The S-1C Static Test Stand was built to withstand the 7.5 million lb of thrust of the firing of the Saturn V rocket engines.

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Testing the Limits: The Marshall Space Flight Center's S-1C Static Test Stand

PRESIDENT JOHN F. KENNEDY epitomized America's ambitions when he spoke at Rice University on September 12, 1962, and challenged the country to put a man on the moon by decade's end. The mission was both a point of national pride and a pragmatic effort to counter the success of the Soviet Union's space program. The apex of that effort was the Apollo Program, the third U.S. human spaceflight program (after Projects Mercury and Gemini).

While the '60s heyday of the National Aeronautics and Space Administration (NASA) brings to mind dramatic launches at Cape Canaveral in Florida and the steady Mission Control operators directing the action from Houston, the Marshall Space Flight Center (MSFC) in Huntsville, Alabama, also played a critical role. Here giant stands were built to test the powerful rockets that would take astronauts into space. In particular, the massive S-1C Static Test Stand allowed NASA engineers to test-fire and refine the engines that powered the launch stage of the mighty Saturn V rocket, the heart of the Apollo missions.

Since its founding in 1960, the MSFC has always had a focus on rockets, says Tom Behrens, an architect with the Historic American Engineering Record (HAER). The space flight center was carved out of the U.S. Army's Redstone Arsenal in an area once used for research and development by the Army Ballistic Missile Agency.

The longtime director of the MSFC was German-born Wernher von Braun. Von Braun was part of Operation Paperclip, the famous effort to bring German scientists, engineers, and hardware to the United States after World War II to try to jump-start the country's lagging missile technology. "A vast number of them ended up in Huntsville, working for the army as the army deconstructed their V-2s," says Behrens. The V-2 was Germany's attempt at a guided ballistic missile. "The guidance was a problem, but the engine kind of worked reliably. That's how Huntsville ended up being in the missile development business."

The Redstone rocket was the American successor to the V-2, and the country's first ballistic missile. Its interim test stand, in use between 1953 and 1961, had been cobbled together while engineers and administrators awaited congressional appropriation for a larger facility.

To test a new generation of larger rockets, a bigger test stand would be needed. According to a 2013 report on the S-1C prepared by HAER and written by University of Virginia historian Douglas Jerolimov, NASA announced plans for a static test facility at MSFC as early as 1960, at a cost of $10.8 million. Aetron, a division of Aerojet-General Corp. (now Aerojet Rocketdyne, of El Segundo, California), designed and engineered the test stand. Initial drawings for the facility were completed in September 1962, and construction, overseen by Boeing, was finished by March 1965.

In the early days of the space program, there was much debate about how to get Americans to the moon; specifically, whether to use a massive rocket that would fly directly there or a multipart assembly that would require the ship to achieve orbit around either the earth or the moon. According to the MSFC's website, NASA "eventually decided to conduct the manned lunar landing mission using a lunar orbit rendezvous (LOR) technique, and they selected the Saturn V as the launch vehicle" for the Apollo spacecraft and lunar module.

The Saturn V would operate in three stages, called S-IC, S-II, and S-IVB. Saturn V measured 363 ft in length and weighed 6.5 million lb, according to Jerolimov. The critical launch stage—S-1C—required five of Rocketdyne's F-1 liquid propellant rocket engines, which collectively were capable of generating 7.5 million lb of thrust.

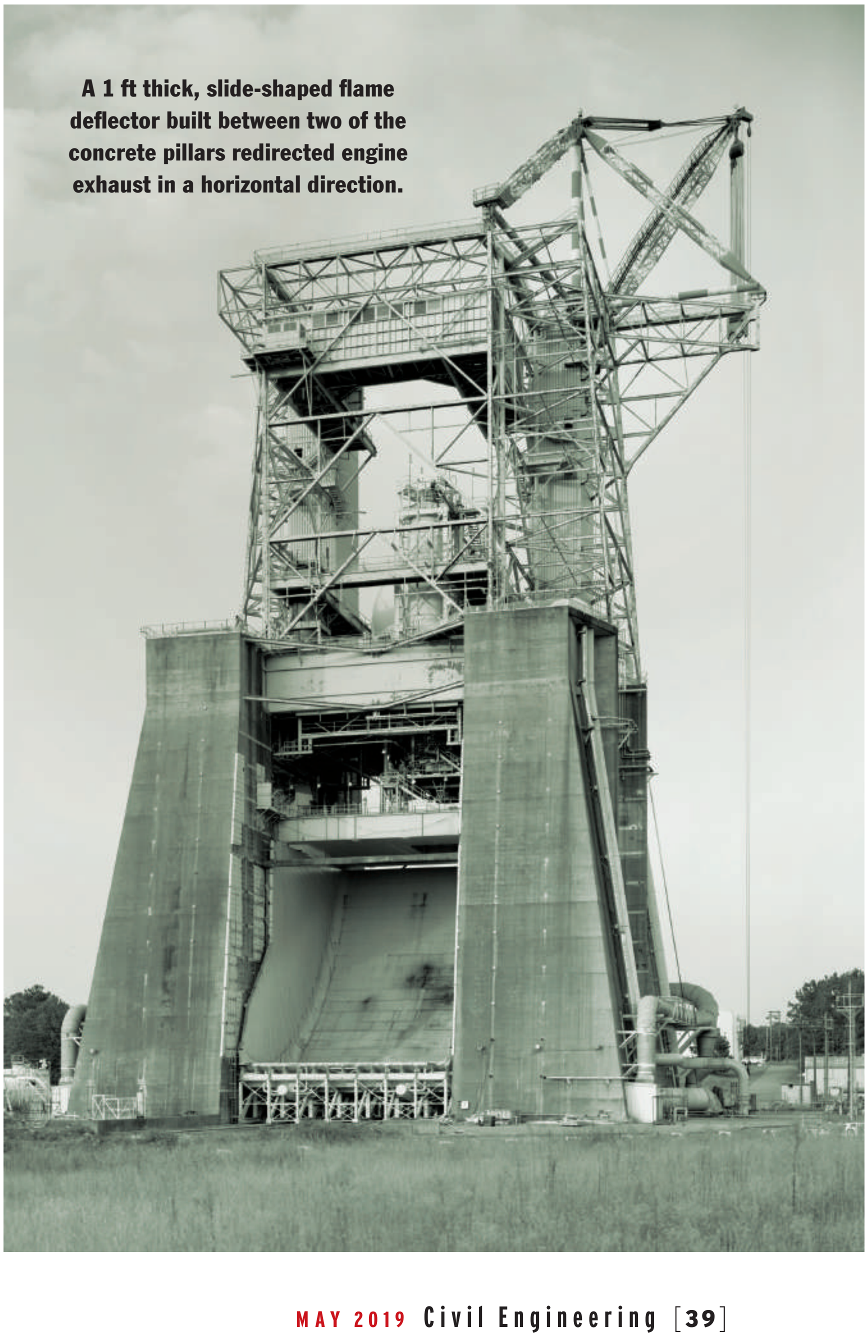
Marshall's S-1C stand was the point of final evaluation for these engines. Their performance—and the performance of the stand itself—was critical to determining whether the engines could successfully take off. When the engine elements passed muster—eventually all five engines would be fired at once—they were sent back to New Orleans for refurbishment, then on to Florida for launch at Cape Canaveral.

Obviously, the test stand would need to be able to withstand enormous thrust loads. Behrens notes, "The test stand itself had to be as neutral as possible. It couldn't deflect and put stresses on the motor assemblies. It needed to stay as still [as it could] and absorb all the energy [it could] and not impact the test article [engine] itself."

The S-1C stand comprised a "steel skeleton atop a four-pillared concrete foundation," according to Jerolimov. The stand's bases were four "massive, reinforced-concrete piers, aligned in a square configuration." The piers were 48 ft square at their bases, tapering inward as they rose, and had walls that were about 4 ft thick. The interior of the piers housed support spaces for personnel, as well staircases and elevator shafts. The piers were set about 68 ft apart from each other and extended 40 ft down to bedrock.

The piers rose 144 ft above ground level. Rising above them was a steel truss superstructure attached to and spanning three of the piers. The northwest corner of the structure was open above the piers to create room for a 150-ton stiff-leg derrick crane that was capable of hoisting 200 tons. The crane, which helped position the engines onto and off of the test stand, brought the height of the stand up to 400 ft.

Construction of the stands was delayed by everything from bad weather to an ironworkers' strike. A more serious problem developed in 1964 when cracks were discovered in the welds of the hold-down arms, which kept the test articles in place during firing. In his HAER report, Jerolimov quotes MSFC test division director Karl Heimburg as explaining that "heavy welds" had been made on "relatively thin girder webs" which, when combined with "loading across the weakest axis of the material" led to concern among the engineers in the test division. The attachment had to be redesigned with tension rods, which transferred rebound loads from the weld to the rods to the top of the platform. Added stiffeners helped the reinforced



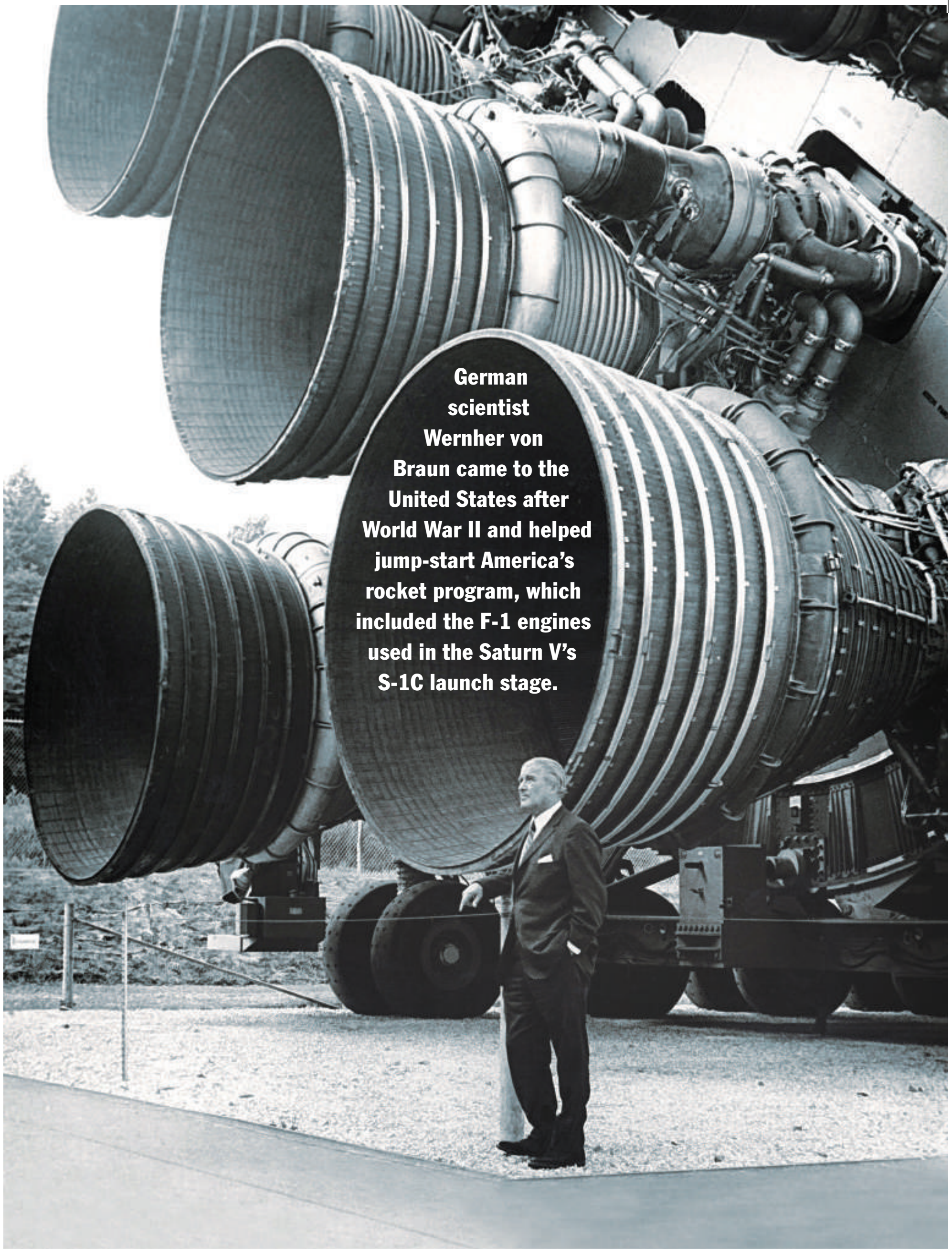
A 1 ft thick, slide-shaped flame deflector built between two of the concrete pillars redirected engine exhaust in a horizontal direction.

HISTORIC AMERICAN ENGINEERING RECORD (LIBRARY OF CONGRESS) load-transfer diaphragms, which had been poorly fabricated.

One of the major features of the S-1C stand was its flame deflector or "flame bucket." Shaped like a playground slide, the 1 ft thick deflector—a hollow assembly framed by 1 in. thick steel plates and internal braces—sat between the pillars of the stand. The bucket "redirected the rocket engines' exhaust from a downward direction to a horizontal direction," wrote Jerolimov.

He added that to prevent the flame bucket from melting under the simultaneous exhaust of five rockets, 300,000 gal. of water, provided by two separate pumping stations, was pumped through the deflector's manifold every minute. The deflector's walls were perforated with thousands of holes so water could also be forced through them to further cool the surface.

Another key feature of the test stand was its array of telemetry equipment, which was used to record the "enormous flow of data" coming from the engine tests. The telemetry gear included "112 channels of analog tape units, 296 channels of oscillograph recorders, 375 channels of digital systems, 117 channels of strip chart recorders," and other equipment, according to Jerolimov's report, which on this point cited MSFC's *Test Facilities Handbook*. The sensors were controlled from a blockhouse near the stand, the blockhouse protected by an earthen bunker. The engine's exhaust gases were directed away from the blockhouse, according to the handbook, to improve visibility—and presumably safety.



German scientist Wernher von Braun came to the United States after World War II and helped jump-start America's rocket program, which included the F-1 engines used in the Saturn V's S-1C launch stage.

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Engineers would test the engines briefly to make sure the engines and the stand were performing properly. "Then they would amp up the time, eventually to full-duration tests," Behrens says.

Finally, engineers also had to consider mitigating test-fire noise on the surrounding community. The timing of engine and stage-test firings was planned carefully to minimize the travel of sound. According to Jerolimov, MSFC engineers used climatological data to determine when the noise would travel the least distance into Huntsville. "A test-horn was sounded before each test, and sound sensors at varying distances around the test stand recorded the sound levels produced from the sounding of the test-horn," he wrote.

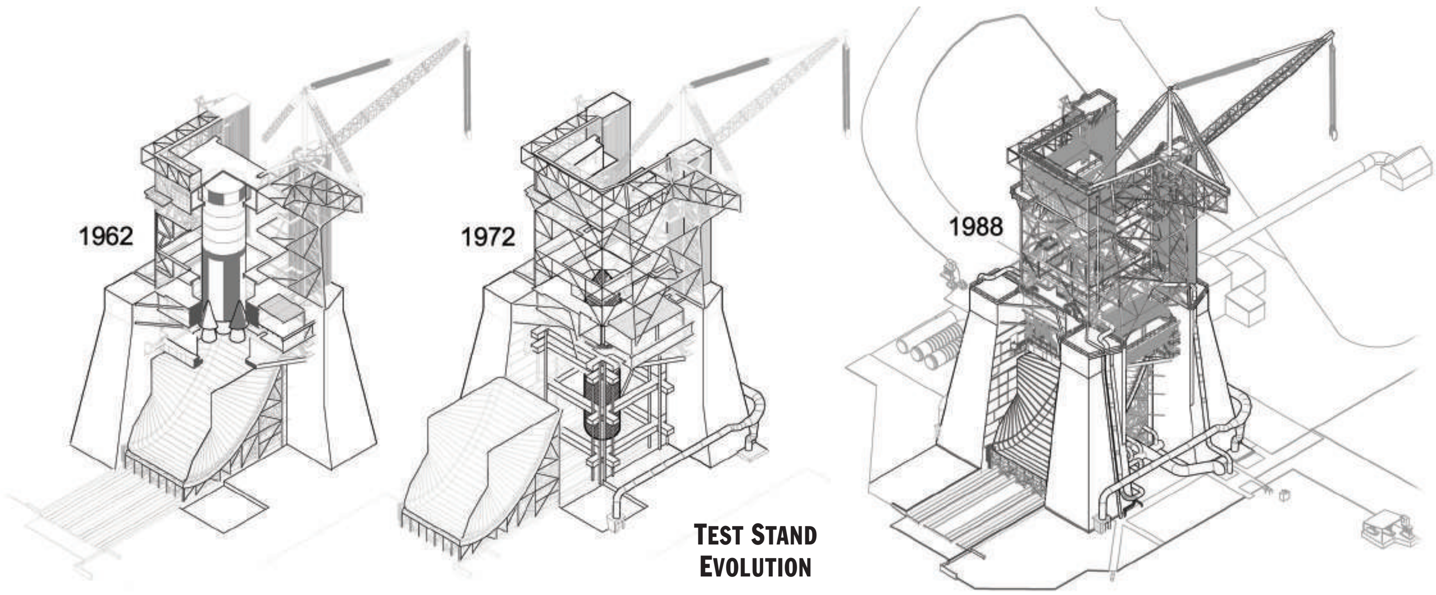
They even experimented with what Jerolimov refers to as a "sound suppression device," which was "a lengthy tunnel appendage positioned at the flame deflector outlet. It muffled the noise of the test by slowing the velocity of the expanding gases exiting the engine's nozzle."

In all, there were 22 test firings between April 9, 1965, and August 3, 1967. The shortest lasted but three seconds; the longest was 159 seconds.

When the Apollo Program ended in 1972, the S-1C stand transitioned to other uses. According to Jerolimov, it became the center of testing for the Space Shuttle engines, after it was made suitable for structural load and pressure tests of the Space Shuttle's external tank as well as its main engine.

It was later used to evaluate the propulsion system of the Atlas III launch vehicle in the late 1990s, which included a Russian-built RD-180 engine. The S-1C stand continued to be modified and was renamed the Advanced Engine Test Facility.

"The remarkable thing about these facilities was not only that they're so robust; they were highly adaptable," says Behrens. "They were like a Swiss Army knife of rocket development technology"—relatively inexpensive to scale up or down to accommodate other engines.



TEST STAND EVOLUTION

The test stand not only proved its versatility over the years, it also epitomized changes in how HAER documents significant examples of America's industrial heritage. In 1996, Behrens and a team of architecture students spent the summer at Marshall documenting the interim test stand. "We got out there with tape measures, graph paper, squares, pencils, and plumb bobs, and literally hand-measured the interim test stand and its command and control center," he says. They completed their report on the interim stand with hand-drawn ink-on-Mylar drawings. (Computer-aided design hadn't quite matured enough by that point to warrant its use.)

The following year, HAER was tasked with documenting multiple facilities on the east test area. One of these, called the T Stand, was too big to hand-measure, so Behrens's team took existing documentation and conducted spot measurements to verify the stand's dimensions. This was not ideal, because, he notes, "Some things change on the fly and are not reflected in the documentation." But the documentation on the T Stand, as it turned out, was "very robust and pretty reliable."

By the early 2000s, HAER was transitioning from hand measurements to laser distance-measuring devices. Behrens wasn't completely convinced about the new technology's effectiveness.

"We wrapped up documentation of the T Stand and the East Test Area in 1997. We returned to Marshall in 2006 to fully document the Neutral Buoyancy Simulator, an interesting facility. This is when I procured a laser distance-measuring device to use instead of tape measures to field-test its accuracy and practicality," he says. "We did another MSFC test facility in 2007 unrelated to engine test stands."

HAER documented the F-1 engine stand—designed to test a single F-1 engine—in 2010. "The F-1 engine test stand was a transition test stand for me," says Behrens. "I was still relying on existing documentation for that. But as an experiment, I brought out the high-definition laser scanner and we scanned it." When Behrens analyzed the scan data, he discovered the scanner had performed very well.

HAER had been testing high-definition laser-scanning for field documentation since 2005 with very mixed results, he says. By the time of the F-1 project, Behrens and his colleagues were getting "consistently good results with laser-scanning solid structures such as buildings. What I was uncertain about was how well it would handle a massive and highly skeletal structure. Would it clearly convey a differentiation between structural steel, pipes and tubes, and steel grating? Also, would it return accurate data as we were scanning the height of essentially a 20-story building from the ground?

"The scanning of the F-1 engine test stand served to underscore the versatility of the scanning technology and, with the particular system we adopted, the ability to produce accurate point-cloud data of large, complex sites and features," he says.

In all, six Apollo missions landed 12 astronauts on the moon between 1969 and 1972 (12 more astronauts flew to the moon without walking on its surface). That effort required the collaboration of approximately 300,000 people, 20,000 contractors, and 200 universities, working across 80 nations.

Currently, the Space and Rocket Center just outside of the MSFC contains a complete Saturn V rocket assembly that is composed primarily of mock-ups and test articles, according to Behrens. At Cape Canaveral, there is also a complete Saturn V rocket assembly that is composed of pieces that were, at one time, flight-ready articles.

While NASA dreams of sending humans to Mars this century, nothing has quite captured the public's imagination as the moon landings a century ago.

"I think the hardest thing to convey is the scale; everything is enormous," says Behrens, when asked about the experience of working with the test stand up close. "I guess that the test stands are a physical manifestation of the enormity of the undertaking of what Kennedy requested: sending a man to the moon and returning him safely to earth."

—T.R. WITCHER


Witcher

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