The Army's Current Multidomain Inflection Point and Potential Lessons from the Early Space Race

Lt. Col. Jerry V. Drew II, U.S. Army

When the Bumper 8 rocket team arrived to its Florida launch site in July 1950, the site was a desert wasteland filled with deer, alligators, mosquitos, scorpions, and raccoons that "got into the instrumentation."[1] The security detail, comprised of 3rd Infantry Division soldiers from Fort Benning (now Fort Moore), Georgia, regularly went to sleep knowing that by morning, their tent would be full of rattlesnakes trying to keep warm.[2] To further add to the difficulties, the on-loan Army Signal Corps team from Fort Monmouth, New Jersey, found the radio signals of "taxi cabs from Houston interfering with [the] command destruct systems."[3] Despite the difficulties of the conditions, however, the Bumper program had exceeded the available range of the vast White Sands Proving Ground (WSPG), leaving the Army little choice but to look toward the Eastern Seaboard to launch its future rockets.

As the first rocket launch from the Florida coast, Bumper 8 marked an inflection point in rocket development for the United States and the Army. It represented the culmination of a fruitful collaboration between two early rocket development efforts—an American-led effort by the Jet Propulsion Laboratory (JPL) and a German effort the U.S. government transplanted to the American southwest after World War II.[4] As a program, Bumper had successfully demonstrated the Nation's first multistage rocket, a hypergolic second stage at extreme altitude, and the feasibility of postlaunch communication relay through the Caribbean islands—all essential developments for the Space Age.[5] Furthermore, from Bumper's lessons emerged the Jupiter-C that launched JPL's Explorer I satellite in 1958, the Mercury Redstone rocket that launched Alan Shepard in 1961, and the Saturn V rockets that launched the Apollo missions to the moon. Yet at the peak of its prowess in the military's early space efforts, new strategic realities required the Army to divest its space operations expertise, forcing it into an ancillary role in the Nation's space efforts.

The Army faces a similar situation today. Following a period of conflict, the Army once again seeks an organic, long-range fire capability that is likely to put the service at loggerheads with the U.S. Air Force. Once again, at unprecedented capacity, the mandates of policy and strategy require the Army to transfer some of its most significant space equities—this time to the U.S. Space Force. Although the future is not certain, a possible

A jet-assisted airplane successfully takes off during a test circa August 1941. The airplane on the ground is attempting to take off without rocket assistance. (Photo courtesy of the Jet Propulsion Laboratory)

future sees the Army stripped of its most significant space missions, returning to a focus on ground combat against nation-state threats. As the Army's space capability once again diminishes, a historical perspective can inform the decisions of the institution as it navigates the uncertainty of a multidomain future—one that mandates near-term divestiture for the efficacy of the joint force and for the good of the Army's core mission.

The Beginning of the Jet Propulsion Laboratory

The combination of technologies that produced Bumper and its successor boosters was not foreseeable in 1936 when the California Institute of Technology (CALTECH) established a small organization for rocket research under the patronage of renowned aeronautics expert Dr. Theodore von Karmen.[6] The new organization, led by Frank Malina, was little more than a handful of students and rocket enthusiasts. Named the GALCIT (Guggenheim Aeronautical Laboratory) Rocket Research Project at CALTECH, Malina set a goal of building a rocket that could reach one hundred thousand feet to study the upper atmosphere.[7] Considering that Dr. Robert Goddard, the father of American rocketry, did not reach altitudes of nine thousand feet until 1941, GALCIT's goal was decidedly ambitious.[8]

In 1939, with the Second World War already engulfing Europe, GALCIT temporarily abandoned its scientific goals to support the Army Air Corps' development of small rockets for jet-assisted takeoff (JATO).[9] The JATO rockets allowed an aircraft to more quickly reach takeoff speeds and solved three of the most significant problems of solid rocket development: how to achieve a controlled burn (vice an explosion), how to manufacture shelf-stable substrates (so rockets would not explode after being in storage), and how to pour liquid ingredients into molds to create solid rocket motors (vice molded or extruded solid motors).[10] These technologies proved foundational to every solid rocket system that followed, including the spin stabilization apparatus on Bumper, the upper stages of Jupiter-C, and the Army's Pershing missile.

While solid motor development provided the nascent JPL with its first successes, solid and liquid rocket development continued throughout the war on both sides of the Atlantic. In 1943, the first British intelligence reports of German missiles found their way to the desk of Karman. If they were to be believed, despite JPL's efforts, the United States was woefully behind the Germans in developing liquid-propellant missiles.[11] Army Ordnance accepted JPL's funding proposal for longer-range missile research to counter the threat. Although the air and naval arms of the service continued to maintain their ties with JPL, from 1944 until its annexation by the National Aeronautics and Space Administration (NASA) in 1958, Army Ordnance bore responsibility for JPL's facilities and equipment, and provided the majority of its funding.[12] At the end of the summer of 1944, however, American forces were pushing through France, and JPL produced preliminary designs of its next evolution of rockets: Private A, the WAC Corporal, and the Corporal E.[13]

The first Private flew at Leach Spring, Camp Irwin (now Fort Irwin), California, on 1 December 1944.[14] Although little more than four JATOs welded to a rocket body with fins, at eight feet tall, Private A was the first of its kind in the United States.[15] At a total weight of around five hundred pounds, it had flown just over one mile (5,400 feet) with a sixty-pound payload.[16] In contrast to the solid propellant of Private, the WAC Corporal and the Corporal used hypergolic propellant, meaning the fuel and oxidizer—kept separately in their tanks within the rocket body—combusted when mixed.[17] The programs also advanced the ground operations procedures necessary to track and receive in-flight data in addition to the propulsion research. Like the Private, the engineers viewed WAC Corporal and the Corporal as existing for research and development purposes, but the Army was anxious for practical weapons systems.[18] While the JPL team built the necessary testing infrastructure for its powerful liquid-propellant engines at the Army Air Force's Muroc facilities (today's Edwards Air Force Base), a second operation involving both the Army and JPL was already underway to capture German missile technology.[19]

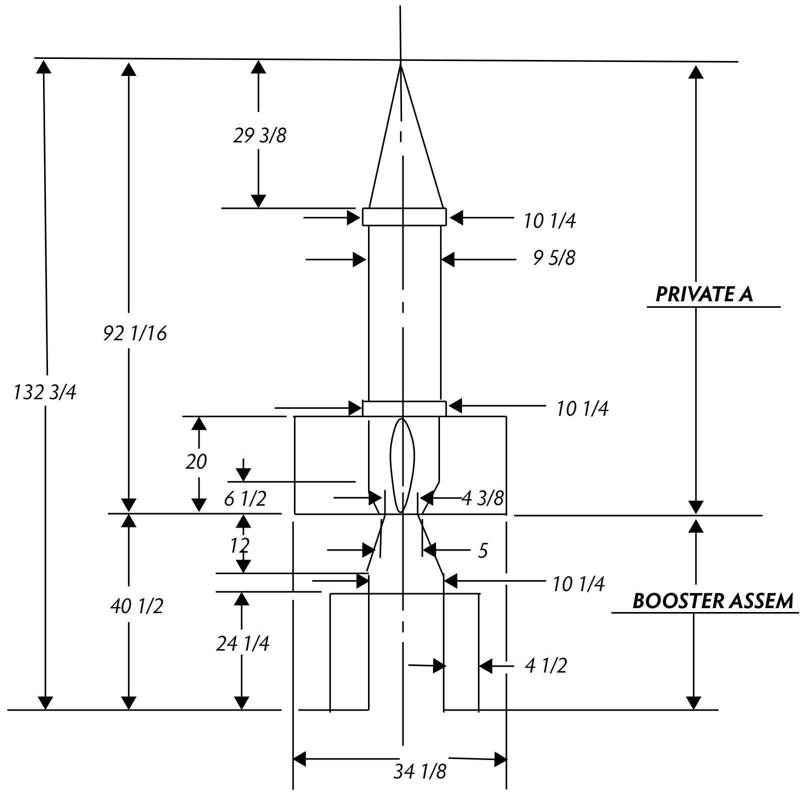
German Scientists, German Technology

On 11 April 1945, 104th Infantry Division soldiers liberated Nordhausen, a concentration camp filled with enslaved people who labored in the Schutzstaffel's underground missile construction facility.[20] It was just what Army Ordnance Technical Intelligence in Paris hoped to find.[21] The Army believed it could leverage the new technology to affect the still-raging war in the Pacific, but due to the unconditional surrender of the Japanese the following September, no German rockets ever found their way to that theater.[22] On the same day U.S. troops entered Nordhausen, the second version of Private, Private F, flew at Hueco Range, Fort Bliss, Texas.[23] The Private F, based on the same solid-propellant motor as Private A, was primarily an experiment using fins to stabilize the rocket for extended flight. Significantly, Private F demonstrated that a winged missile required a guidance system to ensure stable flight.[24]

Two days after the liberation of

Lt. Col. Jerry V. Drew II, U.S. Army, serves as an assistant professor in the Department of Joint, Interagency, and Multinational Operations at the U.S. Army Command and General Staff College, Fort Leavenworth, Kansas. He is a 2017 Art of War Scholar and a 2018 graduate of the School of Advanced Military Studies. Among his many space assignments, Drew served as a member of the planning teams that established U.S. Space Command and the U.S. Space Force. He is the coauthor of *The Battle Beyond: How to Fight and Win the Coming War in Space* (Amplify Publishing, 2024).

Nordhausen, elements of the 1st Infantry Division discovered the Hermann Göring Aeronautical Research Center at Völkenrode with its highly advanced aeronautics facilities.[25] Fortunately for the Americans, a team of German rocket scientists led by Dr. Wernher von Braun—the very people who had developed many of the plans and models found at Völkenrode—were looking for a new patron. On the morning of 2 May 1945, Braun's younger brother Magnus, the group's most capable English speaker, surrendered to Pfc. Fred P. Schneikert of Sheboygan, Wisconsin, on the group's behalf.[26] Following the success of Ordnance's Special Mission V-2, more than 360 metric tons of German missile parts began their journey to New Mexico. To accommodate their expanding missile efforts, Army Ordnance established a facility at Wallops Island, Virginia, for air-to-air missile and sounding rocket testing (the inaugural launch on 27 June 1945) and a larger facility at WSPG near Las Cruces, New Mexico.



Schematic of a Private A rocket with booster. Measurements are in inches. (Graphic courtesy of James W. Bragg, *Development of the Corporal: The Embryo of the Army Missile Program*, vol. 1 [1961])

On 11 August 1945, JPL exhibited two German missiles. Although uncertain about the missiles' capabilities, the group estimated that the first ran on liquid oxygen and alcohol, producing about three thousand pounds of thrust, while the second possibly ran on hydrogen peroxide.[27] At three thousand pounds, the estimated thrust output was double the amount produced by JPL's most powerful vehicle, the WAC Corporal. In September, however, the hypergolic fuel propelled the WAC for forty-five seconds, achieving an American altitude record of forty-three and a half miles, finally achieving the original goal of one hundred thousand feet set by the original GALCIT team nearly a decade before.[28] The Army's hopes for even greater performance than the WAC Corporal rested with the Corporal E, a more powerful member of the Corporal family with a twenty thousand-pound thrust motor (double the power of the original Corporal), which promised greater range and larger payload capacity.[29]

In addition to significant progress on the Corporal E, autumn 1945 also saw the arrival of the German engineers in the American southwest. Braun arrived at Fort Bliss on 8 October 1945 with a lone Army escort, and three additional groups of Germans joined him throughout the winter.[30] By the end of January 1946, the same month that the War Department began canceling its wartime contracts, Project Hermes, Army Ordnance's efforts to reconstruct and improve the V-2s, was in full swing. General Electric served as the prime contractor, and despite three hundred rail cars full of German rocket parts and more than one hundred German experts headquartered at Fort Bliss, Ordnance could only manage to assemble two complete V-2s in the beginning.[31]

With the promise of a large number of forthcoming V-2s, the Rocket Development Branch of Army Ordnance established the V-2 Upper Atmospheric Research Panel, which included representatives from all services, the Army Air Forces, the Army Signal Corps, the Naval Research Laboratory, numerous civilian

Frank Malina, director of CALTECH's Jet Propulsion Laboratory, stands beside a WAC Corporal rocket in 1945. (Photo courtesy of the Keck Institute for Space Studies)

research institutions, and General Electric.[32] One of the significant contributors to the V-2 experimentation program was Dr. James Van Allen of the University of Iowa, who oversaw the radiation detection payloads for the Explorer satellite program a decade later.[33]

Like the V-2 experimentation program, the WAC Corporal payloads performed upper atmospheric radiation experiments, took photographs, and collected atmospheric data. The Army Signal Corps, which often supported the WSPG test launches with communications and weather balloon activities, was a key beneficiary of the WAC Corporal's meteorological instruments.[34] These payloads did not achieve orbit, but they served as stepping stones toward achieving the technology necessary for future satellites, and at the end of 1947, such sounding rocket technology was "expected to give the United States a dominant position in upper atmospheric research."[35]

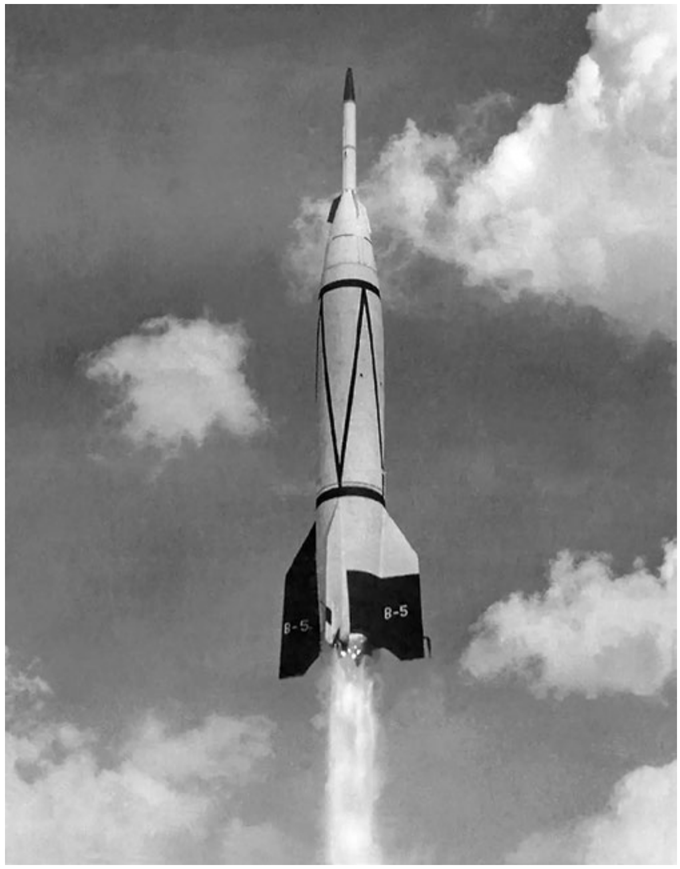
Unfortunately, the V-2 design was still imperfect and had "considerable problems" from the time of its initial employment that had never been entirely resolved by the Germans or in testing at WSPG.[36] Among the V-2's problems were aerodynamic instability and a lack of quality control in parts manufacturing that contributed to 50 percent failure rates during testing.[37] Despite these challenges—contributing factors to some of the Bumper program's failures—Bumper remained a significant technological achievement. It was the Army's first missile to involve staging and the first to combine American missiles with German ones—a modified V-2 as the first stage and a modified WAC Corporal as the second stage.[38] The modified WAC Corporal, known as a Bumper WAC, included attached spin-stabilization rockets that caused the upper stage to spin during flight, thereby stabilizing its trajectory.[39] These spin-stabilization rockets consisted of solid motors with a direct lineage stemming from the original JATO and Private experiments.[40] While work with Corporal and Bumper progressed at WSPG, Army Ordnance looked to two deactivated facilities still on the Army's wartime books to use in their development of larger liquid-propellant missiles. The Ordnance Research and Development Division Suboffice of Rockets at Fort Bliss took over the Huntsville Arsenal, and the nearby Redstone Arsenal became the Ordnance Guided Missile Center in November 1948.[41]

Long-Range Fires and Satellites

With the repurposing of the Alabama arsenals, the Army and its rocketeers intended to develop missiles of unprecedented range. From an institutional perspective, the Army's ballistic missile development programs were a significant part of its strategy for Cold War relevancy and fit within larger defense establishment notions of waging future wars through the air.[42] The Army's 1949 version of Field Manual 100-5, *Operations*, envisioned nuclear artillery at higher echelons to disrupt enemy forces before they came into contact with the friendly main body, which still held conventional artillery to affect the closer fight.[43] With Corporal missiles progressing toward fielding, the Bumper program remained essential to both long-range missile development and the future role of the Army in the atomic era. The success of the Bumper 8 flight in July 1950 signaled both a significant advance toward the dual goals of long-range firepower and a true space-launch vehicle.

The latest evolution of Project Hermes' C1 variant, rechristened as the "Redstone" rocket on 8 April 1952, took advantage of the lessons learned from Bumper and resolved the instability and quality control issues that had plagued the V-2 and its successors.[44] Although a single-stage missile, the Redstone was capable of greater range than the Corporal E, and when employed in tandem, the pair promised a defense-in-depth capability for the tactical Army. For the Nation, however, the Redstone played a much more significant role. Following the launch of the Soviet Union's two Sputnik satellites in late 1957, public concern about falling behind the Communists in the new space race soon grew into paranoia.[45] The failure of the U.S. Navy's Vanguard program to launch a satellite increased national anxiety to the point that President Dwight Eisenhower transferred the responsibility for the initial launch from Vanguard to the Army.[46] On 28 January 1958, a modified Redstone, the Jupiter-C, carried America's first satellite, JPL's Explorer I, into orbit.

Over the twenty years preceding the launch of Explorer I, the Army had overseen the development of—among other variants—the Corporal short-range ballistic missile, the Redstone medium-range ballistic missile, and the Jupiter intermediate-range ballistic missile. Vital to those efforts were the JPL and German rocketeers who eventually formed the Army Ballistic Missile Agency (ABMA). Under the dynamic political environment of the new Space Age, however, these two organizations did not remain under the Army's control.



A V-2 launches from White Sands Proving Ground as part of Project Hermes. (Photo courtesy of L. D. White, *Project Hermes V-2 Missile Program*, Final Report [Schenectady, NY: General Electric, 1952], via the Smithsonian Libraries)

Although CALTECH continued to administer JPL, control of the laboratory officially transferred from the Army to the newly formed NASA on 1 December 1958.[47] Unlike the fairly immediate transfer of JPL, the ABMA remained in Army control for nearly two years after the creation of NASA. Following the successes of Redstone and Jupiter, ABMA continued with Saturn, its super-booster program. The Army had no use for such a vehicle within its service responsibilities, but NASA continued Saturn's sponsorship.[48] While Saturn matured, Project Mercury began in October 1958 and required the ABMA to provide NASA with ten Redstones and three Jupiters in support of the new manned spaceflight program.[49] In the subsequent acquisition of ABMA, NASA gained more than five thousand employees to support its mission of putting an astronaut

Maj. Gen. John B. Medaris (*seated at center*), commanding general of the Army Ballistic Missile Agency, and Dr. Wernher von Braun (*second from right*) gaze at Explorer I in this undated photo. (Photo courtesy of the U.S. Army Aviation and Missile Life Cycle Management Command)

into space.[50] In the spring of 1961, Mercury-Redstone missiles launched Alan Shepherd and Virgil "Gus" Grissom, the first and second Americans into space.[51]

No longer under the employ of an army for the first time since the age of nineteen, Braun and his team continued developing the Saturn program, which eventually produced the Saturn V, the missile that put Americans on the moon. Without the JPL and ABMA, the Army no longer possessed the organizational structure to continue its satellite and missile development roles in the same capacity. As an institution, however, its various components (e.g., the Army Corps of Engineers, the Army Signal Corps, and the Army Ordnance Corps) remained essential to U.S. activity in space and missile development throughout the Cold War.

Where Do We Go Now?

The Army's successes in the early days of the Cold War space race offer two significant parallels to the Army's current evolution of multidomain operations and provide insight into a possible future: its quest for long-range fires and its divestiture of space capabilities on behalf of the greater good. If the current attitudes of the service toward space, the interservice competition over long-range fires, and the growth of competing bureaucracies are indicators, the Army will once again lose its quest to contribute significantly to the joint force's space and missile efforts.

Unfortunately for the future of Army space, the institution's current attitudes toward space compare well to the attitudes of the service at the dawn of the Space Age. Much like the Army of the 1950s and 1960s, the contemporary Army knows that space capabilities are essential to the future of ground combat, but the service is having difficulty articulating how these capabilities should be employed and the reason that those capabilities need to belong to the ground component. As in the late 1950s, a small group is advocating for the Army's space equities, but space operations continue to be ancillary to the Army's core mission as a ground combat force.

Following a period of protracted, disquieting conflict and the subsequent specter of reduced defense budgets, the Army of the late 1950s sought to transform itself into an organization more capable of facing the envisioned strategic environment. To remain relevant on the extended battlefield against a nuclear-capable adversary, the Army of the early Cold War sought to develop various new organizations and material solutions including organic, long-range fires. This operating concept stood at loggerheads with the U.S. Air Force's vision of warfare, which required aircraft to strike deep inside of enemy territory. A very similar situation is occurring today with the discussions over extended range and hypersonic munitions, and as in the 1950s, both service identities and service budgets are threatened.[52]

In another historical parallel, the Army is once again transferring significant space equities to a new space organization. Rather than NASA, however, the beneficiary this time is the U.S. Space Force, which of course belongs to the Department of the Air Force. As of this writing, Space Force is absorbing Army space operations missions as NASA did in the wake of Sputnik. In the summer of 2022, the Army's satellite communications management mission under the 1st Satellite Operations Brigade transferred to the Space Force (along with 502 billets).[53] At the beginning of fiscal year 2024, the direct-downlink satellite-based missile warning mission (the Joint Tactical Ground Station, or JTAGS) transferred to the Space Force, taking approximately another hundred billets with it.[54] With these two transfers, the Army has divested its two continuous, near-global, space operations missions and the only successfully fielded program of record in the Army space portfolio, the JTAGS system. Some force structure and equipment remain, but for the U.S. Army Space and Missile Defense Command, a three-star command that consisted of a mere 2,800 people at the creation of the Space Force, one must ask what the future of Army space is.[55]

The Army has found itself at another inflection point regarding space. The ultimate paradox may be that the Army at large (meaning the preponderance of soldiers in the service), does not understand space operations, but the Space Force does not understand combat. Some combination of the two cultures is necessary to forge a joint force that is not only space-capable but also has aspirations for space-dominance in advance of the next conflict. The Department of the Air Force, meanwhile, seems unlikely to abandon its traditional position as the provider of long-range fires and satellites—even though it culturally balks at the ground-support mission—and will likely end up in the most advantageous position.

How these dynamics will unfold are anyone's guess. Still, the historical case of this article reveals an instance where the Army was the institutional loser in both space and long-range fires, but through that loss, it regained focus on its core competency of ground combat. The whole of the U.S. government was postured to advance more effectively the goals of national policy in the face of a significant Communist threat. A similar outcome may occur this time unless the Army can convincingly articulate why space and missiles are uniquely Army missions and then successfully field those capabilities as part of a truly multidomain force. ■

The Redstone family of missiles are displayed on 12 June 2017 in Huntsville, Alabama. *Left to right:* Mercury Redstone, Jupiter-A, Saturn IB (*background*), Juno II (*foreground*), a tactical Redstone variant, Jupiter-C. (Photo courtesy of author)

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Notes

1. Hermann Bank, "Bumper 8, 50th Anniversary of the First Launch on Cape Canaveral, Group Oral History, Kennedy Space Center, Held on July 24, 2000," 24 July 2000, 27, JPL 232, Group Oral History-Kennedy Space Center, Jet Propulsion Laboratory Archives (hereinafter cited as "Bumper 8," 24 July 2000, JPL Archives).

2. Ibid., 28.

3. Dick Jones, "Bumper 8," 24 July 2000, 21, JPL Archives.

4. Amy S. Teitel, *Breaking the Chains of Gravity: The Story of Spaceflight before NASA* (New York: Bloomsbury, 2016), 196–97.

5. Paul H. Satterfield and David S. Akens, *Army Ordnance Satellite Program* (Redstone Arsenal, AL: Army Ordnance Corps, 1958), 44; Jones, "Bumper 8," 10–12.

6. Franklin O'Donnell, ed., *JPL 101* (Pasadena: California Institute of Technology, 2002), 4.

7. P. Thomas Carroll, "Historical Origins of the Sergeant Missile Power Plant," August 1972, 4, folder 13, Walt Powell Collection, Articles by Other than Powell, JPL Archives.

8. Ray A. Williamson and Roger D. Launius, "Rocketry and the Origins of Space Flight," in *To Reach the High Frontier: A History of U.S. Launch Vehicles*, ed. Dennis R. Jenkins and Launius (Lexington: University Press of Kentucky, 2002), 36.

9. "Chronological Survey of Rocket Development at the Jet Propulsion Laboratory-California Institute of Technology," n.d., JPL 119, folder 6, Historical File Organization 1945 to 1970, JPL Archives.

10. Carroll, "Historical Origins," 6, 8; J. Frank Malina, "Origins and First Decade of the Jet Propulsion Laboratory," in *The History of Rocket Technology*, ed. Eugene M. Emme (Detroit: Wayne State University Press, 1964), 57.

11. Carroll, "Historical Origins," 10–11.

12. James B. Medaris, *Countdown for Decision* (New York: G. P. Putnam's Sons, 1960), 234; Historical File Organizational Charts 1945-1970, n.d., JPL 119, folder 6, JPL Archives. The organization charts depict a formal liaison structure between the Army and the Jet Propulsion Laboratory (JPL) during this period. Following the war, the liaison structure expanded to include elements of Army Ordnance, Army Air Forces Materiel Command, the Navy Bureau of Ordnance, Army Ground Forces, and the Army Signal Corps.

13. "Chronological Survey."

14. Carroll, "Historical Origins," 12.

15. "Organized Research in Jet Propulsion," n.d., JPL 64, folder 16, Walt Powell Collection, JPL Archives.

16. James W. Bragg, *Development of the Corporal: The Embryo of the Army Missile Program*, Historical Monograph No. 4, vol. 1 (Redstone Arsenal, AL: Army Ballistic Missile Agency, 1961), 35.

17. Not surprisingly, fuel/oxidizer combinations varied throughout testing and development. The variation in fuels derives from two sources: (1) Minutes of JPL-1 Conference, 10 September 1945, 5, JPL 64, folder 8, Walt Powell Collection, JPL Archives; and (2) "Organized Research in Jet Propulsion," 19. Bragg, *Development of the Corporal*, xv, xvii. While eliminating the need for an ignition system and thereby simplifying the engine design, the fueling process required extreme care. The hazards of this process, however, did not preclude the approval of the Corporal as the first U.S. atomic missile in December 1950 or the activation of three Corporal battalions in March 1952—the Nation's first ballistic missile units.

18. William Pickering, "Bumper 8," 24 July 2000, 17, JPL Archives. Pickering later recalled that the JPL engineers viewed Corporal E as a research and development vehicle, but the Army was anxious to field it as a weapon, which it did in 1954.

19. "The ORDCIT Test Station Muroc Army Air Base," n.d., JPL 64, folder 6, Walt Powell Collection, JPL Archives.

20. Annie Jacobsen, *Operation Paperclip: The Secret Intelligence Program that Brought Nazi Scientists to America* (New York: Little, Brown, 2014), 46–47.

21. William E. Burroughs, *This New Ocean: The Story of the First Space Age* (New York: Modern Library, 1999), 111.

22. Jacobsen, *Operation Paperclip*, 90.

23. "Chronological Survey."

24. Bragg, *Development of the Corporal*, xiii.

25. Jacobsen, *Operation Paperclip*, 52.

26. Burroughs, *This New Ocean*, 116. Aside from his linguistic skill, Burroughs makes the point that Magnus von Braun was chosen to surrender partly because he was the least essential to the group from an engineering standpoint.

27. "Minutes of JPL-1 Conference," 11 August 1945, 1, JPL 64, folder 8, Walt Powell Collection, JPL Archives.

28. "Organized Research in Jet Propulsion," 19.

29. "The ORDCIT Test Station Muroc Army Air Base."

30. Teitel, *Breaking the Chains of Gravity*, 96.

31. Ibid., 91.

32. Burroughs, *This New Ocean*, 130.

33. James Van Allen, "What Is a Space Scientist? An Autobiographical Example," *Annual Review of Earth and Planetary Sciences* (June 1989), James Van Allen Papers, 1938–1990, American Institute of Physics, University of Iowa Archives, http://history.aip.org/history/ead/19990077.html.

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35. Ibid.

36. Konrad Dannenberg, "Bumper 8," 24 July 2000, 16, JPL Archives.

37. Stanley Starr, "The Launch of Bumper 8 from the Cape, the End of an Era and the Beginning of Another" (paper presentation, 52nd International Astronautical Congress, Toulouse, FR, 1–5 October 2001), 1–2.

38. Bank, "Bumper 8," 7.

39. Carroll, "Historical Origins," 34.

40. Ibid.; Teitel, *Breaking the Chains of Gravity*, 105.

41. Teitel, *Breaking the Chains of Gravity*, 105.

42. Ingo Trauschweizer, *The Cold War U.S. Army: Building Deterrence for Limited War* (Lawrence: University Press of Kansas, 2008), chap. 1–3. The idea that the rise of the U.S. Air Force and the incorporation of a tactical nuclear capability for limited warfare drove the Army's reforms of the late 1940s and early 1950s is the central thesis of Trauschweizer's first three chapters.

43. Walter Kretchik, *U.S. Army Doctrine from the American Revolution to the War on Terror* (Lawrence: University Press of Kansas, 2011), 170–71.

44. Teitel, *Breaking the Chains of Gravity*, 129.

45. Burroughs, *This New Ocean*, 200.

46. Franklin O'Donnell, *Explorer I* (Pasadena: California Institute of Technology, 2007), 22.

47. O'Donnell, *JPL-101*, 44.

48. Robert L. Rosholt, *An Administrative History of NASA, 1958–1963*, NASA SP-4101 (Washington, DC: NASA, 1966), 108.

49. Lee Mohon, "Mercury-Redstone Launch Vehicle," NASA, 16 September 2016, https://www.nasa.gov/centers/marshall/history/mercury-redstone.html.

50. Nels A. Parson Jr., *Missiles and the Revolution in Warfare* (Cambridge, MA: Harvard University Press, 1962), 45.

51. Mohon, "Mercury-Redstone Launch Vehicle."

52. See, for example, Jon Harper, "Sibling Rivalry: Military Services in High-Stakes Tussle Over Long-Range Fires," *National Defense* (website), 1 June 2021, https://www.nationaldefensemagazine.org/articles/2021/6/1/military-services-in-high-stakes-tussle-over-long-range-fires.

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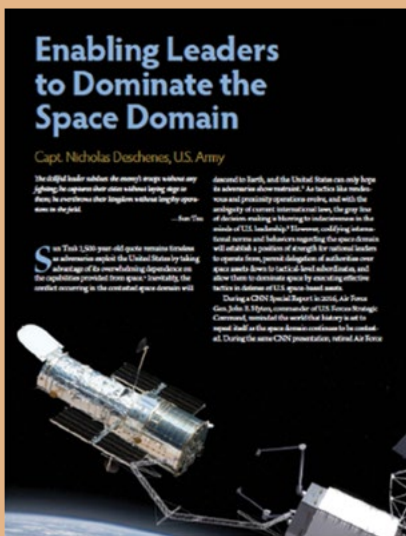

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