of the original structure or which alter the characteristics of the

facility which were specified as the reason for its Landmark designation; or

4. Changes in function, purpose, or use of a facility.

B. When the proposed undertaking is limited to the following activities that will not alter the characteristics of the facility which were specified as the reason for its landmark designation, NASA shall develop and implement mitigation measures in accordance with Stipulation III:

1. Replacement of historic hardware or components;
2. Modification of the original structure or equipment used in engineering structures, or buildings housing facilities; or
3. New construction compatible with existing structure, purpose, and operation of the facility.

NASA shall include a description of such activities and mitigation measures in the annual summary of its activities prepared pursuant to Stipulation IV.A.

C. When the proposed undertaking involves none of the activities specified above, NASA may proceed without consultation or the implementation of mitigation measures.

II. Consultation Process

A. Consultation required under Stip. I.A. shall be conducted as follows:

1. NASA shall provide the following documentation to the SHPO for review:
   a. a description of the undertaking, with photos, maps, and drawings;
   b. a description of the affected Landmark;
   c. a description of the effects of the undertaking on the affected Landmark;
   d. a description of alternatives to the proposed action, which were considered if any, and reasons not chosen;
   e. a description of any mitigation measures proposed;
   f. a description of NASA's effort, if appropriate, to obtain and consider views of affected interested persons on the proposed undertaking, including a copy of any comments received; and
   g. the planning and approval schedule for the proposed undertaking.

Whenever feasible, NASA shall give the SHPO advance notice that such documentation is under preparation, and advise the SHPO of a date certain that it intends to submit the documentation to the SHPO.

2. The SHPO shall respond to a written request for consultation (accompanied by the documentation specified in Stip. II.A.1) within 20 working days, and agree, conditionally agree, or disagree with NASA's proposal.

3. If NASA does not accept the SHPO's conditions, or if NASA and the SHPO disagree, NASA shall notify the Council and forward copies of the documentation specified in Stip.II.A.1, above, along with other information relevant to the dispute.

4. Within 20 working days, the Council shall either: (1) attempt to resolve the dispute; (2) provide NASA with recommendations to be taken into account in implementing the activity; or (3) decide to comment, and comment within 45 working days of that decision. At NASA's request, the time periods in Stips. II.A.2. and II.A.4. will run concurrently. In exceptional circumstances NASA may request accelerated consideration under Stip. II.A.4. and the Council will make a good faith effort to accommodate such requests. The Council may consult with the National Park Service of the Department of the Interior during its review period.

B. The Council and the NCSHPO recognize that operational emergency situations may arise where NASA must take immediate action without prior consultation with the appropriate SHPO or the Council. In such situations, NASA shall notify the Council and the SHPO of such actions as soon as practicable.

III. Mitigation

Mitigation measures shall be carried out prior to undertaking actions specified in Stips. I.A. and I.B.

A. Recordation

1. Recordation shall be done in accordance with the Secretary of the Interior's "Standards for Architectural and engineering Documentation" (Standards) (<u>Federal Register</u>, 48 FR 190, pp. 44730-44734, September 29, 1983).

2. Because original "as-built" drawings and other records are on file at the installations containing Landmark facilities, documentation will normally include the following: (1) reproduction of existing "as-built" drawings and site plans modified on standard size (19 x 24 or 24 x 36) mylar; and (2) provision of black and white archival quality photos with large format negatives of exterior and interior views, as appropriate, as well as special technological features or engineering details.

3. Original copies of all documentation shall be provided to the Secretary of the Interior in accordance with the Standards for incorporation into the National Architectural and Engineering Records in the Library of Congress as provided in Section 101 of the National Historic Preservation Act and implementing procedures. Copies of the documentation shall also be provided to the appropriate SHPO.

B. Salvage

NASA will apply its agreement with the Smithsonian Institution (NASA Management Instruction 4310.4) to determine appropriate retention and curation activities with respect to significant artifacts.

IV. Continuing Coordination

A. On or about December 1, 1990, and annually thereafter, NASA will provide a summary of its activities under this Agreement to the Council and to the NCSHPO.

B. In consultation with the appropriate SHPO, the Council may review and comment upon individual undertakings when it determines that historic preservation issues warrant such action.

C. NASA will provide appropriate public information about activities under Stip.I.A. to interested parties upon request.

D. Any party to this Agreement may terminate it by providing 60 days notice to the other parties, provided that the parties will consult during the period prior to termination to seek agreement on amendments or other actions that would avoid termination.

Execution of this Programmatic Agreement and carrying out its terms evidences that NASA has afforded the Council and the NCSHPO a reasonable opportunity to comment on its programs affecting Landmarks under Sections 106 and 110(f) of the National Historic Preservation Act, and that NASA has taken into account the effects of its programs on these Landmarks.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

By: ______________________ 9/20/89
Associate Administrator for Management — Date

NATIONAL CONFERENCE OF STATE HISTORIC PRESERVATION OFFICERS

By: ______________________ 10/6/89
President — Date

ADVISORY COUNCIL ON HISTORIC PRESERVATION

By: ______________________ September 18, 1989
Chairman — Date

ATTACHMENT 1

NASA's NATIONAL HISTORIC LANDMARKS

(as of 2/24/89)

1. Variable Density Tunnel (Langley Research Center, Hampton, VA)
2. Full Scale Tunnel (Langley Research Center, Hampton, VA)
3. Eight-Foot High Speed Tunnel (Langley Research Center, Hampton, VA)
4. Unitary Plan Wind Tunnel (Ames Research Center, Moffett Field, CA)
5. Rocket Engine Test Facility (Lewis Research Center, Cleveland, OH)
6. Zero-Gravity Research Facility (Lewis Research Center, Cleveland, OH)
7. Spacecraft Propulsion Research Facility (Lewis Plum Brook Operations Facility)
8. Redstone Test Stand (George C. Marshall Space Flight Center, AL)
9. Propulsion and Structural Test Facility (George C. Marshall Space Flight Center, AL)
10. Rocket Propulsion Test Complex (Stennis Space Center, MS)
11. Saturn V Dynamic Test Stand (George C. Marshall Space Flight Center, AL)
12. Lunar Landing Research Facility (Langley Research Center, Hampton, VA)
13. Rendezvous Docking Simulator (Langley Research Center, Hapmton, VA)
14. Neutral Bouyancy Space Simulator (George C. Marshall Space Flight Center, AL)
15. Space Environment Simulation Laboratory (Lyndon B. Johnson Space Center, Houston, TX)
16. Spacecraft Magnetic Test Facility (Goddard Space Flight Center, Greenbelt, MD)
17. Twenty-Five-Foot Space Simulator (Jet Propulsion Laboratory, Pasadena, CA)
18. Pioneer Deep Space Station (Goldstone Deep Communications Complex, CA)
19. Space Flight Operations Facility (Jet Propulsion Laboratory, Pasadena, CA)
20. Apollo Mission Control Center (Lyndon B. Johnson Space Center, Houston, TX)

APPENDIX D: Qualifications of Key Personnel

QUALIFICATIONS OF KEY PERSONNEL

Joan Deming

Joan Deming, co-principal and Vice President of Archaeological Consultants, Inc., has more than 30 years of Cultural Resource Management experience. A Registered Professional Archaeologist (RPA), she received an M.A. in Anthropology/Public Archaeology from the University of South Florida in 1976, and has completed advanced training in Section 106 Agreement Document Preparation, Cultural Resource Management Plans: Preparation and Implementation, and Integrating NEPA and Section 106. She also has specialized training and experience in Native American coordination under the Native American Graves Protection and Repatriation Act (NAGPRA), as well as archaeological collections and records management.

Since 1990, Ms. Deming has managed all ACI's work on behalf of the National Aeronautics and Space Administration (NASA) at the Kennedy Space Center (KSC) and for the U.S. Air Force at Cape Canaveral Air Force Station. These investigations include a multi-year KSC-wide archaeological survey and preparation of one site location predictive model; archaeological surveys of several proposed development parcels conducted in compliance with Section 106 of the National Historic Preservation Act; the development of standard operating procedures for the management of NASA's records pertaining to cultural resources; an inventory and assessment of archaeological collections and the evaluation of curatorial facilities; survey and evaluation of NASA-controlled facilities within the KCS; and preparation of a Cultural Resource Management Plan (CRMP) for the KSC. She is currently managing a NASA-wide survey and evaluation of historic facilities in the context of the Space Shuttle Program, including work on behalf of NASA's Glenn Research Center in Ohio; Dryden Flight Research Center in California; the Marshall Space Flight Center in Alabama; the Johnson Space Center in Texas; the White Sands Flight Facility in New Mexico; and the KSC in Florida.

Patricia Slovinac

Patricia (Trish) Slovinac is an Architectural Historian for Archaeological Consultants, Inc. (ACI). She attended The University of Virginia (UVA) where she completed course work for the degree of Master of Architectural History, with a Certificate in Historic Preservation. Prior to joining ACI, Ms. Slovinac was employed by the National Architectural Trust in Washington, D.C., focusing on the donation of Conservation Easements. This involved evaluating historic structures for the purpose of determining their significance as part of a National Register of Historic Places (NRHP) historic district. Ms. Slovinac has experience in the preparation of historic contexts, historical/architectural field survey and site documentation, National Register nominations, and mitigation measures for historic resources, including HABS/HAER documentation. She has experience in hand drafting to HABS/HAER standards, and is skilled in black and white photography.

As part of ACI's NASA-wide survey and evaluation of historic facilities in the context of the Space Shuttle Program, Ms. Slovinac is assisting in the development of a historic context, and has taken the lead on the field survey at various NASA Centers including the KSC, the Marshall Space Flight Center, the Johnson Space Center (JSC), the Glenn Research Center, the Dryden Flight Research Center, and the White Sands Flight Facility. Work consists of a review of the facilities in terms of eligibility for the National Register of Historic Place, and for KSC, the preparation of National Register nominations and updating KSC's Multiple Property cover nomination.

KAREN J. WEITZE *Architectural-Engineering Research, Analysis, and Documentation*
Aerospace and Military History

Weitze Research
708 Bristol Avenue 209.943.1142
Stockton, California 95204

Expertise and Education

Ph.D. Architectural History, Stanford University, 1978
M.A. Architectural History, Stanford University, 1976
B.A. History and Architectural History, University of Texas, 1973

Employment

2001- Weitze Research
Sole Proprietor / President
1998-2001 KEA Environmental, Inc., San Diego, California
Principal Investigator / Project Manager
1994-1997 Geo-Marine, Inc., Plano, Texas
Principal Investigator /Project Manager
1989-1994 Dames & Moore, Inc., Austin, Texas.
Senior Architectural Historian / Principal Investigator / Project Manager
1978-1988 Assistant Professor, Kansas State University
Assistant Professor, University of California, Davis
Associate Environmental Planner, Caltrans, Sacramento (California DOT)
Architectural Historian, California Office of Historic Preservation, Sacramento

Representative Government Projects

United States Air Force

2007 *Historic Range Context Air Armament Center Eglin Air Force Base (1936/1939-1996)*. Two volumes. Volume I: *Narrative and Appendix A (Radar and Instrumentation Sites / Santa Rosa Island / Water Ranges)*. Volume II: *Land Test Areas*.
2006 *Mountain Home Air Force Base Historic Building Inventory and Evaluations*.
2006 *Historic Buildings and Structures Inventory Douglas Missile Test Facility*.
2006 *PAVE PAWS Beale Air Force Base HAER No. CA-319*
2005-2006 *Air Combat Command Data Base, Phase I*.
2005 *Historic Facilities Groups at Air Combat Command Installations: A Comparative Evaluation*
2005 *Strategic Air Command (SAC) Alert Historic District Request for Determination of Eligibility Eglin Air Force Base*
2003 *Keeping the Edge: Air Force Materiel Command Cold War Context (1945-1991)* Three volumes. Volume I: *Command Lineage, Scientific Achievement, and Major Tenant Missions*. Volume II: *Installations and Facilities*. Volume III: *Index*. Partner, EDAW, Inc.
2003 *Eglin Air Force Base Inventory of Historic Properties 2001-2003. Parts I, II, and III.*
2001 *Eglin Air Force Base, 1931-1991: Installation Buildup for Research, Test, Evaluation, and Training*
2001 *Eglin Air Force Base Inventory of Historic Properties FY 2000.*
1999 *Cold War Infrastructure for Air Defense: The Fighter and Command Missions*

1999 *Cold War Infrastructure for Strategic Air Command: The Bomber Mission*
1998 *PAVE PAWS Large Phased-Array Radar Historic Evaluation and Context*
1997 *Guided Missiles at Holloman Air Force Base: Test Programs of the United States Air Force in Southern New Mexico, 1947-1970*
1996 *Inventory of Cold War Properties. Andrews, Charleston, Dover, Grand Forks, McChord, Scott, and Travis Air Force Bases*
1996 Architectural Inventory and Evaluation of Cold War Structures at Minot Air Force Base
1994 *Aeromedical Evacuation Annotated Bibliography*
1994 *National Register of Historic Places Evaluation Peacekeeper Rail Garrison Vandenberg Air Force Base*
1993 *Historic Architectural Engineering Survey Atlas ABRES-A Vandenberg Air Force Base*
1993 *Request for Determination of Eligibility Atlas 576 G Vandenberg Air Force Base*
1992 *Re-evaluation of the NRHP Eligibility for the White Alice Installations at Bethel, Middleton Island, and Pedro Dome, Alaska* (tropospheric communications network)
1991 *Request for Determination of Eligibility SLC-2W and SLC-2 Blockhouse Structures Vandenberg Air Force Base* (Thor intermediate ballistic missile launch complex)

National Aeronautics and Space Administration

2007 *Hugh L. Dryden Flight Research Center, Edwards, California: Survey and Evaluation of NASA-Owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program*.
2004 *Historical Assessment for the Equipment Boneyards at the Marshall Space Flight Center*
2003 *Historical Assessment of Marshall Space Flight Center*

United States Army

2007 *National Stockpile Sites Alpha, Baker, Charlie, and Dog: Design and Development, 1946-1955*.
2005 *Cold War Properties at West Fort Hood: Research Overview and Preliminary Identification*
1999 *Seacoast Fortifications Preservation Manual Golden Gate National Recreation Area San Francisco*
1996 *Dugway Proving Ground, German Village Complex HAER No. UT-35* (Utah)
1996 *Aurora Pulsed Radiation Simulator HAER No. MD-144* (Maryland)
1996 *Detroit Arsenal West Site R&D Facilities HABS Level IV Inventory*

United States Navy

2000 *The Marine Corps Air Station, Tustin, Lighter-than-Air Ship Hangars HABS No. CA-2707* (California)

Government Projects in Progress

2007 Inventory for the Santa Susana Field Laboratory, southern California. For the NASA Marshall Space Flight Center. Team member for Archaeological Consultants, Inc.
2007 Research and analysis of the German Village (World War II incendiary test area) at the Dugway Proving Ground, Utah.
2006-2007 *Inventory and National Register Evaluation Selected Buildings in the Baker Area, Dugway Proving Ground, Utah*.
2006-2007 *Marshall Space Flight Center, Huntsville, Alabama: Survey and Evaluation of NASA-Owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program*.
2006-2007 *Rocketdyne's Space Shuttle Main Engine (SSME) Manufacturing Site, Canoga Park, California: Survey and Evaluation of NASA-Owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program*.

2006-2007 *Rocketdyne's Space Shuttle Main Engine (SSME) Test Stands, Santa Susana, California: Survey and Evaluation of NASA-Owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program*.

2006-2007 *Rockwell International's Assembly of the Shuttle at Site 1, Air Force Plant (AFP) 42, Palmdale, California: Survey and Evaluation of NASA-Owned Historic Facilities and Properties in the Context of the U.S. Space Shuttle Program*.

2006-2007 *Integrated Cultural Resources Management Plan (ICRMP) Update, Hickam Air Force Base, Hawaii*.

2006-2007 *Air Combat Command Data Base, Phase II*.

Publications

Upcoming *Hart Wood, Architect*. Co-authored with Don Hibbard and Glenn Mason. Manuscript under contract at University of Hawaii Press. Publication in 2008.

1997 "Sumner P. Hunt" and "Arthur B. Benton," in *Toward a Simpler Way of Life: The Arts and Crafts Architects of California*, Los Angeles, University of California Press.

1996 "Midwest to California: The Planned Arts and Crafts Community," in *The Substance of Style: Perspectives on the American Arts and Crafts Movement*, Hanover and London, University Press of New England.

1993 "Utopian Place Making: The Built Environment in Arts and Crafts California," in *The Arts and Crafts Movement in California: Living the Good Life*, New York, Abbeville Press. Publication accompanied an exhibition at the Oakland Museum, the Renwick Gallery at the Smithsonian, Washington, D.C., and the Cincinnati Art Museum.

1986 Introductory essay for Harold Kirker's *California's Architectural Frontier*, Salt Lake City, Gibbs M. Smith, Inc.

1984 *California's Mission Revival*, Los Angeles, Hennessey & Ingalls, Inc.

1980 "Charles Beasley, Architect (1827-1913): Issues and Images," article in *Journal of the Society of Architectural Historians*. Society of Architectural Historians' Founders Award.

1976 "Stanford and the California Missions," essay in *The Founders and the Architects*, Stanford, Department of Art. Second edition 1984.

Public Service and Affiliations

Society of Architectural Historians, 1975 to the present
Texas Review Board, 1991-1995 (governor appointment)

References

Dr. Frederick Shaw, Chief, Research Division, USAF Historical Research Agency (ret.). 334.277.3237
Dr. Paul Green, HQ ACC/CEVP, Langley Air Force Base, Virginia. 757.764.9335