Rocket Systems Area

Plum Brook Station 1961–1974

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Glenn Research Center

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ROCKET SYSTEMS AREA

In the 1960s NASA Glenn Research Center's[1] remote testing facility at Plum Brook Station in Sandusky, Ohio, was an essential element in the development of liquid-hydrogen propulsion systems for rocket engines. At its peak, Plum Brook contained 15 different facilities with at least 24 test rigs and cells. This Web site is dedicated to the Rocket Systems Area—a collection of smaller facilities that tested turbopumps, engine components, and propellant tanks for these hydrogen-powered rocket systems. Glenn's development of hydrogen pumping, handling, and storage systems was critical to the success of the Saturn and Centaur upper-stage rockets, the development work for proposed nuclear rockets, and future long-duration human missions to other planets.

J-1 Firing

The Rocket Systems Area contained the Liquid Hydrogen Pump Facility (A Site), the Turbopump Facility (C Site), the Controls and Turbine Test Facility (D Site), the Dynamics Stand (E Stand), the Hydraulics Laboratory (F Site), the Pump and Turbine Facility (Pilot Plant or G Site), the Fluorine Pump Facility (I Site), the Rocket Systems Test Laboratory (J Site), and the Cryogenic Propellant Tank Facility (K Site). The Rocket Systems Area also included two larger test stands: the High Energy Rocket Engine Research Facility (B–1) and the Nuclear Rocket Dynamics and Control Facility (B–3).

NASA closed Plum Brook Station and the Rocket Systems Area in 1974 as budgets for long-term projects were cut. Plum Brook reopened in the late 1980s, but the Rocket Systems Area was not sound enough to be brought back online. Despite the eventual demolition of the Rocket Systems Area, Plum Brook Station remains active today, operating several large test facilities—including the world's largest vacuum chamber, a rocket test stand that can fire upper-stage rockets in simulated space conditions, and a hypersonic wind tunnel.

[1]NASA Glenn has undergone numerous name changes over the years but will be primarily referred to as the Lewis Research Center, or just Lewis, on this Web site.

Documents:

- Plum Brook Tour Brochure (1960s) (PDF, 4.88MB)
- Plum Brook Facilities (c1970) (PDF, 1.95MB)
- Plum Brook Station's Current Test Facilities

RSA Site montage

Control Room

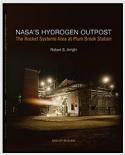
I Site Rig

Atlas Arrival

K Site Chamber

NASA'S HYDROGEN OUTPOST

NASA's Hydrogen Outpost: The Rocket Systems Area at Plum Brook Station (PDF, 92.5 MB) (NASA SP-2016-628) provides an in-depth look at the Rocket Systems Area's research, facilities, and personnel based at NASA Glenn Research Center's remote testing area at Plum Brook Station. This history also examines the critical role the center played transforming liquid hydrogen's theoretical potential into a flight-ready propellant. The Rocket Systems Area—with its nine test sites and three test stands—played a little known, but important role in the center's hydrogen research efforts in the 1960s and early 1970s. NASA has utilized liquid hydrogen for the Apollo missions, to propel dozens of spacecraft across the universe, orbit scores of satellite systems, and power the space shuttle. The book also describes the Rocket Systems Area's contributions to the development of hydrogen technologies for nuclear rockets to send humans on long-duration journeys to other planets.



NASA Center for AeroSpace Information (CASI)
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http://ntrs.nasa.gov/search.jsp
help@sti.nasa.gov

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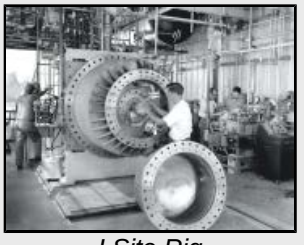
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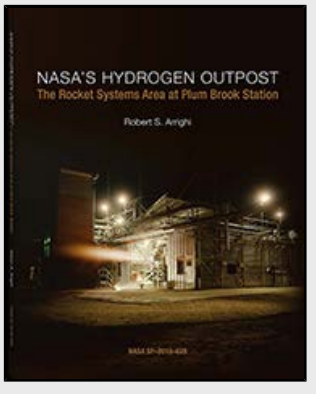

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HISTORY

J–2 Rocket Stand

The Rocket Systems Area sites provided important, but unrecognized, support to Lewis Research Center's high-energy propellant research in the late 1950s and 1960s. Lewis began to study liquid fuels for rocket engines after World War II. As the effort grew in the 1950s, management realized that additional rocket facilities would pose potential danger at the crowded Lewis campus. In 1958 the Center leased 2760 acres at the military's unused Plum Brook Ordnance Works (PBOW) in Sandusky, Ohio, to build a series of new test sites known as the Rocket Systems Area.

Lewis researchers used the Rocket Systems Area to perfect methods for pumping and storing high-energy cryogenic fluids such as liquid hydrogen, liquid oxygen, and fluorine. The site also included a shake tower to verify the structural integrity of missiles in simulated launch conditions. In the 1960s, the Rocket Systems Area also supported two major programs—the Centaur upper-stage rocket and the Nuclear Engine for Rocket Vehicle Application (NERVA). Budget cuts forced NASA to terminate operations at the Rocket Systems Area in 1974, and the Agency demolished the sites in the 2010s.

Read more about the history:

I. Design and Construction: NASA Lewis Research Center acquired the Plum Brook property in several stages in the late 1950s and early 1960s and constructed a number of test sites to study liquid-hydrogen rocket systems.

II. Turbopump Research: NASA used the Rocket System Area to perfect methods for pumping the cryogenic hydrogen propellant from the tank to the engine.

III. Centaur Testing: Lewis used the Rocket System Area to test the structural dynamics of the Atlas-Centaur, the Centaur Standard Shroud, and proposed insulation systems.

IV. Nuclear Rocket Research: The Rocket Systems Area tested the propellant flow system, the heat exchanger, and nozzle cooling for nuclear rocket systems.

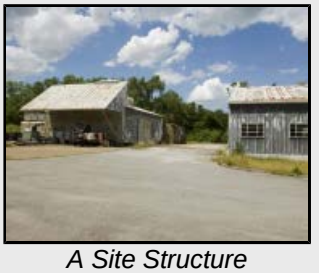
V. Tank Research: The Rocket System Area tested insulation systems, structural integrity, and expulsion alternatives for liquid-hydrogen tanks.

VI. Shutdown: NASA ceased its research at Plum Brook Station in 1974. Lewis reopened the station in the late 1980s and brought several of the facilities back online. Not one of the facilities in the Rocket Systems Area, however, was included.

Pilot Plant Construction

Pilot Plant Interior

D Site Controls



A Site Structure

History
Rocket Systems Area

DESIGN AND CONSTRUCTION

E Stand Construction

The NASA Lewis Research Center began experimenting with high-energy propulsion systems for rockets in the mid-1940s. After comparing the performance and handling difficulties of many fuels, researchers determined that liquid hydrogen was the optimal propellant. To mitigate the danger of testing high-energy propellants at the Center, NASA built its new test sites at the sprawling Plum Brook Ordnance Works (PBOW) in Sandusky, Ohio. The majority of these new Rocket Systems Ares sites became operational in 1961.

LIQUID HYDROGEN

Rocket Engine Test Facility

Early rocket scientists Konstantin Tsiolkovsky and Robert Goddard foresaw the benefits of using liquid hydrogen to fuel rocket engines. Hydrogen, however, which must be kept at –423 °F to retain its liquid form, was difficult to manufacture and even more difficult to handle. After the success of the German's liquid-kerosene-fueled V—2 rocket during World War II, the U.S. military became interested in developing missile technology. The military also sponsored studies of liquid hydrogen as a fuel at the Ohio State University, the Jet Propulsion Laboratory, and Aerojet. Although these programs yielded some positive results, the military's interest had waned by 1950. It was at this time that Lewis researchers began increasing their studies of high-energy propellants.

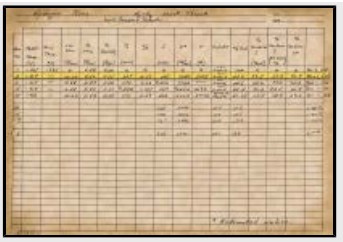
In 1941 the National Advisory Committee for Aeronautics (NACA) established the Aircraft Engine Research Laboratory (the future Lewis and Glenn Research Centers) in Cleveland, Ohio. It was the NACA's third research laboratory and the only one dedicated to engines. By the mid-1940s the lab focused its energy on the new turbojet, ramjet, and rocket technologies that emerged during World War II. Researchers in the rocket field concentrated on the study of high-energy propellants and engine cooling.

The lab built a small collection of outdoor test cells, known as the Rocket Lab, to facilitate the studies. The researchers first examined propellants with extremely high theoretical values such as diborane and hydrazine. These performed much better than traditional rocket fuels, but were very toxic and difficult to handle. In the early 1950s Lewis researchers began focusing on liquid hydrogen. In 1954, they successfully burned gaseous hydrogen in a turbojet combustor and fired a small liquid-hydrogen/liquid-oxygen rocket engine. These early studies demonstrated hydrogen's capabilities and led to further development.

Documents:

- Liquid Hydrogen as Jet Fuel for High-Altitude Aircraft (PDF, 1.9MB)
- Liquid Hydrogen as a Propulsion Fuel, 1945–1959
- "Seizing the Space Initiative"

Rocket Lab



Rocket Lab Logbook

Engine at Rocket Lab

PLUM BROOK STATION

Plum Brook Station

In early 1941 the U.S. Government seized roughly 9000 acres of farmland near Sandusky, Ohio, to construct the PBOW. This fenced-in industrial complex produced trinitrotoluene (TNT), dinitrotoluene (DNT), and pentolite powder for shells during World War II. The PBOW ceased production immediately after the war and remained vacant for 10 years. In 1955 the NACA leased 500 acres at the PBOW to build a nuclear test reactor.

The NACA became a part of the new National Aeronautics and Space Administration (NASA) in 1958. The new Agency leased an additional 2725 acres at Plum Brook to build a series of rocket test facilities known as the Rocket Systems Area. NASA also began planning other facilities, such as the Spacecraft Propulsion Research Facility (B–2) and the Space Power Facility (SPF). PBOW was officially renamed Plum Brook Station in February 1962. On March 15, 1963, Lewis officially took control of the 500 acres leased for the reactor, the 2725 acres leased for the Rocket Systems Area, and the remaining 2800 acres. NASA decided to raze the unwanted PBOW structures at this time.

Documents:

- Saga of the Plum Brook Ordnance Works (PDF, 2.3MB)
- NACA Construction House Bill (PDF, 2.0MB)
- Additional Facilities to be Built at Plum Brook (PDF, 40KB)
- Evaluation of Plum Brook Ordnance Works (PDF, 75KB)
- Science in Flux: NASA's Nuclear Program at Plum Brook (PDF, 2.3MB)

Administration Building

TNT Storage Bunker

Property Review

Burning Buildings

DESIGN AND CONSTRUCTION

E Stand

Lewis engineers began designing the new Rocket Systems Area facilities in the fall of 1957. They based several of the facilities on smaller rigs previously built at Lewis. Construction crews began preparing the new test sites in the fall of 1958, and many of the buildings were in place in the following spring. The installation of the infrastructure, test equipment, data systems, and other components required years of additional work. The facilities then went through months or years of checkout runs to verify that the equipment functioned properly.

In December 1958, the Pilot Plant (G Site) became the first facility to be completed. Engineers incorporated PBOW equipment into the facility's design to expedite the construction. The Dynamics Stand (E Stand), the Turbopump Facility (C Site), and several of the rigs at the Rocket Systems Test Laboratory (J Site) began operating in the summer of 1961. The Fluorine Pump Facility (I Site), Liquid Hydrogen Pump Facility (A Site), and the Tank Test Facility (J–4) went online in the spring of 1962, and the Hydraulics Laboratory (F Site) began its checkouts in April 1963. The High Energy Rocket Engine Research Facility (B–1) test stand was completed in late 1963. The Cryogenic Propellant Tank Facility (K Site) and the Nuclear Rocket Dynamics and Control Facility (B–3), which Lewis later added to the plan, were completed in the fall of 1965 and March 1966, respectively.

Documents:

E Site Progress Report (PDF, 0.7MB)
Two Facilities Completed at Plum Brook (PDF, 1.6MB)
Plum Brook Today (PDF, 1.7MB)
Plum Brook in the Space Age (PDF, 0.8MB)
Construction of the B–1 and B–3 Test Stands

F Site Construction

Pilot Plant Controls

First Test

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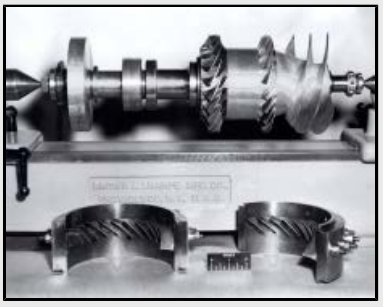
TURBOPUMPS



3-Stage Turbopump

Turbopump test facilities were an integral component of the Rocket Systems Area. High-performance liquid-fueled rockets require turbopumps to pump the fuel and oxidizer from their tanks to the fuel injectors at high rates of speed. These devices must operate at hundreds of rotations per minute and be able to restart themselves numerous times during a mission. Hydrogen pumps pose particular challenges. Hydrogen is usually stored just under its –423 F boiling point so it is often evaporating, forming bubbles, as it enters the pump. Researchers strove to reduce this cavitation, which causes inefficiencies and can damage the hardware. Engineers designed impellers and inducers at the pump's inlet to reduce the effects of cavitation.

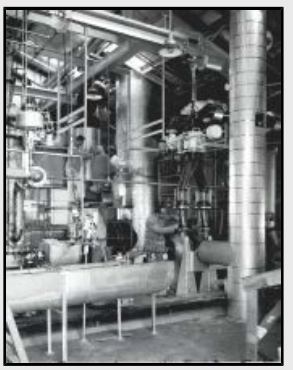
The Liquid Hydrogen Pump Facility (A Site) tested inlets and inducers for hydrogen and oxygen pumps, the Turbopump Facility (C Site) analyzed pumps in boiling hydrogen, the Controls and Turbine Facility (D Site) tested turbines that powered the pumps, the Pilot Plant (G Site) studied small-scale pump components, and the Fluorine Pump Facility (I Site) focused on liquid-fluorine pumping. NASA Lewis Research Center research was key to the manifold increase in turbopump performance during the 1960s.

Documents:

- NASA Axial-Flow Turbopump
- NASA Centrifugal Turbopump
- Liquid Rocket Turbopump Inducers

IMPELLERS AND INDUCERS

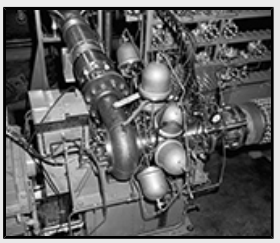
Researchers used A Site's hydrogen test loop to study different impeller and inducer designs on centrifugal and axial-flow turbopumps. They were particularly interested in the coordination of different inducer and impeller designs to optimize flow and limit the effects of cavitation. Each test was run over three speeds while the liquid-hydrogen flow decreased from a maximum level to the point where the pump stopped. The researchers found that inducers with a flow rate that was higher than that of the impeller reduced cavitation but did little to stabilize the propellant flow. They also used A Site to compare the performance of impellers with and without shrouds, which were designed to prevent recirculation of the fluid.



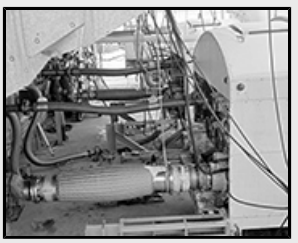
A Site Rig

Documents:

- Flow Range and Stability of Three Inducer-Impeller Combinations (PDF, 13MB)



A Site Test Rig



Hydrogen Trailers

Inducers

A Site Controls

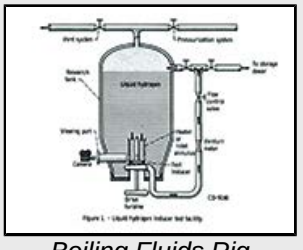
CAVITATION

Insufficient pressure in the propellant flow lines can cause the cryogenic liquid hydrogen to boil. This results in pockets of air, known as cavitation, that impair the performance of the turbopump and eventually cause physical degradation. NASA designed the Boiling Fluids Rig at C Site specifically to study pumps operating in cavitating conditions. The experimental turbopump was submerged in a large tank of boiling hydrogen. Lewis researchers conducted extensive studies into the relationship between inducer and pump performance. Inducers were spiral-shaped rotors that increased flow into the pump inlet. They analyzed the inducer blade thickness and angles, the length of the propellant supply line, and the effect of radiation heating on the fluid. They also investigated the pumping of colder slush hydrogen, which could reduce the size of the fuel tanks.

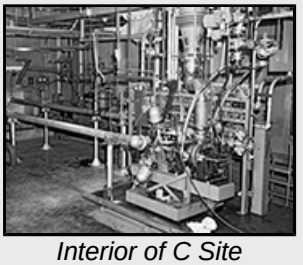
Boiling Fluids Rig

Reports:

- Performance of 78° Helical Inducer in Hydrogen (PDF, 10MB)
- Effect of Leading Edge Thickness on Inducer Performance (PDF, 1.2MB)
- Performance of Line-Mounted 80° Inducer in Hydrogen (PDF, 7.8MB)
- Performance of Helical Inducer Operated in 37 and 42 °R Hydrogen (PDF, 10MB)
- Change in Pressure Requirement in Low Temperature Hydrogen (PDF, 2.2MB)

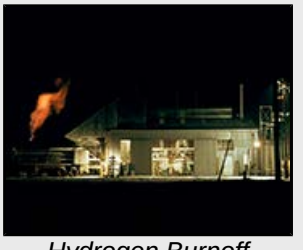


Boiling Fluids Rig



Interior of C Site

Instrumentation



Hydrogen Burnoff

FLUORINE PUMPS

In the 1960s rocket designers were interested in using liquid fluorine as an oxidizer with the liquid-hydrogen fuel. Fluorine was lighter and produced more energy than the traditional liquid oxygen, but it was extremely toxic and volatile. Researchers used the large test chamber at J–5 to study the ability of certain seal materials to withstand exposure to high-power fluorine or fluorine/oxygen flow present in turbopumps. They also erected an external stand at J–5 to investigate the effect of a fluorine spill on various materials commonly found at launch sites, including sand, gravel, water, and other fuels. Some interactions yielded fiery explosions and others lingering toxic fumes. The researchers identified charcoal as a good mitigation tool.

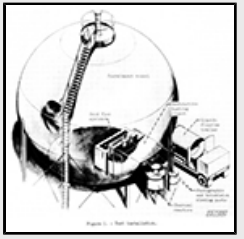
Fluorine Spill Rig

Researchers from Lewis and Pratt & Whitney used I Site to investigate the use of liquid fluorine in turbopumps. Lewis conducted a multiyear study of a centrifugal pump with an inducer to improve performance in cavitating conditions and seals made from Kentanium (tungsten carbide) K–162B (Kennametal Inc.). Despite an explosion that gutted I Site, the program successfully demonstrated that cavitation would not be a significant problem for fluorine pumps. Pratt & Whitney testing in I Site demonstrated that fluorine could be substituted for oxygen in the turbopumps for their successful RL–10 engines. Despite Lewis' overall success with liquid fluorine, there have been no commercial fluorine rocket engines to date.

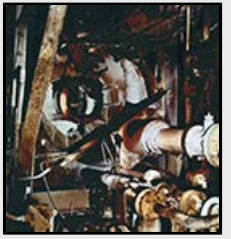
Reports:

- Handling of Fluorine Mixtures in Rocket Systems (PDF, 13.4MB)
- Compatibility of Materials with Fluorine Mixtures (PDF, 9.2MB)
- Reaction of Spills of Fluorine upon Various Materials (PDF, 3.3MB)
- Operation of Liquid Fluorine Pump in Cavitating Flow (PDF, 11.2MB)

J-5 Hortonsphere



J-5 Layout



Pump Damage

I Site

History
Rocket Systems Area

CENTAUR

Atlas Centaur-3

General Dynamics designed the Centaur rocket in 1957 and 1958 as a second-stage for its Atlas missile. The vehicle was powered by two Pratt & Whitney liquid-hydrogen-fueled RL–10 engines, the first commercially produced hydrogen engines. NASA sought to use the Atlas-Centaur to send Surveyor spacecraft to explore the lunar surface before the Apollo landings. However, the new vehicle suffered a number of developmental problems that culminated with the explosion of its first launch attempt in 1962. NASA decided to put Lewis Research Center, with its hydrogen experience, in charge of program. After several years of intensive work, an Atlas-Centaur successfully launched the first Surveyor in 1966. Centaur has since launched hundreds of spacecraft and satellites and continues to serve as the Nation's primary space tug. The Rocket Systems Area made several contributions to the Centaur Program.

Documents:

- Taming Liquid Hydrogen: The Centaur Upper-Stage Rocket (PDF, 2.16MB)
- Centaur Launch (1962–2012)
- History of Centaur (press release, 1984)

PROPELLANT TANK INSULATION

Centaur required insulation to keep the cryogenic liquid-hydrogen fuel from evaporating during the launch. General Dynamics designed foam insulation panels that were jettisoned as the vehicle exited the atmosphere. The failure of those panels caused the loss of the first Atlas-Centaur launch. Lewis researchers explored a new insulation system that would remain intact throughout the mission. They analyzed several different options before pursuing a system that used a Mylar (Dupont Tejjin Films) and aluminum wrap to affix foam panels to the Centaur tank. The researchers first tested the performance of the system on a small tank at the J–3 and J–4 sites under simulated ground hold and launch conditions. They then applied the insulation to a full-scale tank and tested it at J–4. This constrictively wrapped insulation performed as well as, and was safer than, the existing system, but General Dynamics retained the jettionsable panels until the 1990s.

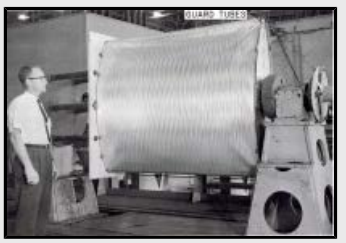
Centaur Tank in J-4

Reports:

- External Insulation System for Hydrogen Tanks (PDF, 24MB)
- Ground Hold Study of Insulation Systems for Hydrogen Tanks (PDF, 2MB)

J-3 Tank

Centaur Insulated Tank



Insulated Centaur Tank

Centaur at E Stand

STRUCTURAL DYNAMICS

Rocket vehicles experienced substantial vibrations during a launch. These vibrations can shake components loose, compromise the vehicle's structure, or disrupt the guidance system. After this phenomena caused the failure of numerous missiles, Lewis designed the Dynamics Stand (E Stand) to test missiles in simulated launch conditions. Researchers used E Stand almost exclusively to test the new Atlas-Centaur vehicle during the 1960s.

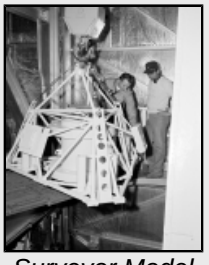
Atlas Installation

Atlas and Centaur were both lightweight vehicles with pressurized balloonlike propellant tanks. Because there was concern regarding their structural integrity in the severe conditions that they would experience, the staff subjected the Atlas with a dummy Centaur to maximum loads and vertical vibrations to verify its strength before the second Atlas-Centaur launch in November 1963. They added an actual Centaur stage for a series of lateral vibration tests with and without a mockup Surveyor spacecraft. Researchers then worked with General Dynamics to demonstrate that the vehicle was stronger than the design specifications indicated. They applied enough force to damage the Atlas tank, but the outer skin retained its seal and pressurization. They then attempted to break the vehicle but could not. The Atlas-Centaur proved to be significantly more robust than originally believed.

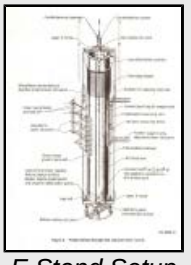
Reports:

Atlas-Centaur-Surveyor Longitudinal Dynamics Tests (PDF, 1.25MB)
Experimental Lateral Bending of Atlas-Centaur-Surveyor (PDF, 1.2MB)
Bending Strength of Atlas Booster Beyond Skin Wrinkling (PDF, 7.8MB)

Centaur Transportation



Surveyor Model



E Stand Setup

Atlas Test

NEW CENTAUR MISSIONS

After proving itself with several Surveyor launches, NASA decided in the late 1960s to use the Atlas-Centaur to launch a series of space probes and satellites. Lewis worked with General Dynamics to improve the Centaur. As part of this process, engineers sought to streamline the flow system by removing the boost pumps. Lewis conducted initial tests at the Rocket Systems Area High Energy Rocket Engine Research Facility (B–1) stand and later at the Spacecraft Propulsion Research Facility (B–2).

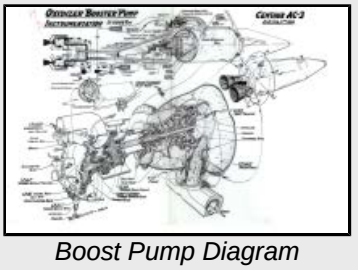
Titan-Centaur Launch

NASA introduced a series of new space exploration missions for the 1970s, including the interplanetary Voyager spacecraft and the Viking Mars landers. To accomplish these heavy launches, NASA paired Centaur with the Titan III launch vehicle. This required the design of a new shroud for the vehicle. Lewis tested this Centaur Standard Shroud in the Nuclear Rocket Dynamics and Control Facility (B–3) test stand and the Space Power Facility.

Documents:

Centaur D–1A (pamphlet, 1973) (PDF, 13.4MB)
Titan/Centaur—NASA's Newest Launch Vehicle (PDF, 9.2MB)
Titan/Centaur Viking B Flight Report (PDF, 3.3MB)

Centaur Shroud



Boost Pump Diagram

Centaur Shroud Test

Preparations at B-3

History
Rocket Systems Area

NUCLEAR ROCKETS

Kiwi-B Nozzle

After World War II, missile and aircraft designers became interested in utilizing the massive power of atomic fission for propulsion. In 1945 the military began sponsoring efforts to develop an atomic aircraft. Engineers, however, could not overcome issues involving the required shielding for the crew or the fear of radiation at crash sites. In 1955 the military partnered with the Atomic Energy Commission (AEC) to develop reactors for nuclear rockets under Project Rover. The nuclear rocket would be an upper stage not fired until it entered space—reducing the threat of crash-induced contamination on Earth. The nuclear rocket would use fission to heat liquid-hydrogen and expel it as thrust at rates that would supersede those of chemical rockets.

NASA became involved in Project Rover in 1959 with the Lewis Research Center serving as the primary center. In 1961 work began on a complete rocket system known as the Nuclear Engine for Rocket Vehicle Application (NERVA). The AEC worked to develop the reactor for the engine, and Lewis concentrated on the vehicle's liquid-hydrogen system. The Rocket Systems Area provided resources to conduct basic research on nuclear engine systems and to test pumping systems for the NERVA effort.

Documents:

- To the End of the Solar System: The Story of the Nuclear Rocket
- The NERVA Nuclear Rocket Program (PDF, 11.1MB)
- A Historical Perspective on the NERVA Nuclear Rocket Program (1991) (PDF, 1.09 MB)

NOZZLE HEAT TRANSFER

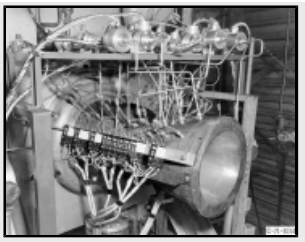
Engineers design nuclear rocket engines to operate at extremely hot temperatures to maximize efficiency. The regenerative cooling system, which flows cold liquid nitrogen through tubes surrounding the nozzle, is an essential element of the design. Unlike chemical rockets, nuclear engines employ a nozzle that narrows sharply before expanding. It was difficult to cool the contraction area. To address this problem, Lewis researchers sought a better understanding of the heat transfer process in the nozzle. They installed experimental copper and steel engines in the J–1 test facility at Plum Brook. After the staff repeated the brief engine firings many times, the researchers used the test results to create a mathematical formula to predict the transfer of heat from the exhaust to the nozzle. They then expanded the investigation by introducing different propellants and injector shapes. They determined that the injector design needed to be tailored to the shape of the nozzle.

Heat Transfer Nozzle

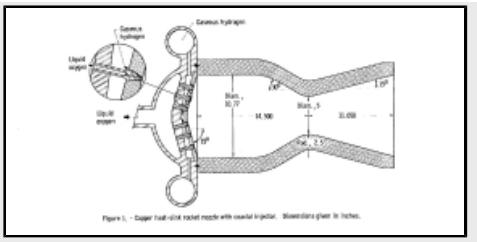
Reports:

- Investigation of Hot-Gas Side Heat Transfer (1965) (PDF, 1MB)
- Hot-Gas-Side Heat Transfer in Hydrogen-Oxygen Rocket (1971) (PDF, 3MB)
- Hot-Gas-Side Heat Transfer with/without Film Cooling (1972) (PDF, 1.7MB)
- Coolant-Side Heat Transfer Rates for Rocket (1973) (PDF, 6.9MB)

J-1 Test Stand



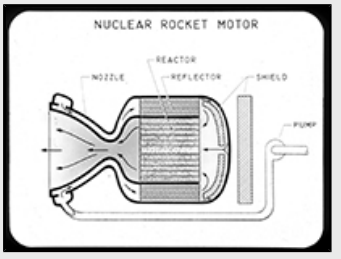
Instrumented Nozzle



Copper Nozzle

HEAT EXCHANGER

Nuclear rocket engine designs included a moderator that used water to slow down fast-moving neutrons. This improved the efficiency of the reactor fission. A heat exchanger transferred the heat from the moderator's water to the cryogenic liquid hydrogen, which cooled the moderator. The exchanger was a tube within a tube. The hot moderator water flowed through the inner tube, and the cold hydrogen flowed through the outer tube. The formation of ice on the heat exchanger's surface posed a potential problem, particularly when the propellant supply was low. The ice could degrade the exchanger's performance and could potentially block the flow passages. In response, Lewis undertook a multiyear effort to measure the ice levels and study the conditions that created the ice.



Nuclear Engine

The researchers installed a triangular 19-tube heat exchanger between the Hydraulics Laboratory's (F Site's) two hydrogen supply tanks to determine whether ice buildup varied on each of the tubes. They flowed the hydrogen and water through the system in opposite directions first, then in the same direction. The tests verified their predictions for conditions without ice formation, but their estimates for when ice was present proved to be significantly low.

Report:

Heat Transfer of Water-to-Hydrogen Heat Exchanger (PDF, 1.25MB)

F Site

Heat Exchanger

PROPELLANT FLOW SYSTEM

NASA was interested in developing nuclear rockets to carry out long-duration human missions to other planets, and the engine's ability to restart under its own power in space was a vital aspect of the design. Similar to chemical rockets such as Pratt & Whitney's RL–10, the nuclear engine would release a small amount of hydrogen to power the turbopump's turbine. The turbine would activate the complete pump, which would supply fuel to the combustion chamber. NASA used the High Energy Rocket Engine Research Facility (B–1) and Nuclear Rocket Dynamics and Control Facility (B–3) test stands to study this bootstrap activity for Kiwi reactor designs.

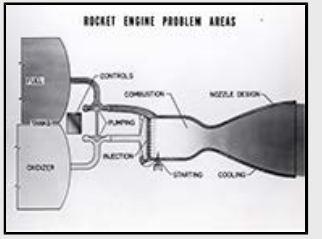
Kiwi Engine in B-1

NASA introduced a series of new space exploration missions for the 1970s, including the interplanetary Voyager spacecraft and the Viking Mars landers. To accomplish these heavy launches, NASA paired Centaur with the Titan III launch vehicle. This required the design of a new shroud for the vehicle. Lewis tested this Centaur Standard Shroud in the Nuclear Rocket Dynamics and Control Facility (B–3) test stand and the Space Power Facility.

Kiwi B Engine at B-1

B-1 and B-3 Stands

B Control Building



Nuclear Engine Problems

Responsible NASA Official: Anne K. Mills
Web Curator: Robert S. Arrighi (Alcyon Technical Services)
Last Updated: 8/12/2016

> Privacy Policy and Important Notices
> Documents and Media Viewers

History
Rocket Systems Area

PROPELLANT TANKS

Tank at K Site

Cryogenic propellant tanks for space applications must be lightweight and sturdy. The tanks use a heavy gas such as helium to naturally push the liquid into the supply line leading to the turbopump. Too much of this pressurant gas would require thicker tank walls, adding to the vehicle's weight. Not enough gas would slow the flow of the cryogenic fluid, resulting in boiling, also known as cavitation. Tanks also require insulation to prevent the cryogenic fuel from evaporating. Lewis Research Center used the Rocket Systems Area to study tank durability, pressurant variations, and insulation systems for both spacecraft and proposed in-space fuel depots.

The Hydraulics Laboratory (F Site) included a pressurized liquid-hydrogen tank, small tanks that could be tested in the J–3 vacuum chamber, and the J–4 stand, which permitted vertical tank testing. The Cryogenic Propellant Tank Facility (K Site), which included a 25-ft-diameter vacuum chamber, was the largest and most frequently used tank-testing site at Plum Brook Station.

Report:

Liquid Rocket Metal Tanks and Components

TANK DURABILITY

Designers sought to minimize the weight of the tank while maximizing its strength. Stainless steel and steel alloys were the preferred materials for cryogenic tanks in the 1960s. The most common method of testing a tank's durability was cold shocking. The tank was filled with liquid nitrogen or another stable cryogenic fluid. The staff then emptied the tank and checked to see if the cold temperatures affected any of the welds, couplings, and lines.

Tank Test at J-4

Engineers used several of the Rocket Systems Area's sites to cold shock a variety of propellant tanks. This was sometimes at the request of the manufacturer, sometimes to check the tank before performing another type of test, and sometimes to recheck it after a test run. The cold shock tests included Centaur tanks in F Site and J–3, the Arthur D. Little tanks at J–4 and K Site, and a variety of tanks ranging from 5 to 13 ft in diameter at K Site.

PRESSURIZATION

Lewis researchers used K Site to study the performance of several pressurant gases and injectors and to determine the effect of internal temperatures on cryogenic propellant tanks. The staff installed the tank in the test chamber, filled it with hydrogen, adjusted the temperature, introduced the pressurant gas, and measured the resulting hydrogen flow from the tank. They varied the injector types and temperatures, introduced vibrations to the tests, and changed the type of gas. The K Site tests assisted Lewis researchers in refining their predictive tools. The researchers also compared the performance of different pressurant gases in tanks containing liquid methane.

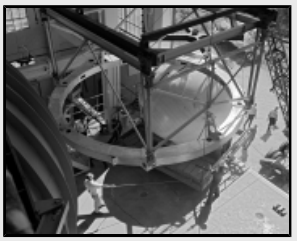
Tank at K Site

Lewis also initiated a study on the necessity of boost pumps for the Centaur propellant flow system. These pumps accelerated the propellant flow from the tank

to the turbopump but also increased the vehicle weight. Researchers conducted tests at the High Energy Rocket Engine Research Facility (B–1) test stand to determine if improved pressurant gas performance eliminated the need for the boost pumps.

Reports:

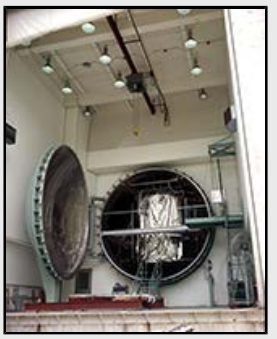
Pressurant for Discharge of Methane From Tank (PDF, 12MB)
Hydrogen Discharge of Hydrogen From 5-ft Tank (1969) (PDF, 4.6MB)
Helium Discharge of Hydrogen From 5-ft Tank (1970) (PDF, 2.8MB)
Hydrogen Discharge of Hydrogen From 13-ft Tank (1969) (PDF, 4.2MB)
Helium Discharge of Hydrogen From 13-ft Tank (1970) (PDF, 2.5MB)


Tank Installation

K Site Model

B-1 and B-3 Test Stands

INSULATION SYSTEMS


Cryoshroud in K Site

NASA researchers used the Rocket Systems Area site to examine methods for insulating cryogenic propellant tanks to prevent fuel evaporation during launch and over time in space on long-duration missions. Even minor temperature increases could lead to the loss of enough fuel to cause a mission failure. By the early 1960s engineers determined that foam or multilayered aluminum was sufficient for short-term missions, whereas the use of shields to block solar radiation were the key to storage on long-term missions.

Lewis analyzed multilayer insulation systems designed by the Linde and Arthur D. Little corporations at the Vacuum Environment Facility (J–3) and Tank Test Facility (J–4). The former consisted of an aluminum and fiberglass layer encapsulated in an aluminum and Mylar jacket; the latter was a gold, Mylar, and aluminum layer separated by mesh silk layers. They also investigated the use of multilayer insulation shaped into removable blankets. The study provided information on methods of applying the blankets to the tank and the optimal number of layers to include. Lewis researchers also developed a unique self-evacuating multilayer insulation (SEMI) to prevent air from contacting the tank during ground holds. They verified SEMI performance at K Site.

Lewis researchers designed a Cryogenic Storage Test Vehicle to study the integration of shadowshields and multilayer insulation into a realistic tanking system for long-duration missions. The vehicle included hydrogen and oxygen tanks, a simulated engine, and a nozzle. The researchers installed the vehicle in the K Site test chamber with a cold wall to simulate temperatures in space. They then verified the system's performance in simulated near-Earth and deep space conditions.

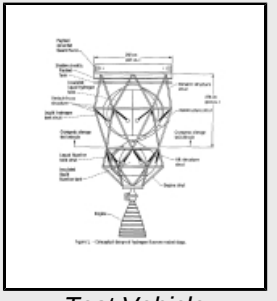
Reports:

Compressed Multilayer Insulation System for Rocket (1963)
Study Under Groundhold Conditions of Insulation Systems (1965)
Multilayer Insulation Containing 20 to 160 Layers
Lightweight, Self-Evacuated Insulation Panels (1970)
SEMI Prefabricated Panels for Cryogenic Tanks
Performance of Replaceable Multilayer Insulation
Integrated Thermal Protection for Long-Term Storage (1977)

J-3 Preparations

Superinsulated Tank

Insulation Installation



Test Vehicle

History
Rocket Systems Area

Home
History
- Construction
- Turbopumps
- Centaur
- Nuclear Rockets
- Propellant Tanks
- Shutdown

Facilities
- A Site
- C Site
- D Site
- E Stand
- F Site
- G Site
- I Site
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- Support

Research
- Documents
- Technical Reports
- Monthly Reports
- Events Timeline
- Tests Timeline

Mitigation
- RSA Project

SHUTDOWN

B–3 Stand in Disrepair

The steady reduction of NASA's budget in the late 1960s and early 1970s coincided with the Agency's decision to develop the space shuttle. NASA shelved other major programs, such as a space station and long-duration human journeys to other planets. This eliminated the near-term need for a nuclear rocket. In December 1972 NASA canceled all of its nuclear propulsion and power programs, resulting in the closure of Plum Brook Station. There was very little activity at Plum Brook until the late 1980s when Lewis Research Center reactivated four test sites and resumed testing. The Center did not bring the Rocket Systems Area sites, which had fallen into disrepair during the suspension, back online. In the 2010s NASA demolished the Rocket Systems Area as part of the Agency's effort to eliminate its unused structures. Plum Brook Station, however, continues to support NASA and industry with its four large test facilities today.

PLUM BROOK STATION CLOSURE

On January 5, 1973, Lewis Center Director Bruce Lundin traveled to Plum Brook to inform the staff personally that the station would be closed down. He instructed the employees to shut down the reactor facility immediately and to mothball the other sites over the next 18 months. Some staff members found new positions at Lewis, but hundreds of others were soon out of work. Lewis set up a job placement office at Plum Brook to assist those affected. Lewis management also actively solicited other agencies and institutions to use Plum Brook for their test programs. The job placement activities went well, but the attempts to elicit outside interest in Plum Brook failed.

Centaur in B–3

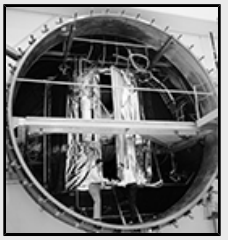
Meanwhile engineers carefully deactivated the facilities in such a way that they could be restored in the future. Plum Brook continued worked to complete several tests during this period, including the first runs at the Hypersonic Tunnel Facility, a choked-propellant flow study at the Hydraulics Laboratory (F Site), and an advanced cryogenic fluid storage investigation in the Cryogenic Propellant Tank Facility (K Site). The testing of the Centaur Standard Shroud for the upcoming Titan-Centaur launch of the Viking spacecraft was the most notable of these final Rocket Systems Area studies. By May 1974 the staff had mothballed all of the Rocket Systems Area sites.

Documents:

- Termination of Plum Brook Activities (PDF, 1 MB)
- Lundin's Speech at Plum Brook (PDF, 0.1 MB)
- Plum Brook Phased Down article (PDF, 0.7 MB)
- Dugan Helps Plum Brook article (PDF, 0.4 MB)
- Capabilities and Facilities of Plum Brook (PDF, 7.8 MB)

Lundin with Astronauts

B Controls Staff



K Site Cryoshroud

Engineering Building

STANDBY

By 1975 there were only a handful of NASA employees left at Plum Brook Station to supervise the contractors that maintained the facilities. Other Federal agencies, including the Environmental Protection Agency, the Federal Bureau of Investigations, and the Department of the Interior, set up offices in the empty Engineering Building. The Center's continued efforts to entice outside groups to utilize the inactive facilities remained ineffective. By the late 1970s, NASA decided to continue the maintenance of the reactor, Space Power Facility (SPF), Spacecraft Propulsion Research Facility (B–2), K Site, and the Hypersonic Tunnel Facility (HTF), but ceased protecting the Rocket Systems Area sites.

In the 1970s the Center expanded the scope of its work into new areas, such as renewable energy sources. As a result, Lewis partnered with the Energy Research and Development Administration (ERDA) to construct a series of experimental large horizontal axis wind turbines. The first was a 100-kW experimental wind turbine at Plum Brook that Lewis researchers erected and operated. Between 1975 and 1985, the researchers investigated several different configurations on the machine. NASA and ERDA constructed larger wind turbines at other sites around the country to study the integration of wind energy into the local power grids. The program demonstrated several technologies employed by large wind turbines today. Overall, however, Plum Brook remained quiet.

Documents:

Wind Turbine 10th Anniversary (PDF, 0.6MB)
NASA Large Wind Turbine Program (report, 1982) (PDF, 0.9MB)
Plum Brook Chronology 1940–85 (PDF, 0.2MB)
Plum Brook Facilities Status (PDF, 0.3MB)

Wind Turbine

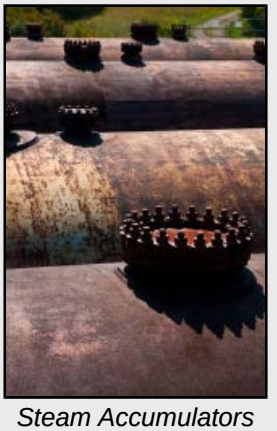
EPA Test Track

Wind Turbine

Turbine Blades

DEMOLITION

In 1985 the Office of Management and Budget recommended that NASA relinquish control of Plum Brook Station. A multiagency commission, however, reviewed the assessment and came to a different conclusion. They called on NASA to restore the test facilities at Plum Brook and resume operation. Lewis reactivated the B–2 vacuum chamber in 1987, SPF and K Site in 1988, and the Hypersonic Tunnel Facility (HTF) in 1993. The reactor and Rocket Systems Area remained shuttered. In 2007 the Cryogenic Components Laboratory replaced K Site.


Steam Accumulators

In 2004 NASA began funding the demolition of unused facilities across the Agency. Glenn began making plans to remove a number of its old test sites, including the Rocket Systems Area at Plum Brook. The sites, which had been exposed to the elements for years, were beyond restoration. In addition, safety officials considered several sites to be hazards. In November 2004 the Dynamics Stand (E Stand) became the first to fall. NASA demolished the Liquid Hydrogen Pump Facility (A Site), the Turbopump Facility (C Site), F Site, and I Site in late summer and fall of 2009. The Gas Handling Area was removed in March 2010, followed by the High Energy Rocket Engine Research Facility (B–1) and B–3 facilities in fall 2010. The Center completed the effort with the demolition of the H Control Building, K Site's control building, and the J–5 hortonsphere in late 2012. In addition, the Center decided to begin removing the Plum Brook Ordnance Works (PBOW) concrete bunkers that had stored munitions during World War II and NASA records and equipment in later years.

Documents:

Lewis' Best Kept Secret (PDF, 0.4MB)
Plum Brook Current Facilities (PDF, 0.4MB)
Plum Brook Able to Pay Own Way (PDF, 0.4MB)
NASA-Ohio Preservation Office Agreement (PDF, 8MB)

A Site in 2007

B–1 Falls

B–3 Demolition

Facilities

Rocket Systems Area

FACILITIES

E Stand

NASA Lewis Research Center engineers quickly designed a series of comparatively small test facilities in the late 1950s and early 1960s to study the handling and storage of liquid hydrogen and other cryogenic fluids. The three primary areas of study for the facilities were experimental rocket components, turbopumps, and propellant tanks. They also created one facility to verify the structural dynamics of launch vehicles. The names of the sites, which often included more than one test rig, frequently changed over the years, so the staff assigned each an alphanumeric name (A Site, B–3, etc.) to clarify the situation.

The operations engineers could conduct tests at multiple sites from a single control building. Each facility included its own explosion-proof wiring, burnoff stacks, shop areas, locker rooms, and remote television monitoring system. The sites utilized the station's digital computer, service air, communications, warning, and other systems. The Gas Handling area supplied the liquids and gases necessary to operate the sites and conduct the tests.

Documents:

- Plum Brook Research Test Areas memo (PDF, 1.9MB)
- Plum Brook Facilities Descriptions (PDF, 1.95MB)
- Plum Brook Tour Brochure (PDF, 4.9MB)
- Rocket Systems Area Facilities map

Physical Descriptions:

I. A Site: Liquid Hydrogen Pump Facility

II. B–1: High Energy Rocket Engine Research Facility

III. B–3: Nuclear Rocket Dynamics and Control Facility

IV. C Site: Turbopump Facility

V. D Site: Controls and Turbine Test Facility

VI. E Stand: Dynamics Stand

VII. F Site: Materials Compatibility Laboratory

VIII. G Site: Pilot Plant – Pump and Turbine Facility

IX. I Site: Fluorine Pump Research Facility

X. J Site: Rocket Systems Test Laboratory

XI. K Site: Cryogenic Propellant Tank Facility

XII. Support Systems: H Control, Gas Handling Area, Administration Building

Rocket Systems Area Layout

K Site Chamber

J-5 Facility

Facilities

Rocket Systems Area

A SITE—LIQUID HYDROGEN PUMP FACILITY

Years: 1961 to 1968

The Liquid Hydrogen Pump Facility, or A Site, was designed to test impellers and inducers for high-flow hydrogen and oxygen pumping systems. The facility included separate test loops for hydrogen and oxygen turbopumps. Researchers utilized these test loops to determine the performance of high-power turbopumps with experimental inducers and impellers in conditions comparable to those experienced when integrated into a liquid chemical rocket engine.

A Site

Documents:

A Site Description (PDF, 0.25MB)
A Site Monthly Status Reports (PDF, 8MB)

SITE DESCRIPTION

A Site was located on Fox Road near the northwest corner of the Rocket Systems Area. The A Site test loops were contained in a single 1,605-square foot Butler Building that included large access doors on the north and south ends and a 3-ton overhead crane. Hardware included gas turbines, gearboxes, and bedplates. An addition along the east wall contained an Instrument Room, Controls Room, and Electrical Mechanical Room. NASA added a large shop building just east of the facility to prepare test articles. Twelve tubular storage Dewars and a small pump house were located just north of the facility. Propellant trailers connected to the facility along the west wall, and a gaseous-hydrogen line ran south from the building to a small burnoff stack.

A Site Complex

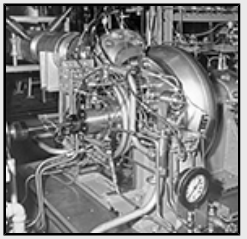
A and E Sites

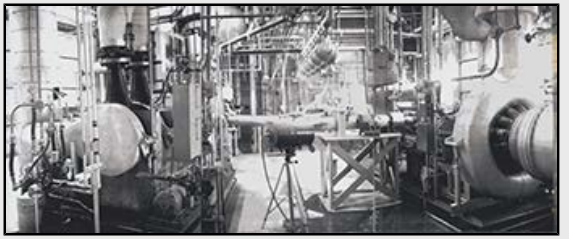
Trailer Hookups

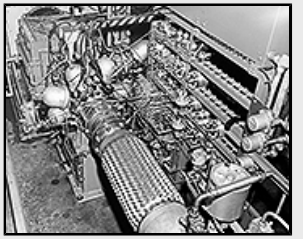
A Site in 2007

OPERATION

The staff installed the experimental turbopump on the drive shaft of either the hydrogen or oxygen test loop with an automatic thrust-balance compensator. The pump then transferred the fluid through a 3-in. stainless steel pipe from one 6000-gal Dewar to another. A gaseous-hydrogen-powered three-stage axial-flow turbine spun the drive shaft at up to 60,000 rpms to operate the pump. The hydrogen and oxygen loops could pump up to 20,000 and 1500 gal/min, respectively. To facilitate photographic analysis of the pump flow, designers gave the turbopump a transparent casing and put viewing ports in the test loop. The staff operated the tests and recorded the data from H Control about a quarter mile from the site.


Hydrogen Loop


A Site Interior


Hydrogen Pump

TESTS

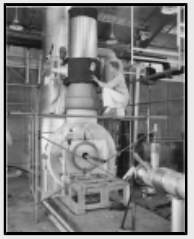
Lewis Research Center investigators used A Site's liquid-hydrogen loop to study centrifugal and multistage axial-flow pump designs incorporating several different types of impellers and inducers. Researchers were only able to use the oxygen test loop, which suffered from many technical problems, for one series of tests. Its basic contribution was the problem-plagued testing of four NASA-designed impellers to support the M–1 engine program.

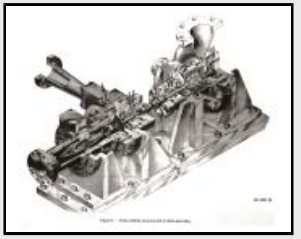
Hydrogen Test Loop
1961–62 Liquid-hydrogen centrifugal pump
1963–64 Impeller designs for liquid-hydrogen centrifugal pump
1965–66 Inducer blade loadings on a liquid-hydrogen centrifugal pump
1967–68 Four-stage axial-flow hydrogen pump

Oxygen Test Loop
1964 Oxygen turbopump for the M–1 engine

Documents:

Flow Range and Stability of Three Inducer-Impeller Combinations (PDF, 13MB)


Mechanic with Rig


Pump Diagram

Explosion Damage

Control Room

Facilities

Rocket Systems Area

C SITE—TURBOPUMP FACILITY

Years: 1962 to 1968

C Site was designed to study pump inducers that operate in boiling hydrogen and to test experimental turbopumps. C Site contained two test setups—a liquid-hydrogen turbopump and the Boiling Fluids Rig. Researchers used the former to investigate the matching of inducer and impeller stages for high-speed liquid-hydrogen turbopumps. The Boiling Fluids Rig allowed the analysis of experimental pumps at the near-boiling temperatures often found in hydrogen rocket systems.

C Site

Documents:

- C Site Description and Floor Plans (PDF, 1MB)
- C Site Monthly Status Reports (PDF, 22MB)
- Lewis Facilities for Investigations of Cavitation in Pumps (PDF, 16MB)

SITE DESCRIPTION

C Site was located on Ransom Road along the western portion of the Rocket Systems Area. The 2093-square foot test area was contained in a Butler Building, with the vertical tank for the Boiling Fluids Rig at the south end and the hydrogen pump loop on a steel plate at the north. The instrument, control, mechanical, and electrical rooms were in an annex off the north end. The portals and pumps used to transfer the propellants from portable 6000-gal trailers into the test Dewar were along the south wall. A vacuum pump room and two tank storage areas were in an extension of the western wall. A small pump house further east of the facility supplied high-pressure hydrogen gas to drive the turbine. C Site had a large shop building just to the east of the facility to prepare test articles.

C Site

Hydrogen Hookups

C Site in 2007

Mechanic

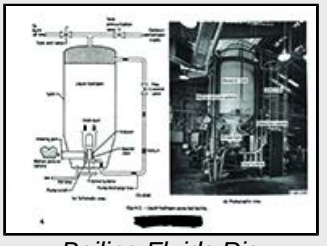
OPERATION

The liquid-hydrogen turbopump at C Site worked similarly to the A Site loops. High-pressure hydrogen gas powered the turbine, which in turn spun the drive shaft connected to the experimental pump. The turbopump rapidly pumped the fluid from one 6000-gal tank to another. The rig accommodated run durations up to 5 min. Test engineers, which operated C Site remotely from the H Control Building, could independently adjust the fluid flow, speed, and pressure.

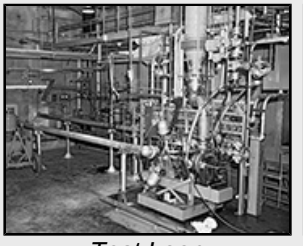
The Boiling Fluids Rig was a 2500-gal stainless-steel hydrogen tank with a transparent turbopump submerged at the bottom. The gaseous-hydrogen-powered drive turbine was located beneath the tank, whereas the pump's inducer and

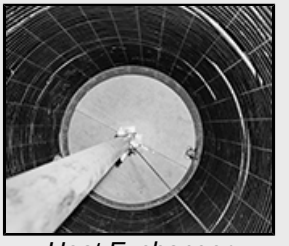
Construction

impeller were in the tank. A shaft penetrating the bottom of the tank connected the pump and the turbine. The experimental pump recirculated the fluid out the bottom of the tank and into the top. The tank included viewing ports and a strobe lighting system that permitted the filming. Engineers added a cylindrical heater at the inlet to simulate temperatures in a nuclear engine.


Boiling Fluids Rig

Rig Construction


Test Loop


Heat Exchanger

TESTS

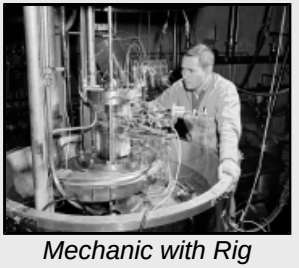
Researchers used C Site's Turbopump Rig to study inducers with angles of varying degrees as well as their performance in cavitation. Researchers used the Boiling Fluids Rig to study the rates of net positive suction head at the turbopump inlet when the liquid hydrogen was at higher temperatures and the effect of temperature, pressure, and flow rate on cavitation. Researchers also explored the use of slush hydrogen to reduce the size of the propellant tanks.

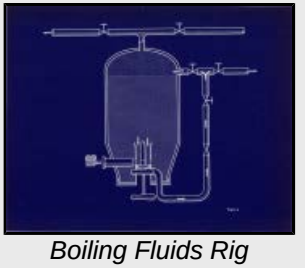
Boiling Fluids Rig
1962 Liquid-hydrogen pump
1963–64 Inducer performance in heat from nuclear rocket
1964 Inducer performance in slush hydrogen
1966 Minimal pressure required to pump hydrogen
1968 Comparison of different inducer blade shapes and angles

Hydrogen Turbopump Rig
1963–66 Impeller matching with centrifugal hydrogen pump

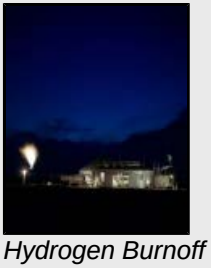
Reports:

Performance of 78° Helical Inducer in Hydrogen (PDF, 1.25MB)
Effect of Leading Edge Thickness on Inducer Performance (PDF, 1.2MB)
Performance of Line-Mounted 806° Inducer in Hydrogen (PDF, 17.8MB)
Performance of Helical Inducer Operated in 37 and 42 °R Hydrogen (PDF, 10MB)
Change in Pressure Requirement in Low Temperature Hydrogen (PDF, 2.2MB)


Mechanic with Rig


Boiling Fluids Rig

C Site Controls


Hydrogen Burnoff

Facilities

Rocket Systems Area

D SITE—CONTROLS AND TURBINE TEST FACILITY

Years: 1963 to 1965

D-Site consisted two test rigs for testing multistage turbines that powered turbopumps on chemical and nuclear rocket engine systems. The staff unsuccessfully struggled for several years to get the facility to operate properly.

Documents:

D Site Description (PDF, 0.25MB)
D Site Monthly Status Reports (PDF, 8MB)

D Site

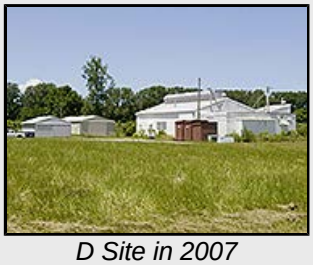
SITE DESCRIPTION

D Site is located at the intersection of Ransom and Fox roads at the northwest corner of the Rocket Systems Area. The test equipment was contained in a 1,511 square foot rectangular Butler Building with mechanical, control, and instrument rooms added along the east end. Liquid-oxygen and liquid-hydrogen tank pits with their respective gas generator rooms were located outside the north wall. The main test area included a large office and electronic shop and two overhead cranes (5 ton and 1.5 ton). A shop building and a small pump house were located to the southeast, and a hydrogen burnoff line extended from the facility to the north.

D Site

Rear of D Site

D Site Exterior



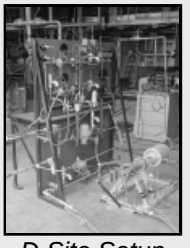
D Site in 2007

OPERATION

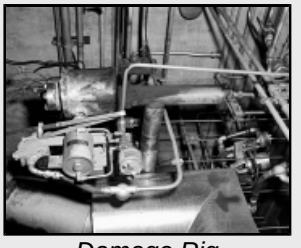
The staff was able to install two 15,000-hp, 60,000-rpm turbines simultaneously at D Site. Each rig included its own gas generators, high-speed gearbox, and eddy-current dynamometers. The gas generators converted the liquid propellants into gas to operate the turbines. The dynamometers, also mounted to the bedplate, acted like brakes on the turbine and measured the turbine's output. The staff operated D Site from the H Control Building.

Interior Setup

Pipe Installation



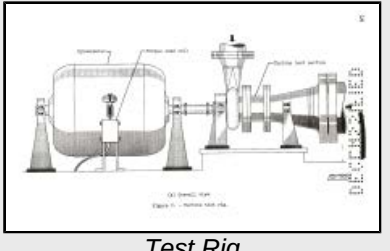
D Site Setup



Damage Rig

TESTING

Researchers installed an eight-stage turbine in one of D Site's test rigs and a three-stage turbine in the other. The turbines were intended for a 100,000-lb-thrust hydrogen-oxygen engine and a nuclear rocket engine. Delays and equipment problems prevented successful testing for several years. Lewis Research Center decided to permanently shut down the two rigs in 1964 and 1965.



Test Rig

Damaged Pipe

D Site Mechanic

H Control Building

Facilities

Rocket Systems Area

E STAND—DYNAMICS STAND

Years: 1962 to 1968

E Stand was designed to verify the structural integrity of missiles in launch conditions and to study full-scale vehicle pressurization and propellant flow systems. The tower simulated the vibrations and forces that occur during launches without having to fire the engines. Lewis Research Center used it primarily to test the Atlas-Centaur vehicle.

E Stand

Documents:

- E Stand Description and Floor Plans (PDF, 1MB)
- E Stand Monthly Status Reports (PDF, 8MB)
- E Stand Construction articles (PDF, 3MB)

SITE DESCRIPTION

The 7-story E Stand was located on Fox Road in the northwest region of the Rocket Systems Area. It had a 14-ft-diameter test section that ran the length of the seven-level tower. NASA extended the height of the stand from its original 117 ft to 144 ft to accommodate the new Atlas-Centaur vehicle with its payload. There were several work platforms at different levels in the stand. E Stand included an electrodynamic shaker and an I-beam support frame at its base and four spring boxes and load cells that were connected to cables that supported the rocket vertically. A spring at the bottom of the tower supported the rocket from below, and cables supported it from the sides to replicate free flight. The stand includes several fluid systems to study the effect of vibrations on pumping systems. Adjacent to the base of the stand were instrument, control, and mechanical rooms. The tower included a large overhead crane, a 125-ft-tall door, and an elevator. The site also contained a small shop and a large deionized water tank.

E Stand Exterior

E Stand Aerial

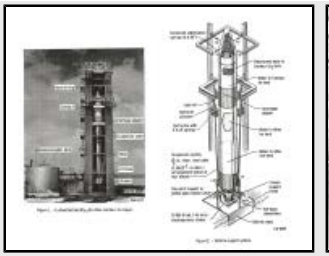
E Stand Front

E Stand in 2004

OPERATION

The vehicle was secured to the frame with horizontal and vertical stabilization springs connected to cables that were suspended from the top of the tower. Four spring boxes and load cells were connected to cables that supported the rocket vertically. A large vibrational exciter shook the rocket from below with 15,000 lb of force and a 200-lb exciter provided horizontal force. The exciters were actuated by a power amplifier in a concrete block house beside the tower. The facility was operated from the Central Control Building located 1000 ft away.

Interior of E Stand


E Stand Diagram

Upper Level

View out Door

TESTS

Researchers used E Stand extensively to subject the Atlas/Centaur launch vehicle and its Surveyor payload to dynamic lateral and longitudinal forces. Notable achievements include verification that the Atlas could support the Centaur stage and testing the vehicle's resilience after purposely bending the vehicle. Researchers also used E Stand for the vibration testing of smaller items, including the Mercury Evaporation and Condensing Analysis (MECA) payload, instrumentation for the Sky Bolt rocket, and a Ranger payload accelerometer.

1962 Vibrational analysis on the Space Electric Rocket Test (SERT) I, Ranger accelerometer, and Sky Bolt instrumentation
1962–63 Vibrational analysis on MECA program
1963 Atlas load tests
1964 Atlas/Centaur longitudinal and latitudinal dynamics
1965 Centaur fairing loads
1966 Atlas/Centaur post-wrinkling strength
1967 Atlas/Centaur bulkhead and duct dynamics
1968 Atlas/Centaur duct dynamics

Documents:

Atlas-Centaur-Surveyor Longitudinal Dynamics Tests (PDF, 8.7MB)
Experimental Lateral Bending of Atlas-Centaur-Surveyor (PDF, 20MB)
Bending Strength of Atlas Booster Beyond Skin Wrinkling (PDF, 25MB)

Atlas-Centaur Nose Cone

Atlas Test

Centaur at E Stand

Atlas at E Stand

Facilities

Rocket Systems Area

F SITE—HYDRAULICS LABORATORY

Years: 1963 to 1974

The Hydraulics Laboratory (F Site), also referred to as the Hydrogen Flow Facility, was designed to study the flow conditions of cryogenic fluids as they passed through an experimental turbopump. Researchers also used the facility to study a liquid-hydrogen heat exchanger for nuclear rockets.

Documents:

F Site Description and Floor Plans (PDF, 0.5MB)
F Site Monthly Status Reports (PDF, 12MB)

F Site

SITE DESCRIPTION

F Site, located on Fox Road, was the westernmost Rocket Systems Area facility. The primary structure was a rectangular Butler Building that had a hydrogen test area in the west section, another test area was to the east, and a third test area on the mezzanine level. The Instrument Room, the Control Room, and the Electric Mechanical Room were located between the two test sections. A rectangular shop area abutted against the north side of the structure. F Site contained a liquid-hydrogen storage vessel and a catch basin with the experimental flow hardware set up in between. A small pump house was located to the north of the structure, and a hydrogen burnoff line was located to the south.

F Site Complex

F Site Exterior

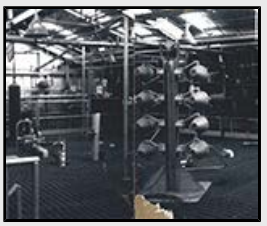
Construction

F Site in 2007

OPERATION

The experimental component, usually a turbopump, was installed in the test loop between the two hydrogen tanks. The operator pressurized the propellant run tank and stabilized the system. The valves were then released as the pump transferred the fluid from one tank to the other. The staff could modify the fluid temperature during the test by introducing ambient gas into the liquid. The operators conducted the tests from the H Control Building.

Interior of F Site



Upper Level

Hydrogen Lines

F Site Interior

TESTS

Researchers used F Site to analyze a triangular hydrogen heat exchanger for a nuclear rocket, to cold shock a Centaur 5–C tank, and to study the choked flow of liquid oxygen.

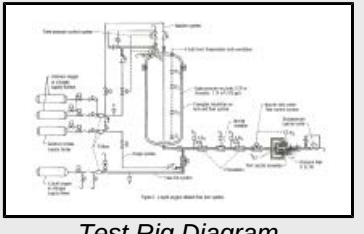
1963–66 Hydrogen-water heat exchanger for nuclear rocket
1963–64 External insulation system for Centaur tank
1968 Centaur tank cold shock
1974 Liquid-oxygen choked flow

Documents:

Heat Transfer of Water-to-Hydrogen Heat Exchanger (PDF, 1.9MB)
Two-Phase Choked Flow of Oxygen and Nitrogen (PDF, 3MB)

Control Room

Mechanic



Test Rig Diagram

Shop Room

F Site Piping

Facilities

Rocket Systems Area

G SITE—PILOT PLANT/PUMP AND TURBINE FACILITY

Years: 1958-1964

Purpose: The Pump and Turbine Facility, better known as the Pilot Plant, was designed to test models of Lewis-designed rocket pumps and turbines with cryogenic propellants before the designs were provided to manufacturers for production.

Documents:

Plum Brook Today article (PDF, 0.5MB)
G Site Status Reports (PDF, 12MB)

G Site

SITE DESCRIPTION

The Pilot Plant was located on Fox Road in the northcentral portion of the Rocket Systems Area. The site had two test facilities—the Liquid Hydrogen Pump and the Turbine Test Facility—located 350 feet north from its control and instrument rooms. These rooms were repurposed 9-ft-diameter steel tanks from the Plum Brook Ordnance Works (PBOW) that were covered with an earthen mound. The Turbine Test Facility contained a test section for the experimental turbines, a pressure-controlled inlet duct system, and an exhaust duct that vented directly to the atmosphere. The test equipment included the turbine, housing, and the dynamotor. There was a shop building to the east of the two test facilities and a pump house to the south.

G Site

G Site Building

G Site Exterior

Hydrogen Trailers

OPERATION

The staff installed the model pump or turbine in the corresponding test building, connected a roadable hydrogen Dewar to the equipment, and stabilized the pressure and temperature levels. The pump circulated the gaseous hydrogen or nitrogen propellant from the Dewar and back into a catch basin. The operator, located in the onsite underground control room, could control the inlet flow and exhaust with valves in the test apparatus. Strain gauges measured the torque, and a tachometer measured the turbine speed.

Test Rig

Control Room

Turbine Air Brake

G Site Mechanic

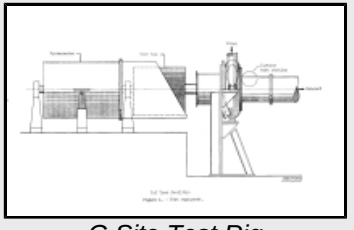
TESTS

Researchers used G Site's Turbine Test Facility to test the performance of experimental axial-flow turbines for nuclear rocket engines and to test liquid-hydrogen-cooled bearings. The Liquid Hydrogen Pump was used to test small-scale axial-flow turbopumps.

Liquid Hydrogen Pump
1961 15,000-rpm hydrogen axial-flow pumps
1964 Small-scale axial-flow hydrogen pump

Turbine Test Facility
1961 Three-stage Nuclear Engine for Rocket Vehicle Application (NERVA) turbine and six-stage Hy-Nut Turbine
1963–64 Three-stage axial-flow hydrogen pump for hydrogen-cooled bearings

Control Room


G Site Test Rig

G Site Damage

Exterior Damage

Facilities
Rocket Systems Area

Home
History
Construction
Turbopumps
Centaur
Nuclear Rockets
Propellant Tanks
Shutdown
Facilities
A Site
C Site
D Site
E Stand
F Site
G Site
I Site
J Site
K Site
Support
Research
Documents
Technical Reports
Monthly Reports
Events Timeline
Tests Timeline
Mitigation
RSA Project
Other Projects

I SITE—FLUORINE PUMP FACILITY

Years: 1962 to 1967

Purpose: The Fluorine Pump Facility (I Site) was designed the test liquid-fluorine turbopumps that operate at 20,000 rpm and produce flow rates up to 50 lb/sec.

Documents:

- I Site Description and Floor Plans (PDF, 1MB)
- I Site Monthly Status Reports (PDF, 4MB)
- Plum Brook Today (PDF, 1MB)

I Site

SITE DESCRIPTION

I Site was located on Taylor Road near the center of the Rocket Systems Area. The main structure was a rectangular Butler Building with an open interior in which the test loop was set up. The actual pump test section was in a 855-square foot annex along the southeastern wall that opened to the exterior. The I Site setup was a closed-loop system in which liquid fluorine was circulated by the research turbopump. This pump was enclosed inside a 9500-lb stainless steel containment vault and wrapped in what was called a “burn wire,” which automatically closed emergency valves in the case of a fire. Trailer tankers supplied the facility through ports in the northeastern wall. Small instrument, control, and mechanical equipment rooms lined the northwest wall of the building. A large shop building was located to the east of the primary I Site structure.

Tankers at I Site

Construction

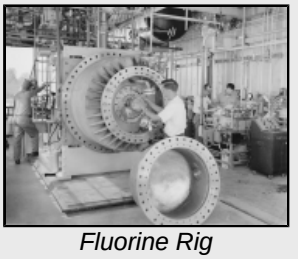
I Site Exterior

I Site in 2007

OPERATION

The staff passified the system before the test with a gaseous-fluorine system. The liquid fluorine was stored in a 600-gal run tank that was pressurized with helium. A heat exchanger maintained the fluid temperature to extend run times. The operator, located 1200 ft away in the H Control Building, opened the valves to allow the fluorine to flow into the loop. Then the experimental pump circulated the fluorine through the loop and back into the Dewar. The pump, powered by an airbreathing turbine, initially operated at lower speeds then increased until it reached normal operating speeds.

Pump Rig



Fluorine Rig

Fluorine Trailer

Interior of I Site

TESTS

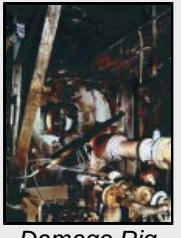
Researchers established a test program at I Site to obtain the performance characteristics of NASA-designed fluorine pumps during cavitation, study the effect of cavitation on the fluoride surface coating, and analyze rotating shaft seal designs. Pratt & Whitney researchers also used I Site to determine if fluorine could be used in their RL–10 engines and to explore the use of a methane-fluorine/oxygen (FLOX) propellant in the engine. 1962–64 Lewis liquid-fluorine centrifugal turbopumps 1963–65 Pratt & Whitney RL–10 fluorine turbopumps 1964 Fluorine turbopump seals 1966 Pratt & Whitney FLOX/methane turbopump

Documents:

Operation of Liquid Fluorine Pump in Cavitating Flow (PDF, 11.2MB)

Fluorine Rig

Fluorine Vaporization



Damage Rig

Control Room

Facilities

Rocket Systems Area

J SITE—ROCKET SYSTEMS TEST SITE

J Site, which was located on Taylor Road near the center of the Rocket Systems Area, consisted of five different test facilities used to investigate issues regarding rocket combustion, propellant storage, heat transfer, and fluorine handling. The main structure was a C-shaped building that housed two test rigs with an external liquid-hydrogen tank between them. The vertical test stands were located just off the north and east sides of the building. A large round tank was nearby further east. The main control room for the site was located in portable trailers behind earthen mounds to the southwest.

J Site Complex

Links to J Site Facilities

J-1 Site
J-2 Site
J-3 Site
J-4 Site
J-5 Site

Documents:

J Site Description and Floor Plans (PDF, 1.5MB)

J Site

J Site

Control Trailers

J–1

Years: 1961 to 1968

The J–1 rocket stand was built to study heat transfer between a nuclear engine's hot exhaust gases and its nozzle.

Documents:

J–1 Monthly Status Reports (PDF, 1.5MB)

Test Rig

J–1 SITE DESCRIPTION

J–1 was a horizontal rocket test stand located in the northwest half of J Site's main structure. The structure's walls consisted of earth encased in metal siding. Mobile propellant tanks fed the facility from the south wall, and there was a permanent liquid-hydrogen tank just outside the east wall. The J–1 rig was elevated approximately 5 ft above the ground and fired horizontally through a large door in the north wall.

J–1 OPERATION

The staff installed the experimental engine and opened the building's sliding doors. The operators, located in the J Control trailers, adjusted the propellant and coolant pressure to the desired levels. They then initiated the test, which automatically opened the supply valves and fired the engine. The runs typically lasted only a few seconds. The coolant flow was sent to a burnoff system instead of to the injector so that it did not influence the nozzle's heat transfer data.

J–1 TESTS

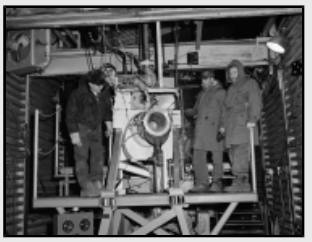
Researchers used J–1 for a multiyear study of the heat transfer to and from liquid hydrogen in regeneratively cooled nuclear rocket nozzles and basic hydrogen-oxygen engine tests.

1961–62 Gaseous-hydrogen/liquid-oxygen rocket engine
1963 Hydrogen burnoff tests for the Hydrogen Heat Transfer Facility (HHTF) design
1962–63 Copper hydrogen-oxygen engine for nuclear rocket heat transfer
1964–68 Injectors for steel hydrogen-oxygen engines
1964–68 Regeneratively cooled liquid-hydrogen engines

Reports:

Investigation of Hot-Gas-Side Heat Transfer (PDF, 1MB)
Hot-Gas-Side Heat Transfer in Hydrogen-Oxygen Rocket (PDF, 3MB)
Hot-Gas-Side Heat Transfer With/Without Film Cooling (PDF, 1.7MB)
Coolant-Side Heat Transfer Rates for Rocket (PDF, 6.9MB)>

J–1 at Night


Test Preparation

Hydrogen Tank

Rocket Firing

J–2

Years: 1961 to 1966

J–2 was a rocket test stand designed to study throttling and heat transfer in rocket engines that used high-energy propellants such as liquid hydrogen and liquid fluorine.

Documents:

J–2 Monthly Status Reports (PDF, 1.5MB)

J–2 Stand

J–2 SITE DESCRIPTION

The J–2 vertical stand was located outside of the northeastern wall of the main J Site structure. The approximately 25-ft-high stand allowed the oxidizer tank to be mounted above the fuel tank for a more realistic simulation. The tower had rollup doors on either side to provide ventilation during the tests. The engine fired downward into a U-shaped duct, which directed the exhaust horizontally out into the atmosphere.

J–2 OPERATION

The operation of J–2 was similar to J–1. The test engineers in the control trailers adjusted the propellant pressure rates then initiated the test. The propellant flow and chamber pressure were closed-loop systems with automatic controls. The engine fired briefly and expelled its exhaust into the atmosphere.

J–2 TESTS

Researchers ran a gaseous-hydrogen/liquid-fluorine engine at J–2 and studied throttling and combustion instability in a liquid-oxygen/liquid-hydrogen pressure-fed engine. Researchers also used J–2 to study the heat transfer to and from the hydrogen in regeneratively cooled nuclear rocket nozzles.

1961 Gaseous-hydrogen/liquid-fluorine engine
1962 Liquid-oxygen/liquid-hydrogen pressure-fed engine
1963 Throttling of a liquid-oxygen/liquid-hydrogen engine
1965 K Site 13-ft tank system

J-2 Stand

Rocket Nozzle

J–2 Door

Exhaust Vent

J–3—VACUUM ENVIRONMENT FACILITY

Years: 1961 to 1968

J–3 was designed to test liquid-hydrogen propellant tank durability and insulation systems in simulated space conditions. This test stand was initially the Center's only facility capable of rapid pumpdown testing.

Documents:

J–3 Monthly Status Reports (PDF, 27MB)

J-3 Vacuum Tank

J–3 SITE DESCRIPTION

J–3 was located in the souththeastern half of J Site's main building. This stand contained a modest-sized cylindrical zero-leak high-vacuum chamber in which small propellant tanks were installed. The fill line and vent line entered from the top. J–3 and J–4 shared the same hydrogen flow system.

J–3 OPERATION

The staff hung the experimentally insulated tank from its neck inside the J–3 vacuum chamber. After purging the tank, they then filled it with liquid hydrogen and allowed it to stabilize. A mechanical pump reduced the chamber's pressure level to simulate high altitudes. Infrared lamps simulated solar heating on one side of the tank. The operator then allowed the propellant to boil off to measure the performance of the insulation system.

J–3 TESTS

Researchers used J–3 to test the thermal retention capability of various tank insulation systems, including the Linde superinsulation, Lewis Research Center's constrictive wrap and self-evacuating insulation, and foil systems from the Arthur D Little Company.

1963–64 Linde superinsulaton
1963–64 Centaur constrictively wrapped tank
1964 Arthur D. Little gold Mylar insulation
1966–67 Linde Self-Evacuating Multilayer Insulation (SEMI)
1966–68 Arthur D. Little insulation
1968 Copper heat transfer tank

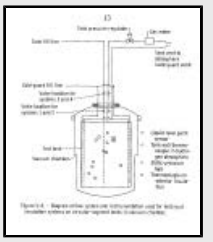
Reports:

Compressed Multilayer Insulation System for Rocket (1963)
Ground Hold Study of Insulation Systems for Hydrogen Tanks (PDF, 2MB)
External Insulation System for Hydrogen Tanks (PDF, 24MB)

Mechanics

Insulated Tank

J-3 Piping


Test Chamber

J–4—TANK TEST FACILITY

Years: 1962 to 1964

J–4 was a vertical test stand designed to study loading issues and the performance of various insulation systems in ground-hold situations.

Documents:

J–4 Monthly Status Reports (PDF, 6MB)

J–4 stand

J–4 SITE DESCRIPTION

J–4 was a vertical semi-enclosed test stand located off the eastern corner of the main J Site structure. The approximately 25-ft-tall stand contained experimental oxidizer and fuel tanks mounted above one another. The tank structure consisted of an inner shell, insulation, and outer shell. J–4 and J–3 shared the same hydrogen flow system.

J–4 OPERATION

The staff loaded the experimental tank into the stand and purged it with nitrogen gas and helium. They then flowed the liquid hydrogen and opened the tank's vent valve. They allowed the liquid to boil off to measure the insulation system's effectiveness. The operators conducted the tests from the J Site control trailer.

J–4 TESTS

Researchers used J–4 used to test Goodyear, Linde, and Arthur D. Little insulation systems, and they proposed jettisonable and constrictively wrapped insulation for the Centaur rocket.

1962 Goodyear insulation system
1963 Linde superinsulated tank
1963 Centaur constrictively wrapped tank
1964 Arthur D. Little gold Mylar insulation
1964 Centaur jettisonable insulation system

J–4 stand

J-4 at Night

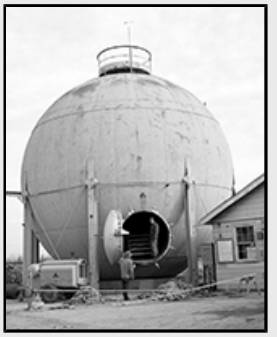
Insulated Tank

Tank Test

J–5—MATERIALS COMPATIBILITY FACILITY

Years: 1961 to 1965

The Materials Compatibility Facility (J–5), also known as the Fluorine Hydraulics Laboratory, was designed to test the durability of materials subjected to high-pressure fluorine or fluorine-oxygen flow. NASA added a stand outside the facility to study fluorine's interaction with other materials in spill conditions.


J–5 Hortonsphere

Documents:

J–5 Monthly Status Reports (PDF, 21MB)

J–5 SITE DESCRIPTION

The J–5 dynamic materials compatibility test rig was enclosed in a 38-ft-diameter steel hortonsphere that had a poured-concrete floor to provide a level working surface. The rig's test section was located between a supply and receiver tank. External to the facility were a separate control room, shop, safety showers, and gas storage. The control room, which was located just east of the facility, was inside a cylindrical tank buried in an earthen mound for protection. NASA added an elevated stand northeast of the facility for spill testing. This stand included an elevated 3.5-gal stainless steel tank with a 4-in.-diameter spill pipe that traveled downward through an aluminum blast shield and into a spill pan.

J–5 OPERATION

Two flanges secured the materials sample in the test section, which was immersed in liquid nitrogen. The staff wrapped burn wire around the test section to automatically shut down the run if fire was present. The operators, located nearby in the J–5 control room, controlled the flow rate as the liquid fluorine passed from the supply tank, through the test section, and into the receiver tank. The spill tower tests released the liquid fluorine from the elevated tank and allowed it to splash into a pan filled with various materials to document the reaction.

J–5 TESTS

Researchers used J–5 for two series of tests. One studied the ability of different materials to withstand high-pressure fluorine flow to determine if they were suited for use in seals for fluorine engines. The other analyzed fluorine's reaction with materials typically found near storage tanks to determine what would happen with a major fluorine spill.

1963–64 Fluorine/fluorine-oxygen (FLOX) materials compatibility
1964 Fluorine/FLOX spills

Reports:

Compatibility of Materials with Fluorine Mixtures (PDF, 9.2MB)
Reaction of Spills of Fluorine Upon Various Materials (PDF, 3.3MB)

J–5 Rear

Equipment in J–5

Spill Test

Spill Rig

Facilities

Rocket Systems Area

K SITE—CRYOGENIC PROPELLANT TANK FACILITY

Years: 1962 to 1968

K Site was designed to test cryogenic propellant tanks up to 18-ft-diameter in a simulated space environment. These studies included proof testing ground storage devices, tank pressurization issues, and the development of long-term insulation systems.

Documents:

K Site Description and Floor Plans (PDF, 1MB)
Large Scale Cryogenic Fluid Systems Testing (PDF, 8MB)

K Site

SITE DESCRIPTION

K Site was located on Ransom Road just northwest of the main Rocket Systems Area. The facility had a 9500-ft3, 25-ft-diameter spherical chamber with a 20-ft-diameter access door. The facility's main structure was a two-story concrete building that formerly served as a boiler plant for the Plum Brook Ordnance Works (PBOW). The test chamber occupied the western half of the building. The eastern half was a large clean area and overhead crane for test preparation. A small addition was added to the north wall for instrumentation equipment. NASA built an external 626-square foot semicircular control room southwest of the main building and a shop and burnoff line to the west.

Control Room

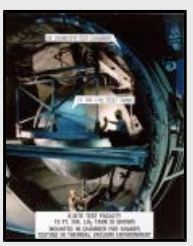
Burnoff Line

K Site in 1989

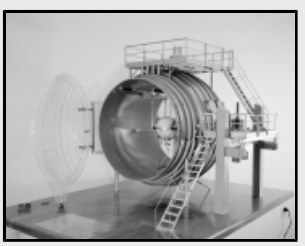
K Site in 2007

OPERATION

The staff installed the experimental tank into the test chamber, filled the tank with hydrogen, allowed it to settle, and adjusted the pressure and temperature to the researcher's specifications. They then opened the tank vents, activated the data-recording equipment, and initiated the test. K Site included a large hydraulic actuator that could simulate launch vibrations and a cryoshroud that simulated the cold temperatures of space. Data-recording equipment tracked the hydrogen boiloff rate to determine the effectiveness of the insulation.

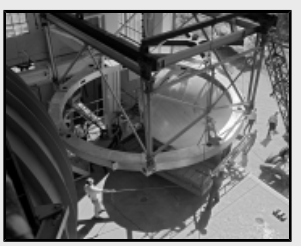


Test Setup



K Site Model

K Site



K Site Interior

TESTS

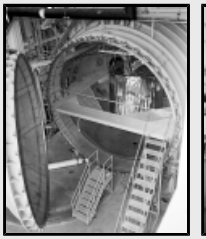
Researchers used K Site to determine the boiloff rates of different size tanks; to study insulation methods such as use of multilayer blankets, self-evacuating layers, spray-on materials, and shadowshields; and to test propellant transfer between two tanks.

1962 Vibrational analysis on the Space Electric Rocket Test (SERT) I, Ranger accelerometer, and Sky Bolt instrumentation
1962–63 Vibrational analysis on MECA program
1963 Atlas load tests
1964 Atlas/Centaur longitudinal and latitudinal dynamics
1965 Centaur fairing loads
1966 Atlas/Centaur post-wrinkling strength
1967 Atlas/Centaur bulkhead and duct dynamics
1968 Atlas/Centaur duct dynamics

Documents:

Pressurant for Discharge of Methane From Tank (PDF, 12MB)
Hydrogen Discharge of Hydrogen From 5-ft Tank (PDF, 4.6MB)
Helium Discharge of Hydrogen From 5-ft Tank (PDF, 2.8MB)
Hydrogen Discharge of Hydrogen From 13-ft Tank (PDF, 4.2MB)
Helium Discharge of Hydrogen From 13-ft Tank (PDF, 2.5MB)
Multilayer Insulation Containing 20 to 160 Layers
Lightweight, Self-Evacuated Insulation Panels (1970)
SEMI Prefabricated Panels for Cryogenic Tanks (1968)
Performance of Replaceable Multilayer Insulation (1977)
Integrated Thermal Protection for Long-Term Storage (1977)

Cryoshroud in Chamber


Test Setup

Cryogenic Test Vehicle

13-Foot Tank

Facilities

Rocket Systems Area

Home
History
Construction
Turbopumps
Centaur
Nuclear Rockets
Propellant Tanks
Shutdown
Facilities
A Site
C Site
D Site
E Stand
F Site
G Site
I Site
J Site
K Site
Support
Research
Documents
Technical Reports
Monthly Reports
Events Timeline
Tests Timeline
Mitigation
RSA Project
Other Projects

SUPPORT BUILDINGS

Testing at the Rocket Systems Area would not have been possible without the services of an extensive team of individuals and support facilities. Researchers at Lewis' main campus in Cleveland generally conceived the ideas for the test programs. They worked with Plum Brook's Rocket Systems Division to determine the best site and establish the parameters for the test. Management required a safety permit before it would approve a test. The researchers then worked with a site's facility engineer, electricians, and mechanics to install the equipment, instrumentation, and data-recording equipment. The test was preprogrammed on computer punch cards. The Gas Handling Unit supplied the facilities with the necessary propellants and pressurized gas. The tests were conducted from remote control rooms, primarily the Control and Instrument Building, to mitigate the danger of high-energy propellants.

Gas Handling

CONTROL AND INSTRUMENT BUILDING

H Control was located on Ransom Road in the northwest region of the Rocket Systems Area. This 12,258-square foot reinforced-concrete building contained the control panels and data-recording devices for the Liquid Hydrogen Pump Facility (A Site), the Turbopump Facility (C Site), the Rocket Turbine and Controls Site (D Site), the Dynamics Stand (E Stand), the Hydraulics Research Laboratory (F Site), and the Fluorine Pump Research Facility (I Site). H Control contained the data-recording equipment for all of the Plum Brook facilities. The rectangular structure sent and received data from the test sites through over 13,000 overhead lines. Although the building supplied many sites, it could record data from only one test at a time and could swap interchangeable patchboard panels to decrease the lag time between tests. The staff could remotely view testing at the sites via closed-circuit television systems.

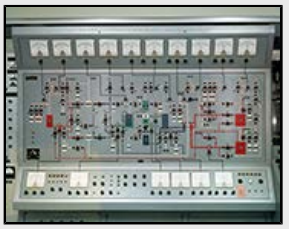
Facility Engineer

The 11,508-square foot B Control was located near the center of the Rocket Systems Area. NASA added the building to provide safe operation of the High Energy Rocket Engine Research (B–1) and Nuclear Rocket Dynamics and Control Facility (B–3) test stands, and later of the Hypersonic Tunnel Facility (HTF) and the Space Propulsion Research Facility (B–2). Each of these sites had its own control room. B Control possessed a number of data recording systems. The Rocket Systems Test Laboratory (J Site), Cryogenic Propellant Tank Facility (K Site), and the Pilot Plant (G Site) had their own on-site small control structures. H Control recorded the test data for these sites.

H Control

C Site Panel

Data Recorders



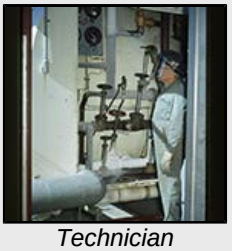
Propellant Flow Controls

GAS HANDLING AREA

The Rocket System Area required large quantities of hydrogen, oxygen, fluorine, nitrogen, and helium. The Gas Handling Area, which was near a major railway route, consisted of four small structures and two permanent dewars located on Ransom Road just northwest of the Rocket Systems Area. These buildings created gaseous nitrogen,

hydrogen, and helium, and they provided a storage structure. In addition, the Gas Handling Unit purchased liquid hydrogen from industrial suppliers. The Center owned four railcar tanks that transported liquid hydrogen to the station from other states. The unit supplied the sites with the required gases or liquids via rail or truck-based storage tanks. A massive 200,000-gal liquid-hydrogen storage vessel was located near the B–1 and B–3 test stands.

Gas Handling Area



Technician

Compressors

Nitrogen Trailer

Railcar Tanks

ADMINISTRATION AND ENGINEERING BUILDINGS

The Rocket Systems Area was supported by the staff in the Plum Brook Station's Rocket Systems Division and Facilities Division. These people, along with the station's management and civil engineers, were initially located in the former Plum Brook Ordnance Works' (PBOW's) 25,700-square foot Administration Building located near the main gate at the north end of Plum Brook. The single-story wooden E-shaped building contained 53 modest offices, four conference rooms, and a cafeteria in the basement. The Administration Building also housed the printing and computing machines.

Engineering Building

In the mid-1960s Plum Brook constructed the two-story 57,625-square foot Engineering Building to house personnel. The L-shaped building possessed 69 offices, four conference rooms, a library, cafeteria, and large assembly area. NASA continued to use the Administration Building even after the new structure was complete. Test engineers had offices in these buildings but spent much of their time out at the test sites.

Administration Building

Ad Building Exterior

Cafeteria

Engineering Bldg Exterior

OTHERS

Plum Brook Station relied upon a host of other structures for daily operations and to support the test facilities. These include the maintenance shop, garage, medical services building, locomotive shop, guard house, chemistry lab, substations, power houses, warehouses, and two water intake stations on Lake Erie. Most of these buildings were built during the Ordnance Works era.

Pump House

Locomotive Shop

Combine Shop

Plant Protection

Bunkers

Responsible NASA Official: Anne K. Mills
Web Curator: Robert S. Arrighi (Alcyon Technical Services)
Last Updated: 8/12/2016

> Privacy Policy and Important Notices
> Documents and Media Viewers

Research
Rocket Systems Area

HISTORIC RESEARCH

Technical reports, correspondence, facility reports, specifications, articles, and other documents regarding the Rocket Systems Area at NASA Glenn Research Center's Plum Brook Station tests stands were collected during the research effort. Some of these reference materials are included here for researchers.

Control Room

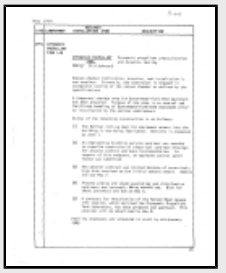
I. Documents: This page contains original documents, articles, pamphlets, reports, and speeches. These materials are related to Plum Brook Station, construction, related programs, and shutdown.

II. Technical Reports: This page provides links to NASA technical reports regarding the testing at the Rocket Systems Area sites.

III. Rocket Systems Division Test Operations Reports: Lewis used the Rocket System Area to test the structural dynamics of the Atlas-Centaur, the Centaur Standard Shroud, and proposed insulation systems.

Articles

Reports



Test Operations

Research
Rocket Systems Area

HISTORICAL DOCUMENTS

The following are digital versions of various historical documents related to the Rocket Systems Area. These include newspaper articles, correspondence, speeches, reports, and other documents.

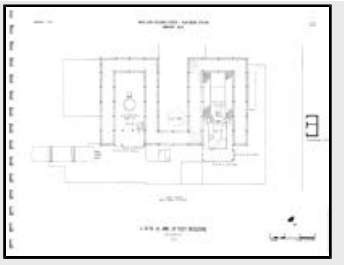
Plum Brook Station
Plum Brook Chronology (1940-85) (PDF, 0.5MB)
Plum Brook Acquisition documents (1956–63) (PDF, 4MB)
Saga of the Plum Brook Ordnance Works (article, 1944) (PDF, 2.3MB)
Evaluation of Plum Brook Ordnance Works (1958) (PDF, 75KB)
Plum Brook Facilities Operations Report (1961–62) (PDF, 1.95MB)
Plum Brook Facilities (c1970) (PDF, 1.95MB)
Plum Brook Tour Brochure (PDF, 5.06MB)
Plum Brook Station Tour Program (1964) (PDF, 1.3MB)
Plum Brook Station Tour Program (1965) (PDF, 5.6MB)
Plum Brook Station Tour Program (1971) (PDF, 1.6MB)
Plum Brook Station Review (1976) (PDF, 25.5MB)
Plum Brook Picnic articles (PDF, 5.06MB)

Rocket Systems Area
Rocket Systems Research Facility (1959) (PDF, 451KB)
Research Test Areas (PDF, 1.9MB)
Small Sites Floor Plans (1969) (PDF, 5.3MB)
Lewis' Cavitation Study Facilities (1964) (PDF, 15.8MB)
Rocket Systems Division Organization (1964) (PDF, 272KB)
H Control Building Data Sheet (1959) (PDF, 250KB)
First Fluorine Rocket at PBS (1960) (PDF, 169KB)
E Stand Testing Articles (1959-64) (PDF, 1.9MB)
E Stand Progress Report (1959) (PDF, 703KB)
I Site Description (1966) (PDF, 64KB)
K Site Description (1992) (PDF, 1.9MB)
K Site Design Review (1964) (PDF, 1.36B)

Construction
Plum Brook Facilities Meeting (PDF, 2MB)
NACA Construction House Bill (1957) (PDF, 2MB)
Additional Facilities to be Built at Plum Brook (article, 1958) (PDF, 40KB)
Plum Brook Today (1959–60) (PDF, 1.68MB)
"E Site Progress Report" (article, 1959) (PDF, 0.7MB)
"Two Facilities Completed at Plum Brook" (article, 1959) (PDF, 1.6MB)
Plum Brook Today (articles, 1959–60) (PDF, 1.7MB)
"Plum Brook in the Space Age" (article, 1960) (PDF, 0.8MB)
Construction of the B–1 and B–3 Test Stands
Rocket Systems Area Sites Floor Plans (1969) (PDF, 5.3MB)

Programs
Centaur Program Overview (1963) (PDF, 1.0MB)
Taming Liquid Hydrogen: The Centaur Upper-Stage Rocket (PDF, 2.16MB)
Lewis Launch Vehicle Experience (c1974) (PDF, 2.58MB)
Centaur Launch (1962–2012)
History of Centaur (press release, 1984)
High-Energy Upper Stage Research Expansion (1959) (PDF, 5.2MB)

To the End of the Solar System: The Story of the Nuclear Rocket



The NERVA Nuclear Rocket Program (1965) (PDF, 11.1MB)
A Historical Perspective on the NERVA Nuclear Rocket Program (1991) (PDF, 1.09MB)

Liquid Hydrogen as Jet Fuel for High-Altitude Aircraft (PDF, 1.9MB)
Liquid Hydrogen as a Propulsion Fuel, 1945–1959
"Seizing the Space Initiative" from Engines and Innovation: Lewis Laboratory and American Propulsion Technology (NASA SP–4306)

NASA Axial-Flow Turbopump (manual, 1978)
NASA Centrifugal Turbopump (manual, 1973)
Liquid Rocket Turbopump Inducers (manual, 1971)
Handling of Fluorine Mixtures in Rocket Systems (PDF, 13.4MB)
High Energy Rocket Propellants Talk (PDF, 5.1MB)
Hydrogen-Fluorine and Hydrogen-Oxygen Rocket Research (1961) (PDF, 11.6MB)
Liquid Hydrogen Program Stepped Up (1962) (PDF, 844KB)

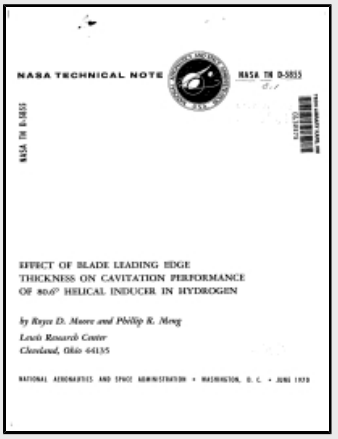
Liquid Rocket Metal Tanks and Components

Shutdown and Demolition
Termination of Plum Brook Activities (PDF, 1MB)
Plum Brook Closure (press release, 1973) (PDF, 48.6KB)
Bruce Lundin's shutdown speech (1973) (PDF, 39.3KB)
Dugan Helps Plum Brook (1973) (PDF, 0.5MB)
Plum Brook Phased Down (article, 1974) (PDF, 702KB)
Plum Brook Facilities Status (1985) (PDF, 0.5MB)
NASA—Ohio Preservation Office Agreement (PDF, 8MB)
Wind Turbine 10th Anniversary (article, 1985) (PDF, 0.6MB)
NASA Large Wind Turbine Program (report, 1982) (PDF, 0.9MB)
Lewis' Best Kept Secret (article, 1991) (PDF, 0.4MB)
Plum Brook Current Facilities (PDF, 0.4MB)
Plum Brook Able to Pay Own Way (article, 2003) (PDF, 0.4MB)

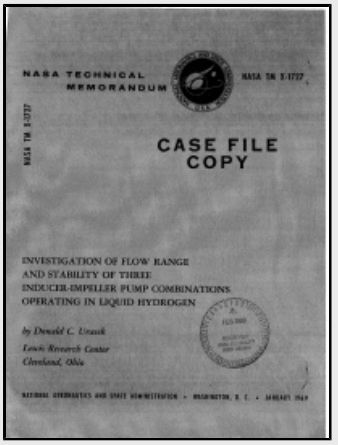
Research
Rocket Systems Area

TECHNICAL REPORTS

The following are links to NASA technical reports related to tests at the Rocket Systems Area sites.



80 Degree Inducer Thickness



Inducer-Impeller Flow Range

A Site—Liquid Hydrogen Pump Facility
Flow Range and Stability of Three Inducer-Impeller Combinations (PDF, 13 MB)

B–1 and B–3 Test Stands—High Energy Rocket Engine Research Facility
and Nuclear Rocket Dynamics and Control Facility
B–1 and B–3 Reports

C Site—Turbopump Facility
Performance of Radial-Bladed 4-in.-Diameter Centrifugal Pump (PDF, 4 MB)
Cavitation Performance of 83° Inducer in Liquid Hydrogen (PDF, 4 MB)
Investigation of Two-Phase Hydrogen Flow in Pump Inlet Line (PDF, 1 MB)
Cavitation and Noncavitation Performance of 78° Inducer in Hydrogen (PDF, 1 MB)
Cavitation Performance of 84° Inducer in Liquid Hydrogen (PDF, 3.42 MB)
Cavitation Performance of 80.6° Inducer in Liquid Hydrogen (PDF, 1 MB)
Net Positive Suction Head Requirements in Low Temperature Hydrogen (PDF, 1 MB)
Cavitation Performance of Line-Mounted 80.6° Inducer (PDF, 8 MB)
Cavitation Performance of 80.6° Inducer With Blunt Edges (PDF, 1 MB)
Investigation of Two-Phase Hydrogen Flow in Pump Inlet Line (PDF, 1 MB)
Thermodynamic Effects of Cavitation of 80.6° Inducer (PDF, 1 MB)
Effect of Blade Leading Edge Thickness on Cavitation (PDF, 1 MB)
Cavitation Performance of 80.6° In-Line Inducer With Centerbody (PDF, 2 MB)
Noncavitation and Cavitation Performance for 78°, 80.6°, and 84° Inducers (PDF, 1 MB)
Performance of Helical Inducer Operated in 37 and 42 °R Hydrogen (PDF, 10 MB)
Change in Pressure Requirement in Low Temperature Hydrogen (PDF, 2.2 MB)

E Stand —Dynamics Stand
Atlas-Centaur-Surveyor Longitudinal Dynamics Test (PDF, 9 MB)
Strength of Atlas LV–3C Booster Beyond Compressive Skin Wrinkling (PDF, 25 MB)
Lateral Bending Dynamics of Atlas-Centaur-Surveyor Vehicle (PDF, 21 MB)

F Site—Hydraulics Research Laboratory
Two-phase Choked Flow of Subcooled Oxygen and Nitrogen (PDF, 3 MB)
Heat-Transfer of a Water-to-Cryogenic Hydrogen Heat Exchanger (PDF, 2 MB)

G Site—Pilot Plant

I Site—Fluorine Pump Research Facility
Liquid Fluorine Pump, Impeller, and Inducer Resistance to Cavitation (PDF, 2 MB)
Fluorine/Oxygen (FLOX)/Methane Pump-Fed Engine Technology Review (PDF, 7 MB)

Operation of Liquid Fluorine Pump in Cavitating Flow (PDF, 11.2 MB)

J Site—Rocket Systems Test Laboratory

J–1
Variations in Hot-Gas-Side Heat-Transfer Rates in a Hydrogen-Oxygen Rocket (PDF, 2 MB)
Hot-Gas-Side Heat-Transfer Rates in a Hydrogen-Oxygen Rocket (PDF, 2 MB)
Coolant-Side Heat-Transfer Rates for Hydrogen-Oxygen Rocket (PDF, 7 MB)
Hot-Gas-Side Heat Transfer on Simulated Nuclear Rocket Thrust Chamber (PDF, 2 MB)

J–2
Handling of Fluorine and Fluorine-Oxygen Mixtures in Rocket Systems (PDF, 10 MB)

J–3
Constrictive-Wrapped External Insulation for Liquid-Hydrogen Tanks (PDF, 23 MB)
Compressed Multilayer Insulation for a Liquid-Hydrogen-Fueled Rocket

J–4
Full-Scale-Tank Ground-Hold Tests (PDF, 2 MB)

J–5
Compatibility of Materials With Fluorine and Fluorine-Oxygen Mixtures (PDF, 5 MB)
Spills of Fluorine and Fluorine-Oxygen Mixtures on Various Materials (PDF, 2 MB)

K Site—Cryogenic Propellant Tank Facility
Helium Requirements for 5-ft-Diameter Spherical Tank (PDF, 2.8 MB)
Helium Requirements for 13-ft-Diameter Spherical Tank (PDF, 2.5 MB)
Pressurant Requirements for Liquid Methane in 5-ft-Diameter Tank (PDF, 12 MB)
Gaseous Hydrogen Requirements for 5-ft-Diameter Spherical Tank (PDF, 5 MB)
Gaseous Hydrogen Requirements for 13-ft-Diameter Spherical Tank (PDF, 4 MB)
Multilayer Insulation System With 20 to 160 Layers (PDF, 2 MB)
Modularized Replaceable Multilayer Insulation (PDF, 35 MB)
Self-Evacuated Multilayer Insulation of Prefabricated Panels (PDF, 1.5 MB)
Evaluation of Purged Multilayer Insulation for Hydrogen Tankage (PDF, 3.5 MB)
Lightweight Self-Evacuated Insulation Panels (PDF, 0.5 MB)
Self-Evacuated Multilayer Insulation of Prefabricated Panels (PDF, 2 MB)
Evaluation of Shadow Shields and Support Members (PDF, 2 MB)
Shadow Shield Experimental Studies (PDF, 3 MB)
Shadow Shields and Structural Members in Vacuum (PDF, 4 MB)
Shadow Shields for Thermal Protection of Cryogenic Tanks (PDF, 7 MB)
Cryogenic Thermal Control Technology Summaries (PDF, 5 MB)
Integrated Thermal Protection for Long-Term Cryogenic Storage (PDF, 98 MB)

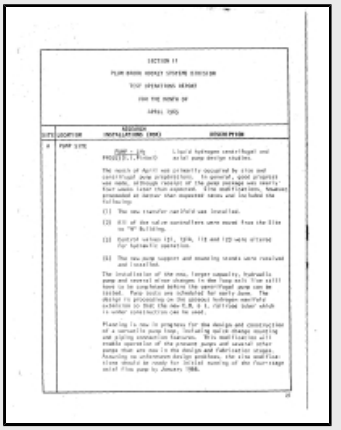
Contact Information
NASA Glenn History Office
21000 Brookpark Road
Cleveland, OH 44135
history@grc.nasa.gov

NASA Glenn History Officer: Anne K. Mills
Archivist: Robert S. Arrighi, Alcyon Technical Services (JV), LLC

Research
Rocket Systems Area

ROCKET SYSTEMS DIVISION REPORTS

Plum Brook facilities managers were required to contribute updates to station management on the activities at each facility during a given month. Management compiled this information into a Test Operations Report or Status Reports for the entire station. These volumes have been divided by particular facility for this Web site.



Test Operations Reports

Reports

A Site Test Operations Reports (1963–68) (PDF, 8MB)
B–1 and B–3 Stands Monthly Status Reports
C Site Test Operations reports (1963–68) (PDF, 22MB)
D Site Test Operations reports (1963–65) (PDF, 4MB)
E Stand Test Operations reports (1963–68) (PDF, 8MB)
F Site Test Operations reports (1963–74) (PDF, 12MB)
G Site Test Operations reports (1963–64) (PDF, 3MB)
I Site Test Operations reports (1963–67) (PDF, 4MB)
J Site Test Operations reports (1963–68) (PDF, 14MB)
K Site Test Operations reports (1964–74) (PDF, 25MB)

Research
Rocket Systems Area

EVENTS TIMELINE

1941
War Department seizes property to build Plum Brook Ordnance Works (PBOW)
The NACA begins construction of its engine laboratory [future NASA Lewis].

1943
The new NACA lab officially begins operations in Cleveland.

1945
World War II ends.
PBOW closes after producing record amounts of ammunition for the war.
Major NACA reorganization is done to focus on turbojets and high-speed flight.
NACA begins modest nuclear propulsion research.
Military sponsors initial hydrogen engine studies at OSU[1] and JPL.[2]

1946
Matthew-Lavio and Sons manages idle Plum Brook property.
Air Force approves development of surface-to-surface intercontinental missile.
Research begins on nuclear propulsion for aircraft.

1947
Rocket Lab begins operation at the NACA lab in Cleveland, Ohio.
First supersonic flight by Chuck Yeager in X–1.
Cleveland Lab renamed the Lewis Flight Propulsion Laboratory.

1948
Lewis hosts conference that discusses high-energy fuels.
Lewis researchers begin calculating fluorine's performance.

1950

1951
NACA establishes a Special Subcommittee on Rocket Engines.

1952
New Cryogenics Engineering Lab begins producing liquid hydrogen.
United States tests first hydrogen bomb.

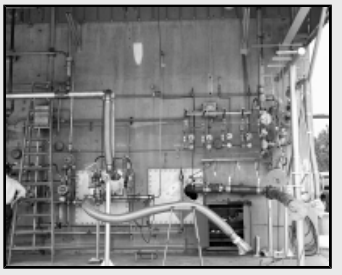
1954
Ravenna Arsenal begins management of Plum Brook.
Lewis improves Cell 22 at the Rocket Lab.

First liquid-hydrogen/liquid-oxygen engine firing occurs at Rocket Lab.
Lewis tests gaseous hydrogen in turbojet combustor.

1955
Congress approves funding for NACA test reactor at Plum Brook.
Air Force and Atomic Energy Commission (AEC) begin Project Rover.
Rocketdyne and Aerojet begin design of hydrogen turbopumps.
Lewis tests 10,000-lb-thrust fluorine engines.

1956
Groundbreaking ceremony for Plum Brook Reactor in September.
Lewis performs initial decontamination at Plum Brook.
Project Bee aircraft performs liquid-hydrogen-powered flights.

1957
Lewis creates Fluid Systems Components and Nuclear Reactor Divisions.
Congress approves funding for Rocket Systems Area.
General Dynamics begins design of the Centaur second-stage rocket.
Lewis hosts NACA Inspection and Flight Propulsion Conference.
Soviet Union launches Sputnik and Sputnik II.
Navy's launch of Vanguard fails.
Regeneratively cooled hydrogen-fluorine engine run at Rocket Lab.



1958
Lewis leases additional land at Plum Brook for Rocket Systems Area.
Construction of Rocket Systems Area begins.
Silverstein transferred to Headquarters.
Lewis inventories PBOW structures and equipment.
AEC approves Rocketdyne axial-flow turbopump.
NASA is officially founded on October 1.
Pratt & Whitney begins developing RL–10 engine.
Pilot Plant begins operation at Plum Brook.

1959
AEC conducts first low-power test of Kiwi-A reactor.
Silverstein-led committee recommends high-energy fuels for upper-stage rockets.
NASA requests additional 3500 acres at Plum Brook from the Army for additional sites.
NASA replaces Air Force in the Rover program.

1960
High Energy Engine Research Facility (B–1) construction underway.
AEC conducts first full-scale Kiwi-A reactor test.
Space Nuclear Propulsion Office (SNPO) created on August 31.

1961
Yuri Gagarin becomes first human in space.
President Kennedy calls for manned lunar landing.
AEC and NASA accept Aerojet-Westinghouse NERVA[3] proposal.

Pratt & Whitney struggles with RL–10 engine problems.
Rocket Systems Area becomes operational in the fall.
Rocket Systems Division established at Plum Brook.
Silverstein named Director of Lewis Research Center.

1962

E Stand, I Site,and J Site become operational.
Alan “Hap” Johnson named Plum Brook Director.
Congress approves $40 million for Nuclear Rocket Dynamics and Control Facility
(B–3) stand, Space Power Facility (SPF), and Spacecraft Propulsion Research Facility (B–2) expansion.
Surveyor program substitutes Centaur for Agena rocket.
First attempt to launch an Atlas-Centaur rocket fails on May 8.
NASA transfers Centaur Program from Marshall to Lewis.
Lockheed Martin designs Titan III booster.
AEC test of Kiwi-B4-A reactor at Nevada Test Site fails.

1963

All PBOW property officially transferred to NASA.
NASA razes many PBOW structures.
200,000-gal hydrogen Dewar built at Plum Brook.
Researchers conduct tests at the B–1 facility; checkout tests run throughout the fall.
B–3 facility construction begins.
Second Atlas-Centaur launch attempt successful.
E Stand modified to accommodate Atlas-Centaur.

1964

Engineering Building, B–2, and B–3 under construction.
AEC tests Kiwi-B4 reactor design at Nevada Test Site.
B–1 begins testing Kiwi reactor flow system.
AEC successfully runs NERVA[3] NRX–A2 engine at Nevada Test Site.

1965

NASA budget peaks.
Attempts to get Rocket Turbine and Controls Site (D Site) working cease.
K Site[4] begins operation.

1966

B–3 begins operation.
Atlas-Centaur sends first *Surveyor* spacecraft to lunar surface.
Engineering Building opens at Plum Brook.
Lewis staff levels reach peak.
Lewis converts Hydrogen Heat Transfer Facility (into Hypersonic Tunnel Facility.

1967

Lewis begins reacquiring property around Plum Brook perimeter.

1968

Apollo 8 circles Moon.

1969

Final test conducted at B–1.
Abe Silverstein retires and is replaced by Bruce Lundin.
AEC tests NERVA[3] XE engine at Nevada Test Site.
Apollo 11 makes first lunar landing.

1970

B–2 and SPF begin operation.
Apollo 13 astronauts return to Earth following aborted mission.

1971
NERVA[3] is redesigned as smaller rocket engine.

1972
President Nixon approves Space Shuttle Program.
NASA fiscal year 1973 budget submitted in September without NERVA.[3]
Apollo 17 mission in December is final *Apollo* flight.

1973
NASA cancels nuclear rocket and power programs.
Lundin announces that Plum Brook will shut down.
Symposium fails to generate external interest in Plum Brook Station.
B–3 commences preparations for Centaur Standard Shroud testing.
Staff begin mothballing the reactor and most of the Rocket Systems Area.

1974
F Site,[5] B–3, HTF, B–2, and K Site[4] conduct final runs and are mothballed.
Titan-Centaur's initial test flight fails.

1975
Plum Brook wind turbine begins operation.

1976
NASA review of Plum Brook outlines future options.
Titan-Centaur sends *Viking* vehicles to Mars.

1977
NASA cannibalizes some mothballed facilities.
Titan-Centaur launches two *Voyager* spacecraft.

1982
Lewis reduces B–1 and B–3 readiness status to Category 3.

1985
Operation of Plum Brook Wind Turbine ceases.
Office of Management and Budget recommends excessing Plum Brook.

1986
Office of Management and Budget decides to restore Plum Brook.

1987
Plum Brook begins reactivating its large test facilities.

1989
First test run conducted in reactivated SPF chamber.
K Site[4] operational with new slush hydrogen generator.

1993
HTF begins operations.

1996
B–2 facility fully restored.

1998
Demolition of Plum Brook Reactor Facility commences

2004
NASA offers centers funding to remove unused facilities.
E Stand demolished.

2007
Lewis makes plans to remove Rocket Systems Area.

2009
A Site,[6] C Site,[7] F Site,[5] and I Site[8] are demolished.

2010
B–1 and B–3 stands and Gas Handling Area are demolished.

2012
H Control Building, K Site's[4] control building, and J–5[9] hortonsphere are demolished.
Plum Brook Reactor decommissioning is completed.

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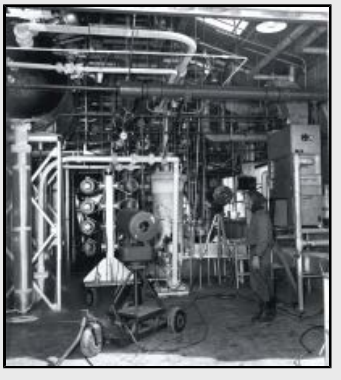
[1]OSU, Ohio State University.
[2]JPL, Jet Propulsion Laboratory.
[3]K Site, Cryogenic Propellant Tank Facility.
[4]NERVA, Nuclear Engine for Rocket Vehicle Application.
[5]F Site, Hydraulics Research Laboratory.
[6]A Site, Liquid Hydrogen Pump Facility.
[7]C Site, Turbopump Facility.
[8]I Site, Fluorine Pump Research Facility.
[9]J–5, Materials Compatibility Facility.

Research
Rocket Systems Area

TESTS TIMELINE



1958
Small gas generators (G Site)

1959
Small gas generators (G Site)

1960

1961
Liquid-hydrogen centrifugal pump (Liquid Hydrogen Pump Facility (A Site) Hydrogen Loop)
15,000-rpm hydrogen axial-flow pumps (Pilot Plant (G Site) Liquid Hydrogen Pump)
Three-stage NERVA[1] turbine and six-stage Hy-Nut turbine (G Site Turbine Facility)
Gaseous-hydrogen/liquid-oxygen engine (J–1)
Gaseous-hydrogen/liquid-fluorine engine (J–2)

1962
Liquid-hydrogen centrifugal pump (A Site Hydrogen Loop)
Liquid-hydrogen pump (C Site[2] Boiling Fluids Rig)
Vibrational analysis on SERT I,[3] Ranger accelerometer, and Sky Bolt instrumentation (E Stand [4])
Vibrational analysis on Mercury Evaporating Condensation Analysis (MECA) program (E Stand [4])
Lewis liquid-fluorine centrifugal turbopumps (Fluorine Pump Research Facility, I Site)
Gaseous-hydrogen/liquid-oxygen engine (J–1)
Copper hydrogen-oxygen engine for nuclear rocket heat transfer (J–1)
Liquid-oxygen/liquid-hydrogen pressure-fed engine (J–2)
Tank boiloffs (Tank Test Facility, J–4)

1963
Impeller designs for liquid-hydrogen centrifugal pump (A Site Hydrogen Loop)
Inducer performance in heat from nuclear rocket (C Site Boiling Fluids Rig)
Impeller matching with centrifugal hydrogen pump (C Site Pump Rig)
Vibrational analysis for MECA program (E Stand [4])
Atlas load tests (E Stand)
Hydrogen-water heat exchanger for nuclear rocket (Hydraulics Research Laboratory, F Site)
External insulation system for Centaur tank (F Site)
Pump with hydrogen-cooled bearings (G Site Turbine Building)
Lewis liquid-fluorine centrifugal turbopumps and P&W RL–10 fluorine turbopumps (I Site)
Hydrogen burnoffs for Hydrogen Heat Transfer (HHTF) design (J–1)
Copper hydrogen-oxygen engine for nuclear rocket heat transfer (J–1)
Throttling of a liquid-oxygen/liquid-hydrogen engine (Vacuum Environment Facility, J–3)
Linde superinsulation and Centaur constrictively wrapped tank (J–3 and J–4)
Fluorine/fluorine oxygen (FLOX) materials compatibility (Materials Compatibility Facility, J–5)

1964
Impeller designs for liquid-hydrogen centrifugal pump (A Site Hydrogen Loop)
Oxygen turbopump for the M–1 engine (A Site Oxygen Loop)
NERVA[1] engine bootstrapping and chilldown (B–1[5])
Inducer performance in heat from nuclear rocket; slush hydrogen (C Site Boiling Fluids Rig)

Impeller matching with centrifugal hydrogen pump (C Site Pump Rig)
Atlas/Centaur longitudinal and latitudinal dynamics (E Stand [4])
Hydrogen-water heat exchanger for nuclear rocket (F Site)
External insulation system for Centaur tank (F Site)
Pump with hydrogen-cooled bearings (G Site Turbine Building)
Small-scale axial-flow hydrogen pump (G Site Pump Building)
Lewis liquid-fluorine centrifugal turbopumps and P&W RL–10 fluorine turbopumps (I Site)
Injectors for hydrogen-oxygen engines; regeneratively cooled hydrogen engines (J–1)
Linde superinsulation (J–3)
Arthur D. Little gold Mylar insulation (J–3 and J–4)
Fluorine/FLOX materials compatibility and fluorine spills (J–5)

1965
Inducer blade loadings on a liquid-hydrogen centrifugal pump (A Site Hydrogen Loop)
Impeller matching with centrifugal hydrogen pump (C Site Pump Rig)
Centaur fairing loads (E Stand [4])
Hydrogen-water heat exchanger for nuclear rocket (F Site)
P&W RL–10 fluorine turbopumps (I Site)
Injectors for hydrogen-oxygen engines; regeneratively cooled hydrogen engines (J–1)
K Site 13-ft tank system (J–2)

1966
Inducer blade loadings on a liquid-hydrogen centrifugal pump (A Site Hydrogen Loop)
NERVA[a] engine turbopump, bootstrap, and chilldown (B–3[6])
Minimal pressure required to pump hydrogen (C Site Boiling Fluids Rig)
Impeller matching with centrifugal hydrogen pump (C Site Pump Rig)
Atlas/Centaur post-wrinkling strength (E Stand [4])
Hydrogen-water heat exchanger for nuclear rocket (F Site)
Pratt & Whitney FLOX/methane turbopump (I Site)
Injectors for hydrogen-oxygen engines; regeneratively cooled hydrogen engines (J–1)
Self-Evacuating Multilayer Insulation (SEMI) (J–3)
5-ft tank (Cryogenic Propellant Tank Facility, K Site)

1967
Four-stage axial-flow hydrogen pump (A Site Hydrogen Loop)
Advanced Centaur boiloff (B–1[5])
Atlas/Centaur bulkhead and duct dynamics (E Stand [4])
Injectors for hydrogen-oxygen engines; regeneratively cooled hydrogen engines (J–1)
Arthur D. Little insulation (J–3)
13-ft tank and 9-ft tank (K Site)

1968
Four-stage axial-flow hydrogen pump (A Site Hydrogen Loop)
Advanced Centaur boiloff and outflow (B–1[5])
Comparison of different inducer blade shapes and angles (C Site Boiling Fluids Rig)
Atlas/Centaur duct dynamics (E Stand [4])
Centaur tank cold shock (F Site)
Injectors for hydrogen-oxygen engines; regeneratively cooled hydrogen engines (J–1)
Arthur D. Little insulation and copper heat transfer tank (J–3)
7-ft tank and 5-ft tank (K Site)

1969
Advanced Centaur outflow (B–1[5] Test Stand)
5-ft tank and multilayer and self-evacuating insulation (K Site)

1970
Shadowshield (K Site)

1971
Shadowshield and multilayer insulation (K Site)

1972

Centaur shroud half-scale, hinges, and jettison (B–3[6])
Multilayer insulation (K Site)

1973

Centaur shroud tanking, seal, and structural integrity (B–3[6])
Cryogenic Storage Test Vehicle (K Site)

1974

Centaur shroud twang and structural integrity (B–3[6])
Liquid-oxygen choked flow (F Site)
Cryogenic Storage Test Vehicle (K Site)

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[1]NERVA, Nuclear Engine for Rocket Vehicle Application.
[2]C Site, Turbopump Facility.
[3]SERT, Space Electric Rocket Test.
[4]E Site, Dynamics Stand.
[5]B–1, High Energy Rocket Engine Research Facility.
[6]B–3, Nuclear Rocket Dynamics and Control Facility.

Mitigation
Rocket Systems Area

MITIGATION PROJECT

Pump House in 2007

The NASA Glenn Research Center has a number of historic facilities, some which, like the Rocket Systems Area, are no longer in use. The Center has demolished several of these unused facilities in recent years.

Although the Center had not used the Rocket Systems Area sites for decades, the sites had made important contributions to the development of advanced cryogenic technologies and to NASA's achievements in space. Glenn management felt that it was important to document the Rocket Systems Area to preserve its legacy permanently.

The Glenn History Office maintains a collection of historical materials, assists researchers, and documents historical topics through Web sites, documentaries, and publications. The History Office has previously conducted several mitigation projects for other historic facilities.

Documents:

Programmatic Agreement Among NASA, NCSHPOs, and ACHP (PDF, 0.25MB)
NASA's Historic Preservation Program (2010) (PDF, 8MB)
Protection of Historical Properties (PDF, 8MB)

I. Rocket Systems Area Mitigation Project: Description of this latest effort to document the Rocket Systems Area facilities and testing.

II. NASA Glenn History Office: Introduction to the Glenn History Office, its services, and publications.

III. Other Glenn Mitigation Projects: Overview of previous historical mitigation projects at Glenn.

Research

History Office

Other Projects

Mitigation
Rocket Systems Area

ROCKET SYSTEMS AREA MITIGATION

I Site

This Web site is part of a wider effort to document the history of the Rocket Systems Area. Section 106 of the National Historic Preservation Act requires that Federal agencies document their historic facilities before any significant structural changes, demolitions, or relocations are made. Although the Rocket Systems Area was not eligible to be a National Historic Landmark, Glenn felt that its contributions to the Nation's space program warranted permanent documentation to record the history of these facilities and disseminate that information to the public. This project formally began in 2012 and concluded in 2016.

The documentation included the collection of documents from the Plum Brook Station archives, the Glenn History Office archives, retirees, the NASA Technical Reports Server, newspaper databases, and other sources. It also included the scanning of negatives and conducting of interviews with former employees. The documents, many of which were scanned, are available on this Web site and are permanently stored in the Glenn History Office. The collected information was used to write a 300-page history of the Rocket Systems Area and to create this Web site.

Documents:

Mitigation Agreement (PDF, 8MB)
Architectural Survey of Plum Brook Station (PDF, 192KB)

Research

Products

Mitigation

Rocket Systems Area

OTHER MITIGATION PROJECTS

The NASA Glenn History Office has undertaken the task of documenting many of the historic facilities that have been demolished. This documentation includes the collection of documents, photographs, and films; photographic surveys; and creation of artistic renderings of the facilities. The information had led to a number of publications, documentaries, exhibit displays, and Web sites.

PLUM BROOK REACTOR FACILITY

The Plum Brook Reactor Facility at Plum Brook Station operated from 1962 to 1973. The National Advisory Committee for Aeronautics (NACA) purchased the land in 1956 to build a test reactor to support nuclear propulsion research, first for aircraft then rockets. The 60-MW reactor conducted over 70 experiments, most of which studied the effects of radiation on various materials. The reactor ceased operation in 1973 when the Nation's nuclear rocket program was canceled. Decommissioning began in 1998.

Reactor Products

Books:

Science in Flux: NASA's Nuclear Program at Plum Brook Station (PDF, 2.32MB)
NASA's Nuclear Frontier: The Plum Brook Reactor Facility

ROCKET ENGINE TEST FACILITY

The Rocket Engine Test Facility (RETF) was a National Historic Landmark located at the NASA Glenn from 1957 to 2003. The facility played an integral part in the development of high-energy liquid propellants. Testing of subscale rocket engines in RETF expanded understanding of combustion and led to new designs. RETF made valuable contributions to Pratt & Whitney's RL–10 engine and Rocketdyne's F–1 and J–2 engines.

RETF Products

Documents:

RETF Web site
Ideas into Hardware: A History of the Rocket Engine Test Facility (PDF, 2.12MB)

ALTITUDE WIND TUNNEL

When constructed in the early 1940s, the Altitude Wind Tunnel (AWT) was the Nation's only wind tunnel capable of studying full-scale engines under realistic flight conditions. It played a significant role in the development of the first U.S. jet engines as well as technologies such as the afterburner and variable-area nozzle. In the late 1950s, the Center removed the tunnel's interior components to test hardware for Project Mercury in altitude conditions. In 1961, the tunnel was converted into one of the country's first large vacuum tanks to support the Centaur rocket program.

AWT Products

Documents:

AWT Web site (PDF, 8MB)
Revolutionary Atmosphere: History of the AWT and the Space Power Chambers (PDF, 13.4MB)

PROPULSION SYSTEMS LABORATORY NO. 1 AND 2

The Propulsion Systems Laboratory (PSL) was the NACA's most powerful facility for testing full-scale aircraft engines at simulated flight altitudes. Researchers used PSL to study the increasingly powerful jet engines of the early 1950s and the ramjets for missile programs. With the advent of the space program, the facility was used to study complex rocket engines, including the seminal Pratt & Whitney RL–10. In the mid-1960s, PSL returned its focus to jet engines, which continued to grow in size and performance.

PSL Products

Documents:

PSL Web site (PDF, 8MB)

Pursuit of Power: NASA's Propulsion Systems Laboratory No. 1 and 2

Mitigation
Rocket Systems Area

GLENN HISTORY OFFICE

History Banner

The Glenn History Office was created in 1999 to preserve and promote our rich heritage for current and future researchers. Services include basic and in-depth reference and research; documentation of facilities, projects, and people; publications in NASA's Historical Publications Series; management of the Glenn archives; oral history interviews; development of historical programs, exhibits, and handouts; and appraisal of historical materials.

HISTORY OFFICE COLLECTIONS

The archive contains the Center's newsletter and telephone directories dating back to the 1940s, copies of historic files from the Director's Office, an oral history collection, historic audio/visual materials and artwork, press kits from major NASA missions, and a range of collections regarding individuals, facilities, and programs.

History Office

PUBLICATIONS

The Glenn History Office has sponsored and created a number of books, Web sites, and documentaries on the Center's history. In addition, Virginia Dawson wrote Engines and Innovation: Lewis Laboratory and American Propulsion Technology—a history of the Center from the 1940s through 1990. These are listed in the following section.

Books

Virginia Dawson, Engines and Innovation: Lewis Laboratory and American Propulsion Technology (Washington, DC: NASA SP–4306, 1991).

William Leary, We Freeze to Please: A History of NASA's Icing Research Tunnel and the Quest for Flight Safety (Washington, DC: NASA/SP—2002-4226, 2002).

Mark Bowles and Robert Arrighi, NASA's Nuclear Frontier: The Plum Brook Reactor Facility (Washington, DC: NASA/SP—2004-4533, 2004).

Virginia Dawson and Mark Bowles, Taming Liquid Hydrogen: The Centaur Upper Stage Rocket 1958–2002 (Washington, DC: NASA/SP—2004-4230, 2004).

RETF Products

Virginia P. Dawson and Mark D. Bowles, editors, Realizing the Dream of Flight: Biographical Essays in Honor of Centennial of Flight (Washington, DC: NASA/SP—2005-4112, 2005).

Virginia Dawson, Ideas Into Hardware: A History of the Rocket Engine Test Facility at the NASA Glenn Research Center (Washington, DC: NASA, 2004).

Mark Bowles, Science in Flux: NASA's Nuclear Program at Plum Brook Station 1955–2005 (Washington,

DC: NASA/SP—2006-4317, 2006).

Robert Arrighi, Revolutionary Atmosphere: The Story of the Altitude Wind Tunnel and Space Power Chambers (Washington, DC: NASA/SP—2010-4319, 2010).

Robert Arrighi, Pursuit of Power: NASA's Propulsion Systems Laboratory No. 1 and 2 (Washington, DC: NASA/SP—2012-4548, 2012).

Robert S. Arrighi, Bringing the Future Within Reach—Celebrating 75 Years of the NASA John H. Glenn Research Center (Washington, DC: NASA/SP—2016-627, 2016).

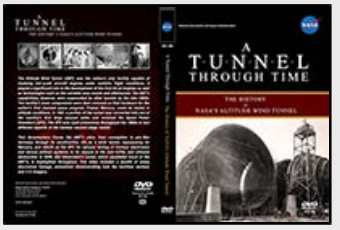
Video Documentaries

Of Ashes and Atoms—An Emmy-nominated full-length documentary on the Plum Brook Reactor Facility

Fueling Space Exploration—A documentary on the Rocket Engine Test Facility (RETF)

A Tunnel Through Time: The History of NASA's Altitude Wind Tunnel—A history of the Altitude Wind Tunnel and Space Power Chambers

Fueling Space Exploration—A documentary on the Rocket Engine Test Facility



DVD cover

Web Sites and Multimedia

NASA Glenn History Office —This Web site is a gateway to the history of Glenn Research Center and the Plum Brook Station.

Rocket Engine Test Facility (RETF)—This Web site was designed to preserve the legacy of the RETF. It includes photographs and videos of the RETF and interactive lessons on rocket engine testing.

Altitude Wind Tunnel and Space Power Chambers—This Web site provides an interactive look at what was one of NASA's most significant wind tunnels. It includes images, videos, reports, timelines, and materials for students.

Websites copy

Propulsion Systems Laboratory—This Web site is dedicated to PSL's history and facility. It includes related documents and reports, an interactive layout, and a section for students.

Lessons of a Widowmaker (and Other Aircraft)—This interactive history of NASA's research aircraft focuses primarily on former NASA Glenn vehicles. It includes images, histories, and specifications for 17 aircraft, as well as educational materials and videos.

High Energy Rocket Engine Research Facility (B–1) and Nuclear Rocket Dynamics and Control Facility (B–3)—This Web site provides the history and physical description of the B–1 and B–3 Test Stands at Plum Brook Station. It includes photographs, documents, timelines, and the 100-plus page Historic American Engineering Record (HAER) Report.

Glenn—The Early Years—This photographic retrospective of the first 40 years of operation at the Center (1941–79) was drawn from a large collection of archived photographs. The gallery of images add the in-depth descriptions provided offer a unique look into the research, people, and activities that have generated numerous technological advancements over the years. It is available for both the Web and iPad.

The NACA Inspections—This site serves as a repository for images, presentations, media materials, correspondence, and other documents from the NACA's post-war Inspections. The materials provide a snapshot of the state of the NACA, its aeronautical research, and its major personalities during this era.

Glenn's NACA-Era Aircraft— This Web site contains images, histories, and specifications for 11 aircraft used at Glenn between 1943 and 1958.

Links

Rocket Systems Area

ADDITIONAL RESOURCES

High School Visitors

Glenn History Web Sites
Glenn History Program
NASA Glenn The Early Years—A Pictorial History
Glenn Name Changes

Historic Facilities
Altitude Wind Tunnel
Rocket Engine Test Facility
Propulsion Systems Laboratory
High Energy Rocket Engine Research Facility (B–1)
and Nuclear Rocket Dynamics and Control Facility (B–3)

Historic NASA Glenn Facilities Publications
NASA's Nuclear Frontier: The Plum Brook Reactor Facility
Science in Flux: NASA's Nuclear Program at Plum Brook Station (PDF, 3.42 MB)
Ideas Into Hardware: A History of the Rocket Engine Test Facilityl (PDF, 2.13 MB)
Revolutionary Atmosphere: Altitude Wind Tunnel and Space Power Chambers (PDF, 13.4 MB)
Pursuit of Power: NASA's Propulsion Systems Laboratory No. 1 and 2
NASA History Series Publications

Current Glenn Facilities
Glenn Research Facilities
Plum Brook Station Test Facilities

Additional Research Tools
Headquarters History Office
NASA Technical Report Server
NASA Images
NASA Technical Dictionary

Historical Preservation
Ohio State Historical Preservation Office
Advisory Council on Historic Preservation
National Park Service Historic Documentation Programs

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Cleveland, OH 44135
history@grc.nasa.gov

NASA Glenn History Officer: Anne K. Mills
Archivist: Robert S. Arrighi, Alcyon Technical Services (JV), LLC