GRAY & PAPE
HERITAGE MANAGEMENT

NASA Agency-Wide Approach for the Management of Resources Less than 50 Years of Age

Resource Significance Framework

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ACRONYMS

AACS	Attitude and Articulation Control Subsystem
ACEE	Aircraft Energy Efficiency
ACHP	Advisory Council on Historic Preservation
ADECS	Adaptive Digital Engine Control System
AERL	Aircraft Engine Research Laboratory
AFB	Air Force Base
AFRC	Armstrong Flight Research Center
ARC	Ames Research Center
ARMD	Aeronautics Research Mission Directorate
ATF	Armstrong Test Facility
BWB	Blended Wing Body
CAPA	Central Airborne Performance Analyzer
CAPCS	Cooperative Airframe/Propulsion Control System
CAS	Control Augmentation System
CCAS	Cape Canaveral Air Station
CCG	National Register of Historic Places Criteria Consideration G
CCS	Command Computer Subsystem
CEOS	Committee on Earth Observation Satellites
CFD	Computational Fluid Dynamics
CHIPS	Cosmic Hot Interstellar Plasma Spectrometer
COBE	Cosmic Background Explorer
CRM	Cultural Resource Managers
CZCS	Coastal-Zone Color Scanner
DEEC	Digital Electronic Engine Control
DEFCS	Digital Electronic Flight Control System
DIRBE	Diffuse Infrared Background Experiment
DFBW	Digital Fly-by-Wire
DMR	Differential Microwave Radiometer
DOE	Department of Energy
DSN	Deep Space Network
DSIF	Deep Space Instrumentation Facility
DoD	Department of Defense
ELF	Ellington Field

EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
ERBS	Earth Radiation Budget Experiment
ERTS	Earth Resources Technology Satellite
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESDMD	Exploration Systems Development Mission Directorate
ESSB	Earth System Science Building
FCCS	Facility Classification Coding System
FIRAS	Far Infrared Absolute Spectrophotometer
FRED	Facilities and Real Estate Division
FT	Feet
FUSE	Far Ultraviolet Spectroscopic Explorer
FY	Fiscal Year
GALCIT	Guggenheim Aeronautical Laboratory of the California Institute of Technology
GDSCC	Goldstone Deep Space Communication Complex
GRACE	Gravity Recovery and Climate Satellite
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HARV	High Alpha Research Vehicle
HATP	High Angle-of-Attack Technology Program
HEOMD	Human Exploration and Operations Mission Directorate
HESSI	High Energy Solar Spectroscopic Imager
HIDEC	Highly Integrated Digital Electronic Control
HGA	High-Gain Antenna
HSG	Herndon Solutions Group
HTSF	Highly Technical or Scientific Facilities
ICRMP	Integrated Cultural Resource Management Plan
IPCS	Integrated Propulsion Control System
ISS	International Space Station
JAXA	Japan Aerospace Exploration Agency
JBLE	Joint Base Langley-Eustis
JEM	Japanese Experiment Module
JPL	Jet Propulsion Laboratory

JSC	Johnson Space Center
KSC	Kennedy Space Center
LAFB	Langley Air Force Base
LaRC	Langley Research Center
LEED	Leadership in Energy and Environmental Design
LEO	Low Earth Orbit
LIMS	Limb Infrared Monitoring of The Stratosphere
LLRV	Lunar Landing Research Vehicle
LOX	Liquid Oxygen
LSI	Land Surface Imaging
LTV	Ling-Temco-Vought
M	Meter
MAF	Michoud Assembly Facility
MDAP	Mars Data and Analysis Program
MPD	Multiple Property Documentation form
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MTF	Microwave Test Facility
NAA	North American Aviation
NACA	National Advisory Committee for Aeronautics
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NEO	Near-Earth Object
NETS	NASA Environmental Tracking System
NHL	National Historic Landmark
NHPA	National Historic Preservation Act
NICER	Neutron Star Interior Composition Explorer
NLI	National Land Imaging
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRHP	National Register of Historic Places
NRP	NASA Research Park
NSTL	National Space Technology Laboratories
NuSTAR	Nuclear Spectroscopic Telescope Array

OAPEC	Organization of Arab Petroleum Exporting Countries
PAM	Payload Assist Module
PBOW	Plum Brook Ordnance Works
PBS	Plum Brook Station
PCA	Propulsion Controlled Aircraft
PFO	Program Formulation Office
PSC	Performance Seeking Control
PSL	Propulsion Systems Laboratory
RD&T	Research, Development, And Testing
RMS	Remote Manipulator System
RPMS	Real Property Management System
RSF	Resource Significance Framework
RTG	Radioisotope Thermal Generators
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SCaN	Space Communications and Navigations
SCTF	Sonny Carter Training Facility
SCW	Supercritical Wing
SHPO	State Historic Preservation Officer
SMD	Science Mission Directorate
SMEX	Small Explorer
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOI	Secretary of the Interior
SOHO	Solar and Heliospheric Observatory
SOMD	Space Operations Mission Directorate
SRFCS	Self-Repairing Flight Control System
SSC	Stennis Space Center
SSFL	Santa Susana Field Laboratory
SSP	Space Shuttle Program
STADAN	Satellite Tracking and Data Acquisition Network
STDN	Spaceflight Tracking and Data Network
STG	Space Task Group
STMD	Space Technology Mission Directorate
STScl	Space Telescope Institute
STOL	Short Takeoff and Landing

TACT	Transonic Aircraft Technology
TCE	Trichloroethylene
TDRSS	Tracking and Data Relay Satellite System
TESS	Transiting Exoplanet Survey Satellite
THIR	Temperature-Humidity Infrared Radiometer
TRRA	Tilt Rotor Research Aircraft
UCAR	University Corporation for Atmospheric Research
UAV	Unmanned Aerial Vehicle
USAF	U.S. Air Force
USDI	U.S. Department of Interior
USGS	United States Geological Survey
V/STOL	Vertical/Short Takeoff and Landing
VEXAG	Venus Exploration Analysis Group
WFF	Wallops Flight Facility
WMAP	Wilkinson Microwave Anisotropy Probe
WSTF	White Sands Test Facility

1.0 INTRODUCTION

As defined by the National Register of Historic Places (NRHP), resources less than 50 years of age (<50) are generally not eligible for listing (i.e., they are not historic properties) unless they possess exceptional importance under the Criteria. However, NASA is a young agency with a scientific mission that makes it atypical among Federal agencies in both the character of its historic properties and the nature of the National Historic Preservation Act (NHPA) Section 106 undertakings. While most Federal agencies' historic preservation programs prioritize resources that have reached 50 years of age (50+) and only evaluate resources under NRHP Criteria Consideration G (CCG) in limited cases of readily apparent significance (e.g., Cold War, Civil Rights), NASA is a scientific agency that defines the state-of-the-art in its fields of endeavor. Its achievements are often immediately and broadly recognized as exceptionally important, and as such NASA has the responsibility to consider the historical significance of the facilities associated with those achievements. At the same time, NASA must maintain state-of-the-art facilities to support its mission, which requires that the agency continually assess, modify, recycle, demolish, and construct facilities. In this environment, identification and management of historic properties <50 is more challenging and requires an approach that is tailored to NASA.

Resources <50 make up 56% of NASA's assets (3,000 of 5,341), and 19% of its 862 identified historic properties, many of which were determined NRHP eligible well in advance of turning 50 years of age for their association with the Apollo and Space Shuttle Programs. Approximately 36% of NASA's <50 assets have been evaluated for NRHP listing under at least one context. But in most cases resources <50 have not been evaluated comprehensively (i.e., individually and as a contributing resource, under a range of potential areas of significance). Additionally, the Federal initiative to reduce its overall facilities' costs by disposing of older and/or underutilized assets and consolidate former functions into energy efficient and up-to-date facilities means that new facilities are coming online at NASA Centers while others will be demolished, modified, or repurposed. It is also often the case at NASA Centers that highly technical or scientific facilities (HTSF) acquire exceptional historical significance well before reaching 50 years of age and need to be comprehensively evaluated before potential modifications or demolition.

Due to the changing nature of how NASA conducts business, from commercialization of space mission support to computer-aided technology, the agency is increasingly needing to modify, transfer, and dispose of its resources to support this evolving NASA mission. The need for an efficient approach to the identification of historic properties <50 will only become more acute as the mission evolves. Preliminary estimates suggest that up to 17% of NASA's <50 real property assets may be eligible for listing in the NRHP under CCG: however, that means that 83% are not, suggesting that traditional comprehensive (resource-by-resource) survey of <50 resources is neither practical nor necessary. NASA is seeking an efficient way to focus its limited resources on the types of resources with the greatest potential to fall within that 17%.

NASA contracted Herndon Solutions Group (HSG) and Gray & Pape, Inc. (Gray & Pape) to develop a programmatic approach for the identification and management of NASA <50 real property assets. The purpose is to develop a single agency-wide approach to managing <50 real property assets that can be easily applied at NASA Centers through:

- developing an approach for identifying assets <50 most likely to be eligible for listing in the NRHP under CCG—a Resource Significance Framework (RSF); and

- incorporating streamlined management of assets <50 into an agency-wide Section 106 Programmatic Agreement (APA).

This RSF provides a list of the types of properties (Exemplary Property Types) with the greatest ability to convey NRHP historical significance under CCG, based on a representative sample of NASA's most historically significant achievements (Apex Events) of the last 50 years (i.e., 1973) in four major Areas—Aeronautics, Human Exploration and Operations, Science, and Architecture. The RSF also provides a summary discussion of the significant themes within which these achievements may be understood for purposes of NRHP evaluation (Themes). This analysis forms the basis of a predictive model (RSF Model) that assesses the likelihood of a <50 asset to be eligible for listing in the NRHP. NASA can then use the RSF Model to guide management of unevaluated real property assets <50, thereby enabling the agency to use its limited financial and staff resources in a more efficient and strategic manner. This approach to assets <50 has been incorporated into an APA, currently in draft form, aimed at focusing NASA's limited resources on assets with the greatest ability to convey the historical significance of NASA's achievements to the public.

2.0 METHODOLOGY

2.1 Scope of Study

The following general limitations have been applied at the outset of the RSF study to define the universe of resources to be examined. The RSF addresses the 3,000 real property assets that are:

- NASA owned and controlled, including properties leased to other entities;
- located in the U.S.;
- aboveground resources (i.e., not archaeological resources); and
- were built in or after 1973.

NASA acknowledges that a limited number of personal property assets <50, such as aircraft, may be eligible for listing in the NRHP. Because they are relatively few in number and managed separately from real property assets, they are not the focus of this study.

2.2 Terminology

The RSF is intended to be understood within the context of the NRHP and cultural resources management, and as such an attempt has been made to use terms of art such as “resource,” “historic property,” and “evaluation” consistent with the NRHP. Within the NASA real property management context, terms such as “asset,” “facility,” and “building” can be used interchangeably to refer to what the NRHP would call a building, structure, or a collection of such resources (i.e., district). In the RSF, these terms are used in a more general, undefined sense except for “asset,” which throughout the RSF is used as specifically defined in Section 2.1 above.

2.3 Qualifications of Preparer

The RSF has been prepared by Gray & Pape under the direction of Carrie Albee, History/Architecture Practice Lead and architectural historian with 25 years of experience in the field. Ms. Albee and report contributors Michael Langmyer, Patrick O’Bannon, Ryan VanDyke, and Katie Watts meet the Secretary of the Interior’s Professional Qualification Standards for architectural history and/or history.

2.4 Project Development

As originally envisioned, this study sought to take a traditional approach to identifying aboveground historic properties—i.e., conduct research, develop historic contexts, define areas of exceptional significance. Property types would be defined in a manner similar to that used for NRHP Multiple Property Documentation (MPD), and eligibility thresholds established. The study would then be used at the Center level to evaluate specific assets pursuant to the procedures laid out in a Section 106 program alternative. This approach was intended to provide Center Cultural Resource Managers (Center CRMs) with enough information to make an informed, good-faith determination of eligibility in house.

Early project planning involved discussions with CRMs to determine their challenges in managing resources <50 and ways in which the project might address them. Cultural resource management documents, including Integrated Cultural Resource Management Plans (ICRMPs) and aboveground resource surveys were reviewed, and the NASA Environmental Tracking System (NETS) was studied to obtain an understanding of the agency's inventory of real property assets <50 and NRHP evaluation status. The publications of the NASA History Office were reviewed and those with broad applicability studied in more detail. This background work formed the basis of a Research Design, initially submitted to NASA in October 2019. The Research Design included an assessment of the extent to which NASA's exceptionally important activities had been documented in existing sources and linked to built resources as an indicator of the level of effort that would be required to prepare this study. The Research Design provided recommendations directed towards ensuring that the study would be aligned with NASA's goals for the project, and proposed agency-specific criteria for exceptional importance.

During January and February 2020, Gray & Pape worked to identify areas of significance. The areas of significance were intended to be generally consistent with the NRHP definition and would form the basis of the historic context. Many different organizational structures were considered in developing proposed areas of significance. The areas of significance were initially developed consistent with the NRHP evaluation process—for example, human space exploration, satellite communications, human health, robotics—and an attempt was made to associate specific programs and missions with the areas. This proved to be a significant challenge due to the interconnectivity of the areas—i.e., human health is an aspect of earth-based programs as well as manned space exploration, and robotics are employed in a broad range of NASA programs, etc. NASA's own organizational structure and the agency's technology taxonomy were considered, as they offered the benefit that NASA was already using these to organize major programs and historical documentation. NASA solicited the input of internal stakeholders, including the CRMs and NASA History Office[1], as the areas of significance were being developed. A tentative working list of 11 areas of significance under which it was known or expected that NASA had achieved exceptional importance was determined, and included primary missions (e.g., manned space exploration, unmanned space exploration, aeronautics, and earth science), support missions (e.g., propulsion, human health, robotics), and architecture and design.

The first area of significance to be explored in detail was aeronautics. It was selected because it was expected to be relatively functionally discrete with respect to NASA's numerous activities and achievements. The intended approach was to develop a historic narrative, describe areas of exceptional importance, and then describe the associated property types with the ability to convey that importance. In preparing the draft aeronautics chapter several facts became clear: 1) the goal of developing a historic context for aeronautics—or any of NASA's primary missions—that could purport to be comprehensive through a traditional NRHP evaluation approach was well beyond the expected level of effort for the study; and 2) research into a broad range of NASA's achievements in aeronautics since 1973 was revealing the same goals, processes, and assets at play time and time again. This suggested that a comprehensive exploration of exceptional importance was not necessary to achieve NASA's cultural resources management goals. Therefore, an exhaustive compilation of all of NASA's apex events was not included in this document, as the patterns that emerged routinely indicated a finite set of assets. NASA shared the draft aeronautics chapter with the Advisory Council on Historic Preservation (ACHP) and the National Conference of State Historic Preservation Officers (NCSHPO) members in January 2021. Based upon feedback received and lessons learned from the aeronautics chapter, the study evolved from a more traditional and definitive NRHP historic context approach to its current

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[1] The cultural resource management and history programs at NASA are organizationally separate, but they collaborate and coordinate on projects relevant to both. Individuals from both programs were engaged in the development of this RSF.

manifestation as a management tool and a predictive model for identifying assets <50 most likely to convey exceptional importance under NRHP CCG.

2.5 Understanding Exceptional Importance

The RSF in its current form examines the types of properties (Exemplary Property Types) with the ability to convey NRHP historical significance under CCG through the examination of a representative sample of NASA's most historically significant achievements (Apex Events) and individuals since 1973 in four major areas (Areas)—Aeronautics Research, Human Exploration and Operations, Science, and Architecture. There is also a summary discussion of themes within which the significance of these achievements may be understood (Themes of Exceptional Importance).

2.5.1 Areas of Significance

The first three Areas addressed in the RSF—Aeronautics Research (Area 1), Human Exploration and Operations (Area 2), and Science (Area 3)—are three of the four primary mission directorates recognized by NASA today. Mission Directorates are discussed in greater detail in Chapter 3, and they serve as an organizational structure for the agency. The Space Technology Mission Directorate supports the other three and as such was not incorporated into the organization of the RSF. The fourth Area in the RSF—Architecture (Area 4)—is intended to capture exceptional importance under NRHP Criterion C.

2.5.2 Apex Events

Exceptional importance in Areas 1, 2, and 3 is demonstrated through Apex Events, which are events, discoveries, inventions, or innovations that: (1) represent the successful resolution of a challenge or goal; or (2) that initiate a shift in perspective or trajectory in a manner that redefines those challenges or goals. The Apex Events have been selected to illustrate the range of NASA's achievements of exceptional importance in that Area as determined by NASA and its peers, and as such, is not a comprehensive summary of all of NASA's achievements in each Area. Professional technical associations, academic institutions, professional journals, and other external sources have been consulted for objective verification of the relative importance of NASA's Apex Events. All Apex Events presented in the RSF have been deemed by the preparer to be of extraordinary importance as required under NRHP CCG. However, because of the extraordinary nature of NASA's everyday activities, additional criteria were developed to aid in the identification of exceptional importance.

- Apex Events must fall within NASA's current or historic core missions, as defined by the agency;
- Apex Events must be internationally or nationally significant;
- Apex Events must have had a broad impact beyond NASA;
- Apex Events are those in which NASA played a primary role; and
- Apex Events must be broadly recognized as exceptionally important by the scientific (or other peer) community, or they must be deemed as exceptionally important by the general public.

Apex Events as presented are directly illustrative of specific events under NRHP Criterion A in the areas of communications, engineering, exploration/settlement, health/medicine, invention, military, science, and transportation. But collectively they represent broad patterns, as well, referred to in the RSF as themes of exceptional importance (Themes). NASA assets eligible under NRHP Criterion A may also be eligible for listing in the NRHP under Criterion C for their design, but consideration of Apex Events and Themes suggests that it is unlikely that an asset <50 would be eligible under Criterion C independent of Criterion A—i.e., purely for design. This potential is explored in Area 4.

Apex Events and their significance are summarized in the chapters for Areas 1, 2, and 3. A more detailed presentation of the Apex Events is provided in Appendix B.

2.5.3 Significant People

The potential for assets <50 to be eligible for listing in the NRHP under Criterion B was considered in the preparation of the RSF. The exceptionally significant individuals that have made NASA's achievements possible are likewise too numerous to enumerate here, but a representative sample is presented for Areas 1, 2, and 3 in tabular form, with biographical sketches provided in Appendix C. These individuals spent much of their careers at NASA Centers, and as such would have utilized many of the assets at those Centers, from offices to cafeterias to parking facilities. However, only a limited number of assets <50 would be truly representative of that individual's "productive life" as required by the NRHP—likely the same assets eligible under Criterion A. Because of the progressive nature of NASA's achievements—i.e., they are the result of numerous incremental steps advanced by many significant individuals using the same built assets—rarely will a NASA resource be so particularly associated with a single person such that it would support eligibility under Criterion B alone.

2.5.4 Area 4 – Architecture

The fourth Area in the RSF—Architecture (Area 4)—is intended to capture exceptional importance under NRHP Criterion C for architectural design and as such is not necessarily based upon NASA's historical achievements. Because it is not a functional area of NASA activities, the recommended approach to identifying significance and property types is more conventional.

2.6 Citations

Unless otherwise noted, information contained in this report is derived from NASA-owned information and publications. The RSF is not intended to be work of scholarship based upon new and original research, but rather a summary and analysis of existing information. NASA-owned sources have not been independently verified and are assumed to be accurate. They are not generally cited in the text or in footnotes; however, major sources of information are provided in the References section, organized by topic.

3.0 AGENCY OVERVIEW

With the establishment of the National Advisory Committee for Aeronautics (NACA) in 1915, the Federal government made a formal commitment to advance civil aviation through investment in "the scientific study of the problems of flight with a view to their practical solution".[2] When NASA was created in 1958, it subsumed the NACA, absorbing its traditional aeronautical missions, facilities, and personnel, and expanding its purview to space. But the core value that it "should be devoted to peaceful purposes for the benefit of all mankind" remained constant. More specifically, the National Aeronautics and Space Act of 1958 stipulated that NASA's activities would contribute to one of the following objectives:

1. The expansion of human knowledge of phenomena in the atmosphere and space;
2. The improvement of the usefulness, performance, speed, safety, and efficiency of aeronautical and space vehicles;
3. The development and operation of vehicles capable of carrying instruments, equipment, supplies and living organisms through space;
4. The establishment of long-range studies of the potential benefits to be gained from, the opportunities for, and the problems involved in the utilization of aeronautical and space activities for peaceful and scientific purposes;
5. The preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof to the conduct of peaceful activities within and outside the atmosphere;
6. The making available to agencies directly concerned with national defenses of discoveries that have military value or significance, and the furnishing by such agencies, to the civilian agency established to direct and control nonmilitary aeronautical and space activities, of information as to discoveries which have value or significance to that agency;
7. Cooperation by the United States with other nations and groups of nations in work done pursuant to this Act and in the peaceful application of the results, thereof; and
8. The most effective utilization of the scientific and engineering resources of the United States, with close cooperation among all interested agencies of the United States in order to avoid unnecessary duplication of effort, facilities, and equipment.[3]

NASA's achievements have had a profound impact on the American, and human, experience. The most visible of its programs—the Apollo Program (1960–1975) and the Space Shuttle Program (SSP, 1969–2011)—were immediately recognized around the world as exceptionally important, and people that watched the moon landing from their living room television and the Space Shuttle launches from the beaches of the Florida Space Coast knew that they were experiencing history being made. But NASA is an agency that makes history every day, and one that is committed to documenting its achievements and sharing them with both the scientific and lay communities. NASA is among the most publicly accessible Federal agencies—not only because of the inherent human interest in its activities, but also

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[2] Public Law 271, 63d Cong., 3d sess., passed 3 March 1915 (38 Stat. 930). The historical overview derives in large part from David H. Dutton and Robert J. Taylor, Jr., *Phase I Reconnaissance Survey of Architectural Resources at the National Aeronautics and Space Administration, Langley Research Center*, prepared by Dutton + Associates, LLC., Virginia, for NASA Langley Research Center and Science Applications and International Corporation, 2010.

[3] Public Law 568, 85th Cong., 2d sess., passed 29 July (72 Stat. 426).

because NASA cultivates its relationship with the public in a way that other agencies do not. The viability of NASA long term depends upon public and political support. NASA engenders that support by telling its story and sharing its achievements through a broad range of media that includes everything from written historical publications through NASA's History Office to live broadcasting of historic launches such as NASA's SpaceX Crew-1 to the International Space Station (ISS) which returned NASA's astronauts to space aboard a U.S. vehicle after a nine-year hiatus.

3.1 Mission Directorates

These basic tenets have directed NASA's activities since its creation and are reflected in its modern organizational structure, which clusters its activities in four major areas: the Aeronautics Research Mission Directorate; the Human Exploration and Operations Mission Directorate; the Science Mission Directorate; and the Space Technology Mission Directorate.

Often referred to as "the first 'A' in NASA," the Aeronautics Research Mission Directorate (ARMD) focuses on six areas of research that develop solutions to the major challenges and opportunities for aviation: a growing demand for mobility; the sustainability of energy and the environment; and technology advances in information, communications, and automation. Current research areas include:

- safe, efficient growth in global operations;
- innovation in commercial supersonic aircraft;
- ultra-efficient commercial vehicles;
- transition to low-carbon propulsion;
- in-time system-wide safety assurance; and
- assured autonomy for aviation transformation.

The Human Exploration and Operations Mission Directorate (HEOMD) provides leadership and management of NASA space operations related to human exploration in and beyond low-Earth orbit. HEOMD also oversees low-level requirements development, policy, and programmatic oversight. Its activities include:

- the ISS;
- management of commercial space transportation;
- exploration systems development;
- human space flight capabilities;
- advanced exploration systems; and
- space life and physical sciences research and applications.

The directorate is also responsible for NASA launch services, space transportation, and space communications in support of both human and robotic exploration programs.

In September 2021, NASA split the HEOMD into two new directorates, with one focused on existing space operations (Space Operations Mission Directorate [SOMD]) and the other focused on exploration systems for the Artemis missions (Exploration Systems Development Mission Directorate [ESDMD]). Because the reorganization happened after substantial work for this study had been completed, and because the two new space directorates comprise NASA's human exploration and operations mission, HEOMD will be used throughout this study.

NASA's Science Mission Directorate (SMD) seeks to use the vantage point of space to achieve with the science community and our partners a deep scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effects on the solar system, and the universe beyond. Through its activities, the directorate lays the intellectual foundation for the robotic and human expeditions of the future while meeting today's needs for scientific information to address national concerns, such as climate change and space weather. Its activities from robotic spacecraft are grouped into four broad scientific pursuits:

- Earth Science, the study of Earth from space to advance scientific understanding and meeting societal needs;
- Planetary Science, to advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space;
- Heliophysics, to understand the Sun and its effects on Earth and the solar system; and
- Astrophysics, to discover the origin, structure, evolution, and destiny of the universe, and search for Earth-like planets.

The Space Technology Mission Directorate (STMD) develops transformative space technologies to enable future missions. STMD rapidly develops, demonstrates, and infuses revolutionary, high-payoff technologies through transparent, collaborative partnerships, expanding the boundaries of the aerospace enterprise. By investing in bold, broadly applicable, disruptive technology that industry cannot tackle today, STMD seeks to mature the technology required for NASA's future missions in science and exploration while proving the capabilities and lowering the cost for other government agencies and commercial space activities.

3.2 NASA Locations

In fiscal year (FY) 2021 NASA had a budget of $23.3 billion, 17,000 full-time civilian employees, and 16 Centers and their component facilities (collectively referred to as Centers in this report) (Table 3-1, Figure 3-1). Each Center is associated with one of NASA's three primary mission directorates.

Table 3-1. NASA Centers

Acronym	Name	Location	Est.	Acreage	Real Property Assets (2020)
Aeronautics Research Mission Directorate					
AFRC	Armstrong Flight Research Center	California	1954	762	214
ARC	Ames Research Center	California	1939	1,874	397
GRC	Glenn Research Center	Ohio	1941	307	218
LaRC	Langley Research Center	Virginia	1917	767	316
Human Exploration and Operations Mission Directorate					
ATF	Armstrong Test Facility (component facility of GRC)	Ohio	1956	6,458	169
JSC	Johnson Space Center	Texas	1962	1,634	418
KSC	Kennedy Space Center	Florida	1958	140,000	928

Acronym	Name	Location	Est.	Acreage	Real Property Assets (2020)
MAF	Michoud Assembly Facility (component facility of MSFC)	Louisiana	1964	832	170
MSFC	Marshall Space Flight Center	Alabama	1960	1,841	343
SSC	Stennis Space Center	Mississippi	1962	13,800	422
SSFL	Santa Susana Field Laboratory (component facility of MSFC)	California	1954	451	38
WSTF	White Sands Test Facility (component facility of JSC)	New Mexico	1962	26,900	230
Science Mission Directorate					
GDSCC	Goldstone Deep Space Communication Complex (component facility of JPL)	California	1958	28,170	166
GSFC	Goddard Space Flight Center	Maryland	1959	1,844	552
JPL	Jet Propulsion Laboratory	California	1958	175	205
WFF	Wallops Flight Facility (component facility of GSFC)	Virginia	1959	6,200	555
			TOTALS	**232,395**	**5,341**

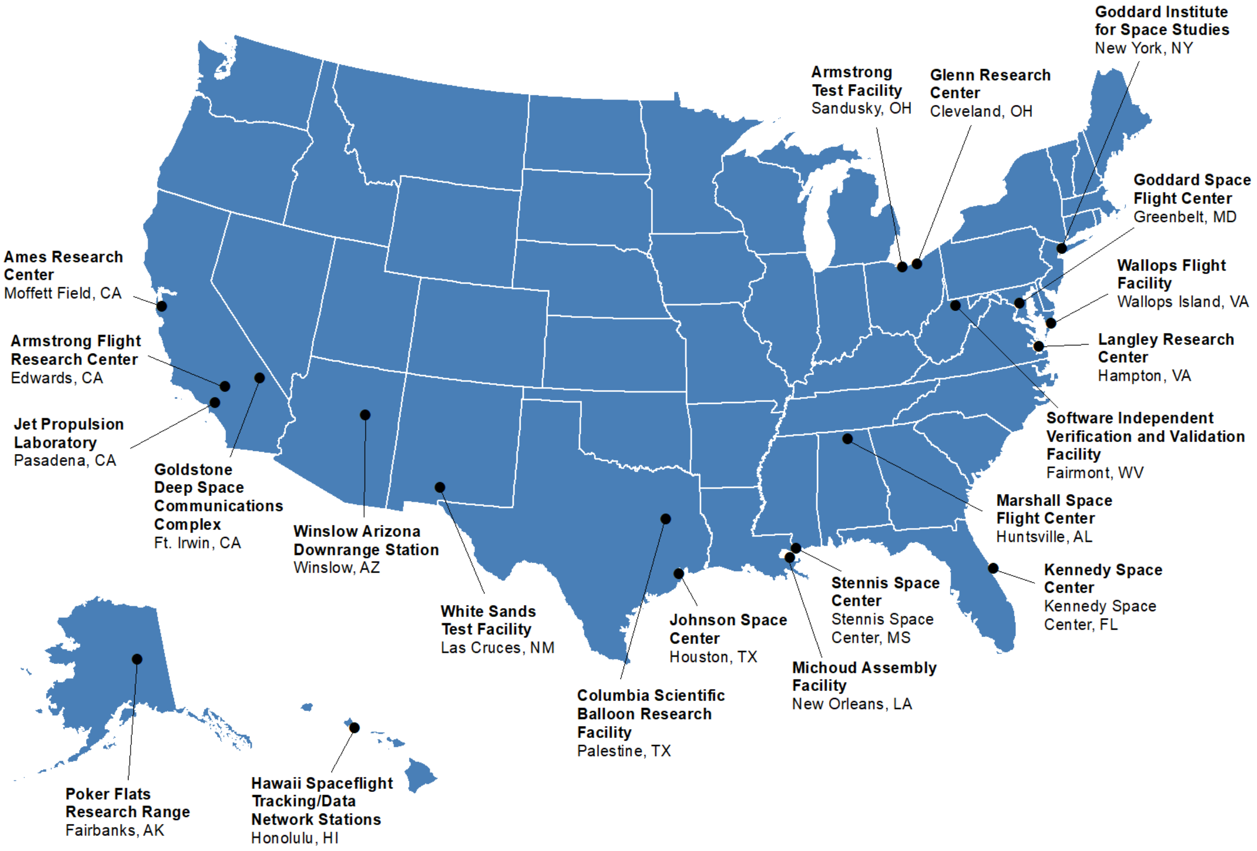

Figure 3-1. NASA U.S. Locations

3.3 Real Property Assets

NASA's U.S. inventory of real property consists of 5,341 assets: 2,341 (44%) are 50 years of age and older; and 3,000 (56%) are less than 50 years of age. Real property assets are enumerated in NASA's Real Property Management System (RPMS), a database maintained by the FRED. The RPMS includes a data field for historic status that is imported from NETS, which is maintained by center CRMs and the primary asset database for NASA's cultural resources.

Approximately 50% of real property assets have been evaluated for NRHP eligibility under at least one context, and 862 (16%) have been found to be eligible for listing, either individually or as a contributing resource to another property or district (Table 3-2). Historic properties are identified by center gate-to-gate surveys, updated periodically, and to a lesser extent, through Section 106 consultation. Two agency-wide thematic surveys have been conducted—the NHL Theme Study "Man in Space," completed by the National Park Service (NPS) in 1984, and the SSP Survey in the 2000s.

Table 3-2. Evaluation Status of Real Property Assets by Center

Center	50 Years of Age and Older			Less than 50 Years of Age			All Ages		
	Total No.	No. Evaluated*	% Evaluated	Total No.	No. Evaluated*	% Evaluated	Total No.	Total Evaluated*	% Evaluated
AFRC	62	61	98%	152	92	61%	214	153	71%
ARC	259	173	67%	138	86	62%	397	259	65%
ATF	279	238	85%	108	67	62%	387	305	79%
GDSCC	78	31	40%	88	2	2%	166	33	20%
GSFC	128	42	33%	424	26	6%	552	68	12%
JPL	120	79	66%	85	8	9%	205	87	42%
JSC	196	193	98%	222	170	77%	418	363	87%
KSC	280	187	67%	648	397	61%	928	584	63%
LaRC	154	119	77%	162	73	45%	316	192	61%
MAF	104	42	40%	66	8	12%	170	50	29%
MSFC	175	133	76%	168	48	29%	343	181	53%
SSC	104	61	59%	318	9	3%	422	70	17%
SSFL	31	16	52%	7	2	29%	38	18	48%
WFF	274	167	61%	281	16	6%	555	183	33%
WSTF	97	76	78%	133	67	50%	230	143	62%
TOTALS	**2,341**	**1,618**	**69%**	**3,000**	**1,071**	**36%**	**5,341**	**2,689**	**50%**

* *Unevaluated resources include those that are generally considered to have a low potential to be NRHP eligible, such as utility lines, sewer features, street furniture, pump houses, storage sheds, and other utilitarian resources. Also included are parcels of land such as easements, which are recorded in RPMS for tracking purposes.*

4.0 AREA 1: AERONAUTICS RESEARCH

4.1 Historical Overview

The year 2015 marked the 100th anniversary of the founding of NASA's predecessor, the NACA. Since that seminal event, aeronautics research has expanded from the fundamentals of flight to hypersonic air vehicles, from measuring the static performance of airfoils to understanding the behavior of complex human-machine systems, and from wood-and-canvas structures to adaptive shape-changing materials. Throughout the last century, research has involved a combination of empirical knowledge gained from ground and flight testing, development of theory and analytic methods, and confirmation by physical demonstration. This research has encompassed an ever-broadening array of technologies, enabling increased performance, enhanced safety, greater efficiency, and reduction of adverse environmental impact.

NASA's lineage can be traced back to the establishment of the NACA on March 3, 1915, by a rider to the Naval Appropriations Act. The legislation chartered the new organization to "supervise and direct the scientific study of the problems of flight, with a view to their practical solution."[4] Initial NACA research focused on the physics of flight, with work involving wind-tunnel tests and flight tests of both models and full-scale aircraft. These tests and the development of theory addressing the aerodynamics of aircraft resulted in greatly increased aircraft speed, payload, and range. Prior to World War II the NACA developed airfoil shapes for wings and propellers that found their way into the designs of many U.S. aircraft of the time, including several important World War II-era aircraft such as the P-51 Mustang. This period also saw the expansion of NACA research into flying qualities to examine aircraft behavior as a human-machine system. In 1941, a pioneering NACA report, "Requirements for Satisfactory Flying Qualities of Airplanes," by Robert Gilruth, who went on to lead NASA's early efforts in space, defined the first set of requirements for the handling characteristics of an aircraft; this work grew into the Cooper-Harper Handling-Qualities Rating Scale for aircraft, which is still in use today.

After World War II, the NACA began to work on the goal of supersonic flight, working closely with the Air Force and Bell Aircraft to design the first supersonic airplane—the X-1 experimental aircraft. This collaboration marked the NACA's first effort in dealing with the initial design, construction, and flight testing of a research airplane. At the same time, development in theoretical understanding led to further aerodynamic improvements, such as development of the swept-wing concept by Robert T. Jones in 1945, the invention of the area rule concept by Richard Whitcomb in 1951, and Harvey Allen's "blunt body concept" for atmospheric reentry, published in 1953. Development of the axial flow compressor in the 1940s, which became the basis for modern turbojet and turbofan engines, reflected further expansion of the NACA's research horizons.

The Propulsion Systems Laboratory (PSL) at the NACA Lewis Flight Propulsion Laboratory in Cleveland, Ohio opened in 1952. It was the nation's largest facility for testing full-scale engines in simulated flight conditions. The PSL had two altitude chambers that could simulate the internal airflow conditions experienced by engines over a full range of power and altitude levels. The PSL allowed researchers to analyze the engine's thrust, fuel consumption, airflow limits, blowout levels, acceleration, starting characteristics, and eventually noise reduction, flutter, inlet distortions, and engine controls. The 1950s at the PSL was primarily staff from the NACA's Lewis Engine Research Division managing ramjet and

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[4] Public Law 271, 63d Cong., 3d sess., passed 3 March 1915 (38 Stat. 930).

turbojet research. The PSL primarily tested jet engines, but did complete periodic ramjet and rocket studies.

Following the passage of the National Aeronautics and Space Act of 1958, which established NASA as the successor to the NACA, aeronautics research expanded to address flight beyond Earth's atmosphere. The X-15 research aircraft set an altitude record of 354,000 feet in 1963 and a record speed of Mach 6.7 in 1967. Research topics supporting this, and other efforts included compressible flow aerodynamics, high-temperature materials, aircraft structures, and reaction controls. By the 1960s, the PSL was testing rocket systems in both altitude chambers, and by the end of the decade was again studying airbreathing engines for aircraft, which included propulsion systems for civilian aircraft too. Other notable achievements include development of the widely used NASA Structural Analysis tools during the 1960s, and initial development and application of computational fluid dynamics (CFD) during the 1970s.

During the 1970s and 1980s, research in supercritical airfoils, winglets, riblets, laminar flow control, and propulsion enabled further advances in performance. These advances were embodied in a vigorous flight demonstration program that included the Quiet Short-haul Research Aircraft, XV-15 tilt rotor research aircraft, and X-29 forward-swept-wing flight research aircraft. In this period, the scope of aeronautics research grew to include a number of important safety and performance enhancements such as digital fly-by-wire controls, "glass cockpits," airborne wind-shear detection, microwave landing systems, and heads-up displays. NASA's research contributed significantly to a transformation of commercial air transportation following the introduction of jet airliners beginning in the 1960s. Aircraft cruise speed increased 70% between 1960 and 1990, and energy efficiency doubled in terms of passenger miles per unit of fuel consumed. In the U.S., during the same period, accidents per departure dropped by 90% and annual passenger miles flown increased tenfold. From the 1970s through the 2000s, NASA also made notable contributions to lowering emissions and noise reduction based on research at Lewis Flight Propulsion Laboratory (GRC).

Accomplishments since 1990 demonstrate not only further expansion of aeronautics research, but also a shift to treating aviation as a complex network of systems that integrates a wide variety of technologies to provide safe, efficient, and environmentally sustainable air transportation. These accomplishments include the following, among many others:

- Development of FutureFlight Central full-scale airport operations simulator, simulations of the National Airspace System, and development of air traffic control and air traffic management tools;
- Exploration of air vehicle and propulsion concepts for energy efficient aircraft, including flight demonstrations of the Blended Wing Body (BWB) X-48B testbed and initiation of research into electric propulsion technology;
- Integration of human factors, guidance, displays, and intelligent flight controls into safety research;
- Further research in aircraft structures, composites, and high-temperature materials;
- Flight demonstration of techniques to shape sonic boom signatures to reduce sonic boom intensity; and
- Further development of physics-based and multidisciplinary tools for aircraft design and analysis.

These and other efforts have made significant contributions to the advancement of aviation in the U.S. and around the world. U.S. passenger miles have grown by more than 50% since 1990, while flying has become safer and aircraft have become quieter and more energy efficient. Thanks, in large measure to technology features attributable to NASA research, accident rates worldwide have continued to decline while commercial aircraft now entering service are 20% more energy efficient and have a noise footprint 60% smaller than the previous generation of aircraft.

NASA consistently undertakes research and development efforts that are outside the scale, risk, and payback criteria that govern commercial investments, with the purpose of proactively transitioning the research findings to the aviation community. NASA aeronautics research has delivered results producing substantial benefits for air transportation in the established focus areas of fundamental aeronautics, vehicle systems and configurations, air traffic management, and aviation safety. These results have transformed aviation to the benefit of the national economy, national defense, the traveling public, and the transportation industry, as well as fostering efforts to minimize environmental impacts.

This brief historical overview illustrates how NASA aeronautics research has produced significant benefits by enabling transformative and far-reaching advances in aeronautics. Development of a sound knowledge base and advances in analysis and simulation have enabled NASA to expand its aeronautical research perspectives within necessarily constrained resources. The history of NASA aeronautics also underscores the continuing need to expand and adjust the scope of research to address the public good, meet emerging needs of the aviation community, and exploit new technologies not previously associated with aviation. NASA's strategy continues to focus on making efficient investments to enable the transformation of aviation to serve future needs, enable demonstrable benefits, and leverage technology advances both within and outside of traditional aviation disciplines.

4.2 Aeronautics Research Centers

NASA's four aeronautics research centers are all NACA legacy sites:

- Ames Research Center (California);
- Armstrong Flight Research Center (California);
- Glenn Research Center, including Armstrong Test Facility[5] (Ohio); and
- Langley Research Center (Virginia).

Though the NACA was a civilian organization, all four NACA legacy centers were originally established adjacent to U.S. military airfields—Moffett Field, Muroc Field, Lewis Field, and Langley Field, respectively.

4.2.1 Ames Research Center

Ames Research Center (ARC) is located adjacent to Mountain View, California, at the south end of San Francisco Bay. ARC encompasses the site of the former Naval Air Station (NAS) Sunnyvale and is now divided into five developed zones and two undeveloped zones. In the western portion of ARC, starting at the north end and moving south is an undeveloped wetlands area; the Bay View area, which is currently under development pursuant to an Enhanced Use Lease; NASA Ames Campus; and NASA Research Park (NRP) at the southwest corner. NRP includes Shenandoah Plaza and the former U.S. Navy

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[5] As a component facility of GRC, Armstrong Test Facility was assigned to the Aeronautics Area of Significance in this draft. However, it will be reassigned to Human Exploration and Operations in subsequent drafts.

Berry Court housing and support area. The eastern portion of the center consists almost entirely of Moffett Federal Airfield (Eastside Airfield), with the exception of an area at the southeast end that is an outgrant to the California Air National Guard. The Eastside Airfield includes two parallel runways; Hangars 1, 2, and 3; munitions magazines; the golf course at Moffett Field; a munitions bunker area; and a safety buffer zone. Jurisdiction of the ARC site is divided between NASA and the Air National Guard. ARC hosts several dozen partners who occupy ARC buildings, including private industry, academic, and nonprofit partners. ARC also holds ground-lease agreements with several entities, including Google (Planetary Ventures) in the Bay View area and University Associates Silicon Valley LLC in the NRP area.

In December 1939, the NACA began construction of the Ames Aeronautical Laboratory off the northwest corner of the NAS Sunnyvale airfield. Ames was the NACA's second laboratory, established after Langley (Hampton, Virginia), and named for Dr. Joseph S. Ames, NACA Chairperson from 1927 to 1939. One of the first buildings constructed at Ames Aeronautical Laboratory was a hangar for research aircraft, now called Flight Research Facility N-210. In October 1940, the NACA's first research aircraft, a North American O-47 observation plane, arrived at the airfield. By 1941, the NACA built and operated wind tunnels, testing airflow of high-speed fighter aircraft during World War II. In the mid-1940s, the NACA added a second aircraft hangar (N-211) to supplement N-210, and extended the ramps and taxiways connecting the airfield to the NACA area. Around this time, the NACA was constructing more wind tunnels and had started a vigorous flight test program on the airfield. One such program, focusing on deicing technologies, won the Collier Trophy in 1946 and validated technology important to the air war in the Pacific during World War II.

The airfield improvements related to Navy Air Transport Service operations in the late 1940s, especially the addition of a longer runway (32R-14L), allowed a significant expansion in the NACA's flight test program. Soon after the end of World War II, the NACA flight test program focused on problems with high-speed aircraft. After Chuck Yeager broke the sound barrier in the Bell X-1 in 1947, NACA test pilot George Cooper broke the sound barrier in dives of aircraft over Moffett Field. The supersonic research carried out by the NACA at Moffett Field in the 1940s resulted in some of the most significant advancements in aeronautical engineering up to that time.

The NACA was renamed NASA in 1958. In the 1960s, the Ames Aeronautical Laboratory continued its research program, and the airfield was the site of extensive research into short takeoff and landing technologies and vertical takeoff and landing aircraft. In 1965, the Army also located its Aeromechanics Laboratory at Moffett Field, and the airfield became the primary site for research on helicopters during the latter years of the Vietnam War. In the mid-1970s, NASA made a major commitment to advancing the technology of tilt-rotor aircraft, and the XV-15, the forerunner of the V-22 Osprey, was test-flown at Moffett Field. The site hosted a fleet of airborne science aircraft that made major discoveries in the discipline of infrared astronomy, and on which the earliest instruments for high-altitude observation of Earth were validated. The airfield became the staging area for some of the most significant earth sciences missions of the 1970s and 1980s. Into the 21st century, ARC has evolved into a diverse and sophisticated research campus.

4.2.2 Armstrong Flight Research Center

NASA Armstrong Flight Research Center (AFRC) is located on the shoreline of Rogers Dry Lake, within the boundaries of Edwards Air Force Base (AFB) in Edwards, Kern County, California. Situated 85 miles north of Los Angeles in the Mojave Desert, the remote area allows AFRC year-round flying weather and the necessary visibility to test research aircraft. AFRC also operates a facility located in Palmdale, California—Building 703. This building and ancillary structures support the Airborne Sciences Program.

AFRC consists of a complex of 214 real property assets. These structures include administrative offices, research laboratories, shops, aircraft service hangers, and storage buildings that support flight-testing and aeronautical research operations. Edwards AFB is comprised of over 300,000 acres, which precludes any concentration of non-military population and affords the AFRC main campus a considerable degree of isolation. The 16-acre AFRC Building 703 facilities include two retention ponds, an asphalt parking lot, and adjacent common areas, in addition to the flight ramp, taxiway, and aircraft ramp area.

AFRC had its beginnings at Edwards in 1946 with the arrival of five NACA scientists [and engineers] at Muroc Army Airfield. They were sent from the NACA Langley Laboratory in Virginia to assist the Army Air Forces with supersonic flight research. Perhaps the most widely known accomplishment at AFRC was achieved by Air Force Captain Charles "Chuck" Yeager in October 1947 when he successfully exceeded the speed of sound in the Bell X-1 rocket plane. After the X-1 series of aircraft demonstrated that one could successfully fly faster than the speed of sound, more questions about aircraft control at transonic speeds were tackled in the D-558-2 Program, whose highly swept wings revealed difficulties at certain points in flight. Air Force and NACA researchers at the Rogers Dry Lake base jointly explored control in a swept wing jet with the X-4, an almost tailless aircraft. Its stability problems could only be solved with advances in computers that came decades later. The X-5 demonstrated that an aircraft's wings could be swept in flight, leading to aircraft capable of both low-speed flight and supersonic flight, that later improved aerodynamic efficiency. The X-15 explored hypersonic flight (above Mach 5), attaining a speed of 4,520 mph on one flight; and exo-atmospheric flight, reaching an altitude of 67 miles; as well as conducting countless experiments on human physiology outside the Earth's atmosphere; control of a vehicle in space; and dynamic heating.

AFRC also tested and validated the Lunar Landing Research Vehicle (LLRV) as a free flying aircraft to train astronauts for landing on the moon. Subsequently, AFRC validated the concept of lifting body aircraft that created lift without conventional wings; applied new technology to install digital computers and small electric motors in place of mechanical and hydraulic controls; conducted research leading to the development of self-repairing and intelligent flight control systems; demonstrated the efficiency of a supercritical wing; conducted research with aerodynamic fairings on trucks; and tested the structural strength of general aviation aircraft. AFRC supported the SSP as the location of the emergency landing site.

More recently, the center has become involved in environmental research, including serving in critical roles in programs to conduct atmospheric sensing, examine previous civilizations' ruins with synthetic aperture radar, and develop infrared imaging of crops to help farmers determine the most opportune time to harvest. Furthermore, AFRC has played a central role in the development of different platforms for this research, including solar powered aircraft, ER-2s, and a fully instrumented DC-8, and of unmanned aerial vehicles (UAVs) that are used to conduct in situ investigation remotely. In 2007, the center's Predator B helped fire fighters locate and track the hottest spots in some of the Western state's raging forest fires and has been involved in the effort to enable UAVs to operate in the national air space.

In the seven decades that have passed since the center was established, AFRC has been the host and participating partner in numerous joint programs with industry, international entities, and the Air Force, to name a few. Armstrong has validated thrust vectoring on jet aircraft, explored methods of attenuating over and under pressure of sonic shock waves, and helped demonstrate an unmanned combat aerial vehicle and the international Stratospheric Observatory for Infrared Astronomy (SOFIA) Program. AFRC also has partnered with the Air Force on a program to develop a collision avoidance system for fighter aircrafts. Additionally, a team of NASA and industry partners are flight testing a blended wing body, a design capable of carrying far more than today's aircraft can. Today, the facility remains the nation's supreme aerospace testing and research facility. AFRC continues to pioneer programs that develop technology for new aircraft and spacecraft, aid the U.S. general aviation community in global economic competition, increase safety for the flying public, and support national security.

4.2.3 Glenn Research Center

NASA's Glenn Research Center (GRC) consists of two geographically separate stations: Lewis Field and Neil Armstrong Test Facility (ATF), discussed in Section 5.0. Lewis Field is a 320-acre facility located in western Cuyahoga County, Ohio, predominantly within the limits of the City of Brook Park, approximately 20 miles southwest of downtown Cleveland. Armstrong Test Facility is a 6,454-acre test installation site located in Erie County, approximately 4 miles south of Sandusky, Ohio, and approximately 50 miles west of Lewis Field. NASA GRC frames their mission by saying, "we design game-changing technology for spaceflight that enables further exploration of the universe. We create cutting-edge aeronautical technology that revolutionizes air travel. We inspire the next generation of explorers to dream big."

In 1940, acting upon a recommendation from the NACA, Congress allocated $8.4 million for construction of a laboratory devoted to scientific research on aircraft engine design. A selection committee chose to locate the new Aircraft Engine Research Laboratory (AERL) in Cleveland on a 200-acre parcel immediately east of the Cleveland Municipal Airport. Construction began in January 1941. During World War II, AERL was involved in "trouble shooting" existing piston engines for the War as well as testing newly developed jet engines. Research conducted at AERL led to numerous aeronautical innovations, including the afterburner and variable-area nozzle. Following World War II, the laboratory focused nearly exclusively on research and development of the jet engine. In April 1947, AERL was renamed the Flight Propulsion Research Laboratory to reflect its expanding (rockets, ramjets, etc.) propulsion research; the name was changed again the next year to the Lewis Flight Propulsion Laboratory in honor of George William Lewis, the NACA's first Director of Aeronautical Research.

On October 1, 1958, Lewis became part of NASA. Lewis continued on the work it had started in the late-1940s on high-energy rocket engines and fuels, especially the use of liquid hydrogen. The development of liquid hydrogen propulsion technology was a critical aspect of the U.S.' successful manned and unmanned space missions. Lewis Field remains engaged in research, technology, and systems development programs. On March 1, 1999, the Lewis Research Center was officially renamed the NASA John H. Glenn Research Center at Lewis Field.

4.2.4 Langley Research Center

NASA Langley Research Center (LaRC) is located in Hampton, Virginia, on 767 acres of government-owned land and divided into two areas by the runway facilities associated with Joint Base Langley-Eustis (JBLE). Established in accordance with the 2005 Base Realignment and Closure Commission, JBLE is comprised of two military installations, Langley Air Force Base (LAFB) and Ft. Eustis. LaRC is comprised of research facilities located in two areas which are approximately 3 miles apart. The two areas, commonly called the West Area and the East Area, are divided by the runways of LAFB. The East Area is located on approximately 3 acres of land permitted to NASA by LAFB. This area is the original 1917 portion of LaRC and contains several wind tunnels, research facilities, and administrative offices. The West Area occupies 764 acres of land and contains the major portion of LaRC with the majority of the facilities located there. NASA LaRC is comprised of over 30 major research facilities and approximately 150 administrative and support facilities.

Currently, the primary functions at the center revolve around the science of aeronautics for military, commercial, and general aviation applications; space research and technology; space transportation; space science and exploration; and the study of atmospheric sciences and aeronautical impact on the environment. Center programs are focused to support NASA's Mission "to pioneer the future in space exploration, scientific discovery, and aeronautics research." NASA staff includes professional engineers and scientists who are technical experts in the fields of aerodynamics, loads and structures, thermodynamics, electronics, space technology, computational analysis, and related fields.

NASA LaRC had its beginnings in 1917 when the War Department purchased land in Elizabeth City County, now Hampton, Virginia. This land was procured for the joint use of the Army and the NACA. It was then designated Langley Field after Professor Samuel Pierpont Langley, an early pioneer in flight. The onset of war in 1917 caused a major change of direction for the new facility, as its mission turned to training, which in turn created a historical role in the transferring of the Army's airpower to the U.S. Air Force, which was formed in 1947. For roughly 25 years, the NACA and the airfield coexisted side by side. As the NACA's mission grew and more space was needed, land on the West side of the airfield was acquired by the NACA from the Air Force.

In 1958, the NACA's "Langley Laboratory" became officially designated "the Langley Research Center of the National Aeronautics and Space Administration." During the years that followed, NASA LaRC grew rapidly. A large majority of LaRC's infrastructure was built during the 1950s and 1960s, and research during that time helped aircraft break the sound barrier and played a major role in helping Americans reach the moon. In the 1970s, research at the center focused on aircraft design to cut emissions and noise, and on testing space shuttle concepts. From the 1980s to the present, NASA LaRC has continued to provide important research support and technological advances in the areas of space exploration and civil and military aviation.

4.3 Themes of Exceptional Importance

Exceptional importance in the Area of Aeronautics Research is demonstrated through the Apex Events, a summary of which are presented in Section 4.4, below. Apex Events are events, discoveries, inventions, or innovations that: (1) represent the successful resolution of a challenge or goal; or (2) that initiate a shift in perspective or trajectory in a manner that redefines those challenges or goals. Apex Events and their significance are summarized in the following. A more detailed presentation of the Apex Events is provided in Appendix B.

NRHP Criterion A recognizes properties that are associated with "events that have made a significant contribution to broad patterns of our history." Individually, the Apex Events each represent an "event" of exceptional importance in NASA aeronautics research since 1973. Together, they illustrate "broad patterns" of exceptional importance (Themes), any one of which could form the basis of a NRHP historic context study. The Themes that are most clearly demonstrated in the selected Apex Events that follow include:

- Increased sustained aircraft speed, altitude, and range;
- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground;
- Increased fuel efficiency; and
- Reduced environmental impact.

These Themes are themselves interrelated—computerization has enabled greater safety, increased fuel efficiency has reduced the environmental impact of flight, etc. As such they are parallel research threads within NASA's aeronautics research program that are woven together by the military and commercial users driving the industry and pushing it forward. Additionally, the Apex Events illustrate the process by which problem-solving and innovation occurs within the science and technology fields—i.e., observation, research, design/development, experimentation/testing, observation/analysis, and refinement.

4.4 Apex Events

4.4.1 Winglets Development and Testing (1974–1980)

Description. Winglets are vertical extensions of wingtips that improve an aircraft's fuel efficiency and cruising range. Designed as small airfoils, winglets reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. By reducing wingtip drag, fuel consumption goes down and range is extended.

Statement of Significance. Originally developed by NASA in the 1970s at a time when energy concerns drove research in the area of fuel economy, winglets are today found on aircraft of all types and sizes, from single-seat hang gliders and ultralights to global jumbo jets. Winglets are one of the most successful examples of a NASA aeronautical innovation being utilized around the world.

Significance Criteria. The development of the winglet is exceptionally important in the NRHP areas of engineering, invention, and transportation and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Increased fuel efficiency; and
- Reduced environmental impact.

Period of Significance. The recommended period of significance is 1974–1980. It includes the initial concept and design development by Dr. Richard Whitcomb, model testing at LaRC, and the KC-135 flight testing program at AFRC from 1979–1980.

4.4.2 Aerodynamic Truck Fairings (1973–1980)

Description. Fairings are structural elements of an aircraft or vehicle body that serve the purpose of reducing drag. During the 1970s and 1980s, NASA's aerodynamic truck studies developed fairings for the front, top, sides, and back of tractor-trailers to help reduce aerodynamic drag and improve fuel efficiency.

Statement of Significance. Part of NASA's efforts in the 1970s to enhance fossil fuel efficiency, AFRC's aerodynamic truck studies resulted in the development of fairings, an innovation adopted by the U.S.

trucking industry. Today's highly-faired long-haul trucks are a direct product of this project, resulting in dramatic improvement in fuel efficiency of long-haul trucks and delivery step vans.

Significance Criteria. The development of truck fairings is exceptionally important in the NRHP areas of engineering, invention, and transportation and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Increased fuel efficiency; and
- Reduced environmental impact.

Period of Significance. The recommended period of significance is 1973–1980, reflecting the origination and peak productive years of the aerodynamic truck studies at AFRC.

4.4.3 Digital Fly-by-Wire Flight Control System Development and Testing (1969–1985)

Description. Fly-by-wire (FBW) is a system that replaces the conventional manual flight controls of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term) and flight control computers determine how to move the actuators at each control surface to provide the ordered response. The Digital Fly-by-Wire (DFBW) Flight Control System is an electronic flight-control system coupled with a digital computer.

Statement of Significance. NASA's FBW research program is considered one of the most significant and most successful aeronautical programs in its history, as it validated the principal concepts of all-electric flight control systems now used on nearly all modern high-performance aircraft and on military and civilian transports. This, in turn, laid the groundwork for leading, not only the U.S., but to a great extent the entire world's aeronautics community into the new era of DFBW flight controls.

Significance Criteria. The DFBW program is exceptionally important in the NRHP areas of communications, engineering, invention, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground; and
- Increased fuel efficiency.

Period of Significance. The recommended period of significance is 1969–1985. It includes the concept development and application to aircraft, and the full duration of the flight-testing program utilizing the F-8 Crusader "802" at AFRC.

4.4.4 Integrated Propulsion Control System Development and Testing (1973–1976)

Description. The Integrated Propulsion Control System (IPCS) replaced the traditional hydro-mechanical systems with integrated digital engine and inlet controls in a General Dynamics F-111 Aardvark for the purpose of testing the feasibility of integrated propulsion controls at supersonic speeds.

Statement of Significance. The IPCS was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized Highly Integrated Digital Electronic Control (HIDEC) Program.

Significance Criteria. The IPCS is exceptionally important in the NRHP areas of communications, engineering, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground; and
- Increased fuel efficiency.

Period of Significance. The recommended period of significance is 1973–1976. It includes the concept development at GRC and AFRC, and the full duration of the flight-testing program utilizing the F-111E Aardvark at AFRC.

4.4.5 Cooperative Airframe/Propulsion Control System Development and Testing (1977–1978)

Description. The Cooperative Airframe/Propulsion Control System (CAPCS) was a cooperative ("Co-Op") digital control system that integrated the engine inlet control, autopilot, autothrottle, airdata, navigation, and stability augmentation systems installed in the Lockheed YF-12C Blackbird to improve overall aircraft control.

Statement of Significance. The CAPCS was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized HIDEC Program.

Significance Criteria. The CAPCS is exceptionally important in the NRHP areas of communications, engineering, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground; and
- Increased fuel efficiency.

Period of Significance. The recommended period of significance is 1977–1978. It includes the period of aircraft preparation and modification to install the CAPCS and the full duration of the flight-testing program utilizing the YF-12C (SR-71A) Blackbird.

4.4.6 Digital Electronic Engine Control System Test Program (1981–1983)

Description. The Digital Electronic Engine Control (DEEC) system was an engine mounted, fuel-cooled, single-channel digital controller that received inputs from the aircraft airframe and engine to control a wide range of engine functions. The DEEC system was initially applied to Pratt & Whitney's F100 turbofan engine in order to transition F-15 aircraft from hydro-mechanical propulsion control to digital. The DEEC was to engine controls what DFBW was to flight controls.

Statement of Significance. Development of the DEEC is looked upon as a milestone in propulsion control, and a major transition from hydro mechanical to digital control. Benefits of the system are substantial and include reduced operating and maintenance costs—plus major boosts in engine performance and extended engine life. The DEEC was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized HIDEC Program. Through the F-15A testing program, NASA played an integral role in the refinement and demonstration of successful operation of the DEEC system.

Significance Criteria. The DEEC System Test Program is exceptionally important in the NRHP areas of communications, engineering, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground; and
- Increased fuel efficiency.

Period of Significance. The recommended period of significance is 1981–1983, when the DEEC System Test Program was carried out at AFRC utilizing the F-15A 835.

4.4.7 Highly Integrated Digital Electronic Control Program (1983–1993)

Description. The HIDEC Program was a flight test program carried out at AFRC from 1983 to 1993 with an F-15A aircraft (tail number 835). The HIDEC Program studied and validated the integration of aircraft engine operations with air data and flight control systems to improve aircraft performance. The major elements of HIDEC were a Digital Electronic Flight Control System (DEFCS), the engine-mounted DEECs, an on-board general-purpose computer, and an integrated architecture allowing all components to "talk to each other."

Statement of Significance. The HIDEC Program, utilizing the F-15A 835, was an important step in the digital computerization of aircraft operations. It demonstrated the feasibility of integrating what had been two separate development paths in aeronautics – digital flight control and digital engine control – and illustrated the significant benefits that it offered with respect to fuel efficiency, aircraft maintenance, and operation costs. The advantages of extended engine life and enhanced engine and flight performance also give the aircraft a greater safety margin, a factor that can be appreciated by aircrews as well as passengers. Elements of the HIDEC Program were incorporated into military, commercial, and general-purpose aircraft.

Significance Criteria. The HIDEC Program is exceptionally important in the NRHP areas of communications, engineering, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Enhanced aircraft maneuverability;
- Computerization and integration of aircraft systems and diagnostics;
- Greater safety in the air and on the ground; and
- Increased fuel efficiency.

Period of Significance. The recommended period of significance is 1983–1993, they years during which the F-15A 835 was used for the HIDEC Program at AFRC.

4.4.8 Lifting Body Program (1963–1975)

Description. The Lifting Body Program (1963–1975) was an exploration of wingless aircraft design that was intended to provide an alternative to ballistic reentry from space such as that used by the Apollo capsule, so that a crew could fly back through Earth's atmosphere and land at an airfield.

Statement of Significance. The Lifting Body Program demonstrated the ability of pilots to maneuver in the atmosphere and safely land a wingless vehicle. The information the Lifting Body Program generated contributed to the data base that led to development of the Space Shuttle orbiter. The X-24A shape was used for the X-38 Crew Return Vehicle technology demonstrator, designed as an escape vehicle for the ISS.

Significance Criteria. The Lifting Body Program is exceptionally important in the NRHP areas of engineering and invention, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Increased sustained aircraft speed, altitude, and range;
- Enhanced aircraft maneuverability; and
- Greater safety in the air and on the ground.

Period of Significance. The recommended period of significance is 1963–1975, beginning with the initial concept development at NASA and concluding with the end of the flight test program.

4.4.9 Bell XV-15 Tilt Rotor Research Aircraft Development and Testing (1971–1983)

Description. Tilt rotor aircraft have upward-facing rotors that spin to lift the aircraft, like a helicopter. However, the rotors also are able to shift to face forward, thus changing the configuration from a helicopter, which can take off vertically without a runway and hover in place, to that of a traditional propeller airplane, which can move faster and has a longer range. These combined qualities make tilt rotors ideal for search and rescue operations, for transport to remote locations and for shorter-range passenger travel. Tilt rotors can land on small airfields in the centers of cities and thus reduce total travel time.

Statement of Significance. The XV-15 TRRA project, a joint project between NASA and the Army, is recognized as one of the most significant to have been pursued at ARC. The flight test program was an integral part of the development of the world's first successful tilt rotor production aircraft, the V-22 Osprey. Although the XV-15 was built by the Bell Helicopter Company, the government (the Army and NASA) successfully wrote the specifications for and fostered the introduction of a new aircraft type into the U.S. aviation market. The technology validation and the demonstrations provided by the TRRA gave the government and the aviation industry the confidence to invest in the tilt rotor technology. Today approximately 400 of the V/STOL V-22 are in service today with the U.S. Navy, Marines, and Air Force, as well as the Japanese self-defense force.

Significance Criteria. The TRAA Program is exceptionally important in the NRHP areas of engineering, invention, military, and transportation, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Increased sustained aircraft speed, altitude, and range; and
- Enhanced aircraft maneuverability.

Period of Significance. The recommended period of significance is 1971–1983, from the formal establishment of the TRRA joint program at ARC, testing and refinement of the XV-15 aircraft, to the selection of Bell-Boeing to manufacture the production version V-22 Osprey.

4.4.10 High Angle-of-Attack Technology Program (1985–1996)

Description. Angle of attack (alpha) is an aeronautical term that describes the angle of an aircraft's body and wings relative to its actual flight path. During maneuvers, pilots often fly at extreme angles of attack—with the nose pitched up while the aircraft continues in its original direction. This can lead to conditions in which the airflow becomes separated over large regions of the lifting surfaces (airfoils). This can result in insufficient lift to maintain altitude or control of the aircraft and a corresponding increase in drag—a condition known as stall. NASA's High Alpha Research Vehicle (HARV), an F/A-18, was used to research ways to reduce the situations in which a stall occurred and increase the angle of attack possible to safely execute in high-performance aircraft.

Statement of Significance. Between 1985 and 1996 the High Angle-of-Attack Technology Program (HATP) used the F/A-18 HARV aircraft to demonstrate stabilized flight at angles of attack between 65 and 70 degrees using thrust vectoring vanes, a research flight control system, and forebody strakes. This combination of technologies provided carefree handling of a fighter aircraft in a part of the flight regime that was otherwise very dangerous. Flight research with the HARV increased understanding of flight at high angles of attack, enabling designers of U.S. fighter aircraft to design airplanes that fly safely in portions of the flight envelope that pilots previously had to avoid. In addition, the HARV made a significant contribution to the applicability of CFD to high angle-of-attack flows by providing a comparison of CFD, wind-tunnel, and flight data at the same scale. Research conducted in the HATP has informed the designs for the F-22 Advanced Tactical Fighter and prototypes of the Joint Strike Fighter.

Significance Criteria. The HATP is exceptionally important in the NRHP area of engineering and military, and illustrates the following Themes of NASA's aeronautics research program in the last 50 years:

- Increased sustained aircraft speed, altitude, and range;
- Enhanced aircraft maneuverability; and
- Greater safety in the air and on the ground.

Period of Significance. The recommended period of significance is 1985–1996, from the beginning of the HATP and extending the full duration of flight tests undertaken with the F/A-18 HARV aircraft.

4.5 Significant People

A representative sample of extraordinary people who have worked to accomplish NASA's exceptional achievements of the last 50 years in the Area of Aeronautics Research are presented below. More complete biographical information on each person is available in Appendix C.

Table 4-1: List of Significant People in the Area of Aeronautics Research

Person	Association
Harvard Lomax (1922–1999)	Computational Fluid Dynamics
Marta Bohn-Meyer (1957–2005)	F-16 XL Supersonic Laminar Flow Control Project

Dr. Richard T. Whitcomb (1921–2009)	Winglets Development and Testing
Mary Winston Jackson (1921–2015)	Supersonic Pressure Tunnel
Thomas C. McMurtry (1935–2015)	Winglets Development and Testing
John A. Manke (1932–2019)	Lifting Body Program
Katherine Johnson (1918–2020)	Human Space Flight Program
Robert MacCormack	Computational Fluid Dynamics
Daniel Mikkelson	Turbo Propfan Project

4.6 Summary

The history of NASA aeronautics underscores the continuing need to expand and adjust the scope of research to address the public good, meet emerging needs of the aviation community, and exploit new technologies not previously associated with aviation. NASA's strategy continues to focus on making efficient investments enabling the transformation of aviation to serve future needs, realize demonstrable benefits, and leverage technology advances both within and outside of traditional aviation disciplines. With an understanding of the exceptional importance of NASA's aeronautics research as demonstrated through a range of representative Apex Events, it is possible to begin to identify the types of real property assets that best illustrate that significance.

5.0 AREA 2: HUMAN EXPLORATION AND OPERATIONS

5.1 Historical Overview

The Cold War between the United States and the former Soviet Union gave birth to the space race and an unprecedented program of scientific exploration. The Soviets sent the first person into space in April 1961. In response, President John F. Kennedy challenged our nation "to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to earth."[6] It took eight years and three NASA programs—Mercury, Gemini and Apollo—to meet this challenge.

Project Mercury, the first U.S. program to put humans in space, made 25 flights, six of which carried astronauts between 1961 and 1963. The objectives of the program were: to orbit a human spacecraft around Earth, investigate a person's ability to function in space, and recover both the astronaut and spacecraft safely. Mercury showed that humans could function for periods up to 34 hours of weightless flight.

The Gemini program followed the Mercury program, and primarily tested equipment and procedures and trained astronauts and ground crews for future Apollo missions, which would go to the Moon. The program's main goals were to test an astronaut's ability to fly long duration flights (14 days); to understand how a spacecraft could rendezvous and dock with another vehicle in Earth orbit; to perfect re-entry landing methods; to further understand the effects of longer spaceflights on astronauts; and extravehicular activity (EVA) was another important component of Gemini.

In 1969, Project Apollo landed the first humans on the lunar surface and returned them safely to Earth, fulfilling President Kennedy's challenge. The Apollo program and its staff also developed technology to meet other national interests in space, conducted scientific exploration of the Moon, and developed humanity's capability to work in the lunar environment.

Following the successful conclusion of the Apollo program in the early 1970s, NASA sought new goals for the human exploration of space. Initial goals focused on the establishment of an orbital space station that could serve as a platform for observations and a laboratory/workshop for a wide variety of experiments, and a reusable transportation vehicle to service it.

Skylab was the first United States space station. Launched in May 1973 it was operated by three separate three-astronaut crews, designated as Skylab 2, Skylab 3, and Skylab 4. The space laboratory included an orbital workshop and a solar observatory, where major operations included Earth observations and hundreds of experiments. Skylab's orbit decayed and it disintegrated upon reentry into the atmosphere in July 1979.

The Apollo-Soyuz Test Project was the first manned international space mission, carried out jointly by the United States and the Soviet Union in July 1975. In the 1970s, U.S.-Soviet political tensions began to thaw and competition in space gave way to cooperation, as exemplified in the Apollo-Soyuz Test Project. International collaboration became the norm during the Space Shuttle era and led to the successful establishment and operation of the ISS. These partnerships have taught us more about the

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[6] President John F. Kennedy, "Address to Joint Session of Congress," 25 May 1961.

universe, improved our lives at home, and expanded the possibilities for future exploration into deep space. In addition to its political significance, the Apollo-Soyuz mission also demonstrated docking techniques and mechanisms for international missions.

The SSP constituted the United States' primary means for sending astronauts into space: a program that continued for more than thirty years. Conceived as a system of reusable manned space vehicles, the system sought to reduce the cost of spaceflight and support ambitious follow-on programs including permanent orbiting space stations and a human landing on Mars. Between 1981 and 2011, 135 Shuttle missions carried people into orbit repeatedly; launched, recovered and repaired satellites; conducted cutting-edge research; and built the largest structure in space, the ISS. The Space Shuttle fleet demonstrated the viability of reusable boosters and spacecraft and achieved significant successes that serve as the foundation for ongoing efforts in space exploration. These include placing the Hubble Space Telescope (HST) into Low Earth Orbit (LEO), servicing the HST and orbiting satellites, and launching higher Earth orbit and interplanetary missions using the Payload Assist Module (PAM-D) or the Inertial Upper State (IUS) technologies. Two shuttles, Challenger and Columbia, were destroyed, in 1986 and 2003 respectively. These losses resulted in the death of 14 astronauts and led to an increased focus on mission safety.

In recent years NASA's human exploration programs have been centered in the HEOMD. HEOMD manages the ISS and develops the next generation of rockets, spacecraft, and other capabilities that will extend human presence throughout the solar system. The establishment in 2017 and rapid expansion of the Artemis program to return humans to the Moon by 2024 prompted NASA in 2021 to reorganize HEOMD into two areas: the Exploration Systems Development Mission Directorate (ESDMD) focused on Artemis, and the Space Operations Mission Directorate (SOMD), which manages NASA's current and future space operations in and beyond low-Earth orbit (LEO), including commercial launch services to the ISS.

Because NASA, as an agency, is forward looking, the most recent definition of the roles and responsibilities of the HEOMD only addresses current efforts. HEOMD's present focus is upon the following programs:

International Space Station. Now assembled and fully operational, the ISS serves as the largest scientific and technological cooperative program in history. The Station draws from the resources and scientific expertise of the United States, Canada, multiple European states, Japan, and Russia. The ISS supports exploration goals—with an emphasis on understanding how the space environment affects astronaut health and capabilities—and also serves as a technology testing ground for future long-duration space missions (including work on crew health and safety systems). NASA also conducts research into fundamental space biology and physical sciences aboard the ISS. HEOMD has entered into an agreement with a not-for-profit organization to manage non-NASA research conducted aboard the ISS in its role as a national laboratory. The ISS will continue to serve as a critical science platform in Earth's orbit until at least 2024.

Commercial Space Flight Development. Commercial space transportation is vital to the future of human space exploration. As NASA charts a new course to send humans deeper into space, it is working with private industry to spur economic growth in the commercial space sector. HEOMD is partnering with both long-established and emerging aerospace companies that are developing new rockets and other capabilities to carry both cargo and astronauts to the ISS and other destinations in LEO. These partnerships will create the capabilities that will continue to send humans into space on American-made vehicles, assuring access to the ISS, strengthening America's space industry, and providing a catalyst for future business ventures to capitalize on affordable access to space. As part of these partnerships, NASA is building alliances with private companies to build and reuse NASA facilities for commercial space programs.

Deep Space Exploration. Under the auspices of HEOMD's Exploration Systems Development program, NASA is developing the next generation of vehicles that will take astronauts beyond LEO on deep space missions to places where no one has gone before, including asteroids, Lagrange points, and, ultimately, Mars. The Multi-Purpose Crew Vehicle (MPCV), which has incorporated dozens of technology advancements and innovations into the spacecraft's subsystem and component design, will be the primary spacecraft to transport astronauts. It will be capable of conducting regular in-space operations such as rendezvous, docking, and allowing astronauts to conduct spacewalks. The Space Launch System (SLS) will be a heavy-lift rocket capable of carrying the MPCV and the large payloads necessary for human missions to deep space. The SLS, will ultimately be capable of carrying 130 metric tons to LEO, using both the proven Space Shuttle main engines (RS-25D/E) and newly developed J-2x rocket engines in the core, as well as advanced boosters. In addition to development of the vehicles necessary to take humans to deep space, NASA will build the infrastructure necessary to support the SLS and commercial launches at Kennedy Space Center and other NASA flight facilities. HEOMD's Advanced Exploration Systems program will develop innovative systems and robotic precursors to sustain human missions beyond LEO.

Launch Services. HEOMD oversees Agency launch requirements, including providing launches on commercial expendable launch vehicles (ELVs). Unpiloted ELVs have carried some of NASA's most important space science missions, including Voyagers 1 and 2 and the Mars Exploration Rovers, Spirit and Opportunity. They also carried Earth science missions, such as Terra, Aqua, and Aura. The Launch Services Program features two annual "on-ramp" opportunities, during which private launch providers may be added to the NASA Launch Services II contract. This helps encourage the launch services market and provides NASA with increased options for selecting launch vehicles for its science missions.

Space Communications and Navigation. To track and acquire data for the Agency's space flight missions, NASA operates space communications networks such as the Near Earth Network, the Deep Space Network, and the Tracking and Data Relay Satellite System (TDRSS). The space communications networks communicate with launch vehicles, Earth-orbiting spacecraft (including the ISS), and spacecraft throughout the solar system.

Human Space Flight Capabilities. HEOMD is responsible for human space flight capabilities, including Space Flight Crew Operations (SFCO), the Mission Operations Directorate at Johnson Space Center, extravehicular activity (EVA) training, and work at the Michoud Assembly Facility in Louisiana. SFCO focuses on critical health and safety risks and risk-management solutions that improve crew performance and protect our astronauts from space travel hazards. Human space flight capabilities also involve managing NASA's Rocket Propulsion Test efforts.

5.2 HEOMD Centers

The Centers assigned to HEOMD are:

- Armstrong Test Facility (Ohio), a component facility of GRC;
- Johnson Space Center (Texas);

- Kennedy Space Center (Florida);
- Marshall Space Flight Center (Alabama);
- Michoud Assembly Facility (Louisiana), a component facility of MSFC;
- Santa Susana Field Laboratory (California), a component facility of MSFC;
- Stennis Space Flight Center (Mississippi); and
- White Sands Test Facility (New Mexico), a component facility of JSC.

All of these facilities were originally established during the period 1958–1964 for the purpose of advancing human space exploration.

5.2.1 Armstrong Test Facility

Until recently known as Plum Brook Station, the Neil A. Armstrong Test Facility (ATF) dates to 1941, when the War Department acquired about 9,000 acres of land to construct the Plum Brook Ordnance Works (PBOW). The development of PBOW entailed the construction of approximately 598 buildings used for the manufacture and storage of explosives. PBOW produced munitions including nitroaromatic explosives (also known as TNT) until the end of World War II. After World War II, PBOW closed and the site remained generally idle until 1956 when the NACA leased 500 acres for construction of a nuclear test reactor. The Plum Brook Reactor Facility, designed to study the effects of radiation on materials used in space flight, was the first of 15 test facilities eventually built by the NACA and its successor agency, NASA, at ATF. By 1963, NASA had acquired the entire 9000-acre site at Plum Brook for these additional facilities.

In 1973, after successfully completing the Apollo moon program, congressional budget constraints caused NASA to defer many of its research and development programs and to cease operations at several research facilities. The major test facilities at ATF were placed in standby mode, capable of being reactivated for future use. The reactor facility was shut down and all the nuclear fuel removed and shipped offsite for disposal or reuse. In 1987, NASA, along with several other government agencies and the private sector, expressed a renewed interest in the unique facilities at ATF, and several major test facilities there were reactivated. Today active facilities at the ATF include the Space Environments Complex, the In-Space Propulsion Facility, the Combined Effects Chamber, the Hypersonic Tunnel Facility, and the NASA Electric Aircraft Testbed.

5.2.2 Johnson Space Center

The Lyndon B. Johnson Space Center (JSC) is NASA's center for human spaceflight. Established in 1961 as the Manned Spacecraft Center (MSC), the facility was renamed in 1973 in honor of U.S. President and Texas native Lyndon B. Johnson. JSC is NASA's center for human spaceflight training, research, and flight control. JSC comprises a complex of approximately 100 buildings on 1,634 acres southeast of Houston.

NASA's Space Task Group (STG) was originally located in Virginia at LaRC. With the establishment, in 1959, of the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, plans were made to incorporate the STG, creating a new "space projects center." However, by 1961, it was obvious that the STG needed to develop into an autonomous center, and President John F. Kennedy's speech committing the United States to "landing a man on the moon and returning him safely to the Earth" reinforced that idea.

NASA selected Houston as the location for what would become the MSC because it met key criteria: availability for water transportation by large barges; a moderate climate; availability of all-weather commercial jet service; an in-place industrial economy with technical facilities and labor; a culturally attractive community near a university; at least 1,000 acres of land; and strong electric and water suppliers. Construction at the Texas site began in 1962 and by June 1964 the MSC opened at in its new location, although construction continued on many facilities, including the Space Environment Simulation Laboratory, the Mission Control Center, the Flight Acceleration Facility, and the Vibration and Acoustic Test Facility. MSC assumed formal responsibilities as the home of the Mission Control Center for the Gemini program in 1964.

Since then, JSC has continued to make history in space exploration, highlighted by scientific and technological advancements as well as engineering triumphs. From JSC's inception, it was to be the primary center for U.S. space missions involving astronauts; however, through the years JSC has expanded its role in a number of aspects in space exploration. These include serving as the lead NASA center for the International Space Station (ISS)—a sixteen-nation, U.S.-led collaborative effort that is constructing and supporting the largest, most complex human facility to ever operate in space. Home to NASA's astronaut corps, JSC trains space explorers from the U.S. and the space station partner nations, preparing these individuals as crew members for long-duration missions on the ISS. JSC also executed the NASA Commercial Orbital Transportation Services (COTS) program from 2006 to 2013, which was a public-private partnership that allowed commercial spacecraft to deliver cargo to the ISS.

The center led the Apollo-Soyuz and Skylab projects and was home to the SSP office beginning in 1970. It currently leads ISS operations and missions, development of the Orion spacecraft, and numerous other advanced human exploration projects. JSC also plays an important role in NASA's Commercial Crew program. JSC has pioneered in research and development of manned spacecraft systems; development of astronaut and crew life support systems; development and integration of experiments for space flight activities; and application of space technology, and supporting scientific, engineering, and medical research.

5.2.3 Kennedy Space Center

The John F. Kennedy Space Center (KSC) was originally established in 1958 as the NASA Launch Operations Center (LOC). KSC is adjacent to Cape Canaveral Space Force Station (CCSFS, formerly Canaveral Air Force Station [CCAFS]) and the management of the two facilities work closely together. In 1958 CCAFS provided NASA with several facilities, including office, hangars, and Launch Complexes 5, 6, 26, and 34 at CCAFS. The former Missile Firing Laboratory (MFL) was renamed the Launch Operations Directorate (LOD) and became a branch of the Marshall Space Flight Center (MSFC). As LOD responsibilities grew and the launch team expanded, KSC was designated a field center named the Launch Operations Center (LOC), separating it from MSFC.

KSC maintains operational control over approximately 700 facilities on a 140,000-acre site located in Brevard and Volusia counties on the east coast of Florida. The major areas for facilities include the Industrial Area, the Vehicle Assembly Building (VAB) Area (also known as the LC-39 Area), and the Shuttle Landing Facility (SLF) Area. The Industrial Area was developed to support administrative/technical functions and to provide areas for processing hazardous payloads. This area includes the Headquarters Building, the Neil Armstrong Operations and Checkout (O&C) Building, Space Station Processing Facility, and the Kennedy Data Center. The VAB Area was developed primarily to support launch vehicle operations and related launch processing activities. It contains the VAB, Launch Control Center (LCC), OPF1 & 2, Launch Pads 39A and 39B, Solid Rocket Booster (SRB) processing facilities, and other support facilities.

The SLF Area contains the SLF Runway, SLF operations buildings, and landing aids systems support facilities. During the SSP, SLF facilities supported mate-demate operations, Space Shuttle carrier aircraft operations, and astronaut flight training activities. Future operations and development at the SLF will accommodate commercial spaceflight programs, horizontal launch and landing activities, testing of unpiloted aerial vehicles, testing of experimental spacecraft, and ground-based research and training.

CCAFS served as the location for the launch of the first Apollo flights, as well as all the Project Mercury and Gemini flights, though these launches were managed by NASA. Since December 1968 KSC has been NASA's primary launch center for human spaceflight. Launch operations for the Apollo, Skylab, and Space Shuttle programs were conducted at Launch Complex 39. KSC also manages the NASA Western Test Range Operations Office at Vandenberg, California, which is responsible for the integration, test, checkout, and launch of unmanned light and medium vehicles.

5.2.4 Marshall Space Flight Center

Established in 1960, the George C. Marshall Space Flight Center (MSFC) in Huntsville, Alabama is the major NASA installation of propulsion operations and program management in support of manned and unmanned space missions. MSFC is a tenant of the U.S. Army's Redstone Arsenal, located in Madison County, Alabama.

The area now designated as MSFC was initially purchased in 1941 by the U.S. Army as part of a 32,255-acre acquisition for the Chemical Warfare Service. Before the purchase, the land was largely farmed in cotton, corn, hay, and small grains. MSFC was activated as a NASA field installation in July 1960 and named in honor of General George C. Marshall. A renewable 99-year lease agreement transferred buildings, land, and space projects from the U.S. Army to MSFC. The original Army-NASA agreement included an area of 1,346 acres as well as the existing buildings and facilities used by the Army Ballistic Missile Agency. Successive land transfers from the U.S. Department of Defense (DoD) and the Tennessee Valley Authority (TVA) have increased MSFC's total acreage to approximately 1,840.

MSFC has played a major role in the development of NASA's launch vehicle, dating back to the Mercury program's Redstone rocket. MSFC developed the Saturn Vehicle, used by the Apollo program. Through its significant contributions to the development of new space technologies, the Saturn Program became a cornerstone in the advancement of the space program. Saturn rockets first took man to the moon and then put Skylab into orbit. NASA's original development plan for the Saturn Program called for the Saturn I to serve as a building block in the development of larger Saturn rockets, eventually known as the Saturn IB and Saturn V. The Saturn V, the largest rocket ever attempted, was designated to be the vehicle to send man to the moon. The lift-off of the first Saturn V, in November 1967, was a significant milestone for MSFC and NASA. The Saturn V made possible it to leave Earth's atmosphere and complete Earth orbital missions for the Apollo and later for Skylab.

Before the 1960s were over MSFC began to broaden its perspectives and look to other projects, including Skylab and the Space Shuttle. NASA first seriously considered various space station concepts for long-duration, Earth-orbital missions in 1962. By August 1965, NASA had created the Apollo Applications Office, which brought plans for a space station closer to realization. MSFC began then to focus on designs for an S-IVB orbital workshop where astronauts could live and conduct scientific experiments.

The Skylab project was one of MSFC's most comprehensive mission involvements. MSFC's responsibilities included early definition studies, development and integration of Skylab hardware elements, providing launch vehicles, development of the various manned modules, development and assembly of the scientific payload, systems engineering and integration, development of crew procedures, and providing real-time mission support. During Skylab's development, new capabilities grew in response to the unusual technical and managerial challenges.

In the late 1960s and early 1970s, NASA made plans to conclude the Apollo Program while preparing Skylab for launch and initiating work on the Space Shuttle. When NASA initiated the SSP, MSFC became responsible for the development of the advanced propulsion systems. The principal propulsion elements of the Shuttle included the Orbiter, Main Engines, External Tank, and SRBs. MSFC managed the development of each of these elements, except for the Orbiter. MSFC developed unique solutions for many of the challenges associated with each of the propulsion elements. The end result was a totally new launch vehicle.

The Main Engines were reusable rocket engines capable of producing nearly 1 million pounds of thrust. The first Main Engine was completed in 1975 and after extensive testing were installed in the Space Shuttle Columbia in 1980. The External Tank is the largest component of the Space Shuttle. During the first 8.5 minutes of flight, it supplied the main engines with liquid hydrogen and liquid oxygen (LOX). In 1994, MSFC began development of a lightweight External Tank that allowed for an increase in payload weight. The development of the lightweight external tank was key in the launching of the ISS. The SRBs for the Shuttle were the first solid propellant rockets built for a manned space vehicle and the largest solid rockets ever flown. The boosters generate a combined 5.8 million pounds of thrust for the first 2 minutes of flight. At burnout, the SRBs separated from the external tank and dropped by parachute to the ocean for recovery, refurbishment, and reuse. The third generation, Super Lightweight External Tank was first flown in 1998 and was still in use in 2005.

The MSFC manages a broad and diverse portfolio of programs and projects. The center leads NASA's development of advanced spacecraft and launch vehicles designed to take human and robotic explorers deeper into the solar system. The center also manages the Chandra X-ray Observatory; the *Discovery*, New Frontiers, and Lunar Quest programs; the Technology Demonstration Missions program; the Centennial Challenges program; the SERVIR environmental imaging network; and numerous other Earth and space science activities.

5.2.5 Michoud Assembly Facility

MSFC manages the Michoud Assembly Facility (MAF), an 832-acre site located in New Orleans, Louisiana. Acquired by NASA in 1964, MAF is the agency's premier site for the manufacture and assembly of large-scale space structures and systems. It is a multi-tenant complex where commercial and government contractors, as well as government agencies, are permitted to use the site.

MAF includes one of the largest production buildings (43 acres of controlled environment) in the country, a vertical assembly building used for stacking tank components, buildings for pneumostatic and systems tests, a deep-water port for transportation over water, and manufacturing and assembly support buildings and administrative offices. The original structures at MAF, including the main manufacturing facility were constructed during World War II. Several significant structures, including the Vertical Assembly Building were built during the 1960s in support of the Apollo program. Additional structures, including the High Bay Addition, the Tank Ablator Spray Facility, Liquid Hydrogen (LH2) External Wash

Cell P, and the Component Ablator Facility were constructed specifically for the SSP. A new Vertical Assembly Building was constructed in 2009 to support the now cancelled Constellation Program.

MAF served as the factory for the Saturn IB and Saturn V rockets used by the Apollo program and the Space Shuttle's external fuel tank. MAF is presently manufacturing and assembling some of the largest elements for NASA's planned Space Launch System and the Orion crew spacecraft.

5.2.6 Santa Susana Field Laboratory[7]

The Santa Susana Field Laboratory (SSFL) is located in the Simi Hills in Ventura County, California. It contains approximately 2,850 acres and is bordered on the east by the San Fernando Valley and on the north by the Simi Valley. The SSFL contains four administrative areas and two undeveloped areas. Boeing Company owns Areas I, III, and IV and both undeveloped areas. Area II (409.5 acres) and a small portion of Area I (41.7 acres) are owned by the U.S. Government and used by NASA. The U.S. Department of Energy (DOE) has a lease on land in Area IV. Area II and the LOX Plant portion of Area I have been used primarily for rocket testing.

The North American Aviation (NAA) leased and purchased land in the Simi Hills for rocket engine testing. The NAA-formed Rocketdyne, an aerospace company, was merged with Rockwell International Corporation. In 1954, NAA obtained an additional adjacent area consisting of 838-acres of undeveloped land, which would become Area II and the 41.7 acres of Area I. In 1958, the NAA deeded the property to the U.S. Air Force (USAF). Approximately 409.5 acres became known as USAF Plant 57 (Area II) and Parcel 3 became known as USAF Plant 64 (now LOX Plant). Area II has been operated by Boeing, Rockwell, and NAA under USAF facility contracts. In 1973, the USAF Plant 57 (Area II) was transferred to NASA and that designation was no longer used. In 1976, the U.S. General Services Administration (GSA) transferred the USAF Plant 64 from the USAF to NASA, but the Air Force retained possession of the structures. Rockwell administered the LOX plant for NASA, but the plant was removed in the early 1970s except for a small weigh station and concrete tank supports.

The NAA built the Alfa, Bravo, Coca, and Delta test stands in Area II between 1954 and 1957 while under contract with the USAF. Rockwell tested rocket engines in Area II. Liquid-fuel rocket engines burned a variety of fuels including kerosene, which also required trichloroethylene (TCE) flushing to remove residual hydrocarbons that were combustible and potentially explosive when exposed to LOX. In 1961, a TCE recycling system was implemented. Use of the Delta area ceased in the 1970s, but engine and component testing continued in the Alfa, Bravo, and Coca areas. Use of TCE was discontinued at Coca in 1988 when the test stands were deactivated and in 1994 at the Alfa and Bravo areas. The LOX Plant was located in Area I, but the buildings and tanks were removed in the early 1970s. Asbestos and soil were removed in the late 1980s, as well as several drums. Additional asbestos removal occurred in 1990 and 2007. The LOX Plant foundations were removed in 1996 and the land was regraded. The truck scales were refurbished in 1992 and are the only remaining structures at the LOX Plant.

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[7] SSFL is a component facility of MSFC; however, it is inactive, in the process of being cleaned up for excess, and managed under the 2014 *Programmatic Agreement among the National Aeronautics and Space Administration, the California State Historic Preservation Office, and the Advisory Council on Historic Preservation regarding Demolition and Soil and Groundwater Cleanup at Santa Susana Field Laboratory, Ventura County, California*. Assets at SSFL are included in NASA raw asset counts but as there are no unevaluated assets there less than 50 years old, the RSF Model would not apply.

5.2.7 Stennis Space Center

The John C. Stennis Space Center (SSC) is NASA's largest rocket engine test facility. SSC occupies approximately 13,250 acres, surrounded by a 125,400-acre acoustic buffer zone, along the East Pearl River, near the northern edge of the Gulf of Mexico, approximately 55 miles northeast of New Orleans.

By 1960 the United States had launched an all-out effort to lead the world in space exploration. MSFC in Huntsville, Alabama served as the major NASA installation for propulsion operations and program management in support of manned and unmanned space missions, with the MAF in New Orleans as a support facility. A need evolved for a water-accessible test site near MAF for development and acceptance testing (static firing) of the large liquid propellant rocket systems assembled at MAF. In October 1961, NASA announced selection of a site northeast of MAF, largely within Mississippi. This Mississippi Test Facility (MTF) occupied a 217-square-mile tract along East Pearl River between Bay St. Louis and Picayune, Mississippi. The facility consisted of two separate Zones. An Inner Zone, about five miles square, was established where test stands and supporting facilities were constructed. This Zone was purchased and is owned in fee simple by the Government. A surrounding Acoustical Buffer Zone was established where livestock raising, silviculture, and agriculture could be conducted; however, all structures had to be removed and no people were permitted to live within this area.

The selection of the site for the test facility was based upon its accessibility by water. The large booster rockets had to be transported from the assembly site at MAF to the test site. This necessitated dredging a harbor and canals to the firing stands. The Saturn boosters were ferried up East Pearl River on barges, entered the harbor by way of a canal, crossed the harbor, were lifted into other canals by means of a lock, and were moved onto the firing stands, some of which were about seven miles further inland. Three test stands (A-1, A-2, and B-1/B-2) were constructed for this purpose. These test stands are now National Historic Landmarks. The MTF became operational in April 1966. Its initial mission was testing the Apollo-Saturn V second stage booster and flight-models of the first and second stage boosters. Testing in support of the Apollo Program continued until the early 1970s.

During the interim between the Apollo and Space Shuttle programs, the MTF experienced significant growth and was renamed. The MTF became the National Space Technology Laboratories (NSTL) in 1974 and the first test of the Space Shuttle Main Engine (SSME) was conducted in May 1975. Existing test stands were modified to accommodate testing of individual engines as well as clusters of three.

In October 1988 President Reagan renamed the facility the John C. Stennis Space Center, in honor of Senator Stennis of Mississippi. The designation elevated SSC to the status of a "field center," as opposed to its former role under the direction of MSFC. The center expanded its functions and capabilities in the 1990s and 2000s. SSC continued to serve as the flight certification facility for SSMEs, beginning with initial testing in 1975 and ending with the last scheduled test at the A-2 Test Stand in June 2009. Test Complex E (Component Test Facility) was constructed in 1998 to test a variety of new engine concepts. The testing process includes determining operational limits of critical engine components before they are assembled. A series of tests conducted at Test Complex E led to the commercialization of hybrid rocket motors, one of which was used to power the first privately funded spaceship, Scaled Composites SpaceShipOne. Beginning in 2001 this complex underwent extensive upgrades and is considered crucial to NASA's development of second-generation propulsion systems.

NASA assigned SSC responsibility for managing and integrating rocket propulsion testing for the proposed Crew Launch Vehicle Project in June 2006. Beginning in 2007 the A-1 Test Stand was used to evaluate J-2X engine components for the now cancelled Constellation program. Work was completed in 2009 on Test Stand A-3 for testing these engines.

5.2.8 White Sands Test Facility

A component facility of JSC, the White Sands Test Facility (WSTF) was established during the Mercury program in 1963. WTSF occupies 26,900 acres on the White Sands Missile Range east of Las Cruces, New Mexico. The WSTF was designed to support space exploration by evaluating materials and components for use in propulsion, and many other systems through simulations and testing. WSTF was also responsible for materials testing and evaluation of the Challenger and Columbia shuttle remains. Today, WTSF's primary mission is to support NASA's the ISS program. It supported the SSP until the termination of that program in 2011. It is the official JSC Propulsion Systems Development Facility and is considered a leader in propulsion systems testing.

5.3 Themes of Exceptional Importance

Exceptional importance in the Area of Human Exploration and Operations is demonstrated through the Apex Events, a summary of which are presented in Section 5.4, below. A more detailed presentation of the Apex Events is provided in Appendix B. Several significant Themes emerge from the history of NASA's efforts in human exploration during the fifty years since 1973. These Themes are interrelated, and all reflect NASA's principal objective for human exploration during this period—the establishment of a permanent space station supplied and maintained by the Space Shuttle fleet. The Themes that are most clearly demonstrated in the selected Apex Events that follow include:

- Exploration of the effects of long-term exposure to microgravity on astronauts;
- Increased focus on observation and experimentation conducted in microgravity environments;
- Building international partnerships;
- Development of technologies vital for future manned missions;
- Development of reusable rockets and manned vehicles; and
- Emphasis on risk management and crew safety as a result of increased use of non-military astronauts.

NASA's Apex Events in human exploration over the past 50 years are necessarily all associated with meeting the agency's principal goal of establishing a permanent space station. Specific Apex Events may be associated with several of the Themes and may incorporate multiple NASA programs or missions. They also illustrate the incremental process through which problem-solving and innovation occurs within NASA. Each technological breakthrough or scientific advance serves as the building block for the next. Failures may be just as significant as successes, as they can redirect efforts towards better solutions.

5.4 Apex Events

5.4.1 Apollo-Soyuz Test Project (1972–1975)

Description. The Apollo-Soyuz Test Project was the first manned international space mission, carried out jointly by the U.S. and the Soviet Union in July 1975. In the 1970s, U.S.-Soviet political tensions began to thaw and competition in space gave way to cooperation, as exemplified in the Apollo-Soyuz Test

Project. International collaboration became a normal practice between nations during the Space Shuttle era.

Statement of Significance. The Apollo-Soyuz Test Project between the U.S. and the Soviet Union was the first joint space mission between the two superpowers during the middle of the Cold War. This joint mission helped connect the two nations and helped bring an end to the Cold War. It also set a precedent for work in the field of space as a collaborative effort between nations rather than a competition between them. This successful endeavor led to many other joint missions to space between nations, including the establishment and maintenance of the ISS.

Significance Criteria. NASA's development with the Soviet Union of the Apollo Soyuz Test Project is exceptionally important in the NRHP areas of communications, exploration/settlement, and politics/government, and illustrates the following Themes of NASA's human exploration program in the last 50 years:

- Increased focus on observation and experimentation conducted in microgravity environments;
- Building international partnerships; and
- Development of technologies vital for future manned mission.

Period of Significance. The recommended period of significance is 1972–1975, when an agreement was reached between the U.S. and the Soviet Union to meet in space and when the meeting was carried out between the two counties in 1975.

5.4.2 Skylab (1973–1979)

Description. Skylab was the first United States space station to orbit the planet Earth. Launched in May 1973 it was operated by three separate three-astronaut crews, designated as Skylab 2, Skylab 3, and Skylab 4. Major operations included an orbital workshop, a solar observatory, Earth observations, and the completion of hundreds of experiments. Skylab's orbit decayed and it disintegrated upon reentry into the Earth's atmosphere in July 1979.

Statement of Significance. NASA's development of Skylab was the first space-based station and solar observatory. Skylab's program led to new technologies and a better understanding of how humans can interact with the environmental settings of space. This space station established the foundation for future development of the idea to create the ISS.

Significance Criteria. NASA's development of Skylab is exceptionally important in the NRHP areas of engineering, exploration/settlement, invention, science, and transportation, and illustrates the following Themes of NASA's human exploration program in the last 50 years:

- Exploration of the effects of long-term exposure to microgravity on astronauts;
- Increased focus on observation and experimentation conducted in microgravity environments; and
- Development of technologies vital for future manned mission.

Period of Significance. The recommended period of significance is 1973–1979. This time period includes the launch of Skylab until its destruction in 1979.

5.4.3 International Space Station (1984–present)

Description. The ISS was and is a combined effort between 15 countries, including the U.S., Russia, Canada, Japan, the European Space Agency (ESA). The ISS is a space station permanently occupied by astronauts of the various countries involved in the program. Today, the ISS serves as the largest scientific and technological cooperative program in history.

Statement of Significance. The ISS is currently in use as an international hub for space research and occupation and is set to remain in service until at least 2024. Currently, the space station has been in service for 23 years when the first module was launched and assembled in 1998. The ISS is significant for its cross-cultural connection between nations of the world, first established by the Apollo-Soyuz Test Mission in 1975. The ISS is also significant for its continual technological development of space related scientific research and experiments.

Significance Criteria. NASA's development in cooperation with other space agencies from around the world of ISS is exceptionally important in the NRHP areas of Communications, Engineering, Invention, and Politics, and illustrates the following Themes of NASA's human exploration program in the last 50 years:

- Exploration of the effects of long-term exposure to microgravity on astronauts;
- Increased focus on observation and experimentation conducted in microgravity environments;
- Building international partnerships;
- Development of technologies vital for future manned mission; and
- Development of reusable rockets and manned vehicles.

Period of Significance. The recommended period of significance is 1984 to present. The period of significance begins with President Ronald Reagan's January 25th State of the Union Address in which he directed NASA to develop a permanently manned space station within a decade. The ISS period of significance is currently on-going as the station is still in operation and additional information is still to be obtained from the ISS before its decommissioning in the near future.

5.4.4 Space Shuttle Program (1969–2011)

Description. The cost of access to space is the major deterrent in space exploration and space utilization. A reusable launch vehicle provides an opportunity to lower costs and provide reliable and on-demand space access. NASA began exploring the possibility of reusable spacecraft as early as 1969. As initially conceived, the Space Shuttle, designed to be completely reusable, was 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 for a proposed space station. The reusable nature was expected to reduce payload costs, but ultimately, NASA made the decision to go with a system that was not entirely reusable.

The Space Shuttle included a reusable orbiter vehicle with three clustered main engines, a pair of recoverable and reusable solid rocket boosters, and an expendable external fuel tank containing liquid hydrogen and LOX, that provided fuel for the orbiter's main engines. The solid rocket boosters were jettisoned before the vehicle reached orbit, and the external fuel tank was jettisoned just before orbit insertion. At the conclusion of the mission the orbiter fired its maneuvering engines and reentered the atmosphere, gliding to a runway landing.

Statement of Significance. The development of the Space Shuttle demonstrated the feasibility of reusable rocket boosters and space vehicles, which represented an important effort to promote the use of space as a commercially and economically viable activity, and which pointed the way towards the current generation of privately built reusable launch vehicles. While the Shuttle program failed to accomplish its intended goal of reducing launch costs below those of ELVs, it did pave the way for the present generation of reusable launch systems and vehicles. NASA gave responsibility for developing the orbiter and for overall management of the SSP to the MSC (now JSC) in Houston. MSFC was responsible for development of all propulsion-related tasks. Engineering design support continued at MSC, MSFC and LaRC, while engine fabrication took place at MAF and engine tests were performed at NASA's Mississippi National Space Technology Laboratories (NSTL, now SSC) and at the Air Force's Rocket Propulsion Laboratory in California (SSFL). KSC, responsible for designing the launch and recovery facilities, was to develop methods for shuttle assembly, checkout, and launch operations.

Significance Criteria. NASA's development of the SSP is exceptionally important in the NRHP areas of engineering, invention, science, and transportation and illustrates the following Themes of NASA's human exploration program in the last 50 years:

- Development of technologies vital for future manned mission;
- Emphasis on risk management and crew safety as a result of increased use of non-military astronauts; and
- Development of reusable rockets and manned vehicles.

Period of Significance. The recommended period of significance is 1969–2011. It includes the initial concept and design development associated with the SSP through the last operational flight.

5.4.5 Reusable Solid Rocket Propulsion (1969–2011)

Description. The need for Solid Rocket Propulsion was needed with the development of the SSP in 1969; however, NASA did not reach a decision about solid rocket boosters until 1972. The need for a solid full source over the previously used propulsion source of liquid hydrogen was due to the weight of the space shuttle with its cargo. The solid rocket fuel increased the power of the launch vehicle to get the space shuttle into orbit.

Statement of Significance. The SRB system used for the SSP experienced development and change to increase the safety of the SRB with a major change in the SRB after the *Challenger* accident in 1986. The SRB are associated with the development of the SSP, connected with the KSC, MSFC, and JSC facilities.

Significance Criteria. NASA's development of the SRB is exceptionally important in the NRHP areas of engineering, invention, and transportation, and illustrates the following Themes of NASA's human exploration program in the last 50 years:

- Development of technologies vital for future manned mission;
- Development of reusable rockets and manned vehicles; and
- Emphasis on risk management and crew safety as a result of increased use of non-military astronauts.

Period of Significance. The recommended period of significance is 1969–2011. It includes the initial concept and design development associated with SSP through the last operational flight.

5.4.6 Challenger and Columbia Accidents and Safety Development (1986–present)

Description. NASA's SSP experienced two fatal accidents that resulted in the loss of the vehicle and its crew. In 1986 the Space Shuttle Challenger broke apart shortly after its launch killing all seven crew members. The disaster resulted from the failure of a joint in the Shuttle's SRB caused by the failure of O-ring seals used in the joint. The disaster resulted in a 32-month cessation of Shuttle flights. In 2003 the Shuttle Columbia disintegrated on reentry into the Earth's atmosphere killing all seven crew members. A piece of foam insulation had broken off the external fuel tank during launch, damaging the carbon-reinforced leading edge of the orbiter's port wing. The damage permitted hot atmospheric gases to penetrate the wing and destroy the internal wing structure, resulting in disintegration. This disaster resulted in a more than two-year suspension of operations.

Debris from Challenger is currently stored in two abandoned Minuteman missile silos at Cape Canaveral Air Force Station in Florida. The silos were not intended as a burial or memorial, but simply as a storage site. As of 2015, debris from Columbia was stored in a converted room on the 16th floor of the Vehicle Assembly Building at KSC and was available to researchers for study.

Statement of Significance. The Challenger and Columbia disasters forced NASA to reexamine its organizational culture, which dated to the 1960s and included an acceptance of risk and danger by an astronaut corps comprised of military officers. The loss of these two shuttles resulted in an increased focus on risk assessment and mitigation, and a reexamination of issues related to crew safety and the provision of escape mechanisms. Ultimately, the loss of Challenger and Columbia led to a greater emphasis upon risk assessment, risk mitigation, more robust design, and crew safety. This shift reflected the increasing move towards civilian use of space.

Significance Criteria. The wave of safety developments that were made in response to the Challenger and Columbia accidents and the subsequent shift in culture is exceptionally important in the NRHP areas of engineering, invention, and transportation, and illustrates the following Theme of NASA's human exploration program in the last 50 years:

- Emphasis on risk management and crew safety as a result of increased use of non-military astronauts.

Period of Significance. The recommended period of significance is 1986–present. It includes the increased emphasis upon risk assessment and astronaut safety that emerged in NASA following the loss of Challenger and that continues to the present.

5.4.7 Space Communication Networks (1963–2000)

Description. The space communications networks communicate with launch vehicles, Earth-orbiting spacecraft (including the ISS), and spacecraft throughout the solar system. These systems include the Near Earth Network, the Deep Space Network, and the Tracking and Data Relay Satellite System (TDRSS).

Statement of Significance. The development of each communication system (the Near Earth Network, the Deep Space Network, and the TDRSS) is a vital part of space travel and exploration, necessary for the discussion and transfer of data between instruments in space, such as satellites and their equipment, and the people on Earth who study that information. These communications centers provide the network necessary to gather data from space. GDSCC and JPL, which serve as anchors for the system, are both significant to the development and operations of these communication systems.

Significance Criteria. NASA's development of the Near Earth Network, the Deep Space Network, and the TDRSS is exceptionally important in the NRHP areas of communications, engineering, invention, and science, and illustrates the following Theme of NASA's human exploration program in the last 50 years:

- Development of technologies vital for future manned mission.

Period of Significance. The recommended period of significance is 1963–2000, incorporating the finalized completion and start of operations for each communication system developed by NASA.

5.5 Significant People

A representative sample of extraordinary people who have worked to accomplish NASA's exceptional achievements of the last 50 years in the Area of Human Exploration and Operations are presented below. More complete biographical information on each person is available in Appendix C.

Table 5-1: List of Significant People in the Area of Human Exploration and Operations

Person	Association
Wernher von Braun, Ph.D. (1912–1977)	Saturn V launch vehicle; Redstone-Mercury
Robert R. Gilruth (1931–2000)	Project Mercury
Neil Armstrong (1930–2012)	First man on the moon; Gemini 8; Apollo 11
George E. Mueller, Ph.D. (1918–2015)	Gemini and Apollo programs
Sally Kristen Ride, Ph.D. (1951–2021)	First American female astronaut; Challenger
Guion "Guy" Bluford, Ph.D.	First African American astronaut; Challenger
Mae Jemison, M.D.	Shuttle Avionics Integration Laboratory; *Endeavor*
Kathryn Clark, Ph.D.	Chief Scientist on International Space Station
William Shepherd	STS-27; STS-41; STS-52; Expedition-1 crew (ISS)
Thomas P. Stafford	Gemini and Apollo programs

5.6 Summary

Human Exploration and Operations is perhaps the most widely recognized Area of Significance for NASA, from the first U.S. program to put humans in space, Project Mercury, to the ISS, still in orbit today, NASA's achievements in this area have been among the most remarkable of the modern age. Until recently, human space exploration was achievable only through the substantial investment of the U.S. and other federal governments, and the built assets that supported the programs were highly unique if not one-of-a-kind. As private industry moves into human spaceflight, it utilizes many of NASA's specialized assets, enhancing their exceptional historical significance.

6.0 AREA 3: SCIENCE

6.1 Historical Overview

NASA's science vision focuses on using the vantage point of space to achieve a deep scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effect on the solar system, and the universe beyond. The Science Mission Directorate (SMD) is divided into four main research divisions: Earth (Earth Science), the solar system (Planetary Science), the Sun (Heliophysics), and the universe (Astrophysics). The SMD uses space observatories to conduct scientific studies of the Earth from space, samples from other bodies in our solar system, and views from the Galaxy and beyond in each of the four research areas. The SMD seeks to answer profound questions including:

- How and why are Earth's climate and the environment changing?
- How and why does the Sun vary and affect Earth and the rest of the solar system?
- How do planets and life originate?
- How does the universe work, and what are its origin and destiny?
- Are we alone?

The oldest science division is the Heliophysics Divison and the initiative predates NASA. The first U.S. space satellite, Explorer 1, discovered Van Allen radiation belts in 1958, which are a fundamental feature of planetary magnetospheres. Heliophysics focuses on the study of the Sun and how it influences the nature of space and in turn the atmosphere of planets and technology. In addition, space weather is an underlying focus. In the early decades of NASA heliophysics, research focused on near-Earth assets—this has expanded in recent decades to the solar system and interstellar space.

The Planetary Science Division was the main thrust of research during the 1960s and continues to focus on extending the human presence throughout the solar system with robotic space probes to the moon, other planets and their moons, asteroids and comets, and icy bodies of the outer solar system. However, funding began to diminish in the 1970s. In the 1980s, diminished support for planetary exploration almost shut down the division, but the scientific community protested. Small and competitive proposals were solicited as part of the Discovery Program. Several low-cost planetary observers were launched in the 1990s in addition to the Discovery Program missions.

The Earth Science Division became a focus of SMD in the 1970s, reflecting larger global trends towards environmental awareness. Researchers study Earth from space and explore its diverse components, including the oceans, atmosphere, continents, ice sheets, and life. The focused study of Global changes began with the Landsat program in 1972, which has provided the longest continuous global record of Earth's surface. The interest and focus on Earth science continues with the launch of Landsat 9 in September 2021. The Earth Science Division works in partnership with the National Oceanic and Atmospheric Administration (NOAA), the United States Geological Survey (USGS), and the Environmental Protection Agency (EPA) to improve national capabilities to predict the weather, climate, and natural hazards; manage resources; and develop environmental policies.

In the 1980s and 1990s, the Astrophysics Division began focusing on discovering how planetary systems form and how environments hospitable to life develop. The three "Great Observatories" were planned in the 1980s and include the Hubble Space Telescope, the Chandra X-ray Observatory, and the Fermi

Gamma-ray Space Telescope. Each of these Great Observatories focused on collecting knowledge of the universe and many have achieved their original objectives but continue to operate and produce results. Smaller missions, such as Neil Gehrel's Swift Observatory, the Nuclear Spectroscopic Telescope Array (NuSTAR), Transiting Exoplanet Survey Satellite (TESS), the Neutron Star Interior Composition Explorer (NICER) mission, and SOFIA, complement the goals of the Astrophysics Division. In the early 1990s, the expansion of the universe was a popular topic of discussion in the scientific community. The 1998 observations of the Hubble Space Telescope showed that the expansion of the universe was actually accelerating rather than slowing down due to gravity as previously thought. Theorists began attempting to explain this phenomenon and studies branched into dark energy, dark matter, blackholes, the big bang, galaxies, stars, and exoplanet exploration.

On a broader level, the SMD seeks to explore and make discoveries on behalf of the world. To that end, SMD has overlaid four overarching priorities onto its science missions: Exploration and scientific discovery, innovation, interconnectivity and partnerships, and inspiration.

Priority 1. Exploration and scientific discovery seeks to discover the secrets of the universe, search for life, and protect and improve the Earth. This priority is accomplished via four strategies which include:

- Execute a balanced science program based on discipline-specific guidance from the National Academies of Sciences, Engineers, and Medicine, Administration priorities, and direction from Congress;
- Participate as a key partner and enabler of the exploration initiatives, focus on scientific research of and from the Moon, lunar orbit, Mars, and beyond;
- Advance discovery in emerging fields; and
- Develop a Directorate-wide, target-user focused approach to applied programs. A balanced portfolio includes flight missions, research and analysis, technology development, and applications.

Priority 2. Innovation seeks excellence through continuous innovation and learning. To answer questions defined in Priority 1, SMD relies on innovation and has four strategies to help aid innovation, which include: 1) foster a culture that encourages innovation and entrepreneurship; 2) foster a culture that encourages collaboration; 3) focus on high intellectual risk/high impact research investments; and 4) drive innovation focused in technology areas.

Priority 3. Interconnectivity and partnerships recognizes that scientific discovery does not occur in isolation. SMD directly supports researchers and recognizes that NASA Centers, other federal agencies, private industry, academia, non-profits, community-based organizations, and international partners are vital in making NASA's scientific vision a reality. Strategies to accomplish this priority include:

- Engage NASA Centers to make informed strategic decisions to further NASA scientific goals;
- Seek collaborations with international partners based on unique capabilities and mutual goals;
- Engage with other federal agencies to make informed decisions, cooperate in scientific research, and pursue partnerships to further national interests;

- Provide opportunities for research institutions to contribute; and
- Use public-private partnerships in shared interests with industry.

Priority 4. Inspiration seeks to inspire learners of today and develop the leaders of tomorrow through two strategies. These two strategies seek to increase diversity of thought and backgrounds through a more inclusive environment and engage purposefully and actively with audiences and learners of all ages to share the NASA integrated science program. One of the SMD's goals is to reduce barriers to entry for all people of all ages and backgrounds to joining the scientific and engineering community.

NASA's science program celebrated 60 years in 2018. SMD has over 55 science missions currently in operation and 25 new science missions in development, with more in planning stages.

6.2 Science Centers

NASA's five SMD centers include:

- Goddard Space Flight Center (Maryland);
- Jet Propulsion Laboratory (California);
- Goldstone Deep Space Communication Complex (component facility of JPL) (California); and
- Wallops Flight Facility (component facility of GSFC) (Virginia).

6.2.1 Goddard Space Flight Center

The main campus of the Goddard Space Flight Center (GSFC) is located in Greenbelt, Maryland, just outside Washington, D.C. GSFC is the nation's largest organization of scientists, engineers, and technologists involved in the building of spacecraft, instruments, and technology necessary to the study of Earth, the Sun, the solar system, and the universe. The main facility of the GSFC in Maryland contains five geographic areas: the Main Campus, the 100 Area, the 200 Area, the 300 Area, and the 400 Area. NASA directly owns approximately 1,148 acres and the Department of Agriculture owns the remainder, approximately 149 acres, which is controlled through a revocable lease.[8] The 100 Area (the Antenna Test Facility) is located north of the Main Campus and contains 47.87 acres. The 200 Area (the Ground Plane Test Facility and the Optical Research Facility) contains 121 acres and is located on Springfield Road to the north of the Main Campus on Department of Agriculture property leased to NASA. Both the 300 Area (Magnetic Test Facility) and the adjacent 400 Area (the Bi-Propellant Test Facility) are located on 250 acres east of the Main Campus. GSFC also has additional remote campus areas in the U.S. that include Wallops Flight Facility (discussed in a separate section below) located in Virginia; Goddard Institute for Space Studies in New York City; the Katherine Johnson Independent Verification and Validation Facility in West Virginia; the Columbia Scientific Balloon Facility in Texas; and a small complex at White Sands Test Facility in New Mexico.

The GSFC began construction in 1959 and served as one of the key research facilities for NASA. The facility continues to support NASA missions as the space agency's laboratory for developing and operating unmanned scientific spacecraft and by managing many Earth observation, astronomy, and space physics missions for NASA. The mission for the GSFC is to "revolutionize knowledge by discovering the secrets of the Universe, searching for life elsewhere, and safeguarding and improving

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[8] Information on GSFC in this section is largely derived from Kathryn M. Kuranda, Kirsten Peeler, and Travis Shaw, *An Historic Context for NASA's Goddard Space Flight Center*, report prepared by R. Christopher Goodwin and Associates for Parsons Infrastructure & Technology Group and NASA Goddard Space Flight Center, Greenbelt, Maryland, August 2012.

life on Earth." Early work focused on the development and operation of satellites to enable scientific observations of Earth and the universe beyond. Laboratories were constructed to test spacecraft performance under extreme temperatures, vibration, and magnetic fields and to test new electronics and materials. GSFC also served as NASA's tracking, telemetry, and data acquisition center. A global network of tracking stations was constructed to enable orbiting satellites to downlink data as they traveled. Past missions include: Explorer 6 through 18; Aquarius; Ariel 1 through 3; the Cosmic Hot Interstellar Plasma Spectrometer (CHIPS); the Cosmic Background Explorer (COBE); Echo; the Earth Radiation Budget Experiment (ERBS); the Far Ultraviolet Spectroscopic Explorer (FUSE); ICEsat; IMAGE; Landsat; Pioneer 5; Polar; Rossi X-ray Timing Explorer; Spartan; Telestar; and the Wilkinson Microwave Anisotropy Probe (WMAP). Current and future missions include the GOES mission, the Hubble Space Telescope, the James Webb Space Telescope, the Mars Curiosity rover, Solar Dynamics Observatory, Parker Solar Probe, and many others.

Construction at the main Greenbelt campus occurred in three phases: Phase 1 (1959 to 1965), Phase 2 (1966 to 1969), and Phase 3 (1970 to the present). Site selection began during the late 1950s and focused on a preferred location with close proximity to Washington, D.C. The selected site was adjacent to the Baltimore-Washington Parkway (MD 295) and located on relatively undeveloped property owned by the Department of Agriculture's Agricultural Research Center. Shortly after the land was acquired, the first phase of construction began and resulted in the construction of Buildings 1 through 20 and Building 24 between 1960 and 1965. The aggressive construction program met the most immediate needs and allowed most GSFC-assigned personnel to relocate to the Greenbelt facility. However, insufficient space spurred the construction of additions to existing buildings and new facilities were planned.

Phase 2 of construction consisted of the completion of buildings identified in the GSFC master plan prepared during the early 1960s and many were needed to support increased mission priorities resulting from the Apollo program. Three facilities were under construction, three additional facilities were in various stages of the construction process, and other planned projects were undertaken during the late 1960s. Buildings 21 through 23 were under construction in 1964. Buildings constructed during the first two phases of construction generally consisted of workspaces or modules that could be configured in a variety of ways to facilitate collaboration among scientists across scientific disciplines. These early buildings originally were designed as "flex-space," which could be easily and quickly reconfigured.

Phase 3 began in late 1965 when the GSFC determined the need for a new facility to function as a clearinghouse for data retrieved from satellites and experiments related to space science discoveries. The Space Science Data Center (Building 26) was constructed in 1967 to support a fundamental NASA mission: the dissemination of data generated from research and development projects to the broader community. Between 1970 and 2011 only 11 new buildings were constructed; however, most construction projects consisted of updating, renovating, or adapting existing facilities to accommodate new or expanded missions. During the late 1980s, GSFC prepared for the Hubble Space Telescope and constructed Building 29 in 1990 to support it. New missions dedicated to Earth science in the late 1990s resulted in the construction of two buildings, Building 32 (the Earth Observing System Data and Information System Building) completed in 1994 and Building 33 (the Earth Systems Science Building) completed in 1998. In general, buildings constructed during the late twentieth and early twenty-first centuries were designed to house scientists and engineers within similar disciplines in one building. This design strategy represents a departure from the original design intent of the campus, where scientists and engineers from across the spectrum of NASA research were spread throughout the GSFC buildings.

Four test areas were established to support GSFC test missions and include the Antenna Test Range (100 Area), the Ground Plane Test Facility and the Optical Research Facility (200 Area), the Magnetic

Fields Component Test Facility (300 Area), and the Bi-Propellant Test Facility (400 Area). The 100 Area was designed in 1961 and originally consisted of an antenna test range. The antennas and other instrumentation were designed to test spacecraft before launching to ensure functionality of the craft. GSFC created an anechoic chamber capable of shielding satellites from radio frequencies and test antennas were constructed at the Antenna Test Range; however, the antennas are no longer extant. The 200 Area (Optical Research Facility) was designed in 1962 to support optical research and included observatories, telescopes, tracking, and testing facilities used for calibrating, ranging, and tracking satellites. The facility is located on land leased from the Department of Agriculture. The facility supported the Satellite Laser Ranging program, which provided accuracy when determining the altitude and position of GSFC satellites. The 300 Area (Magnetic Fields Component Test Facility) was constructed in 1962 and included the Magnetic Test Facility (Building 305), which calibrates sensitive spacecraft magnetometers. Building 305 is a designated NHL. The Bi-Propellant Test Facility (400 Area) was designed in 1965. Cryogenics, testing facilities, and other buildings were constructed as part of bi-propellant research, which focused on ways to cool and propel spacecraft. An additional mission was added to the facility by the late 1960s when an Altitude Test Facility was constructed at the 400 Area.

6.2.2 Jet Propulsion Laboratory

The Jet Propulsion Laboratory (JPL) is located in the San Gabriel Valley of Los Angeles County, California and is situated near the City of La Cañada-Flintridge, near Pasadena. The main campus occupies approximately 177 acres. JPL also operates the Goldstone Deep Communications Complex (GDSCC) in Fort Irwin, California, which is discussed in a following section. The JPL is federally funded and managed by the California Institute of Technology (Caltech) for NASA. The JPL Oak Grove main campus consists of a complex with 205 real property buildings and structures. These structures include administrative, research, laboratory, service, hangar, storage buildings, vaults, trailers, and antennas that aid in the facility's mission to observe Earth, study climate, discover distant worlds, and capture signals from the Deep Space Network. JPL is the leader of the nation's planetary exploration program and is focused on deep space navigation and communication, digital image processing, imaging systems, intelligent automated systems, instrument technology, microelectronics, and more.

JPL began in 1930s with Caltech professor Theodore von Karman's pioneering work on rocket propulsion and was known as the Guggenheim Aeronautical Laboratory of the California Institute of Technology (GALCIT). Graduate student, Frank Malina, and rocket enthusiasts moved their work off the Caltech campus to the Arroyo Seco, a dry canyon near Pasadena, California. The first alcohol-fueled rocket motor occurred on October 31, 1936. Von Karman, who previously served as an advisor for the U.S. Army Air Corps, persuaded the Army to fund mounted-jet developments for propeller planes to take off from short runways. The Army aided in the acquisition of land in the Arroyo Seco for testing and temporary workshops. Nearby naval bases provided flight locations to test designs and concepts. The organization was first referred to as the "Jet Propulsion Laboratory" by von Karman and his research team in a 1943 analysis for the Army on the German V-2 program. The U.S. Army Ordnance Corps funded the lab's early efforts in technology beyond aerodynamics and propellant chemistry. The JPL was officially established in November 1944 as a division of Caltech in Pasadena, California.

By 1945, the staff numbered close to 300 with launch and test sites near Leach Springs in the Mojave Desert and White Sands, New Mexico. Missile technology was the focus during World War II and the rest of the 1940s. Caltech sold 31.5 acres to the United States in October 1945 and by 1946, JPL had 385 staff members consisting of 66 professional, 96 administrative, and 223 skilled and unskilled employees. Facilities included two engineering buildings, a machine shop, a welding shop, a solid propellant processing lab, a 500-foot hydrobomb towing channel, seven liquid propellant rocket unit test pits, three solid propellant rocket unit test pits, two propellant test pits, three ramjet test pits, a hydraulic lab, a compressor house, a special materials research lab, a high temperature materials lab, and a ramjet wind tunnel. Only two of the pre-1946 buildings exist today.

In 1954, the JPL proposed launching a satellite with the Army's Redstone Arsenal in Alabama. While the proposal was rejected, the JPL began working on testing nuclear warhead re-entry technology and suborbital missions occurred in 1956 and 1957 to prove warheads could return from space without burning up. The JPL's first satellite, Explorer 1, was launched in coordination with the Army Ballistic Missile Agency on January 31, 1958. By 1956, the JPL had divided employees into 14 technical sections including Aerodynamics, Propellants, Liquid Propulsion Systems, Guidance Research and Development, Instrumentation, Systems Engineering, Personnel and Technical Services, Materials Services, Accounting, Purchasing, Plant Services, Fabrication Services, and Mechanical Services. The campus contained 100 buildings by 1957 with several under construction and more in the "planned for construction" status. Once NASA was formed on December 3, 1958, the JPL was immediately transferred from the Army to the newly formed NASA.

In the 1960s, JPL began robotic spacecraft development to explore other planets. The Ranger and Surveyor missions to the Moon led to the Apollo astronaut lunar landings. In addition, the JPL carried out Mariner missions to Mercury, Venus, and Mars. JPL coordinated with Langley's Research Center on the Viking's biological mission to Mars in 1976. In 1977, JPL launched their grandest mission, the Voyager 1 and 2 spacecraft, to visit the four gas giants, Neptune, Saturn, Jupiter, and Uranus. While NASA began focusing on the Space Shuttle mission, the funding for planetary exploration diminished and the JPL broadened its research into non-space related areas, including energy technology, communication, transportation, and solar technology. In the 1980s, JPL began working on Department of Defense work and developed a battlefield management tool for the U.S. Army known as the All-Source Analysis System. In addition, the 1970s decreased emphasis and funding on planetary exploration led the JPL to branch out into astronomy and Earth science tasks, such as the 1978 Seasat—a mission to measure surface temperature, height, and wind velocity. The Earth Observing System was developed in the 1980s to advance the understanding of the planet's processes and JPL developed a number of instruments that won awards. A parallel program of small, low-cost missions, known as the Earth System Science Pathfinders were developed by NASA and JPL developed the Gravity Recovery and Climate Satellite (GRACE) as part of the program in 2002. CloudSat was launched in 2018 for cloud research and the Orbiting Carbon Observatories were launched to measure atmospheric carbon dioxide.

Threats to close the JPL and its planetary exploration mission occurred in 1981; however, protests from the scientific community, Caltech, and Congress rallied to get new planetary missions funded. The only planetary mission throughout this period was the Galileo mission to Jupiter in 1977 but delays and the Challenger loss delayed it until 1989. The Magellan mission to Venus was authorized in 1983. A series of low-cost planetary missions called "Planetary Observers," started with the Mars Observer, which was launched on a Titan III rocket in 1992. While the Mars Observer was lost, it helped enable NASA to gain approval for another planetary mission program, the Discovery Program, which required NASA centers and university-based scientists to submit proposals to competitions that were to be held every few years. The first two Discovery missions were assigned, and the JPL was awarded the Mars Pathfinder mission, which introduced the planetary rover. Mars Pathfinder's micro-rover, named Sojourner, for abolitionist Sojourner Truth, became the first robotic rover to explore the Red Planet in 1997. The Mars Pathfinder mission also began the new policy of releasing real-time imagery to the public via the internet. Two additional rovers, Spirit and Opportunity, were launched in 2003 and were equipped for robotic geology. Other Discovery program missions include Stardust to collect particles from a comet in 2004, Deep Impact mission in 2005, GRAIL mission to produce high resolution gravity maps of the moon, and Dawn mission used solar-electric propulsion to visit dwarf planet Ceres and Vesta asteroid belt. JPL managed the development of the Kepler exoplanet astronomy mission in 2009. JPL has a future Discovery program mission, Psyche, planned in the late 2020s to explore the unusual main belt asteroid 16 Psyche.

6.2.3 Goldstone Deep Space Community Complex

The Goldstone Deep Space Community Complex (GDSCC) is part of the JPL and is located in Barstow, California. The antenna complex is part of NASA's Space Communications and Navigations (SCaN) program and the Deep Space Network (DSN), which is an international network of facilities used to communicate with spacecraft as they explore the solar system. The site of GDSCC was chosen due to its remote location away from power lines, commercial radio interference, and television transmitters that can impede the reception of the weak signals sent by far away spacecraft. The Mojave Desert provided a perfect location near the mining ghost town of Goldstone and the 52-square mile facility was constructed in 1958. Originally, the DSN was known as the Deep Space Instrumentation Facility (DSIF) and consisted of three stations in Goldstone, California; near Woomera, Australia; and Johannesburg, South Africa. While the original Woomera station closed in 1972 and the original Johannesburg station closed in 1972, the Goldstone station has been in active use since the first antenna was constructed in 1958. Additional facilities were opened to replace the two closed stations with one in Ceberos, Spain in 1964 and Canberra, Australia in 1962. The principal responsibility of the GDSCC is to provide support for radio and radar astronomy observations in the continuing exploration of the solar system and the universe. Radio frequency bands are used to transmit data from spacecraft through the Earth's atmosphere to the receiving antennas on the ground. The GDSCC's network is divided into two general categories: 1. Functions associated with in-flight support and tracking spacecraft and 2. Activity that supports testing, training, and network operations control functions. The first category includes the DSN Tracking System (generates radio metric data and transmits raw data to mission control), DSN Telemetry System (receives, decodes, records, and retransmits engineering and scientific data from spacecraft to mission control), and the DSN Command System (accepts coded signals from mission control via the Ground Communication Facility [GCF] and transmits the signals to spacecraft). The second category includes the DSN Monitor and Control System (instruments, transmits, records, and displays parameters to DSN to verify configuration and validate network and provides operational direction and configuration control of the network and primary interface with flight project mission control personnel) and the DSN Test and Training System (generates and controls simulated data to support development, test, training, and fault isolation within the DSN).

The GDSCC is composed of seven deep space station sites and two Spaceflight Tracking and Data Network (STDN)/Satellite Tracking and Data Acquisition Network (STADAN)/Manned Space Flight Network (MSFN) sites. Each site is located several miles from each other in order to decrease the potential interference of radio signals. Each of the sites is named after a project or planetary objective of early missions. The first antenna, DSS-11, was constructed in 1958 as part of the Pioneer Station, which served the Pioneer 3 and 4 probes to the moon. DSS-11 is a 26-meter polar mounted antenna and became the proto-type for the DSN antennas across the world. The antenna was used for tracking all the Pioneer spacecraft, Echo balloon projects, Ranger, Lunar Orbiter, Surveyor, Apollo, Helios, Mariner, Viking, and Voyager missions. The antenna was officially mothballed in 1981 and was declared a National Historic Monument in 1985. The Echo Site originally contained a 26-meter antenna constructed in 1959 for Project Echo, which was an experiment to bounce signals off the surface of a balloon-type satellite. The original antenna was moved to the Venus Site in 1962 and in the 1970s, the station converted a 26-meter antenna into a 34-meter antenna. The conversion occurred after the Viking landed on Mars in 1976 and the focus shifted to exploring the outer planets of Jupiter, Saturn, Uranus, and Neptune. The conversion project was completed in 1979. The Mojave Site is a STADAN site that was constructed in 1961 after NASA moved the former Naval Research Laboratory Minitrack Station at Brown Field, California to Goldstone. The Venus Site was established in 1962 as the main research and development station for the DSN at Goldstone. The site contains DSS-13, which was the original Echo antenna that provided the first radar observations of the planet Venus. It was moved from the Echo site to the Venus site in 1962 and renamed the Venus Antenna. The Microwave Test Facility (MTF) is a DSN site located near the Echo Site established in 1963. The site contains a high-powered test laboratory, machine shop, microwave screen room, and offices. The Apollo Site is a MSFN/STDN site built in 1966 to support the Apollo manned missions to the moon. The Apollo antenna (DSS-16) was a 26-meter diameter antenna designed for the MSFN and managed by GSFC. Following the end of the Apollo manned missions, the site became a part of the STDN and was used for tracking Earth-orbiter satellites. The antenna has an X-Y mount that allows the antenna to point to a low point on the horizon and pick up the fast-moving Earth orbiters. The Mars Site was completed in 1966 and contains the first 64-meter Azimuth/Elevation antenna. The antenna was designed and built by the Rohr Corporation and is the largest antenna at GDSCC. The first signal it received was from the Mariner 4, which was on a Mars mission, in March 1966. It became known as the "Mars" antenna and the "Mars" site. The antenna was enlarged in 1988 to 70 meters in order to support the Voyager 2's mission to Neptune. The Uranus Site is located adjacent to the Mars Site and contains a single 34-meter, high efficiency antenna which supported the Voyager 2's mission to Uranus in 1986. The Gemini Site was named after the twin stars in the Gemini constellation rather than a mission. The site contains two 34-meter waveguide antenna, which were originally built for the Department of Defense and transferred to the DSN in 1994 to support the Solar and Heliospheric Observatory (SOHO). Additional 34-meter antennas are located at the Uranus, Venus, Apollo, and Mars sites to support the SOHO.

6.2.4 Wallops Flight Facility

The Wallops Flight Facility (WFF) was established in 1945 and is managed by the GFSC. The facility is located in northeastern portion of Accomack County in Virginia's Delmarva Peninsula. The facility covers approximately 6,500 acres and includes three areas: Wallops Main Base, Wallops Mainland, and Wallops Island. The Main Base is approximately 1,800 acres and located to the north and west of Watts Bay, Simoneaston Bay, and Jenny's Gut and south of Little Mosquito Creek. The Main Base contains offices, laboratories, maintenance and service facilities, an airport, air traffic control facilities, hangars, runways, and aircraft maintenance and ground support buildings. It also includes NOAA administrative facilities, U.S. Navy administration and housing, and U.S. Coast Guard housing. The Wallops Mainland facility consists of 100 acres located across Cat's Creek from Wallops Island, which is connected via a causeway. The inland facility consists of radar, communication, and optical tracking installations. Wallops Island extends south along the Atlantic Coast from Chincoteague Inlet and includes approximately 4,600 acres. The facility contains launch and testing facilities, blockhouses, rocket storage buildings, assembly shops, dynamic balancing facilities, tracking facilities and U.S. Navy and Mid-Atlantic Regional Spaceport facilities, which is a commercial spaceport operated by the Virginia Commercial Space Flight Authority and is licensed by the Federal Aviation Administration for orbital launches.

The WFF was constructed as a test site for aerospace technology experiments; however, the WFF has transitioned to supporting scientific research through carrier systems. In 1945, the U.S. Navy established a Naval Auxiliary Air Station, which became the Main Base. It was named Chincoteague Naval Auxiliary Air Station in 1946 and included runways and support buildings. The base was used for training naval aviation units for the war effort. In 1945, the NACA's Langley Field Research Center also established a base in Wallops Island and launched a rocket in June 1945. The NACA originally purchased 85 acres and leased an additional 1,000 acres from the Wallops Island Club. Temporary facilities, including Quonset huts, were constructed for housing. After WWII, the NACA began permanent construction on the island. By 1949, the U.S. government purchased the remainder of the island and it was used by both the Navy and the NACA. Piloted orbit plans were considered at Wallops as early as 1958 and the Space Task Group and Project Mercury were begun. The privacy of Wallops Island provided an ideal testing location for Project Mercury and between 1958 and 1959, 26 full size capsules and 28 scale models were launched at Wallops Island. In July 1959, NASA officially assumed control of the Chincoteague Naval Auxiliary Air Station and the land was formally transferred in 1961. In addition, NASA purchased 100 acres on the Wallops Mainland. The facility was renamed Wallops Station in 1961. The Space Task Group was moved from Langley to Houston, and the missions were also moved from the WFF to White Sands, New Mexico in 1961-62. The Wallops Station began focusing on space science research.

In 1974, the Wallops Station was renamed the Wallops Flight Center to reflect its new research focus on runways and aircraft noise reduction, as well as continuing as a launch site for orbital and suborbital flights. Earth studies of ocean processes were added to the research program in the 1970s. In 1981, the WFF was consolidated into the GSFC and renamed Wallops Flight Facility (WFF). Wallops became the primary facility for suborbital programs and in the 1990s, shuttle-based and small orbital projects were added to the facility's mission.

6.3 Themes of Exceptional Importance

Being research-oriented, science naturally has a different methodological bent. Its activities revolve almost entirely around research, launching, collecting and analyzing data, and making scientific discoveries. It encompasses the use of research facilities, radars, antennas, laboratories, and other facilities. The science directive has been involved in many of the large scale and expensive missions, such as the Hubble Space Telescope. In addition to the large missions, the science directive is also involved in small-scale missions, such as the Earth-orbiters. The science directive has always been a main focus of NASA and each of its four divisions has individual missions focused on answering specific scientific questions.

Heliophysics. The Heliophysics Division studies the nature of the Sun and how it influences the nature of space. As space is not completely empty, we live in the extended atmosphere of an active star, our Sun, which sends out a steady output of particles, energy, and magnetic system. NASA seeks knowledge of near-Earth space and how space weather interferes with communications, satellites, and power grids. One of the missions of the Heliophysics Division is to map the interconnected system, which requires a holistic study of the Sun's influence on space, Earth, and other planets. Spacecraft is strategically placed throughout the solar system to observe the Sun's effect. The recent Parker Probes at the Sun observe the beginning of solar winds. Research subjects in heliophysics includes the Sun's 11-year solar cycle; giant solar explosions (solar flares and coronal mass ejections); the constant stream of solar particles called solar wind; the magnetic environment near Earth; what drives change in the charged particles surrounding Earth and in the ionosphere; and the boundaries of the solar system as it travels through the interstellar neighborhood.

Planetary Science. One of the oldest and most popular divisions of NASA's SMD is Planetary Science. This science program focuses on the observation and discovery of our solar system through planetary objects in order to better understand the history of the solar system and the distribution of life it. Decades of research have advanced the scientific communities' understanding of the solar system and has pushed technology such as spacecraft and robotics. Every planet has been visited by NASA spacecraft. In addition, spacecraft have visited a variety of small bodies and new missions are focused on bringing samples back from different destinations. Current missions are focused on developing the understanding of the origin and history of the solar system. Missions explore Mercury, Mars, the Moon, the outer reaches of the Solar System, Pluto, and the Kuiper Belt Objects. The Planetary Science Division uses Earth-orbiting telescopes and ground-based sensors to detect, track, catalog, and characterize near-Earth objects (NEOs). NASA robotic explorers gather data to help scientists understand how planets were formed, what triggered evolutionary paths at different planets, what processes have occurred and are active, how Earth became habitable, as well as other questions. Research shows that the inner solar system bodies are rocky and include the planets of Mercury, Venus, Mars, and Earth. These planets are believed to have been formed from the accretion of dust into planetismals, then into proto-planets, and finally into planets. The outer solar system bodies consist of the four gas giants, Jupiter, Uranus, Saturn, and Neptune. These planets do not have defined surfaces with Jupiter and Saturn mostly consisting of hydrogen and helium and Uranus and Neptune consisting mostly of water, methane, and ammonia. Small bodies in the solar system include comets, asteroids, objects in the Kuiper Belt and Oort Cloud, small planetary satellites, Triton, Pluto, Charon, and interplanetary dust. Some are thought to have minimal alterations from their state in the young solar nebula and may provide insight into the formation and evolution of the solar system.

Earth Science. The Earth Science Division focuses on expanding the understanding of our planet's interconnected systems and on answering key questions such as:

- How is the global Earth system changing?
- What causes these changes in the Earth system?
- How will the Earth system change in the future?
- How can Earth system science provide societal benefit?

The research uses observations from satellites, instruments on the International Space Station, airplanes, balloons, and ships to map the connections between the planet's vital processes and the climate effects of ongoing natural and human-caused changes. The Earth Science Division has seven overarching science goals to guide the research, selection of investigations, and other programmatic decisions. These goals include:

- Atmospheric Composition: understand the changes in the Earth's radiation balance, air quality, and ozone layer;
- Weather: improve the capability to predict weather and extreme weather events;
- Carbon Cycle and Ecosystems: detect and predict changes in Earth's ecosystems and biogeochemical cycles;
- Water and Energy Cycle: enable better assessment and management of water quality and quantity to predict how the global water cycle evolves;

- Climate Variability and Change: improve ability to predict climate change and better understand the roles and interactions of the oceans, atmosphere, land, and ice in the climate system;
- Earth Surface and Interior: characterize the dynamics of Earth's surface and interior; and
- Societal Benefits: use knowledge of Earth's system to inform decisions and provide benefits to society.

Astrophysics. The Astrophysics division, which studies the universe, builds on the fundamental questions of:

- Are we alone?
- How did we get here?
- How does the universe work?

The current missions of the Astrophysics Division include the Hubble Space Telescope, the Chandra X-ray Observatory, the Fermi Gamma-ray Space Telescope, which explores Innovative Explorer missions, and SOFIA.

What follows is a representative sample of some of NASA's most exceptional achievements (Apex Events) in the Area of Science research in the last 50 years. The Apex Events reflect a range of significant themes (Themes) that have characterized NASA's SMD activities during the last half-century:

- Heliophysics;
- Planetary Science;
- Earth Science;
- Astrophysics; and
- Technology.

6.4 Apex Events

6.4.1 Pioneer 10 and 11 (1972–2006)

Description. The Pioneer 10 and Pioneer 11 were both small, nuclear powered, spin stabilized spacecraft intended to visit the outer planets of the solar system. Pioneer 10 was launched on March 2, 1972 and was also the first spacecraft to visit Jupiter, cross the asteroid belt, and the first human-made object to leave the solar system. Pioneer 11 was the sister spacecraft to the Pioneer 10 and was launched on April 5, 1973. It was the first spacecraft to study Saturn up close.

Statement of Significance. Originally designed for a 21-month mission, the Pioneer 10's lifetime lasted more than 30 years. The Pioneer 10 was NASA's first mission to the outer planets and was launched on March 2, 1972. The spacecraft became the first to fly beyond Mars' orbit, through the asteroid belt, and close to Jupiter, blazing a trail for the two Voyager spacecraft that were to follow and conduct more in-depth surveys. During the passage by Jupiter, Pioneer 10 obtained the first close-up images of the planet, charted Jupiter's intense radiation belts, located the planet's magnetic field, and discovered that Jupiter is predominantly a liquid planet. Pioneer 10 transmitted data on the magnetic fields, energetic particle radiation and dust populations in interplanetary space.

Pioneer 11 was the first mission to explore Saturn and the second spacecraft in the outer solar system. The spacecraft carried instruments to study magnetic fields, the solar wind and the atmospheres, moons and other aspects of Jupiter and Saturn.

Significance Criteria. NASA's Pioneer 10 and 11 mission is exceptionally important in the NRHP areas of education, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's science program in the last 50 years:

- Planetary Science;
- Astrophysics; and
- Technology.

Period of Significance. The recommended period of significance is 1972–2006, which includes the launch, journey of the spacecraft through the outer solar system, collection of data, and dissemination of data provided by both spacecrafts. The last communication attempt with the Pioneer 10 was in 2006.

6.4.2 Mariner 10 (1969–1975)

Description. NASA's JPL in Pasadena, California developed the Mariner Space Program to explore the inner solar system, focusing on Mercury, Venus, and Mars. The program was for planetary exploration, completing assessments and taking photographs of the planet's surface from above its atmosphere. The program had seven successful missions, with its final mission, Mariner 10, launching on November 3, 1973.

Statement of Significance. Mariner 10 was the last and greatest of the Mariner Space Program in that it was the first probe to successfully use the gravity-assist method of space travel, which was previously theorized about since the 1920s. The use of the gravity-assist was linked to another significant event in planetary science, the first up-close encounter of Mercury. This first up-close study of Mercury added information previously unknown about the solar system, helping to identify the early history of the planet, as well as its chemical and physical makeup. The success of the Mariner Space Program and Mariner 10 also helped launch the Voyager Space Program, the first to explore interstellar space.

Significance Criteria. NASA's development of the Mariner Space Program and Mariner 10 is exceptionally important in the NRHP areas of engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's space research program in the last 50 years:

- Planetary Science; and
- Technology.

Period of Significance. The recommended period of significance is 1969–1975. It includes the initial approval of the project by NASA, through the use of the gravity-assist, until the spacecraft was deactivated by NASA.

6.4.3 Landsat (1970–2013)

Description. Landsat is a cooperative program between the United States Geological Survey (USGS) and NASA, and is a series of missions to place Earth Observation satellites in orbit around the earth to acquire multi-spectral and multi-thematic imagery of the earth's land surface. Landsat is a part of NASA's SMD and operates under the NASA's Earth Science Division at the GSFC and the USGS's

National Land Imaging (NLI) program. Landsat data is processed and hosted at the USGS Earth Resources Observation and Science (EROS) Center.

Statement of Significance. The importance of the Landsat program cannot be understated; it is the only source of high quality, global, calibrated, moderate spatial resolution measurements of the Earth's surface that can be compared to previous data records. The 50-year, continuous data archive provides essential land change data and trending information not otherwise available. Landsat is a cooperative and multi-agency, -disciplinary, -purpose, and -decade program that has applications across Earth sciences: cartography, land cover, land use, agricultural productivity, glaciology, urban growth, forest resources, geological and mineral resources, seismology, natural resource management, hydrology, water availability, water quality, ecosystem health, oceanography, marine resources, environmental pollution and degradation, navigation, and meteorological phenomena. For 50 years Landsat satellites have had the optimal ground resolution and spectral bands to efficiently detect, document, measure, and track changes (natural processes, human and environmental pressures) on the Earth due to climate change, urbanization, drought, wildfire, biomass changes (carbon assessments), and a host of other changes. Landsat has greatly improved human's understanding of the Earth.

Land managers, policymakers, researchers, scientists, and public-private partnerships around the world are using open-source Landsat data for research, business, education, and other activities ranging from engineering, computing, research, communications, archaeology, demographics, and supporting disaster response. One testament to the unequivocal success of the Landsat program is Landsat 5 which provided high-quality, global, land surface data of the Earth for nearly 29 years.

The Landsat program has made huge advancements in hardware and software related to remote sensing, data collection, data processing, data management, data storage and archiving. The Landsat program has created innovation in geospatial, image, and thermal resolution, precise calibration that is the validation choice for coarse resolution sensors, excellent data quality, and consistent global archiving scheme of data. These advancements started with the MSS deployed on Landsat 1 and later Thematic Mapper (TM) instruments on Landsat 4 and 5 that were replicated and improved with the Enhanced Thematic Mapper Plus (ETM+) on Landsat 7.

Significance Criteria. NASA's and USGS's development of the Landsat program is exceptionally important in the NRHP areas of education, engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's science program in the last 50 years:

- Earth Science; and
- Technology.

Period of Significance. The recommended period of significance is 1970-2013. It includes the design and manufacture of the MSS and the launch of Landsat 1 through the decommission of Landsat 5, which carried the MSS and TM (later improved as the ETM+ with Landsat 7). Though the Landsat program continues into the current day, Landsat 5 was a hallmark of the program, continuously collecting data for nearly 29 years (1984-2013).

6.4.4 Nimbus 7 (1978–1994)

Description. The Nimbus Space Program was a NASA meteorological research-and-development satellite program with a prime objective of testing new technology, including the introduction of sensor technology. The secondary objective was to provide atmospheric data for improved weather forecasts and data on the Earth's environmental patterns. However, the series grew more into a major Earth sciences program to the study of oceans, land surfaces, and atmosphere with the availability of better sensing instrumentation. The information gathered by the Nimbus Space Program has been used by various agencies, including the National Oceanic and Atmospheric Administration (NOAA).

Statement of Significance. The Nimbus 7, along with the legacy of the Nimbus Program that launched the Nimbus 7, provided the start to other space programs that use satellite imagery, sensors, and mapping to evaluate Earth's ecological components, including its layers of the atmosphere, oceans, lands, and weather. The data gathered by Nimbus 7 and the precedent it provided for the monitoring of Earth is significant to the history of NASA and humankind's evaluation of the Earth.

Significance Criteria. NASA's development of Nimbus 7 is significant in the NRHP areas of education, engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's space research program in the last 50 years:

- Earth Science; and
- Technology.

Period of Significance. The recommended period of significance is 1978–1994 when the spacecraft was in service, orbiting Earth.

6.4.5 Voyager 1 and Voyager 2 (1977–present)

Description. NASA launched the twin spacecraft from Cape Canaveral, Florida with Voyager 2 lifting off on August 20, 1977 and Voyager 1 entering space on a faster, shorter trajectory on September 5, 1977. Voyager 1 entered the Jovian system and explored the moons, Io and Europa. Voyager 2 explored Jupiter's moons, then traveled on to Saturn, and encountered Uranus and Neptune. Voyager 1 and Voyager 2 explored all the giant outer planets, 48 of their moons, and the unique systems of rings and magnetic fields those planets possess. In 1993, Voyager 2 also provided the first direct evidence of the long-sought after heliopause—the boundary between our Solar System and interstellar space.

Statement of Significance. The Voyager missions marked many firsts in NASA's research into the four giant planets in the outer solar system. Both Voyager 1 and 2 visited Jupiter and Saturn and returned images that changed what scientists originally believed about the planets. Voyager 2 provided the first close-up images of both Uranus and Neptune and revealed key information on planet formation, geology of the moons and planets, and images of dark rings around both planets. Voyager 1 was the first human-made object in interstellar space and provided important information regarding the heliosphere, heliopause, and the heliosheath. Voyager 2 is NASA's longest-operating mission, which was previously set by Pioneer 6.

Significance Criteria. The data gathered from the Voyager spacecraft is exceptionally important in the NRHP areas of education, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's science program in the last 50 years:

- Planetary Science,
- Heliophysics; and
- Technology.

Period of Significance. The recommended period of significance is 1977– present. It includes the initial design and launch, data collection and dissemination, and entry into interstellar space.

6.4.6 Solar Maximum Mission (1980–1989)

Description. The Solar Maximum Mission (SMM) spacecraft was designed to provide observations of solar activity and contained seven instruments to study short-wavelength and coronal manifestations of solar flares. By 1986, over 400 papers based on SMM data and observations had appeared in scientific journals.

Statement of Significance. The SMM provided observations and data for more than 400 scientific papers by 1986 and included several important contributions to the understanding of the Sun, including 1. The Sun as a star, 2. Solar flares, and 3. The active solar atmosphere. During the first five years of the SMM's operation, the total radiant output decreased slightly but leveled off as the minimum of solar activity approached. The rotation of the large sunspot is correlated with small but measurable decreases in solar radiative output. The frequencies of one class of global solar oscillations were observed to change slightly and the frequencies of another class of global solar oscillations disagreed with the standard solar model predicted frequencies. Solar flares were the key focus of the SMM and most of the evidence indicated that the energetic radiation emitted during the impulsive phase of solar flares resulted from the dissipation of energy in beams of high-energy charged particles accelerated in magnetic loop structures. The size of the loops is constrained by the duration of hard X-ray emission. Particle acceleration takes place in a limited region by the production of hard X-rays and y-rays. High energy mesons and neutrons were detected in some intense flares. Certain element abundancy varies from flare to flare and often changes during the course of an individual flare. One of the SMM instruments obtained the first direct measurements of the magnetic fields in the transition region, which includes several thousand kilometers above the visible surface of the Sun or the photosphere.

Significance Criteria. The data gathered from the SMM is exceptionally important in the NRHP areas of education, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's science program in the last 50 years:

- Heliophysics; and
- Technology.

Period of Significance. The recommended period of significance is 1980–1989. It included the initial design and launch, data collection and dissemination, and reentry into Earth's atmosphere.

6.4.7 Cosmic Background Explore (1989–1994)

Description. The Cosmic Background Explore (COBE) mission focused on taking precise measurements of the diffuse radiation between 1 micrometer and 1 centimeter over the whole celestial sphere and the results of the mission revolutionized the scientific understanding of the early cosmos. COBE was launched on November 18, 1989 and carried three instruments. The spacecraft precisely measured and mapped the oldest light in the universe. The COBE mission ushered in new era of precision measurements and paved the way for deeper exploration of microwave backgrounds, including NASA's Microwave Anisotropy Probe (WMAP) mission and ESA's Planck mission.

Statement of Significance. The COBE mission and data revolutionized the understanding of early cosmos and confirmed the Big Bang theory of the origin of the universe. The cosmic microwave background, the oldest light in the universe, was precisely measured and mapped with the spectrum measured with a precision of 0.005%. The mission ushered in a new era of precision measurements and paved the way for deeper exploration of the microwave background. In 2006, John Mather and the COBE team was awarded the Gruber Cosmology Prize for their "groundbreaking studies of the spectrum and spatial structure of the relic radiation from the Big Bang." In addition, John Mather from GSFC and George Smoot from the University of California, Berkeley shared the 2006 Nobel Prize in Physics for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation measured by COBE.

Significance Criteria. The data gathered from the COBE mission is exceptionally important in the NRHP areas of education, exploration/settlement, invention, and science and illustrates the following Themes of NASA's science program in the last 50 years:

- Astrophysics; and
- Technology.

Period of Significance. The recommended period of significance is 1989–1994. It includes the initial design, redesign, launch, data collection and dissemination, and transition to WFF as a test satellite.

6.4.8 Hubble Space Telescope (1977–2009)

Description. The Hubble Space Telescope is photographic instrument developed by NASA to capture images of the universe for the benefit of science. The telescope is named after Edwin Hubble, an astronomer from the early twentieth century who identified galaxies outside of the Milky Way Galaxy. The Hubble Space Telescope helps scientists take pictures of the universe not available from telescopes on Earth's surface.

Statement of Significance. The Hubble Space Telescope was the first of its kind to be placed in space for the function of photographing the universe. The telescope provided a solution to an issue Earth based telescopes had, trying to clearly pierce through the atmosphere by placing the telescope above the atmosphere. The Hubble Space Telescope has also been in service for twice as long as originally intended and is continuing to serve scientists on the study of the universe. The Hubble Space Telescope has been used by scientists and universities around the world to document phenomena within our solar system, galaxy, and throughout the universe.

Significance Criteria. NASA's development of the Hubble Space Telescope is exceptionally important in the NRHP areas of engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's space research program in the last 50 years:

- Astrophysics;
- Planetary Science; and
- Technology.

Period of Significance. The recommended period of significance is 1977–2009. This time span includes the construction of the telescope, its various upgrades made throughout its construction prior to launch, its launch in 1990 on the Space Shuttle *Discovery*, and all five service missions to the telescope, with the last mission being made in 2009.

6.4.9 Mars Pathfinder (1994–1997)

Description. The Mars Pathfinder mission was a new technology designed primarily to demonstrate an innovative, economical method of delivering scientific instruments and a free-ranging, remote-controlled, robotic rover to another planet, with Mars as the proving ground. The mission also sought to collect and transmit geological, soil, magnetic property, and atmospheric data back to Earth. The Mars Pathfinder mission was a part of NASA's SMD, under NASA's Planetary Science Division, and was managed by the Mars Exploration Program (MEP) and the JPL.

Statement of Significance. The Mars Pathfinder mission, and the MEP in general, operating under the Discovery Program, was a groundbreaking approach to planetary science missions to design, develop, launch, land, and operate a rover using innovative technologies for an economical cost. The bag landing system and innovative petal design was a success, which has been used in various incarnations since, to land other rovers on Mars. Pathfinder was not only proof of concept of this technology, innovative landing system, and remote rover operation, but also a validation of the "feed-forward" goals of the MEP and the innovation and economy mandates of the Discovery Program. The Mars pathfinder mission held the attention of researchers, scientists, and the public, also fulfilling the MEP outward looking goals such as communicating their activities to help develop and further scientific literacy in the nation and interaction with the national and international planetary and Mars science community.

Significance Criteria. NASA's development of the Mars Pathfinder is exceptionally important in the NRHP areas of education, engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's planetary science research in the last 50 years:

- Planetary Science; and
- Technology.

Period of Significance. The recommended period of significance is 1994–1997. It includes the formation of the MEP and the Mars Pathfinder.

6.4.10 Solar and Heliospheric Observatory (SOHO) (1995–2011)

Description. Scientists using the joint European Space Agency (ESA)/NASA Solar and Heliospheric Observatory (SOHO) spacecraft discovered "jet streams" or "rivers" of hot, electrically charged plasma flowing beneath the surface of the Sun. These findings helped scientists understand the famous 11-year sunspot cycle and associated increases in solar activity that can disrupt the Earth's power and communications systems.

Statement of Significance. The SOHO provided an unprecedented amount of data about the Sun, including its interior, hot and dynamic atmosphere, solar wind, and its interaction with the interstellar medium. Some of the key results include:

- Revealing the first images of a star's convection zone (turbulent outer shell) and the structure of the sunspots below the surface.
- Providing the most detailed and precise measurements of the temperature structure, the interior rotation, and gas flows in the solar interior.
- Measuring the acceleration of the slow and fast solar wind.

- Identifying the source regions and acceleration mechanism of the fast solar wind in the magnetically "open" regions at the Sun's poles.
- Discovering new dynamic solar phenomena such as coronal waves and solar tornados.
- Revolutionizing the ability to forecast space weather, by giving three days' notice of Earth-directed disturbances and playing lead role in the early warning system for space weather.
- Monitoring the total solar irradiance (solar constant) as well as variations in the extreme ultraviolet flux, which is important to understand the impact of solar variability on Earth's climate.

The SOHO is one of the most prolific discoverers of comets with more than 2,000 comets found by the SOHO as of January 2011.

Significance Criteria. The SOHO mission is exceptionally important in the NRHP areas of education, engineering, exploration/settlement, invention, and science, and illustrates the following Themes of NASA's science program in the last 50 years:

- Heliophysics;
- Universe; and
- Technology.

Period of Significance. The recommended period of significance is 1995–2011, which includes the launch in 1995, multiple mission extensions of the spacecraft, and the dissemination of data.

6.5 Significant People

A representative sample of extraordinary people who have worked to accomplish NASA's exceptional achievements of the last 50 years in the Area of Science are presented below. More complete biographical information on each person is available in Appendix C.

Table 6-1: List of Significant People in the Area of Science

Person	Association
Reuven Ramaty, Ph.D. (1937–2001)	High energy astrophysics pioneer
Neil Gehrels, Ph.D. (1952–2017)	Voyager 1 and 2
Michael H. Freilich, Ph.D. (1954–2020)	Scatterometer (NSCAT); Seasat
Jakob van Zyl, Ph.D. (1957–2020)	Synthetic aperture radar systems; Juno, Dawn, Cassini
Suzanne Dodd	Voyager; Cassini; Spitzer Space Telescope
Lori Glaze, Ph.D.	DAVINCI, VERITAS
John C. Mather, Ph.D.	Cosmic Background Explorer (COBE)
James E. Hansen, Ph.D.	Climate change science
Edward C. Stone, Ph.D.	Voyager mission
Paul A. Newman, Ph.D.	Stratospheric dynamics and chemistry

6.6 Summary

NASA's Science Mission Directorate focuses on using the vantage point of space to achieve a deep scientific understanding of our planet, other planets and solar system bodies, the interplanetary environment, the Sun and its effect on the solar system, and the universe beyond. SMD conducts scientific studies of the Earth from space, collects samples from other bodies in our solar system, and records images within the Galaxy and beyond. The hundreds of spacecraft that carry out NASA's science missions are all supported by a ground-based network of communications, tracking, and data processing facilities—assets whose utilitarian appearance belies the extraordinary nature of the information being relayed. Consideration of the types of Apex Events that illustrate SMD's exceptional activities over the last 50 years provides a foundation for identifying Exemplary Property Types.

7.0 AREA 4: ARCHITECTURE

7.1 The Aesthetic of Function

Under Criterion C of the NRHP, properties may be eligible for listing

> if they 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.[9]

The NPS clarifies that Criterion C "applies to properties significant for their physical design or construction, including such elements as architecture, landscape architecture, engineering, and artwork. As presented in Sections 4.0 through 6.0 of this study, NASA's <50 assets are most likely to be eligible for listing in the NRHP under Criterion A for their association with exceptionally important and specific achievements (i.e., Apex Events) that have occurred at or because of unique and specialized HTSF eligible under Criterion C for engineering. NASA's extraordinary achievements are carried out by scientists, engineers, and pilots that are exceptionally important within their respective fields of endeavor, and whose significance is most effectively conveyed at NASA Centers through the HTSF where they performed their work. In most cases Criteria A and C are codependent: in the absence of one or the other an asset is not eligible.

While engineering certainly is design, this section seeks to address the potential for <50 assets to be eligible solely under Criterion C for architecture—in the traditional "aesthetic" sense of the word—and therefore not otherwise identified as eligible under CCG. To understand the potential for NASA properties to be eligible for listing in the NRHP for architecture, it is helpful to consider the history of the agency and its approach to facilities planning and construction since its inception. Since 1915, NASA (and its predecessor the NACA) has been an agency focused on scientific research and development, and as such the construction of facilities has always been and continues to be directed towards advancing those needs in an expedient and cost-effective manner. Personnel does not live on site, as is the case with military installations, so there are no housing areas where aesthetics are typically a significant consideration. NASA Centers have limited public visibility—while of considerable interest to the public, the Centers are not "public" in the same sense as many other Federal buildings, such as a post office or courthouse, which have traditionally been designed with aesthetics and public experience in mind. As secure sites, Centers are generally not accessible to or used by the public, and for this reason NASA has fulfilled its mandate to "provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof" in large part through information sharing (e.g., public-private partnerships, televised launches, traditional and web-based publications, and special programs).[10] Additionally, in much the same way as specialized research HTSF, which must be routinely modified as technology advances, NASA Centers are consistently changing—facilities are constructed to accommodate new programs and evolving needs, obsolete assets are demolished and replaced, and Centers are altered in response to Federal real property directives.

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[9] National Park Service, *How to Apply the National Register Criteria for Evaluation,* (formerly National Register Bulletin 15), 1990, revised 1997.

[10] National Aeronautics and Space Act of 1958 (Public Law #85-568, 72 Stat., 426), Sec. 203 (a)(3).

Accordingly, the predominant aesthetic of NASA Centers is one of functionality and economy. Aesthetics are secondary, integrated only insofar as they may be without diminishing those two primary goals. Within this context, opportunities for comprehensive design and high-style architectural expression are limited, and primarily reserved for the most public-facing of its buildings and structures—central administrative buildings and visitor's centers. This makes sense, as these are the buildings where NASA is most directly presenting itself to the outside community. Review of NASA's portfolio of real property assets and aboveground cultural resource surveys confirm that well-known architecture and planning firms were retained to design the early and/or peak phases of construction at the Centers. Perhaps the best example of a designed Center is JSC, built specifically for NASA on previously undeveloped land to serve as the nerve center for the space program. The result was a quintessentially Modern-style research campus that incorporated design concepts espoused in President John F. Kennedy's *Guiding Principles for Federal Architecture* (1962), as well as broader national trends in private corporate campus design.[11] GSFC, JPL, and SSC also convey a strong mid-century Modern aesthetic that has come to be associated with NASA and the Space Race in the collective consciousness. At the other end of the spectrum are GDSCC and WFF. These Centers have always been acutely focused on relatively narrowly defined technical activities and as such they convey an entirely HTSF aesthetic.

By the end of the Apollo Program in 1972, all of NASA's Centers and component facilities were well established, substantially built out, and the general aesthetic determined—some according to the plans of well-known design firms, and others through fits and bursts of more ad hoc construction. And outside of initial planning and construction, examples of strong architectural expression of such significance as to support NRHP eligibility under Criterion C and CCG are rare and most likely to fall into a few narrowly defined categories.

7.1.1 Architectural Style

A NASA <50 asset may meet NRHP Criterion C if it is an exemplary work of a master architect, engineer, or designer, or if it is an exceptional example of a significant architectural style. Broadly recognized American architectural styles since 1973 that may be found at NASA Centers include Brutalism and New Formalism, both commonly employed in government buildings.[12] However, to be exceptionally important examples of architectural styles, assets would have to be highly exemplary of the style, rather than generally representative.

Brutalism (1960s–1980s). Brutalism as an architectural movement was formed in Great Britain in the 1950s. The British architectural critic Reyner Banham defined Brutalism as having three major points: "The building as a unified visual image, clear and memorable;" "Clear exhibition of its [the building's] structure;" and "A high valuation of raw, untreated materials". Other phrases that were used to describe Brutalism in the 1950s were "clean virgin surfaces," "heavily corrugated volumes, but of prismatic simplicity," and "services exposed to view". The idea was that the buildings needed to show structural materials, preferably ones that were rough. Large, clear shapes were also valued over small details. A bold visual appearance for the building was a high priority in the design of Brutalist structures. The Brutalism movement was one where honesty and exposure of the functional elements of the building

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[11] These concepts are discussed in Kuranda, Peeler, and Shaw, and Jennifer Keys and Adam Graves, *Historic and Architectural Survey and Evaluation of Facilities*, report prepared by Ayuda Companies and GRAVitate, LLC for NASA Johnson Space Center, 6 November 2017.

[12] Discussion of styles is largely derived from Roy Hampton, Maria Burkett, and Christine Trebellas, "Historic Context for Evaluating Mid-Century Modern Military Buildings," Prepared by Hardlines Design Company for the Department of Defense Legacy Resource Management Program, Project Number 11-448.

were prized. A Brutalist design would expose the structural materials that held up the building but might also expose other necessary and functional elements, such as pipes or ventilation ducts. The whole idea was to express a sense of honesty by showing the viewer the guts of the building—what held it together structurally and what made it function—while at the same time creating an interesting, visually striking design. In the United States, the result was buildings that typically showcased bold geometrical exterior and interior forms, with large expanses of exposed structural concrete on the exterior. Buildings of this description became very common in the late 1960s and early 1970s, as the movement reached its peak in the United States. It was most commonly used for large and medium-sized government-funded buildings, university buildings, museums, and hospitals.

New Formalism (1960s–1970s). Another movement that originated in the 1950s and achieved widespread popularity in the 1960s was New Formalism. In this movement, buildings were still designed with modern materials, and sculpted details and moldings were avoided. However, the overall proportions and layouts of the buildings were influenced by traditional ideas of Classical balance and symmetry, and sometimes simple abstracted Classical elements like arches were included. In contrast to the massive, often blocky forms of Brutalism, New Formalist buildings often had well-ordered compositions with a clear definition of the base, middle, and top of the building, a tendency inherited from Classical architecture. The idea was not to revive the details of Classical architecture but instead to apply a sense of Classical balance and order to buildings that were still modern, with simple unornamented forms and modern materials. These buildings often have symmetrical front porches with square posts, a feature that recalls the porticos of Classical buildings, and the porches are often veneered in stone or executed in light-colored poured concrete to achieve a stone-like effect.

Postmodernism (1960s–Present). Postmodernism is an eclectic, colorful style of architecture and the decorative arts that appeared from the late 1970s and continues in some form today.[13] It emerged as a reaction to Modernism and the Modern Movement and the dogmas associated with it. By the 1970s Modernism had begun to seem elitist and exclusive, despite its democratic intentions. The failure of building methods and materials and alienating housing estates was a focus for architects and critics in the early 1970s. A book published in 1966 by architect Robert Venturi, *Complexity and Contradiction in Architecture*, was a key influence on the development of Postmodernism. Venturi extolled the ambiguities, inconsistencies, and idiosyncrasies of the Mannerist and Baroque architecture of Rome, but also celebrated popular culture and the ordinary architecture of the American main street. Postmodern architecture is characterized by use of bright colors, playfulness and whimsy, Classical motifs, and variety of materials and shapes.

High Tech Design (1960s to Present). Influenced by engineering and new technology, High Tech is a style that accentuates a building's construction.[14] High Tech is a facet of Modern architecture that originated in the 1960s as a stylistic expression of the increasing integration of computer technology into science, medicine, research, and industrial fields. It was a concept of design based on engineering, construction and other aspects, such as the manipulation of space. High Tech was marked by a preference for lightweight materials and sheer surfaces, a readiness to adopt new techniques from engineering and other technologies, and the celebratory display of a building's construction and services. High Tech buildings are characterized by exposed structures (usually of steel and or other metals), with services (pipes, air ducts, lifts etc.) often picked out in bright colors, a smooth, impervious

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[13] Royal Institute of British Architects, "Postmodernism in architecture," available at www.architecture.com/explore-architecture/postmodernism, accessed November 2021.

[14] Royal Institute of British Architects, "High Tech in architecture," available at www.architecture.com/explore-architecture/high-tech, accessed March 2022.

skin (often of glass) and a flexibility to create internal service zones, rather than rooms or sequences of rooms.

7.1.2 Sustainable Design and LEED

Following the Energy Crisis of 1973, the Federal government took aggressive steps to attain energy independence for the nation. The Federal initiatives had a significant impact on NASA. Fuel efficiency has always been one of the primary challenges for flight, but the increased government focus in the 1970s brought greater public visibility, political support, and funding to NASA's ongoing research in this area. NASA's Aircraft Energy Efficiency (ACEE) program's Advanced Turboprop Project, under the leadership of GRC engineer Daniel Mikkelson, solved a long-standing limitation with the sweeping propeller, for which the team was awarded the prestigious Collier Trophy in 1987. NASA's role in raising awareness of climate change, particularly with the NIMBUS-7 satellite in the 1970s and responding to the larger environmental considerations for air and spaceflight has engendered a culture of energy efficiency that has become more pronounced as the American public has become more educated on the issues.

The impact of the Energy Crisis was felt around the world as awareness of overuse of resources and dependence on fossil fuels grew. In the 1980s, the word *sustainability* began to be used more in terms of the sustainability of how humans live on the planet. Today, the most common definition of sustainability is that of *sustainable development*, defined by the Brundtland Commission of the United Nations in 1987: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." In 1993 the non-profit U.S. Green Building Council (USGBC) was formed to promote the design and construction of buildings that are environmentally responsible, profitable, and healthy places to live and work. In 2000 the USGBC introduced the Leadership in Energy and Environmental Design (LEED) program, a third-party green building certification program and the globally recognized standard for the design, construction and operation of high-performance green buildings and neighborhoods. The LEED program gained traction quickly and today the USGBC reports that there are nearly 80,000 LEED projects in 162 countries. Often called the real estate manager for the Federal government, the General Services Administration (GSA) has endorsed the LEED program for new construction of Federal buildings.

In 2006 NASA completed its first LEED-certified building at MSFC—Building 4220, a five-story glass and steel structure built to house 400 workers, including the SLS Office. Building 4220 was designed by the Nashville-based architectural firm of Thomas Miller & Partners, and constructed by BL Harbert of Birmingham, Alabama. NASA has since constructed LEED-certified buildings at GSFC, WSTF, and LaRC, and now tracks certification in the RPMS. Although LEED is not a style *per se*, there is a discernible aesthetic to LEED-certified construction, and the philosophy of sustainable design is highly representative of larger social and government trends beginning in the late 20th century, and a case can be made for exceptional importance within this context.

7.2 Summary

As opposed to the preceding three Areas of Significance, which are based upon NASA's activities and therefore tied to the function of an asset, the Area of Architecture is one of aesthetic. As such, the assets <50 that possess exceptional importance solely under NRHP Criterion C would not necessarily be linked to their function, nor are they likely to be uniquely associated with NASA. Assets eligible for listing in the NRHP as examples of exceptionally important architectural design will be readily identifiable through cursory observation by a qualified architectural historian from the exterior without the need to understand specific activities that take place within.

8.0 EXEMPLARY PROPERTY TYPES

The exploration of exceptional importance under NRHP Criteria A, B, and C revealed that NASA's achievements are numerous and illustrate many areas of significance: however, there is a finite number of assets where these activities occur. Additionally, there is a clear distinction between those assets that are commonplace in both form and function and those that are uniquely representative of NASA's activities and therefore capable of conveying exceptional importance. To group these assets into property types, several sources of existing information were considered.

The NRHP recommends that when seeking to nominate "groups of related significant properties," a MPD form may be used to present "the themes, trends, and patterns of history shared by the properties… organized into historic contexts and the property types that represent those historic contexts".[15] Within the MPD framework, the NRHP defines a property type as "a grouping of individual properties, characterized by common physical and/or associative attributes" that "ties the historic context to specific historic properties, so that National Register eligibility can be assessed". There have been several efforts to identify NASA historic properties in a manner analogous to that of the MPD. These efforts proved useful in developing the RSF Exemplary Property Types.

8.1 Previous Studies

8.1.1 Man in Space National Historical Landmark Theme Study

The first of these was the Man in Space National Historical Landmark (NHL) Theme Study (Man in Space), initiated in 1980 and culminating in a 1984 NPS report. Public Law 96-344, signed by President Carter in September 1980, directed the Secretary of the Interior (SOI) to conduct a study of "locations and events associated with the historical theme of Man in Space," to include "potential action alternatives" for their protection. Recognizing that a high bar was necessary for such a task, the NPS used the NHL theme study approach to guide the selection of "properties at which events occurred that have significantly contributed to, are identified prominently with, or outstandingly represent, the broad cultural, political, economic, military, or social history of the Nation, and from which an understanding and appreciation of the larger patterns of our American heritage may be gained". NHLs are a higher-level designation than the NRHP, reserved for properties of national significance that are:

- the location of an event that had a significant impact on American history overall;
- the property most strongly associated with a nationally significant figure in American history;
- an outstanding illustration of a broad theme or trend in American history overall;
- an outstanding example of an architectural style or significant development in engineering;
- part of a group of resources that together form a historic district; or
- able to provide nationally significant archaeological information.

Out of what were likely hundreds of NASA and U.S. Air Force assets, and only 15 years after the moon landing, the study recommended 24 sites for NHL designation among 12 types deemed to be directly associated with the theme. Identified types were:

- National Advisory Committee for Aeronautics (NACA) wind tunnels (4 properties);

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[15] National Park Service, *National Register Bulletin: How to Complete the National Register Multiple Property Documentation Form* (formerly National Register Bulletin 16B), 1991, revised 1999.

- rocket engine development facilities (3 properties);
- rocket engine test stands (3 properties);
- rocket test facilities (1 property);
- rockets (1 property);
- launch pads (1 property);
- Apollo training facilities (4 properties);
- Apollo hardware test facilities (1 property);
- unmanned spacecraft test facilities (2 properties);
- tracking stations (1 property);
- mission control centers (2 properties); and
- other support facilities (1 property).

Although not explicitly presented as such, the categories of sites are consistent with the NRHP definition of property type. The 24 identified properties, in addition to two that were already designated prior to the study, were deemed to be the most historically significant and best able to convey the national significance of the American manned space program.

8.1.2 Space Shuttle Program Survey

The second theme-based historic resource study was related to the SSP.[16] In 2004 President George W. Bush publicly announced that the SSP would be retired. Recognizing the Section 106 implications of the termination of the program, NASA initiated an agency-wide survey to identify assets eligible for listing in the NRHP for their association with the SSP. Implemented separately at the Center level, the survey evaluated 335 assets at 16 NASA Centers and component facilities and identified 70 NASA-owned historic properties (21%). Twenty-four of these were previously determined eligible for listing under "Man in Space," and 46 were newly identified. Again, 12 types were defined:

- resources associated with transportation (17 properties);
- vehicle processing facilities (12 properties);
- launch operation facilities (10 properties);
- mission control facilities (1 property);
- news broadcast facilities (1 property);
- communication facilities (4 properties);
- engineering and administrative facilities (26 properties);
- space flight vehicle (3 properties);
- manufacturing and assembly facilities (6 properties);
- resources associated with the training of astronauts (8 properties);
- resources associated with space flight recovery (7 properties); and
- resources associated with processing payloads (3 properties).[17]

Because the study identified NRHP-eligible resources, the NRHP definition of "property type" was used. The approach was similar to that used for "Man in Space," but the types were more broadly defined by functional area. The SSP survey was completed in 2008, NASA's 50th anniversary, and the eligible

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[16] Joan Deming and Patricia Slovinac, *NASA-wide Survey and Evaluation of Historic Facilities in the Context of the U.S. Space Shuttle Program: Roll-up Report*. Prepared by Archaeological Consultants, Inc., for National Aeronautics and Space Administration, Environmental Management Division, Office of Infrastructure & Administration, Headquarters, Washington, D.C., 2008.

[17] The report notes that some resources fall into more than one property type.

resources ranged in construction date from 1943 to 1996, but all were found to have achieved significance under NRHP CCG.

8.1.3 Highly Technical or Scientific Facilities

In 2021 NASA completed an agency-wide study to identify HTSF among its assets.[18] The concept of HTSF within the context of the NRHP came into use with the ACHP's publication on the subject entitled "Balancing Historic Preservation Needs with the Operation of Highly Technical or Scientific Facilities," which responded directly to the challenges that agencies like NASA encounter in managing historic properties consistent with the NHPA.[19] Issued in part due to NASA concerns about the implications of the "Man in Space" study, the ACHP publication aimed to demonstrate how historic HTSF can be managed consistent with the NHPA, in particular Section 106, if the respective parties—preservation regulators and agency resource managers—understand and account for one another's goals. A major theme in this publication was the acknowledgement that modification is expected and necessary to maintain active use of HTSF.

The ACHP publication defines an HTSF as a site, structure, building, object, or district (i.e., one of the five NRHP resource types) that was built, installed, or established for unique technological engineering or scientific research purposes, including housing unique technological equipment or instruments, which are:

- "active 'pure' or 'applied' research facilities carrying out essential, often state-of-the-art research and development;" or
- "active 'frontline' operational facilities engaged in programs supporting scientific or defense-related missions."

Active facilities are those that are currently in use and operating to achieve scientific goals or missions. "Pure" research facilities are those that conduct basic research in order to better understand fundamental concepts within a scientific field, while "applied" research facilities are focused on solutions to a specific problem or project. An operational facility considered "frontline" uses innovative, cutting-edge technology that requires up-to-date facilities to successfully achieve its mission.

In its HTSF study, NASA further defined HTSF as real or personal property owned or controlled by NASA that:

- is directly associated with scientific experimentation, discovery, or mission; or
- is integral to research and development, unique equipment manufacturing or assembly, training, observation and communications, mission control, or exploration in support of scientific experimentation, discovery, or mission implementation.

The HTSF study classified assets into six categories based upon the associated program and/or function:

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[18] M.K. Meiser and Kirsten Johnson, *Inventory of NASA's Highly Technical or Scientific Facilities for the Purposes of Compliance with Section 106 of the National Historic Preservation Act*. Prepared by AECOM for the National Aeronautics and Space Administration, NASA Headquarters Environmental Management Division, Washington, D.C., 2021.

[19] Advisory Council on Historic Preservation, *Balancing Historic Preservation Needs with the Operation of Highly Technical or Scientific Facilities*, A report to the U.S. House of Representatives, Committee on Interior and Insular Affairs, Subcommittee on National Parks and Public Lands, and the Committee on Science, Space, and Technology, 1991.

- space exploration;
- advancement of fundamental scientific concepts and theories;
- training;
- manufacturing and assembly;
- testing; and
- observation and communications.

While the HTSF study is intended to inform NASA cultural resource management, it does not identify NRHP-eligible properties and the asset categories are not NRHP property types. But the categorization shares some similarities to that of the previous "Man in Space" and SSP studies.

8.2 NASA Facility Classification Coding System

NASA's Facility Classification Coding System (FCCS) is used by the Facilities and Real Estate Division (FRED) to categorize real property assets in the Real Property Management System (RPMS) (Appendix A). Based on numerical codes, the FCCS serves as the framework for identifying, categorizing, and analyzing the agency's inventory of facilities around the world, and consists of Facility Class (level 1), Category Group (level 2), Basic Category (level 3), and NASA Code (Figure 2-1). Ten Facility Classes are subdivided into 42 Category Groups, 79 Basic Categories, and 321 NASA Codes that together provide a great deal of specificity on asset use.

As an example, the Magnetic Standards Lab (Building N217) at Ames Research Center is coded in RPMS as 310-20. The Facility Class "3" is Research, Development, & Testing (RD&T); the Category Group "31" is RD&T Buildings; the Basic Category "310" is RD&T Laboratories; and the NASA Code is "20." The NASA Codes are variable and simply used for additional distinction as needed (e.g., a concrete runway is "10," and a bituminous runway is "20").

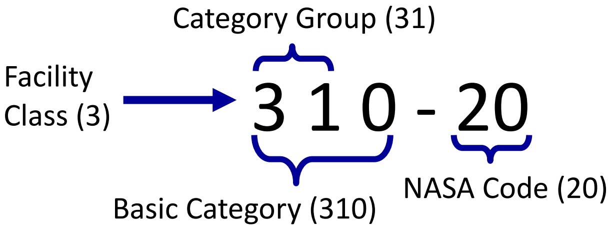

Figure 8-1. FCCS Code for Research, Development, & Testing Laboratories

Consideration of the Facility Classes reveals a functional grouping structure that shares some similarities with the "Man in Space" study and the SSP survey:

- Operational, Including Tracking & Data Acquisition & Training;
- Maintenance & Production;
- Research, Development & Testing (RD&T);
- Supply;
- Hospital & Medical;
- Administrative;
- Housing & Community;
- Utility & Ground Improvements;
- Land; and
- Leasehold Improvements.[20]

Although the FCCS is a real property management tool that has not been developed for cultural resource management, it does offer an efficient mechanism to associate assets with property types without requiring resource-by-resource consideration of all 3,000 assets <50 in NASA's inventory. The FCCS is a required component of RPMS, which is NASA's comprehensive inventory of NASA assets and the foundation of its real property management. RPMS is actively maintained and routinely updated, and readily accessible to CRMs. As a functional grouping system, it is applicable to NRHP property types. It is possible, then, to use the FCCS as an organizational framework to link NASA's historical significance to its real property assets.

8.3 Description of Property Types

Research conducted under the three functional areas of Aeronautics Research, Human Exploration and Operations, and Science resulted in the identification of 11 property types (Exemplary Property Types) deemed to have the greatest potential to convey exceptional importance under CCG (Table 8-1). The property types house activities that are essential to NASA's most significant programs and achievements of the last 50 years, and uniquely representative of specialized functions.

Table 8-1. Exemplary Property Types by Area

Exemplary Property Type	**FCCS, Basic Category**		**Areas**		
	Code	**Name**	**Aeronautics Research**	**Human Exploration & Operation**	**Science**
Communications Facilities	131	Communication Buildings	No	Yes	Yes
	132	Communications Facilities – Other than Buildings	No	Yes	Yes
Tracking Station Facilities	140	Tracking Station Buildings	No	Yes	Yes
	141	Tracking Station Facilities – Other than Buildings	No	Yes	Yes

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[20] Land (Facility Class 9) and leasehold improvements (Facility Class 10) are not built assets and therefore not applicable included in this study.

Exemplary Property Type	FCCS, Basic Category		Areas		
	Code	**Name**	**Aeronautics Research**	**Human Exploration & Operation**	**Science**
Training Facilities	171	Training Buildings	Yes	Yes	No
	179	Training Facilities – Other than Buildings	Yes	Yes	No
Fabrication and Assembly Facilities	220	Fabrication and Assembly Buildings	Yes	Yes	Yes
	221	Payload Fabrication, Assembly, and Checkout	No	Yes	Yes
Research, Development, and Testing Laboratories	310	Research, Development, and Test Laboratories	Yes	Yes	Yes
	320	Research, Development, and Test Laboratories – Other than Buildings	Yes	Yes	Yes
Data Processing Centers	310	Research, Development, and Test Laboratories	Yes	Yes	Yes
	320	Research, Development, and Test Laboratories – Other than Buildings	Yes	Yes	Yes
Wind Tunnels	330	Wind Tunnels	Yes	No	No
	332	Wind Tunnel Facilities – Other than Buildings	Yes	No	No
Engine and Vehicle Test Facilities	340	Engine Test Complexes	No	Yes	No
	350	Vehicle Static Test Complex Buildings	No	Yes	No
	355	Vehicle Static Test Facilities – Other than Buildings	No	Yes	No
Launch Complex Facilities	381	Launch Complex Buildings	No	Yes	No
	382	Launch Complex Facilities – Other than Buildings	No	Yes	No
Simulators and Mockups	N/A	N/A	Yes	Yes	No
Aircraft/Spacecraft and Models	N/A	N/A	Yes	Yes	No

8.3.1 Communications Facilities (Basic Categories 131, 132)

The FCCS describes Basic Category 131 as "buildings that contain communication equipment, such as radio, radar, relay, telephone, telemetry, base, net and similar operations other than those at tracking stations," and 132 as "individual components of communication systems, excluding buildings, used to transmit or receive signals and the infrastructure required for support." Included are satellite communications assets, antennas, communication lines and weather towers.

Communications Facilities are Exemplary Property Types for Area 2 (Human Exploration and Operations), and Area 3 (Science). One of the most important aspects of NASA's activities in these areas are the collection and transmission of data and images from satellites and spacecraft to facilities on Earth for collection and processing. For HEOMD, communication facilities in support of manned space programs are essential for instrumentation to receive, monitor, process, display and/or record information from the space vehicle during test, launch, and/or flight. For SMD, the remote collection of data and transmittal to Earth for study is its *raison d'etre*.

8.3.2 Tracking Station Facilities (Basic Categories 140, 141)

Tracking Station Facilities are described in the FCCS as assets "used in data acquisition and tracking of manned and unmanned spacecraft and satellites," and include the functions of telemetry and command, radar, antennas, microwave towers, and telescopes.

Tracking Station Facilities are Exemplary Property Types for Area 2 (Human Exploration and Operations), and Area 3 (Science). This category includes mission control facilities, which support the design, development, planning, training and flight control operations for manned spaceflight. Likewise for unmanned and science missions, NASA engineers and scientists must be able to track the route of spacecraft as they travel through the solar system, and in some cases, outside the solar system. The spacecraft send signals to receivers on the Earth's surface that include antennas of varying width and height, towers, and beacon poles. Additional buildings house the equipment that receives, decodes, records, and retransmits the data from the spacecraft to mission control.

8.3.3 Training Facilities (Basic Categories 171, 179)

Training Facilities in these categories are specialized assets used in flight or mission simulation and training. They are distinguished in the FCCS from general training facilities (170) such as classrooms, auditoriums, and libraries.

Training Facilities are Exemplary Property Types for Area 1 (Aeronautics Research) and Area 2 (Human Exploration and Operations), where pilots and astronauts are required. Human space exploration involves a large amount of training for the astronauts who are a part of the space program. A part of NASA's mission for HEOMD is the training of astronauts and other involved in the human exploration of space. These facilities may include neutral buoyancy tanks, flight simulators, and training aircraft.

Simulators and Mockups. Flight simulators and spacecraft mockups are a subset of assets under Training Facilities. Flight simulators provide a venue by which the human element of flight (i.e., pilot, air traffic controller) and aircraft performance may be safely observed and tested without risking life or expense. Spacecraft mockups, such as the ISS modules at JSC, enable crews to familiarize themselves with the spatial environmental within which they will be operating. Simulators and mockups may also be found inside of RD&T Facilities, and like wind tunnels they have been a signature component of NASA aeronautics research and space exploration over the last 50 years that have increased in importance and complexity as computerization has been integrated into all aspects of flight.

8.3.4 Fabrication and Assembly Facilities (Basic Categories 220, 221)

Fabrication and Assembly Facilities as described in the FCCS are facilities used to fabricate and assemble materials and equipment. Included are model shops used in the manufacturing of models, prototypes, and other items used in direct research, development, testing, and evaluation; instrument fabrication shops, designed for assembly, testing and calibration of instruments; and vehicle assembly buildings utilized in the special assembly of vehicles for launching shuttles, satellites, or other payloads into earth orbit or outer space.

Fabrication and Assembly Facilities are Exemplary Property Types for all three Areas. For aeronautics research, Fabrication and Assembly Facilities are the buildings in which aircraft components and aircraft models are fabricated. These facilities are a character-defining feature of NASA's aeronautics research laboratory complexes, as they are the touchpoint where the theoretical research and practical development becomes a physical reality that can be tested. In cases where NASA is modifying an aircraft testbed for a specific testing program, such as the Advanced Turboprop Project in the 1970s, the various designs for propellers would have been built in Fabrication and Assembly Facilities. These are also the buildings where aircraft scale models are constructed prior to wind tunnel and other testing, and where instruments may be calibrated or adjusted. While some machinery found in fabrication and assembly facilities may be typical of other industrial fabrication facilities, specialized or unique machinery is also used.

For spaceflight, this property type includes facilities where major flight components are manufactured or assembled. Vehicle processing facilities administer such operations as assembly, testing, checkout, refurbishment, and protective storage for launch vehicles and spacecraft. For the SSP, examples include the Shuttle Orbiter Final Assembly Facility, the Vehicle Assembly Building (VAB), the Vertical Assembly Building, and the Orbiter Processing Facility (OPF).

8.3.5 Research, Development, and Testing Facilities (Basic Categories 310, 320)

Research, Development, and Testing (RD&T) Facilities are defined by the FCCS as scientific structures and facilities used for direct research, development, testing, and evaluation activities. Included are a broad range of subcategories including physical science, data collection and reduction, space science, spacecraft and vehicle RD&T, propulsion, life science, aeronautical and aerodynamic RD&T, and materials.

RD&T Facilities are an Exemplary Property Type for all three Areas. This is a broad category of NASA assets at the core of NASA's missions, as they are where the most skilled technical experts in their fields develop new solutions that expand human capabilities and knowledge, using highly specialized, and in some cases one-of-a-kind, equipment and machinery. The RD&T Facilities most relevant to Aeronautics Research are those dedicated to the fundamental aspects of flight: including aerodynamics, propulsion, acoustics, thermal structures and materials, specific aircraft components (e.g., rotors), and avionics and electronic instrumentation. RD&T laboratories are often large, utilitarian buildings that belie the activities within and the specialized spaces and structures on the interior, such as wind tunnels (see below) and simulators. Additionally, RD&T laboratories are very rarely single isolated buildings, but often are accompanied by smaller support buildings such as smaller labs, chemical and materials storage structures, substations, and fabrication shops.

Data Processing Centers. Data Processing Centers are a subset of RD&T in the FCCS. The advances made by NASA since 1973 in all Areas have largely been enabled by the concurrent development of digital computing. NASA became a pioneer in computer technology during the Apollo Program, and this experience was quickly adapted to other missions. Successful application depended on state-of-the-art central data reduction and processing facilities—i.e., supercomputers that could keep up with rapidly expanding demand, and new computing facilities were constructed at NASA centers in the 1970s and 80s to address the need. Large, purpose-built central computing centers are found at NASA Centers, but smaller data processing centers may also be located inside RD&T Facilities.

8.3.6 Wind Tunnels (Basic Categories 330, 332)

Wind Tunnels are defined in the FCCS as buildings and facilities, including storage vessels and evacuator-compressor systems, used in studies, basic and applied research, development and testing, and in simulation of piloting problems, and atmospheric and space flight. Types of Wind Tunnels include conventional, hypersonic, pressure, supersonic, helium, transonic, and icing wind tunnels.

Wind Tunnels are an Exemplary Property Type for the Area of Aeronautics Research. Wind Tunnels are structures that create an artificial environment within which the performance of aircraft can be tested and observed in a controlled, pilotless environment. They are physically distinctive and possess particular significance as an important and innovative aspect of the NACA's aeronautics research since its early days. Small-scale wind tunnels are contained within laboratory buildings, but large wind tunnels are fully freestanding with their own support structures. With the rise of CFD in the last few decades, some testing that used to be carried out in wind tunnels is now done on computers. However, CFD has not yet reached the point at which it can model all data points that must be considered in developing aircraft, for which wind tunnels continue to be necessary.

8.3.7 Engine and Vehicle Test Facilities (Basic Categories 340, 350, 355)

These categories of assets include: engine test complexes (340), assets used in research development and production acceptance of static testing of engines for space vehicles; vehicle static test complexes (350 and 355), assets used in acceptance static testing of stage boosters for space vehicles. The test complex control center, observation bunkers, test stands, and propellant and fuel systems are all captured in this category. Engine and Vehicle Test Facilities are Exemplary Property Types in the Area of Human Exploration and Operations.

8.3.8 Launch Complex Facilities (Basic Categories 381, 382)

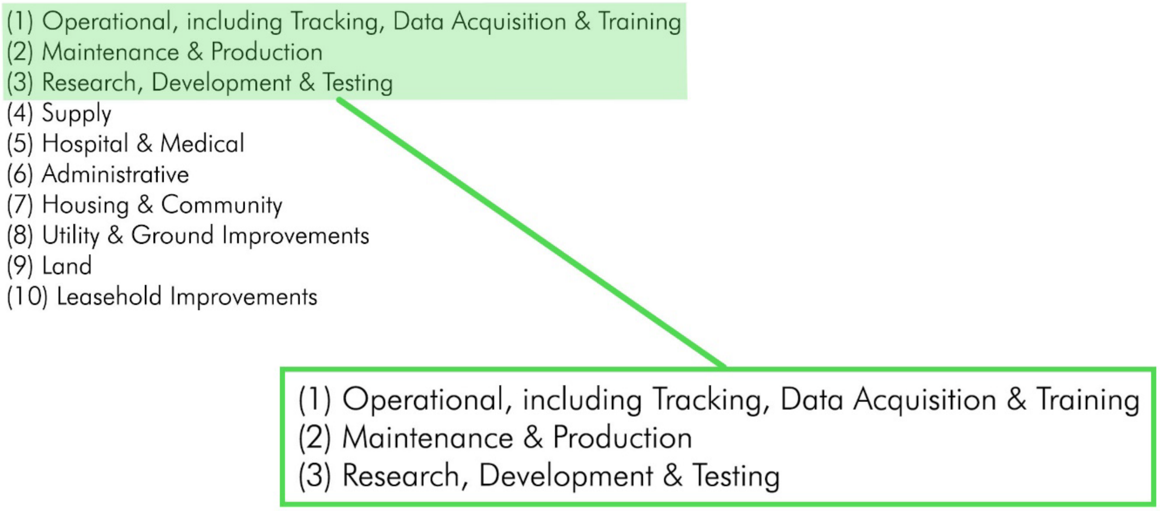
The FCCS defines Launch Complex Facilities as assets used in the launching of manned and unmanned space vehicles and spacecraft and include launch control buildings, data collection and reduction assets, assembly and checkout buildings, and instrumentation buildings, as well as launch pads, crawler ways, umbilical tower, cameras, blockhouses, and propellant and fuel storage. Launch Complex 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. Launch Complex Facilities are an Exemplary Property Type in the Area of Human Exploration and Operations.

8.3.9 Aircraft/Spacecraft and Models

Aircraft and aircraft models are managed by NASA as personal property and not real property assets tracked using the RPMS. As such they are not the focus of the RSF; however, their importance justifies their mention here as an Exemplary Property Type. These assets are often one-of-a-kind and uniquely representative of NASA's RD&T processes, as are aircraft and spacecraft models fabricated by NASA. These resources are a record of the evolution of flight over time that are readily recognizable to the public—something that may not be said of other property types.

8.3.10 Other FCCS Codes

As shown in Table 8-1, Exemplary Property Types fall into one of three FCCS Facility Classes: (1) Operational, including Tracking, Data Acquisition & Training; (2) Maintenance & Production; and (3) Research, Development & Testing.



(1) Operational, including Tracking, Data Acquisition & Training
(2) Maintenance & Production
(3) Research, Development & Testing
(4) Supply
(5) Hospital & Medical
(6) Administrative
(7) Housing & Community
(8) Utility & Ground Improvements
(9) Land
(10) Leasehold Improvements

(1) Operational, including Tracking, Data Acquisition & Training
(2) Maintenance & Production
(3) Research, Development & Testing

Figure 8-2. FCCS Facility Classes most likely to contain Exemplary Property Types

Assets able to convey exceptional importance are not likely to be found in the remaining FCCS Facility Classes. Other classes may include assets that are directly associated with and generally representative of NASA's missions in the three Areas but are not themselves unique or characteristic of NASA's exceptional contributions to the field. These more common assets will be found in other, non-NASA locations where flight and scientific research activities occur. Other assets with no unique or characteristic association with NASA's mission include those with basic, operational functions such as guard houses, heat plants, etc. These resources may have collective value or significance within other contexts, but do not have the ability to convey exceptional importance specific to the Areas under CCG. Upon reaching 50 years of age, the standard by which NRHP significance is measured is lower, and assets in Facility Classes 4 through 8 may become eligible.

8.4 Quantifying Exemplary Property Types

In determining the potential universe of Exemplary Property Types, this study grouped Centers according to their respective Areas. Although Centers are assigned to primary Areas, it is understood that there are related activities that occur at other Centers and that there is not a hard division between Center functions. However, for the purpose of identifying assets <50 with the ability to convey exceptional importance, it is reasonable to conclude that the most exemplary assets in an Area will be found at the Centers dedicated to functions in that Area.

The number of assets with the potential to be exceptionally important as required by CCG is summarized below for each Area. For all three Areas combined, the total number of potential exemplary assets is 608, which is 11% of the total number of real property assets, and 20% of those <50.

High-level review of the specific assets in each Exemplary Property Type confirms that only some of them would meet the criteria, so the number of assets that can convey the exceptional importance of NASA's Areas will be less than the total number of assets coded to that number.

8.4.1 Area 1: Aeronautics

RPMS indicates that in 2020 there were 1,145 real property assets at the four Aeronautics Research Centers combined, 530 of which are <50 (i.e., built in or after 1973). This breaks down by Center as:

- ARC – 397 total assets (138 assets <50);
- AFRC – 214 total assets (152 assets <50);
- GRC – 218 total assets (78 assets <50); and
- LaRC – 316 total assets (162 assets <50).

As shown in Table 8-2, the total universe of real property assets <50 at the four Aeronautics Research Centers with the potential to be categorized as Exemplary Property Types is 75—7% of all real property assets at those centers, and 14% of those <50.

Table 8-2. Potential Assets Representing Exemplary Property Types in the Area of Aeronautics Research

Exemplary Property Type	**FCCS Codes**		**No. <50 Assets, Aeronautics Centers**
	Basic Category, Code	**Basic Category, Name**	
Training Facilities	171	Training Buildings	1
	179	Training Facilities – Other than Buildings	0
Fabrication and Assembly Facilities	220	Fabrication and Assembly Buildings	7
RD&T Laboratories, including Data Processing Centers	310	Research, Development, and Test Laboratories	48
	320	Research, Development, and Test Laboratories – Other than Buildings	9
Wind Tunnels	330	Wind Tunnels	10
	332	Wind Tunnel Facilities – Other than Buildings	0
		Total Potential Assets	**75**

8.4.2 Area 2: Human Exploration and Operations

RPMS indicates that in 2020 there were 2,680 real property assets at seven HEOMD Centers and component facilities combined, 1,585 of which are now <50.[21] This breaks down as follows:

- ATF – 169 total assets (30 assets < 50);
- JSC – 418 total assets (222 assets <50);
- KSC – 928 total assets (648 assets <50);
- MAF – 170 total assets (66 assets < 50);
- MSFC – 343 total assets (168 assets <50);
- SSC – 422 total assets (318 assets <50); and

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[21] SSFL is not included.

- WSTF – 230 total assets (133 assets < 50).

Table 8-3 shows the total universe of real property assets <50 at the seven HEOMD Centers and component facilities with the potential to be categorized as Exemplary Property Types is 330—12% of all real property assets at those centers, and or 21% of real property assets <50.

Table 8-3. Potential Assets Representing Exemplary Property Types in the Area of Human Exploration and Operations

Exemplary Property Type	FCCS Codes		No. <50 Assets, Four HEOMD Centers
	Basic Category, Code	Basic Category, Name	
Communications Facilities	131	Communications Buildings	39
	132	Communications Facilities – Other than Buildings	19
Tracking Station Facilities	140	Tracking Station Buildings	5
	141	Tracking Station Facilities – Other than Buildings	19
Training Facilities	171	Training Buildings	7
	179	Training Facilities – Other than Buildings	7
Fabrication and Assembly Facilities	220	Fabrication and Assembly Buildings	14
	221	Payload Fabrication, Assembly, and Checkout	0
RD&T Laboratories, including Data Processing Centers	310	Research, Development, and Test Laboratories	90
	320	Research, Development, and Test Laboratories – Other than Buildings	34
Engine and Vehicle Test Facilities	340	Engine Test Complexes	35
	350	Vehicle Static Test Complex Buildings	9
	355	Vehicle Static Test Facilities – Other than Buildings	16
Launch Complexes	381	Launch Complex Buildings	15
	382	Launch Complex Facilities – Other than Buildings	21
		Total Potential Exemplary Assets	**330**

8.4.3 Area 3: Science

RPMS indicates that in 2020 there were 1,478 real property assets at four Science Centers and component facilities combined, 878 of which are now <50. This breaks down as follows:

- GSFC – 552 total assets (424 assets <50);
- JPL – 225 total assets (95 assets <50);
- GDSCC – 146 total assets (78 assets <50);
- WFF – 555 total assets (281 assets <50).

Table 8-4 shows the FCCS classification codes where the real property assets that fall into Exemplary Property Types in the Area of Science are most likely to be found. The total universe of real property assets <50 at the SMD Centers with the potential to be categorized as Exemplary Property Types is 204—14% of all real property assets at those centers and 23% of assets <50.

Table 8-4. Potential Assets Representing Exemplary Property Types in the Area of Science

Property Type	**FCCS Codes**		**No. <50 Assets, Five Science Centers**
	Basic Category, Code	**Basic Category, Name**	
Communications Facilities	131	Communications Buildings	18
	132	Communications Facilities – Other than Buildings	11
Tracking Facilities	140	Tracking Station Buildings	44
	141	Tracking Station Facilities – Other than Buildings	63
Fabrication and Assembly Facilities	220	Fabrication and Assembly Buildings	3
	221	Payload Fabrication, Assembly, & Checkout	3
RD&T Laboratories, including Data Processing Centers	310	Research, Development, and Test Laboratories	53
	320	Research, Development, and Test Laboratories – Other than Buildings	9
		Total Potential Exemplary Assets	**204**

8.4.4 Area 4: Architecture

General consideration of NASA assets suggests that after the establishment and initial build-out of Centers, the use of high-style and expressive architecture is irregular, unpredictable, and not necessarily related to the function. Research undertaken for this study identified few assets constructed after 1973 with the potential to be NRHP eligible purely for architectural design. Examples were noted during this study, but no predictable pattern could be discerned. For these reasons, it is not possible to link sensitivity to any particular function or fixed factor like the FCCS, and therefore this Area is not factored in to the RSF Model presented in Section 9. Unlike those historically significant for their function, however, assets with the potential to be eligible for architecture may be readily identified by SOI-qualified architectural historians during survey based upon their exterior physical characteristics, so there is no need for NASA to indirectly assess potential for eligibility under this Criterion through a predictive model.

9.0 PREDICTIVE MODEL

Based upon the findings presented in Sections 4.0 through 8.0, the RSF Model (Model) has been developed as an objective way to assess the probability that an unevaluated asset <50 is eligible for listing in the NRHP—i.e., a predictive model. This is useful to NASA for several reasons.

First, while the NHPA places the responsibility of identifying historic properties under its control on Federal agencies, comprehensive identification—that is, the evaluation of all buildings, structures, objects, sites, and districts of all ages under all NRHP Criteria and all contexts within which significance may be achieved—is not feasible for many reasons, not the least of which are time and cost to agencies whose primary missions are not historic preservation. Recognizing this, the ACHP has reinforced that Section 106 does not require comprehensive evaluation of all assets, but rather "reasonable and good faith" identification of historic properties, such that the agency may "take into account past planning, research and studies; the magnitude and nature of the undertaking and the degree of federal involvement; the nature and extent of potential effects on historic properties; and the likely nature and location of historic properties within the APE."[22] A predictive model is one way to conduct reasonable and good faith identification.

Second, while properties <50 can be eligible for listing in the NRHP, as recognized by the NPS in its bulletin *How to Apply the National Register Criteria for Evaluation*, "fifty years is a general estimate of the time needed to develop historical perspective and to evaluate significance… [that guards] against the listing of properties of passing contemporary interest and ensures that the National Register is a list of truly historic places."[23] While there are cases where the passage of time is not required to recognize historical significance, as with the moon landing, these cases are rare. Accepting this limitation—i.e., that temporal distance is required for a subjective individual or culture to assess historical significance—then a rating system based upon sensitivity factors offers a relatively objective path to historic property identification.

Federal agency response to the ambiguity of evaluating assets <50 has been to focus efforts on evaluating the NRHP eligibility of those that have reached 50 years of age, with the result that properties <50 are deliberately excluded from surveys or inadvertently overlooked. Architectural history surveys may attempt to address more obvious, or more easily justifiable, areas of significance under CCG either by identifying a few individually-eligible properties or by establishing an end period of significance within the last 50 years. But these efforts are inconsistent at best and often met with resistance by the agency. A predictive model that consistently applies a baseline level of effort to identifying NRHP-eligible assets <50 is an alternative solution to this challenge.

Third, NASA at present has only two fully-dedicated cultural resources professionals on staff, both of whom meet the SOI Professional Qualification Standards in archaeology. Many NASA CRMs have years of valuable experience in the role and a wealth of knowledge on the history and importance of NASA's built assets, and some are supported by on-call cultural resources consultants that meet the SOI standards. But there is wide variability in CRM technical backgrounds and areas of expertise, the amount of time they have to spend on cultural resource management duties, and the funding available for

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[22] ACHP, "Meeting the 'Reasonable and Good Faith' Identification Standard in Section 106 Review, 15 November 2011, available online at https://www.achp.gov/sites/default/files/guidance/2018-05/reasonable_good_faith_identification.pdf, accessed 4 September 2022.

[23] NPS, *How to Apply the National Register Criteria for Evaluation*, p. 41.

historic property identification. Application of a predictive model prepared by SOI-qualified architectural historians offers consistency and meets the reasonable and good faith standard.

9.1 Sensitivity Factors

The Model assesses potential NRHP eligibility (i.e., sensitivity) based upon four factors derived from readily accessible NASA data: 1) FCCS code (i.e., function); 2) Exemplary Property Types as determined through the preceding study of exceptional importance; 3) HTSF status of the asset, which considers its relative importance to the mission; and 4) the age of the asset. The four factors are each assigned a sensitivity rating from 1 to 4, with 1 being the most likely to be NRHP eligible and 4 being the least likely. The final asset sensitivity rating is determined by adding the four ratings and dividing by four.

9.1.1 Factor 1: Real Property Class Code "Default" Rating

In RPMS, each real property asset is assigned one of 322 Real Property Class Codes from the FCCS that that reflects its primary function. The FCCS provides a great deal of specificity regarding the function and character of an asset that can be used to assess sensitivity.

For the Model, the potential significance of each Real Property Class Code (e.g., 111-10) was assigned a preliminary default sensitivity rating based upon the relationship of their associated functions, as suggested by their Real Property Class Name (e.g., runway[concrete]), to NASA's mission-critical activities in general, and the requirements of the NRHP, specifically the criteria of exceptional importance—i.e., how likely was it that an asset in that class would meet the NRHP Criteria and possess the ability to convey that significance, should it be present. Because this rating was to be the baseline data point, only ratings 2, 3, and 4 were used, as indicated below.

- A sensitivity rating of 2 was assigned to classes with the potential to be individually eligible.
- A sensitivity rating of 3 was assigned to classes with the potential to support exceptional significance but not likely to convey it on their own.
- A sensitivity rating of 4 was assigned to those classes not likely to possess or convey exceptional significance.

For example, hypersonic wind tunnels are assigned Real Property Class Code 330-20. This reflects Facility Class 3 (Research, Development, & Test), Category Group 33 (Wind Tunnel Facilities), Basic Category 330 (Wind Tunnel Buildings). Given what is known about the importance of the wind tunnels to the history of NASA and the development of aircraft and spacecraft, class code 330-20 was assigned a default sensitivity rating of 2—it is more likely than other assets to be directly associated with NASA's achievements of exceptional importance, as a highly specialized and unique property type it is more likely than other assets to be able to convey that significance as an individual resource.

An air control tower, assigned Real Property Class Code 181-50, is in Facility Class 1 (Operational, Including Tracking & Data Acquisition & Training), Category Group 18 (Miscellaneous Operational Facilities), Basic Category 181 (Miscellaneous Operational Buildings). It is an important feature of any airfield, but as a commonplace resource at any airfield, it would be unlikely that it could convey exceptional importance on its own. This class code was therefore assigned a default sensitivity rating of 3.

Jet engine fuel storage, assigned Real Property Class Code 411-50, is in Facility Class 4 (Supply), Category Group 41 (Liquid Fuel Storage Facilities), Basic Category 411 (Bulk Liquid Fuel Storage Facilities). Such a structure is also a commonplace feature of airfields, but is a minor support resource that would not be expected to convey exceptional importance, and thus was given the lowest default sensitivity rating of 4.

The default sensitivity rating assigned to each Real Property Class Code is provided in Appendix A.

9.1.2 Factor 2: Real Property Class Code "Adjusted" Rating

The second factor is also based upon the Real Property Class Codes. All sensitivity ratings from Factor 1 are duplicated for Factor 2, except for class codes identified as Exemplary Property Types in Section 8.0, which were assigned a sensitivity rating of 1 at Centers in their respective Area.

- A sensitivity rating of 1 was assigned to all class codes identified as Exemplary Property Types in the Area of Aeronautics Research at AFRC, ARC, GRC (with ATF), and LaRC (Table 8-2). All other class codes at those Centers remained unchanged from the default rating.

- A sensitivity rating of 1 was assigned to all class codes identified as Exemplary Property Types in the Area of Human Exploration and Operations at JSC (with WSTF), KSC, MSFC (with MAF), and SSC (Table 8-3). All other class codes at those Centers remained unchanged from the default rating.

- A sensitivity rating of 1 was assigned to all class codes identified as Exemplary Property Types in the Area of Science at GSFC (with WFF), and JPL (with GDSCC) (Table 8-4).[24] All other class codes at those Centers remained unchanged from the default rating.

The intent of this "adjusted" rating was to recognize the higher likelihood that an asset associated with a Center's core competency would be NRHP eligible. The adjusted sensitivity rating assigned to each Real Property Class Code is provided in Appendix A.

For example, the Real Property Class Codes for communication buildings (131) and communication facilities (132) were assigned a default sensitivity rating of 2, the highest default sensitivity rating. This rating reflects the significant role of communications in tracking and interacting with aircraft and spacecraft within the context of NASA activities. However, as shown in Table 8.1, communications facilities are Exemplary Property Types for HEOMD and Science missions. Therefore, the adjusted sensitivity rating for class codes 131 and 132 is 1 at NASA Centers associated with HEOMD and Science. Communications facilities are not Exemplary Property Types within the Area of Aeronautics Research, and therefore the adjusted sensitivity rating remains 2 (i.e., unadjusted).

9.1.3 Factor 3: HTSF Inventory Rating

NASA's mission, and the research-test-improve process by which it advances the fields of aeronautics, human exploration and operations, and Earth and space science, depends entirely upon its HTSF assets. Factor 3 accounts for this by elevating the sensitivity rating of NASA's most important HTSF, as determined in AECOM's 2021 final study. As noted previously, the HTSF inventory did not address

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[24] SSFL is not included in the Model because Factor 3 data was not available at the time of this study.

NRHP eligibility *per se*, but it did incorporate guidance put forward in the ACHP's *Balancing Historic Preservation Needs with the Operation of Highly Technical or Scientific Facilities*.

The HTSF inventory was based in part on NASA's Mission Dependency Index (MDI) Adjectival Rating Scale, recorded in RPMS. NASA's MDI identifies the relative importance of facilities in terms of mission requirements from the perspective of managers who use the facilities to perform their functions, rather than from the perspective of the real property and facilities engineering community. As explained in the HTSF inventory, the NASA Mission Dependency Index (MDI) Adjective Rating Scale assigns the relative importance of a facility to NASA's mission under the following five ratings: Dependent; Necessary; Important; Contributing; and Non-Dependent.

- Dependent facilities provide "a unique capability (potentially one of a kind) that is required for achieving mission success. An alternate facility is not in existence or cannot be configured in a timely manner to meet the agency's need." A sensitivity rating of 1 was assigned to assets identified as HTSF that are MDI Dependent.

- Necessary facilities are "required or a specific NASA program's mission or missions will be severely impacted. Failure or loss of the facility will result in serious impact to mission success." A sensitivity rating of 2 was assigned to assets identified as HTSF that are MDI Necessary.

- Important facilities support "a specific NASA program or mission. Failure or loss would result in an impact to the mission." A sensitivity rating of 3 was assigned to assets identified as HTSF that are MDI Important.

- Contributing facilities support NASA Centers, but "[f]ailure or loss would result in a minimal impact to the center's operation." A sensitivity rating of 4 was assigned to assets identified as HTSF that are MDI Contributing.

- Non-Dependent facilities are not specific to NASA Centers' missions and include out-leased facilities. A sensitivity rating of 4 to these and all other assets, including those that are not HTSF.

The HTSF inventory considered the MDI rating in the identification of potential HTSFs. The "Dependent" and "Necessary" MDI ratings indicated the facilities with the highest importance and unique capabilities, either independently or as part of a larger complex. The "Important" and "Contributing" MDI ratings related to facilities that were less important but contributing to the mission and could still present an HTSF function. The "Non-Dependent" MDI rating was treated as a general parameter for facilities that could not be considered HTSFs, with rare exceptions. It should be noted that the MDI reflects contemporary conditions, only. An asset that was mission dependent in the 1970s under the SSP, for example, may be less essential today and this would be reflected in the MDI.

At the time of this study, NASA FRED was in the process of replacing the MDI rating system with a new mission relevance scale. At such time as a new scale is implemented, the HTSF ratings—and the RSF Model—will need to be updated. This is not expected to substantially change the RSF Model output, in part because the HTSF status is just one of 4 factors considered, but also because how an asset is used by NASA and its relative importance will be reflected in the scaling system and not determined by it.

9.1.4 Factor 4: Age of Asset

As initially developed and tested, the RSF Model only considered the previous three data points—Real Property Class Codes (default and adjusted) and HTSF status. Sensitivity under Factors 1, 2, and 3 is assigned without regard to the age of the asset—as with NRHP CCG, there is no distinction made between an asset that is 1 year old and an asset that is 49 years old. However, upon considering the results of this original 3-factor model, in which assets that were just completed could be rated the same as those that were close to reaching 50 years of age, it was determined that age is an important consideration in a successful predictive model. As recognized by the NRHP, the passage of time allows for the evaluation of significance with broader perspective. This was evident in identifying Apex Events for this study. Research revealed a general consensus among NASA, the technical community, and the public about the most important NASA achievements and lines of research into the 1990s; however, a consensus was not yet evident with respect to many NASA activities from the 1990s to the present. This was most often because the technology has yet to be adopted broadly, either because: a pressing need, generally as determined by the military or private industry, does not exist (e.g., solar-powered flight); and/or the technology is one among several possible solutions; and/or the technology has yet to be refined to the point of practical implementation. Additionally, the older a NASA asset is, the more likely it is to have acquired exceptional importance because of the increased number of programs and missions that the asset has supported. Factor 4 is intended to account for the greater likelihood that an older asset would be NRHP-eligible under CCG. For Factor 4, assets were assigned

- A sensitivity rating of 1 was assigned to assets aged 40 to 49;
- A sensitivity rating of 2 was assigned to assets aged 30 to 39;
- A sensitivity rating of 3 was assigned to assets aged 20 to 29; and
- A sensitivity rating of 4 was assigned to assets less than 20 years of age.

9.1.5 Additional Considerations

In addition to the above data points, a fifth factor was tested but ultimately rejected. The Real Property Class Code of assets of all ages that have been previously evaluated for NRHP eligibility were assigned a rating based upon the evaluation status in NETS: a sensitivity rating of 1 was assigned to NHLs, a 2 to individually NRHP-eligible assets, a 3 to contributing resources, and a 4 to assets found ineligible for listing. However, comparison with the 4-factor model revealed that the consideration of this additional factor did not result in more accurate or differentiated ratings, and accordingly it was not incorporated into the final RSF Model.

9.2 Model Results

The results of the RSF Model are summarized by Center in Tables 9-1 and 9-2, and the highest rated assets—those with a rating less than 2—are listed by Area and Center in Tables 9-3 through 9-5. Note that many of the assets presented in the tables have been evaluated for NRHP eligibility. For the purposes of this exercise, the Model has been run on all <50 assets, regardless of their current NRHP evaluation status. It should be noted that Facility Class 9 is ascribed to land rather than buildings and structures, and so assets in this class have not been rated.

The Model found 70 assets to have the greatest potential to meet the NRHP Criteria for resources less than 50 years of age (CCG)—approximately 2% of NASA's total assets <50. The number of high sensitivity assets per Center ranged from 13 at LaRC to 0 at ATF, GDSCC, MAF, and WFF.

A total of 453 assets were found to have high-to-moderate sensitivity to meet the NRHP Criteria for resources <50—roughly 15% of NASA's total assets <50—and ranging from 81 assets at KSC to 2 assets at MAF.

Table 9-1. Summary of Asset Ratings by Center, All Assets <50

		High Sensitivity	High-to-Moderate Sensitivity	Moderate-to-Low Sensitivity	Low Sensitivity	Total Assets Rated	Assets Not Rated
		Ratings of 1.3, 1.5, and 1.8	Ratings of 2.0, 2.3, 2.5, and 2.8	Ratings of 3.0, 3.3, 3.5, and 3.8	Ratings of 4.0		
Aeronautics	**AFRC**	4	11	90	47	152	0
	ARC	10	21	91	16	138	0
	GRC	6	10	22	36	74	4
	LaRC	13	18	52	77	160	2
Human Exploration and Operations	**ATF**	0	8	4	18	30	0
	JSC	4	33	122	48	207	15
	KSC	6	81	372	177	636	12
	MAF	0	2	39	17	58	8
	MSFC	7	44	59	58	168	7
	SSC	1	57	184	74	316	2
	SSFL	*No HTSF Data*					
	WSTF	4	23	50	49	126	7
Science	**GDSCC**	0	29	36	12	77	1
	GSFC	8	59	147	189	403	21
	JPL	7	15	44	25	91	4
	WFF	0	42	130	109	281	0
	Totals	70	453	1,442	952	2,917	83

The 83 assets shown in the table as "not rated" consisted of 54 assets classified in RPMS as land (i.e., Facility Class 9). For the remaining 29 assets, one or more of the data points required for the Model was not available at the time of this study.

Table 9-2. Summary of Asset Ratings by Center, Unevaluated Assets <50 Only

		High Sensitivity	High-to-Moderate Sensitivity	Moderate-to-Low Sensitivity	Low Sensitivity	Total Assets Rated	Assets Not Rated*
		Ratings of 1.3, 1.5, and 1.8	Ratings of 2.0, 2.3, 2.5, and 2.8	Ratings of 3.0, 3.3, 3.5, and 3.8	Ratings of 4.0		
Aeronautics	**AFRC**	1	1	26	32	60	0
	ARC	1	5	35	11	52	0
	GRC	0	0	4	5	13	4
	LaRC	0	5	8	74	87	2
	ATF	0	8	2	18	28	0

		High Sensitivity	High-to-Moderate Sensitivity	Moderate-to-Low Sensitivity	Low Sensitivity	Total Assets Rated	Assets Not Rated*
		Ratings of 1.3, 1.5, and 1.8	Ratings of 2.0, 2.3, 2.5, and 2.8	Ratings of 3.0, 3.3, 3.5, and 3.8	Ratings of 4.0		
Human Exploration and Operations	**JSC**	0	7	3	32	42	10
	KSC	3	23	108	108	242	9
	MAF	0	1	38	17	56	2
	MSFC	2	28	33	57	120	0
	SSC	1	54	179	74	308	1
	SSFL	*No HTSF Data*					
	WSTF	0	8	7	44	59	7
Science	**GDSCC**	0	27	36	12	75	1
	GSFC	2	54	138	184	378	20
	JPL	6	15	44	25	91	4
	WFF	0	36	120	109	265	0
Totals		16	269	778	801	1,864	65

** Denotes assets in Facility Class 9 (land), and for which one or more data point were not available.*

9.3 Model Testing

Once the RSF Model had been developed, a Center from each Area was selected for ground-truthing—ARC for Aeronautics Research, JSC for Human Exploration and Operations, and GSFC for Science. Together these three Centers reflect 26% of NASA's real property assets <50. Testing consisted of face-to-face meetings with the CRM to review the Model results. Assets rated the highest (i.e., those with a rating less than 2.0) were reviewed with the CRM, and assets rated less than 2.0 that the CRM did not think were exceptionally important were discussed. Assets rated 3.0 and below were also reviewed, and the CRM was asked to identify any outliers—i.e., assets that they felt were more significant than the Model rating reflected. The Model ratings for assets <50 that had been evaluated were reviewed, as well, to assess how close the Model results were to formal determinations of NRHP eligibility. Following these discussions, the CRM or their designee led a tour of the Center to observe and discuss assets <50. Center visits concluded with a general discussion of the strengths and weaknesses of the Model.

9.3.1 ARC Center Visit (Table 9.3)

Unevaluated assets. The Center visit to ARC was conducted in August 2022. Of ARC's 397 real property assets recorded in RPMS, 138 are <50, and 52 of these are shown as unevaluated in NETS. Of the 52, the RSF Model identified one unevaluated asset <50, the Outdoor Aerodynamic Research facility (Building N-249), built in 1975, as being most likely to be NRHP eligible with a sensitivity rating of 1.8. This asset is not discussed in either of the Center's architectural surveys, but is featured in a tour of primary facilities prepared by the Center "Historic Preservation Office" in 2012, in which it is described as having been "used for static testing of V/STOL models and rotary wing models, for acoustic testing, and for the analysis of aircraft models prior to testing in the 40x80-foot or 80x120-foot wind tunnels."[25]

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[25] Ames Research Center Historic Preservation Office, "NASA Ames Research Center Self-Guided Tour of Primary Facilities," Fall 2012, available online at https://historicproperties.arc.nasa.gov/tour_arc_rschfacility/tour_arc_rschfacility_guide_2012.pdf, accessed 5 September 2022.

As presented in Section 4.4.9, the development of V/STOL technology via the Bell XV-15 Tilt Rotor Research Aircraft is an area of exceptional significance for NASA's Aeronautics Research program with a period of significance from 1971 to 1983. The asset is currently mothballed, and Center representatives indicated during the Center visit that they intend to dispose of it. In this case, one can conclude that the RSF Model successfully identified an unevaluated asset <50 with a high probability of being eligible for listing in the NRHP under CCG.

Evaluated Assets. If applied to the 86 evaluated assets <50 at ARC, the RSF Model identifies 9 assets with a high potential to be eligible for listing in the NRHP. These assets share the following characteristics:

- They are located within the area of ARC constructed for NASA, or the NASA main campus, denoted by an "N" building number;
- They were constructed in or prior to 1990;
- All but one are RD&T facilities (i.e., Facility Class 3);
- They are HTSFs; and
- They are Exemplary Property Types for the Area of Aeronautics Research.

A cursory review of the RPMS data on the 9 evaluated assets suggests that they are associated with ARC's historically significant activities the kind of resources that have the potential to be eligible for listing in the NRHP under CCG.

According to NETS, the 9 evaluated assets have been determined to be ineligible for listing in the NRHP (i.e., evaluated, not historic). Review of the architectural survey, completed in 2006 by Page & Turnbull, indicates that all 9 were "automatically considered to be ineligible for listing… due to their age, which does not meet the fifty year threshold for historic resources."[26] From this language it appears that the 9 assets were not actually evaluated for NRHP listing under CCG, and thus may be more appropriately shown as "not evaluated" in NETS and considered under the RSF Model.

9.3.2 JSC Center Visit (Table 9.4)

Unevaluated assets. The Center visit to JSC was conducted in August 2022. Of JSC's 418 real property assets <50 recorded in RPMS, 222 are <50 and 52 are shown as unevaluated in NETS. and The RSF Model identified no unevaluated assets <50 likely to be eligible for listing in the NRHP under CCG.

Evaluated assets. If applied to the evaluated 170 assets <50 at JSC, the RSF Model identifies 4 assets with a high potential to be eligible for listing in the NRHP. One of these is the Sonny Carter Training Facility (a.k.a. Neutral Buoyancy Laboratory), built in 1992 and shown in NETS as being individually eligible for listing in the NRHP and contributing to the JSC Historic District. As one of NASA's signature astronaut training facilities and a mission-dependent HTSF, the Sonny Carter Training Facility is clearly eligible for listing in the NRHP under CCG. The other 3 assets are shown in NETS as "evaluated, not historic." Cursory review of the RPMS data on 2 of the 3 suggests that they are associated with JSC's historically significant activities and are the kind of resources that have the potential to be eligible for listing in the NRHP under CCG. However, the most recent JSC architectural survey, prepared in 2017

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[26] Page & Turnbull, Inc., *NASA Ames Research Center, Moffett Field, California, Survey & Rehabilitation Recommendations,"* 22 May 2006, pp. 5-6.

and concurred upon by the Texas Historical Commission in 2018, includes a sufficient evaluation of the 3 these assets individually under NRHP CCG.

9.3.3 GSFC Center Visit (Table 9.5)

Unevaluated assets. The Center visit to GSFC was conducted in February 2022. Of GSFC's 552 real property assets recorded in RPMS, 424 are <50, and 398 of these are shown as unevaluated in NETS. The RSF Model identified two high sensitivity unevaluated assets <50—the EOSDIS Building (Building 32), built in 1994, and the ESSB (Building 33), built in 1998—both with a sensitivity rating of 1.8. Conceived in the 1980s as part of an international effort to research global change including global warming, ozone layer depletion, acid rain deposition, and deforestation/desertification, the Earth Observing System (EOS) mission was by the early 1990s NASA's largest research program.[27] EOS is comprised of a series of coordinated polar-orbiting satellites designed to monitor key components of the climate system and their interactions through long-term global observations. Today the EOS missions focus on the following climate science areas: radiation, clouds, water vapor, and precipitation; the oceans; greenhouse gases; land-surface hydrology and ecosystem processes; glaciers, sea ice, and ice sheets; ozone and stratospheric chemistry; and natural and anthropogenic aerosols. NASA's exceptional contributions to this area of scientific research are well-established, including the Landsat program, presented in Section 6.4.3 with a period of significance from 1970 to 2013.

The Earth Observing System Data and Information System (EOSDIS) is a core capability of NASA's Earth Science Data Systems Program that provides end-to-end capabilities for managing NASA Earth science data from various sources including satellites, aircraft, and field measurements. For EOS satellite missions, EOSDIS provides capabilities for command and control, scheduling, data capture and initial processing.[28] Building 32 contains the operations centers where the EOS, including the Terra, Aqua, and Aura spacecraft, and Landsat program spacecraft and instruments are monitored and controlled. The Earth System Science Building (ESSB, Building 33) houses offices and facilities for the analysis of earth observation data, and was envisioned as a centralized environment for interdisciplinary scientific communication and collaboration for research in global change. These two buildings, both assigned Real Property Class Code 310-15 (Data Collection and Reduction Buildings) are GSFC's largest. On-site observation during the Center visit suggested that Building 32 may also be NRHP eligible for its exemplary architectural design. Both of these assets remain in active use, and while less than 30 years old, the RSF Model's identification of the two buildings as having a high probability of being eligible for listing in the NRHP under CCG appears appropriate.

Evaluated Assets. If applied to the 26 evaluated assets <50 at GSFC, regardless of their evaluation status, the RSF Model identifies 6 assets with a high potential to be eligible for listing in the NRHP. These assets share the following characteristics:

- They are located at the GSCF main campus in Greenbelt;
- They were constructed in or prior to 2000;
- They are RD&T facilities (i.e., Facility Class 3);
- All except for one are mission-dependent HTSFs; and

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[27] Greenhorne & O'Mara, Inc., *Environmental Assessment for the EOSDIS and ESSB Facilities, Goddard Space Flight Center, National Aeronautics and Space Administration*, February 1991, available online at https://code200-external.gsfc.nasa.gov/250/sites/code250/files/250/docs/nepa-eosdisandessbea1991.pdf, accessed 5 September 2022.

[28] NASA, "An Overview of EOSDIS," available online at https://www.earthdata.nasa.gov/eosdis/science-system-description/eosdis-services, accessed 5 September 2022.

- They are Exemplary Property Types for the Area of Science.

A cursory review of the RPMS data on the 6 evaluated assets suggests that they are associated with GSFC's historically significant activities and are the kind of resources that have the potential to be eligible for listing in the NRHP under CCG.

According to NETS, the 6 assets that have been evaluated include 2 that contribute to a historic district, and 4 that do not contribute to a historic district. The Goddard Space Flight Center Historic District was determined to be eligible for listing in the NRHP by the Maryland Historical Trust in 2012 based upon the recommendation and documentation of R. Christopher Goodwin & Associates, Inc. The period of significance for the district was defined as 1960-1969, representing the first decade of development at GSFC. The determination of eligibility form for the historic district (PG: 64-19) identifies the EOS program as a potential area of significance, but states that sufficient time had not elapsed to assess its contributions.[29] NETS identifies only 5 assets at GSFC that are individually eligible for listing in the NRHP, and all 5 are 50+. This suggests that most of the assets at GSFC have only been evaluated as contributing or non-contributing resources to the one identified historic district. If this is the case, then the application of the RSF Model to all assets <50 to meet the requirement for reasonable and good faith identification may be appropriate.

9.3.4 Model Assessment

Analysis of the RSF Model results and review and discussion with NASA and external stakeholders suggest that it can be successfully applied to identify unevaluated assets <50 with the potential to be eligible for listing in the NRHP under CCG. However, the Model will only be as good as the data on which it is based. Detailed review of the Model with NASA CRM and FRED personnel revealed the following weaknesses in the input data.

- FCCS class codes are not always accurately or consistently assigned in RPMS, and when an asset is repurposed, the FCCS may or may not be updated. It is particularly problematic when the class code for a repurposed asset is reassigned, as it may no longer reflect its historical function.
- FCCS class codes do not directly distinguish between primary facilities and their ancillary support facilities. RPMS shows that some Centers will assign support facilities such as substations, equipment sheds, and fuel storage the class code designated for these functions, other Centers will assign them the class code of the primary asset, such as a major RD&T facility. The result is that RD&T support facilities may be rated higher by the RSF Model than they should actually be, a disparity that can easily be identified by the CRM.
- MDI data in RPMS reflects the current use of the asset, rather than its importance historically to the mission. Additionally, FRED is developing a new way to assess mission dependency, and MDI will be obsolete. However, the Model can be easily updated when the new data is ready.
- The NRHP evaluation status in NETS is not always accurate. The most problematic status is "Evaluated, Not Historic," as this would mean that the RSF Model is not applied. Fact-checking evaluation status data against cultural resources reports reveals that many assets

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[29] Kirsten Peeler, Travis Shaw, Kathryn Dixon, and Rebecca Gatewood, "Goddard Space Flight Center (PG:64-19)," Maryland Historical Trust Determination of Eligibility Form, July 2012.

shown as "Evaluated, Not Historic," have only been evaluated within the context of a historic district (i.e., contributing or non-contributing), or under a single program (e.g., SSP).

The entry of NETS data is the responsibility of the CRMs, and it is entirely within their control. Therefore, CRMs are in a position to check the accuracy of NETS data and to make corrections where necessary. Any implementation plan for the RSF Model should at a minimum be accompanied by NETS data verification.

9.4 Model Implementation

NASA is exploring the possibility of integrating the RSF Model into NETS so that the Model factors are automatically populated in NETS and high-sensitivity assets identified. However, NASA recognizes that the RSF Model is a tool to aid NASA in good faith identification in a particularly challenging area (i.e., <50 and CCG), and that Model results should be verified by knowledgeable personnel and in consultation with State Historic Preservation Officers (SHPOs). One way to do this is through a Section 106 agreement.

NASA is currently in the process of negotiating an agency-wide programmatic agreement (APA) that will govern a range of individual undertakings and their effects on historic properties. While the consultation process for the APA is ongoing, the draft document illustrates one way in which the RSF Model could be implemented. Under the APA, assets are managed according to their known or potential historical significance. Every NASA asset is assigned to a Management Category based upon NRHP evaluation status—Category 1 is the most significant, Category 2 is significant, and Category 3 is the least significant. NASA and the SHPOs consult on the appropriateness of the assigned Management Category every ten years.

To determine the Management Category for unevaluated assets <50, the RSF Model is applied. Assets with a Model rating less than 3.0 would be managed as Category 1 assets, generally equivalent to individual eligibility on a national level, or Category 2 assets, generally equivalent to individual eligibility on a state or local level, as determined through consultation. Assets with low sensitivity ratings of 3.0 through 4.0 would be managed as ineligible for individually NRHP listing (i.e., they could be considered contributing to a district, or they could be entirely lacking in historical significance).

Once consensus on the asset lists is reached, NASA can focus time and resources on comprehensive and consistent NRHP evaluation of assets 50 years of age and older, for which historical significance—or lack thereof—is more clearly established.

Incorporation into the APA is one example of how the RSF Model could be implemented. The RSF Model could also be implemented at the Center level though the Center-specific PAs. Outside of an agreement document, NASA could utilize the RSF Model to identify assets <50 that should be prioritized by the Centers for formal evaluation under the NRHP Criteria and CCG. Any of these applications could meet the requirement for reasonable and good faith identification.

Table 9-3. List of High Sensitivity Assets in the Area of Aeronautics

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
AFRC	Armstrong Flight Research Center	4840*	WALT WILLIAMS RESEARCH AIRCRAFT INTEGRATION FACILITY	1990	310-40	2	1	Dependent	1	2	1.5
AFRC	Armstrong Flight Research Center	4838*	DATA ANALYSIS FACILITY (DAF)	1985	310-15	2	1	Dependent	1	2	1.5
AFRC	Armstrong Flight Research Center	4847*	SPECIAL PROJECTS BUILDING	2000	310-20	2	1	Dependent	1	3	1.8
AFRC	Armstrong Flight Research Center	NB229	ATMOSPHERIC RADAR EQUIPMENT BUILDING	1985	320-60	2	1	Necessary	2	2	1.8
ARC	AMES Research Center	N229A*	3.5 HYPERSONIC WT.AUX.BLD	1976	330-20	2	1	Dependent	1	1	1.3
ARC	AMES Research Center	N233A*	INST.FOR ADV.COMPUTATION	1973	310-15	2	1	Dependent	1	1	1.3
ARC	AMES Research Center	N269*	AUTOMATION SCIENCES RESEARCH FACILITY	1990	310-15	2	1	Dependent	1	2	1.5
ARC	AMES Research Center	N262*	HUMAN PERFORMANCE RESEARCH LAB	1990	310-30	2	1	Dependent	1	2	1.5
ARC	AMES Research Center	N260*	FLUID MECHANICS LAB	1987	310-41	2	1	Dependent	1	2	1.5
ARC	AMES Research Center	N258*	NASA ADVANCED SUPERCOMPUTING FACILITY (NAS)	1986	310-41	2	1	Dependent	1	2	1.5
ARC	AMES Research Center	N249	OUTDOOR AERODYNAMIC RESEARCH	1975	320-40	2	1	Important	3	1	1.8
ARC	AMES Research Center	N259*	AIRCRAFT OPERATIONS SUPPORT FACILITY	1984	220-14	2	1	Necessary	2	2	1.8
ARC	AMES Research Center	N257*	CREW VEHICLE SYSTEMS RESEARCH	1982	310-21	2	1	Important	3	1	1.8
ARC	AMES Research Center	N240A*	ENGINEERING INTERGRATION FACILITY	1982	310-50	2	1	Important	3	1	1.8
GRC	Glenn Research Center	0143*	CENTRAL CONTROL BUILDING	1982	310-15	2	1	Necessary	2	1	1.5
GRC	Glenn Research Center	0142*	RESEARCH ANALYSIS CENTER	1980	310-15	2	1	Necessary	2	1	1.5
GRC	Glenn Research Center	0197*	LAB ANNEX	1989	310-22	2	1	Necessary	2	2	1.8

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
GRC	Glenn Research Center	0145*	AEROACOUSTIC PROPULSION LABORATORY	1995	310-40	2	1	Dependent	1	3	1.8
GRC	Glenn Research Center	0150*	AEROACOUSTIC PROPULSION TEST FACILITY	1990	355-15	2	2	Dependent	1	2	1.8
GRC	Glenn Research Center	0333*	POWER SYSTEMS FACILITY	1990	310-20	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1299F*	1299 RESEARCH COMPLEX	1990	310-10	2	1	Dependent	1	2	1.5
LaRC	Langley Research Center	1236D*	NTF COMPLEX	1981	330-60	2	1	Necessary	2	1	1.5
LaRC	Langley Research Center	645A*	20-FOOT VERTICAL SPIN TUNNEL	1979	310-40	2	1	Necessary	2	1	1.5
LaRC	Langley Research Center	1236B*	NTF COMPLEX	1979	330-60	2	1	Necessary	2	1	1.5
LaRC	Langley Research Center	1238A*	1238 COMPLEX	1978	220-13	2	1	Necessary	2	1	1.5
LaRC	Langley Research Center	1265C*	1265 COMPLEX	1984	330-20	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1265B*	1265 COMPLEX	1986	330-20	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1250A*	1250 RESEARCH COMPLEX	1990	310-10	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1293A*	1293 RESEARCH COMPLEX	1986	310-50	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1268D*	1268 RESEARCH COMPLEX	1993	310-40	2	1	Dependent	1	3	1.8
LaRC	Langley Research Center	1247J*	1247 COMPLEX	1991	330-20	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1208A*	ACOUSTICS RESEARCH FACILITY	1991	310-10	2	1	Necessary	2	2	1.8
LaRC	Langley Research Center	1293C*	1293 RESEARCH COMPLEX	1986	310-50	2	1	Necessary	2	2	1.8

**Denotes assets that have been evaluated for NRHP eligibility.*

Table 9-4. List of High Sensitivity Assets in the Area of Human Exploration and Operations

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
JSC	Ellington Field (JSC)	S920*	SONNY CARTER TRAINING FACILITY	1992	171-00	2	1	Dependent	1	2	1.5
JSC	Johnson Space Center	343*	AUXILIARY METROLOGY LABORATORY	1992	310-10	2	1	Dependent	1	2	1.5
JSC	Johnson Space Center	241*	HUMAN RESEARCH FACILITY	1990	310-30	2	1	Necessary	2	2	1.8
JSC	Johnson Space Center	267*	SPACE MATERIALS RESEARCH LABORATORY	1988	310-50	2	1	Necessary	2	2	1.8
JSC	WSTF	272*	HYPERVELOCITY IMPACT FACILITY	1991	310-50	2	1	Dependent	1	2	1.5
JSC	WSTF	270*	270 AREA TEST BUILDING	1990	310-50	2	1	Dependent	1	2	1.5
JSC	WSTF	250*	GASEOUS OXYGEN HIFLOW TEST FACILITY	1989	310-20	2	1	Dependent	1	2	1.5
JSC	WSTF	800*	MATERIAL TEST FACILITY	1976	340-20	2	1	Dependent	1	1	1.3
KSC	Kennedy Space Center	M7-1354	PAYLOAD HAZARDOUS SVC FACILITY	1986	310-21	2	1	Dependent	1	2	1.5
KSC	Kennedy Space Center	M7-0360*	SPACE STATION PROCESSING FACILITY	1992	310-21	2	1	Dependent	1	2	1.5
KSC	Kennedy Space Center	K6-0494*	ROTATING/PROCESSING BUILDING	1984	381-30	2	1	Dependent	1	2	1.5
KSC	Kennedy Space Center	K6-0900A	BATTERY ROOM	1988	381-10	2	1	Necessary	2	2	1.8
KSC	Kennedy Space Center	M7-1104	MULTI-PAYLOAD PROCESSING FAC.	1995	310-21	2	1	Dependent	1	3	1.8
KSC	Kennedy Space Center	M7-0505A*	LAUNCH EQUIPMENT TEST FACILITY	1976	320-10	2	1	Necessary	2	1	1.5
MSFC	Marshall Space Flight Center	4718*	X-RAY AND CRYOGENIC FACILITY	1991	310-21	2	1	Dependent	1	2	1.5
MSFC	Marshall Space Flight Center	4533	TEST STAND 300 SUPPORT BLDG.	1987	350-20	2	1	Dependent	1	2	1.5
MSFC	Marshall Space Flight Center	4572A	STRUCTURAL STRENGTH TEST & STAGING FACILITY	1978	310-21	2	1	Important	3	1	1.8
MSFC	Marshall Space Flight Center	4542*	TEST SUPPORT BUILDING	1992	340-20	2	1	Dependent	1	2	1.5

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
MSFC	Marshall Space Flight Center	4629*	INFORMATION MISSION CONTROL CENTER	1991	310-15	2	1	Dependent	1	2	1.5
MSFC	Marshall Space Flight Center	4524*	TEST STAND SUPPORT BUILDING	1987	350-20	2	1	Dependent	1	2	1.5
MSFC	Marshall Space Flight Center	4532*	TEST SUPPORT BUILDING	1983	350-20	2	1	Dependent	1	2	1.5
SSC	Stennis Space Center	4012	DELUGE WATER SYSTEM	2000	340-20	2	1	Dependent	1	3	1.8

**Denotes assets that have been evaluated for NRHP eligibility.*

Table 9-5. List of High Sensitivity Assets in the Area of Science

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
GSFC	GODDARD SPACE FLIGHT CENTER	028A*	LANDSAT DIRECT READOUT FACILITY (OLD FAC#969)	1981	320-60	2	1	Necessary	2	1	1.5
GSFC	GODDARD SPACE FLIGHT CENTER	029*	SPACECRAFT SYS DEV/INTEGRATION FAC BLDG	1990	310-20	2	1	Dependent	1	2	1.5
GSFC	GODDARD SPACE FLIGHT CENTER	033	ESSB BLDG	1998	310-15	2	1	Dependent	1	3	1.8
GSFC	GODDARD SPACE FLIGHT CENTER	032	EARTH OBSERV SYS DATA INFO SUS (EOS-DIS) BLDG	1994	310-15	2	1	Dependent	1	3	1.8
GSFC	GODDARD SPACE FLIGHT CENTER	005A*	COMPOSITE MATERIALS LAB BLDG	1995	220-13	2	1	Dependent	1	3	1.8
GSFC	GODDARD SPACE FLIGHT CENTER	030*	QUALITY ASSURANCE/DETECTOR DEV LAB BLDG	1993	310-15	2	1	Dependent	1	3	1.8

Center	Site	Property No.	Property Name	Construction Date	FCCS Class Code	Rating by Class Code (Default)	Rating by Class Code (Property Type)	HTSF Status	Rating by HTSF Status	Rating by Age (Factor 4)	Final Rating
GSFC	GODDARD SPACE FLIGHT CENTER	028*	TECHNICAL PROCESSING FAC BLDG	1980	310-15	2	1	Dependent	1	1	1.3
GSFC	GODDARD SPACE FLIGHT CENTER	013*	NETWORK CONTROL CENTER FACILITY BLDG	1979	310-60	2	1	Dependent	1	1	1.3
NASA Management Office	JPL	306	OBSERVATIONAL INSTRUMENTS LAB	1989	310-20	2	1	Dependent	1	2	1.5
NASA Management Office	JPL	298	FREQUENCY STANDARDS LAB	1986	310-20	2	1	Dependent	1	2	1.5
NASA Management Office	JPL	300	EARTH & SPACE SCIENCE LABORATORY	1985	310-20	2	1	Dependent	1	2	1.5
NASA Management Office	JPL	318	OPTICAL INTERFEROMETRY DEVELOPMENT LABORATORY (OID	2002	310-20	2	1	Dependent	1	3	1.8
NASA Management Office	JPL	317	IN-SITU INSTRUMENTS LAB	2001	310-20	2	1	Dependent	1	3	1.8
NASA Management Office	JPL	302*	MICRODEVICES LABORATORY	1986	310-20	2	1	Dependent	1	2	1.5
NASA Management Office	JPL/Table Mtn Observatory	TM-28 (TM-29 in NETS)	REMOTE SENSING INSTRUMENTS LABORATORY	1998	220-13	2	1	Dependent	1	3	1.8

**Denotes assets that have been evaluated for NRHP eligibility.*

10.0 CONCLUSION

For a property to be listed in the NRHP under CCG, it must possess exceptional importance under the significance Criteria (i.e., Criteria A, B, C, and D). The NPS explains the 50-year marker as "a general estimate of time needed to develop historical perspective and to evaluate significance." As expected, a very small percentage of NRHP-listed properties—about 3% in 2020—have cited CCG as being applicable. NASA's experience with evaluating its historic properties has shown that the exceptional nature of the agency's activities means that a greater percentage of its assets—possibly as high as 17%—may meet CCG, and that where other agencies may reasonably focus identification efforts on resources greater than 50 years of age, this may not be the most successful approach for NASA. NASA does not have the financial or staff resources to evaluate all of its assets <50, and as a result the agency has sought to find more efficient ways to narrow down the potential universe of NRHP-eligible assets <50 to a more manageable subset.

This RSF provides a logical basis and viable approach for NASA to identify potential historic properties <50 based upon sensitivity. The Apex Events presented in the RSF demonstrate that NASA's exceptional achievements, regardless of the area of pursuit, are the product of the scientific process—theorize, test, observe, and refine—and that this process relies upon the same elite collection of specialized and unique assets for which NASA is known and around which its Centers are built. In many ways this is intrinsic to HTSF and intuitive to the agencies that routinely work with them. But the FCCS provides a built-in system through which real property assets may be linked to historical significance without comprehensive technical knowledge of the assets—the kind of knowledge that requires a lot of time and effort when performing a traditional NRHP evaluation.

The testing and analysis of the RSF Model supports its use as a reasonable and good faith approach to identifying historic properties <50. The Model suggests that NASA may focus identification efforts on a subset of FCCS Facility Classes (1) Operational, including Tracking and Data Acquisition, and Training, (2) Maintenance and Production, and (3) Research, Development, and Testing. With respect to the management of the most significant assets <50, NASA may utilize familiar cultural resources tools such as standard operating procedures and Section 106 agreements to further focus its resources on real property assets most likely to convey exceptional importance. Outside of an agreement document, NASA could utilize the RSF Model to identify assets <50 that should be prioritized by the Centers for formal evaluation under the NRHP Criteria and CCG.

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APPENDIX A: RSF Model Factors 1 and 2, NASA Facility Classification Coding System

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
Facility Class 1 – Operational, Including Tracking & Data Acquisition & Training					
3				111-10	Runway (Concrete)
3				111-11	Runway (Bituminous)
3				111-12	Runway (Miscellaneous)
3				111-20	Helicopter Landing Pad (Concrete)
3				111-22	Helicopter Landing Pad (Miscellaneous)
4				112-10	Taxiway (Concrete)
4				112-12	Taxiway (Miscellaneous)
4				113-20	Aircraft Parking, Access or Maintenance Apron (Concrete)
4				113-21	Aircraft Parking, Access or Maintenance Apron (Bituminous)
4				113-22	Aircraft Parking, Access or Maintenance Apron (Miscellaneous
3				116-10	Compass Calibration Pad, Surfaced
4				116-20	Aircraft Washing Pad Surfaced
4				121-10	Aircraft Direct Fueling Station
4				121-20	Aircraft Truck Fueling Facility
4				123-10	Filling Station
4				123-20	Natural Gas Filling Station
4				123-90	Land Vehicle Fuel Dispensing (Miscellaneous)
4				126-90	Miscellaneous Fueling and Dispensing
3		1	1	131-60	Communications Building
2		1	1	131-70	Aircraft Navigation Building
2		1	1	131-80	Satellite Communications Building
3		1	1	132-10	Antenna - Tower Supported
4		1	1	132-50	Public Address System - Outdoor
2		1	1	132-60	Aircraft Navigation Facility
4		1	1	132-70	Communications Lines
4		1	1	132-80	Weather Towers
4				136-10	Approach Lighting
4				136-20	Parking and Service Area Lighting
4				136-30	Runway Lighting
4				136-50	Taxiway Lighting
4				136-90	Airfield Pavement Lighting (Miscellaneous)
3		1	1	140-10	Operations Buildings (Tracking Stations)
3		1	1	140-50	Support Buildings - Mechanical (Tracking Stations)
4		1	1	141-15	Antenna Foundations
3		1	1	141-25	11-Meter up to 25 Meter Antennas
3		1	1	141-30	Communications (Structures)
3		1	1	141-35	26-Meter up to 34 Meter Antennas
3		1	1	141-60	70-Meter Antennas (Antenna Structure and installed systems)
4				152-20	Berthing Wharf

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
4				152-60	Supply Wharf
4				152-90	Waterfront Operational Facilities (Miscellaneous)
4				153-10	Marine Cargo Handling Facility
4				153-90	Marine Cargo Handling Facilities (Miscellaneous)
4				154-10	Bulkheads
4				154-30	Seawalls
4				163-10	Mooring Dolphin
4				163-90	Moorings Facilites (Miscellaneous)
4				164-30	Levees
4				164-90	Marine Improvements (Miscellaneous)
2	1	1		171-00	Training Buildings
2	1	1		179-00	Training Facilities Other Than Buildings
4				181-10	Miscellaneous Operations Support Building
3				181-20	Aviation Operations Building
4				181-30	Operations Supply Building
4				181-40	Operations Support Lab
3				181-50	Air Control Tower
4				189-10	Miscellaneous Operations Support Facility
4				189-30	General Purpose Small Arms Range
4				189-40	Miscellaneous Operations Shelter (Shed)
4				189-50	Decontamination facility (other than buildings)
Facility Class 2 – Maintenance & Production					
4				212-10	Launch Vehicle Maintenance Facility
4				214-10	Aircraft Maintenance Hangar
4				214-20	Aircraft Corrosion Control Hangar
4				214-30	Aircraft Maintenance Shop
4				216-10	Installation Support Equipment Maintenance Shop
4				216-20	Land Vehicle Shop
4				216-30	Equipment Maintenance Facility (other than a building)
4				219-10	Public Works or Maintenance Shop
4				219-11	Maintenance Shop (Installation Facilities)
3	1	1	1	220-10	Metal Shop
2	1	1	1	220-11	Model Shop
2	1	1	1	220-13	Instrument Fabrication Shop
2	1	1	1	220-14	Vehicle Assembly Buildings (Other than at Launch Sites)
2		1	1	221-10	Payload Assembly, Servicing, and/or Checkout (Processing) Bu
Facility Class 3 – Research, Development, & Test (RT&T)					
2	1	1	1	310-10	Physical Science (R&D & Test Buildings)
2	1	1	1	310-15	Data Collection and Reduction Building
2	1	1	1	310-20	Space Science (R&D & Test Buildings)
2	1	1	1	310-21	Spacecraft and Vehicle R&D Test Buildings
2	1	1	1	310-22	Propulsion Buildings
2	1	1	1	310-30	Life Science Buildings
2	1	1	1	310-40	Aeronautical (R&D & Test Buildings)

SENSITIVITY RATING				REAL PROPERTY CLASS	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
2	1	1	1	310-41	Aerodynamics (R&D & Test Buildings)
2	1	1	1	310-50	Materials (R&D & Test Buildings)
2	1	1	1	310-60	Tracking and Data Acquisition Buildings
2	1	1	1	310-70	Electronic and Communication R&D Buildings
3	1	1	1	310-80	Miscellaneous Item and Equipment R&D Buildings
2	1	1	1	320-10	Physical Science (Structures and Facilities)
2	1	1	1	320-20	Space Science (Structures and Facilities)
2	1	1	1	320-21	Spacecraft and Vehicle Systems (Structures and Facilities)
2	1	1	1	320-22	Propulsion (Structures and Facilities)
2	1	1	1	320-30	Life Science (Structures and Facilities)
2	1	1	1	320-40	Aeronautical (Structures and Facilities)
2	1	1	1	320-50	Materials R&D & Test (Structures and Facilities)
2	1	1	1	320-60	Tracking and Data Acquisition (Structures and Facilities)
2	1			330-10	Conventional Wind Tunnels (Buildings)
2	1			330-20	Hypersonic Wind Tunnels (Buildings)
2	1			330-30	Pressure Wind Tunnels (Buildings)
2	1			330-40	Supersonic Wind Tunnels (Buildings)
2	1			330-60	Transonic Wind Tunnels (Buildings)
2	1			330-70	Icing Research Wind Tunnels (Buildings)
2	1			330-90	Wind Tunnels (Miscellaneous)
2	1			332-40	Supersonic Wind Tunnels (Non Buildings)
2		1		340-10	Test Control Center Buildings (Engine Test)
2		1		340-20	Test Support Buildings (Engine Test)
2		1		350-10	Control Center (Vehicle Static Test)
2		1		350-20	Test Support Buildings (Vehicle Static Test)
2		1		355-10	Observation Bunkers (Vehicle Static Test)
2		1		355-15	Vehicle Static Test Stand
3		1		355-20	Propellant/Fuel Stg, Transfer Systems (Vehicle Static Test)
2		1		381-10	Launch Control Center Buildings (Launch Complex)
2		1		381-20	Data Collection & Reduction Center Bldgs (Launch Complex)
2		1		381-30	Assembly and Checkout Buildings (Launch Complex)
2		1		381-40	Instrumentation Buildings (Launch Complex)
3		1		381-50	Service Buildings (Launch Complex)
3		1		381-60	Remote Air Intake Buildings (Launch Complex)
2		1		382-10	Launch Pad (Launch Complex)
2		1		382-11	Crawlerways (Launch Complex)
2		1		382-12	Umbilical Tower (Launch Complex)
3		1		382-13	Camera Pads & Structures (Launch Complex)
3		1		382-15	Blockhouses (Launch Complex)
4		1		382-30	Propellant and Fuel Systems + Storage Tanks (Launch Complex)
4		1		382-31	High Pressure Gas Systems (Launch Complex)
Facility Class 4 – Supply					
4				411-20	Aviation Gasoline Storage
4				411-30	Diesel Oil Storage

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
4				411-40	Motor Gasoline Storage
4				411-50	Jet Engine Fuel Storage
4				411-60	Liquefied Petroleum Fuel Gas Storage
4				411-80	Lubricant Storage
4				411-83	POL Building- Storage of petroleum, oil and lubricant produc
4				411-90	Liquid Fuel Storage - Bulk (Miscellaneous)
4				421-30	Inert Storehouse - Bulk
4				421-90	Solid Fuel Storage - Bulk (Miscellaneous)
4				422-15	Fuse and Detonator Magazine - Ready Issue
4				422-20	Inert Storehouse - Ready Issue
4				422-30	Small Arms and/or Pyrotechnics Magazine
4				422-90	Explosive Storage (Miscellaneous)
4				423-10	Liquid Propellant Storage
4				423-20	Liquid Propellant Pumping Facility
4				423-30	Liquid Propellant Pipeline (May include pumping facilities)
4				423-40	Liquid Propellant Storage Building
4				423-90	Liquid Propellant Storage (Miscellaneous)
4				424-20	Nitrogen Storage Facility
4				424-30	Oxygen Storage Facility
4				424-50	Gaseous Pipelines (other than for heating)
4				424-90	Other Gaseous Storage Facility
4				432-10	Cold Storage Warehouse - Ready Issue
4				442-10	General Warehouse - Ready Issue
4				442-20	Dehumidified Warehouse - Ready Issue
4				442-30	Flammables Storehouse - Ready Issue
4				442-40	Underground Storage - Ready Issue
4				442-50	Transit Shed
4				442-70	Loading Platform/Ramp
4				442-90	Covered Storage (Miscellaneous)
4				452-10	Open Storage Area - Ready Issue
4				461-10	Cryogenic Fluids Tank
4				461-20	Pumps and Transfer Piping Facilities (Cryogenic Fluids)
4				461-30	Control Console Facilities (Cryogenic Fluids)
4				461-90	Cryogenic Fluid Storage (Miscellaneous)
Facility Class 5 – Hospital & Medical					
4				510-00	Hospital Buildings
Facility Class 6 - Administrative					
3				610-10	Administration Buildings
4				610-20	Photo Laboratory
4				610-30	Receiving and Shipping Buildings
4				610-40	Printing and Reproduction Building
4				610-50	Conference Centers
4				610-90	Administrative Buildings (Miscellaneous)
4				630-31	Trailers, Office use

SENSITIVITY RATING				REAL PROPERTY CLASS	
Default	Adjusted				
	Aero	HEO	Sci	Code	Name
4				630-32	Trailers, Institutional use
4				630-34	Trailers, Storage use
4				630-36	Trailers, Service use
4				630-37	Trailers, R&D use
4				690-10	Flagpole
4				690-20	Monument or Memorial
4				690-90	Miscellaneous Administrative Structures
Facility Class 7 – Housing & Community					
4				711-00	Family Housing - Dwellings
4				730-10	Fire Station
4				730-20	Police Station
4				730-25	Gatehouse (Buildings)
4				730-65	Personnel Shelter
4				730-90	Community Facilities - Personnel Support and Service (Miscel
4				740-14	Vending Machine Building
4				740-26	Cafeteria - Restaurant
4				740-30	Gas Service Station
4				740-33	Post Office
4				740-34	Mail Handling Facility
4				740-35	Public Restroom/Shower
4				740-37	Exchange Sales Facility
4				740-43	Gymnasium and Physical Conditioning Building
4				740-50	Pavilion A facility that supports outdoor recreation
4				740-54	Recreation Building
4				740-56	Theatre
4				740-73	Museum
4				740-75	Hobby And Craft Center
4				740-76	Library
4				740-85	Exchange Warehouse
4				740-87	Nursery and Child Care Facility
4				740-88	Education Center
4				740-90	Community Facilities-Morale, Welfare & Recreational (Miscell
4				740-95	Non-Appropriated Fund Structure
4				750-10	Playing Court
4				750-20	Playing Field and Facilities
4				750-30	Outdoor Swimming Pool
4				750-40	Golf Course
4				750-50	Outdoor Theatre
4				750-90	Community-Morale, Welfare & Recreational - Exterior (Miscell
4				750-95	Non-Appropriated Fund Building
Facility Class 8 – Utility & Ground Improvements					
4				811-10	Electric Power Plant - Diesel
4				811-60	Stand-by Generator Plant
4				811-90	Electricity - Source (Miscellaneous)

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
4				812-10	Substation
4				812-20	Exterior Lighting
4				812-30	Distribution Systems
4				812-35	Electrical and Communications Duct System
4				812-40	Airfield Perimeter Lighting
4				812-60	Distribution Transformers
4				812-80	Traffic Control Lighting
4				812-85	Energy Management and Control System
4				812-90	Electricity - Distribution and Transmission Lines (Miscellan
4				821-10	Heating Plant and Other Related Facilities - Coal-Fired
4				821-20	Heating Plant and Other Related Facilities - Oil-Fired
4				821-30	Heating Plant and Other Related Facilities - Gas-Fired
4				821-50	Steam Plant - Power and Other Related Facilities
4				822-10	Steam and Condensate Lines
4				822-20	Hot Water Lines
4				822-30	Pump Stations
4				823-20	Gas Storage Tanks
4				823-30	Gas Meter Shelter
4				823-40	Gas Compressor Facility
4				823-50	Gas Vaporizer Facility
4				824-10	Gas Pipe Line
4				824-30	Gas Valve Facility
4				824-40	Gas Odorizer Facility
4				826-10	Air Conditioning Plant
4				826-20	Combined Air Conditioning and Heating Plant
4				827-10	Chilled Water and Refrigerant Distribution Line
4				827-20	Chilled Water Plant
4				831-10	Sewage Treatment Plant
4				831-30	Septic Tank and Drain Field
4				831-40	Contaminated Waste Storage
4				831-50	Radioactive Waste Handling Facility
4				831-60	Industrial Waste Treatment
4				831-90	Sewage and Waste (Miscellaneous)
4				832-10	Sewer and/or Industrial Waste Line
4				832-20	Combined Sewer
4				832-30	Sewage Pumping Station
4				832-40	Industrial Waste Systems
4				833-10	Incinerator
4				833-30	Garbage Stand
4				833-40	Waste Storage Building
4				833-90	Refuse and Garbage (Miscellaneous)
4				841-10	Water Treatment Facilities
4				841-30	Storage Tanks - Elevated - Potable
4				841-35	Storage Tanks - Elevated - Nonpotable

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
4				841-40	Storage Tanks - Ground Level - Potable
4				841-45	Storage Tanks - Ground Level - Nonpotable
4				841-50	Wells and Associated Facilities - Potable
4				841-53	Water Reservoirs
4				841-55	Wells and Associated Facilities - Nonpotable
4				841-70	Chlorinator Building
4				842-10	Water Distribution Pipeline (Potable)
4				842-20	Water Pump Facility, Potable
4				842-30	Water Distribution Pipeline (Nonpotable)
4				842-35	Other Nonpotable Water Distribution Pipeline Facilities
4				842-40	Water Pump Facility, Non-Potable
4				843-10	Fire Protection Pipeline
4				843-20	Fire Protection Pumping Station
4				843-30	Water Storage Tank
4				843-40	Fire Protection System Nonpotable
4				843-50	Fire Protection Pond or Reservoir
4				851-10	Roads (Concrete)
4				851-11	Roads (Bituminous)
4				851-12	Roads (Other)
4				851-20	Vehicular Bridges (Concrete)
4				851-21	Vehicular Bridges (Bituminous)
4				851-22	Vehicular Bridges (Other)
4				852-10	Parking Area (Concrete)
4				852-11	Parking Area (Bituminous)
4				852-12	Parking Area (Other)
4				852-20	Sidewalk (Concrete)
4				852-22	Sidewalk (Other)
4				852-32	Pedestrian Bridges (Other)
4				852-40	Miscellaneous Paved Area/Pad- Paved surfaces for pedestrian
4				860-10	Railroad Trackage
4				860-30	Railroad Bridge and Trestle
4				860-90	Miscellaneous Railroad Trackage Facilities
4				871-10	Storm Sewer
4				871-20	Drainage Ditch
4				871-30	Irrigation Facility
4				871-40	Dykes or Dams
4				871-50	Retaining Walls
4				871-60	Storm Drainage Pumping Station
4				871-70	(Unassigned)
4				871-90	Ground Improvement Structures (Miscellaneous)
4				872-10	Security Fencing and Walls
4				872-20	Guard and Watch Towers
4				872-40	Kennel
4				872-90	Security Structures (Miscellaneous)

SENSITIVITY RATING				**REAL PROPERTY CLASS**	
Default	**Adjusted**				
	Aero	**HEO**	**Sci**	**Code**	**Name**
4				880-10	Fire Alarm System
4				880-20	Watch Reporting System
4				891-10	Utility Building
4				891-40	Miscellaneous Pump Station
4				891-80	Miscellaneous Utility Facility
4				892-25	Compressed Air Plant
4				892-30	Compressed Air Distribution System
4				892-60	Valve Station
4				892-70	Utility Tunnel
4				892-75	Cooling Tower
4				892-85	Air Dryer System
4				892-95	Vehicle Scales
4				892-97	Miscellaneous Storage Tank and Basin
Facility Class 9 – Land					
N/A				911-10	Land - Purchase
N/A				911-20	Land - Donation (Private)
N/A				911-21	Land - Donation (State and Local Government)
N/A				911-22	Land - Donation (Federal Government)
N/A				911-30	Land - Transfer from Air Force
N/A				911-31	Land - Transfer from Army
N/A				911-32	Land - Transfer from Navy
N/A				911-33	Land - Transfer from other Federal Agencies
N/A				911-40	Land - Condemnation
N/A				912-11	Land - Public Domain Withdrawal (Public Land Order)
N/A				921-10	Land - Easement (By Purchase)
N/A				932-10	Site Improvement
N/A				932-50	Site Landscaping

APPENDIX B: Apex Events

Aeronautics Research

Winglets Development and Testing

Description. Winglets are vertical extensions of wingtips that improve an aircraft's fuel efficiency and cruising range. Designed as small airfoils, winglets reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. By reducing wingtip drag, fuel consumption goes down and range is extended.

Summary. In 1969 the price of oil was at an historic low, but in October 1973 political tensions between the U.S. and Russia flared after the attack of Israel by Egypt and Syria. The Soviet Union's support of the Arab position prompted the U.S. to back Israel, to which the Organization of Arab Petroleum Exporting Countries (OAPEC) responded by raising the price of oil and proclaiming an embargo. Shortages and price hikes sparked an acute energy crisis in the U.S. until the end of the embargo in March 1974. However, the panic had rattled the U.S. and resulted in a national shift towards energy efficiency and exploration of alternatives to fossil fuels that lasted until the collapse of oil prices in the early 1980s. Although the reduction of fuel consumption had always been a consideration in the field of aeronautics, due to both the cost and weight, the Energy Crisis made this a high priority at NASA during the 1970s. NASA's Aircraft Energy Efficiency (ACEE) Program, which ran from 1973 to 1987, sought ways to conserve energy in aviation in response to the Energy Crisis.

As part of the ACEE effort, LaRC's Dr. Richard Whitcomb conducted computer and wind tunnel tests to explore his hypothesis that a precisely designed, vertical wingtip device—which Whitcomb called a "winglet"—could weaken wingtip vortices and thus diminish induced drag. Less drag would translate into less fuel burn and better cruise efficiency. The winglet concept provided a better option than simple wing extensions which, while offering similar aerodynamic benefits, would require weight-adding strengthening of the wings and could render a plane too wide for airport gates.

Winglets increase an aircraft's operating efficiency by reducing what is called induced drag at the tips of the wings. An aircraft's wing is shaped to generate negative pressure on the upper surface and positive pressure on the lower surface as the aircraft moves forward. This unequal pressure creates lift across the upper surface and the aircraft is able to leave the ground and fly. Unequal pressure, however, also causes air at each wingtip to flow outward along the lower surface, around the tip, and inboard along the upper surface producing a whirlwind of air called a wingtip vortex. The effect of these vortices is increased drag and reduced lift that results in less flight efficiency and higher fuel costs. Winglets produce a forward thrust inside the circulation field of the vortices and reduce their strength. Weaker vortices mean less drag at the wingtips and lift is restored. Improved wing efficiency translates to more payload, reduced fuel consumption, and a longer cruising range that can allow an air carrier to expand routes and destinations.

Whitcomb refined the winglets concept with wind tunnel tests and computer studies and predicted that transport-size aircraft with winglets would realize improved cruising efficiencies of between 6% and 9%. Studies at LaRC included tests with a DC-10 model in a wind tunnel that showed that the winglets on the model reduced overall drag by 5% compared to the model without the devices. After evaluating a range of winglet designs, Whitcomb published his findings in 1976, predicting that winglets employed on transport-size aircraft could diminish induced drag by approximately 20%. This led the U.S. Air Force to consider the possible installation of winglets on KC-135 and C-141 transport aircraft.

The subsequent winglet flight test program brought together NASA, the U.S. Air Force, and Boeing, which began the effort with configuration studies and contractual work to design and manufacture the test articles which measured 9 feet high and 6 feet across at the base. Wind tunnel studies were carried out at LaRC where researchers tested the winglet models at various air speeds and also in a variety of flap and aileron configurations to validate the design work. Wind tunnel results predicted a 6% drag reduction on the winglet-equipped test aircraft.

A U.S. Air Force-furnished Boeing KC-135A Stratotanker test aircraft, a military version of the Boeing 707 jetliner, was delivered to AFRC in late 1977 for the installation of sensors and recorders that would obtain in-flight performance data. The winglets and the test aircraft's modified outer wing panels arrived at AFRC from Boeing in May 1979, setting up an installation and checkout period that culminated with the program's first test flight on July 24, 1979, with Thomas McMurtry piloting. During the 48-flight test program, the winglets, designed with a general-purpose airfoil that remained the same from root to tip, could be adjusted to seven different angles to give researchers a broad picture of their performance in a variety of flight conditions.

The KC-135 winglet flight tests, which ran from 1979 to 1980, demonstrated a 7% increase in lift-drag ratio with a 20% decrease in induced drag—directly in line with Whitcomb's original findings. Furthermore, the winglets had no adverse impact on the airplane's handling. The AFRC test program results demonstrated to the entire aviation industry that winglets were a technology well worth its attention. Smaller jet aircraft manufacturers Learjet and Gulfstream were the first to incorporate the technology. In 1989 Boeing introduced its winglet-enhanced 747-400 aircraft, and in 1990 the winglet-equipped McDonnell Douglas MD-11 began commercial flights following winglet testing by the company at NASA under the ACEE program. Boeing is also offering winglet options on new advanced models of the 737 series of passenger jets.

Winglets now appear on powerless hang gliders soaring above mountain ridges and from seaside cliffs. Retrofitting winglets to existing business jets is also a fast-growing market within the aviation industry itself. Many winglet marketing firms report their products help increase aircraft roll rates and lower approach and takeoff speeds. Since the 1980s aerodynamicists have developed a variety of derivatives of the winglet, including the blended winglet, the split-tip, and the raked wingtip.

Statement of Significance. Originally developed by NASA in the 1970s at a time when energy concerns drove research in the area of fuel economy, winglets are today found on aircraft of all types and sizes, from single-seat hang gliders and ultralights to global jumbo jets. Winglets are one of the most successful examples of a NASA aeronautical innovation being utilized around the world.

Aerodynamic Truck Fairings

Description. Fairings are structural elements of an aircraft or vehicle body that serve the purpose of reducing drag. During the 1970s and 1980s, NASA's aerodynamic truck studies developed fairings for the front, top, sides, and back of tractor-trailers to help reduce aerodynamic drag and improve fuel efficiency.

Summary. Starting in 1973 the AFRC began a project to assess aerodynamic long-haul truck drag with an eye its reduction. In 1973 the US was in the midst of the nation's first non-war related gas crisis. Led by Edwin "Ed" Satlzman, the AFRC measured a Ford van, then modified into the Shoebox by covering it with flat aluminum sides, top and underside, and calculating its drag as a baseline. It then gradually modified that shape in order to reduce its aerodynamic drag. With this data, the project tackled long-haul tractor-trailers to see how their efficiency could be improved. Disseminating their results, the U.S. trucking industry gradually adopted devices the center pioneered: today's highly-faired long-haul trucks derive directly from this project, and the consequence is dramatic improvement in fuel efficiency of long-haul trucks and delivery step vans.

Statement of Significance. Part of NASA's efforts in the 1970s to enhance fossil fuel efficiency, AFRC's aerodynamic truck studies resulted in the development of fairings, an innovation adopted by the U.S. trucking industry. Today's highly-faired long-haul trucks are a direct product of this project, resulting in dramatic improvement in fuel efficiency of long-haul trucks and delivery step vans.

Digital Fly-by-Wire Flight Control System Development and Testing

Description. Fly-by-wire (FBW) is a system that replaces the conventional manual flight controls of an aircraft with an electronic interface. The movements of flight controls are converted to electronic signals transmitted by wires (hence the fly-by-wire term) and flight control computers determine how to move the actuators at each control surface to provide the ordered response. The Digital Fly-by-Wire (DFBW) Flight Control System is an electronic flight-control system coupled with a digital computer.

Summary. The first fly-by-wire vehicle to fly was the Lunar Landing Research Vehicle, at the AFRC. It was controlled by three analog computers. Several engineers from the center that worked on the project decided to apply their experience to an aircraft with wings, and to use a digital computer. (The first production aircraft to be fully fly-by-wire, the F-16, employed analog computers, and many of these aircraft still fly today.) The engineers used a spare Apollo Guidance Computer for the project and first flight test of a DFBW flight control system in an aircraft was by NASA in 1972 on a modified Vought F-8C Crusader at AFRC. The NASA DFBW program was the forerunner of the flight control systems later used on the Space Shuttles and on today's military and civil aircraft to make them safer, more maneuverable, and more efficient.

A flight control system links impulses or input from the pilot to the moveable parts of an aircraft that dictate how the plane climbs, banks, and descends. Originally, flight control systems were mechanical constructs made up of wires, cables, pulleys, and rods. Later augmented by hydraulics, they directly connected the pilot's control stick and rudder pedals with control surfaces on the aircraft's wings and tail. These mechanical flight control systems were heavy and bulky, adding to the size and weight of the aircraft, making it slower and less fuel efficient. The need for stability constrained aircraft design, dictating the size, shape, and placement of elements such as the tail, fuselage, and wings. This design, in turn, impaired the maneuverability of a plane, making it harder for the pilot to handle.

Analog computer fly-by-wire systems were in active use by the mid-20th century, when digital computing was in its infancy. AFRC developed the LLRV with an analog fly-by-wire system to help Apollo astronauts train for their moon landings. NASA selected the Massachusetts Institution of Technology Instrumentation Lab, under the direction of Charles Stark Draper, to develop the guidance, navigation, and control system for Apollo – the first completely DFBW system. Apollo 8 (1968) became the first manned space mission to test the DFBW system, going around the moon and back.

By the late 1960s, engineers at AFRC began discussing how to apply Apollo DFBW technology to aircraft. Support for the concept at NASA HQ came from Neil Armstrong, former research pilot at AFRC, who supported the proposed project and proposed that the AFRC team use an AGC, which they did. NASA modified the F-8, replacing the entire hydro-mechanical flight-control system with wires from the control stick in the cockpit to the control surfaces on the wings and tail surfaces. The heart of the system was an off-the-shelf backup Apollo digital flight-control computer and inertial sensing unit which transmitted pilot inputs to the actuators on the control surfaces.

On May 25, 1972 NASA 802, piloted by Gary Krier, became the first aircraft to fly completely dependent upon a digital electronic flight-control system. The first phase of the DFBW program validated the concept and quickly showed that a refined system – especially in large aircraft – would greatly enhance flying qualities by sensing motion changes and applying pilot inputs instantaneously. It had a backup DFBW system in the event of a failure in the Apollo computer unit, but it was never necessary to use the system in flight. For the second phase of research, carried out in partnership with LaRC, the original Apollo system was replaced with a triple redundant digital system that would provide backup computer capabilities if a failure occurred.

The DFBW research program lasted 13 years and demonstrated the benefits of the system. It was safer because of its redundancies and because, for military aircraft, wires were less vulnerable to battle damage than the hydraulic lines they replaced. It was more maneuverable because computers could command more frequent adjustments than a human pilot and designers could eliminate features that made the plane more stable and thus harder to maneuver. For airliners, computerized flight control could also ensure a smoother ride. Finally, DFBW was more efficient because it was lighter and took up less volume than hydraulic controls and thus either reduced the fuel required to fly and/or permitted carrying more passengers or cargo. It also required less maintenance than older systems.

One of the most far-reaching contributions to come out of the DFBW program has been the concept's impact in aircraft design, from total configuration to internal engineering features. Departures from traditional military designs are evident in two of the first U.S. military aircraft to be developed with DFBW, the F-18 used by the U.S. Navy and Marine Corps and the Air Force F-16. Both designs evolved into extremely versatile, agile, and successful aircraft. The F-117 fighter, B-2 bomber, the F-22 advanced tactical fighter and the F-35 Joint Strike Fighter are examples of even more evolutionary designs of U.S. military aircraft to utilize DFBW. Each aircraft display individual design, maneuverability, and flight characteristics that could not have been achieved without the benefits of DFBW. Digital controls technology transferred from NASA and aerospace to the automotive industry: virtually every new car employs digital drive-by-wire for braking and throttle control, and some even have steer by-by-wire. Harley-Davidson introduced digital throttle-by-wire on its top of the line motorcycles.

Launched into production during 1984, the Airbus Industries Airbus A320 became the first airliner to fly with an all-DFBW control system, and every new airliner designed since it entered service in 1988 has incorporated DFBW technology. Computerized flight control systems sense turbulence-induced deviations and make control corrections before they are hardly noticed by flight crews and passengers. The capability of DFBW systems to maintain constant flight speeds and altitudes over long distances is another way of increasing fuel efficiency.

Statement of Significance. NASA's FBW research program is considered one of the most significant and most successful aeronautical programs in its history, as it validated the principal concepts of all-electric flight control systems now used on nearly all modern high-performance aircraft and on military and civilian transports. This, in turn, laid the groundwork for leading, not only the U.S., but to a great extent the entire world's aeronautics community into the new era of DFBW flight controls.

Integrated Propulsion Control System Development and Testing

Description. The Integrated Propulsion Control System (IPCS) replaced the traditional hydro-mechanical systems with integrated digital engine and inlet controls in a General Dynamics F-111 Aardvark for the purpose of testing the feasibility of integrated propulsion controls at supersonic speeds.

Summary. While AFRC and LaRC were developing DFBW capabilities for aircraft flight control, GRC and AFRC were investigating an electronic versus a conventional hydro-mechanical controlled engine in supersonic aircraft. By the early 1970s, propulsion system hardware had steadily increased in complexity, placing even greater demands on the propulsion control hardware. With the engine and inlet operating at higher levels of performance, there was a need for improvements in control system technology. In addition to increased sensing and computation, the various inlet and engine control functions needed to be integrated to achieve maximum propulsion system stability and performance during all flight conditions.

The three-year exploratory research program for the design, development, and flight evaluation of an IPCS was a joint effort by GRC and AFRC, the U.S. Air Force Flight Propulsion Laboratory, and the Boeing, Honeywell, and Pratt & Whitney companies. The primary objectives of this program were to establish through flight test the potential improvements in steady-state and transient propulsion system performance that can be achieved as a direct result of new modes of control, more direct sensing of engine and inlet parameters, and the use of more sophisticated, high-speed digital computation.

The first IPCS was installed on an F-111E, a long-range tactical fighter-bomber airplane. The General Dynamics F-111 Aardvark aircraft was selected for the IPCS program because it incorporated a variable geometry inlet and an afterburning turbofan engine and had two engines, one of which could remain in the normal configuration to ensure flight safety. It featured variable sweep wings, a crew of two, and a maximum Mach capability of 2.5. The left engine of the F-111E was selected for modification to an all-electronic system. The Pratt & Whitney TF30-P-9 engine was modified and extensively laboratory and ground-tested before installation into the F-111E. The F-111E engine and inlet were normally equipped with independent hydromechanical control systems. For the IPCS program, a full-authority digital engine control system was developed and implemented in an onboard research computer. Either a digital implementation of standard hydromechanical control or a new digital control mode could be selected. The TF30 engine digital controller was also integrated with the control of the variable geometry external compression inlet.

The F-111E made 27 IPCS flights from 1975 through 1976. Flight data were compared with results of tests run in an altitude test chamber, demonstrating the usefulness of an altitude chamber for developing a software and testing hardware. The digital system was found to be capable of duplicating the standard engine and inlet control systems. Use of the IPCS was found to yield advantages that included faster accelerations (both gas generator and afterburner performance), better thrust and flight control, reduced flight idle thrust, reduced engine ground trim, extended service ceiling, automatic stall detection, and stall recovery detection. Significant performance benefits included stall-free operation, faster throttle response, increased thrust, and increased range at Mach number 1.8. Most importantly, the IPCS test program proved an engine could be controlled electronically, leading to the more efficient Digital Electronic Engine Control (DEEC) System flown in the F-15.

Statement of Significance. The IPCS was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized Highly Integrated Digital Electronic Control (HIDEC) Program.

Cooperative Airframe/Propulsion Control System Development and Testing

Description. The Cooperative Airframe/Propulsion Control System (CAPCS) was a cooperative ("Co-Op") digital control system that integrated the engine inlet control, autopilot, autothrottle, airdata, navigation, and stability augmentation systems installed in the Lockheed YF-12C Blackbird to improve overall aircraft control.

Summary. Another evolutionary step in NASA's advancement of digital control and integration of aircraft systems was the research program on flight control systems and propulsion system-flight control interactions as observed through the YF-12C testbed. The Lockheed YF-12 was a prototype interceptor aircraft developed in the late 1950s and early 1960s for reconnaissance (i.e., stealth) missions at the request of the Central Intelligence Agency. The YF-12 was one of three models in the highly classified Blackbird family, along with the A-12 and SR-71, which had been flight tested at AFRC since 1970. The YF-12C, tail number 06937, was an SR-71A, but the fictitious name was given to keep the existence of the SR-71 secret. The YF-12 didn't have the stealthy qualities of the other Blackbirds in that it lacked the anti-radar treatments (radar absorbent structures) of the A-12 and SR-71 variants of the Blackbird family, which made it a little less sensitive.

The YF-12 and SR-71 originally suffered from severe control issues that affected both the engines and the physical control of the aircraft. Wind testing at AFRC and YF-12 research flights developed computer systems that nearly completely solved the performance issues. Testing revealed vortices from the nose chines interfering with intake air, which lead to the development of a computer control system for the engine air bypasses. A computer system to reduce unstarts was also developed, which greatly improved stability. They also developed a flight engineering computer program called Central Airborne Performance Analyzer (CAPA) that relayed engine data to the pilots and informed them of any faults or issues with performance and indicated the severity of malfunctions.

The YF-12C airplane was a twin-engine, delta-winged airplane designed for long-range cruise at Mach 3.2+ and altitudes above 85,000 feet. High-speed supersonic cruise at Mach numbers greater than 2.5 and at altitudes above 70,000 feet highlighted many new airframe-propulsion system interdisciplinary problems that impacted efficient aircraft operation. At such high speeds even minor changes in direction caused the aircraft to change position by thousands of feet, and often had severe temperature and pressure changes. Early flight research results showed strong interactions between control systems. Integration of subsystems was an effective way to take advantage of favorable interactions and to minimize unfavorable interactions. Studies by NASA indicated that problems such as these may be solved by developing an integrated-cooperative control system for supersonic cruise vehicles. Other benefits that could result included improved inlet stability and reduced engine temperatures, propulsion system drag, trim drag, weight, and control surface size.

NASA began preparing the U.S. Air Force-supplied YF-12C in early 1977 through a series of tests aimed at acquiring the baseline propulsion/airframe interaction data necessary to define control logic for the CAPCS. The cooperative digital control system was installed, replacing several separate analog-mechanical control systems of the aircraft. Inlet control, autopilot, autothrottle, airdata, and navigation were performed in a single computer. Once the system was installed, flight testing was conducted between May and September 1978, with the CAPCS system exceeding the designers' goals. The central digital computer control provided more accurate and faster response computations. The improved altitude- and Mach-hold autopilot logic was incorporated. Airdata computations were improved, and lag compensation was applied. In addition, more precise inlet control was obtained with the digital system while inlet stability margins were reduced.

Based on the success of the digital flight-propulsion control system on the YF-12C, the Air Force and Pratt & Whitney incorporated the cooperative control system concepts as part of a major avionics up-grade to the entire SR-71 (the production version of the YF-12C) fleet in 1983. In fleet use, this system realized range improvements of 7% and eliminated the occurrence of inlet unstarts. Thus, the flight demonstration served to speed the transition of the technology developed in the YF-12C flight-propulsion control research to the operational SR-71 fleet.

Statement of Significance. The CAPCS was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized HIDEC Program.

Digital Electronic Engine Control System Test Program

Description. The Digital Electronic Control (DEEC) system was an engine mounted, fuel-cooled, single-channel digital controller that received inputs from the aircraft airframe and engine to control a wide range of engine functions. The DEEC system was initially applied to Pratt & Whitney's F100 turbofan engine in order to transition F-15 aircraft from hydro-mechanical propulsion control to digital. The DEEC was to engine controls what DFBW was to flight controls.

Summary. As the CAPCS control system was beginning to produce results on the YF-12C, Pratt & Whitney began development of a production-quality DEEC for the Pratt & Whitney F100 engines used to power F-15 and F-16 fighters. Participants in the program to fully test and evaluate the DEEC included, in addition to Pratt & Whitney, the U.S. Air Force, GRC which tested a prototype DEEC on an F100 engine in an altitude facility in 1978, and AFRC, which conducted the DEEC flight test and evaluation program from 1981 to 1983.

The aircraft used in the DEEC tests was a McDonnell Douglas F-15A (tail number 835) that AFRC had obtained from the U.S. Air Force in 1976 for use as a flight research platform. The broad objective of the DEEC test program was to demonstrate and evaluate the system as it applied to a modern turbofan engine flown in a high-performance fighter to all corners of the flight envelope. Within this objective, program officials would assess fault detection, evaluate performance and durability, and compare flight test performance against data generated by design predictions and ground tests activities.

Prior to flight, the F-15 test aircraft was instrumented to collect data typical of most research flights – airspeed, altitude, attitude (pitch, roll, yaw), accelerations, and control surface positions. The DEEC-equipped engine was installed in the left bay and was extensively instrumented to record all parameters associated with its performance, including malfunctions. Instrumentation on the right engine displayed its operational status only and it did not produce test data. The data stream generated by instrumentation on the DEEC engine was recorded on the aircraft and also transmitted to a real-time flight monitoring facility at AFRC where it was then made available for post-flight processing.

NASA's DEEC program logged 30 test flights, including seven aerial refuelings, with a total of 35.5 hours of flight time over a two-year period (1981–1983). The entire operational envelope of the F-15 and the F100 engine was covered in a variety of flight conditions, with test points obtained at speeds up to Mach 2.36 and at altitudes up to 60,000 feet. By the end of the test and evaluation program, improvements in the DEEC system and improvements in the operational capabilities of the F100 engine had been demonstrated and system performance objectives had been met. These included stall-free operations across the entire F-15 flight envelope, faster throttle responses, improved air-start capability, and an increase of more than 10,000 feet altitude in afterburner without pilot restrictions on throttle use.

The study was completed 1.5 years ahead of schedule and allowed the introduction of the DEEC system on operational engines much sooner than originally anticipated. After the DEEC program ended at AFRC, the U.S. Air Force successfully evaluated the system for F-16 aircraft, and the system was installed on several operational Air Force F-15 aircraft. Over a period of time, the DEEC-equipped engines displayed improved reliability and maintainability, they improved mean-time between failures by a factor of two, and unscheduled engine removals were reduced by a factor of nine. Improved engine and flight performance in the NASA program and in the F-16 evaluation opened the door for DEEC-equipped engines to be installed in all F-15 and F-16 aircraft.

The DEEC was developed for the Pratt & Whitney F100 turbofan engine, but its technology is now incorporated on other engine models. NASA's successful test and evaluation program allowed the U.S. Air Force and Pratt & Whitney to place the DEEC into standard use on F100-PW-22- and F100-PW-220-229 engines that power F-15 and F-16 aircraft of the U.S. and several foreign nations. Pratt & Whitney also incorporated the DEEC system into its PW 2037 turbofan engines used on 757 commercial jetliners. The lineage of similar digital engine control units used on other engines, offering comparable operational improvements, can be traced to results of NASA's DEEC test and evaluation program.

Statement of Significance. Development of the DEEC is looked upon as a milestone in propulsion control, and a major transition from hydro mechanical to digital control. Benefits of the system are substantial and include reduced operating and maintenance costs—plus major boosts in engine performance and extended engine life. The DEEC was an essential evolutionary step in the digital computerization and integration of aircraft systems and a prerequisite to the advances made under the more broadly recognized HIDEC Program. Through the F-15A testing program, NASA played an integral role in the refinement and demonstration of successful operation of the DEEC system.

Highly Integrated Digital Electronic Control Program

Description. The Highly Integrated Digital Electron Control (HIDEC) Program was a flight test program carried out at AFRC from 1983 to 1993 with an F-15A aircraft (tail number 835). The HIDEC Program studied and validated the integration of aircraft engine operations with air data and flight control systems to improve aircraft performance. The major elements of HIDEC were a Digital Electronic Flight Control System (DEFCS), the engine-mounted DEECs, an on-board general-purpose computer, and an integrated architecture allowing all components to "talk to each other."

Summary. The effort to operational link engine and flight control systems was a natural outgrowth of the successful DEEC unit flight tested on the F-15A at AFRC between 1981 and 1983. The same aircraft was used for HIDEC – the McDonnell Douglas F-15A (tail number 835), an air superiority fighter acquired from the U.S. Air Force in 1976. The F-15 had a top speed of Mach 2.5 and display excellent transonic maneuverability. It has a large shoulder-mounted swept-back wing, twin vertical stabilizers, and large horizontal stabilizers. Two-afterburning turbofan Pratt & Whitney F100-PW-100 or -220 engines normally power F-15s.

The HIDEC F-15 used advanced versions of the F100 called the F100 EMD (engine model derivative). Both of the engines on the HIDEC aircraft were equipped with DEEC units in 1983 following the completion of the DEEC test and evaluation project. For its research role with NASA, most of the aircraft's weapons systems were removed and much of this space was devoted to instrumentation and data collection systems, and experiments associated with specific projects. The standard F-15 had a mechanical flight control system that provided control of the ailerons, rudders, and stabilizers. An analog electronic control augmentation system (CAS) operated in all three axes. On the HIDEC aircraft, a DEFCS augmented the standard flight control system and replaced the analog CAS.

Over a span of about 15 years, the HIDEC was used to develop several modes of integrated engine and flight control systems that took advantage of the HIDEC's digital electronic flight control system to improve aircraft engine and operational performance.

<u>Adaptive Digital Engine Control System (ADECS)</u>. ADECS improved engine performance in a demanding flight environment by borrowing an engine's excess stall margin through the integrated and computerized flight and engine control systems. An engine's stall margin is the amount that engine-operating pressures must be reduced to supply a margin of safety to prevent an engine stall because of excessive pressure. It was continually monitored and adjusted by the integrated system, based on the flight profile and real-time performance needs. Using this information, ADECS freed up engine performance that would otherwise be held in reserve to meet the stall margin requirement. Improved engine performance could take the form of increased thrust, reduced fuel usage, or lower engine operating temperatures because peak thrust was not always needed.

<u>Performance Seeking Control (PSC)</u>. PSC optimized total aircraft engine performance during steady-state engine operation. It was essentially a follow-on project of the ADECS, which enhanced engine performance in dynamic flight situations. PSC measures many parameters to identify the condition of engine components and optimize them to achieve the best efficiency based on actual engine conditions and flight environment. PSC reduced turbine operating temperatures, which can significantly extend the life of jet engines. Flight test results also showed that PSC substantially improved thrust at varied flight conditions, including accelerations and climbs. PSC incorporated the capability to detect engine wear and the impending failure of certain components. Such data, combined with routine preventative maintenance, can help improve the dependability of propulsion systems on many types of aircraft.

<u>Self-Repairing Flight Control System (SRFCS)</u>. The SRFCS is a software addition to an aircraft's digital flight control system that detects failures and damage to ailerons, rudders, elevators, and flaps. The system, which can be used on nearly all aircraft with digital flight control systems, then compensates for the component loss by reconfiguring the remaining control surfaces so flight crews can land their aircraft safely. Installed on military aircraft, the unique system would allow aircrews experiencing a control surface failure to complete missions. A standout feature of the SRFCS is a cockpit display that presents pilots a visual warning explaining the type of system failure the aircraft has experienced due to a malfunction or combat damage. The readout, which can be presented on a heads-up display, gives pilots new flight limits such as reduced speed and maneuvering limitations that the failure or damage may impose. The SRFCS also had the capability of identifying failures in electrical, hydraulic, and

mechanical systems, which reduced the need for time-consuming ground maintenance diagnostic tests to identify the malfunction.

Self-Repairing Flight Control System (SRFCS) originated and was executed at AFRC. The F-15 ACTIVE (Advanced Control Technology for Integrated Vehicles) extended the SRFCS project, as did the IRAC project (Integrated Resilient Aircraft Control), both initiated/executed at and by the AFRC.

Propulsion Controlled Aircraft (PCA) System. The PCA concept was developed by AFRC engineer, Frank W. “Bill” Burcham, in response to the crash of a United Airlines DC-10 in Sioux City, Iowa, in 1989 when flight controls to the horizontal stabilizer and rudder were severed when the tail-mounted engine suffered a catastrophic failure. PCA uses computer-augmented engine thrust to give flight crews faced with a flight control system failure enough pitch, yaw, and roll authority to fly the aircraft until an airport is reached and a safe landing can be made. The F-15A HIDEC was modified to serve as the first-ever aircraft to intentionally demonstrate this PCA capability. Flight tests of PCA by AFRC concluded with a successful landing on April 21, 1993, using only engine power to turn, climb, and descend. A successful follow-on program with a transport aircraft (jetliner) conclusively demonstrated the success of the technology when on November 28, 1995 NASA research pilot Gordon Fullerton made the first-ever safe, fully automated landing of a transport aircraft using only engine thrust for control in a PCA-equipped MD-11.

Statement of Significance. The HIDEC Program, utilizing the F-15A 835, was an important step in the digital computerization of aircraft operations. It demonstrated the feasibility of integrating what had been two separate development paths in aeronautics – digital flight control and digital engine control – and illustrated the significant benefits that it offered with respect to fuel efficiency, aircraft maintenance, and operation costs. The advantages of extended engine life and enhanced engine and flight performance also give the aircraft a greater safety margin, a factor that can be appreciated by aircrews as well as passengers. Elements of the HIDEC Program were incorporated into military, commercial, and general-purpose aircraft.

Lifting Body Program

Description. The Lifting Body Program was an exploration of wingless aircraft design that was intended to provide an alternative to ballistic reentry from space such as that used by the Apollo capsule, so that a crew could fly back through Earth’s atmosphere and land at an airfield.

Summary. The original idea of lifting bodies was conceived around 1957 by Dr. Alfred J. Eggers Jr., then the assistant director for Research and Development Analysis and Planning at ARC (then called the Ames Aeronautical Laboratory). Eggers found that by slightly modifying a symmetrical nose cone shape, aerodynamic lift could be produced. This lift would enable the modified shape to fly back from space rather than plunge to Earth in a ballistic trajectory. In 1962, AFRC Director Paul Bikle approved a project to build a lightweight, unpowered lifting body as a prototype to flight test the wingless concept. With a limited budget, NASA personnel cobbled together the first concept vehicle – the M2-F1, completed in 1963 – using a wooden shell built by a sailplane company and salvaged parts from other aircraft. The first flight tests were over Rogers Dry Lake at the end of a tow rope attached to a modified Pontiac convertible driven at speeds up to about 120 mph. These initial tests produced enough flight data about the M2-F1 to proceed with flights behind a NASA R4D tow plane at greater speeds.

While the concept of a lifting body originated with several engineers at the ARC, the first to build and flight test a human-rated lifting body came at the AFRC, in 1963. It was center engineer R. Dale Reed who first took the concept seriously and, after testing and filming (by his wife, Donna his own models in flight, convinced then-center director Paul Bikle to fund a project. Only after the M2-F1 demonstrated the concept, and after NASA agreed to fund the follow-on work, did the Air Force join the program. The Air Force was, at the time, pursuing its own re-entry vehicle, the X-20 Dyna-Soar, which never flew.

By 1965, the lifting body experiments had attracted the attention of the U.S. Air Force, and the Lifting Body Program, a partnership between NASA and the Air Force, was formally established. Generally speaking, NASA AFRC held responsibility for design, contracting, and instrumentation, while the Air Force supplied the launch aircraft for drop tests, assorted support aircraft, and medical personnel. The success of the M2-F1 had been promising enough that decisionmakers at NASA authorized the development and construction of two aluminum heavyweight lifting bodies – the M2-F2 and the HL-10 – both built by the Northrop Corporation. The two aircraft had different fin and fuselage configurations. After the crash of the M2-F2, the plane was rebuilt as the M2-F3 with an additional vertical fin and a rocket motor. The HL-10 (Horizontal Lander no. 10), an LaRC design with a flat bottom and rounded top fuselage reached Mach 1.86 and an altitude of 90,000 feet.

The Air Force took the program to the next step with the X-24A, built by the Martin Company and subsequently rebuilt as the X-24B. Test flights of the X-24A began in 1969 with unpowered glides upon release from a B-52 tow, followed by powered flights through 1971. In 1972 the X-24A was modified into the delta-shaped X-24B, with a flat bottom and rounded top that provide additional flight stability. The X-24A and X-24B reached a maximum speed of around Mach 1.6 and an altitude of roughly 71,400 feet. In 1975 NASA research pilot John Manke landed the X-24B on the paved runway at Edwards AFB, the first time a lifting body did so.

Statement of Significance. The Lifting Body Program (1963–1975) demonstrated the ability of pilots to maneuver in the atmosphere and safely land a wingless vehicle. The information the Lifting Body Program generated contributed to the data base that led to development of the Space Shuttle orbiter. The X-24A shape was used for the X-38 Crew Return Vehicle technology demonstrator, designed as an escape vehicle for the ISS.

Bell XV-15 Tilt Rotor Research Aircraft Development and Testing

Description. Tilt rotor aircraft have upward-facing rotors that spin to lift the aircraft, like a helicopter. However, the rotors also are able to shift to face forward, thus changing the configuration from a helicopter, which can take off vertically without a runway and hover in place, to that of a traditional propeller airplane, which can move faster and has a longer range. These combined qualities make tilt rotors ideal for search and rescue operations, for transport to remote locations and for shorter-range passenger travel. Tilt rotors can land on small airfields in the centers of cities and thus reduce total travel time.

Summary. The XV-15 tilt rotor research aircraft program resulted in part from earlier investigations by the U.S. military seeking new and more efficient concepts for air support of field operations. In 1955, a decade before founding the new laboratory and years before NASA was created, the U.S. Army unveiled the XV-3 experimental aircraft, the first in its series of tilt rotor aircraft built by Bell Helicopter Company. The XV-3 was extensively tested in the 40- by 80-foot wind tunnel test section of the NACA's Ames Aeronautical Laboratory. The XV-3 faced significant stability problems that discouraged many supporters and threatened to swamp the program. But it successfully demonstrated the feasibility of transitioning from vertical to forward flight and established the foundation for the next version of the tilt rotor.

The tilt rotor concept was formally revisited in 1971 when ARC established the V/STOL (vertical/short takeoff and landing) Projects Office, and the Tilt Rotor Research Aircraft (TRRA) Project Office, a joint initiative of NASA and the U.S. Army. In 1973 Bell Helicopter was selected to build the next version of a tilt rotor aircraft, the XV-15. The XV-15 was the first proof-of-concept aircraft built as an entirely new airframe to ARC specifications. NASA engineers were involved in every aspect of the design and testing of the XV-15, from the CFD—use of computers to predict aerodynamic behavior—behind the initial design to studies of the best way to present cockpit data to the pilots.

Bell built two prototypes of the XV-15, which were extensively tested and refined by the engineers of the TRRA. Under the leadership of Wallace H. Deckert, the aeronautical facilities at ARC played an important part in the design and testing of these aircraft, including wheel-pod drag tests in the 7- by 10-foot wind tunnel, rotor performance and dynamics tests in the 40- by 80-foot wind tunnel, and a number of control systems development piloted simulations in the Flight Simulator for Advanced Aircraft. Prior to flight envelope expansion, the first XV-15 (NASA tail number 702) was tested in the ARC 40- by 80-foot wind tunnel in mid-1978 for a preliminary evaluation of the aircraft's aerodynamic and aeroelastic characteristics. At the completion of envelope expansion flight tests at AFRC, the second aircraft (NASA tail number 703) was delivered to ARC in mid-1981.

The second XV-15 became the subject of a series of technology development activities. The flight activity included flying qualities and stability and control evaluations, control law development, side-stick controller tests, performance evaluations in all flight modes, acoustics tests, flow surveys, and documentation of its loads, structural dynamics, and aeroelastic stability characteristics. A large digital database from the program was maintained on ARC's computer facilities and made available online for use by U.S. industry and the military services.

Speeds in cruise flight exceeding 300 knots were achieved. The aircraft's large transition envelope and good flying qualities were found to make it easy for pilots to operate in any flight regime from cruise to hover. Operational demonstrations were performed for over 100 military and industry pilots and included nap-of-the-Earth flight (i.e., evasive low-altitude flight), air-to-air combat, aerial refueling, and launch and recovery aboard an aircraft carrier. In recognition of the significant contributions of the XV-15 program, the project team received the American Helicopter Society's Grover E. Bell award in 1980. The aircraft also performed flight displays and was exhibited at the Paris Air Show in 1981.

The same year as the air show the Department of Defense (DoD) has established a task force to select a viable aircraft for vertical lift missions. The validation of tilt rotor analytical methods resulting from the XV-15 flight program provided sufficient confidence in the technology to convince the Joint Services Advanced Vertical Lift Aircraft Program to select it out of four that were being evaluated. The contract for the production version of the XV-15, the V-22 Osprey, was awarded to Bell-Boeing in 1983, but it was not until 2005 that the DoD approved full-rate production of the V-22.

Statement of Significance. The XV-15 TRRA project, a joint project between NASA and the Army, is recognized as one of the most significant to have been pursued at ARC. The flight test program was an integral part of the development of the world's first successful tilt rotor production aircraft, the V-22 Osprey. Although the XV-15 was built by the Bell Helicopter Company, the government (the Army and NASA) successfully wrote the specifications for and fostered the introduction of a new aircraft type into the U.S. aviation market. The technology validation and the demonstrations provided by the TRRA gave the government and the aviation industry the confidence to invest in the tilt rotor technology. Today approximately 400 of the V/STOL V-22 are in service today with the U.S. Navy, Marines, and Air Force, as well as the Japanese self-defense force.

High Angle-of-Attack Technology Program

Description. Angle of attack (alpha) is an aeronautical term that describes the angle of an aircraft's body and wings relative to its actual flight path. During maneuvers, pilots often fly at extreme angles of attack—with the nose pitched up while the aircraft continues in its original direction. This can lead to conditions in which the airflow becomes separated over large regions of the lifting surfaces (airfoils). This can result in insufficient lift to maintain altitude or control of the aircraft and a corresponding increase in drag—a condition known as stall. NASA's High Alpha Research Vehicle (HARV), an F/A-18, was used to research ways to reduce the situations in which a stall occurred and increase the angle of attack possible to safely execute in high-performance aircraft.

Summary. From the late 1970s onward, NASA and the DoD began a series of experimental flight tests that examined different aspects of high-maneuverability flight. On the NASA side, the most productive of these was the High Angle-of-Attack Technology Program (HATP), which ran from 1985 to 1996. LaRC managed the HATP in partnership with ARC, AFRC, and GRC. The primary objectives of the program were to provide flight-validated aircraft design tools to improve the maneuverability of aircraft at high angles of attack. The program has placed particular emphasis on the areas of aerodynamics, propulsion, control law research, and handling qualities. Besides managing the program, LaRC performed subscale wind-tunnel testing, advanced control law synthesis, and CFD. ARC contributed further CFD work and its 80- by 120-foot wind tunnel. GRC worked on inlet and engine integration. AFRC performed the flight research. Other partners came from industry, academia, and the DoD, plus some North Atlantic Treaty Organization (NATO) participants.

HATP engineers modified an existing fighter jet and flight-tested it in three phases from 1987 to September 1996. They acquired a preproduction McDonnell Douglas F/A-18, an aircraft that could fly to a 55-degree angle of attack. AFRC rebuilt and instrumented the aircraft to serve as the HARV.

Phase One (1987–1989). Phase One of "high alpha" flights consisted of 101 research flights in the specially instrumented F-18 at angles of attack as high as 55 degrees. During this phase, there were no external modifications to the aircraft, but technicians equipped it with extensive instrumentation. The purpose of this phase was to obtain experience with aerodynamic measurements at high angles of attack and to develop the flight research techniques needed for this measurement. Researchers conducted visual studies of the airflow over various parts of the aircraft using tracer smoke, yarn (tufts) taped on the aircraft, and anti-freeze with dye in it to illuminate the airflow, and captured it with on-board video and still cameras to enable a comparison with computer and wind tunnel predictions. Additional data they obtained included air pressures. NASA paid particular attention to the location of strong vortices (air in circular motion) that formed off the forebody and wing-body-strake (leading-edge extension) at high angles of attack and their role in inducing tail buffeting (beating by unsteady flow, gusts, etc.).

Phase Two (1991–1994). Phase Two testing consisted of 175 flights that examined the benefits of using vectored thrust (thrust that is manipulated to control attitude or angular velocity of the aircraft) to achieve greater maneuverability and control at high angles of attack. Major hardware and software modifications were made to the HARV to accommodate the thrust vectoring system for control, which could deflect the exhaust flow from the two turbofan engines to provide enhanced maneuverability and control in areas where conventional aerodynamic controls were ineffective. The system resulted in significantly increased maneuverability at moderate angles of attack and some degree of control at angles of attack up to roughly 70 degrees. It also allowed researchers to collect a greater amount of data by remaining at high angles of attack longer than they could have done without it. The subsonic performance of the engines, including afterburning, was largely unaffected by the modifications, but supersonic flight was sacrificed due to the added weight.

The modified flight control computers used a PACE 1750A computer and specially written flight control laws to provide the research flight control capability. These laws commanded the optimum combination of aerodynamic control and vectored thrust to satisfy pilot demand. Program engineers integrated all controls into these flight control laws. The pilot used standard cockpit controls and no special pilot action was required after the system was engaged in flight. In addition to the research flight control computers, pilots also used the original F-18 flight control system both as a backup to the research system and to perform take-offs and landings.

During Phase Two, the HARV aircraft was modified a second time with a sophisticated engine inlet pressure measurements system that provided unprecedented understanding of what happens to engine airflow under extreme maneuver conditions.

Phase Three (1995–1996). The Phase Three effort consisted of 109 flights to evaluate moveable strakes on both sides of the aircraft's nose that provided yaw control at high angles of attack where conventional rudders became ineffective. These strakes, 4 feet long and 6 inches wide, were hinged on one side and mounted to the forward sides of the fuselage. At low angles of attack, they were folded flush against the aircraft skin. At higher angles of attack, they were extended to interact with the strong vortices generated along the nose and thereby produce large side forces for control. Wind tunnel tests indicated strakes could be as effective at high angles of attack as rudders are at lower angles. The availability of the strakes enabled pilots to employ three separate flight modes through varied combinations of thrust vectoring and strakes. These three options were a unique feature of the HARV project. They afforded a great deal of flexibility in research into control power requirements at high angles of attack. They were also a means of achieving detailed investigation of handling qualities at high angles of attack. Use of the proved effective in providing control above 35 degrees angle of attack.

Statement of Significance. Between 1985 and 1996 the HATP used the F/A-18 HARV aircraft to demonstrate stabilized flight at angles of attack between 65 and 70 degrees using thrust vectoring vanes, a research flight control system, and forebody strakes. This combination of technologies provided carefree handling of a fighter aircraft in a part of the flight regime that was otherwise very dangerous. Flight research with the HARV increased understanding of flight at high angles of attack, enabling designers of U.S. fighter aircraft to design airplanes that fly safely in portions of the flight envelope that pilots previously had to avoid. In addition, the HARV made a significant contribution to the applicability of CFD to high angle-of-attack flows by providing a comparison of CFD, wind-tunnel, and flight data at the same scale. Research conducted in the HATP has informed the designs for the F-22 Advanced Tactical Fighter and prototypes of the Joint Strike Fighter.

Human Exploration and Operations

Skylab

Description. Skylab was the first United States space station to orbit the planet Earth. Launched in May 1973 it was operated by three separate three-astronaut crews, designated as Skylab 2, Skylab 3, and Skylab 4. Major operations included an orbital workshop, a solar observatory, Earth observations, and the completion of hundreds of experiments. Skylab's orbit decayed and it disintegrated upon reentry into the Earth's atmosphere in July 1979.

Summary. As the Apollo program wound to a close, NASA sought new missions and opportunities. In 1964, building upon initiatives proposed as early as 1959 by rocket engineer Wernher von Braun, NASA's Manned Spacecraft Center (MSC), in Houston (presently the JSC) proposed development of an expendable lab for missions of 15 to 45 days in space. Design development during the mid-1960s focused upon repurposing a S-IVB second stage of a Saturn IB launch vehicle as the basis for the lab. The largest element of the lab, designated the Orbital Workshop (OWS), consisted of a repurposed S-IVB stage, a cylindrical container 48 feet long and 22 feet in diameter weighing some 78,000 pounds. The original concept called for a "Wet Workshop," in which a specially constructed S-IVB stage would be launched "Wet" (filled with propellants) as a propulsive stage on the S-IB Launch System. The empty hydrogen tank would then be purged and filled with a life-supporting atmosphere. Following the successful lunar landing in July 1969, S-V launch vehicles became available to the Skylab program. As a result, it became feasible to completely equip the S-IVB on the ground for immediate occupancy and use by a crew after it was placed in orbit. Thus, it would not carry fuel and was designated the "Dry Workshop".

Development of the "Dry Workshop" pioneered many aspects of crew habitability, including color schemes, provision of a wardroom for meals and relaxation, improvements in food, and provision for not disposing of waste directly into space. The unmanned Workshop, designated "Skylab," was launched in May 1973 using a modified Saturn V. Three crewed missions, designated Skylab 2, 3, and 4, were made using Apollo command and service modules beginning in May 1973. Skylab 2 was largely concerned with making repairs to damage suffered during the initial launch and deployment of the Workshop.

Skylab crews extended the human record for days in space from 23 (achieved by the Soviet Soyuz 11 crew in 1971) to 84 days. Skylab crews also performed ten spacewalks. Many experiments investigated the crew's adaption to extended periods of microgravity, data critical for the planning of future long-duration missions, was obtained.

MSFC, JSC, and KSC had major responsibilities for the Skylab program. MSFC developed elements of the S-IB and S-V launch vehicles, the OWS, and its various components; developed experiments and supporting hardware; and supported KSC and JSC flight operations and mission evaluations. JSC implemented all flight and recovery operations, provided and trained flight crews, developed elements of the flight hardware, including the modified Apollo command and service modules, and developed experiments. KSC provided launch facilities for the four Skylab launches, prepared, and conducted checkout procedures for the pre-launch checkout of flight hardware and ground support equipment, and planned and executed launch operations.

Statement of Significance. NASA's development of Skylab was the first space-based station and solar observatory. Skylab's program led to new technologies and a better understanding of how humans can interact with the environmental settings of space. This space station established the foundation for future development of the idea to create the ISS.

Apollo-Soyuz Test Project

Description. The Apollo-Soyuz Test Project was the first manned international space mission, carried out jointly by the United States and the Soviet Union in July 1975. In the 1970s, U.S.-Soviet political tensions began to thaw and competition in space gave way to cooperation, as exemplified in the Apollo-Soyuz Test Project. International collaboration became a normal practice between nations during the Space Shuttle era.

Summary. In 1975 the Apollo-Soyuz Test Project demonstrated the possibility of international cooperation in space and provided the political steppingstones that led to the intergovernmental agreements used for the later International Space Station (ISS). The mission entailed docking and linking of an Apollo module with a Soviet Soyuz capsule. The jointly designed, U.S.-built docking module fulfilled the main technical goal of the mission, demonstrating that two dissimilar craft could dock in orbit.

The two crews performed both joint and separate scientific experiments during a brief two-day mission. Experiments on material processing, space investigations, and life science experiments were carried out. A sample of the experiments completed comprised of a Microbial Exchange, In-flight radiation detection, a flight crew health stabilization program, a medical microbiological analysis of the U.S. crew members, and an electrophoresis experiment.

The American crew tested communicating to Mission Control via the ATS-6 communications satellite in geosynchronous orbit positioned over central Africa, enabling the crew to talk and send data to the ground for 55 minutes during each orbit. This represented a significant improvement over previous missions and offered a preview of future communications networks in the Space Shuttle era. Engineering achievements, particularly the development of the docking module provided useful experience for future international missions, including the ISS.

JSC developed the docking module, working with private aerospace contractors. Mission control was located in JSC's Mission Control Center (MCC). The launch of the Apollo vehicle took place at KSC.

Statement of Significance. The Apollo-Soyuz Test Project between the United States and the Soviet Union was the first joint space mission between the two superpowers during the middle of the Cold War. This joint mission helped connect the two nations and helped bring an end to the Cold War. It also set a precedent for work in the field of space as a collaborative effort between nations rather than a competition between them. This successful endeavor led to many other joint missions to space between nations, including the establishment and maintenance of the ISS.

International Space Station

Description. The ISS was and is a combined effort between 15 countries, including the United States, Russia, Canada, Japan, the European Space Agency (ESA). The ISS is a space station permanently occupied by astronauts of the various countries involved in the program. Today, the ISS serves as the largest scientific and technological cooperative program in history.

Summary. In the early 1980s, NASA planned to launch a modular space station named *Freedom* as a counterpart to the Soviet Union's Salyut and Mir space stations, in development since the early 1970s. Momentum for the ISS received a boost when in his State of the Union Address delivered on January 25, 1984, President Ronald Regan directed NASA to develop a permanently manned space station within a decade. In 1984 the ESA was invited to participate in the project, and in 1985 Japan announced that they would provide the Japanese Experiment Module (JEM), or *Kibo*. In 1993 the United States and Russia announced plans for a new space station, which evolved into the ISS. The legal structure that regulates the ISS established obligations and rights between the 15 ISS partners. Known as the Space Station Intergovernmental Agreement (IGA) it provides a long-term international co-operative framework for the detailed design, development, operation, and utilization of a permanently inhabited civilian space station.

As a multi-national collaborative project, the components for the ISS were manufactured in various countries around the world. Beginning in the mid-1990s, U.S. components were fabricated at the Marshall Space Flight Center and the Michoud Assembly Facility, some by private aerospace companies. These modules were delivered to the Operations and Checkout Building (1964) and the Space Station Processing Facility (SSPF) (1994) at KSC for final assembly and processing for launch.

Assembly of the ISS, a major achievement in space architecture, began in November 1998. Russian modules launched and docked robotically, while all other modules were delivered by the Space Shuttle Program, and required installation by ISS and Shuttle crewmembers using the Canadarm 2 and extra-vehicular activities (EVAs). By June 2011, 159 components had been added to the ISS during more than 1,000 hours of EVA.

The first module of the ISS, Zarya, was launched in November 1998 on an autonomous Russian Proton rocket. It provided propulsion, attitude control, communications, and electrical power, but lacked long-term life support functions. A NASA-fabricated connecting node, Unity, was launched two weeks later aboard the Space Shuttle and attached to Zarya by astronauts during EVAs. The Unity node's six ports provide berthing connections for other modules or visiting cargo vehicles. In July 2000, the *Zvezda* module was launched into orbit. *Zvezda* provides all of the station's life support systems, as well as living quarters for two crew members. The first resident crew, Expedition 1, arrived in November 2000 on a Soyuz vehicle, and included astronaut William Shepherd, U.S.A.

The ISS is a modular space station occupying approximately the space of a U.S. football field. Modules can be added to or removed from the existing structure, allowing greater flexibility. By June 2011, the ISS consisted of 15 pressurized modules and the Integrated Truss Structure. Three modules remain to be launched, including the *Prichal* module (scheduled for launch in November 2021), two power modules with large power-generating solar arrays, designated NEM-1 and NEM-2. Russia's latest primary research module *Nauka* docked in July 2021, along with the European Robotic Arm, which is able to "walk" around the Russian segment of the station and will serve as the main manipulator on the Russian segment.

Statement of Significance. The ISS is currently in use as an international hub for space research and occupation and is set to remain in service until at least 2024. Currently, the space station has been in service for 23 years when the first module was launched and assembled in 1998. The ISS is significant for its cross-cultural connection between nations of the world, first established by the Apollo-Soyuz Test Mission in 1975. The ISS is also significant for its continual technological development of space related scientific research and experiments.

Space Shuttle Program

Description. The cost of access to space is the major deterrent in space exploration and space utilization. A reusable launch vehicle provides an opportunity to lower costs and provide reliable and on-demand space access. NASA began exploring the possibility of reusable spacecraft as early as 1969. As initially conceived, the Space Shuttle, designed to be completely reusable, was 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 for a proposed Space Station. The reusable nature was expected to reduce payload costs, but ultimately, NASA made the decision to go with a system that was not entirely reusable.

The Space Shuttle included a reusable Orbiter Vehicle with three clustered main engines, a pair of recoverable and reusable solid rocket boosters, and an expendable external fuel tank containing liquid hydrogen and LOX, that provided fuel for the orbiter's main engines. The solid rocket boosters were jettisoned before the vehicle reached orbit, and the external fuel tank was jettisoned just before orbit insertion. At the conclusion of the mission the orbiter fired its maneuvering engines and reentered the atmosphere, gliding to a runway landing.

Summary. The partial reusability of the Space Shuttle was one of the primary design requirements during initial development. The technical decisions that facilitated the orbiter's return and re-use reduced its per-launch payload capabilities. NASA sought to offset the lower payload limits by increasing the frequency of launches, and estimated costs lower than that for ELVs expendable launch vehicles. However, the actual costs of a Space Shuttle launch proved higher than predicted. Space Shuttle incremental per-pound launch costs ultimately turned out to be considerably higher than those of ELVs. By 2011, the incremental cost-per-flight of the Space Shuttle was estimated at $450 million, or $8,200 per pound. In contrast, the Proton ELV cost as little as $110 million, or approximately $2,300 per pound, despite not being reusable. Additionally, by the mid-1980s the concept of flying frequent shuttle missions proved unrealistic and scheduled launch expectations were reduced by half.

The improvement of ELVs resulted in expendable launch vehicles becoming the primary deployment option for satellites. Nevertheless, the SSP pioneered the use of reusable space vehicles and rocket boosters, practices that are now increasingly commonplace, as evidenced by private corporations such as SpaceX, Virgin Galactic, and Blue Origin.

The orbiter was the world's first reusable spacecraft. It launched like a rocket and returned to Earth like a glider, landing like an airplane on a long concrete runway. It was designed to carry large payloads — such as satellites — into orbit and bring them back, if necessary, for repairs. Its three-part fuselage provided support for the crew compartment, cargo bay, flight surfaces, and engines. The rear of the orbiter contained the main engines, which provided thrust during launch, as well as the Orbital Maneuvering System (OMS), which allowed the orbiter to achieve, alter, and exit its orbit. Each wing had an inboard and outboard elevon to provide flight control during reentry, along with a flap located between the wings and below the engines to control pitch. The orbiter's vertical stabilizer contained a rudder that could split to act as a speed brake. The vertical stabilizer also contained a two-part drag parachute system to slow the orbiter after landing. The orbiter used retractable landing gear with a nose landing gear and two main landing gear.

The orbiter was protected from heat during reentry by its Thermal Protection System (TPS), which uses surface materials with a high temperature capacity in combination with underlying thermal insulation to inhibit conduction of heat to the interior of the vehicle. For the shuttle, NASA chose to use ceramic tiles, which permitted the orbiter to be constructed of lightweight aluminum and allowed for replacement of individual tiles as needed. KSC's Thermal Protection System Facility (TPSF), completed in 1988, supplemented contractor facilities operated by Lockheed and Rockwell International in the production of the tiles.

The payload bay comprised most of the orbiter's fuselage, and provided the cargo-carrying space for the Shuttle's payloads. The bay measured 18 m (60 ft) long and 4.6 m (15 ft) wide and could accommodate cylindrical payloads up to 4.6 m (15 ft) in diameter. Two payload bay doors hinged on either side of the bay, provided a relatively airtight seal to protect payloads from heat during launch and reentry. The payload bay doors also served as radiators to dissipate heat from the orbiter and were opened upon reaching orbit to serve this purpose.

The orbiter could be used in conjunction with a variety of add-on components depending on the mission. These included orbital laboratories, boosters for launching payloads farther into space, the Remote Manipulator System (RMS), also known as Canadarm – a mechanical arm attached to the cargo bay that could be used to grasp and manipulate payloads.

Prior to a launch, the various components of the Shuttle were assembled, or stacked, in the Vehicle Assembly Building (VAB) at Kennedy Space Center. Constructed to serve the Apollo program, the VAB is one of the world's largest buildings by volume. The external fuel tank and Solid Rocket Boosters (SRB) were first mounted to the Mobile Launch Platform, and the orbiter was then mated with the external tank and the SRBs. After completion of a system of tests and verifications, tracked crawler-transporter vehicles moved under the MLP and the Shuttle assembly. The transporters required approximately six hours to move the MLP and the Shuttle assembly to the launch complex.

After landing, ground crews approached the orbiter to conduct safety checks. Teams wearing self-contained breathing gear tested for the presence of a variety of gases to ensure the landing area was safe. Air conditioning and Freon lines were connected to cool the crew and equipment and to dissipate excess heat resulting from reentry. A flight surgeon boarded the orbiter and performed medical checks of the crew before they disembarked. Once the orbiter was secured, it was towed to the Orbiter Processing Facility (OPF) to be inspected, repaired, and prepared for the next mission.

Statement of Significance. The development of the Space Shuttle demonstrated the feasibility of reusable rocket boosters and space vehicles, which represented an important effort to promote the use of space as a commercially and economically viable activity, and which pointed the way towards the current generation of privately built reusable launch vehicles. While the Shuttle program failed to accomplish its intended goal of reducing launch costs below those of ELVs, it did pave the way for the present generation of reusable launch systems and vehicles. NASA gave responsibility for developing the orbiter and for overall management of the SSP to the MSC (later JSC) in Houston. MSFC was responsible for development of all propulsion-related tasks. Engineering design support continued at MSC, MSFC and NASA Langley, while engine fabrication took place at MAF and engine tests were 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.

Reusable Solid Rocket Propulsion

Description. The need for Solid Rocket Propulsion was needed with the development of the Space Shuttle Program in 1969, however, NASA did not reach a decision about solid rocket boosters until 1972. The need for a solid full source over the previously used propulsion source of liquid hydrogen was due to the weight of the space shuttle with its cargo. The solid rocket fuel increased the power of the launch vehicle to get the space shuttle into orbit.

Summary. The Space Shuttle Program's main goal was for the reusability of the spacecraft, including the use of rocket boosters. Solid Rocket Booster (SRB) developed for the Space Shuttle Program provided the majority of the thrust required for liftoff and ascent, and were the largest solid-propellant motors ever flown. Each SRB was 45m (149.2 ft) tall and weighed 68,000 kg (150,000 lbs). The SRB's subcomponents included the solid-propellant motor, nose cone, and rocket nozzle. The motor comprised the majority of the SRB's structure. Its casing consisted of 11 steel sections that comprised four main segments. The nose cone housed the forward separation motors and the parachute systems that were used during recovery.

The rocket motors were each filled with a total 500,000 kg (1,106,640 lbs) of solid rocket propellant and mated to the orbiter and external fuel tank in the Vehicle Assembly Building (VAB) at KSC. In addition to providing thrust during the first stage of launch, the SRBs provided structural support for the orbiter vehicle and external fuel tank, as they were the only part of the shuttle system connected to the Mobile Launcher Platform (MLP). At launch, the SRBs each provided 2.8 million pounds of thrust, later increased to 3 million pounds. After expending their fuel, the SRBs were jettisoned, approximately two minutes after launch at an altitude of approximately 150,000 feet. Following separation, they deployed parachutes, landed in the ocean, and were recovered by crews aboard two NASA-owned recovery vessels *Freedom Star* and *Liberty Star*, Once returned to Cape Canaveral, they were cleaned and disassembled. The rocket motor, igniter, and nozzle were then shipped to a private contractor to be refurbished for reuse on subsequent flights.

NASA's Space Shuttle program experienced two fatal accidents that resulted in the loss of the vehicle and its crew. In 1986 the Shuttle Challenger broke apart shortly after its launch killing all seven crew members. The disaster resulted from the failure of a joint in the Shuttle's SRB caused by the failure of O-ring seals used in the joint. The SRBs underwent several redesigns throughout the life of the Shuttle program. After the Challenger disaster, which resulted from an O-ring failing at low temperature, the SRBs were redesigned to provide a constant seal regardless of ambient temperature. Following the loss of Challenger, plans to fly civilians into space (such as teachers or journalists) were shelved for the next 22 years, until Barbara Morgan, Christa McAuliffe's backup, flew aboard *Endeavour* in 2007.

Statement of Significance. The SRB system used for the Space Shuttle Program experienced development and change to increase the safety of the SRB with a major change in the SRB after the Challenger accident in 1986. The SRB are associated with the development of the Space Shuttle Program, connected with the KSC, MSFC, and JSC facilities.

Challenger and Columbia Accidents and Safety Development

Description. NASA's Space Shuttle program experienced two fatal accidents that resulted in the loss of the vehicle and its crew. In 1986 the Shuttle Challenger broke apart shortly after its launch killing all seven crew members. The disaster resulted from the failure of a joint in the Shuttle's SRB caused by the failure of O-ring seals used in the joint. The disaster resulted in a 32-month cessation of Shuttle flights. In 2003 the Shuttle Columbia disintegrated on reentry into the Earth's atmosphere killing all seven crew members. A piece of foam insulation had broken off the external fuel tank during launch, damaging the carbon-reinforced leading edge of the orbiter's port wing. The damage permitted hot atmospheric gases to penetrate the wing and destroy the internal wing structure, resulting in disintegration. This disaster resulted in a more than two-year suspension of operations.

Debris from Challenger is currently stored in two abandoned Minuteman missile silos at Cape Canaveral Air Force Station in Florida. The silos were not intended as a burial or memorial, but simply as a storage site. As of 2015, debris from Columbia was stored in a converted room on the 16th floor of the Vehicle Assembly Building at KSC and was available to researchers for study.

Summary. The Challenger and Columbia accidents forced NASA to reexamine its prevailing organizational culture and to place greater emphasis upon crew safety. Following the loss of Challenger NASA redesigned the SRB, under supervision of an independent oversight group. NASA also created a new Office of Safety, Reliability and Quality Assurance, though following the loss of Columbia the Columbia Accident Investigation Board (CAIB) concluded that NASA had not effectively set up an independent office for safety oversight.

The CAIB reported a poor assessment of the culture at NASA that had led to the minimization of safety issues over the years. The board noted that "cultural traits and organizational practices detrimental to safety were allowed to develop," and cited a "reliance on past success as a substitute for sound engineering practices." The CAIB recommended NASA ruthlessly seek and eliminate safety problems to ensure astronaut safety on future missions. It noted that "The shuttle is now an aging system but still developmental in character. It is in the nation's interest to replace the shuttle as soon as possible."

The Shuttle's external tank was redesigned, and other safety measures implemented. The shuttle fleet was maintained long enough to complete construction of the ISS, with most missions solely focused on finishing that work. The space shuttle program was retired in July 2011 after 135 missions.

The Challenger and Columbia disasters forced NASA to reexamine its organizational culture, which dated to the late 1950s and included an acceptance of risk and danger by an astronaut corps comprised of military officers and scientists. The loss of these two shuttles resulted in an increased focus on risk assessment and mitigation, and a reexamination of issues related to crew safety and the provision of escape mechanisms. Ultimately, the loss of Challenger and Columbia led to a greater emphasis upon risk assessment, risk mitigation, more robust design, and crew safety. This shift reflected the increasing move towards civilian use of space and overall safety of those who would be traveling into space.

Statement of Significance. The Challenger and Columbia disasters forced NASA to reexamine its organizational culture, which dated to the 1960s and included an acceptance of risk and danger by an astronaut corps comprised of military officers. The loss of these two shuttles resulted in an increased focus on risk assessment and mitigation, and a reexamination of issues related to crew safety and the provision of escape mechanisms. Ultimately, the loss of Challenger and Columbia led to a greater emphasis upon risk assessment, risk mitigation, more robust design, and crew safety. This shift reflected the increasing move towards civilian use of space.

Space Communication Networks

Description. The space communications networks communicate with launch vehicles, Earth-orbiting spacecraft (including the ISS), and spacecraft throughout the solar system. These systems include the Near Earth Network, the Deep Space Network, and the Tracking and Data Relay Satellite System (TDRSS).

Summary. The Near Earth Network was created as it is today in the 1990s; however, it is based on the need for communications with spacecraft in the 1950s and 1960s. The Near Earth Network is a world-wide ground based tracking system connecting scientists and mission control to important data acquired by satellites and spacecraft. The communication system provides space communications support to spacecraft in multiple orbits, including low-Earth orbit, highly elliptical orbits, lunar orbit and even orbits around the Sun-Earth libration points, up to a million miles from Earth. The Near Earth Network has stations on all seven continents and has over 20 tracking sites. Space communication early development started at Goddard Space Flight Center where the Near Earth Network is headquartered at.

The Deep Space Network is the largest telecommunications system in the world and is operated by NASA's JPL in Pasadena California. This communication system was first established in 1959 when NASA established the concept of the Deep Space Network as a separately managed and operated communications facility that would accommodate all deep space missions. the Deep Space Network consists of three facilities spaced equidistant from each other – approximately 120 degrees apart in longitude – around the world. These sites are at Goldstone, near Barstow, California; near Madrid, Spain; and near Canberra, Australia.

TDRSS is a system of communication satellites distributed over the Atlantic Ocean, Pacific Ocean and Indian Ocean. They provide near continuous bent pipe information relay services to over 25 missions. These missions include communications with the Hubble Space Telescope, the ISS, and other Earth observing missions. The first satellite was launched in 1983 and was retired in 2009. Since 1983, a total of three generations of TDRS units have been developed with eight satellites in service today. The newest of these satellites, TDRS-13, was launched in 2017. The Goddard Space Flight Station in Greenbelt Maryland oversees these satellites and their communications.

Statement of Significance. The development of each communication system (the Near Earth Network, the Deep Space Network, and the TDRS) is a vital part of space travel and exploration, necessary for the discussion and transfer of data between instruments in space, such as satellites and their equipment, and the people on Earth who study that information. These communications centers provide the network necessary to gather data from space. The Goddard Space Flight Center of the JPL are both significant to the development and operations of these communication systems as the headquarters for these systems.

Science

Pioneer 10 and 11

Description. The Pioneer 10 and Pioneer 11 were both small, nuclear powered, spin stabilized spacecraft intended to visit the outer planets of the solar system. Pioneer 10 was launched on March 2, 1972 and was also the first spacecraft to visit Jupiter, cross the asteroid belt, and the first human-made object to leave the solar system. Pioneer 11 was the sister spacecraft to the Pioneer 10 and was launched on April 5, 1973. It was the first spacecraft to study Saturn up close.

Summary. Pioneer 10 was the first NASA mission to the outer planets. It was the first vehicle placed on a trajectory to escape the solar system into interstellar space; the first spacecraft to fly beyond Mars; the first to fly through the asteroid belt; the first to fly past Jupiter; and the first to use all-nuclear electrical power (two SNAP-19 radioisotope thermal generators [RTGs] capable of delivering about 140 W during the Jupiter encounter). After the launch by a three-stage version of the Atlas Centaur (with a TE-M-364-4 solid propellant engine modified from the Surveyor lander), Pioneer 10 reached a maximum escape velocity of 32,110 miles per hour (51,682 kilometers per hour). On July 15, 1972, the spacecraft entered the asteroid belt and emerged in February 1973 after a voyage of about 271 million miles (435 million kilometers). During this period, the spacecraft encountered some asteroid hits, although fewer than expected, and also measured the intensity of Zodiacal light in interplanetary space. In conjunction with Pioneer 9, which was in solar orbit, Pioneer 10 recorded details on one of the most violent solar storms in recent record on August 7. On November 26, 1972, the spacecraft reported a decrease in the solar wind and a 100-fold increase in temperature indicating that it had entered Jupiter's magnetosphere. By December 1, 1972, Pioneer 10 was returning better images of the planet than possible from Earth. The spacecraft passed by a series of Jovian moons and obtained photos of Callisto, Ganymede, and Europa. Between November 6 and December 31, 1972 the spacecraft took about 500 pictures of Jupiter's atmosphere with the highest resolution of about 200 miles (320 kilometers), clearly showing the Great Red Spot.

The spacecraft crossed Saturn's orbit in February 1976 and recorded data that indicated that Jupiter's enormous magnetic tail, almost 800 million kilometers long, covered the whole distance between the two planets. Pioneer 10 crossed the orbit of Neptune on June 13, 1983 and became the first human-made object to go beyond the furthest planet. NASA maintained routine contact with Pioneer 10 for over two decades until March 31, 1997, when routine contact was terminated due to budgetary reasons. Intermittent contact continued as permitted by the onboard power source, with data collections from the Geiger tube telescope and the charged particle instrument. The spacecraft returned its last telemetry data on April 27, 2002. On January 23, 2003, it sent its last signal when it was 7.6 billion miles (12.23 billion kilometers from Earth. By that time, it was clear that the spacecraft's RTG power source had decayed, thus delivering insufficient power to the radio transmitter. A final attempt to contact Pioneer 10 failed on March 4, 2006.

Pioneer 11, the sister spacecraft to Pioneer 10, was launched on April 6, 1974. It was the first human-made object to fly past Saturn and also returned the first pictures of the polar regions of Jupiter. During the outbound journey, a number of malfunctions on the spacecraft threatened the mission, including the momentary failure of one of the RTG booms to deploy, a problem with an attitude control thruster, and the partial failure of the asteroidal dust detector. Pioneer 11 passed through the asteroid belt without damage by mid-March 1974. The spacecraft penetrated the Jovian bow shock on November 25, 1974 and its closest approach to Jupiter occurred on December 3, 1974, at a range of about

26,400 miles (42,500 kilometers) from the planet's cloud tops, three times closer than Pioneer 10. It was traveling faster than any human-made object at the time, more than 106,000 miles per hour (171,000 kilometers per hour). Because of its high speed during the encounter, the spacecraft's exposure to Jupiter's radiation belts spanned a shorter time than its predecessor although it was actually closer to the planet. Pioneer 11 repeatedly crossed Jupiter's bow shock, indicating that the Jovian magnetosphere changes its boundaries as it is buffeted by the solar wind. Besides the many images of the planet, Pioneer 11 took about 200 images of the moons of Jupiter. The vehicle then used Jupiter's massive gravitational field to swing back across the solar system to set it on a course to Saturn.

On April 16, 1975, the micrometeoroid detector was turned off since it was issuing spurious commands which were interfering with other instruments. Course corrections on May 26, 1976, and July 13, 1978, sharpened its trajectory towards Saturn. Pioneer 11 detected Saturn's bow shock on August 31, 1979, about 932,000 miles (1.5 million kilometers) out from the planet and provided the first conclusive evidence of the existence of Saturn's magnetic field. The spacecraft crossed the planet's ring plane beyond the outer ring on September 1, 1979. During the encounter, the spacecraft took 440 images of the planetary system, with about 20 at a resolution of about 56 miles (90 kilometers). The images of Saturn's moon Titan showed a featureless orange fuzzy satellite and indicated that the average global temperature of Titan was minus 315 degrees Fahrenheit (minus 193 degrees Celsius).

Pioneer 11's many discoveries included a narrow ring outside the A ring named the F ring and a new satellite 124 miles (200 kilometers) in diameter. The spacecraft recorded the planet's overall temperature at minus 292 degrees Fahrenheit (minus 180 degrees Celsius) and photographs indicated a more featureless atmosphere than that of Jupiter. After leaving Saturn, Pioneer 11 headed out of the solar system in a direction opposite to that of Pioneer 10, toward the center of the galaxy in the general direction of Sagittarius. Pioneer 11 crossed the orbit of Neptune on February 23, 1990, becoming the fourth spacecraft, after Pioneer 10, Voyager 1 and 2, to do so. By 1995, 22 years after launch, two instruments were still operational on Pioneer 11. NASA Ames Research Center made last contact with the spacecraft on September 30, 1995. Scientists later received a few minutes of good engineering data on November 24, 1995, but lost contact again once Earth moved out of view of the spacecraft's antenna.

Statement of Significance. Originally designed for a 21-month mission, the Pioneer 10's lifetime lasted more than 30 years. The Pioneer 10 was NASA's first mission to the outer planets and was launched on March 2, 1972. The spacecraft became the first to fly beyond Mars' orbit, through the asteroid belt, and close to Jupiter, blazing a trail for the two Voyager spacecraft that were to follow and conduct more in-depth surveys. During the passage by Jupiter, Pioneer 10 obtained the first close-up images of the planet, charted Jupiter's intense radiation belts, located the planet's magnetic field, and discovered that Jupiter is predominantly a liquid planet. Pioneer 10 transmitted data on the magnetic fields, energetic particle radiation and dust populations in interplanetary space.

Pioneer 11 was the first mission to explore Saturn and the second spacecraft in the outer solar system. The spacecraft carried instruments to study magnetic fields, the solar wind and the atmospheres, moons and other aspects of Jupiter and Saturn.

Mariner 10

Description. NASA's JPL in Pasadena, California developed the Mariner Space Program to explore the inner solar system, focusing on Mercury, Venus, and Mars. The program was for planetary exploration, completing assessments and taking photographs of the planet's surface from above its atmosphere. The program had seven successful missions, with its final mission, Mariner 10, launching on November 3, 1973.

Summary. The Mariner Space Program were interplanetary probes designed to completed investigations on Mars, Venus, and Mercury. The program was first developed in 1960 with small scale studies on frequent exploration of nearby planets by the JPL in Pasadena, California. Mariner 1 was lunched on June 22, 1962; however, it was lost due to failures in the launch vehicle. The first successful mission, Mariner 2, was launched two months later on August 27, 1962, and headed towards Venus. In total, 10 Mariner probes were developed with seven successful missions. Mariner probes 1, 3 and 8 ended in failure due to issues with the launch vehicle. Of the seven successful probes, Mariners 4, 6, 7, and 9 studied Mars while Mariners 2, 5, and 10 studied Venus. Mariner 10 was the first satellite to visit two planets within one mission, making studies of both Venus and Mercury. The Mariner Space Program finished a series of interplanetary firsts, including the first planetary flyby (Mariner 2), first planetary orbiter (Mariner 9), and first gravity assist (Mariner 10). The program ended in 1975 with the deactivation of the Mariner 10. The Mariner Space Program was going to develop and send an additional two probes, the Mariner 11 and Mariner 12; however, the program evolved into the Voyager Space Program and resulted in Voyager 1 and Voyager 2, an ongoing mission into interstellar space.

The Mariner 10 started development in the early 1960s when JPL developed a systematic gravity-assist technique. The JPL discovered an Earth, Venus, Mercury trajectory becoming available for a 1970 or 1973 launch period, based on the alignment of Venus, Mercury, and the Sun. In addition to this, Professor Giuseppe Columbo from the University of Padua in Italy determined that Mariner 10 could revisit Mercury every six months by using the Sun's gravity. NASA approved the mission in 1969 and established at JPL in January 1970. JPL developed a contract with the Boeing Company in July of 1971 for the design and construction of Mariner 10. The probe was designed with an octagonal main structure, solar cells and battery for electrical power, three axis attitude stabilization controlled by nitrogen gas jets, celestial references, S-Band radio for communication with command, a high-gain antenna, and low-gain antenna, a scan platform, and a hydrazine rocket propulsion system for trajectory corrections when needed. Tools equipped with the spacecraft included a Television Photography System, an infrared radiometer, an ultraviolet spectrometer, plasma detectors, charged particle telescope, and magnetometers.

The mission plan called for launching the spacecraft with an Atlas SLV-3D/Centaur D-1A rocket between October 16 and November 21, 1973. The Atlas portion of the rocket was the base ignition to get the Mariner 10 off the Earth's surface and toward the atmosphere. The upper portion of the rocket, the Centaur, completed the lift off by sending the Mariner 10 out of Earth's atmosphere. This time frame corresponded with the needed encounter with Venus between February 4 and 6, 1974 and, using a gravity assist, reaching Mercury between March 27 and 31, 1974. The launch was located at Cape Canaveral, Florida and took place in the early hours of November 3, 1973. The first stage of the mission was followed by a short orbit around Earth prior to the Centaur stage of the rocket reigniting to send Mariner 10 towards Venus.

Mariner 10 reached Venus on February 5, 1974, and retrieved information about the planet's atmosphere, temperature, and magnetic field. In addition to this information, Mariner 10 sent 4,165 pictures back to Earth. The study completed at Venus was in addition to already existing studies completed on the planet by the United States and the Soviet Union. After Mariner 10 completed its assessment of Venus, the gravity-assist was successfully completed for the first time, directing the small spacecraft to the inner most planet of Mercury.

Mariner 10 reached Mercury by March 10, 1974. During this first visit to the planet, Mariner 10 sent back to Earth over 2000 images of Mercury. The spacecraft also detected a weak magnetic field and a very thin atmosphere composed primarily of helium. The photographs showed the rocky crater filled surface of the planet. Scientist observed the up-close images of Mercury as similar to Earth's moon as a rocky mass covered in craters from meter impacts and having a layer of dust around the entire planet. Professor Columbo's planning was used to make contact with the small planet two more times, with its second contact of Mercury made September 21, 1974, and its third on March 16, 1975. Due to the rotation of Mercury in relation to its revolution around the Sun, the same side of the planet was facing the Sun each pass by, resulting in only 45% of the planet's surface being photographed. Mariner 10 ran out of attitude control fuel on March 24, 1975, resulting in the spacecraft being turned off, placing an end to its mission. In total, Mariner 10 sent over 7,000 pictures of Venus and Mercury, and added a wealth of information, previously unknown to scientists.

Statement of Significance. Mariner 10 was the last and greatest of the Mariner Space Program in that it was the first probe to successfully use the gravity-assist method of space travel, which was previously theorized about since the 1920s. The use of the gravity-assist was linked to another significant event in planetary science, the first up-close encounter of Mercury. This first up-close study of Mercury added information previously unknown about the solar system, helping to identify the early history of the planet, as well as its chemical and physical makeup. The success of the Mariner Space Program and Mariner 10 also helped launch the Voyager Space Program, the first to explore interstellar space.

Landsat

Description. Landsat is a cooperative program between the United States Geological Survey (USGS) and NASA, and is a series of missions to place Earth Observation satellites in orbit around the earth to acquire multi-spectral and multi-thematic imagery of the earth's land surface. Landsat is a part of NASA's SMD and operates under the NASA's Earth Science Division at the GSFC and the USGS's National Land Imaging (NLI) program. Landsat data is processed and hosted at the USGS Earth Resources Observation and Science (EROS) Center.

Summary. The Landsat program had its genesis in highly scientifically charged and exploratory times associated with the atomic age and the age of space exploration in the 1960s, when the first high quality images of the Earth were taken from space during the Apollo program. By the mid-1960s a number of Earth observing satellites orbited the planet. A series of classified U.S. Department of Defense (DoD) satellites were deployed as part of Cold War surveillance and intelligence gathering efforts that obtained highly detailed photos of small, targeted areas. During this time, NASA had launched a series of civilian weather satellites that provided lower resolution imagery but provided global coverage. With the knowledge of the early, demonstrated success and value of previous manned space missions and these Earth observing satellite systems, William Thomas Pecora, director of the USGS, proposed a remote sensing satellite system in 1965 that was specifically targeted to gather data about the Earth's natural resources and terrain. This proposition was met with intense opposition from the Bureau of Budget because of the cost, with high altitude aircraft seen as the more fiscally prudent option, and from the DoD, who thought it would compromise the secrecy of their space-based satellite reconnaissance program. Politically, there were concerns raised about photographing foreign countries without permission.

During this time, NASA was conducting remote sensing of the Earth's surface using aircraft mounted instruments. In 1966 the USGS convinced the Secretary of the U.S. Department of the Interior (DOI), Stewart L. Udall, to announce that the DOI was proceeding with its own Earth-observing satellite program. This political maneuvering prompted NASA to expedite their own program. Over the next four years the feasibility of the program was studied, but the implementation and execution of the NASA program was fraught with challenges and delays due to budgetary constraints and inter- and intra-department disagreements with and within the DOI and the U.S. Department of Agriculture (USDA). This was resolved by 1970 and NASA had the authorization and multi-agency consensus to proceed with the program. Though it was a modified version of the Nimbus 4 meteorological satellite, remarkably within only two years the satellite was ready.

On July 23, 1972, the USGS and NASA launched the Earth Resources Technology Satellite (ERTS-1, also known as ERTS-A) onboard a Delta 900 Rocket from the Western Test Range Vandenburg Airforce Base, California, signaling a new age of space-based remote sensing. Just before the launch of the ERTS-B satellite in 1975, the program was renamed Landsat, in part because of the development of NASA's SEASAT program and the desire for a name with more public appeal than ERTS. ERTS-1 was renamed Landsat 1, with subsequent satellites following this naming convention. In 1975, Landsat 2 launched and since then 7 subsequent Landsat missions have followed with Landsat 9 launching on September 27, 2021.

Landsat 1 was the first Earth-observing satellite specifically conceived, designed, engineered, and launched to monitor and study the planet's landmasses. To achieve its mission, Landsat 1 carried the Return Beam Vidcon (RBV) sensor that was manufactured by Radio Corporation of America (RCA) and designed to obtain visible light and near infrared photographic images. Landsat 1 also carried the Multispectral Scanner System (MSS) sensor, designed by Virginia Norwood and manufactured by the Hughes Aircraft Company. Virginia Norwood is a retired American physicist, who designed the MSS as a six-band radiometric scanner, but Landsat 1 was launched with only a four-band scanner. The MSS was aboard each of the first five Landsat satellites with a seven-band Thematic Mapper included on Landsat 4. While the RBV was intended to be the primary instrument, however, the MSS proved to be superior, providing more complete and better datasets. In July 1972, Dr. Paul Lowman, an innovator in the field of remote sensing at GSFC, drew the first map from a Landsat image.

Statement of Significance. The importance of the Landsat program cannot be understated; it is the only source of high quality, global, calibrated, moderate spatial resolution measurements of the Earth's surface that can be compared to previous data records. The 50-year, continuous data archive provides essential land change data and trending information not otherwise available. Landsat is a cooperative and multi-agency, -disciplinary, -purpose, and -decade program that has applications across Earth sciences: cartography, land cover, land use, agricultural productivity, glaciology, urban growth, forest resources, geological and mineral resources, seismology, natural resource management, hydrology, water availability, water quality, ecosystem health, oceanography, marine resources, environmental pollution and degradation, navigation, and meteorological phenomena. For 50 years Landsat satellites have had the optimal ground resolution and spectral bands to efficiently detect, document, measure, and track changes (natural processes, human and environmental pressures) on the Earth due to climate change, urbanization, drought, wildfire, biomass changes (carbon assessments), and a host of other changes. Landsat has greatly improved human's understanding of the Earth.

Land managers, policymakers, researchers, scientists, and public-private partnerships around the world are using open-source Landsat data for research, business, education, and other activities ranging from engineering, computing, research, communications, archaeology, demographics, and supporting disaster response. One testament to the unequivocal success of the Landsat program is Landsat 5 which provided high-quality, global, land surface data of the Earth for nearly 29 years.

The Landsat program has made huge advancements in hardware and software related to remote sensing, data collection, data processing, data management, data storage and archiving. The Landsat program has created innovation in geospatial, image, and thermal resolution, precise calibration that is the validation choice for coarse resolution sensors, excellent data quality, and consistent global archiving scheme of data. These advancements started with the MSS deployed on Landsat 1 and later Thematic Mapper (TM) instruments on Landsat 4 and 5 that were replicated and improved with the Enhanced Thematic Mapper Plus (ETM+) on Landsat 7.

Nimbus 7

Description. The Nimbus Space Program was a NASA meteorological research-and-development satellite program with a prime objective of testing new technology, including the introduction of sensor technology. The secondary objective was to provide atmospheric data for improved weather forecasts and data on the Earth's environmental patterns. However, the series grew more into a major Earth sciences program to the study of oceans, land surfaces, and atmosphere with the availability of better sensing instrumentation. The information gathered by the Nimbus Space Program has been used by various agencies, including the National Oceanic and Atmospheric Administration (NOAA).

Summary. The Nimbus Space Program first started with the launching of its first spacecraft, the Nimbus 1, in 1964. The Nimbus 1 gave scientists and meteorologists the first global imaging of clouds and large weather patterns. Each spacecraft added to the Nimbus program brought additional tools and technology for better examining Earth and its atmosphere, land surface, ecosystems, weather, and oceans. In total, seven Nimbus spacecraft were launched into space; all seven missions were successful. Over the course of the program's existence from 1964 to 1994, a variety of "firsts" were completed. A sampling of these firsts are provided here:

- First to provide daylight and night-time pictures of intense hurricane clouds viewed from space;
- First to measure ozone columns and profiles from space;
- First to provide quantitative data on the size of volcanic eruptions by measuring sulfur dioxide, a unique tracer of volcanic eruptions;
- First to provide extensive global observations of spectral signatures of ice that indicate the age of the sea ice and first to provide snow depth and snow accumulation rates over the Arctic and Antarctica;
- First to provide global, direct observations of the amount of solar radiation entering and exiting Earth's system; and
- First to create a map of global distribution of photosynthetic organisms, such as phytoplankton, in the world's ocean from space.

In addition to being an overall successful program in the monitoring of Earth's atmosphere, land surface, ecosystems, weather, and oceans, the Nimbus Space Program was the precursor to the Earth Resources Technology Satellite (ERTS), which was later renamed the Landsat Space Program. The Landsat Space Program is an ongoing program between NASA and the USGS that continues to monitor the Earth's ecologic data.

The Nimbus 7 spacecraft was built and integrated by GE Astro Space from Valley Forge, Pennsylvania. The RCA Corporation built the spacecraft power systems, cameras, communication electronics, and the high data rate/volume tape recorders. The spacecraft was fitted with eight instruments and technologies (known as experiments), including a limb infrared monitoring of the stratosphere (LIMS), stratospheric and mesospheric sounder (SAMS), a coastal-zone color scanner (CZCS), stratospheric aerosol measurement II (SAM II), earth radiation budget (ERB), scanning multichannel microwave radiometer (SMMR), solar backscatter UV and total ozone mapping spectrometer (SBUV/TOMS), and a temperature-humidity infrared radiometer (THIR).These sensors and devices attached to the spacecraft were useful at and below the mesospheric level. The mesosphere is a part of the Earth's atmosphere, located above the stratosphere and below the thermosphere.

The spacecraft itself was constructed in the shape of an ocean buoy and designed to serve as a three-axis stabilized, Earth-oriented platform. It consisted of three major elements, including a sensory ring, two solar paddles, and the control system housing. The solar paddles and the control system housing were connected to the sensory ring by a truss structure in the shape of a cone. The Nimbus-7 was 3.04 meter (m) (9.97 feet [ft]) tall, 1.52 m (4.98 ft) in diameter at the base, and 3.96 m (12.99 ft) wide with the solar paddles extended. The sensory ring at the base of the satellite housed the electronics equipment and battery modules. The lower surface of the sensory ring provided mounting space for sensors and telemetry antennas used by the satellite. After construction and testing, Nimbus 7 was launched from Vandenberg Airforce Base, California on October 24, 1978.

Nimbus 7 was actively collecting scientific data from 1978 to 1994. The eight experiments attached to the spacecraft were used for further studies in oceanography, pollution of the atmosphere, and meteorology; measurement of trace gases and particles in the atmosphere; distribution phenomena of air pollution; observation of the ocean's surface color, and of the ocean's temperature, including ice recordation over time, in particular in the coastal regions.

Statement of Significance. The Nimbus 7, along with the legacy of the Nimbus Program that launched the Nimbus 7, provided the start to other space programs that use satellite imagery, sensors, and mapping to evaluate Earth's ecological components, including its layers of the atmosphere, oceans, lands, and weather. The data gathered by Nimbus 7 and the precedent it provided for the monitoring of Earth is significant to the history of NASA and humankind's evaluation of the Earth.

Voyager 1 and Voyager 2

Description. NASA launched the twin spacecraft from Cape Canaveral, Florida with Voyager 2 lifting off on August 20, 1977, and Voyager 1 entering space on a faster, shorter trajectory on September 5, 1977. Voyager 1 entered the Jovian system and explored the moons, Io and Europa. Voyager 2 explored Jupiter's moons, then traveled on to Saturn, and encountered Uranus and Neptune. Voyager 1 and Voyager 2 explored all the giant outer planets, 48 of their moons, and the unique systems of rings and magnetic fields those planets possess. In 1993, Voyager 2 also provided the first direct evidence of the long-sought after heliopause—the boundary between our Solar System and interstellar space.

Summary. During the late 1960s, NASA scientists discovered that the Earth and all the giant planets of the Solar System gather on one side of the Sun once every 176 years. This geometric line-up made possible close-up observation of all the planets in the outer solar system (with the exception of Pluto) in a single flight, the "Grand Tour." NASA launched two spacecraft from Cape Canaveral, Florida in 1977. Both spacecraft were launched aboard Titan Centaur expendable rockets.

The project began as the “Mariner Jupiter/Saturn 1977” mission, before it became the Voyager mission, and was approved by NASA on July 1, 1972. The day-to-day management of the project was led by the JPL in Pasadena, California. The original plans committed to flybys of Jupiter and Saturn. The first science steering group held by the Mariner Jupiter/Saturn 1977 mission team was held on December 13-15, 1972. The mission was renamed in March 1977 to Voyager. The twin spacecraft were built to last five years, but the mission for Voyager 2 has lasted over 40 years. The spacecraft are three-axis stabilized spacecraft that use gyro-referenced attitude control to maintain the pointing of high-gain antennas towards Earth. Each of the spacecraft had 10 instruments in the payload and the command computer subsystem (CCS) provided sequencing and control functions. The CCS provides sequencing and control functions The CCS contains fixed routines such as command decoding and fault detection and corrective routines, antenna pointing information, and spacecraft sequencing information. The Attitude and Articulation Control Subsystem (AACS) controlled the spacecraft’s orientation, maintained the pointing of the high gain antenna towards Earth, controlled attitude maneuvers, and positioned the scan platform. All data was transmitted from and received at the spacecraft via the 3.7-meter high-gain antenna (HGA). Electrical power was supplied by three Radioisotope Thermoelectric Generators (RTGs). As the electrical power decreased, power loads on the spacecraft must be turned off in order to avoid having demand exceed supply. As loads are turned off, some spacecraft capabilities are eliminated.

In February 1979, Voyager 1 entered the Jovian system for its primary objective, explore Jupiter and Saturn. However, it took until March 5, 1979, to arc to the closest point in order to explore Jupiter’s moons, Io and Europa. Highlights of the encounter include the discoveries of the first active volcanoes beyond Earth which were spotted on Io, the Jovian ring system and two moons, Thebe and Metis. In addition, the large red spot was discovered to be a huge cyclone-like storm, tectonic evidence appears on Ganymede, and Jupiter has lightning, which is the first lightning detected beyond Earth. On November 9, 1980, Voyager 1 encountered Saturn and its largest moon, Titan. Highlights from the Saturn encounter include the discovery of three moons, Atlas, Prometheus, and Pandora, which confirm the theory shepherding moons exist around the narrow rings to keep the material in line. Saturn’s Ring F was seen for the first time and appeared as a kinked, multi-stranded ring. Ghostly features resembling wheel spokes were discovered. Titan appeared to show a thick, Earth-like atmosphere, which is the first nitrogen-rich atmosphere found beyond Earth. Voyager 1 went up over Saturn's orbital plane and out of the plane of the planets on its way out of the solar system.

In July 1979, Voyager 2 also explored Jupiter's moons. Highlights include the first images of Jupiter’s ring system, the discovery of a new moon (Adrastea), and revelation of intersecting linear features suggesting cracks in ice over a liquid ocean on the moon Europa. In addition, Voyager 2 witnessed that the six volcanoes erupting on Io during Voyager 1’s mission were still erupting. The spacecraft then traveled on to Saturn and began returning data from Saturn in July 1981. A critical part of this encounter took place on August 26, 1981, when Voyager 2 emerged from behind Saturn to find its aiming mechanism was jammed, which caused the instruments to be pointed out into space. This was corrected and Voyager 2 remained responsive to its Earth-bound controller. Voyager 2's encounter with Saturn revealed several of Saturn's icy moons, including Tethys, Iapetus; the half-young, half-old terrain of Enceladus was captured in imagery and suggests that it might be geologically active; the north pole of Saturn was captured in images that were stitched together to reveal a hexagonal-shaped weather feature circulating around the pole.

In September 1981, Voyager 2 left Saturn behind. With the successful achievement of all its objectives at Jupiter and Saturn in December 1980, Voyager 2 was able to make additional flybys of the two outermost giant planets, Uranus and Neptune. On January 24, 1986, Voyager 2 encountered Uranus, which marked the first time the planet had been seen up close. Images from Voyager 2 revealed 11 new moons, including bewildering images of the moon Miranda that show it likely experienced periods of heating from the pull of the other Uranus moons. The magnetic field of Uranus was determined to be tilted, the poles of its magnetic field are closer to the equator, unlike Earth. The first images of Uranus's dark rings were captured, and temperatures were recorded as low as -353 degrees, making it the coldest planet in the solar system. The Uranus encounter by Voyager 2 also marks the first time NASA's DSN arrays antennas together to improve the quality of the weak radio signals from the distant spacecraft.

Voyager 2 encountered Neptune on August 25, 1989, making it the first spacecraft to observe Neptune up close and the first to visit all four of the giant planets beyond Earth. Six new moons were discovered, the first images of Neptune's rings were captured, and a huge, counterclockwise rotating storm was discovered in the planet's southern hemisphere. The first images of Triton revealed the moon to be bitterly cold with a fractured terrain the texture of cantaloupe rind. Geysers were recorded erupting from pinkish-hued nitrogen ice on the moon's south polar cap. Following the encounter with Neptune, Voyager 2 began traveling outside the solar system. In October and December 1989, NASA engineers turned off Voyager 2's cameras in order to use the remaining power, computer memory, and data rate for other instruments to collect data on solar winds and interstellar space.

Voyager 1 and Voyager 2 explored all the outer planets, 48 of their moons, and the unique systems of rings and magnetic fields those planets possess. In 1993, Voyager 2 also provided the first direct evidence of the long-sought after heliopause, which is the boundary between the Solar System and interstellar space. On February 17, 1998, Voyager 1 passed the distance of the Pioneer 10 to become the furthest human-made object in space. On December 16, 2004, Voyager 1 crossed the termination shock where the solar winds slow down abruptly and heats up as it encounters the interstellar wind. The termination shock marks the inner boundary of the heliosheath, or the turbulent outer layer of the bubble the Sun blows itself and the planets. No ground antennas were scheduled to listen for the data on the day that Voyager 1 crossed the termination shock. However, on August 30, 2007, NASA was given a second chance to collect data as Voyager 2 crossed the termination shock into the heliosheath. Antennas were listening and scientists were able to collect and analyze the first measurements of the passage through the termination shock. Voyager 1 entered interstellar space, beyond the heliopause on August 25, 2012. It is the first time a man-made object has crossed into interstellar space. Voyager 1 made the first measurement of the interstellar magnetic field around the heliosheath. Voyager 2 followed its sister spacecraft into interstellar space on November 5, 2018.

Statement of Significance. The Voyager missions marked many firsts in NASA's research into the four giant planets in the outer solar system. Both Voyager 1 and 2 visited Jupiter and Saturn and returned images that changed what scientists originally believed about the planets. Voyager 2 provided the first close-up images of both Uranus and Neptune and revealed key information on planet formation, geology of the moons and planets, and images of dark rings around both planets. Voyager 1 was the first human-made object in interstellar space and provided important information regarding the heliosphere, heliopause, and the heliosheath. Voyager 2 is NASA's longest-operating mission, which was previously set by Pioneer 6.

Solar Maximum Mission

Description. The Solar Maximum Mission (SMM) spacecraft was designed to provide observations of solar activity and contained seven instruments to study short-wavelength and coronal manifestations of solar flares. By 1986, over 400 papers based on SMM data and observations had appeared in scientific journals.

Summary. The Solar Maximum Mission (SMM) spacecraft was launched on February 14, 1980, to examine solar flares, the most violent aspect of solar activity. The spacecraft carried instruments designed to study solar flares and the active solar atmosphere, including the Ultraviolet Spectrometer and Polarimeter (UVSP), the Active Cavity Radiometer Irradiance Monitor (ACRIM), the Gamma-Ray Spectrometer (GRS), the Hard X-Ray Burst Spectrometer (HXRBS), the soft X-Ray Polychromator (XRP), the Hard X-ray Imaging Spectrometer (HXIS), and the Coronagraph Polarimeter (CP). The spacecraft was 4 meters (13.1 feet) in length and 2.3 meters (7.5 feet) in diameter. It was of modular construction with an instrument module that contained all the solar payload instruments, a Multimission Modular Spacecraft (MMS) containing the systems for attitude control, power, communication, and data handling, and a transition adapter to support the two fixed paddles that supplied the power. Solar flare research required a quick and coordinated response, and on-board coordination of responses were performed in real time. The ground system was designed to facilitate coordinated data evaluation, recordation, planning, observation, and command uplink.

The SMM was repaired by astronauts on the Challenger in April 1984 and serviced in orbit. The SMM collected and transmitted data until November 24, 1989. It reentered Earth's atmosphere on December 2, 1989.

Statement of Significance. The SMM provided observations and data for more than 400 scientific papers by 1986 and included several important contributions to the understanding of the Sun, including 1. The Sun as a star, 2. Solar flares, and 3. The active solar atmosphere. During the first five years of the SMM's operation, the total radiant output decreased slightly but leveled off as the minimum of solar activity approached. The rotation of the large sunspot is correlated with small but measurable decreases in solar radiative output. The frequencies of one class of global solar oscillations were observed to change slightly and the frequencies of another class of global solar oscillations disagreed with the standard solar model predicted frequencies. Solar flares were the key focus of the SMM and most of the evidence indicated that the energetic radiation emitted during the impulsive phase of solar flares resulted from the dissipation of energy in beams of high-energy charged particles accelerated in magnetic loop structures. The size of the loops is constrained by the duration of hard X-ray emission. Particle acceleration takes place in a limited region by the production of hard X-rays and y-rays. High energy mesons and neutrons were detected in some intense flares. Certain element abundancy varies from flare to flare and often changes during the course of an individual flare. One of the SMM instruments obtained the first direct measurements of the magnetic fields in the transition region, which includes several thousand kilometers above the visible surface of the Sun or the photosphere.

Cosmic Background Explore

Description. The Cosmic Background Explore (COBE) mission focused on taking precise measurements of the diffuse radiation between 1 micrometer and 1 centimeter over the whole celestial sphere and the results of the mission revolutionized the scientific understanding of the early cosmos. COBE was launched on November 18, 1989, and carried three instruments. The spacecraft precisely measured and mapped the oldest light in the universe. The COBE mission ushered in new era of precision measurements and paved the way for deeper exploration of microwave backgrounds, including NASA's Microwave Anisotropy Probe (WMAP) mission and ESA's Planck mission.

Summary. COBE was launched on November 18, 1989 and carried a Far Infrared Absolute Spectrophotometer (FIRAS) to compare the spectrum of cosmic microwave background radiation with a precise blackbody, a Differential Microwave Radiometer (DMR) to precisely map the cosmic radiation, and a Diffuse Infrared Background Experiment (DIRBE) to search for the cosmic infrared background radiation. The experiment module contained the instruments, a dewar filled with liquid helium, and a conical sunshade. The base module contained the attitude control, communications, and power system. The satellite rotated on an axis of symmetry to control systematic errors in the anisotropy measurements and allow observations of the zodiac light at various elongation angles. The COBE had two omnidirectional antennas, one to communicate with the Tracking and Data Relay Satellite System (TDRSS) and the other to transmit data stored on tape recorders directly to the ground. The on-board tape recorders and data system allowed 24 hours of data to be directly transmitted to WFF in a single nine-minute pass. The operational orbit was dawn-dusk Sun-synchronous, so that the instruments were shielded from the Sun. The COBE was originally designed to be launched by Delta rocket, but the since the Shuttle was adopted as the NASA standard launch vehicle, the design was redesigned to accommodate a shuttle launch. However, following the Challenger accident in 1986, shuttle launches from the West Coast were ended. The satellite was redesigned to fit the weight and size constraints of a Delta rocket. Instrument operations were terminated on December 23, 1993, and engineering operations concluded in January 1994. The satellite was transferred to Wallops for use as a test satellite.

Statement of Significance. The COBE mission and data revolutionized the understanding of early cosmos and confirmed the Big Bang theory of the origin of the universe. The cosmic microwave background, the oldest light in the universe, was precisely measured and mapped with the spectrum measured with a precision of 0.005%. The mission ushered in a new era of precision measurements and paved the way for deeper exploration of the microwave background. In 2006, John Mather and the COBE team was awarded the Gruber Cosmology Prize for their "groundbreaking studies of the spectrum and spatial structure of the relic radiation from the Big Bang." In addition, John Mather from GSFC and George Smoot from the University of California, Berkeley shared the 2006 Nobel Prize in Physics for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation measured by COBE.

Hubble Space Telescope

Description. The Hubble Space Telescope is photographic instrument developed by NASA to capture images of the universe for the benefit of science. The telescope is named after Edwin Hubble, an astronomer from the early twentieth century who identified galaxies outside of the Milky Way Galaxy. The Hubble Space Telescope helps scientists take pictures of the universe not available from telescopes on Earth's surface.

Summary. The idea of a telescope in space predated the development of NASA by 12 years. Astrophysicist Lyman Spitzer first discussed a telescope in space in 1946 as being beneficial for studying the cosmos. This was due to the natural barrier of Earth's atmosphere between the surface and the universe above. The atmosphere breaks up harmful light wave lengths, such as Infrared light, UV rays, X-Rays, and Gamma Rays, making their observation on Earth's surface difficult or impossible. The solution to this barrier, proposed by Spitzer, was having a telescope above the barrier, positioned in space orbiting the Earth. The idea was further developed by Spitzer and other astrophysicists and astronomers, resulting in the approval for a Large Space Telescope project by the National Academy of Sciences in 1969. The major obstacle for the project was funding. Various sources did provide funds for the project, and along with reductions in the telescope's design, Congress finally approved funding of the project in 1977.

Once the project was funded and approved, the process of creating the telescope and starting the project began. NASA was in charge of the telescope's construction and the project was led by Marshall Space Flight Center in Huntsville, Alabama. NASA's Goddard Space Flight Center in Greenbelt, Maryland was the lead facility in the development of the scientific instruments used on the telescope as well as ground control for the space observatory. The Johnson Space Center in Houston, Texas and the Kennedy Space Center in Cape Canaveral, Florida supplied space shuttle support to get the telescope into space. To round out the program, in 1983, the Space Telescope Institute (STScI) was founded at Johns Hopkins University in Baltimore, Maryland. The STScI was tasked with the evaluation of proposals for use of the telescope and to manage the results observed by the telescope.

NASA contracted out various aspects of the telescope's construction. The Perkin-Elmer Corporation (now Hughes Danbury Optical Systems) developed the optical telescope assembly and fine guidance sensors. Lockheed Missiles and Space Company (now Lockheed Martin) constructed the spacecraft's outer structure and support system module which was comprised of the computer system, power, communications, pointing and control systems. Lockheed Missiles and Space Company was also responsible for the telescope's assembly. Five instruments were added to the housing of the spacecraft, the Faint Object Camera, the Wide Field/Planetary Camera, the Faint Object Spectrograph, the High-Resolution Spectrograph, and the High-Speed Photometer. These five instruments would be used to take photographic images of various spans of light emitted within the universe. The main component of the telescope was its large 238.75-centimeter (94-inch) mirror. This was to be used to clearly photograph distant space and was the most significant functioning part of the telescope. The estimated lifespan of the telescope was 15 years, requiring periodic adjustments and changes to its technology throughout its lifespan. The construction of the telescope was worked on between 1977 and 1983 when the proposed launch date was set; however, this was pushed back due to necessary changes that needed to be made on the telescope. This set back pushed the completion of the telescope back to 1985.

After the telescope was completed, it was set to launch in 1986 abord a Space Shuttle. The telescope was specifically designed to fit into a space shuttle for both its main launch as well as any service missions needed to the telescope in the future. This second launch date had to be postponed with the unfortunate accident of the Challenger Space Shuttle on January 28, 1986. The explosion of the Challenger Space Shuttle grounded the space shuttle fleet for two years, pushing the telescopes debut back. A third launch date was successful with the Space Shuttle Discovery taking the Hubble Space Telescope into space on April 24, 1990.

The Hubble Space Telescope has long outlasted its original lifespan of 15 years, now being in service to the scientific community for 31 years. Five repair missions took place to service the Hubble Space

Telescope between 1993 and 2009. These five repair missions helped keep the Hubble Space Telescope in operation throughout the length of its operation. Throughout its operation, the telescope has taken over 1.5 million observations. With these observations, scientists have used the information from the Hubble Space Telescope to publish over 18,000 peer reviewed articles on a variety of subjects related to the cosmos. Some of the Hubble's discoveries include the Pillars of Creation, the neutron star RX J0806.4-4123, The Butterfly Nebula (NGC 6302), Star Cluster R136, and Galaxy NGC 3021.

No more servicing missions are planned for the Hubble Space Telescope; however, scientists and engineers continue to do everything from Earth to keep the telescope operational. The Hubble Space Telescope has added a wealth of information about our solar system, galaxy, and universe, including information on black holes, construction of galaxies, nebula, stars, and other topics held within the universe. The Hubble Space Telescope has launched a legacy of space observation and is the predecessor to the new James Webb Space Telescope, which launched on December 25, 2021.

Statement of Significance. The Hubble Space Telescope was the first of its kind to be placed in space for the function of photographing the universe. The telescope provided a solution to an issue Earth based telescopes had, trying to clearly pierce through the atmosphere by placing the telescope above the atmosphere. The Hubble Space Telescope has also been in service for twice as long as originally intended and is continuing to serve scientists on the study of the universe. The Hubble Space Telescope has been used by scientists and universities around the world to document phenomena within our solar system, galaxy, and throughout the universe.

Mars Pathfinder

Description. The Mars Pathfinder mission was a new technology designed primarily to demonstrate an innovative, economical method of delivering scientific instruments and a free-ranging, remote-controlled, robotic rover to another planet, with Mars as the proving ground. The mission also sought to collect and transmit geological, soil, magnetic property, and atmospheric data back to Earth. The Mars Pathfinder mission was a part of NASA's SMD, under NASA's Planetary Science Division, and was managed by the Mars Exploration Program (MEP) and the JPL.

Summary. NASA announced the formation of the MEP in 1994, then called the Mars Surveyor Program, with JPL as the lead. The MEP is a science-driven and technologically-enabled study to understand the Mars planetary system: its formation, evolution, past biological potential, future human exploration, and how it relates to the Earth planetary system. The MEP's responsibilities are to conceive, develop, and operate Mars rovers and orbiters, contribute to Mars mission partners (national and international), formulate and develop rover and orbiter missions, and archive mission data in the Planetary Data System.

The MEP missions and programs, such as the, the Mars Data and Analysis Program (MDAP) and Program Formulation Office (PFO), are designed for mutual support and focus on long-range program planning and targeted technology investments. The purpose of the MEP is to develop and demonstrate engineering capabilities for each mission and enable future missions. The data collected during missions is crucial to executing future missions and scientific observations from different missions. One example of the forward-looking goals of the MEP are the orbiters that not only perform remote sensing functions, but that also enhance the data transfer from landed missions by serving as telecommunication relays, enabling significant increases in data return.

MEP's goals also include maintaining a continuous Mars scientific presence, continuing improvements in technical capabilities of robotic Mars missions, ensuring missions continue collecting and using the scientific data necessary to advance the technology that will be required for future human spaceflight to and exploration of Mars. MEP goals also include outward looking goals such as communicating their activities to help develop and further scientific literacy in the nation, and interaction with the national and international planetary and Mars science community. In addition to these cross-cutting activities, MEP conducts overall science strategy optimization, program risk management and risk communication, telecommunication strategy, advanced capability development (technology and program infrastructure), interfaces with future missions, planetary protection, and communications with target NASA audiences.

It is within this larger MEP framework that the Mars Pathfinder mission was designed, developed, and executed. The mission was primarily an engineering demonstration of key technologies and concepts for eventual use in future missions to Mars employing scientific landers. Pathfinder's scientific mission was accomplished through technology experiments and instruments outfitted on a free ranging rover deployed on the planet's surface to investigate the structure of the Martian atmosphere, surface meteorology, surface geology, form, and structure, and the elemental composition of martian rocks and soil. The Mars Pathfinder Mission was the second launch in the Discovery Program, a NASA initiative for planetary missions with a maximum three-year development cycle and a cost cap of $150M (FY92). Within these constraints, the Mars Pathfinder mission was ambitious in its scope - to send a lander and separate remote-control rover, Sojourner, to the surface of Mars. On December 4, 1996, Mars Pathfinder was launched from the Cape Canaveral Air Station (CCAS), Florida aboard a Delta II-7925 launch vehicle which included a payload assist module (PAM)-D upper stage.

On July 4, 1997, seven months after launch, Pathfinder arrived at Mars and its primary mission was initiated with the spacecraft entering the Martian atmosphere using an aeroshell to slow its entry and allow for a supersonic parachute to deploy to slow it even further. Once the lander detached from the aeroshell a series of airbags inflated and three solid-fuel retro rockets fired to further reduce the lander's velocity, which were then jettisoned just above the planet's surface. The lander, stowed within the airbags, impacted the surface at about 46 feet per second, bouncing and tumbling at least 15 times before coming to a stop. The airbags then deflated, uncovering the lander which included the 23-pound, six-wheeled rover, Sojourner, which was deployed from the lander via landing ramps, making it the first wheeled vehicle to be used on any planet. While Pathfinder and Sojourner were planned for only one month and one week of operation respectively, Pathfinder, later renamed the Sagan Memorial Station after the late astronomer Carl Sagan, operated for three months, and Sojourner spent 83 days of a planned seven-day mission conducting technology experiments, scientific data collection, and data transmission. Final contact with Pathfinder was September 27, 1997, and the mission was officially declared over on March 10, 1998.

Statement of Significance. The Mars Pathfinder mission, and the MEP in general, operating under the Discovery Program, was a groundbreaking approach to planetary science missions to design, develop, launch, land, and operate a rover using innovative technologies for an economical cost. The bag landing system and innovative petal design was a success, which has been used in various incarnations since, to land other rovers on Mars. Pathfinder was not only proof of concept of this technology, innovative landing system, and remote rover operation, but also a validation of the "feed-forward" goals of the MEP and the innovation and economy mandates of the Discovery Program. The Mars pathfinder mission held the attention of researchers, scientists, and the public, also fulfilling the MEP outward looking goals such as communicating their activities to help develop and further scientific literacy in the nation and interaction with the national and international planetary and Mars science community.

Solar and Heliospheric Observatory

Description. Scientists using the joint European Space Agency (ESA)/NASA Solar and Heliospheric Observatory (SOHO) spacecraft discovered "jet streams" or "rivers" of hot, electrically charged plasma flowing beneath the surface of the Sun. These findings helped scientists understand the famous 11-year sunspot cycle and associated increases in solar activity that can disrupt the Earth's power and communications systems.

Summary. The SOHO is an international collaboration project between NASA and ESA's Cluster mission to study the Sun from its deep core to the outer corona and solar wind. The SOHO was launched on December 2, 1995, and was built in Europe by a team led by Matra Marconi Space (now EADS Astrium) and under the management of the ESA. NASA was responsible for the launch and mission operations. The SOHO utilized the DSN's large radio dishes around the world for data downlink and command. Mission control is located at GSFC in Maryland. The SOHO was designed to answer three fundamental questions about the Sun:

- What is the structure and dynamics of the solar interior?
- Why does the solar corona exist and how is it heated to the extremely high temperature of about 1,000,000°C?
- Where is the solar wind produced and how is it accelerated?

The SOHO is made of two modules including the Service Module and the Payload Module. The Service Module forms the lower portion of the spacecraft and provides the power, thermal control, pointing and telecommunications, and support for the solar panels. The Payload Module sits above the Service Module and houses all the scientific equipment, which includes 12 instruments. The SOHO spacecraft measures approximately 4.3 meters (14.1 feet) in height, 2.7 meters (8.9 feet) in breadth, and 3.7 meters (12.1 feet) in width. The SOHO was launched on December 2, 1995, on an Atlas II-AS (AC-121) from Cape Canaveral Air Station in Florida. The spacecraft moves around the Sun by slowly orbiting around the First Lagrangian Point (L1), where the combined gravity of the Earth and Sun keep the SOHO in an orbit locked to the Earth-Sun line. The L1 point is approximately 1.5 million kilometers away from Earth. The SOHO has an uninterrupted view of the Sun. All previous solar observatories have orbited the Earth, from where their observations were periodically interrupted as our planet 'eclipsed' the Sun.

The SOHO was designed for a mission lifetime of two years; however, due its success, the mission was extended five time in 1997, 2002, 2006, 2008, and 2010. The SOHO covered the entire 110-year solar cycle and the beginning of a new cycle. Control of the spacecraft was lost in 1998 and was restored through a recovery team. The spacecraft had three on-board gyroscopes, two of which failed immediately and the third failed in December 1998. New on-board software that did not rely on gyroscopes was installed in February 1999, which allowed the spacecraft to return to full scientific operations and provided a greater margin of safety for operations. SOHO became the first three-axis stabilized spacecraft operated without gyroscopes, which was groundbreaking for spacecraft design.

Statement of Significance. The SOHO provided an unprecedented amount of data about the Sun, including its interior, hot and dynamic atmosphere, solar wind, and its interaction with the interstellar medium. Some of the key results include:

- Revealing the first images of a star’s convection zone (turbulent outer shell) and the structure of the sunspots below the surface.
- Providing the most detailed and precise measurements of the temperature structure, the interior rotation, and gas flows in the solar interior.
- Measuring the acceleration of the slow and fast solar wind.
- Identifying the source regions and acceleration mechanism of the fast solar wind in the magnetically “open” regions at the Sun’s poles.
- Discovering new dynamic solar phenomena such as coronal waves and solar tornados.
- Revolutionizing the ability to forecast space weather, by giving three days’ notice of Earth-directed disturbances and playing lead role in the early warning system for space weather.
- Monitoring the total solar irradiance (solar constant) as well as variations in the extreme ultraviolet flux, which is important to understand the impact of solar variability on Earth’s climate.

The SOHO is one of the most prolific discoverers of comets with more than 2,000 comets found by the SOHO as of January 2011.

APPENDIX C: Significant People

Below are more complete biographies of some of the extraordinary people who have worked to accomplish NASA's exceptional achievements of the last 50 years in the three Areas of Significance described in the RSF.

Aeronautics Research

Harvard Lomax (1922–1999)

Harvard Lomax was a pioneer in the field of computational fluid dynamics (CFD), accelerating its development by applying finite-difference techniques to massively parallel computing. His research, spanning a 50-year career from 1944 to 1994, secured the leadership role of ARC in this area. Recognizing the theoretical and practical potential of his work, NASA established CFD as a strategic direction for the laboratory. They brought to ARC computer-savvy aerodynamicists who worked under Lomax's tutelage. During the 1970s and 1980s, CFD advanced at ARC in step with the increasing computer power that management made available to researchers, enabling the numeric wind tunnel to displace physical wind tunnels as the principal method for evaluating airflows. The numeric wind tunnel facilitated significant advances in aerodynamic and propulsion technology for commercial and military aircraft.

Harvard received the NASA Medal for Exceptional Scientific Achievement in 1973, the American Institute of Aeronautics and Astronautics (AIAA) Fluid and Plasma-Dynamics Award in 1977, and the Presidential Rank Award for Meritorious Executive Service in 1983. He was elected an AIAA fellow in 1978 and a member of the National Academy of Engineering in 1987. He received the Prandtl Ring in 1996.

Marta Bohn-Meyer (1957–2005)

Marta Bohn-Meyer was chief engineer at AFRC and a widely known precision aerobatic pilot. She attended Rensselaer Polytechnic Institute in Troy, New York, graduating with a Bachelor of Science degree in aeronautical engineering. Bohn-Meyer came to AFRC in 1979 as an aeronautical research and operations engineer. She was appointed chief engineer in October 2001 after serving in a series of increasingly responsible positions, including director of flight operations, director of safety and mission assurance, deputy director of flight operations, deputy director of aerospace projects and project manager for the F-16 XL Supersonic Laminar Flow Control project. Bohn-Meyer worked on a variety of research projects, specializing in flight test operations, developing test techniques and laminar flow research. Among these projects were flight tests of space shuttle thermal protection tiles with a NASA F-104, B-57 gust gradient evaluations and the F-14 aileron-rudder interconnect and variable sweep transition laminar flow programs, in addition to her work on the F-16XL laminar flow project before becoming project manager.

She was one of two flight engineers assigned to fly in the SR-71 high-speed flight research program at Dryden. She was the first female crewmember from NASA or the U.S. Air Force – and the second woman – to fly in one of the triple-sonic SR-71s. In 1996 she received the NASA Exceptional Service Medal "for exceptional service in flight operations and project management in support of several national flight research programs." She was awarded the Aerospace Educator Award in 1998 from Women in Aerospace and in 1992 received the Arthur C. Fleming Award in the scientific category.

Dr. Richard T. Whitcomb (1921–2009)

Richard T. "Dick" Whitcomb conceived and developed three revolutionary aerodynamic concepts that forever changed airplane design by enabling military and civil aircraft to fly faster, farther, and with less fuel: the area rule, the supercritical wing, and winglets. Whitcomb, a mechanical engineer with a concentration in aeronautics, worked for NACA/NASA LaRC from 1943 until his retirement in 1980.

Whitcomb received the National Medal of Science (personally conferred by President Richard M. Nixon) in 1973, the U.S. Air Force Exceptional Service medal in 1955, the first NACA Distinguished Service Medal in 1956, the NASA Exceptional Scientific Achievement Medal in 1959 and the National Aeronautics Association's Wright Brothers Memorial Trophy in 1974. The engineer was inducted into the National Inventors' Hall of Fame in 2003, the National Academy of Engineering in 1976 for his pioneering research in the aerodynamic design of high-performance aircraft, and the Paul E. Garber First Flight Shrine at the Wright Brothers National Memorial.

Mary Winston Jackson (1921–2015)

Mary Jackson became NASA’s first black aeronautical engineer. A native of Hampton, Virginia, she graduated from Hampton Institute in 1942 with a dual degree in math and physical sciences, and in 1951 she joined LaRC’s segregated West Area Computing section, reporting to the group’s supervisor Dorothy Vaughan. After two years in the computing pool, Jackson received an offer to work for engineer Kazimierz Czarnecki in the 4-foot by 4-foot Supersonic Pressure Tunnel, a 60,000 horsepower wind tunnel capable of blasting models with winds approaching twice the speed of sound. Czarnecki offered Mary hands-on experience conducting experiments in the facility, and eventually suggested that she enter a training program that would allow her to earn a promotion from mathematician to engineer. Jackson completed the courses, earned the promotion, and in 1958 became NASA’s first black female engineer. That same year, she co-authored her first report, “Effects of Nose Angle and Mach Number on Transition on Cones at Supersonic Speeds.”

For nearly two decades she enjoyed a productive engineering career, authoring or co-authoring at least a dozen research reports, most focused on the behavior of the boundary layer of air around airplanes. In 1979, she left engineering to become Langley’s Federal Women’s Program Manager. There, she worked hard to impact the hiring and promotion of the next generation of NASA’s female mathematicians, engineers, and scientists. Mary Jackson retired from LaRC in 1985. Among her many honors were an Apollo Group Achievement Award and being named Langley’s Volunteer of the Year in 1976.

Thomas C. McMurtry (1935–2015)

Thomas C. McMurtry was a research pilot and administrator at AFRC from 1967 to his retirement in 1999. He received his Bachelor of Science degree in mechanical engineering from the University of Notre Dame in June 1957, and served as a U.S. Navy pilot, graduating from the U.S. Navy Test Pilot School, Patuxent River, Maryland. He was a consultant for Lockheed Corporation before coming to NASA in 1967. At NASA McMurtry was a project pilot for the AD-1 Oblique Wing program, the F-15 Digital Electronic Engine Control (DEEC) project, the KC-135 Winglets project and the F-8 Supercritical Wing program for which he received NASA's Exceptional Service Medal. McMurtry was also co-project pilot on the F-8 Digital Fly-By-Wire program, and on several remotely piloted research vehicle programs such as the FAA/NASA 720 Controlled Impact Demonstration and the sub-scale F-15 spin research project. On November 26, 1975, the X-24B lifting body dropped from the sky for the last time, piloted on this 36th flight by McMurtry. He also co-piloted the 747 Shuttle Carrier Aircraft as it transported the prototype Shuttle Enterprise on its first launch on August 12, 1977.

Since becoming a pilot in 1958, McMurtry logged more than 11,000 hours of flying time. Besides the aircraft listed above, he has flown the U-2, the triple-sonic YF-12C, and the F-104. In 1982, McMurtry received the Iven C. Kincheloe Award from the Society of Experimental Test Pilots for his contributions as project pilot on the AD-1 Oblique Wing program. In 1998 he was named as one of the honorees of the Lancaster, CA, ninth Aerospace Walk of Honor ceremonies. In 1999 he was awarded the NASA Distinguished Service Medal, and in 2014, McMurtry was presented the Federal Aviation Administration's Wright Brothers Master Pilot Award.

John A. Manke (1932–2019)

John A. Manke attended the University of South Dakota before joining the U.S. Navy in 1951. He earned a bachelor's degree in electrical engineering from Marquette University, Milwaukee, WI, in 1956. Following graduation, Manke served as a fighter pilot in the U.S. Marine Corps. After leaving the service in 1960, he worked for Honeywell Corp. as a test engineer for two years before joining NASA.

John A. Manke served as a research pilot, Chief of Flight Operations, and as site manager NASA's Flight Research Center, later the Dryden Flight Research Center, at Edwards, California. Manke started at NASA in May 1962, as a flight research engineer. Manke began conducting research flights in the wingless lifting bodies in 1968. Manke flew 42 flights in the lifting bodies, including the X-24B, X-24A, HL-10, and the M2-F3, more than any other pilot. The wingless lifting bodies demonstrated the ability to maneuver and safely land a vehicle with a shape that was designed for space flight. The research provided data and flight techniques used for the design of space shuttles. He made the first supersonic flight in a lifting body and the first landing of a lifting body on a hard-surface runway. That precision landing of the X-24B on Aug. 5, 1975 proved that a low lift-to-drag aircraft could be flown to a precise landing, leading space shuttle designers to eliminate plans to incorporate auxiliary jet engines on the shuttles to aid landing approaches.

Manke later served as Chief of Flight Operations at NASA Dryden, and upon Dryden's integration with NASA's Ames Research Center in October 1981, served both facilities in that role. He also served concurrently as Dryden's facility manager from the time of its merger with Ames until his retirement from NASA in April 1984.

Katherine Johnson (1918–2020)

The 1957 launch of the Soviet satellite Sputnik changed history—and Johnson’s life. In 1957, she provided some of the math for the 1958 document “Notes on Space Technology,” a compendium of a series of 1958 lectures given by engineers in the Flight Research Division and the Pilotless Aircraft Research Division (PARD). Engineers from those groups formed the core of the Space Task Group, the NACA’s first official foray into space travel. Johnson, who had worked with many of them since coming to Langley, “came along with the program” as the NACA became NASA later that year. She did trajectory analysis for Alan Shepard’s May 1961 mission Freedom 7, America’s first human spaceflight. In 1960, she and engineer Ted Skopinski coauthored Determination of Azimuth Angle at Burnout for Placing a Satellite Over a Selected Earth Position, a report laying out the equations describing an orbital spaceflight in which the landing position of the spacecraft is specified. It was the first time a woman in the Flight Research Division had received credit as an author of a research report.

In 1962, as NASA prepared for the orbital mission of John Glenn, Johnson was called upon to do the work for which she would become most known. The complexity of the orbital flight had required the construction of a worldwide communications network, linking tracking stations around the world to IBM computers in Washington, Cape Canaveral in Florida, and Bermuda. The computers had been programmed with the orbital equations that would control the trajectory of the capsule in Glenn's Friendship 7 mission from liftoff to splashdown, but the astronauts were wary of putting their lives in the care of the electronic calculating machines, which were prone to hiccups and blackouts. As a part of the preflight checklist, Glenn asked engineers to "get the girl"—Johnson—to run the same numbers through the same equations that had been programmed into the computer, but by hand, on her desktop mechanical calculating machine. "If she says they're good,'" Katherine Johnson remembers the astronaut saying, "then I'm ready to go." Glenn's flight was a success, and marked a turning point in the competition between the United States and the Soviet Union in space.

When asked to name her greatest contribution to space exploration, Johnson would talk about the calculations that helped synch Project Apollo's Lunar Module with the lunar-orbiting Command and Service Module. She also worked on the Space Shuttle and the Earth Resources Technology Satellite (ERTS, later renamed Landsat) and authored or coauthored 26 research reports. She retired in 1986, after 33 years at Langley. "I loved going to work every single day," she said. In 2015, at age 97, Johnson added another extraordinary achievement to her long list: President Barack Obama awarded her the Presidential Medal of Freedom, America's highest civilian honor.

Robert MacCormack

Robert MacCormack received his bachelor's degree from Brooklyn College and his advanced degrees from Stanford University. After graduating, MacCormack started working at the NASA Ames Research Center within the department of engineering. During his tenure at NASA's Ames Research Center, he held many positions, including Assistant Chief-Computational Fluid Dynamics (CFD) Branch and Senior Staff Scientist in the Thermo and Gas Dynamics Division. While at NASA, he worked with Harvard Lomax, a pioneer in the field of CFD, in which MacCormack is also a part of. Lomax worked on calculations of supersonic flows over blunt objects while MacCormack of the Ames vehicle environment division continued to refine his calculations of viscous flows.

In 1981, after 20 years at NASA, he joined the University of Washington and in 1985 returned to the Stanford University where he is currently Professor in the Department of Aeronautics and Astronautics. Also a member of Air Force Scientific Advisory Board, MacCormack advises and consults with more than a dozen U.S. aerospace companies and government agencies. MacCormack is the recipient of numerous prestigious awards including the AIAA Fluid Dynamics and Theodorsen Lectureship award, NASA Exceptional Scientific Achievement Medal, and the NASA Ames Research Center H. Julian Award. Professor MacCormack is a Fellow of AIAA and is a member of National Academy of Engineering.

Daniel Mikkelson

Daniel Mikkelson was associated with the development of the Advanced Turboprop (ATP) project between NASA's Lewis Research Center and Hamilton Standard. This project was in response to the Energy Crisis of 1973, with the Federal government took aggressive steps to attain energy independence for the nation. The Federal initiatives had a significant impact on NASA. Fuel efficiency has always been one of the primary challenges for flight, but the increased government focus in the 1970s brought greater public visibility, political support, and funding to NASA's ongoing research in this area. Daniel Mikkelson from NASA's Lewis Research Center (now Glenn Research Center [GRC]) and Carl Rohrbach from Hamilton Standard, were already investigating the concept. Based on their findings, Lewis Research Center partnered with Hamilton Standard—the only remaining propeller manufacturer in the U.S.—to kick off the Advanced Turboprop Project. Later, as the project expanded, the Allison Gas Turbine Division of General Motors (GM) and Pratt & Whitney became involved, as did General Electric (GE), Lockheed, McDonnell Douglas, Boeing, and others.

The result—though not ultimately adopted—was potentially industry transforming. This achievement was recognized by the National Aeronautic Association, which awarded the Collier Trophy for the greatest achievement in 1987 in aeronautics to the NASA Lewis Research Center and the NASA/industry advanced turboprop team. In the years since, ATP technology has contributed to a range of aeronautical advances and remains ready to be revisited should fuel conservation become a concern for the airlines industry in the future. Daniel Mikkelson was largely involved with the progress and development of the Advanced Turboprop and was a significant attribute to the program.

Human Exploration and Operations

Wernher von Braun, Ph.D. (1912–1977)

Wernher von Braun was born on March 23, 1912, in Wirsitz, Germany (now Wyrzysk, Poland). In the spring of 1930, while enrolled in the Berlin Institute of Technology, Braun joined the German Society for Space Travel. In 1932, he graduated with a Bachelor of Science degree in mechanical engineering and he joined the German Army where he continued his education at the University of Berlin, earning his doctorate in physics on July 27, 1934. Dr. von Braun remained in the German Army during World War II as a member of Nazi Party and an SS officer where he led the V-2 Ballistic Missile program. The revolutionary V-2 rocket flew at speeds in excess of 3,500 miles per hour and delivered a 2,200-pound warhead to a target 200 miles away. Before the Allied capture of the V–2 rocket complex, Dr. von Braun was sent south, eventually to Bavaria and surrendered to the Americans there, along with other key team leaders. For fifteen years after World War II, he worked as part of a U.S. Army operation called Project Paperclip to develop ballistic missiles. He was part of an initial group of about 125 scientists were sent to America where they were installed at Fort Bliss, Texas. There they worked on rockets for the U.S. Army and assisted in V-2 launches at White Sands Proving Ground, New Mexico.

In 1950, Dr. von Braun's team moved to the Redstone Arsenal near Huntsville, Alabama, where they designed the Army's Redstone and Jupiter ballistic missiles, as well as the Jupiter C, Juno II, and Saturn I launch vehicles. A Jupiter C launched the first U.S Earth orbiting satellite, Explorer I, in 1958. In 1960, President Eisenhower transferred the rocket development center at Redstone Arsenal from the Army to NASA. Its primary objective was to develop the giant Saturn rockets. Accordingly, Dr. von Braun became director of NASA's MSFC and the chief architect of the Saturn V launch vehicle, the superbooster that would propel Americans to the Moon. At Marshall, the group continued work on the Redstone-Mercury, the rocket that sent the first American astronaut, Alan Shepard, on a suborbital flight on May 5, 1961. Shortly after Shepard's successful flight, President John F. Kennedy challenged America to send a man to the Moon by the end of the decade. The July 20, 1969 Moon landing during the Apollo 11 mission fulfilled both Kennedy's mandate and Dr. von Braun's lifelong dream. In 1970, NASA leadership asked him to move to Washington, D.C., to head up the strategic planning effort for the agency. He left his home in Huntsville, Alabama, but in 1972 he decided to retire from NASA and work for Fairchild Industries of Germantown, Maryland.

Robert R. Gilruth (1913–2000)

Robert R. Gilruth was born in Nashwauk, Minnesota in 1913 and attended the University of Minnesota, where he earned a Bachelor of Science degree in aerospace engineering in 1935, and a Master of Science degree in 1936. After graduating, he started his career at the NACA Langley Memorial Aeronautical Laboratory in January 1937. In 1945, Gilruth was assigned the job of organizing a new research group called the Auxiliary Flight Division, with the task of constructing a facility for conducting free-flight experiments with rocket-powered models for investigating high-speed flight. The technique was overwhelmingly supported by industry, which called for an expansion of the NACA capabilities by a factor of three. Under Gilruth's leadership, Langley formed the NACA Pilotless Aircraft Research Division (PARD) and initiated flight tests at Wallops Island, Virginia -- activities that proved to be critical for the transition of the NACA to NASA.

In October 1958, following the shock and in the aftermath of Sputnik, Gilruth was selected to be the Director of the Space Task Group at Langley, the organization responsible for the design, development and flight operations of Project Mercury. He was given authority by NASA Headquarters to assign qualified people within the agency to the group. As a part of his responsibilities, he later helped organize the MSC (now the JSC) in Houston, Texas, and selected its initial, highly competent workforce capable of performing the many diverse functions required for a program of this magnitude. In 1961, Gilruth became the Director of the MSC, with responsibility for the development of spacecraft for manned flight, for flight crew selection and training, and for the conduct of space flight missions. He served in this capacity until January 1972. During his decade-long tenure as MSC Director, Gilruth managed 25 manned-space flights, including Alan Shepard's first Mercury flight in May 1961, the first lunar landing by Apollo 11 in July 1969, the dramatic rescue of Apollo 13 in 1970, and the Apollo 15 mission in July 1971. In January 1972, Gilruth took on a new position with NASA as Director of Key Personnel Development, reporting to the Deputy Administrator in Washington, D.C. In this capacity, he had responsibility for identifying near- and long-range potential candidates for key jobs in the agency and for creating plans and procedures which would aid in the development of these candidates. Gilruth retired from NASA in December 1973 and, in January 1974, was appointed a member of the National Academy of Engineering's Aeronautics and Space Engineering Board; and was asked to serve as a member of the Houston Chamber of Commerce Energy Task Force.

His awards include: the Sylvanus Albert Reed Award from the Institute of Aeronautical Sciences; the U.S. Chamber of Commerce Great Living American Award; the Daniel and Florence Guggenheim International Astronautics Award of the International Academy of Astronautics; American Society of Mechanical Engineers Award; the City of New York Medal of Honor; Spirit of St. Louis Medal of the American Society of Mechanical Engineers; several NASA Distinguished Service Medals; and the President's Award for Distinguished Federal Service. He also received the prestigious Goddard Memorial Trophy of the National Rocket Club, the Louis W. Hill Space Transportation Award, the Reed Aeronautics Award, and the National Aeronautical Association's Robert J. Collier Trophy.

Neil Armstrong (1930–2012)

Neil Armstrong was born in Wapakoneta, Ohio on August 5, 1930. He began his career in Cleveland, Ohio when he joined the NACA in 1955, working as an engineer, test pilot, astronaut, and administrator for the NACA and its successor agency, NASA. Armstrong became an official astronaut in1962 and he was assigned as command pilot for the Gemini 8 mission. Gemini 8 was launched on March 16, 1966, and Armstrong performed the first successful docking of two vehicles in space.

As spacecraft commander for Apollo 11, the first manned lunar landing mission, Armstrong gained the distinction of being the first human to land a craft on the moon and the first to step on its surface. Armstrong, along with the Apollo 11 crew, Edwin E. Aldrin, Jr., and Michael Collins, were trained at the MSC (now JSC) for their flight to the moon. Apollo 11 launched on July 16, 1969 and four days later, at 4:17 PM U.S. Eastern Daylight Time (EDT), the Eagle lunar landing module, guided manually by Armstrong, touched down on a plain near the southwestern edge of the Sea of Tranquility. At 10:56 PM EDT on July 20, 1969, Armstrong stepped from the Eagle onto the Moon's dusty surface. Armstrong and Aldrin left the module for more than two hours and deployed scientific instruments, collected surface samples, and took numerous photographs. On July 21, after 21 hours and 36 minutes on the Moon, they lifted off to rendezvous with Collins and begin the voyage back to Earth. After splashdown in the Pacific Ocean on July 24, the three astronauts spent 18 days in quarantine to guard against possible contamination.

George E. Mueller, Ph.D. (1918–2015)

George E. Mueller was born in St. Louis, Missouri, on July 16, 1918. He was trained as an electrical engineer and earned a Bachelor of Science degree from the Missouri School of Mines in 1939 and a Master of Science from Purdue in 1940. Mueller served as a researcher at Bell Telephone Laboratories during World War II and after the war he taught at Ohio State University while working on his Ph.D. in physics, graduating in1951. By the mid-1950s he was consulting with major aerospace companies and quickly rose to management positions of space programs at the Space Technology Laboratories (STL).

Originally sworn in as the Deputy Associate Administrator for Manned Space Flight on September 1, 1963, he quickly pushed through a reorganization that changed his title to Associate Administrator for Manned Space Flight, a position he held until leaving the agency in 1969. In this new management structure, Dr. Mueller was not only in charge of the Gemini, Apollo and future human space flight programs, but directly supervised the three NASA Centers devoted to human space flight: MSFC, MSC (now the JSC), and the KSC. At the time, all three of these centers were undergoing a massive growth in facilities and staff. Dr. Mueller was a forward-thinking leader who introduced management concepts and practices that not only assured the achievement of landing on the Moon by the end of the decade, but also had a long-lasting impact on NASA operations.

In his six years at NASA Dr. Mueller's impacts were far-reaching, from accelerating Project Gemini, to pushing forward initial designs for Skylab, and laying the groundwork for the Space Shuttle. He may well be best known for his daring solutions to the schedule problems with the Apollo Program. Knowing that the plans he inherited in 1963 would never succeed in achieving the Presidential goal of a Moon mission by the end of the decade, Dr. Mueller overhauled the management system to facilitate concurrent development of the many needed systems. Most importantly, and most controversially, he instituted the "all-up" testing approach, which was a radical change to the building block approach then in use, and vigorously defended by Wernher von Braun and his team developing the Saturn V rocket. Dr. Mueller insisted that testing each stage of the Saturn rocket before adding the next was not necessary and would be impossible to complete by the end of the decade. His logic carried the day, and his calculated risk proved critical in achieving the Moon landing goal.

Sally Kristen Ride, Ph.D. (1951–2012)

Sally Kristen Ride was born on May 26, 1951 in Encino, California. She received a Bachelor of Science degree in physics and a Bachelor of Arts degree in English in 1973 from Stanford University. In 1975, she received her Master of Science in physics and in 1978, received her doctorate in physics from Stanford University. NASA selected Dr. Ride as an astronaut candidate in January 1978 and in August 1979, she completed a one-year training and evaluation period, making her eligible for assignment as a Mission Specialist on future space shuttle flight crews. Dr. Ride was a Mission Specialist on the Space Shuttle Challenger, Mission STS-7, which launched from KSC, Florida, on June 18, 1983. This was the second flight for the orbiter Challenger and the first mission with a five-person crew. During the mission, the STS-7 crew deployed satellites for Canada (ANIK C-2) and Indonesia (PALAPA B-1); operated the Canadian-built Remote Manipulator System (RMS) to perform the first deployment and retrieval exercise with the Shuttle Pallet Satellite (SPAS-01); conducted the first formation flying of the orbiter with a free-flying satellite (SPAS-01); carried and operated the first U.S./German cooperative materials science payload (OSTA-2) and operated the Continuous Flow Electrophoresis System (CFES) and the Monodisperse Latex Reactor (MLR) experiments, in addition to activating seven Getaway Specials. Mission duration was 147 hours before landing on a lakebed runway at Edwards Air Force Base, California, on June 24, 1983.

Dr. Ride also became the first American woman to travel to space a second time when she launched on another Challenger mission, STS-41-G, on Oct. 5, 1984. That mission lasted nine days. On that flight, she used the shuttle's robotic arm to remove ice from the shuttle's exterior and to readjust a radar antenna. Ride was assigned to a third shuttle mission, but her crew's training was cut short by the Challenger disaster in January 1986. Dr. Ride left NASA in 1987 and in 1989, joined the faculty at the University of California San Diego as a Professor of Physics and Director of the University of California's California Space Institute. In 2001, she founded her own company, Sally Ride Science to pursue her long-time passion of motivating girls and young women to pursue careers in science, math and technology. The company creates entertaining science programs and publications for upper elementary and middle school students and their parents and teachers. A long-time advocate for improved science education, Dr. Ride wrote five science books for children: To Space and Back; Voyager, The Third Planet, The Mystery of Mars, and Exploring Our Solar System. She also initiated and directed education projects designed to fuel middle school students' fascination with science. She is the only person to have served on the commissions investigating both the Space Shuttle Challenger and Columbia accidents. Dr. Ride received numerous honors and awards: the Jefferson Award for Public Service; the von Braun Award; the Lindbergh Eagle Award, the NCAA's Theodore Roosevelt Award; and twice was awarded the NASA Space Flight Medal. Dr. Ride is in the National Women's Hall of Fame and the Astronaut Hall of Fame.

Guion "Guy" Bluford, Ph.D.

Guion "Guy" Bluford graduated from Pennsylvania State University, with a Bachelor of Science in aerospace engineering in 1964. After he graduated, Dr. Bluford joined the United States Air Force (USAF) where he served as a pilot during the Vietnam War. After his service in Vietnam, he earned his Master of Science degree in 1974, followed by his doctorate in aerospace engineering and laser physics in 1978, both from the Air Force Institute of Technology. Dr. Bluford went back to school in 1987 to receive his Master of Business Administration from the University of Houston, Clear Lake.

NASA selected Dr. Bluford as an astronaut candidate in 1978 and five years later, completed his first mission into space as the first African American astronaut. Dr. Bluford's 1983 mission aboard the space shuttle Challenger included the deployment of an Indian communications satellite and the first launch and landing of a space shuttle at night. In November 1985, he again flew aboard the space shuttle Challenger on a mission dedicated to German scientific experiments. Dr. Bluford's third spaceflight was aboard the space shuttle *Discovery* on April 28, 1991, and carried unclassified experiments for the U.S. Department of Defense (DoD). The experiments studied the atmosphere and the shuttle's environment. The only classified portion of the mission consisted of a satellite that Dr. Bluford released from the cargo bay. His last mission to space started on December 2, 1992, and was completed aboard the shuttle *Discovery*. As an astronaut, Dr. Bluford worked with space station operations, the Remote Manipulator System, Spacelab systems and experiments, space shuttle systems, payload safety issues and verifying flight software.

Mae Jemison, M.D.

Mae Jemison was born October 17, 1956, in Decatur, Alabama, however, her family moved shortly after her birth to Chicago, Illinois. Jemison received a Bachelor of Science degree in chemical engineering(and fulfilled the requirements for a Bachelor of Arts in African and African-American Studies) from Stanford University in 1977. She then pursued her doctorate degree in medicine from Cornell University in and graduated in 1981. Dr. Jemison completed her internship at Los Angeles County/USC Medical Center in July 1982 and worked as a General Practitioner with INA/Ross Loos Medical Group in Los Angeles until December 1982. From January 1983 through June 1985, Dr. Jemison was the Area Peace Corps Medical Officer for Sierra Leone and Liberia in West Africa. Her task of managing the health care delivery system for U.S. Peace Corps and U.S. Embassy personnel included provision of medical care, supervision of the pharmacy and laboratory, medical administrative issues, and supervision of medical staff.

NASA selected Dr. Jemison for the astronaut program in June 1987 and completed work on launch support activities at the KSC in Florida where she worked on the verification of Shuttle computer software in the Shuttle Avionics Integration Laboratory (SAIL) and completed Science Support Group activities. Dr. Jemison was the science mission specialist on STS-47 Spacelab-J, on the Space Shuttle *Endeavor*. STS-47 was a cooperative mission between the United States and Japan. The eight-day mission was completed during 127 Earth orbits and included 44 Japanese and U.S. life science and materials processing experiments. Dr. Jemison was a co-investigator on the bone cell research experiment flown on the mission. The *Endeavour* and her crew launched from and returned to the KSC in Florida.

After retiring from NASA, she started The Jemison Group, a consulting company that encourages science, technology, and social change. She also began teaching environmental studies at Dartmouth College and directed the Jemison Institute for Advancing Technology in Developing Countries. In 1994, Dr. Jemison created an international space camp for students 12-16 years old called *The Earth We Share* (TEWS). She also created a nonprofit organization called the Dorothy Jemison Foundation for Excellence.

Dr. Jemison has been awarded the National Achievement Scholarship, 1979 CIBA Award for Student Involvement; Recipient of Essence Award (1988), DuSable Museum Award, and Gamma Sigma Gamma Woman of the Year. She has also received the title of Honorary Doctorate of Science from Lincoln College in Pennsylvania, Honorary Doctorate of Letters from Winston Salem College in North Carolina, and is a Montgomery Fellow (1993) at Dartmouth College. Dr. Jemison is a member of the

National Academy of Sciences' Institute of Medicine and has been inducted into the National Women's Hall of Fame, National Medical Association Hall of Fame and Texas Science Hall of Fame.

Kathryn Clark, Ph.D.

Kathryn Clark received her Bachelor of Arts degree from the College of Wooster in 1980, followed by a Master of Science in 1982 from the University of Michigan. After finishing her master's degree, she pursued a doctorate in kinesiology and received her Ph.D. in 1990. After graduating with her doctorate, she joined the Department of Cell and Developmental Biology at the University of Michigan in 1993 as a research investigator. Clark's NASA experience began with a neuromuscular development study that flew on Atlantis in 1994, which were then repeated and enhanced on *Discovery* in 1995. She was also involved in the Neurolab project flown on Columbia in 1998 and that same year, she was appointed as NASA's Chief Scientist for the International Space Station Program. She served in this position from 1998 to 2000 while working at the University of Michigan. In 2000, she was appointed as NASA's Chief Scientist of Human Exploration and Development of Space Enterprises. She held this position until 2002 when she served on the NASA Return to Flight Task Group, a select external advisory body established after the Columbia accident to improve safety of astronauts. Her work is largely focused on the human factor of space travel, including all the elements necessary for health, safety, and efficiency of crews involved in long duration space flight. Her scientific interests are focused on neuromuscular development and adaptation to altered environments such as space or Earth's oceans.

Currently, Dr. Clark is a professional speaker who uses her experience to motivate and inspire others to reach for the stars in their careers. She also works to promote education with groups like the Jean-Michel Cousteau Society, the Square One Education Network, the Argos Foundation, the National Marine Sanctuaries, the Sea World Hubbs Institute, SAS Games, the National Space Grant Foundation, Arnold Schwarzenegger's After School All Stars, and the 27 Foundation. She has many awards, including: the Roskosmos (Russian Space Agency) Certificate of Appreciation in recognition of the 10 Year Anniversary of the Stafford-Anfimov ISS Task Force; the National Aeronautics & Space Administration Certificate of Appreciation in recognition of the 10 Year Anniversary of the Stafford-Anfimov ISS Task Force; the National Aeronautics & Space Administration Public Service Medal for Service on the Return to Flight Task Group; the Western Reserve Academy Morley Science Medal; the NASA GSFC Customer Service Excellence Award; the Women in Aerospace International Award; the Western Reserve Academy Waring Prize for Outstanding Alumni Contributions to the Community; the NASA Space Flight Awareness Team Award; and she was inducted into the National Women's Museum.

William Shepherd

William Shepherd was born on July 26, 1949 in Oak Ridge, Tennessee. Shepherd received a Bachelor of Science degree in aerospace engineering from the U.S. Naval Academy in 1971. In 1978 he earned an Engineer degree in ocean engineering and Master of Science in mechanical engineering from the Massachusetts Institute of Technology. Prior to his time at NASA, Shepherd served with the Navy's Underwater Demolition Team ELEVEN, SEAL Teams ONE and TWO, and Special Boat Unit TWENTY.

NASA selected Shepherd as an astronaut in May 1984 and as veteran of four space flights, Shepherd has logged over 159 days in space. He made three flights as a mission specialist on STS-27 (December 2-6, 1988), STS-41 (October 6- 10, 1990) and STS-52 (October 22 to November 1, 1992). From March 1993 to January 1996, Shepherd was assigned to the Space Station Program and served in various management positions. He was the Commander of the Expedition-1 crew on the ISS (October 31, 2000 to March 21, 2001). William Shepherd retired from NASA in 2002 to pursue private interests.

Thomas P. Stafford

Thomas P. Stafford was born on September 17, 1930 in Weatherford, Oklahoma. Stafford received his Bachelor of Science degree from the U.S. Naval Academy in Annapolis, Maryland and was commissioned as a second lieutenant with the United States Air Force in 1952. He was selected in the second group of astronauts to be positioned with NASA in 1962 and was a part of the early Gemini and Apollo projects. His first trip to space was aboard the Gemini VI in December 1965, helping to prove the basic theory and practicality of space rendezvous. From August 1966 to October 1968, he headed the mission planning analysis and software development responsibilities for the astronaut group for Project Apollo. Stafford was the lead member of the group and helped formulate the sequence of missions leading to the first lunar landing. Stafford was commander of Apollo 10 in May 1969, the first flight of the lunar module to the moon, he descended to nine miles above the moon performing the entire lunar landing mission except the actual landing. He performed the first rendezvous around the Moon and designated the first lunar landing site for the future Apollo 11 mission.

In June 1971, Stafford was assigned as Deputy Director of Flight Crew Operations at the NASA Manned Spacecraft Center (now JSC). He was responsible for assisting the director in planning and implementation of programs for the astronaut group, the Aircraft Operations, Flight Crew Integration, Flight Crew Procedures, and Crew Simulation and Training Divisions. During his tenure at JSC, he was the U.S. commander of the Apollo-Soyuz Test Project between the U.S. and the Soviet Union, leading to the end of the space race. In the same year he flew on the Apollo-Soyuz Test Project, he was promoted to Major General and transferred to command the Air Force Flight Test Center at Edwards Air Force Based, California. General Stafford was again promoted in 1978 to Lt. General and was appointed as the Deputy Chief of Staff of Research, Development and Acquisition at USAF HQ in Washington D.C.

General Stafford has received many awards, including: NASA Distinguished Service Medals (4), NASA Exceptional Service Medals (2), Air Force Distinguished Service Medal with 3 Oak Leaf Clusters, Air Force Distinguished Flying Cross with one Oak Leaf Cluster, Air Force Outstanding Unit Award with one Oak Leaf Cluster, Air Force Commendation Medal, Air Force Command Pilot Astronaut Wings. Other awards include Congressional Space Medal of Honor, Wright Brother Memorial Trophy, the American Institute of Aeronautics and Astronautics (AIAA) Chanute Flight Award, the Veterans of Foreign Wars National Space Award, National Geographic Society's General Thomas D. White USAF Space Trophy, Federation Aeronautique Internationale Gold Space Medal.

Science

Reuven Ramaty, Ph.D. (1937–2001)

Reuven Ramaty was born on February 25, 1937 in Timisoara, a Hungarian enclave in Romania. He immigrated to Israel with his parents in 1948 and graduated from Tel Aviv University in 1961 with a bachelor's degree in physics. He taught high school for three years before attending the University of California, Los Angeles. He graduated in 1966 with a Ph.D. in planetary and space physics. He joined NASA's GSFC in 1967 and became one its leading theorists for 30 years. He was the head of the Theory Office from 1980 to 1993. In 1983, he also became an Adjunct Professor of Physics at the University of Maryland. He served on doctoral dissertation committees at the University of Paris and the

Pierre & Marie Curie University in Paris. Ramaty published over 200 articles and literature regarding his research on solar flare physics, gamma-ray astronomy, and cosmic rays. He is best known for his work on solar flare particle interactions. In coordination with Dr. Richard Lingenfelter, Ramaty first showed that gamma ray line and neutron measurements from flares could be a powerful diagnostic for determining the properties of flare-accelerated particles in 1967. He continued to refine his techniques and used measurements from the Solar Maximum Mission and Compton Gamma Ray Observatory probe. His work inspired the High Energy Solar Spectroscopic Imager (HESSI) mission, which he also served as a co-investigator and founding member. The HESSI was NASA's sixth Small Explorer (SMEX) mission and was launched on February 5, 2002. It was renamed after the launch to the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) and is the first space mission named after a NASA scientist.

Dr. Ramaty received several awards for his research including: the Exceptional Scientific Achievement Medal from NASA in 1981, the Lindsay Award in 1980, a Senior U.S. Scientist Award from the Alexander von Humboldt Foundation in 1975, and the Yodh Prize for lifetime achievement from the International Cosmic Ray Conferenced. The University of Maryland held "A Tribute to Reuven Ramaty's Contributions to High-Energy Solar Physics and Astronomy" on December 11, 2000. He also served as Chairman of the High-Energy Astronomy Division of the American Astronomical Society, Chairman of the Division of Astrophysics and Divisional Councilor for Astrophysics of the American Physical Society, and the Associate Editor of Physical Review Letters. He was a visiting scientist at Caltech, Stanford University, University of California (Berkeley and San Diego), University of Pennsylvania, Washington University in St. Louis, and Nagoya University in Japan.

Neil Gehrels, Ph.D. (1952–2017)

Neil Gehrels began as an undergraduate at the University of Arizona in music but added physics to his studies. He followed his physics passion to Caltech and as a graduate student worked under Robbie Vogt, the R. Stanton Avery Distinguished Service Professor of Physics, Emeritus and Ed Stone, the David Morrisroe Professor of Physics and project scientist of the Voyager mission. Gehrels also worked on calibrating a cosmic-ray instrument on Voyager and that instrument detected the full intensity of cosmic rays when Voyager 1 entered interstellar space in 2012. Gehrels discovered speeding oxygen and sulfur particles in 1979 when the Voyager 1 and 2 flew past Jupiter. These particles were discovered to have origins of volcanos on Jupiter's moon, Io. This discovery was the subject of Gehrels' Caltech Ph.D. He moved to Maryland to work at GSFC in 1980 and began studying highly energetic gamma rays from space. He developed balloon experiments in the late 1980s to study gamma rays from the center of the Milky Way galaxy and from supernovas in other galaxies. He was the project scientist for the Compton Gamma-Ray Observatory from 1991 to 2000. Gehrels served as the principal investigator for Swift, the successor of Compton, from 1999 until his death in 2017. He discovered that gamma-ray bursts likely come from tremendous supernova explosions as well as collisions between neutron stars. He was also the Director of the NASA Astroparticle Physics Laboratory.

Dr. Gehrels received numerous rewards for his research including: the NASA Exceptional Scientific Achievement Medal, NASA Outstanding Leadership Medal, and Goddard's John C. Lindsey Memorial Award, Caltech Distinguished Alumni Award, Physical Sciences Award from the Washington Academy of Science, the Henry Draper Medal from the National Academy of Sciences, and he shared the Dan David prize with Shrinivas Kulkami, the John D. and Catherine T. MacArthur Professor of Astronomy and Planetary Science and director of Caltech's Optical Observatories, and Andrzej Udalski of Warsaw University Astronomical Observatory. He was also a member of the National Academy of Sciences, the

International Academy of Astronautics, and a fellow of the Royal Astronomical Society and the American Association for the Advancement of Science.

Michael H. Freilich, Ph.D. (1954–2020)

Michael H. Freilich was born on January 14, 1954, and grew up in Ardmore, Pennsylvania. He attended Haverford High School and joined the school's oceanography club, which led to a lifetime quest to understand, explain, and interact with the planet's natural forces. He graduated from Haverford College in 1975 with bachelor's degrees in physics and chemistry. He received his Ph.D. in oceanography from Scripps Institution of Oceanography at the University of California at San Diego in 1982. In 1983, Freilich joined the JPL as a mission principal investigator, where he worked until 1991. When he joined in 1983, he was hired as the Scatterometer (NSCAT) project scientist. He was also part of the team analyzing data collected from the Seasat, an Earth-observing satellite that NASA flew in 1978 for 90 days. He served as a science lead on three NASA orbital missions to measure global ocean surface winds. He worked with a team to establish a successful partnership in 1989 with the National Space Development Agency of Japan, which later became the Japan Aerospace Exploration Agency (JAXA). NSCAT demonstrated the value of surface wind observation for science and operational weather forecasts. While NSCAT ended prematurely after only nine months of data collection, Freilich set to work with a team developing SeaWinds, a follow-up NASA scatterometer. In 1992, he accepted the position of associate professor of oceanography at Oregon State University. However, prior to leaving JPL, Freilich made an agreement where he was able to continue his leadership in scattermetry from OSU as a NASA mission principal investigator for QuickSAT and SeaWinds, a role he filled throughout his time at OSU. Freilich stayed at OSU for 14 years as a professor and as an associate dean from 2002 to 2006. He rejoined NASA's JPL in 2006 as the Director of the Earth Science Division. Freilich was a supporter of the international Committee on Earth Observation Satellites (CEOS), Land Surface Imaging (LSI) Constellation, and USGS. In 2008, he supported the Department of Interior's decision to make Landsat data open and free to the public. He led the revitalization of the U.S.'s Earth observing research missions through significant innovation, private sector partnerships, and the expansion of interagency and international partnerships.

Dr. Freilich received several rewards for his research including: an elected Fellow of the American Meteorological Society, JPL's Director's Research Achievement Award, NASA Public Service Medal, Distinguished Presidential Rank Award, Distinguished Achievement Award, NASA's Distinguished Service Medal and AMS Verner Suomi Award.

Jakob van Zyl, Ph.D. (1957–2020)

Jakob van Zyl was a native of Namibia and graduated from Stellenbosch University in South Africa with a degree in electronics engineering in 1979. He moved to the U.S. and graduated with a master's (1983) and Ph.D. (1986) in electrical engineering from Caltech. In 1986, van Zyl joined the JPL and worked on the design and development of the synthetic aperture radar (SAR) systems, including SIR-C, SRTM, AIRSAR, TOPSAR, and GeoSAR. He was the Director of Astronomy and Physics from 2006 to 2011, Associate Director of Project Formulation and Strategy from 2011 to 2015, and the Director of Solar System Exploration from 2016 to 2019. In 2015, van Zyl received an honorary doctorate from Stellenbosch University for his contributions to space missions, contributions as an ambassador for Africa, and for inspiring young scientists and engineers in his home continent of Africa. He managed the implementation and operations of Earth science missions and instruments at JPL. He was a leader of the Solar System Exploration Directorate through the Juno, Dawn, Cassini missions, and through the implementation of InSight and MARCO. Van Zyl was part of the ongoing development of the Europa Clipper, Psyche, and all the JPL instruments and Mars Helicopter for Mars 2020. He retired from JPL in 2019 and co-founded Hydrosat, a startup to develop satellites to measure ground moisture for agricultural applications. Following his death in 2020, NASA's JPL designated the Perseverance rover's observation point as the Van Zyl Overlook, which will record the Ingenuity helicopter tests. The Ingenuity helicopter was one of van Zyl's last projects at JPL. Many of the Mars 2020 staff worked alongside van Zyl and the designation is to pay tribute to their colleague.

Dr. van Zyl received several awards for his research including Fred Nathanson Memorial Radar Award in 1997 for the advancement of radar polarimetry, radar interferometry, and SAR from the Aerospace and Electronics Society of the IEEE and the Distinguished Achievement Award in 2010 from the Geoscience and Remote Sensing Society of the IEEE.

Suzanne Dodd

Suzanne Dodd is from Gig Harbor, Washington and attended Whitman College in Walla Walla, which has a 3-2 engineering program with Caltech in Pasadena, California. She transferred to Caltech after three years at Whitman College and received a bachelor's degree in mathematics/physics from Whitman and a bachelor's degree in mechanical engineering and applied science from Caltech. She received a master's degree in aerospace engineering from the University of Southern California. She began her career at NASA's JPL as part of the Voyager mission in 1984, while the Voyager 2 was en route to Uranus. She was a sequence designer for Voyager 1 when it was on its way to Uranus. She was responsible for commanding the closed approach sequence on the Voyager's flyby of Neptune. Dodd moved on to other projects at JPL in 1989 including the Cassini mission to Saturn. She left JPL for the Spitzer Science Center in 1999 and later, the Infrared Processing and Analysis Center, which archives infrared astronomy data. She has managed the Spritzer Science Center, the Infrared Processing and Analysis Center, and NASA's NuSTAR space observatory. She returned to the JPL and the Voyager mission in 2010.

Suzanne Dodd has received several rewards for her research including: NASA's Exceptional Service Medal, NASA Public Service Medal, NASA Silver Achievement Medal, and NASA Outstanding Leadership Medal.

Lori Glaze, Ph.D.

Lori Glaze is from Arlington, Texas and graduated from the University of Texas with a bachelor's (1985) and master's (1988) in physics. In 1994, she received her Ph.D. from Lancaster University, England in environmental science. Dr. Glaze was the Vice President of Proxemy Research, a private research facility before working at the JPL. Her research is focused on theoretical models for the dynamics of explosive volcanic eruption plumes and the emplacement of lava flows on Earth, Venus, Mars, and Io. She has made concentrated efforts to move NASA back to exploring Venus, including serving as the Chair of the Venus Exploration Analysis Group (VEXAG) and as a member of NASA's Advisory Council's Planetary Science Subcommittee from 2013 to 2016. Dr. Glaze has worked as the Deputy Director for the Solar System Exploration Division and will serve as the principal investigator of the upcoming missions to Venus, the DAVINCI mission and the VERITAS mission.

Dr. Glaze's research interests include the physical processes in terrestrial and planetary volcanology, atmospheric transport and diffusion processes, geological mass movements, environmental and geological hazards, and data analysis and theoretical modeling of surface processes on all terrestrial solar system bodies.

Lori Glaze is a leading NASA scientist and the Director of the Planetary Science Division. Prior to this, Glaze was the chief of the Planetary Geology, Geophysics and Geochemistry Laboratory at NASA's GSFC in Maryland and was the Deputy Director of Goddard's Solar System Exploration Division. She was a member of the Inner Planets Panel during the 2013 Planetary Science Decadal Survey and was on the Executive Committee of NASA's Venus Exploration Analysis Group (VEXAG) as the group's chair from 2013 to 2017.

John C. Mather, Ph.D.

John C. Mather was born on August 7, 1946, in Roanoke, Virginia. He received a bachelor's degree in physics from Swarthmore College, Pennsylvania in 1968 and a Ph.D. in physics from the University of California, Berkeley in 1974. As a National Research Council postdoctoral fellow, he led the proposal effort for the COBE mission (1974–1976) at the Goddard Institute for Space Studies in New York. In 1976, he became a Study Scientist of GSFC and in 1988, he became a Project Scientist and the Principal Investigator for the FIRAS on the COBE. Mather's research on COBE data focused on finding evidence of the Big Bang theory and how stars and galaxies form. The cosmic microwave background radiation was first registered in 1964 and Arno Penzias and Robert Wilson were awarded a Nobel Prize in Physics in 1978 for that discovery. Building upon that research, Mather and George Smoot from the University of California, Berkeley precisely measured the temperature and spectrum of the cosmic microwave background, which represented the afterglow of the big bang that has cooled considerably but does still exist. Mather and Smoot found slight temperature fluctuations within the near uniform light and these fluctuations make life possible. Without the fluctuations, stars, galaxies, and planets would not have formed. Over the course of billions of years, gravity allowed the denser and warmer pockets to attract more matter and heat, which ultimately gave rise to stars, galaxies, and the structure of today. Mather was a driving force behind the COBE project, which also indicated that cosmic background radiation's spectrum corresponds to black-body radiation or radiation emitted by a dark, glowing body. The result provided evidence that the background radiation is a remnant from the creation of the universe in the Big Bang.

Dr. Mather has received numerous rewards for his research including the John C. Lindsay Memorial Award, National Air and Space Museum Trophy, AIAA Space Science Award, Aviation Week and Space Technology Laurels for Space/Missiles, Dannie Heinemann Prize for Astrophysics, Rumford Prize, Benjamin Franklin Medal in Physics, Nobel Prize in Physics, and Gruber Cosmology Prize. His research interests include cosmology, far infrared astronomy and instrumentation, and Fourier transform spectroscopy.

James E. Hansen, Ph.D.

James E. Hansen was born in 1941 and earned his Ph.D. from the University of Iowa. He began at NASA's GSFC in 1967 with his first atmospheric science quarry on the climate of Venus. He created one of the first climate models of Earth and delved into applied energy research. He is most well-known for his research into the impacts of climate change on Earth. He was also a pioneer in the use of computer models to document early evidence of human influence on the global climate. In 1988, he warned Congress of the implications of rising concentrations of carbon dioxide in the atmosphere. He began his activism career more than a decade ago in the early 2000s when he began to speak out forcefully against government inaction regarding climate change and global warming.

Dr. Hansen has received numerous rewards for his research including: the Heinz Award in the Environment, the Leo Szilard Award from the American Physical Society for Understanding Promotion and Use of Physics for the Benefit of Society, the AAAS Award for Scientific Freedom and Responsibility, Sophie Prize in 2010 for his key role in the understanding of climate change, Blue Planet Prize in 2010, and was named one of TIME Magazine's 100 most influential people in 2006.

James E. Hansen was a key contributor to understanding human-induced climate change and was an early predictor of global warming. He began studying the climate of other planets but in the 1970s shifted his focus to the climate of Earth. In 1988, he testified before Congress about the probability that human-induced climate change was a threat to the planet. He met resistance and censorship throughout his career, but he continued to research and advocate against climate change. He served as the head of the Space Studies Division at GSFC until his retirement in 2013.

Edward C. Stone, Ph.D.

Edward C. Stone was born in Knoxville, Iowa in 1936 and graduated from Iowa's Burlington Junior College in 1956. He earned his Ph.D. in physics from the University of Chicago in 1964. He started as a research fellow at Caltech in 1964 and joined the faculty as an assistant professor in 1967. He became the Morrisroe professor in 1994 and the vice provost for special projects in 2004.

In 1972, Stone was the project scientist for the Voyager mission, and he was the project scientist for 47 years. Since the launch of the Voyager spacecrafts in 1977, Stone has led and coordinated 11 instrument teams on the project. He served as the Director of the JPL from 1991 to 2001 and oversaw multiple missions. During his career at the JPL, he was responsible for missions and technology including Magellan, Galileo, Ulysses, TOPEX/Poseidon, Mars Observer, Hubble Wide Field/Planetary Camera, Shuttle Imaging Radar, NASA Scatterometer, Mars Global Surveyor, Mars Pathfinder/Sojourner, Cassini/Huygens, Deep Space 1, QuickSCAT, ARCRIMSAT, Stardust, Mars Climate Orbiter, Mars Polar Lander, Shuttle Radar Topography Mission, Mars Odyssey, Genesis, and Jason 1. He played a key role in the development of the W.M. Keck Observatory in Hawaii. From the mid-1980s through the 1990s, he served as the vice chairman and chairman of the board of directors for the California Association for Research in Astronomy, which was responsible for building and operating the Keck Observatory. He is also involved in the planning and development of the Thirty Meter Telescope, an international partnership between the U.S., Canada, China, Japan, and India.

Dr. Stone has served as a principal investigator on nine missions, co-investigator on five additional missions, authored more than 1,000 publications in professional journals and conferences, and has mentored students, postdocs, and research scientists. He has received numerous rewards for his research including: the President's National Medal of Science in 1991, the Magellanic Premium in 1992, the Carl Sagan Memorial Award in 1999, the Philip J. Klass Award for Lifetime Achievement in 2007, the NASA Distinguished Public Service Medal in 2013, the Howard Hughes Memorial Award in 2014, and the Shaw Prize in Astronomy in 2019 for his leadership in the Voyager project, which has transformed the understanding of the four giant planets, the outer solar system, and interstellar space over the last four decades. The Voyager team and Stone also won a Breakthrough Award from Popular Mechanics.

Paul A. Newman, Ph.D.

Paul A. Newman is a Seattle native who graduated from Seattle University in 1978 with a bachelor's degree in physics and a minor in mathematics. He completed is Ph.D. in physics at Iowa State University in 1984 and was a National Research Council fellow from 1984 to 1986. He worked at the Applied Research Corporation from 1986 to 1989 and the Universities Space Research Associates from 1989 to 1990. Newman joined NASA in 1990 to research stratospheric dynamics and chemistry. NASA's first satellite instrument to measure ozone depletion was put in space in 1970 and the first Antarctic ozone hole pictures were taken in 1985. Since the early 1990s, the GSFC has been instrumental in leading updates to the Scientific Assessment of Ozone Depletion, evaluating how policies impact the atmosphere, and setting new marks for international scientific cooperation. Newman has been a significant asset to the GSFC's research into ozone depletion. He has participated in numerous aircraft field campaigns and leads the GSFC's efforts to analyze data collected from high altitude NASA ER-2 and NASA DC-8, which provide high resolution information about the stratosphere. He also collaborated with various groups in the Atmospheric Chemistry and Dynamics Laboratory on 2-D modeling, 3-D modeling, trajectory analyses, STROZ-LITE lidar work, and the analysis of SBUV and TOMS ozone observations. He is mostly involved in the analysis of stratospheric meteorological and trace gas observations.

Dr. Newman has received several rewards for his research including: the United Nation's highest environmental honor, the Champion of the Earth award, in 2017, and the Cleveland Abbe Award for Distinguished Service to the Atmospheric and Related Sciences by the American Meteorological Society. He received the Cleveland Abbe Award for his sustained leadership and service to science resulting in strengthened policy development for the Montreal Protocol, which is a global agreement to protect the Earth's ozone layer by phasing out chemicals that deplete it. He was significant in the most recent amendment, the Kigali Amendment, which calls for the phase-down of hydrofluorocarbons (HCFs).