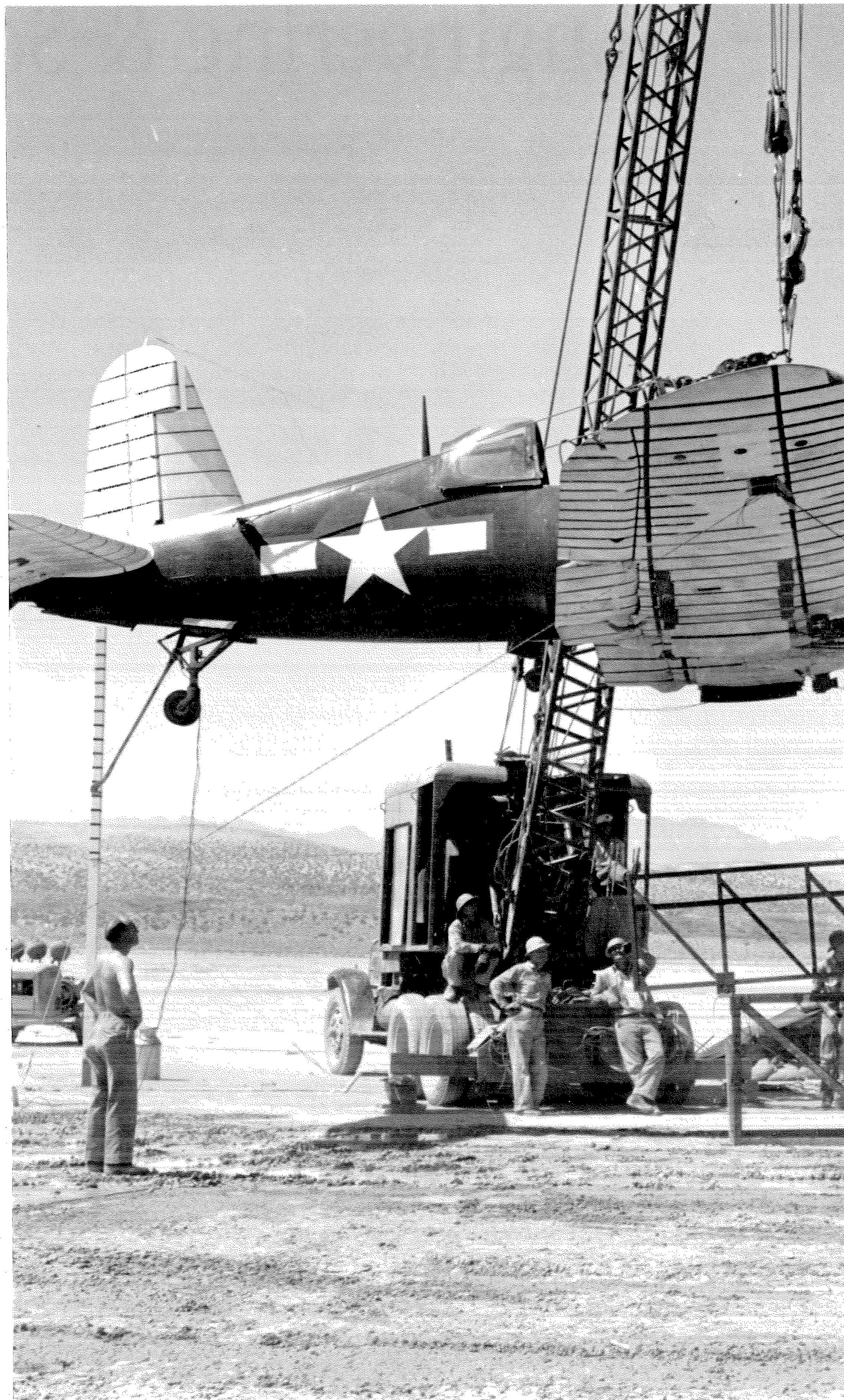


Caltech's *Other* Rocket Project: Personal Recollections

by Conway W. Snyder

I knew nothing about rockets, but neither did anyone else on the project in the beginning.

At the Naval Ordnance Test Station at Inyokern, members of Caltech's rocket project set up for test-firing Tiny Tim, a large aircraft rocket designed by Tommy Lauritsen. Willy Fowler stands at left. It was September 1944.

Caltech has been identified with American rocket science ever since its first successful experiments with liquid-fueled rockets in 1936, which led to the founding of the Jet Propulsion Laboratory and the launching of the space age. But Caltech carried on another *rocket project in the early 1940s—its contribution to the war effort—which is less well known. Although some of today's air-to-air guided missiles may be direct descendants of the first aircraft rockets developed at Caltech, the Institute's war work ended in 1945, allowing its participants to return to their "real" work.*

According to Archivist Judith Goodstein's forthcoming book on the history of Caltech, Millikan's School, *the project grew from an initial government contract of $200,000 in 1941—three months before Pearl Harbor—into an "$80 million war industry" before it ended. Rocket design and production took over all of the Kellogg Radiation Laboratory and a number of other campus buildings (as well as several hundred subcontractors in the Los Angeles area and scattered testing sites), and exploited the talents of a significant fraction of the Institute's top scientists. According to William Fowler (quoted in Goodstein's book), ". . . the upshot was that a large part of Caltech literally became a branch of the Bureau of Ordnance."*

Conway Snyder joined the project as a grad student in 1942. On the occasion of Caltech's Centennial, he thought it "appropriate to recall a significant episode in its history that began exactly half a century ago and that has been unheard of or forgotten by almost everyone who was not involved in it." Snyder (PhD '48) is now retired from JPL.

At eight o'clock on the morning of June 1, 1942, I walked into Willy Fowler's office in room 203 Kellogg. Most of the research staff of the project—about 15 men at that point—were accustomed to assembling in that place at that time every weekday to discuss the latest developments. As a new Caltech graduate student I found the discussion completely baffling, because I did not even understand the technical meaning of the words being used—*motor, grain, perforation,* and so on.

At the end of the session I had not the remotest idea what the project was about, so I asked my office mate who told me they were developing rocket weapons for the Navy. The word "rocket" had not been mentioned in the meeting. I had no idea what an exciting and stimulating time I was to have in the next three years or that most of the rest of my life would be involved with rockets. I knew nothing about rockets, but neither did anyone else on the project in the beginning.

The Caltech rocket project was officially known as contract OEMsr-418 of Division 3, Section L of the National Defense Research Committee of the Office of Scientific Research and Development. NDRC and OSRD were government-funded agencies that had been set up in 1940 to support and coordinate war-related scientific research. The chairman of NDRC Division A (Armor and Ordnance) was Richard C. Tolman, professor of physical chemistry and mathematical physics, and his deputy was Charles C. Lauritsen (PhD '29), professor of physics.

Artillery rockets had been used by the British in 1814, and modern versions had been under development in the 1930s by the Germans, the British, and the Russians (who had first used them in combat in 1941), but the American military services had shown little or no interest in them until late 1940, primarily because of their assumed low velocity and very poor accuracy as compared to cannon. In the next few months two rocket projectiles were developed by projects on the east coast on contracts with the Ordnance Department of the Army. The most successful was a tiny rocket dubbed the "Bazooka," which depended for its armor-penetrating capability on a shaped explosive charge only 2.36 inches in diameter. Both projectiles were propelled by propellant grains (single pieces of solid propellant) in the shape of cylinders about one inch in diameter, because these were the largest that could be made by the process used in the U.S.

In the summer of 1941 Lauritsen was sent to England to investigate, among other things, the British rocket program. He returned after a couple of months with a strong recommendation for an accelerated American rocket program, and he was authorized to set up a project at Caltech, primarily for the development of a high-altitude antiaircraft rocket. In September 1941 he set up shop in Kellogg Laboratory and recruited, among others, his former student William Fowler (PhD '36), then associate professor of physics (and now Institute Professor of Physics, Emeritus, and Nobel laureate); and his son, Thomas Lauritsen (PhD '39), who was always called Tommy, who later also became a professor of physics at Caltech. Also on the original project scientific staff were physicists Ira Bowen (PhD '26) and Ralph Smythe, chemical engineers William Lacey and Bruce Sage, and Donald Clark, assistant professor of mechanical engineering. Professor of Physics Earnest Watson became the administrative head of the project with the title of official investigator. In his office in Bridge Lab he handled finances, liaison with the government, and similar necessary but unglamorous tasks, so that Lauritsen could concentrate on technical problems.

In the summer of 1941 Lauritsen was sent to England to investigate the British rocket program. He returned with a strong recommendation for an accelerated American rocket program, and he was authorized to set up a project at Caltech.

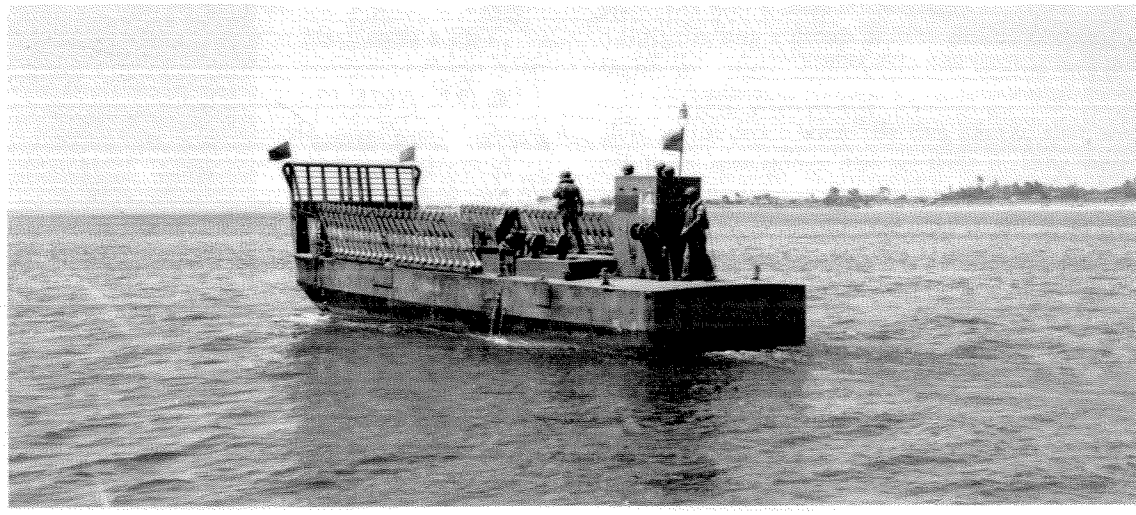
Charles Lauritsen was convinced that the first major problem that needed to be tackled was the production of a suitable propellant. Since rocket motors must be very lightweight, they cannot stand the high pressures that are generated in guns and cannon, and hence require a propellant that will burn evenly and continuously at pressures on the order of 100 atmospheres. An appropriate formulation that was available in the U.S. was a double-base smokeless powder called ballistite, which consisted of about equal parts of nitroglycerine and nitrocellulose. It looked like plastic—black, shiny, and somewhat soft. It was produced in sheets approximately 1 foot by 3 feet by 1/16 inch. The small propellant grains used in the Army rockets were made from the sheets by a process called solvent extrusion, which was not appropriate for larger grains.

Lauritsen had in mind much larger grains, so in the first few weeks of the project, his son put a small extrusion press together out of scrounged parts, mounted it on wheels, hauled it to Eaton Canyon north of Pasadena, and attempted to extrude ballistite without a solvent. According to the project mythology his first product looked rather unpretty, and Tommy thought it might be improved if he evacuated the air from the extrusion cylinder before applying the pressure. It worked, and on November 20, 1941, a good grain 15/16 of an inch in diameter and 30 inches long was extruded. In the next three weeks, Tommy extruded all the ballistite that was readily available into 180 pounds of good-quality grains, and the first major problem was solved. Only later did someone realize that, without the vacuum, the adiabatic compression of air in the chamber could heat it to the combustion temperature of the ballistite and cause an explosion.

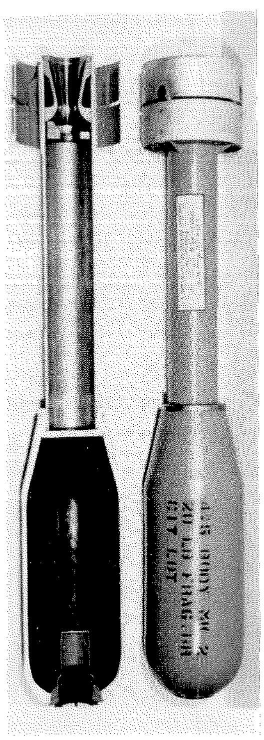
Even as Tommy was building his experimental press, Lacey and Sage were already designing production presses for grains of 1.75- and 2.75-inch diameters, the first step in a project that would ultimately produce hundreds of thousands of grains in various configurations up to a 4.5-inch diameter. These presses were built in Eaton Canyon for the first couple of years, and later at the Naval Ordnance Test Station (NOTS) at Inyokern.

In the early days at Kellogg, procedures were informal. Propellant grains were machined to size in room 106 in Kellogg (now a storage room full of file cabinets), then loaded into the motors (the propulsive units) by whichever staff member was going to conduct the test; the motors were thrown into the back of a station wagon, which was then driven to the test range on Goldstone Dry Lake, 30 miles north of Barstow. The situation changed after March 27, 1942, when a low-level explosion of ballistite in room 106 killed the man working there. Thereafter all handling of ballistite was done at Eaton Canyon, loaded rocket motors were transported in specially equipped vans, and the scientific staff no longer rode along with the rockets.

The first weapon on the project's development schedule was an antisubmarine rocket. In the spring and summer of 1942, we were losing



The 4.5-inch-diameter barrage rocket (below) developed at Caltech was initially used in landing craft such as the one at right with its rockets loaded along the sides, ready to fire. The rocket saw action in every amphibious landing in Europe and in all those in the Pacific beginning with Arawe in December 1943.



about 20 ships per week to German submarines in the Atlantic and the Caribbean. The Allies had sonar to detect the submarines; the tactics available were to position the ship over the sub and drop depth charges over the side. If they missed the sub, they roiled up the water so much that sonar contact could not be reestablished for some time. Consequently, the success rate in engagements was only about 5 percent. What the Navy wanted was a small rocket that could deliver about 300 yards ahead of the ship a small bomb that was fused so as to explode on contact with the sub; thus, if no hits were made, the sonar could maintain contact.

The Antisubmarine Rocket (ASR), which was nicknamed the "Mousetrap," was already being tested when I arrived on the project; a few rounds had been fired at a towed target off San Diego on March 30. One of my first jobs was to take some of them to the firing range on Goldstone Lake to test their range and dispersion at various temperatures. No explosives were ever allowed at the range; the rocket heads (payloads) were filled with a plaster mixture adjusted to the same density as TNT. The ASR was 35 inches long, weighed 65 pounds, and had a head 7.2 inches in diameter. The motor, which was threaded into the rear of the head, was a steel tube 2.25 inches in diameter and 16 inches long, with a fin at the rear the same diameter as the head. The ballistite grain weighed 1.55 pounds, burned for between .3 and .7 seconds, depending on the temperature, and gave the rocket a velocity of about 175 feet per second and a maximum range of about 290 yards. The warhead's fuse, called the HIR (hydrostatic impact rocket) because it was armed by water pressure and detonated by contact with the sub, was developed by a small project group headed by Robert King, a staff member at the Mount Wilson Observatory. Both the rocket and its fuse were soon in quantity production. By the fall of 1942 they were in extensive use in the Atlantic and the Caribbean, and by early 1943 in the Pacific as well.

Shortly after my arrival, the project began development of its second weapon, the 4.5-inch Barrage Rocket (BR), and I was soon firing these at Goldstone. Whereas my tests of the ASR usually involved a dozen rounds or less, I often fired a hundred BRs in a day. The weapon went into quantity production very quickly, first by the project and soon in factories under contract to the Navy Bureau of Ordnance, and a certain fraction of every production lot had to be fired for proof testing to assure that they met specifications.

The need for the BR to be launched from small landing craft was first suggested to Lauritsen in mid-June by the commander of the amphibious forces in the Pacific. The Navy requested the weapon in September, but Charlie did not wait for that formal authorization, and the BR first saw action in the assault on Casablanca on November 8. It used the same motor as the ASR, with different tail fins to match the 4.5-inch diameter of the head—a 21-pound bomb containing 6.5 pounds of TNT. Its burn velocity of 355 ft/sec gave it a maximum range of 1,130 yards. About 1,600,000 of them were

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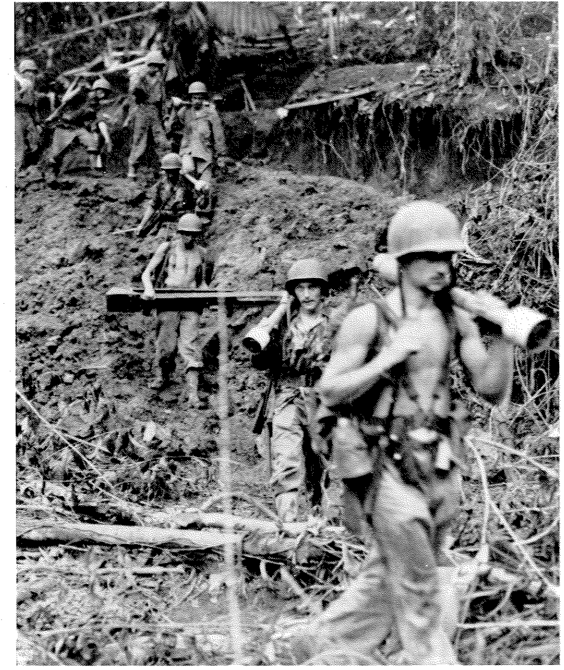
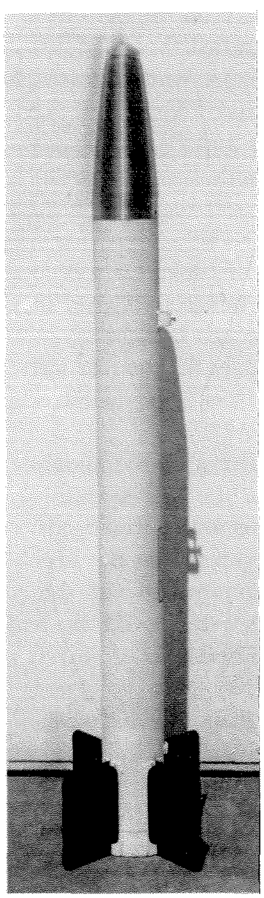


manufactured during the war, and they were installed on hundreds of landing craft and patrol boats and also on some larger ships. They saw action in every amphibious landing in the European Theater and in all those in the Pacific beginning with Arawe in December 1943. They were launched by the thousand onto the beaches in the few minutes prior to the landing, producing the most concentrated bombardment up to that time. Any movie of the war is almost certain to show their flame trails streaking out ahead of the landing craft. I remember well an admiral's coming to Kellogg to report to us on the Arawe landing. He said that the first wave of assault troops in earlier campaigns had always sustained heavy casualties. At Arawe any defenders close to the beach who were not killed were so dazed that they were unable to function for some time, and the first wave was not even shot at. Now, he said, every Marine wants to go in on the first wave.

Various launchers for this rocket were designed by the project and later by the Bureau of Ordnance. Other project groups designed fuses, and some staff members traveled to distant places to instruct the troops on using the weapons. They were soon being mounted on jeeps and trucks and carried into the jungle by hand. The BR was so useful and used in such quantities that the Bureau of Ordnance dubbed it "Old Faithful."

Losses from German submarine attacks continued to increase. (In fact, they did not reach their peak until April 1943.) The best countermeasure appeared to be aircraft, which could

The Caltech barrage rockets were mounted on jeeps and carried by hand. Because they were mobile, the rocket units could use hit-and-run tactics to escape enemy counterfire. At far left, Marines launch rockets at Japanese emplacements on Iwo Jima. Near left: Members of a Marine rocket platoon tote their equipment to the front lines on Bougainville.



scout large areas of ocean, but a suitable weapon was not available. So the Navy took a PBY, called the Catalina (a big, lumbering flying boat with landing wheels) and equipped it with a newly developed instrument called the Magnetic Antisubmarine Detector (MAD), which could signal the moment when the aircraft was directly over the sub. The project designed and attached under each wing of the aircraft a number of launching rails for the ASR. The idea was that the aircraft would fly at precisely the velocity of the rockets, and, when triggered by the MAD, a salvo of ASRs would be launched backward so that they fell vertically down on the sub. As higher velocities were required to match the speeds of various aircraft (up to 400 ft/sec), larger motors, 3.25 inches in diameter, were designed for the "retro" ASRs.

On July 3, 1942, the first test of the system was made at Goldstone—the first time that any rocket had been launched from an American airplane. Somewhat later, I was given the task of designing a submarine to provide a realistic test of the system. My sub did not have to resemble a real one except in one respect—its magnetic field. So we erected two telephone poles about 40 feet apart in the middle of the dry lake, and on them we strung a rectangular multiturn coil of heavy insulated wire, with the bottom side on the ground and the top side at the height of the poles. I connected a set of automobile storage batteries in a series-parallel arrangement to match the voltage of a big old DC generator that we scrounged from somewhere. (It may perhaps once have powered Carl Anderson's cloud chamber.) As the Catalina approached, I would throw a big knife switch to discharge the batteries through the coil and run to get out of the way. Between passes, I would recharge the batteries through another switch. There were perhaps half a dozen passes during the day, and the last planned pass, as dusk was approaching, dropped one ASR squarely on the center of the top run of the coil, effectively ending that test forever.

In the spring of 1943 two squadrons were equipped with the retrorockets; one went to the Pacific, where few submarines were found, and the other went to the Straits of Gibraltar, where it enjoyed some success, although a single squadron could hardly have a significant impact on the war. The rocket is given credit for the last German submarine killed in the war, off the French coast on April 30, 1945.

By sometime in 1943, Caltech's rocket project was up to full strength, with a staff of more than 250 scientific, technical, and administrative personnel and a total employment of about 3,000. It was a group of very skilled people, highly motivated and compatible, and it was a very exciting time, in part because we were so close to the front lines. By this I mean that we could see that things that we were making were being used to great effect by the troops, sometimes within weeks or even days of the time they left our hands.

In three adjacent offices on the second floor of Kellogg were Charlie, Willy, and Tommy, respectively the project director, the deputy director and supervisor of design and development (Section 1), and the Projectile Group supervisor. The organization was rather fluid, and some people changed jobs as conditions changed. Physicists, chemists, biologists, and astronomers did all kinds of things (often including manual labor) that they would not normally be expected to do.

Willy's Section 1 included the Projectile Group under Tommy; the Fuse Group under Bob King; the Theoretical Research Group headed by Leverett Davis (PhD '41), later professor of theoretical physics; the Land and Amphibious Launcher Group; and the Interior Ballistics Research Group under biologist Emory Ellis (PhD '34) and astronomer Franklin Roach (not from Caltech). Section 2, Aircraft and Ballistics, headed by Carl Anderson (PhD '30, professor of physics and already a Nobel laureate), was concerned with launchers and tactics for aircraft rockets, and Ira ("Ike") Bowen, who became director of the Hale Observatories after the war, headed Section 3, Photographic Measurements and Exterior Ballistics. Bowen invented the high-speed movie cameras that were used to measure the velocities and accelerations of the rockets during testing. Joseph Foladare (BS '30) headed the Editorial Section that produced reports and catalogs and kept track of the multitude of statistics on the proliferating number of different rocket models.

Section 5, Propellants and Interior Ballistics, was a very big section with three supervisors—Sage, Clark, and Lacey. It was customarily referred to as "Sage's boys," and he certainly was its vigorous and visible head. Its facilities were located in Eaton Canyon. Among the approximately 20 group supervisors in that section was William Corcoran, who was often the one who had charge of propellant loading for batches of rockets that I then tested. He later became professor of chemical engineering and vice president for Institute relations.

The Development Engineering Section, with headquarters in fancy buildings at 960 E. Green Street, handled the production of metal parts of

Willy spent March and April 1944 touring the Pacific theater, advising the naval officers about rockets and quizzing them about what more Caltech could do for them. Their answer was "more and more rockets."

all kinds, and by war's end it had produced more than a million rocket components through contacts with most of the small machine shops in southern California.

There were two experimental groups that built and used facilities at the lake formed in San Gabriel Canyon by Morris Dam north of Azusa. They were Section 4, Underwater Properties of Projectiles, supervised by Max Mason, chairman of the Observatory Council, and Section 7, Torpedo Launching, headed by Fred Lindvall (PhD '28), professor of electrical and mechanical engineering, who earlier had directed the rocket launcher section.

Charlie mostly stayed in his office, thinking, planning, designing new rockets, and conferring with generals, admirals, and Washington brass like Tolman, so Willy handled the day-to-day direction of the project (i.e., giving orders, conducting staff meetings, etc.). In the early days Tommy "got his hands dirty," but after a few months I realized (to my considerable surprise) that I had become his principal assistant. Often I would sit on a high stool in his office as he explained my next task. Almost always the interview ended with Tommy saying, "If this job was easy, I would do it myself." As a result I think that I got to do as great a variety of unusual and interesting things as anyone on the project.

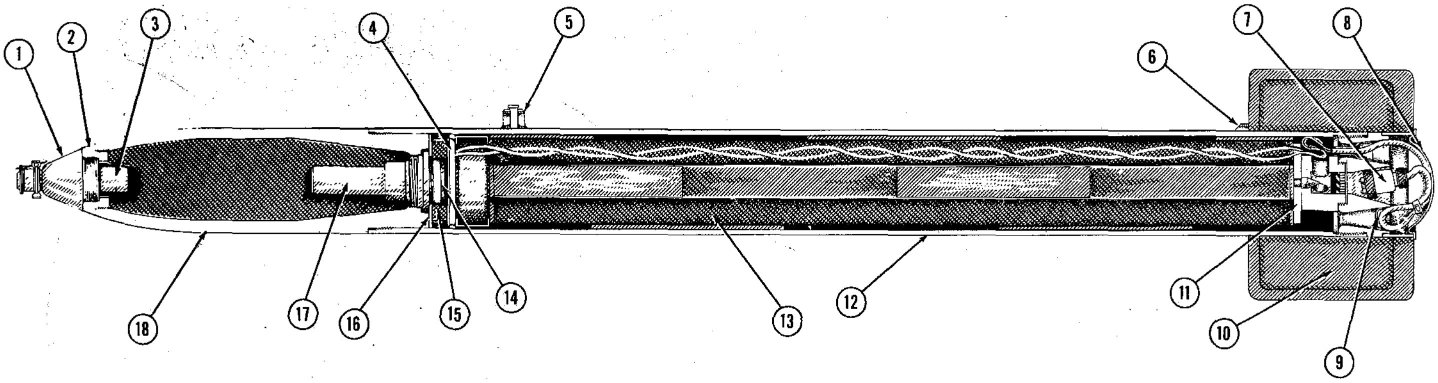
The northeast corner of Kellogg was a big empty room, about 30 by 70 feet in area and four stories high, that had housed the million-volt x-ray tube. As the project began to grow, this room was floored on each level so that the basement floor housed the machine shop (some of which still remains) and the design and drafting group occupied the fourth floor (room 300). I cannot remember who was in room 100, but in room 200 were the desks for the projectile and launcher groups, about 25 people. Members of Sage's group who were not at Eaton Canyon were housed in the old Chemical Engineering Laboratory, and other groups were scattered in various cubbyholes around the campus and in more than 20 other locations in Pasadena.

Meanwhile, by late spring of 1943, the submarine menace was still serious. The subs had begun to change their tactics, choosing to surface and shoot it out with attacking aircraft, over which they had the advantage of greater firepower. Sage's boys had found that the heaviest tubular propellant grain that would function reliably inside a 3.25-inch, 11-gauge, steel tube was only about 6 pounds, so they had developed and begun production of a new "cruciform" design of ballistite grain for our next major product—the 3.5-inch forward-firing aircraft rocket (FFAR). It was patterned after a British rocket that Charlie had seen on his visit in 1940, and which had recently been found effective against subs when fitted with a solid steel head that could penetrate the hull. Our rocket was quite similar to the British one, but with a shorter motor, 45 inches long. With an 8.5-pound propellant grain and fitted with a 20-pound solid steel head 3.5 inches in diameter and four rather large tail fins, it had a velocity of 1,180 ft/sec plus the velocity of the plane that launched it.

Charlie had been given a few of the British rockets, and they were used in the first test of forward firing from an American fighter plane, which took place at Goldstone in July 1943, the month the Allied forces invaded Sicily. The following month, with preliminary testing now completed, aircraft testing with our rocket could begin. These were so successful that the Navy immediately began a crash program of quantity production.

The reason for the notorious inaccuracy of unguided rockets was that their low velocity at the instant of release from the launcher provided insufficient aerodynamic force on the tail fins to stabilize them. When launched forward from aircraft, their velocity at release was already high and the tail fins were effective. Thus their accuracy was about eight times greater than that of ground-fired rockets and quite comparable to cannon. The first AR (aircraft rocket) launchers were about as long as the rocket, to provide stability for the first few feet of travel. It was soon discovered that these were unnecessary, and they were replaced with "zero-length launchers," which guided the rockets only for the first inch of travel and caused much less aerodynamic drag on the aircraft.

I had the fun of conducting all the initial ground testing of these and the later aircraft rockets. When aircraft tests with submerged targets began, it became evident that the steel heads tended to break off on impact with the water. The problem was referred to Ike Bowen, and he and I conducted several tests of aircraft firings into the Haiwee Reservoir in the Owens Valley. Heads of various shapes were tested. It was found that, with a hemispherical nose, the rocket would enter the water and continue in a straight line. However, with a smaller hemisphere at the nose followed by a sort of conical taper back to the full diameter of the head (which provided some lift), the missile would enter the water cleanly, turn upward, and continue along a few feet below the surface until its



The 5-inch high-velocity aircraft rocket was known as Holy Moses. These fins were designed by the author (the Navy eventually abandoned them).
1 fuse
2 fuse liner assembly
3 booster cup
4 igniter
5 lug button
6 suspension mount
7 wire and plug
8 rear seal
9 nozzle seal
10 fin
11 grid
12 motor tube
13 propellant grain
14 front seal
15 felt seal
16 fiber seal
17 base fuse
18 body

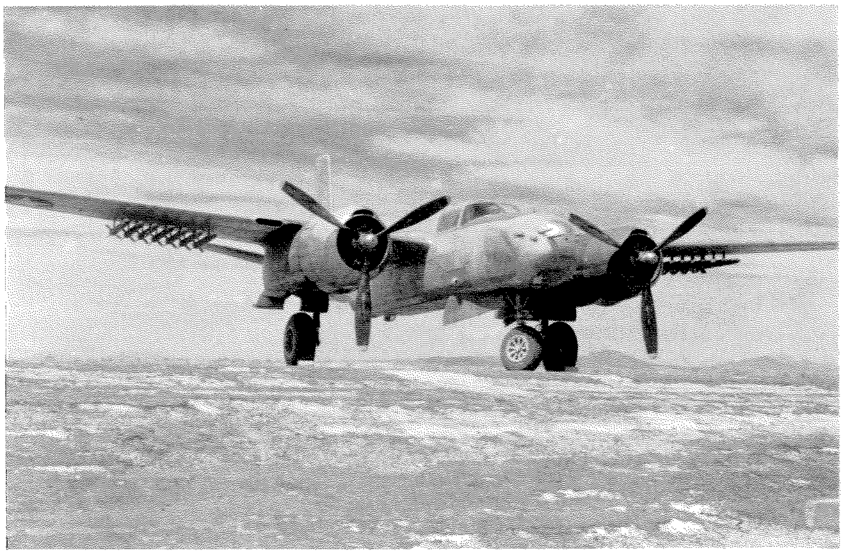
momentum was spent. This performance meant that a submerged submarine would present a target, as seen from the airplane, several times the size of the sub itself.

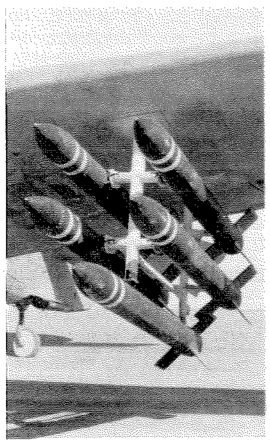
The first confirmed kill with this rocket was on January 11, 1944. It is said that the submarine commander was mystified suddenly to discover two small circular holes in his hull where the rocket had entered and exited, although no projectile had been seen. (I cannot vouch for the truth of this tale.) Submariners were soon to become accustomed to this phenomenon. Their only recourse was to surface and remain exposed to other aircraft and ships with other weapons.

The FFAR motors were soon fitted with explosive heads 5 inches in diameter to produce the 5-inch AR. The increased weight decreased the velocity considerably (to about 700 ft/sec), but they were effective in some circumstances. Willy spent March and April 1944 touring the Pacific theater, advising the naval officers about rockets and quizzing them about what more Caltech could do for them. Their answer was "more and more rockets." The commander in chief of the Pacific requested 100,000 rockets per month. Willy was told that the Marine TBF (torpedo-bomber) squadron using the 5-inch AR had found them to be ineffective against large ships, but that there were plenty of other good targets. They had damaged so many antiaircraft emplacements that those without armored turrets no longer fired against TBFs for fear of revealing their position.

In August 1943 Charlie began scouting around for a suitable site for a Navy rocket testing facility that would gradually be able to take over the project's job and continue the program into peacetime. He settled on a deserted little aircraft landing field east of the inconspicuous village of Inyokern, about 50 miles northwest of Goldstone. The idea and the location were soon accepted by the Navy, and on November 8, the Naval Ordnance Test Station, NOTS Inyokern, was officially established. By December, ARs were being launched on the range, and Sage's group had begun building large extrusion presses nearby. Thereafter, until war's end, the project's test activities were gradually shifted from Goldstone to NOTS.

Tommy assigned occasional small jobs to me in addition to my testing activities. On one occasion the Navy sent a lieutenant from Washington to Pasadena with instructions to launch some rockets underwater. He explained that they wanted to know whether the bubbles produced would be visible from above. We took to Morris Dam a half-dozen rounds of small, so-called subcaliber rockets that were used for training, and a length of steel tubing to use as a launcher. We stationed ourselves near the middle of the lake in a rowboat, lowered the "launcher" on two strings, and touched the igniter wires to a battery. We fired 5 rounds at depths between 4 and 15 feet. The last one emerged from the water about 50 feet from us, and landed on the brush-covered bank. Pleased that we had not started a fire in the dry brush, we left it there and headed home. (Needless to say, the bubbles were clearly visible.) It is a long road from this crude experiment to the





Holy Moses rockets could be mounted under an airplane wing in various configurations.

Navy's submarine-launched Polaris ICBM, but I like to think that I started the development process. Quite possibly this was the first underwater rocket launch in history.

Another morning a phone call from Tommy got me out of bed with a summons to the lab immediately. On the fourth floor was the large steel tank containing Charlie's first Van de Graaff accelerator. Soon some Navy enlisted men brought in on a stretcher a virtually immobile sailor with the bends. He was inserted through the hatch and the tank was pressurized. I spent the day keeping him under observation and gradually reducing the air pressure. By late afternoon he emerged with sore muscles but quite able to function.

Already before the 3.5-inch AR went to war, Tommy had started the design of the 5-inch High-Velocity Aircraft Rocket (HVAR), which would fit the head of the 5-inch AR and give it greater velocity. This was the first rocket development in which I was involved at the outset, and I designed the tail fins. Instead of a large single nozzle, this motor had eight small nozzles in a circle drilled through a steel plate 3.5 inches thick. In the center of the circle was a larger nozzle that was closed by a thin copper shear plate, designed so that it would blow out if the pressure approached the bursting strength of the steel tube, thus lowering the pressure and preventing an explosion. This meant that the rocket could be used safely over a significantly wider range of temperatures than the earlier ones. Its propellant was a larger version of the cruciform grain, weighing 24 pounds.

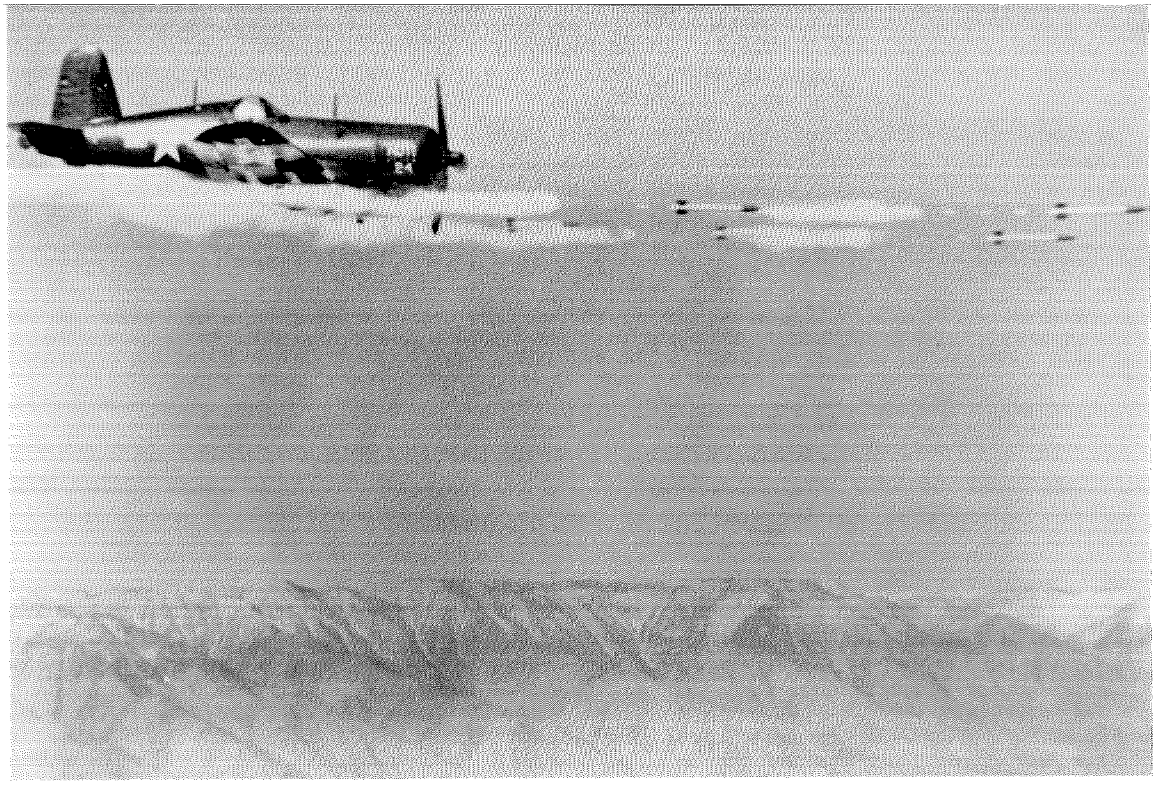
Compared to anything we had seen before, this was an awesome rocket, and on my first ground test at Goldstone (in December 1943, as near as I can remember), I got the idea of giving it the name "Holy Moses," just for the amusement of seeing if the name would catch on. It did—immediately—and the name accompanied the weapon wherever it went. This idea got me my only mention in the history books of the war.

The first aircraft launch of Holy Moses took place at NOTS on March 30, 1944, and I got permission from the pilot to be his passenger. I remember that, after we took off, I began to search my memory for anything that I might have done wrong or failed to do right in the previous ground testing. However, this launch and, to my knowledge, all subsequent ones went very well, and Holy Moses proved to be the best rocket of the war. By the end of the year the Pacific fleet was beginning to get the rockets in quantity and to use them to inflict death blows to Japanese transports, knock out antiaircraft-gun emplacements, and blast away heavy defensive fortifications.

In the autumn of 1943 development of a 3.5-inch, spin-stabilized rocket began. It was believed that it might be more accurate than the fin-stabilized rockets and also, lacking fins, be more compact and easier to handle. A steel plate threaded into the rear of the motor had eight small nozzles in a circle; these were pressed into predrilled holes. They were canted at an angle to impart the spin. Half a dozen rockets were machined in the shop, loaded by Ellis and Roach's group at Eaton Canyon, and sent to Goldstone, where I tested them. It was a fascinating sight. Once off the launcher each rocket began to precess in an ever increasing spiral, giving off a loud whirring noise. Upon landing on the dusty surface of the lake, instead of digging in as other rockets do, it made a neat little circular print in the dust as it continued to spin, and came to rest looking as neat as if it had never been fired.

We knew what the problem was—the rocket was too long (I recall it as being about 3 feet)—but we had no theoretical information to suggest the proper length. So we built another half dozen rockets about four inches shorter, and I took them out to Goldstone the following week with the same result. We repeated this cycle three or four times. Eventually we got the length down to 24 inches, and the rocket performed perfectly. The spin-stabilized rocket (SSR) program was off and running.

At this point a new group in the Projectile Section was formed to handle the "spinners," and



A Corsair fires Holy Moses rockets above Inyokern in February 1945.

I got the idea of giving it the name "Holy Moses," just for the amusement of seeing if the name would catch on. . . . Holy Moses proved to be the best rocket of the war.

I concentrated on the fin-stabilized aircraft rockets. The development and testing of the 3.5-inch SSR were completed, launchers for it were developed and standardized by the launcher group, and the project produced 10,000 rounds, but no quantity procurements resulted because the 5-inch SSR, which was vastly superior, came along shortly. This rocket and several launchers for it were quickly standardized and put into production to supplement the BR in attacking beaches, but at a much longer range (5,000 yards). The combination first proved its worth in the initial landing on Iwo Jima (February 19, 1945), where 12,000 5-inch SSRs and 8,000 4.5-inch BRs were fired, and on Okinawa (April 1, 1945).

Ralph Smythe took on the task of adapting the SSR for aircraft use, because it appeared to have advantages over the HVAR for some applications—greater compactness made for easier handling and might permit launching and reloading from inside an aircraft. The initial trials at Inyokern in October 1944 were disastrous. The rockets precessed even more wildly than the first 3.5-inchers, and the NOTS troops nicknamed them "Willy's Whirling Wockets." In order to determine what was happening, Smythe and Bowen collaborated to design a kind of pinhole movie camera that was installed in the rocket head to produce a record of its orientation during flight. It turned out that, again, the solution was to make the rocket shorter to compensate for the larger aerodynamic force resulting from the initial high velocity.

In the spring of 1944, with the invasion of Normandy approaching, one of the major concerns of the generals was the concrete launching sites for V-2 rockets along the French coast. It was thought in some circles that aircraft rockets might be the best weapon for attacking them. The Army had its 4.5-inch rocket, which had been designed in 1940, somewhat improved since, and manufactured in considerable quantity. It had become clear, however, that the Navy's Holy Moses was a much superior weapon. So on June 19 (D-day was June 6), I had another of my high-stool chats with Tommy and learned that the Army was about to request the shipment by air direct to England of 100 complete Holy Moses rockets per day for an indefinite period beginning as soon as possible.

Once the request was received, Tommy issued a "Confidential" memorandum (virtually all our memos bore this security classification) entitled "Project Moses," which outlined 11 different activities that were required to carry out the project, and designated one or two people to be in charge of each. I was to be the general coordinator, and many of us worked very long days carrying it out for the next three weeks. The first shipment went out on June 22 and the last on July 9. Tommy and Carl Anderson went to England and then to France to assist the Army in getting the rockets into combat and to observe the results.

The typical daily shipment was 100 rocket motors, 100 explosive heads, 100 fuses, and 104 "lug bands" for attaching the rockets to the launching posts under the aircraft wings, although there were some variations in the shipments. In the end, we had dispatched 1,900 rocket motors, 2,000 heads, 1,700 fuses, 1,456 sets of tail fins, 50 sets of launchers, and two boxes of instructions for using the 5-inch HVAR.

A squadron of P-47s, based in England, received the rockets, but by the time they were ready to use, it had been determined that the V-2 launching bunkers had actually been abandoned, so the squadron was diverted to troop support in France, beginning in the Saint-Lô area on July 15. This was just 26 days after we had first heard of the Army's interest. This one squadron destroyed many tanks, armored cars, and pillboxes, and an officer in the Air Technical Service Command characterized the Holy Moses as "the best antitank weapon of the war." The Navy allocated 40 percent of its production to the Army, but the rocket did not see much further action in Europe.

The effect of ARs on the naval war in the Pacific was quite different. By early 1945 all carrier-based and twin-engine land-based combat aircraft were being delivered by the contractors fully equipped to fire rockets. To be brief, I will simply note that they were found to be most effective against point targets—antiaircraft-gun positions, ammunition and oil-storage dumps, planes in revetments, and shipping. Everyone involved with them was enthusiastic. Rocket-firing planes from the carrier *Enterprise* even succeeded in sinking a destroyer. At war's end more than a million Holy Moses rockets had been manufactured.

The outstanding success that the Navy was having with Holy Moses against small targets led Charlie to suggest to the Navy that "a really big rocket" should be equally effective against ships heavier than destroyers. Even before the chief of naval operations had directed its development at the highest priority, Tommy had started designing it and had christened it "Tiny Tim." The tentative specifications for the new rocket were agreed upon in a meeting of the Projectile, Propellant, and Production sections on February 24, 1944; the first ground firing at Inyokern occurred on April 26; and the first firing of a pair from a TBF aircraft in flight was on June 22. The size was chosen because the Navy had a standard 590-pound, semi-armor-piercing bomb 11.75 inches in diameter, containing 150 pounds of TNT, and there was a standard oil-well casing of exactly the same size. Unfortunately, nobody was manufacturing oil-well casings in wartime, and so until production could begin, we were reduced to the expedient of salvaging them from abandoned wells.

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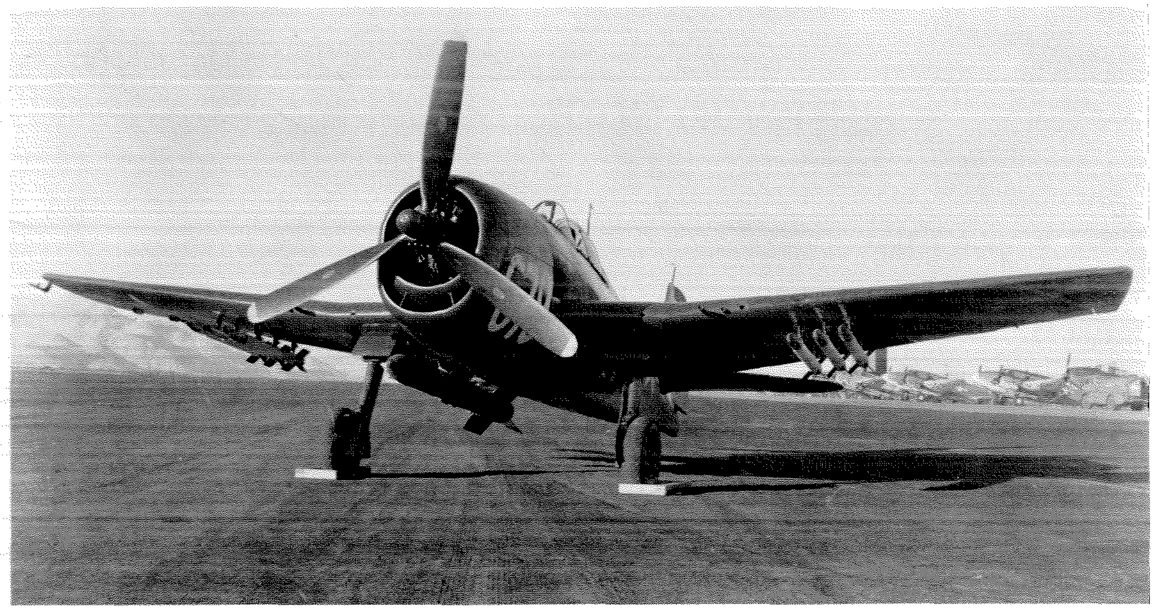
Far Right: An F6F-5 is loaded with six Holy Moseses under the wings and one Tiny Tim (it could carry two) below the fuselage. Right: A Tiny Tim is launched over Inyokern.

It was not feasible to produce a propellant grain as large as the 11.35-inch internal diameter of the casing, so four of the cruciform grains for the 5-inch rockets were used, separated by an X-shaped steel spacer. Upon ignition, this motor ejected 146 pounds of hot gas in about one second, and its first static firing at Eaton Canyon was a spectacular event. The motor was mounted a few feet outside of the open end of a reinforced-concrete catcher, about the size and shape of a one-car garage, which was intended to trap any pieces of unburnt propellant or hot plastic that might be ejected. At the end of the one-second burning, the roof of the catcher had raised up and the three sidewalls had opened out flat on the ground. Tiny Tim was never again fired at the canyon. In fact, all further tests of it took place at NOTS.

This rocket was just over 10 feet long and weighed 1,385 pounds, and in flight the luminous plume of its exhaust gases was more than 25 times its length and 15 times its diameter. In April Carl Anderson and I conducted the first flight test, launching it from above an airplane wing mounted a few feet off the ground. After observing its flame trail, we were as much surprised as pleased to discover that its effect on the wing had been very slight. The first trial from an airplane in flight (June 22, D-Day plus 16) was a success, but serious problems occurred before the weapon could be certified for use.

Coming as late as it did, Tiny Tim barely made it into combat. As in the case of Holy Moses, Tiny Tim's originally contemplated targets no longer needed attacking. Some aircraft



were equipped to carry eight Holy Moseses and two Tiny Tims, a total of 3,800 pounds of potential destruction. Had the war lasted a few weeks longer, they would have made their mark. They did find two noncombat applications. They propelled the rocket sleds at Muroc Dry Lake Test Range (later Edwards Air Force Base) in the Army's early tests of the effect of acceleration (g-forces) on human subjects. They were adopted by JPL as the boosters for their liquid-fueled rocket, the WAC Corporal, which on its first test in October 1945 established an altitude record of more than 40 miles.

As 1944 drew to a close, with Tiny Tim, Holy Moses, the 5-inch spinner, and all their predecessors all in combat, it was clear that we had done about all that we could to arm our troops for this war. Our project was running out of things to do. Many of us became involved with Project Camel (so called to suggest that once Caltech got its nose inside, it would take over the whole tent), which took on a large number and variety of tasks for the Manhattan Project at Los Alamos. But that's another story.

Within a few days of VJ Day, August 15, 1945, nearly everybody except the editorial section left the project, and many of us took up our classwork where we had left off. Because of Charlie's influence, I was able to get fellowships to complete my Caltech degree three years later, and after eight years in the east, I came back to Pasadena to spend 30 years at JPL.

There is a sequel to the story. A few project people moved to NOTS and made a career of rocket development, including Emory Ellis, who became the range supervisor. Several improvements were made on the Holy Moses, incorporating high-tensile tubing and new, more powerful propellants to increase its velocity. In 1967 NOTS was renamed the Naval Weapons Center, and it has remained to this day one of the preeminent naval research and development centers. On the base you can find streets named for Lauritsen, Fowler, Bowen, Sage, and Ellis.

A few months after VJ Day, William McLean (PhD '39) came to the center. He soon had an idea for a heat-seeking guidance system using infrared sensors, and he became the scientific director of the laboratory. He assembled a group to work on his idea, and in the face of continuous indifference and some opposition from the Navy Department, they perfected a complete detection and guidance system that could fit onto a 5-inch rocket motor. Thus the Holy Moses was transformed into the "Sidewinder," one of the earliest and best, and by far the cheapest, air-to-air guided missiles. Since it became operational in 1956, a whole family of Sidewinders has been developed for other applications, and they were adopted by the Navy, the Air Force, NATO, and several countries in the free world. Even the Soviets copied it. The Nationalist Chinese in 1958 were the first to use it in combat, followed by the U.S. against Libyan jets in 1981 and Iraqi jets and other targets in 1991. Although he died in 1976, McLean is still justly remembered in the Navy as the "father of the Sidewinder." I like to think that I have some small claim to being its grandfather. □