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

Prepared for

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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.

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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).

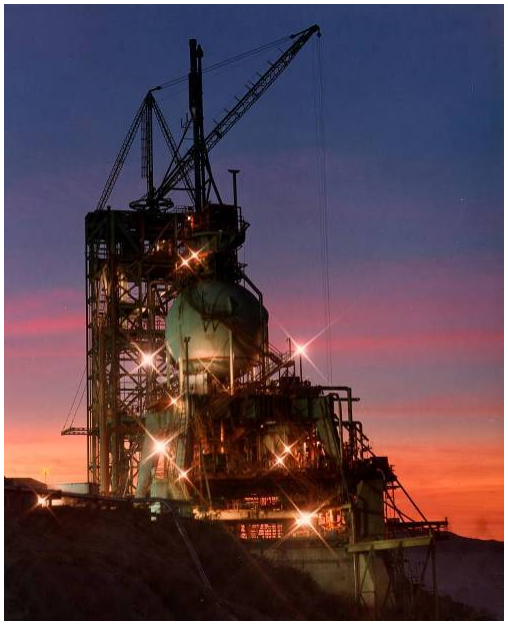

Photo 2.1. Preparations for SSME components test on Coca I (Test Stand A-3) at Santa Susana (NASA Area II), 20 December 1974.
(Source: Boeing, Rocketdyne Historic Photograph Collection, SSFL)

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).

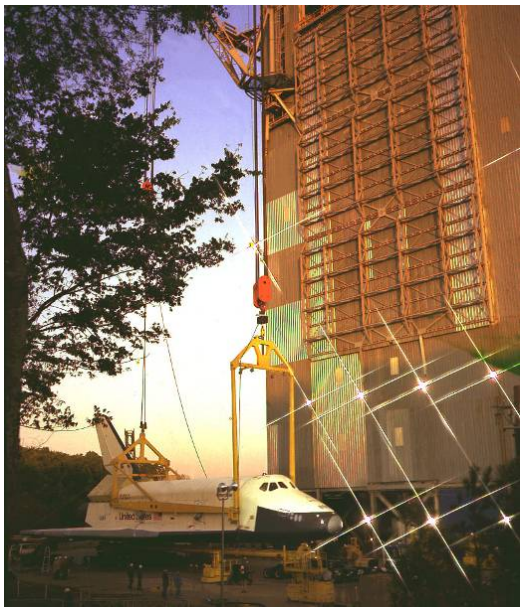

Photo 2.4. Orbiter *Enterprise* on strongback, outside Building 4550 at MSFC, 1978. (Source: NASA Marshall Space Flight Center, MSFC-7889025)

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		Landing Site	Landing Date
				Pad A	Pad B		
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.

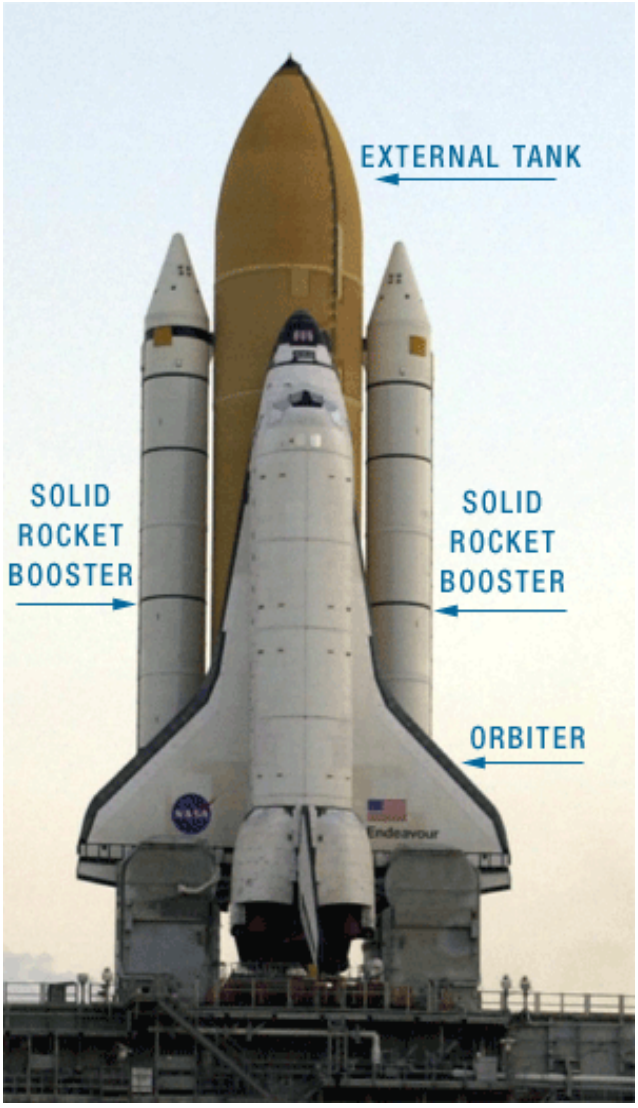

Photo 3.1. The Space Shuttle system. (Source: NASA)

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).

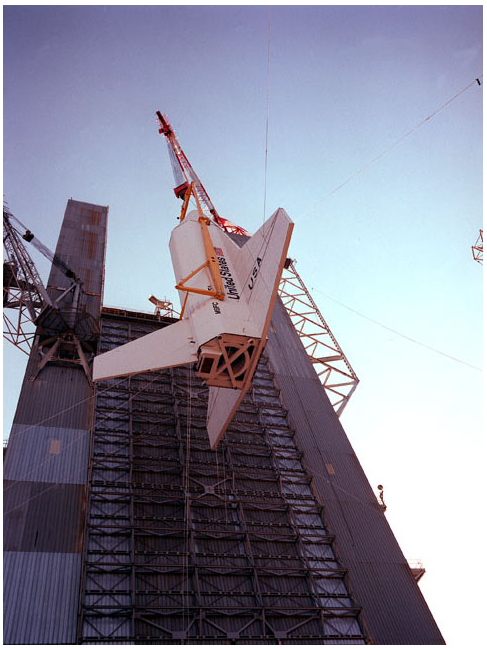

Photo 3.3. Pathfinder Simulator is hoisted into MSFC Dynamic Test Stand, 1977.
(Source: NASA MSFC, NIX No.: MSFC-7885689)

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.

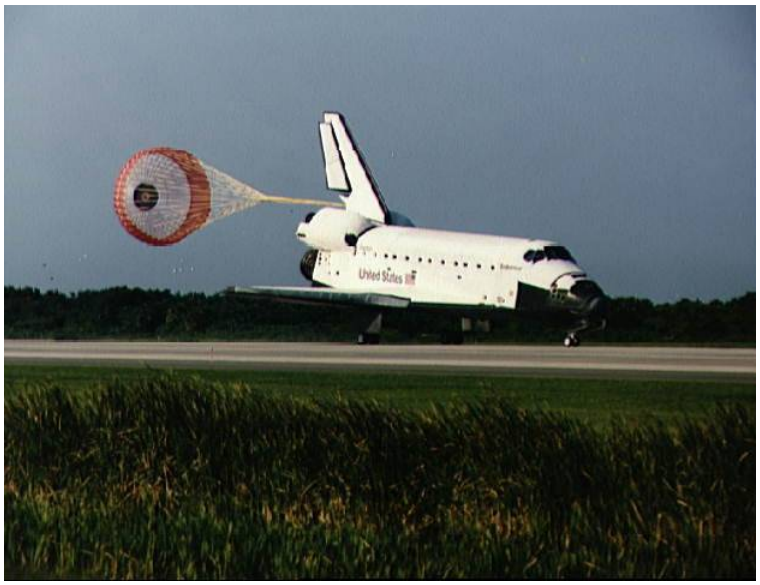

Photo 3.8. Landing of *Endeavour* at Kennedy Space Center, Florida, 1992.
(Source: NASA Lyndon B. Johnson Space Center, STS057(S)082)

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

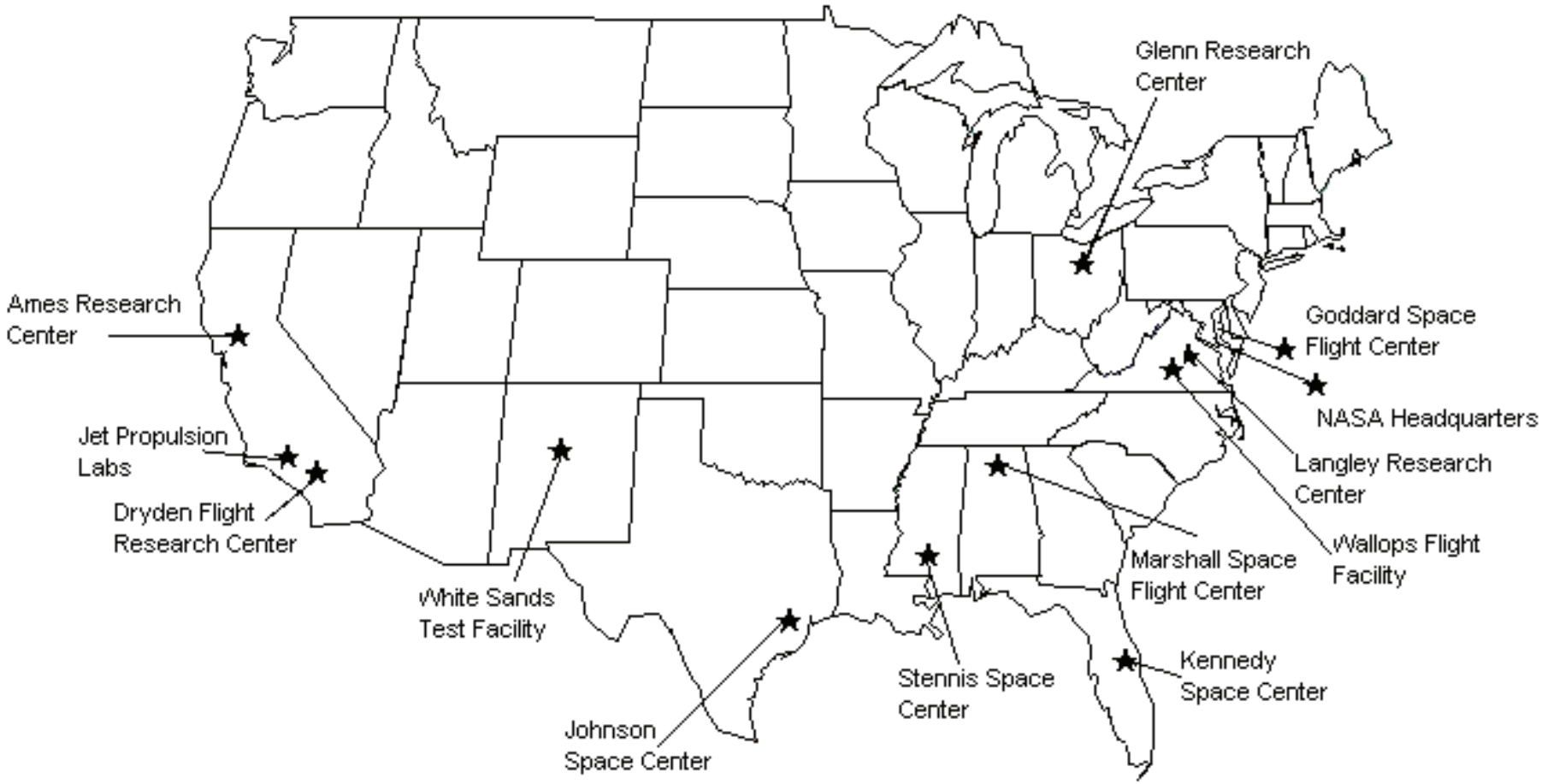

Figure 4.1. Location of NASA Centers (www.nasaexplores.com/extras/maps/center_map.html). The locations of the Michoud Assembly Facility near New Orleans, Louisiana and the Santa Susana Field Laboratory and Canoga Park Facility, both in the greater Los Angeles area, are not depicted.

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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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	Evaluation	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)

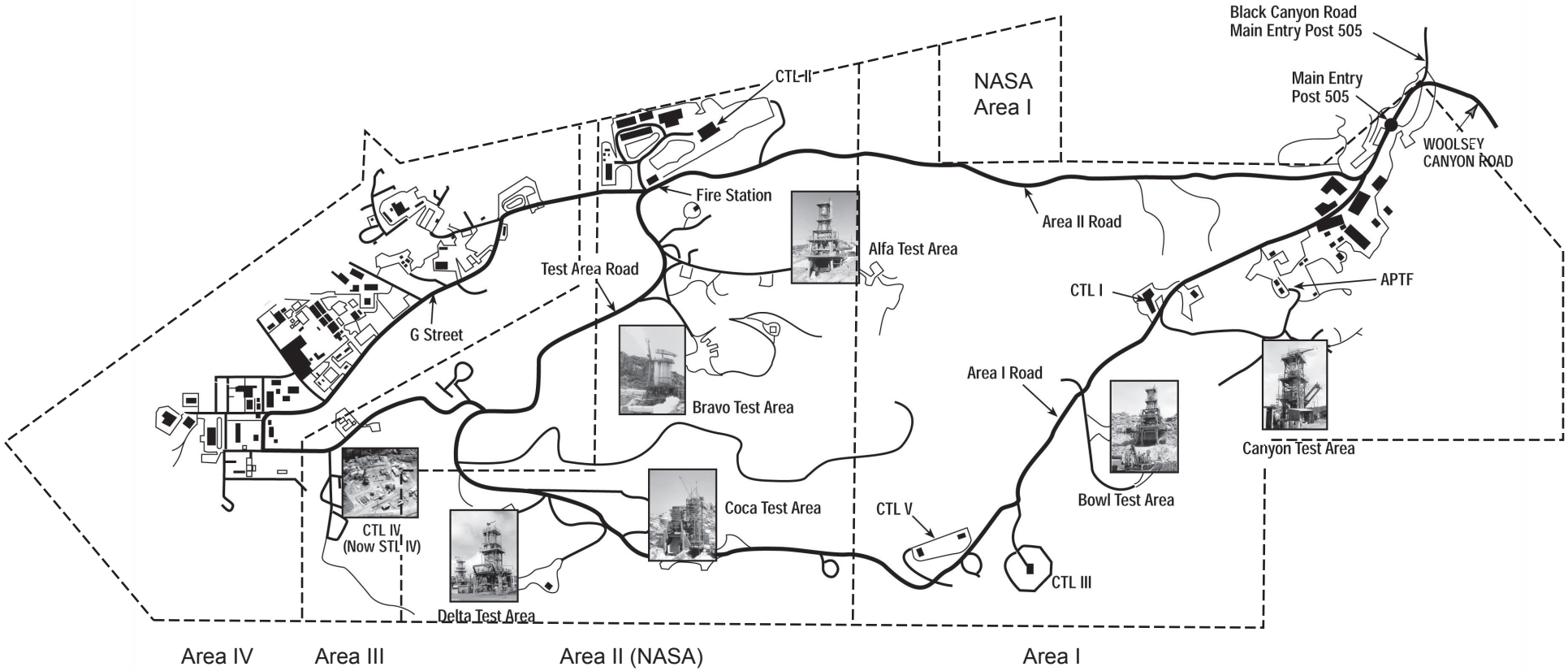

Figure 4.2. Location of the test and other areas within the Santa Susana Field Laboratory (Courtesy of Boeing Corporation).

(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	Evaluation	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	Evaluation	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	Evaluation	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.