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Rehabilitation of the Rocket Vehicle Integration Test Stand at Edwards Air Force Base

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ABSTRACT

Since initial use in 1958 for the X-15 rocket-powered research airplane, the Rocket Engine Test Facility has proven essential for testing and servicing rocket-powered vehicles at Edwards Air Force Base. For almost two decades, several successful flight-test programs utilized the capability of this facility. The Department of Defense has recently demonstrated a renewed interest in propulsion technology development with the establishment of the National Aerospace Initiative. More recently, the National Aeronautics and Space Administration is undergoing a transformation to realign the organization, focusing on the Vision for Space Exploration. These initiatives provide a clear indication that a very capable ground-test stand at Edwards Air Force Base will be beneficial to support the testing of future access-to-space vehicles. To meet the demand of full integration testing of rocket-powered vehicles, the NASA Dryden Flight Research Center, the Air Force Flight Test Center, and the Air Force Research Laboratory have combined their resources in an effort to restore and upgrade the original X-15 Rocket Engine Test Facility to become the new Rocket Vehicle Integration Test Stand. This report describes the history of the X-15 Rocket Engine Test Facility, discusses the current status of the facility, and summarizes recent efforts to rehabilitate the facility to support potential access-to-space flight-test programs. A summary of the capabilities of the facility is presented and other important issues are discussed.

NOMENCLATURE

AFFTC	Air Force Flight Test Center, Edwards, California
AFM	Air Force Manual
AFRL	Air Force Research Laboratory, Edwards, California
Al_2O_3	aluminum oxide
B_2O_3	boron oxide
CO	carbon monoxide
CO_2	carbon dioxide
dB	decibels
dBA	A-weighted decibel scale
EAFB	Edwards Air Force Base
EBS	Environmental Baseline Survey
H_2O_2	hydrogen peroxide
HSFS	High-Speed Flight Station
JP-4	jet propellant-4
lbf	pounds force
LN_2	liquid nitrogen
LOX	liquid oxygen
MATS	multi-axis thrust stand

MOA	memorandum of agreement
NACA	National Advisory Committee for Aeronautics
NO_X	oxides of nitrogen
PM_{10}	particulate matter less than 10 microns in size
PSTS	propulsion system test stand
RCS	reaction control system
RETF	Rocket Engine Test Facility
RP-1	Rocket Propellant-1
RVITS	Rocket Vehicle Integration Test Stand
s	seconds
SO_2	sulfur dioxide
TEA/TEB	triethylaluminum/triethylboron, $Al(C_2H_5)_3$ / $B(C_2H_5)_3$
TNT	trinitrotoluene, $CH_3C_6H_2(NO_2)_3$

INTRODUCTION

A strategic goal of NASA in 2003 was to “Ensure the provision of space access and improve it by increasing safety, reliability, and affordability” (ref. 1). Safe and reliable access to space will be an integral part of supporting the renewed NASA focus on space exploration (refs. 2 and 3). Developing advanced airbreathing and rocket-powered propulsion systems will be the key to gaining safe, affordable, and reliable access to space. Safe flight operations require adequate testing of these vehicles to ensure flight success. Testing must include engine ground runs and full vehicle integration validation. In addition to conducting ground tests for preflight validation, consideration must also be given to the need for testing during an ongoing flight program, including testing of the system and system upgrades. Even with a well-tested, flight-ready engine, problems and anomalies will typically occur that require further testing during the flight program.

In the 1950s, many experimental airplanes, both airbreathing and rocket-powered, were tested at Edwards Air Force Base (EAFB). The dry lakebed was a unique feature for increasing the safety of landing experimental airplanes. In addition, the Rocket Engine Test Facility (RETF) was developed adjacent to the lakebed to provide integrated ground-test firing capability. That facility was used until the mid-1970s.

With the resurgence of interest in investigating less expensive and safer access to space, experimental flight vehicles are again being proposed and developed (ref. 4). Safe, efficient ground-test capability is again needed for advanced vehicles. In response to this need, the three members of the EAFB Alliance (at Edwards, California) [the NASA Dryden Flight Research Center, the Air Force Flight Test Center (AFFTC), and the Air Force Research Laboratory (AFRL)] are studying ways to meet this challenge.

This report presents a brief history of tests of experimental vehicles at the EAFB RETF, the evolution of the RETF and related adjacent facilities, and options investigated. The selected option of a major rehabilitation of the RETF is described in some detail, as are upgrades of related facilities.

Options to Resurrect Ground-Test Capabilities

To meet flight readiness safety criteria of approved access-to-space projects in the most cost-effective manner, an operable EAFB ground-test facility will be required. The infrastructure must be capable of supporting full vehicle integration tests of experimental airbreathing and rocket-powered vehicles. General requirements of the test stand would include the capability of supporting, at a minimum, liquid oxygen (LOX), Rocket Propellant-1 (RP-1), and hydrogen peroxide (H_2O_2) as propellants; and the capability of supporting up to 100,000 pounds force (lbf) thrust requirements in a horizontal test configuration. Integrated rocket vehicle testing and rocket engine operation testing should be possible with the test personnel protected within a bunker control room such that they are close enough to make modifications but protected from a possible explosion of the vehicle. A water deluge system is also required to prevent or mitigate fire hazards as well as a firex system, which is a fire extinguishment system that is activated if an unexpected fire is detected. A concrete pad for propellant servicing of these experimental vehicles will also be required. Since these capabilities have not existed near the flight line at EAFB for over two decades, NASA Dryden investigated three options focused on bringing a facility to an operable state.

The first option considered by NASA Dryden was to build a completely new vehicle test facility. This option considered constructing a thrust stand facility with the capability of supporting up to 150,000-lbf-thrust engines in a horizontal test configuration. The preliminary cost estimate for this first option was over $2 million in 1998. Because of the cost of this first option, other options were concurrently considered.

The second option considered was to build a portion of the rocket test facility elements, and utilize the remaining elements from the existing infrastructure. The Multi-Axis Thrust Stand (MATS) that was transferred to NASA Dryden from the NASA Ames Research Center (Moffett Field, California), and was a newly developing project at the time, became the primary focus for the second option. Figure 1 shows the location of the MATS facility, which was being built at the former General Electric (Evendale, Ohio) aircraft engine ground-test site, 0.5 mi north of the NASA Dryden Space Shuttle mate-demate device. The MATS facility was initially designed to support the testing of vertical takeoff and landing (VTOL) vehicles, such as the X-35 joint strike fighter (JSF) (Lockheed Martin Corporation, Bethesda, Maryland). Some of the major MATS infrastructure that could also be utilized by the rocket test stand included the control bunker, utilities, data acquisition, communications, and facility access way. Because of the obvious advantages of this approach, a design effort was funded to explore the concept and obtain a refined cost estimate. The cost estimate for adding this integrated rocket vehicle test stand to the MATS infrastructure was $1.5 million in 1999. If built, the rocket addition at this facility would be capable of testing large vehicles weighing up to 100,000 lbs, and producing up to 150,000 lbf of thrust, also in a horizontal test configuration. The facility is designed to be fully LOX-compatible, allow easy and safe access for servicing vehicles, and contain potential hazardous spills. The MATS facility has recently been completed, making this a viable future option. With a growth potential to 300,000 lbf of thrust, this proposed facility would meet the long-term requirements for both sub- and full-scale experimental rocket-powered test vehicles.

The third and final option considered was to rehabilitate and upgrade the existing X-15 RETF, utilizing much of that existing infrastructure. After a cleanup phase was completed, a preliminary assessment of the condition of the site was made. It was determined that program requirements could be met by using one of the two existing RETF test stands. Rehabilitation requirements were then established, and the cost of construction and materials was estimated at $500,000 for the north test stand of the RETF.

Considering the cost estimates of these three options as well as the need for an optimally located facility, a decision was made to investigate the feasibility of rehabilitating and upgrading the RETF to become the new Rocket Vehicle Integration Test Stand (RVITS).

Background of the Rocket Engine Test Facility

The late 1940s and early 1950s were an exciting time at EAFB. The supersonic “barrier” was first penetrated in 1947 with the X-1 experimental rocket-powered airplane (ref. 5) (Bell Aircraft Corporation, Buffalo, New York). Earlier that same year, the first flight of the jet-powered D-558-1 (Douglas Aircraft Company, Long Beach, California) occurred; the D-558-1 also conducted much-needed transonic flight research throughout its flight history. Just a few years later, in 1953, the rocket-powered D-558-2 (Douglas Aircraft Company, Long Beach, California) was flown, exceeding Mach 2 for the first time (ref. 6). The rocket-powered version of the D-558-2 was equipped with an engine nearly identical to that of the X-1, providing the D-558-2 with approximately 6,000 lbf of thrust. These vehicles were small enough that ground-test runs were conducted on ramps adjacent to the hangar.

In February of 1954, thoughts were beginning to materialize regarding achieving hypersonic flight with a manned rocket-powered airplane. A hypersonic flight vehicle was primarily pursued because of its presumed military usefulness as well as the necessity of maintaining air supremacy. Initial considerations focusing on modifying an existing experimental vehicle for this new flight regime were quickly eliminated, and it was decided that a new vehicle devoted to hypersonic research would be developed. Immediately thereafter, a task group was formed at the National Advisory Committee for Aeronautics (NACA) Langley Research Center (LaRC), Hampton, Virginia, to develop the requirements and conceptual design of a manned hypersonic vehicle. Operational objectives were determined by the NACA High-Speed Flight Station (HSFS) (now NASA Dryden), powerplant work was conducted at the NACA Lewis Research Center (now the NASA Glenn Research Center), aerodynamic studies were conducted at the NACA Ames Research Center, and hypersonic wind tunnel tests and structural experiments were conducted at the NACA LaRC. In December of 1955 a contract was signed with North American Aviation (Inglewood, California) to build a new hypersonic rocket-powered research airplane, named the X-15, and in February of 1956 Reaction Motors Incorporated (Rockaway, New Jersey) signed a contract to fabricate the XLR-99 rocket engine that would produce 60,000 lbf of thrust. Once accepted by the U.S. Air Force and the U.S. Navy, the completed vehicles were transferred to the NACA for testing at the HSFS at EAFB, the results of which would be shared by all (ref. 7).

A rocket-powered airplane engine this powerful had never been tested at EAFB, with a thrust level an order of magnitude greater than previous engines. Realizing the importance of flight safety and mission assurance, a ground-test stand capable of rocket engine testing as well as rocket-powered airplane integrated vehicle testing would be required to test the X-15. This facility became the X-15 RETF. Figure 1 shows the location of the RETF near the edge of Rogers dry lake, a sufficiently remote location to minimize risk to vehicles, personnel, and other EAFB facilities.

At about the same time that the RETF was under construction on the south side of taxiway D, pads 14 and 15 were added to the north side of taxiway D. Figure 2 shows the location of pads 14 and 15. Figures 2 and 3 show the vehicle servicing area at pad 15, which was specifically constructed for the servicing of rocket vehicles. Advantages of servicing rocket vehicles at pad 15 included the remote location of the area for safety, a sloped concrete slab with a water deck flush system to direct propellant spills away from the servicing operation, and a grated trench with a piping system to transfer LOX from perimeter-located tanks to the vehicle servicing area. At the low end of the concrete area, concrete curbing directed any spilled propellant away from the unimproved lakebed area, thus preventing fire hazards and simplifying any cleanup process. Figures 2 and 4 show pad 14, which featured a system of hydraulic lifts used to mate the X-15 to the B-52B (The Boeing Company, Seattle, Washington) carrier airplane early in the flight-test program (ref. 8). This lift system was later relocated to the ramp at NASA Dryden. Together, pad 14, pad 15, and the RETF provided EAFB with unique capabilities. Combined, these facilities are referred to as the Rocket Plane Servicing and Testing Area and are shown in figure 2.

Two ground-test stands were built at the RETF. Figure 5 is an aerial view of the RETF, and figure 6 shows the general layout of the RETF site. Figure 7 shows the north test stand, which primarily supported engine-only testing. Figure 8 shows the south test stand, which supported full-vehicle integration testing. Original construction of the X-15 RETF began in 1958, and included construction of the north and south test stands. Both test stands were oriented such that the engine plume would be directed toward the dry lakebed and away from populated areas, thus mitigating hazardous conditions. The normal wind direction at EAFB was also considered when testing a vehicle in this test orientation. Blast deflectors were constructed at each stand for plume deflection. Figure 9 shows the plume deflector at the north test stand.

Figure 10 shows the RETF concrete control bunker, also built in 1958, which was constructed in the shape of a truncated pyramid and centered between the two test stands. This bunker provided a safe shelter for control room personnel. Extra personnel could observe testing operations at the south test stand from within three separate, identical underground bunkers, or “pill boxes” that were later added in 1960. Figure 11 shows one of the three pill boxes for observation at the south test stand. Original construction at the X-15 RETF also included a maintenance shop–storage warehouse. Figure 12 shows the maintenance shop–storage warehouse.

A water deluge system was routinely used for fire prevention, since highly explosive propellants were utilized at the facility. This system consisted of a water tank, a pump house, piping, and a containment system. The water tank and pump house provided an ample supply of water to either test stand. Figure 13 shows the RETF water tank and pump house. An underground piping system carried water from the water tank and pump house to both test stands, and ultimately to several nozzles under the test article. Piping and nozzles for deluge under the test stand provided a deck flush to prevent pools of propellant from forming, and this portion of the deluge system was routinely used during testing.

A firex system was also built at both test stands and operated by using the water from the deluge system, routing this water through to several stationary nozzles pointed at the test article. Unlike the deluge system, the firex system was only activated if a fire was observed. The nozzles for the firex system were strategically located at potential fire hazard areas, or areas of concern. On the north test stand, deluge piping and several nozzles directed at the test article were mounted on the two side stands, with one stand on each side of the test article. Figures 7 and 14 show the north test stand deluge nozzles. All deluge was funneled through slopes and trenches toward a deluge containment sump capable of supporting any test requirement. Figure 15 shows the deluge trenches from the north test stand to the deluge containment sump. Figure 16 shows the deluge containment sump.

A supply and issue shop was moved from south EAFB to the RETF in 1960. In 1995, this building was renovated for use as a LOX and liquid nitrogen (LN_2) equipment servicing facility with a clean room. An adjacent concrete patio served as a LOX cart storage area. This facility provides LOX flight systems servicing and LN_2 servicing carts at EAFB. Figure 17 shows the LOX servicing facility.

VEHICLES TESTED AT THE ROCKET ENGINE TEST FACILITY

Several successful flight programs have utilized the capabilities of the X-15 RETF. Some of the vehicles tested there include the X-15, the NF-104A (Lockheed Corporation, Burbank, California), and the engine-only tests for all of the powered lifting body vehicles. The site proved versatile, providing a safe environment for personnel and equipment while testing and servicing various engines and vehicles using a wide range of propellants. A brief description of each will follow.

X-15 Testing and Servicing

The X-15 RETF was initially designed for engine and full-vehicle integration tests of the X-15 rocket-powered research airplane. Figure 18 shows X-15 ship number one at EAFB in 1960. The north test stand was first utilized for engine runs for the X-15 in 1958. Because development of the XLR-99 rocket engine was delayed, early flights of the X-15 were powered by the XLR-11 rocket engine—the same engine that was used for the X-1 (refs. 5 and 9). A virtually identical version of this engine was also used for the D-558-2 (ref. 6). The XLR-11 rocket engine had a cluster of four chambers that burned diluted ethyl alcohol and LOX; each chamber produced approximately 1,500 lbf of thrust (refs. 10 and 11). Two of these engines were used together for the X-15–XLR-11 configuration, producing a total of approximately 12,000 lbf of thrust. Figure 19 shows X-15 ship number one with the XLR-11 rocket engine configuration. A total of 30 flights were made with the X-15–XLR-11 configuration between 1959 and 1961 using the first and second vehicles (ref. 10).

A Propulsion System Test Stand (PSTS) was also created for the engines used in the X-15, and is shown being utilized in figure 20 (ref. 8). The PSTS for the X-15–XLR-11 was built by North American Aviation and was a duplication of the X-15–XLR-11 propulsion system. The PSTS was very valuable for developing propellant systems without tying up the aircraft, as well as for testing. The PSTS was essentially an X-15 mid and aft fuselage, including propellant tanks and thrust structure (ref. 8). The PSTS and the RETF proved beneficial for propellant systems development and testing of subcomponents, (e.g., valves and pressurization systems) even if this testing did not itself require engine runs.

When the more advanced XLR-99 rocket engine became available, it was integrated with the X-15 for all later flights. Figure 21 shows the X-15 with the XLR-99 rocket engine configuration. The XLR-99 rocket engine had one chamber burning anhydrous ammonia and LOX, producing approximately 60,000 lbf of thrust. Figures 22 and 23 show an XLR-99 engine run on the north and south test stands, respectively. A total of 169 flights were made with the X-15–XLR-99 configuration between 1960 and 1968, using all three vehicles (ref. 10). The X-15 also used 90 percent H_2O_2 to power the auxiliary power unit (APU) and engine turbopump, gaseous helium for propellant pressurization, and LN_2 for coolant (ref. 10). The PSTS for the X-15–XLR-99 engine is also visible in figure 22.

The RETF was used continuously for the X-15–XLR-99 configuration. Nine XLR-99 rocket engines were produced for the three X-15 vehicles, with a philosophy of providing 100 percent engine availability for each airplane. Typical use of the north test stand at the RETF consisted of running each engine for a brief period before placing that engine either in storage or in the X-15. The south test stand at the RETF was utilized for one or more engine runs (leak checks) after installation of the engine in the airplane and, initially, before every flight. Figure 23 shows a configuration test on the south test stand. Early in the program, engine runs were also typically conducted between flights, but this requirement was later relaxed if no anomalies had occurred during the previous flight (private communication with Robert G. Hoey, former AFFTC Senior Flight Test Engineer, on January 18, 2002).

In addition to the routine tests described above, the RETF was used to investigate anomalies that occurred. Engine ground-run time and engine flight time for the X-15–XLR-99, shown by the graph in figure 24, show that the X-15 RETF was extensively used up to the end of the X-15 flight program. As should be expected with any flight program, several component change-outs were required during the flight history of the X-15. Table 1 highlights some of the more significant items that were replaced, and their cost (private communication with Robert G. Hoey, former AFFTC Senior Flight Test Engineer, on January 18, 2002).

Table 1. History of high-cost items replaced during the X-15 program.

Item	Cost in 1965 dollars	Number replaced during X-15 program	Primary failure mode
Thrust chamber/Injector assembly	125,000	18	Cracks in tubing, Cracks in injector spud
Pump cases	12,000	6	Corrosion
Igniters	4,000	17	Detonation at shutdown

In addition to the items listed above, several engine overhauls were required, and hours of preventive maintenance. As noted above, any engine anomaly or major modifications to the engine required an engine run prior to that engine being placed in the vehicle, and another run once the engine was installed in the vehicle. The X-15 maintenance team consistently kept engines and parts available to support the aggressive flight schedule, and the RETF was an instrumental tool in this highly successful flight program.

In addition to demonstrating the need for a continued engine ground-run capability, the X-15 program also made regular use of the EAFB lakebed runways (including those located in the EAFB extended range complex). The capabilities provided by the RETF for propulsion system testing and the lakebeds for vehicle landings were significant contributors to the successful execution of the 199-flight X-15 program. The RETF and one of the lakebeds are shown in figure 1. The collocation of these capabilities immediately presents a cost savings and reduction in turnaround time between flights for any flight-test program. Other advantages include commonality of equipment, ground and flight control rooms, and personnel as well as logistic convenience. The savings over a noncollocated facility is substantial when considering the complications of relocating the vehicle, equipment, and personnel whenever engine testing is required. As noted above, the vehicle servicing area (pad 15) was also utilized for each flight of the X-15, and the hydraulic lift area (pad 14) was utilized for the earlier flights of the X-15.

NF-104A Testing and Servicing

In 1959, a single F-104 (Lockheed Corporation, Burbank, California) was modified by the NASA HSFS by adding a rudimentary H_2O_2 reaction control system (RCS). Figure 25 shows F-104 RCS testing. This airplane enabled pilots to experience attitude control dynamics in high-altitude flight that would be beneficial to the later NF-104A and X-15 programs. The NF-104A program that followed soon after provided further experience with RCS attitude control, as well as experience with initial boost-to-orbit profiles, operating in microgravity, and atmospheric reentry phases. Figure 26 shows the NF-104A in a classic zoom climb profile.

On October 1, 1963, the AFFTC accepted delivery of the first NF-104. Three were fabricated, and subsequently flight-tested by the AFFTC through December of 1971 (ref. 12). Primary modifications included the addition of a rocket engine for the zoom climb phase of the mission, and several reaction control jets for the attitude control phase. The RCS thrusters operated by the decomposition of hydrogen peroxide, which was force-fed by gaseous nitrogen, giving the NF-104 attitude control in low atmospheric pressure conditions. The Rocketdyne (Canoga Park, California) LR121-NA-1 rocket engine, also known as the AR2-3, was chosen as the rocket engine for the NF-104. The AR2-3 provided approximately 6,000 lbf of thrust. It was fueled by 90 percent H_2O_2 and jet-propellant-4 (JP-4) (refs. 12 and 13).

Primary use of the X-15 rocket plane servicing and testing area for the NF-104 consisted of vehicle servicing at the vehicle servicing area across from the RETF (private communication with John McTigue, former Lifting Body Project Manager, on October 9, 2001). As with the X-15, this area proved valuable as a safe region in which to service rocket-powered vehicles requiring hazardous chemicals such as the H_2O_2 used on the NF-104. The RETF test stand area was also utilized to test the NF-104 AR2-3 rocket engine near the bunker (ref. 14).

Powered Lifting Body Testing and Servicing

The lifting body program was initiated with the lightweight, unpowered M2-F1 (built as a collaborative effort between NASA Dryden and the Briegleb Glider Company of Mirage Dry Lake, California) at NASA Dryden. When this concept showed great promise, a heavyweight, powered version was built, the M2-F2 (Northrop Aircraft, Hawthorne, California), also shown in figure 27. The powered lifting body vehicles that followed included the M2-F3 (Northrop Aircraft, Hawthorne, California), HL-10 (Northrop Aircraft, Hawthorne, California), X-24A (Martin Aircraft Company, Baltimore, Maryland), and X-24B (Martin Marietta Corporation, Denver, Colorado). The M2-F2, M2-F3, HL-10, X-24A, and X-24B were all powered by the XLR-11 (ref. 15). Figures 27, 28, and 29 show, respectively, the M2-F1 and M2-F2; the X-24A, M2-F3, and HL-10; and the X-24B. Figure 30 shows the XLR-11 rocket engine installed in the X-24A. Table 2 shows a brief flight summary for these lifting bodies (ref. 15).

Table 2. Lifting body flight summary.

Vehicle	Date of first flight	Date of last flight	Number of flights
M2-F2	July 12, 1966	May 10, 1967	16
HL-10	December 22, 1966	July 17, 1970	37
X-24A	April 17, 1969	June 4, 1971	28
M2-F3	June 2, 1970	December 20, 1972	27
X-24B	August 1, 1973	November 26, 1975	36

Like the X-15, these powered lifting bodies required checkout and servicing prior to flight at the RETF. Support of the lifting body program at the RETF included cold-flow testing of the XLR-11 and servicing of all vehicles at the vehicle servicing area (private communication with John McTigue, former Lifting Body Project Manager, on October 9, 2001). As with the X-15, a PSTS was also utilized for testing of the XLR-11 during the lifting body program, and XLR-11 engine runs in the PSTS were conducted at the RETF (private communication with Jerome C. Brandt, former AFFTC Senior Flight Test Engineer, on May 18, 2005). Engine runs of the XLR-11 while installed in the lifting body vehicles were conducted on the ramp near the main building of NASA Dryden.

THE ROCKET VEHICLE INTEGRATION TEST STAND

Like the vehicles that utilized the X-15 RETF in the past, access-to-space vehicles of the future will need to conduct vehicle integration testing and operations at a ground-test facility, preferably at the same location as vehicle flight testing. The X-15 RETF is being rehabilitated and renamed to be the Rocket Vehicle Integration Test Stand (RVITS), and will support future ground-testing requirements of access-to-space vehicles at EAFB.

Completed Efforts at the Rocket Vehicle Integration Test Stand Site

Several activities were initiated to support the restoration of the X-15 RETF into the new RVITS facility. Initial activities included a cleanup phase, an assessment phase, and a design phase. Some of the required construction efforts have also been completed. The completed efforts to date at the RVITS will now be described.

Cleanup Phase

Recognizing future potential, a decision was made to clean up the existing X-15 RETF. The cleanup phase enabled an assessment to be made of the extent of rehabilitation required.

After decades of nonuse, a considerable amount of cleanup was required. Since the control bunker was used as a storage area for several years, a considerable amount of unrelated equipment had to be removed from the area. Weed abatement was performed all around both the north and south test stand, and thousands of pounds of debris were removed from the deluge containment sump area.

Assessment Phase

With the cleanup phase completed, the assessment phase was ready to begin. Assessment determined the amount of rehabilitation required, and what that rehabilitation would include. Rough order of magnitude cost estimates for design and construction would be the final output of the assessment phase, and subsequently the strategy for further project efforts could be established.

Since a future vehicle or engine may want to tie directly into the structure of the north test stand itself, an assessment of the structural integrity of the test stand was necessary. A NASA Dryden structural engineer visually evaluated the structural state of the north test stand. The overall conclusion was that there was no indication of significant degradation or damage since it was last used (about 25 years ago). Minor corrosion around the test stand currently exists; removal of this corrosion, including a cleanup inspection, is still required. Since lead-based paint was common during the period in which the RETF was constructed, an initial test was conducted to determine the contents of the paint; these tests proved that some of the paint tested did contain lead. Further testing should be conducted prior to any modifications that disrupt the painted surfaces.

Assessment of the concrete at the site was primarily focused on LOX compatibility. Small hairline cracks were found in the concrete at the test stand, however, most were insignificant when considering LOX compatibility issues. The few cracks that are large enough to allow LOX to enter will have to be sealed. The original concrete expansion joints at the test stand were made of an asbestos-based material, and new expansion joints will be necessary. Residual oil under the test stand was also found. This surface was thoroughly cleaned with a citrus-based cleaning agent, but more cleaning, sealing, or both, may be required.

The high-temperature 1-in-thick concrete surface layer in the thrust bucket was severely eroded because of normal wear at the site. The extremely high velocities and thermal conditions of the exhaust plumes and water deluges during testing caused considerable damage to this outer layer of concrete. The thrust bucket surface required removal and replacement in this area. Figure 31 shows the RVITS infrastructure and modifications before construction.

The cleanup of the deluge containment sump unveiled a few cracks in the sump walls that were large enough for LOX to easily penetrate. Some of these cracks can be seen in figures 15 and 16, and will be repaired and sealed for LOX compatibility and to mitigate environmental concerns. It was also determined that the deluge containment sump was a percolation pit—a water-catch basin that has no bottom concrete surface. A bottom concrete surface would have to be added to meet current environmental requirements. Figure 32 shows the deluge containment sump concrete repair before construction, with conceptual modifications added graphically.

Asphalt at the site was generally in fair shape, but some areas of the asphalt were elevated or depressed and needed to be leveled to mitigate potential trip hazards. Foreign object debris (FOD) transfer from RVITS back to the taxiway was also a concern. Fortunately, in the summer of 2002, another area of EAFB had just completed asphalt work and there was plenty of excess asphalt. This excess asphalt was enough to completely resurface all of the old original asphalt, paving the entire RVITS area.

Several electrical conduits exist, transferring power and data between the bunker and the test stand. An optical probe check of one of the vacant electrical conduits was conducted to assess the general condition and clarity from the inside. This visual inspection showed that it was in excellent shape. Internal cleaning will be required prior to pulling new wiring through if these original conduits are used. An assessment of the other conduits should also be implemented if existing wiring is deemed inadequate and must be replaced.

The inside length, width, and height measurements of the control room bunker are 39.5, 18.25, and 8.25 ft, respectively. It is an earth-covered structure, heavily reinforced with a concrete exterior. Earth barricading on the sides and rear has a 1.5 horizontal to 1 vertical slope. There is a standard earth cover over the roof, with a reinforced 4- by 4-in steel mesh. Entrance to the bunker is made through two doors in series—an external blast door and an internal door. The external blast door is missing, and must be replaced. The AFRL tasked Bill Lawrence, then with Sparta Incorporated at Edwards Air Force Base, to conduct an explosive safety analysis on the bunker. He performed this analysis with the aid of Karagozian & Case structural engineers (Burbank, California). Their analysis concluded that there is negligible risk of injury to human occupants from structural response or collapse from a maximum credible event up to 3,120 lb of trinitrotoluene (TNT) equivalent on the north test stand. This TNT weight equates to a 31,200-lb weight of LOX–RP-1 propellant at the north test stand. This capability is contingent upon the replacement of the external blast door of the bunker.

Design Phase

After the cleanup and assessment phases had been completed, final cost estimates were established by the AFRL for design and construction based on the baseline requirements of the facility as specified by NASA Dryden and the AFFTC. These estimates confirmed the cost-effectiveness of rehabilitating the X-15 RETF to the new RVITS, and the design effort was then initiated.

Detailed design drawings were created by Sverdrup Technology Incorporated (Edwards Air Force Base, California) and Applied Engineering Services Incorporated (Edwards Air Force Base, California) (AES) through the AFRL that define the modifications required to the site in order to meet these requirements. These drawings are now released to the AFRL configuration control system. Revisions to these drawings beyond the baseline requirements of the site can be made as required.

At the time these detailed drawings were undertaken, the RVITS was being prepared for the requirements as defined by a typical rocket-powered airplane, such as the Orbital Sciences Corporation (Dulles, Virginia) X-34 Technology Testbed Demonstrator. The RVITS was originally designed to support vehicle testing of up to 80,000-lbf-thrust rocket engines in a horizontal configuration utilizing propellants such as RP-1, LOX, or H_2O_2. It was later decided to increase this thrust capability to 100,000 lbf.

Description of New Facilities

There are several tasks that have been completed, or will be completed, for the rehabilitation of RVITS. Some of the major tasks requiring design work will be described below.

The power and instrumentation boxes that were originally located near the test stand were used to send power and data between the test stand and mission control within the bunker. These boxes are unusable, and were removed from the RVITS area. The new power and instrumentation boxes, when added, will be located farther from the test stand on the asphalt (closer to the bunker), requiring tapping into the conduit under the asphalt. This new location will allow space for relatively large vehicle wingspans, and will be more removed from liquid and gaseous propellants. A nitrogen purge system for these boxes can be added if it is required. Figures 7 and 33 show the RVITS infrastructure before and after construction modification, respectively.

The concrete at the test stand required a few modifications. Metallic rails integrated within the concrete were once used to roll in a canopy over the test article during inclement weather. The rails can be seen in figure 7. These rails were removed, and the remaining grooves were refilled with concrete, maintaining the structural integrity of the test stand while reducing trip hazards. Figures 33 and 34 show this concrete area, now free from the rails, which will enable a thrust stand structure to be integrated into the concrete (to be discussed below). Existing asbestos-based concrete expansion joints were also removed. The joints all around the concrete area were then cleaned and refilled with a new non-asbestos-based LOX-compatible sealant. Figure 35 shows an example of the new expansion joint material. Concrete curbs were also added around the concrete stand area. Figures 36, 37, and 38 show different views of the added concrete curbing. These curbs will help contain any spilled liquid propellant by directing it toward the deluge containment sump.

The assessment phase revealed severe erosion to the high-temperature concrete surface layer in the thrust bucket. This was caused by normal wear by the high temperatures and velocities of rocket plumes and water deluges, as discussed above. The eroded concrete surface layer was removed and relined with a new high-temperature concrete surface layer. Figures 36 and 39 show different views of the thrust bucket modifications after construction. The thrust bucket concrete liner may need to be resurfaced again, however, because of the crack formation that occurred in some of the concrete sections during the solidification process; in this condition, the liner does not meet design requirements.

Relocation of the two existing lighting and deluge stands may be required if a vehicle with a wingspan larger than that of the X-15 (22 ft) is tested at the RVITS. A design is in place to move these stands farther from the test stand and integrate them with concrete through concrete piers if required. Also if necessary, the lighting and deluge stands on the north side of a vehicle being tested can be integrated into the existing blast wall. Figure 36 shows the location of the blast wall near the test stand.

Modifications to the deluge containment sump were extensive. In addition to sealing minor cracks on the sloped walls, one of the areas requiring rework was the test stand trench exit into the sump. The cracked concrete trench exit was sawed and reformed, ensuring LOX compatibility and mitigation of environmental hazards by minimizing uncontrolled leaks. Figure 40 shows the modifications to the deluge containment sump trench. A concrete bottom surface was also added to the deluge containment sump, ensuring containment in accordance with current environmental requirements. This surface has been sloped appropriately such that the contents gravitate toward a sump partition, which was also added. Figure 41 shows the deluge containment sump bottom and partition, both added during concrete construction. A valve has been integrated within this partition to allow the contents in the sump to be drained out if determined to be environmentally safe. Figure 42 shows another view of the sump partition and the valve controller.

During the design phase, the current location of the LOX and LN_2 equipment servicing facility was found to be a major point of concern for activation of the RVITS. It was determined that the RVITS could not operate at full test capacity until the servicing facility is relocated, because of the possibility of damage from an explosive incident. The AFFTC is seeking funding to move the servicing facility to a new location.

The ground-testing of relatively large vehicles will require a test stand that is integrated into the concrete at the site, and the test stand must be capable of withstanding the large thrust forces involved. Figure 43 shows an artist's concept of how a typical thrust stand might appear at the RVITS. For clarity, this figure features the X-34 Technology Testbed Demonstrator as an example of a typical test setup.

REQUIREMENTS

Initial requirements at the RVITS are primarily focused on environmental requirements, alliance operating requirements, and safety requirements. Environmental requirements were developed based on the construction and potential impact of full operation at the RVITS. Alliance operating requirements were developed outlining the anticipated contributions of each of the Edwards Alliance members. Safety requirements were focused on the possibility of a vehicle explosion at the RVITS site, and efforts to mitigate the associated hazards. Each of these requirements will be discussed below.

Environmental Requirements

The AFFTC environmental office facilitated obtaining the permits required for operation at the RVITS, and all testing intended for the RVITS was communicated to their office. Preliminary requirements for air and water discharge, as well as requirements for noise attenuation and the environmental baseline survey have been considered.

Air

Because ground-test firings of a rocket will introduce pollutants into the atmosphere, the type and quantity of these pollutants were considered. A rough estimate of generated pollutants was made based on the ground-testing of a typical vehicle that may utilize RVITS, such as the X-37 Advanced Technology Demonstrator or the X-34 Technology Testbed Demonstrator. Since air environmental concerns were greater for the X-34, it was used as a baseline for the air permit. Table 3 lists engine characteristics for the X-34 (ref. 16), and maximum testing at RVITS was estimated as shown in table 4.

Table 3. Engine characteristics of the X-34.

Fuel	Rocket propellant-1
Oxidizer	Liquid oxygen
Burn time for flight	Approximately 155 s
Combustion flowrate	195.5 lb/s
Oxidizer/fuel mixture ratio	2.34
Thrust (vacuum) [30:1 nozzle]	63,939 lbf
Thrust (sea level) [15:1 nozzle]	48,082 lbf

Table 4. Maximum X-34 testing at the rocket vehicle integration test stand.

Maximum ground-run test time	155 s
Maximum ground tests per day	1
Maximum ground tests per month	2
Maximum ground tests per year	8

Based on these assumptions, maximum pollutants generated are as noted in table 5. These estimates were derived from a simplified analysis, taking the combustion products from the chamber pressure through an optimal expansion to standard atmospheric pressure. In addition to water, the primary products of combustion will be carbon monoxide (CO) and carbon dioxide (CO_2). Trace amounts of oxides of nitrogen (NO_X) and sulfur dioxide (SO_2) will also be present, as well as airborne suspended particulate matter less than 10 microns in size (PM_{10}). The quantity of these trace elements is estimated to be proportional to the production of carbon monoxide created in relation to data available on small rocket engines (ref. 17).

Table 5. Estimated X-34 emissions at the rocket vehicle integration test stand site over time.

Unit	CO_2	CO	PM_{10}	NO_X	SO_2
Tons per day	4.57	6.19	0.0164	0.0175	0.0245
Tons per month	9.13	12.38	0.0327	0.0350	0.0491
Tons per year	36.52	49.53	0.1308	0.1402	0.1962

The X-34 also utilizes triethylaluminum–triethylboron (TEA/TEB) as a pyrophoric igniter (a volatile fuel capable of combusting spontaneously with air). Assuming complete combustion of TEA/TEB (85 percent / 15 percent) (ref. 17) with a maximum of 10 lb usage per test, pollutant quantities for the aluminum oxide (Al_2O_3) and boron oxide (B_2O_3) can be estimated as noted in table 6 (ref. 17).

Table 6. Estimated X-34 emissions from triethylaluminum–triethylboron usage.

Unit	Al_2O_3	B_2O_3
lbs per day	3.8	0.54
lbs per month	7.6	1.08
lbs per year	30.4	4.32

These rough estimates were then used to generate pollutant limitations in an air permit, which was subsequently approved by Kern County. In addition, the air permit acknowledges that other propellants may be used, such as H_2O_2 and other kerosene-based rocket fuels. The air permit granted by Kern County is renewed on an annual basis.

Water Discharge

Water environmental requirements were also primarily based on RVITS operations for testing of the X-37 and the X-34. Hazard mitigation in this arena was focused on environmental pollutants discharged into the deluge water at RVITS.

The X-34 utilizes RP-1 and LOX as propellants (ref. 16). The X-37 program initially considered using the AR2-3 rocket engine, which uses JP-4 and H_2O_2 as propellants (ref. 13). Propellant spills from either vehicle are expected to be minimal. If any fuel spillage occurs, an attempt will be made to thoroughly mop it up prior to it funneling into the deluge containment sump. LOX spills will most likely vaporize before reaching the sump, and are not expected to be an environmental concern. H_2O_2 will be treated by dilution with water. As noted above, the X-34 also utilizes TEA/TEB, but this is not expected to be a spill concern since it is a pyrophoric igniter, and it is also contained in small, well-sealed canisters (refs. 16 and 17).

The RVITS deluge containment sump is capable of holding approximately 35,000 gallons of liquid. When full (up to the partitioned side), the surface area exposed for evaporation is approximately 1900 ft^2. If propellant is suspected to be in the deluge containment sump, a test will be conducted on the water within the sump. The Edwards Bio-Environmental Office will conduct the test for water contamination. If it is contaminated, the water will be handled as a hazardous material and pumped into tanker trucks for removal. If it is free of contaminants, the water will be released into the unlined portion of the deluge containment sump where it will be absorbed into the environment through evaporation and percolation.

Expected propellant usage and operational procedures at RVITS were developed to estimate the environmental impact. The Air Force then submitted this information to the California Regional Water Quality Control Board, which later granted an operational waiver for the RVITS site. The waiver will be renewed as required.

Environmental Baseline Survey

The purpose of the Environmental Baseline Survey (EBS) is to assess the site before and after the proposed construction, and ensure that no environmental violations occur during or after the construction. The focus of the EBS is to mitigate the exposure of environmental hazards from the facility to the construction crew, test users of the facility, or the natural wildlife in the surrounding area. The EBS quantifies the environmental state of the facility so that it can be maintained or improved upon.

The impact to the natural wildlife at the RVITS site is expected to be minimal. Construction of the RVITS will not exceed the existing X-15 RETF perimeter, and operation at the RVITS is not expected to exceed the original usage of the facility.

The preconstruction survey identifies any hazardous materials (such as asbestos and lead-based paints) that may be present. Once hazardous materials at the site have been identified, the appropriate protection can be designated for the construction crew, and the necessary precautions can be taken. A preconstruction survey was conducted for initial construction efforts at the RVITS. If additional construction is required, it should be preceded by a relevant preconstruction survey.

The post-construction survey sets the standard by which the facility will be maintained. Each contractor or user of the facility will be responsible for returning it to the same or better environmental condition that it was in before their project began. The overall purpose of the post-construction survey is to ensure that the facility is maintained in an environmentally safe state, and to mitigate the negative effects on the environment. Once construction at the RVITS site is complete, this post-construction survey will be conducted.

Noise Levels

The RVITS site is located near the center of EAFB; EAFB occupies approximately 301,000 acres of desert terrain (ref. 18), which provides an effective physical barrier between the test site and the general public. The test stand orientation at the RVITS is such that the rocket engine exhaust plume would be directed toward the northeast, where most of the noise would be focused over the uninhabited dry lakebed.

The NASA Procedural Requirements on Hearing Conservation set the permissible exposure limits as noted in table 7 (refs. 17 and 19). These limits are more conservative than the Occupational Safety and Health Administration (OSHA) requirements.

Table 7. Permissible exposure limits for continuous noise (NASA Procedural Requirements on Hearing Conservation).

Duration (hours)	Sound level [dBA]
16	80
8	85
4	90
2	95
1	100
0.5	105
0.25	110
0.125 or less	115

The A-weighted decibel scale (dBA), the adjusted sound pressure scale, accounts for the insensitivity of the human ear to low frequencies. The acoustic energy generated by engine testing is concentrated in the low-frequency range (ref. 17).

Sound pressure levels heard by the general public are expected to be mild since relatively low-thrust rockets will be tested at RVITS, several miles within the base. It is uncertain at this time what sound levels will occur at EAFB during rocket testing, but noise levels will be monitored. Noise levels on base will not exceed limits as defined by standards set by NASA and EAFB. To attenuate sound levels, the water deluge system may be required for water injection into the plume of the rocket engine during testing.

Air Force Flight Test Center and Dryden Flight Research Center Operating Agreements

The Edwards Alliance members (NASA Dryden, the AFFTC, and the AFRL) have developed a Memorandum of Agreement (MOA), which documents all aspects of the participation in the construction and utilization of the RVITS facility. The agreement was modeled after a previous MOA that covered the cooperative use of other facilities and shops at NASA Dryden and the AFFTC for the productive benefit of the EAFB community as a whole. The overall intent is to provide ready access of all the member organization facilities, shops, and areas of expertise, to all Edwards Alliance members. This would maximize utilization of all capabilities, and would mitigate the requirement for any member organization to seek outside support for their projects when the required capability was available through another alliance member. The RVITS MOA included the AFRL as a participant in the design, construction, test support and user of the RVITS. The previous MOA was between NASA Dryden and the AFFTC only. The RVITS MOA will be coordinated with and signed by each of the member organizations before it is finalized.

Explosive Hazard Issues

The maximum potential explosive hazard of any testing to be conducted on the RVITS was estimated based on a maximum propellant load of 31,200 lbs of LOX / RP-1. Based on the Air Force Explosive Safety Hazards Standard, Air Force Manual (AFM) 91-201, 31,200 lbs of LOX / RP-1 carries a potential explosive hazard of 10 percent equivalent weight of TNT. The 10 percent equivalent weight also applies to LOX / LH_2 (liquid oxygen / liquid hydrogen) type propellants. The AFM 91-201 goes on to specify that for this equivalent explosive potential, a 600-ft blast hazard (over-pressure) exclusion zone must be maintained around the test stand during hazardous operations. This exclusion zone applies to personnel as well as high-valued facilities such as the LOX servicing facility, which is co-located with the RVITS. In addition to the blast hazard exclusion zone, AFM 91-201 also specifies that a 1,250-ft fragmentation zone must be maintained around facilities that pose significant explosive hazards in populated areas. The fragmentation zone must remain clear of all unprotected personnel during hazardous testing. Taxiway E is beyond this 1,250-ft fragmentation zone, at a safe distance, as can be seen in figure 2. The fragmentation zone can be reduced to 900 ft for areas considered “sparsely populated.” A sparsely populated area is defined as no more than 15 people located in any of eight equally-sized wedge-shaped areas in a circle around the site of the explosion potential. Because of the hazard exclusion zone definitions specified in AFM 91-201, it was determined that the EAFB LOX servicing facility (located 215 ft from the test stand) had to be relocated before hazardous (hot fire) testing could be conducted on the test stand.

The EAFB LOX storage facility was formerly located across taxiway D, positioned approximately 1,050 feet from the RVITS. Since this operation consisted of less than 15 persons, it came under the sparsely-populated area guidelines, and thus was outside both the explosive hazard zone as well as the fragmentation zone. Although safety requirements posed no restrictions to testing at the RVITS because of the proximity of the storage facility from the RVITS, relocation of the storage facility was considered necessary to ensure that the vehicle servicing area at pad 15 could be fully utilized for future rocket-vehicle propellant servicing operations. The AFFTC and NASA Dryden made a decision and committed funds, set aside for the RVITS project, to move the LOX storage facility. The move of this facility from pad 15 to another safe location farther from RVITS was completed in early 2003. The decision to move the storage facility relaxed a self-imposed requirement of the RVITS project which was to install a fragmentation fence to protect the storage facility.

CONCLUDING REMARKS

The history of the X-15 Rocket Engine Test Facility is extensive, and the facility has proven to be a valuable resource for the testing of rocket-powered aircraft at Edwards Air Force Base. Recent interest expressed by the National Aeronautics and Space Administration and the Department of Defense to increase the investment and development of access to space and space exploration vehicles reestablishes the need for thorough testing on a rocket test stand of this caliber, with the capability of full vehicle integration testing of a rocket-powered airplane. Testing at the Rocket Vehicle Integration Test Stand will be used to mitigate flight anomalies, thus increasing flight readiness and flight safety.

The Air Force Flight Test Center, the NASA Dryden Flight Research Center, and the Air Force Research Laboratory are combining their resources through the Edwards Air Force Base Alliance in an effort to reestablish the capability of ground-testing rocket engines and rocket-powered vehicles at Edwards Air Force Base. Each organizational member of this Alliance has put forth considerable effort toward the successful completion of this greatly needed infrastructure. The Rocket Vehicle Integration Test Stand will prove to be beneficial for the Edwards Air Force Base community by increasing flight readiness and flight safety, as well as increasing operational efficiency through the collocation of ground-test capabilities with existing flight-test and research capabilities.

Initial rehabilitation efforts at the Rocket Vehicle Integration Test Stand have commenced with the cleanup and initial assessment of the site having been completed. Baseline requirements for the test stand were established and conceptual designs completed, evolving through the completion of design and detail drawings for the Rocket Vehicle Integration Test Stand. The LOX storage facility was relocated in early 2003. Construction at the Rocket Vehicle Integration Test Stand site is continuing.

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FIGURES

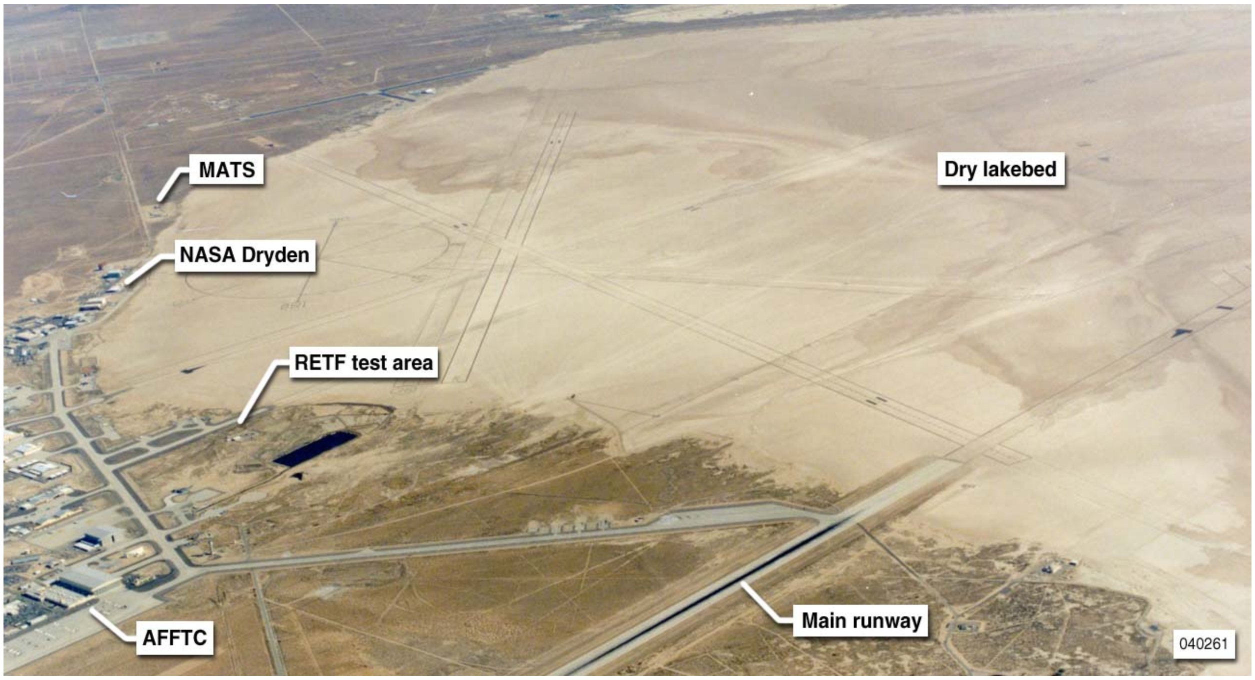


Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 1. The Rocket Engine Test Facility (the future Rocket Vehicle Integration Test Stand) with surrounding capabilities.

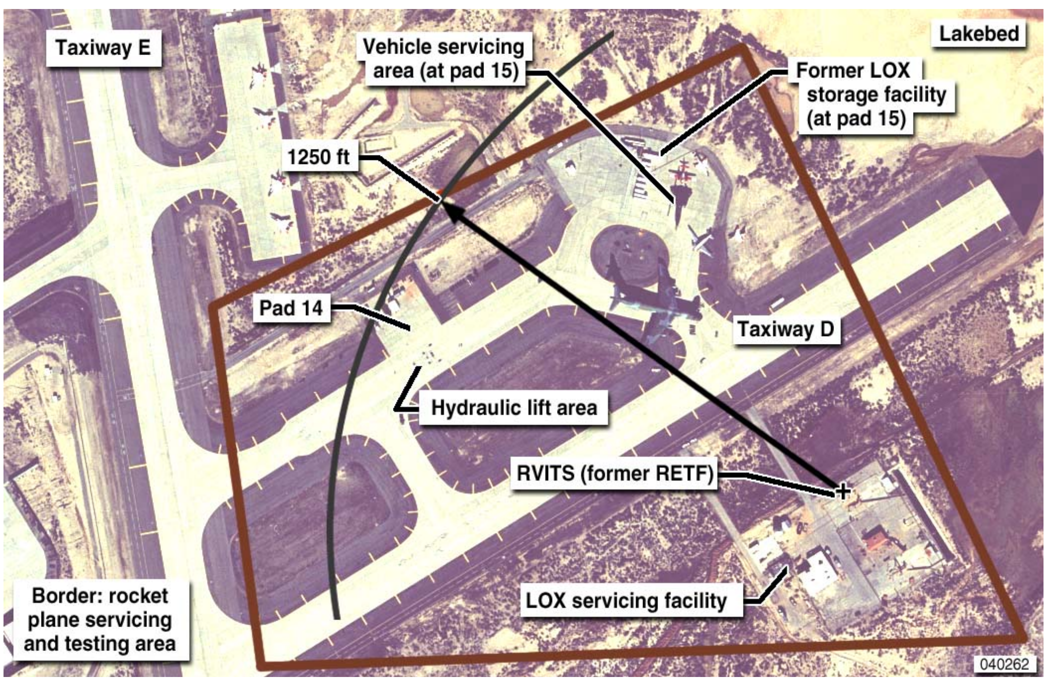


Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 2. The rocket plane servicing and testing area, showing the Rocket Engine Test Facility (the Rocket Vehicle Integration Test Stand before construction), the vehicle servicing area, and surrounding capabilities.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California.

Figure 3. The X-15 rocket-powered research airplane at the vehicle servicing area on pad 15.

E-5104

Figure 4. The hydraulic lift at the vehicle servicing area near pad 14 (December, 1959).

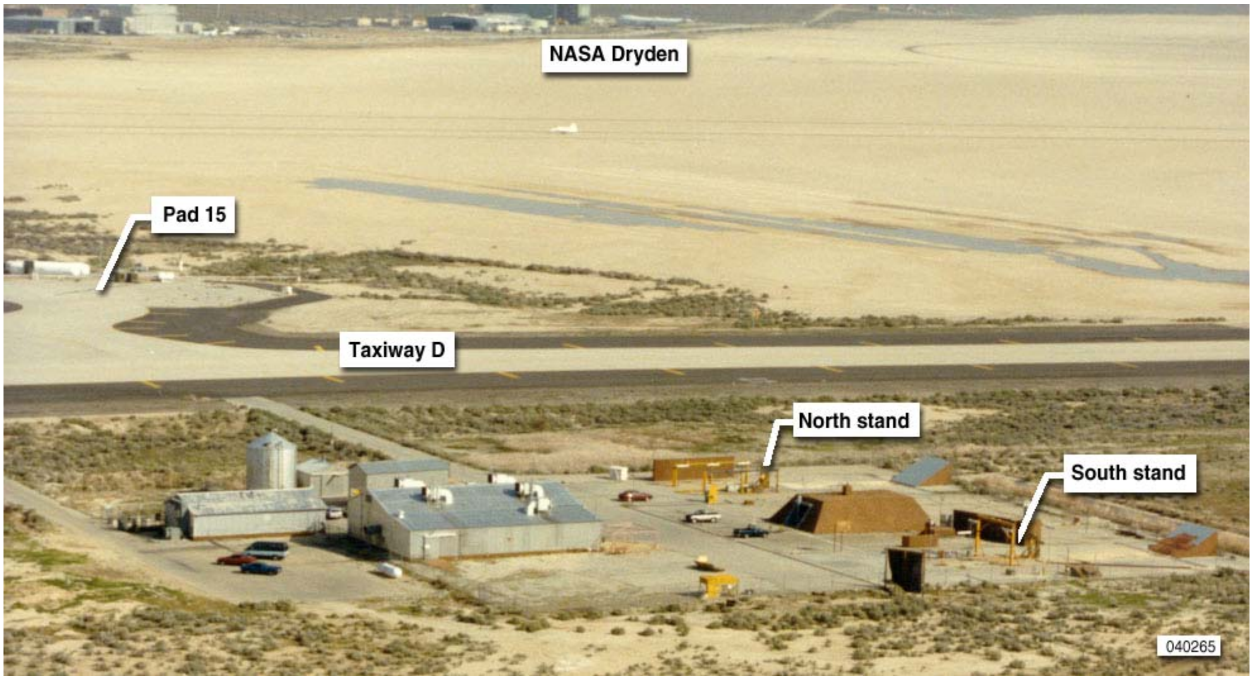


Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 5. Aerial view of the Rocket Engine Test Facility.

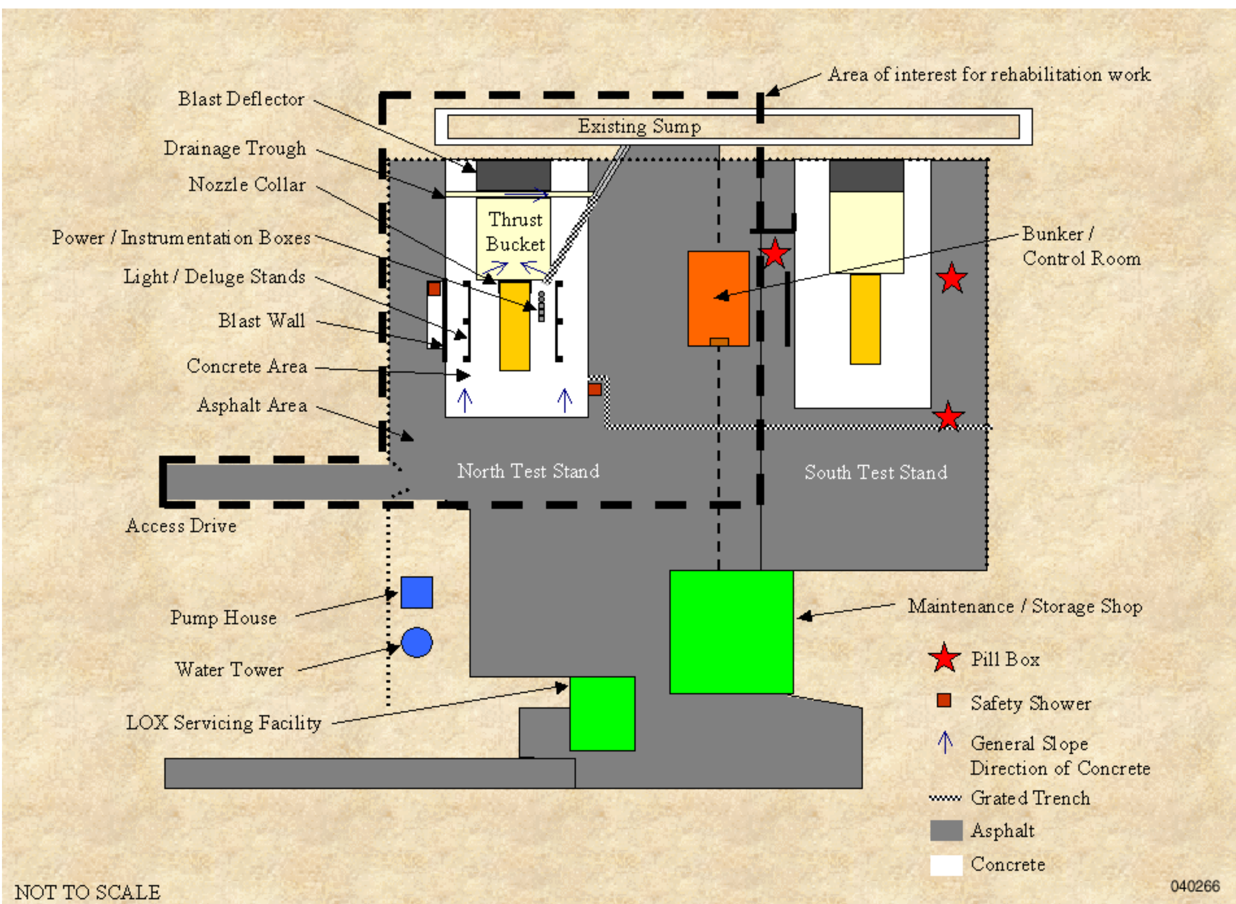


Figure 6. Schematic of the general layout of the Rocket Engine Test Facility site.

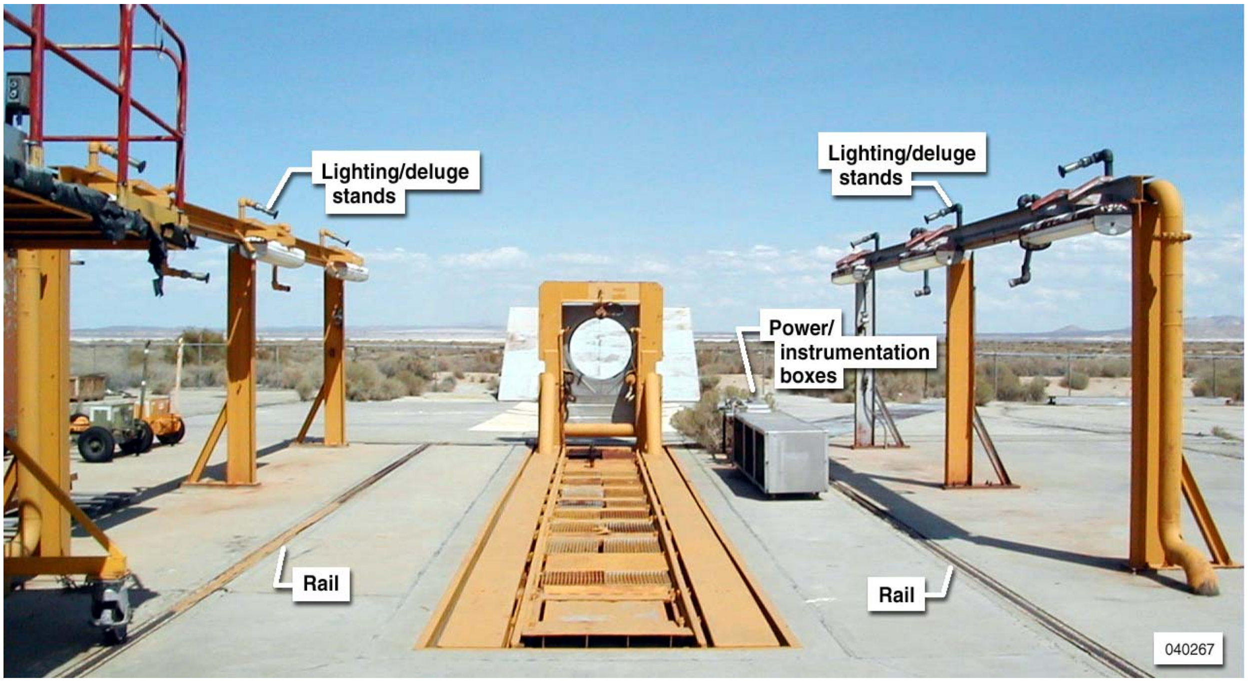


Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Ronald J. Ray and Daniel S. Jones).

Figure 7. The Rocket Vehicle Integration Test Stand infrastructure, (the former north test stand of the Rocket Engine Test Facility) before construction.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 8. The south test stand of the Rocket Engine Test Facility.

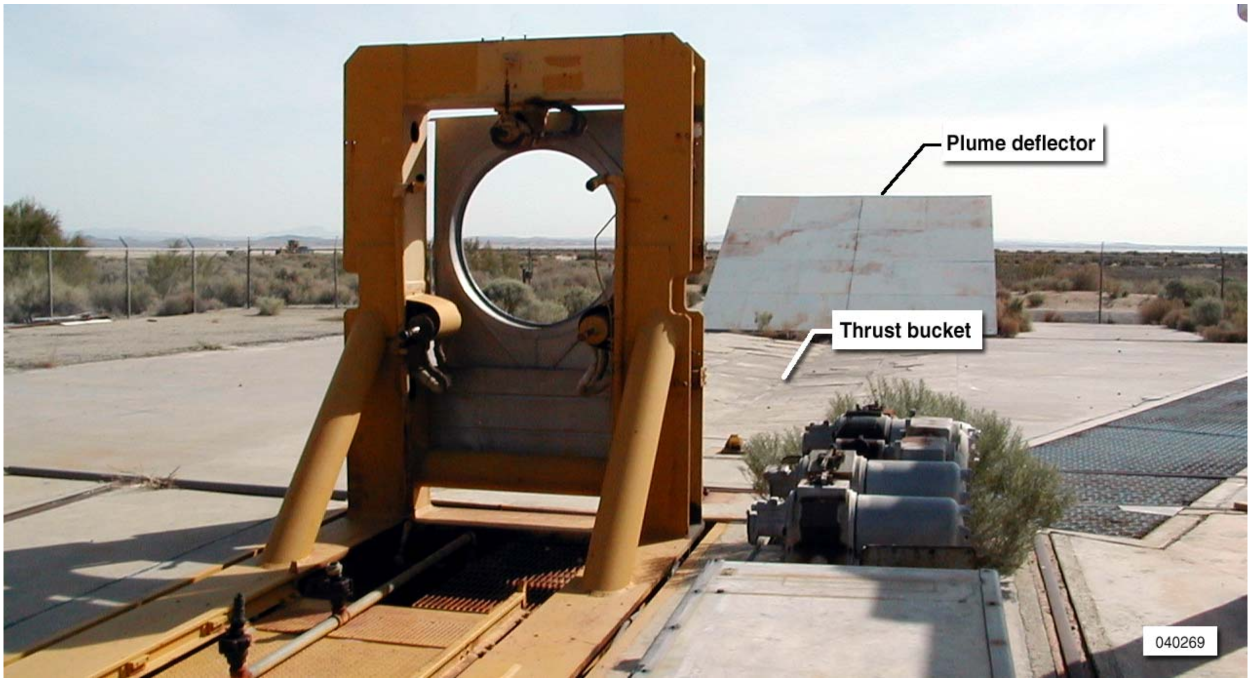


Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 9. The north test stand blast deflector at the Rocket Engine Test Facility.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 10. The Rocket Engine Test Facility control bunker.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 11. One of the three pill boxes for test observation at the south test stand of the Rocket Engine Test Facility.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 12. The Rocket Engine Test Facility maintenance shop-storage warehouse.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 13. The Rocket Engine Test Facility water tank and pump house.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 14. North test stand deluge nozzles.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 15. North test stand deluge trenches to the deluge containment sump.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

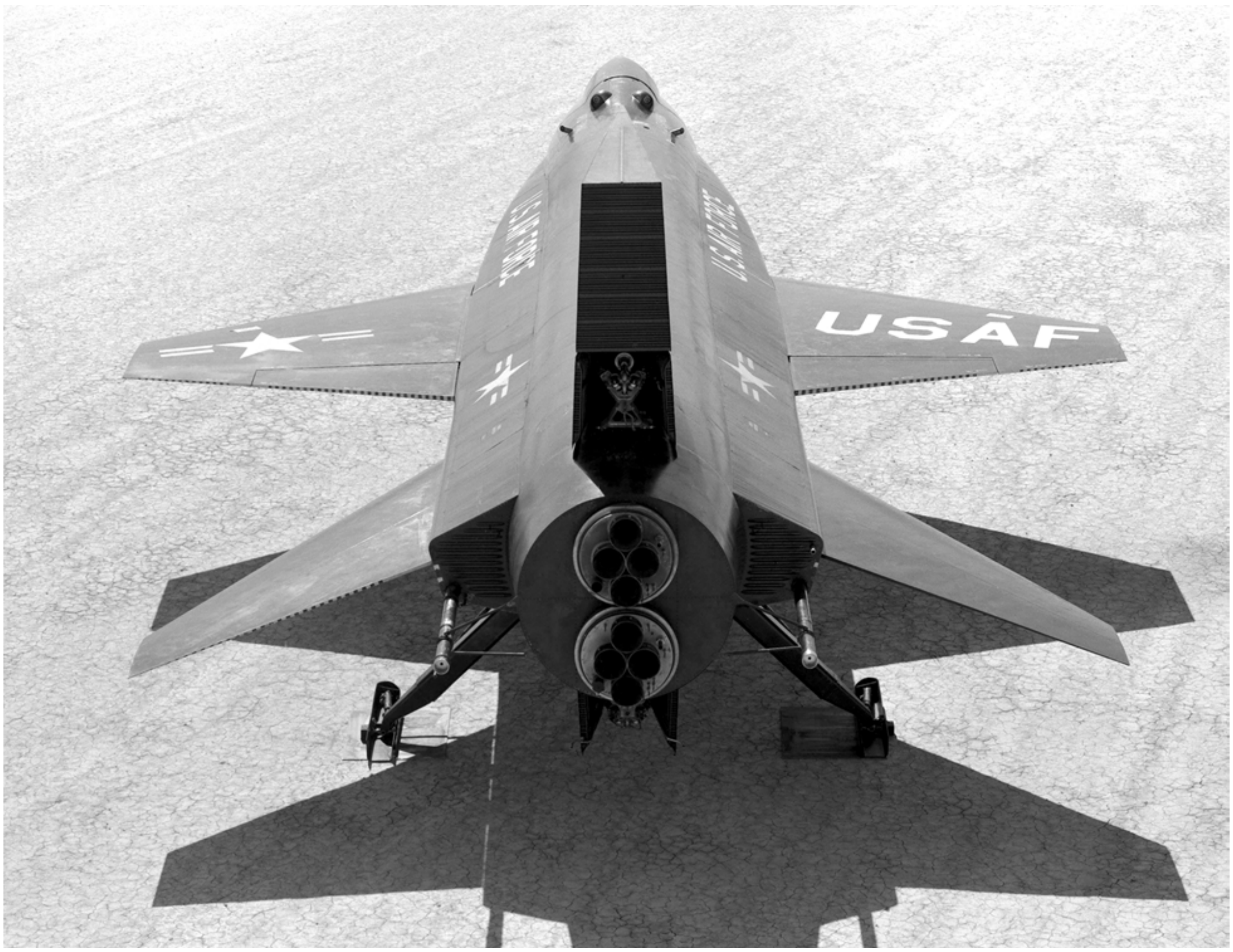
Figure 16. The deluge containment sump.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 17. The liquid oxygen servicing facility.

E-5251

Figure 18. The X-15 rocket-powered research airplane, ship number 1, at Edwards Air Force Base, 1960.



E-5256

Figure 19. The X-15 rocket-powered research airplane, ship number 1, with the XLR-11 rocket engine configuration, at Edwards Air Force Base, 1960.

Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 20. Testing the XLR-11 rocket engine for the X-15 rocket-powered research airplane on the north test stand, using the propulsion system test stand with liquid oxygen and alcohol propellant (January, 1959).

E-7413

Figure 21. The X-15 rocket-powered research airplane with the XLR-99 rocket engine configuration.

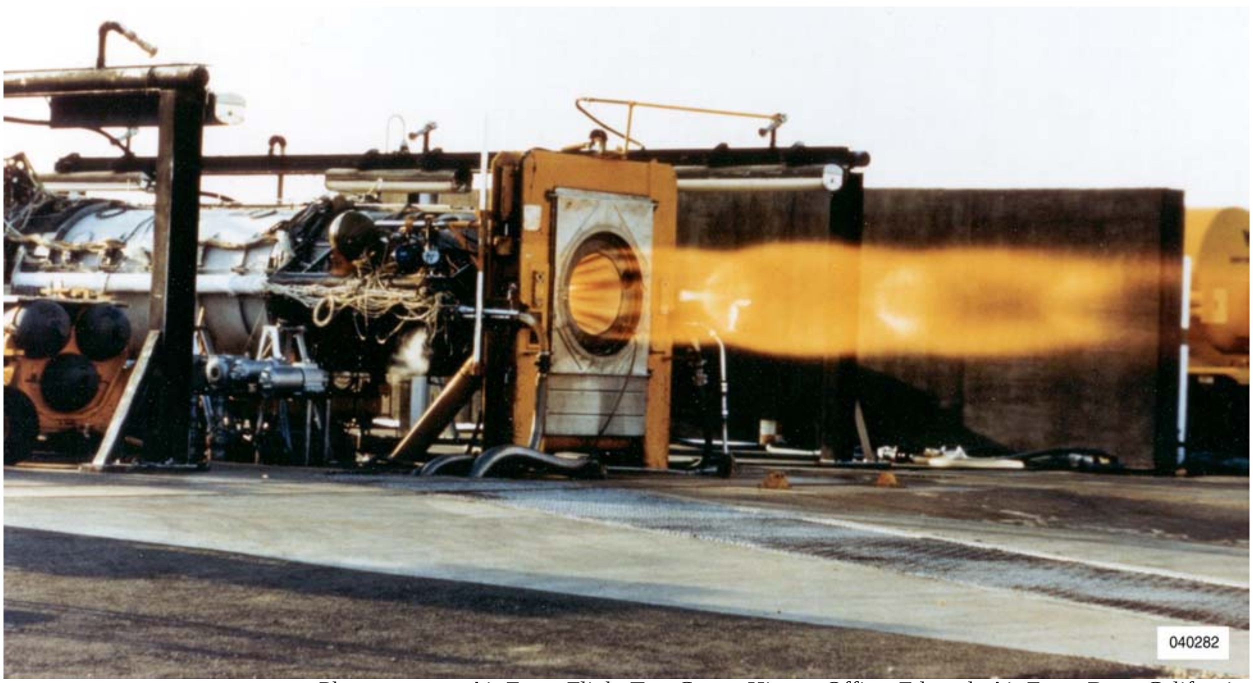


Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 22. An XLR-99 rocket engine run on the north test stand, using the propulsion system test stand with liquid oxygen and anhydrous ammonia propellants.

E-10336

Figure 23. The X-15 rocket-powered research airplane with the XLR-99 rocket engine configuration during testing on the south test stand.

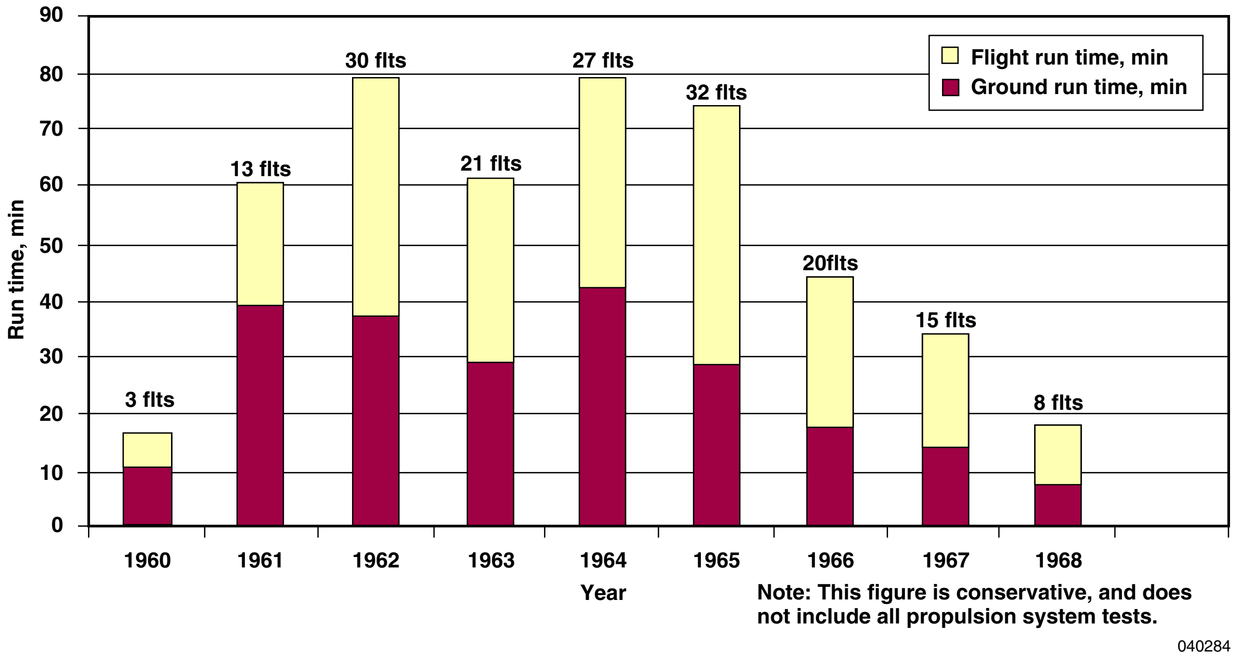


Figure 24. Engine run time for the X-15 rocket-powered research airplane with the XLR-99 rocket engine configuration.

ET-95

Figure 25. Testing the F-104 reaction control system at Edwards Air Force Base, December, 1960.

Photo courtesy Air Force Flight Test Center History Office, Edwards Air Force Base, California.

Figure 26. The NF-104A in boost phase, with jet propellant and hydrogen peroxide rocket engine, and hydrogen peroxide reaction control system.

ECN-1107

Figure 27. The M2-F1 and M2-F2 lifting bodies at Edwards Air Force Base, 1966.

EC69-2523

Figure 28. The X-24A, M2-F3, and HL-10 lifting bodies, all powered by the XLR-11 rocket engine, at Edwards Air Force Base, 1972.

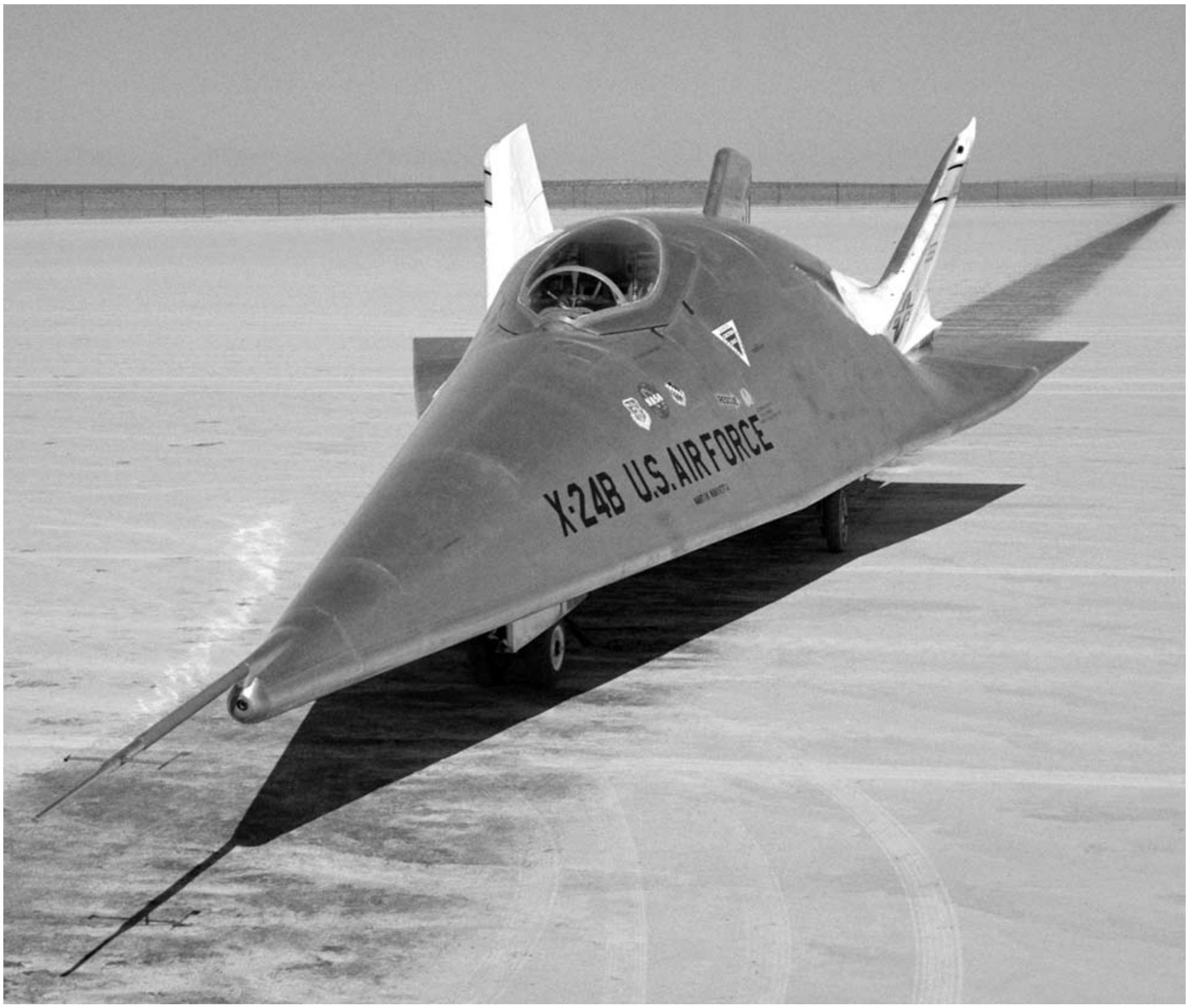


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Figure 29. The X-24B, powered by the XLR-11 rocket engine, at Edwards Air Force Base, 1973.

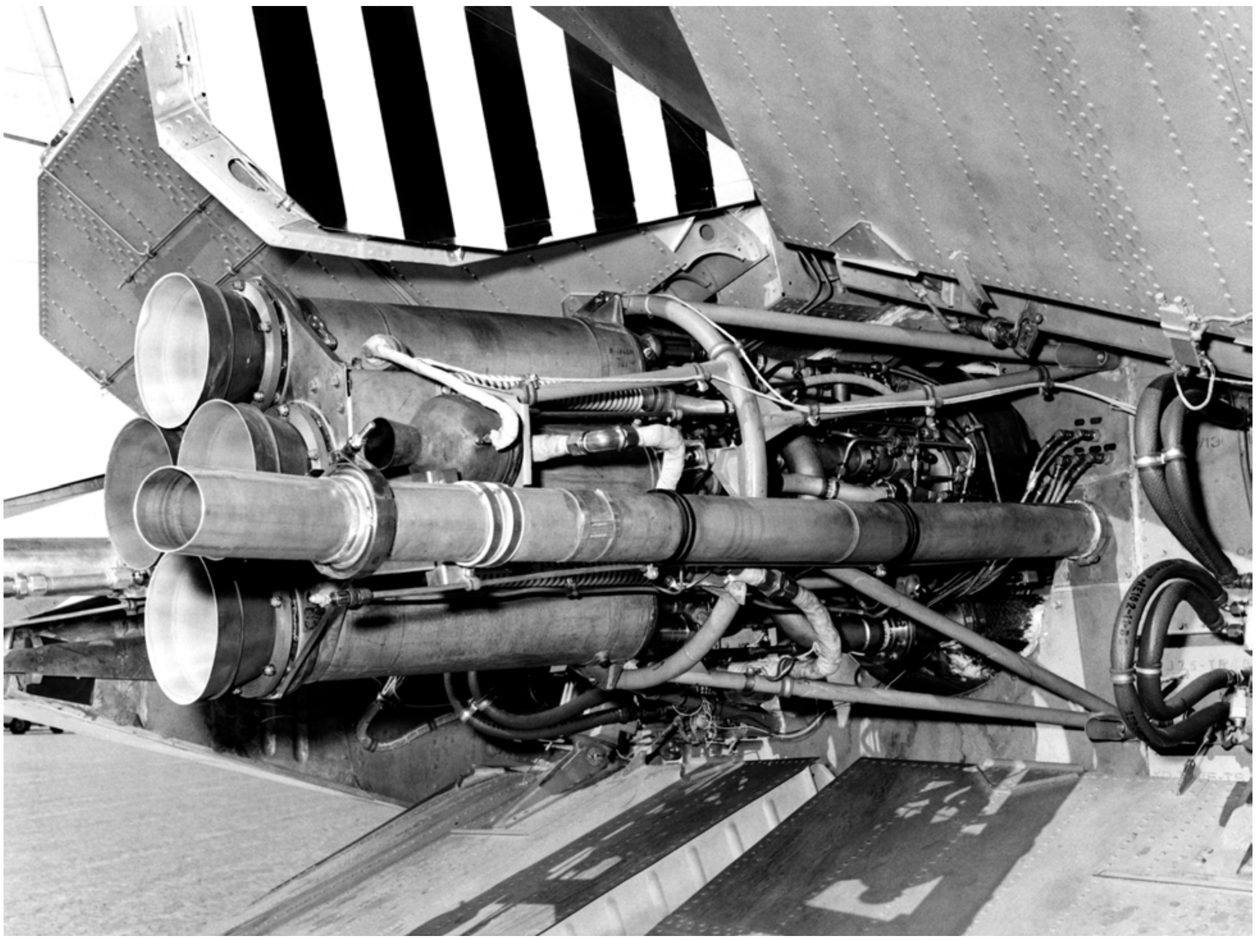

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Figure 30. The XLR-11 rocket engine in the X-24A lifting body, 1971.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 31. The Rocket Vehicle Integration Test Stand infrastructure and modifications, before construction, with concrete curbing added conceptually.

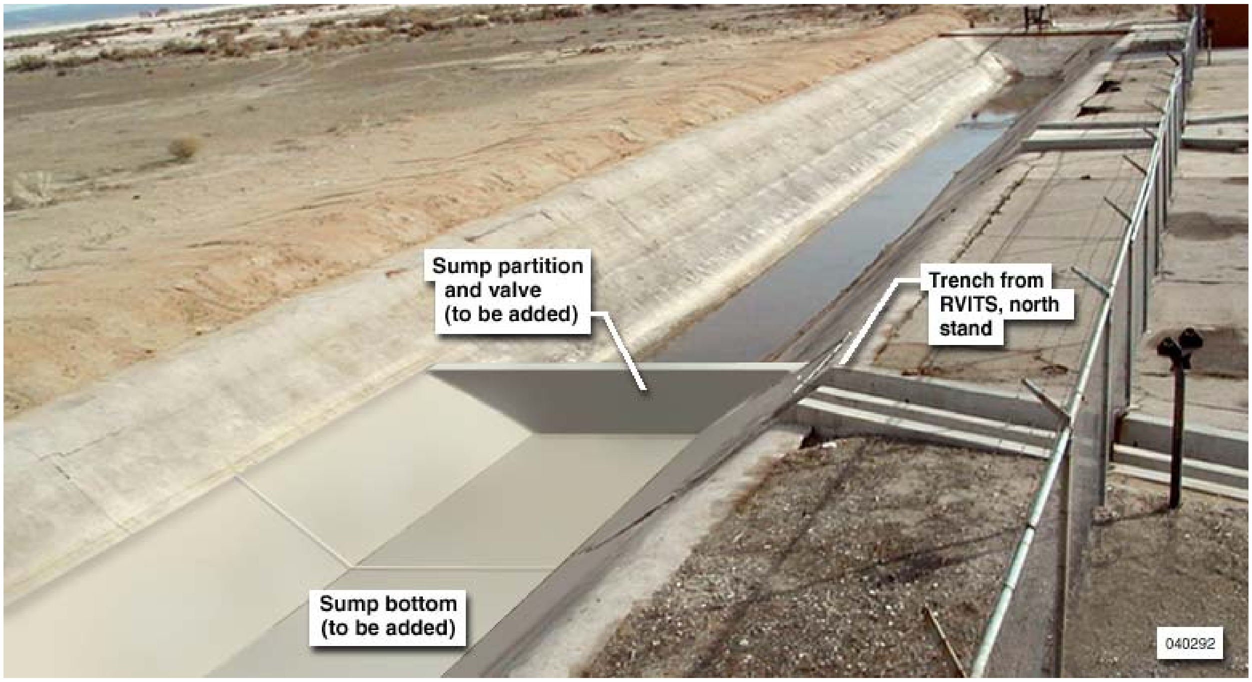

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 32. Deluge containment sump concrete repair, before construction, with conceptual modifications.

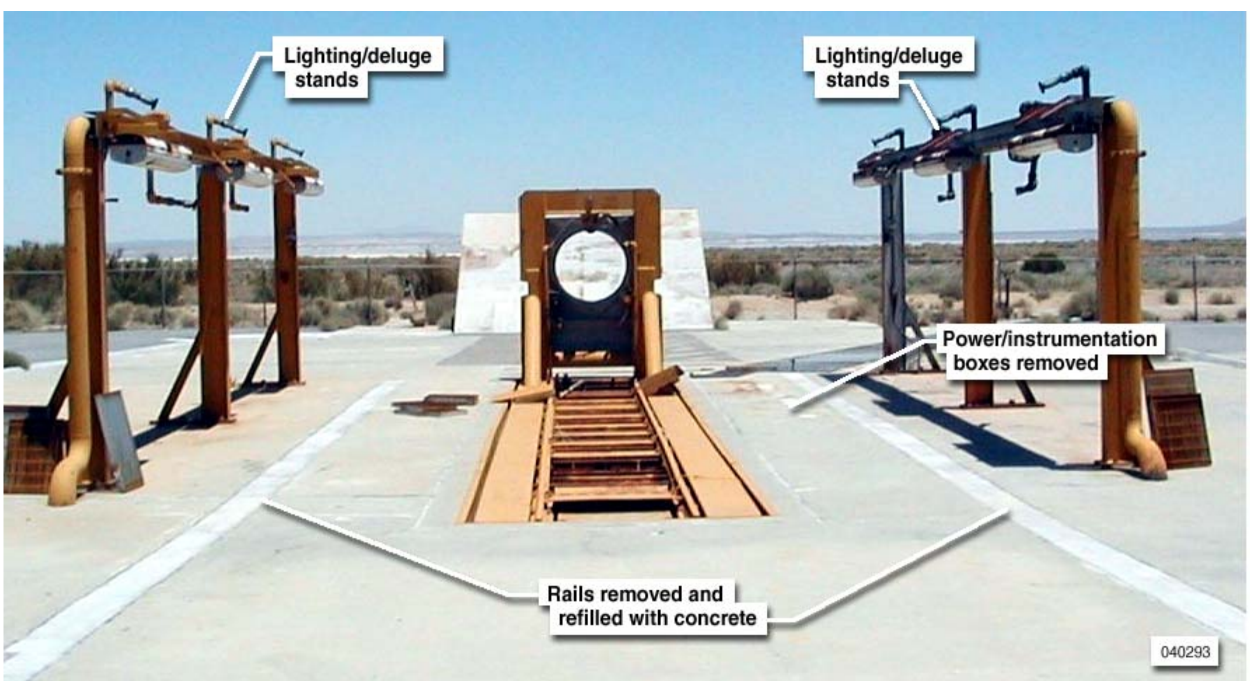

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 33. The Rocket Vehicle Integration Test Stand infrastructure, after construction modifications.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 34. Concrete construction, showing one of the two rails removed and refilled.

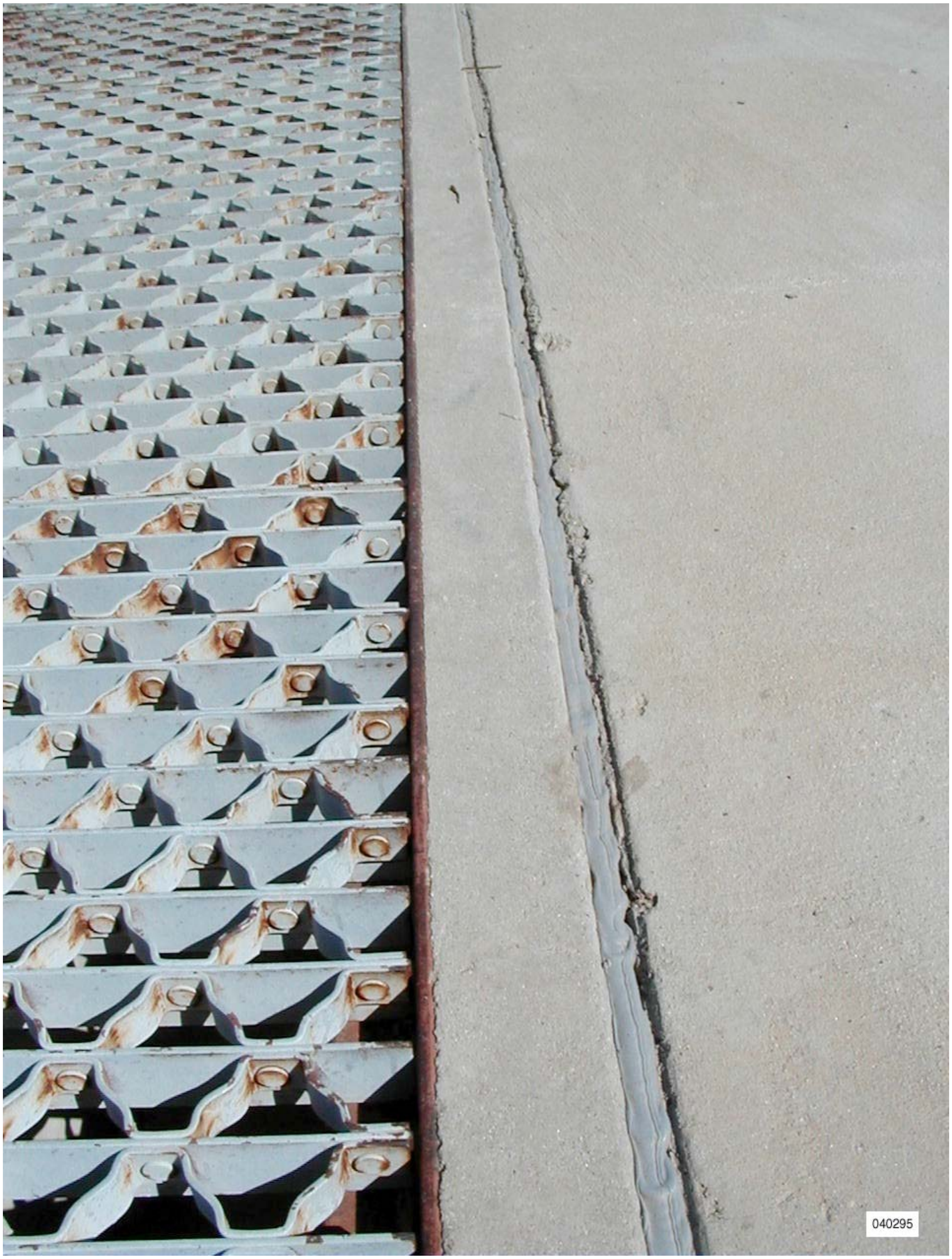

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 35. Concrete construction, showing an example of the new liquid-oxygen-approved concrete expansion joint near the trench.

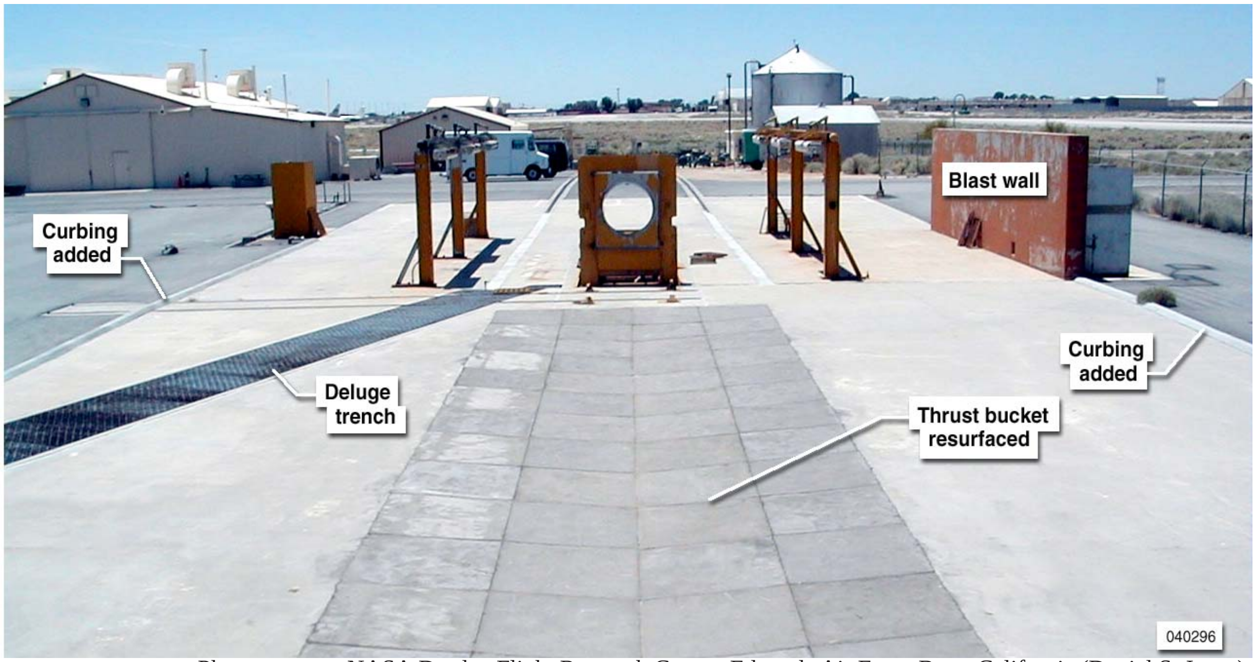

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 36. The Rocket Vehicle Integration Test Stand infrastructure, after construction modifications.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 37. Concrete modifications to the Rocket Vehicle Integration Test Stand, showing one side of added curbing around the test stand.

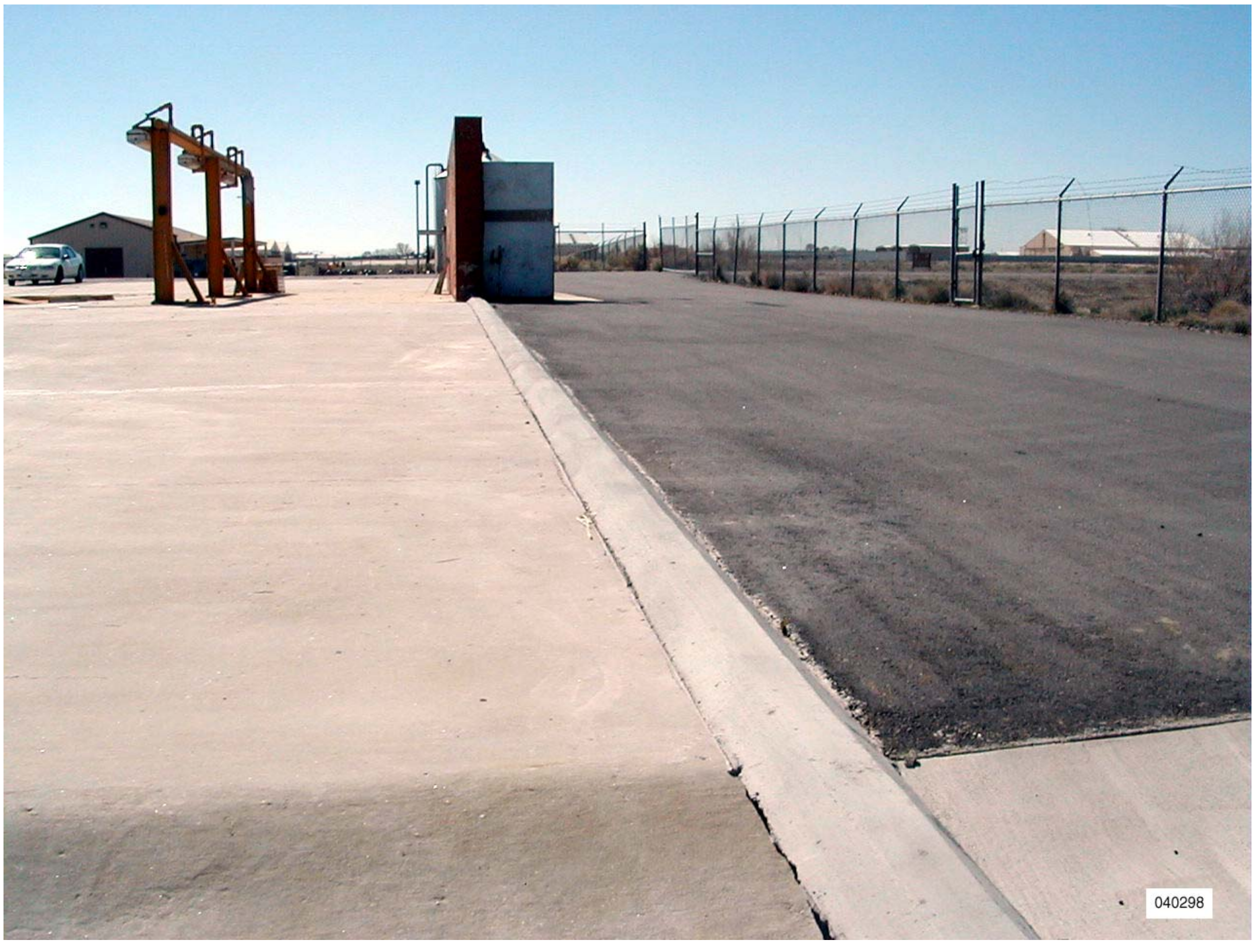

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 38. Concrete modifications to the Rocket Vehicle Integration Test Stand, showing a second side of added curbing around the test stand.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 39. Thrust bucket modifications to the Rocket Vehicle Integration Test Stand, after construction.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 40. Deluge containment sump modifications near the trench of the Rocket Vehicle Integration Test Stand, after construction.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 41. Deluge containment sump modifications showing the addition of the sump bottom and partition to the Rocket Vehicle Integration Test Stand, after construction.

Photo courtesy NASA Dryden Flight Research Center, Edwards Air Force Base, California (Daniel S. Jones).

Figure 42. General deluge containment sump modifications to the Rocket Vehicle Integration Test Stand, after construction.

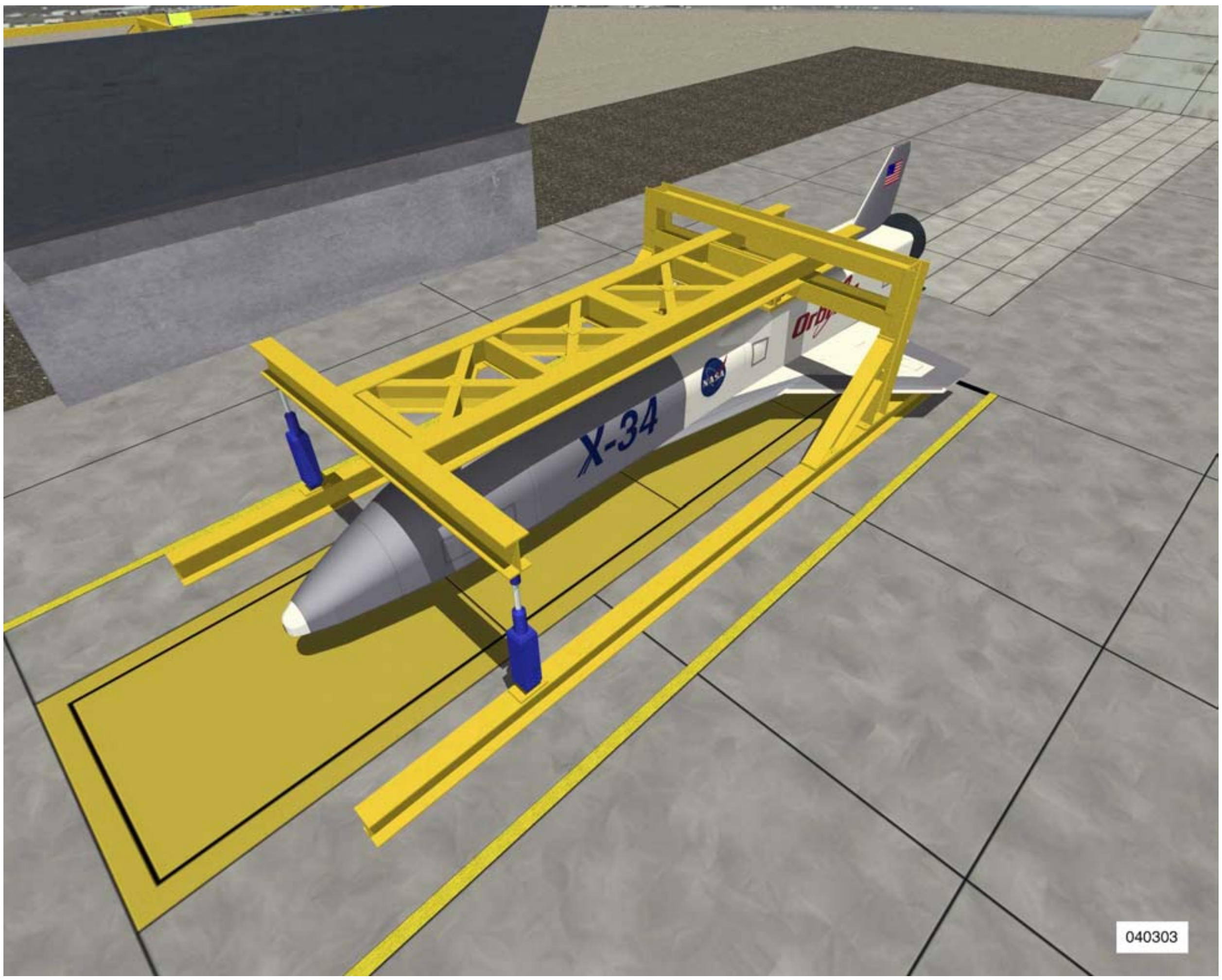

Figure 43. Conceptual view of a possible thrust stand integrated with the Rocket Vehicle Integration Test Stand site at the north test stand.

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14. ABSTRACT

Since initial use in 1958 for the X-15 rocket-powered research airplane, the Rocket Engine Test Facility has proven essential for testing and servicing rocket-powered vehicles at Edwards Air Force Base. For almost two decades, several successful flight-test programs utilized the capability of this facility. The Department of Defense has recently demonstrated a renewed interest in propulsion technology development with the establishment of the National Aerospace Initiative. More recently, the National Aeronautics and Space Administration is undergoing a transformation to realign the organization, focusing on the Vision for Space Exploration. These initiatives provide a clear indication that a very capable ground-test stand at Edwards Air Force Base will be beneficial to support the testing of future access-to-space vehicles. To meet the demand of full integration testing of rocket-powered vehicles, the NASA Dryden Flight Research Center, the Air Force Flight Test Center, and the Air Force Research Laboratory have combined their resources in an effort to restore and upgrade the original X-15 Rocket Engine Test Facility to become the new Rocket Vehicle Integration Test Stand. This report describes the history of the X-15 Rocket Engine Test Facility, discusses the current status of the facility, and summarizes recent efforts to rehabilitate the facility to support potential access-to-space flight-test programs.
A summary of the capabilities of the facility is presented and other important issues are discussed.

15. SUBJECT TERMS

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