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# Orbital Decay: Space Junk and the Environmental History of Earth's Planetary Borderlands

Lisa Ruth Rand

University of Pennsylvania, [lisarand@sas.upenn.edu](mailto:lisarand@sas.upenn.edu)

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# Orbital Decay: Space Junk and the Environmental History of Earth's Planetary Borderlands

## **Abstract**

What is space junk, and who defines pollution in an environment seemingly devoid of nature as we know it? Beginning with the launch of Sputnik in 1957, spacefaring nations transformed the region between the upper atmosphere and the moon from a wilderness into a landscape. Like any terrestrial industry, the construction of a satellite infrastructure in orbit also yielded a system of byproducts—human-made waste colloquially known as “space junk.” Although remote and largely invisible to the majority of space technology users, the orbital environment nonetheless played a critical role in Cold War geopolitics. Contrary to current space policy literature that portrays space junk and awareness of space junk as recent phenomena, communities around the world were both aware and concerned about space junk from the very first moments of the Space Age. By tracing convergent changes in the orbital landscape and in the political landscape below during the Cold War, concurrent with the rise of mainstream environmentalism, this dissertation reveals the roots of an international understanding of the borderlands between Earth and outer space as a natural environment at risk. Focusing on highly mobile, unruly space junk artifacts illuminates the many ways that humankind mutually shaped and was shaped by the global ecosystem surrounding our planet during the Cold War. Situated at the intersection of the histories of science, technology, and the environment, this dissertation illustrates how space junk in orbit and falling to Earth brought geographically and politically disparate states into dangerous proximity during the Cold War. An international consciousness of outer space as a fragile environment emerged early in the Space Age, and influenced the negotiation of new modes of international scientific and environmental governance in near-Earth space.

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John Tresch

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Adelheid Voskuhl

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ORBITAL DECAY: SPACE JUNK AND THE ENVIRONMENTAL HISTORY OF  
EARTH'S PLANETARY BORDERLANDS

Lisa Ruth Rand

A DISSERTATION

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in

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Degree of Doctor of Philosophy

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Supervisor of Dissertation

Co-Supervisor of Dissertation

---

John Tresch

---

Adelheid Voskuhl

Associate Professor, History and  
Sociology of Science

Associate Professor, History and  
Sociology of Science

Graduate Group Chairperson

---

Beth Linker, Associate Professor, History and Sociology of Science

Dissertation Committee

Ruth Schwartz Cowan, Professor Emerita, History and Sociology of Science

Etienne Benson, Assistant Professor, History and Sociology of Science

Sara Pritchard, Associate Professor, Science & Technology Studies, Cornell University

ORBITAL DECAY: SPACE JUNK AND THE ENVIRONMENTAL HISTORY OF  
EARTH'S PLANETARY BORDERLANDS

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*For my parents, Robin Rand and Marco Rand  
for understanding that there are many paths to outer space.*

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Lillie Sorkin and Jerry Sorkin taught me from an early age to think differently about discarded things. My grandfather built thrones out of carpet remainders and passé wood paneling, and should anything from toys to appliances break, we all knew to utter two magic words: "Poppy fix." If her children or grandchildren expressed regret over a misstep, my grandmother replied with a simple, powerful reminder: "Nothing you do is ever wasted." Though Grandma and Poppy both departed as I worked on this dissertation, their memory endures as its bedrock.

I grew up just north of the Floridian Space Coast. One evening in December 1993, my father, Marco Rand, took me outside and gestured at two bright points of light crossing overhead. These weren't shooting stars, he told me, but the space shuttle *Endeavour* and the Hubble Space Telescope. I marveled, incredulous that these could be things made by human hands. It was my very own "Sputnik experience." Seventeen years later, after encouraging me through Space Camp and Space Academy, a semester of astrophysics at the Biosphere 2, and half a doctoral degree, my mother, Robin Rand, drove with me to a nearby beach to watch the final launch of the shuttle *Discovery*. My mother and father have long allowed themselves a single indulgence—their children's education. Though I can never pay back this monumental favor, I do hope to pay it forward whenever and however I can. I dedicate this dissertation to them, with love and gratitude.

## ABSTRACT

ORBITAL DECAY: SPACE JUNK AND THE ENVIRONMENTAL HISTORY OF  
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Lisa Ruth Rand

John Tresch  
Adelheid Voskuhl

What is space junk, and who defines pollution in an environment seemingly devoid of nature as we know it? Beginning with the launch of Sputnik in 1957, spacefaring nations transformed the region between the upper atmosphere and the moon from a wilderness into a landscape. Like any terrestrial industry, the construction of a satellite infrastructure in orbit also yielded a system of byproducts—human-made waste colloquially known as “space junk.” Although remote and largely invisible to the majority of space technology users, the orbital environment nonetheless played a critical role in Cold War geopolitics. Contrary to current space policy literature that portrays space junk and awareness of space junk as recent phenomena, communities around the world were both aware and concerned about space junk from the very first moments of the Space Age. By tracing convergent changes in the orbital landscape and in the political landscape below during the Cold War, concurrent with the rise of mainstream environmentalism, this dissertation reveals the roots of an international understanding of the borderlands between Earth and outer space as a natural environment at risk. Focusing on highly mobile, unruly space junk artifacts illuminates the many ways that humankind mutually shaped and was shaped by the global ecosystem surrounding our planet during

the Cold War. Situated at the intersection of the histories of science, technology, and the environment, this dissertation illustrates how space junk in orbit and falling to Earth brought geographically and politically disparate states into dangerous proximity during the Cold War. An international consciousness of outer space as a fragile environment emerged early in the Space Age, and influenced the negotiation of new modes of international scientific and environmental governance in near-Earth space.

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## INTRODUCTION

On February 10, 2009, a defunct Russian communications satellite and a functioning American commercial communications satellite approached each other from opposite directions. As they crossed over Siberia, Kosmos 2251 and Iridium 33 collided head-on, destroying both satellites and generating two intersecting plumes of debris clustered along their former orbital paths. Widely considered the most destructive on-orbit accident in history, the event validated a prediction made over thirty years earlier by Donald Kessler and Burton Cour-Palais in the *Journal of Geophysical Research*.<sup>1</sup> In the 1978 article, Kessler and Cour-Palais suggested that, given the growing volume of satellites and other objects being launched into orbit by an ever-increasing club of spacefaring nations, the first major orbital collision would occur within the next few decades.<sup>2</sup> This as yet hypothetical destructive chain reaction, now called the Kessler Syndrome, has become a bogeyman among the international space policy community.

The 2009 Cosmos-Iridium accident was by no means the first on-orbit collision, nor did it yield the largest amount of orbital debris from a single incident. Two years earlier, China intentionally destroyed one of its own defunct weather satellites using a

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<sup>1</sup> Frank Jr. Moring, "Collision Of Satellites Was Worst Ever," *Aviation Daily & Defense Report*, February 12, 2009, <http://aviationweek.com/awin/collision-satellites-was-worst-ever>; Paul Marks, "Satellite Collision 'more Powerful than China's ASAT Test'," *New Scientist*, February 13, 2009; Geoff Brumfiel, "Kapotnik Chaos Could Kill Hubble," *Nature*, February 17, 2009, 940–41.

<sup>2</sup> Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research* Vol. 83, No. A6 (1978): 2637–2646



projectile anti-satellite (ASAT) weapon.<sup>3</sup> The resulting debris cloud accounted for a 60 percent spike in the number of observable orbital debris.<sup>4</sup> The detritus produced by both the 2007 ASAT test and the 2009 Iridium-Cosmos collision continues to circle the globe at speeds upwards of eight kilometers per second. This orbital debris, or “space junk,” moves so quickly that even the small pieces could damage or destroy functioning satellites.

In late 2011, the National Research Council (NRC) published a report that painted a grim picture of the built environment in Earth orbit. The authors of the report emphatically argued that the quantity of human-made objects orbiting the planet had grown to such an extent that a state of continuous collision and cascading spacecraft failure will almost certainly arise in the surprisingly near future—that the planetary periphery had reached a “tipping point.”<sup>5</sup> This characterization draws much of its rhetorical strength from its association with climate change research. The term “tipping point” describes a delicate threshold after which global scale change cannot be stopped or reversed.<sup>6</sup> A majority of climate researchers worldwide have agreed that the planetary

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<sup>3</sup> Frank Jr. Moring, “China ASAT Test Called Worst Single Debris Event Ever,” *Aviation Week & Space Technology*, February 12, 2007, <http://aviationweek.com/awin/china-asat-test-called-worst-single-debris-event-ever>.

<sup>4</sup> Nicholas L. Johnson et al., “History of On-Orbit Satellite Fragmentations, 14th Edition” (Houston, TX: NASA Lyndon B. Johnson Space Center, June 2008), i.

<sup>5</sup> National Research Council, *Limiting Future Collision Risk to Spacecraft: An Assessment of NASA’s Meteoroid and Orbital Debris Programs* (Washington, D.C.: The National Academies Press, 2011).

<sup>6</sup> For more on the rhetoric of thresholds and tipping points in climate science and public discourse, see Richard D. Besel, “Communicating Climate Change: Climate Rhetorics and Discursive Tipping Points in United States Global Warming Science and Public Policy” (Dissertation, University of Illinois at Urbana-Champaign, 2007). For an accessible take on the idea of tipping points in different contexts, see Malcolm Gladwell, *The Tipping Point: How Little Things Can Make a Big Difference* (Little, Brown, 2000).

climate has already crossed the threshold. A famous 2006 *Time* cover story featuring a polar bear balanced precariously on a tiny ice floe proclaimed to the world that Earth had reached the point of no return.<sup>7</sup> Past the tipping point, ocean ice will shrink away, greenhouse gases will stifle the atmosphere, shorelines will bulge, and global temperatures will rise with drastic consequences for biodiversity, ecological resilience, and human environments.

The orbital tipping point, perhaps, cannot be as alarmingly and effectively illustrated—no charismatic, imperiled polar bears circle the planet, no ice floes encapsulate landscape change in a landless, illegible, invisible environment. And yet, to anyone who has noticed the regularity of news stories about astronauts taking shelter as debris approaches the International Space Station, satellites disabled by space junk, and spacecraft riskily moved to avoid collision with other objects in orbit, the NRC argument that a looming debris crisis may be imminent provides a fitting analog.<sup>8</sup> These dramatic encounters between functioning spacecraft and orbital debris—defined by NASA, the United Nations, and the Inter-Agency Space Debris Coordination Committee as human-made objects in space, or reentering the atmosphere, that do not serve a designated purpose—comprise only the most recent newsworthy incidents capping half a century of

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<sup>7</sup> Naomi Oreskes, “The Scientific Consensus on Climate Change,” *Science* 306, no. 5702 (December 3, 2004): 1686; “Earth at the Tipping Point: Global Warming Heats Up,” *Time*, April 3, 2016.

<sup>8</sup> “NASA: Space Station Dodged Debris 16 Times in Past 15 Years,” accessed February 19, 2014, <http://www.networkworld.com/community/blog/nasa-space-station-dodged-space-debris-16-times-past-15-years>; Leonard David, “Russian Satellite Hit by Chinese Anti-Satellite Test Debris,” *SPACE.com*, March 8, 2013, <http://www.space.com/20138-russian-satellite-chinese-space-junk.html>; “The Day NASA’s Fermi Dodged a 1.5-Ton Bullet,” *NASA*, April 30, 2013, [http://www.nasa.gov/mission\\_pages/GLAST/news/bullet-dodge.html](http://www.nasa.gov/mission_pages/GLAST/news/bullet-dodge.html).

mounting material evidence of a growing anthropogenic waste system encircling the planet.<sup>9</sup>

On the surface, the story of humankind's presence in near-Earth space since the launch of Sputnik on October 4, 1957 might seem like a textbook narrative of environmental decline. Operating under Big Sky Theory—the belief that space is so vast as to be unfillable—a small club of spacefaring nations launched ever more objects into orbit and transformed the foothills of the mythical final frontier into an unmanageable, moving junkyard.<sup>10</sup> Many current space policy analysts portray orbital debris as a recent problem—the gradually compounding result of ignorance at best and negligence at worst on behalf of the Soviet and American space industries of the 1960s.<sup>11</sup> This misconception

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<sup>9</sup> “Handbook for Limiting Orbital Debris,” NASA-HANDBOOK 8719.14 (Washington, D.C.: National Aeronautics and Space Administration, July 30, 2008), 21; “Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space” (United Nations Office for Outer Space Affairs, January 2010); Inter-Agency Space Debris Coordination Committee, “IADC Space Debris Mitigation Guidelines,” September 2007.

<sup>10</sup> Big Sky Theory's antecedent, Big Sea Theory, has also been challenged by the presence of an unmanageable, moving junkyard, in the form of so-called “garbage patches”—plastic and chemical debris, mostly microscopic, caught in several of the major ocean gyres. The Great Pacific Garbage Patch has been estimated to be the size of Texas. Lindsey Hoshaw, “Researchers Explore Growing Ocean Garbage Patches,” *The New York Times*, November 9, 2009.

<sup>11</sup> Representations of the history of orbital debris awareness in space policy analysis of recent decades vary. Research staff at the NASA Orbital Debris Program Office typically recognize early awareness among those in the space industry, but in at least one publication make the false argument that orbital debris only entered the public eye very recently. See for example Nicholas L. Johnson, “Orbital Debris Research in the U.S.,” in *Proceedings of the 4th European Conference on Space Debris (ESA SP-587)* (4th European Conference on Space Debris (ESA SP-587), Darmstadt, Germany, 2005); Jer-Chyi Liou, “The Near-Earth Orbital Debris Problem and the Challenges for Environment Remediation” (3rd International SPACE World Conference, Darmstadt, Germany, November 6, 2012). However, outside of NASA, presumptions of ignorant negligence on the part of the American and Soviet space industries during the Cold War perennially crop up in policy documents and presentations. See for example Marshall H. Kaplan, “An Integrated Approach to Orbital Debris Research and Management” (Space Traffic Management Conference, Embry-Riddle Aeronautical University, 2014), 1–2; Marietta Benko and Kai-Uwe Schrogl, “Space Debris in the United Nations: Aspects of Law and Policy,” in

erases a remarkably longstanding transnational environmental dialog about outer space—a dialog that brought spacefaring and non-spacefaring nations into material and discursive contact during the early years of the Cold War Space Race, and influenced the development of new, tenuous models of international governance in near-Earth space.

In recent decades environmental historians investigating the histories of terrestrial landscapes and envirotechnical systems have charged that such a declensionist, presentist—and often racist and classist—approach ignores the categorically messier ways that humans and the non-human biological and geophysical world interact and mutually shape one another over time.<sup>12</sup> Histories of environments on Earth merit a closer look at a broader range of actors, physical forces, and living and nonliving actants. A similarly nuanced, multivalent approach to environmental change also more accurately illuminates the history of humankind’s virtual and material encounter with the outer space environment. I refer to the near-Earth space environment as the planetary borderlands to call attention to the ways that the physical ecosystem of outer space collapse geography and bring states and polities into proximity. Additionally, this categorization explicitly counters the racial and teleological undertones of the Turnerian

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*Proceedings of the Second European Conference on Space Debris: ESOC, Darmstadt, Germany, 17-19 March 1997*, SP 393 (Noordwijk, The Netherlands: European Space Agency, 1997), 749.

<sup>12</sup> See for example Mark Fiege, *Irrigated Eden: The Making of an Agricultural Landscape in the American West* (University of Washington Press, 1999). Frank Uekötter, “The Old Conservation History — and the New: An Argument for Fresh Perspectives on an Established Topic,” *Historical Social Research / Historische Sozialforschung* 29, no. 3 (109) (January 1, 2004): 171–91. Carolyn Merchant, *Reinventing Eden: The Fate of Nature in Western Culture* (New York, NY: Routledge, 2003) In referring to outer space as an envirotechnical system, I am borrowing Sara Pritchard’s term to describe the overlap and mutual influence of natural and technical systems. Sara B. Pritchard, “An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima,” *Environmental History* 17, no. 2 (April 1, 2012): 219–43.

frontierism that motivated the Soviet and American space programs, and acknowledges the global and extraterritorial attributes of the orbital environment.<sup>13</sup>

In exploring a half-century of environmental change in an extreme, remote environment, the historical analysis in this dissertation traces early perceptions of outer space as an environment at risk. It prioritizes these historiographical imperatives of environmental history and merges them with a theoretical grounding in the histories of science and technology. The conceptual frameworks of the social construction of technology and technological momentum apply to both the history of the early development of satellite technology and a coinciding new perception of space as a pollutable natural environment. Space junk itself, it will be shown, is socially constructed.<sup>14</sup> In many cases, then and now, on Earth and in space, one person's useful spacecraft can be another person's dangerous space junk. Perhaps surprisingly, given its lack of colonized peoples or biota, near-Earth space—for the purposes of this analysis, defined as the regions of cislunar space that contain the majority of human-made space

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<sup>13</sup> For an overview of the origins and trajectory of borderlands historiography, see Daniel H. Usner, "Borderlands," in *A Companion to Colonial America*, ed. Daniel Vickers (New York: John Wiley & Sons, 2008); for the conceptualization of the borderlands as a response to the Turner frontier thesis, see David J. Weber, "Turner, the Boltonians, and the Borderlands," *The American Historical Review* 91, no. 1 (February 1986): 66–81; for outer space as one among many frontiers in Western political thought, see Will Wright, *The Wild West: The Mythical Cowboy and Social Theory* (Washington, DC: SAGE, 2001), 123–137.

<sup>14</sup> Many of the foundational texts on the social construction of technology apply to the history of space objects. See Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology: How the Refrigerator Got Its Hum*. (Milton Keynes, UK: Open University Press, 1985); Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History? The Dilemma of Technological Determinism* (Cambridge, Mass: The MIT Press, 1994); Wiebe E. Bijker et al., eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, anniversary edition (Cambridge, Mass: The MIT Press, 2012).

objects—has been a subject of environmental concern since the first days of human access.<sup>15</sup>

Near-Earth space fits remarkably well within classical narratives of both wilderness and landscape. As a region “where man himself is a visitor who does not remain,” the orbital regions of planet Earth fit nearly perfectly into the definition of wilderness set forth in the landmark Wilderness Act of 1964.<sup>16</sup> Once humankind began to cultivate orbit by constructing a satellite infrastructure, it also became a place well described by John Brinckerhoff Jackson’s characterization of landscape as “a composition of man-made or man-modified spaces to serve as infrastructure or background for our collective existence.”<sup>17</sup> Considering David Nye’s suggestion that Western society views modern landscapes only through inventions and interventions of a largely technical visual culture, near-Earth space may be considered an extreme example of a technological landscape. Cultivated by human interventions, the very satellites that enable valued technological practices on the ground are all but invisible to the majority of Earthbound users.<sup>18</sup> Only specialized equipment and abstract modeling allow direct visualization of an infrastructure that has become, in the words of Paul Edwards, “the connective tissues and the circulatory systems of modernity”—invisible structures that

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<sup>15</sup> The rhetoric of contact in the context of outer space both harkens to and clashes with other histories of colonialism. The bodily racial components of colonization so crucial to late 20<sup>th</sup>-century American frontier history do not map directly onto the initial technological colonization of near-Earth space, though the movement and reentry of space debris brings bodies and race back into the picture (see Chapter 3 of this dissertation for a brief example).

<sup>16</sup> Wilderness Act of 1964, 16 U.S.C. 1131-1136, 78 Stat. 890 (1964)

<sup>17</sup> John B. Jackson, *Discovering the Vernacular Landscape* (New Haven: Yale University Press, 1984), 8.

<sup>18</sup> David Nye, introduction to *Technological Landscapes: From Reaping to Recycling*, ed. David Nye (Amherst, MA: University of Massachusetts Press, 1999), 16.

we only notice on the rare occasions when they fail.<sup>19</sup> During the first decades of the Cold War Space Race, the United States and the Soviet Union constructed an information infrastructure in orbit, thereby shaping the true wilderness of outer space into a landscape.

While popularly portrayed as a void—the opposite of verdant green-and-blue nature portrayed by environmentalists and artists alike—the nearest reaches of outer space support an abiotic ecosystem consisting of energy exchanges, radioactivity, natural rocky objects and energetic plasmas, and gravitational forces. Space has its own “weather” driven by regular solar cycles that affect the matter and energy in near-Earth space, including artificial satellites and uncontrolled orbiting waste.<sup>20</sup> Near-Earth space even boasts self-cleaning mechanisms to rival any river or wind current—the atmosphere expands and contracts along regular solar cycles, exerting drag on space junk until it falls back to Earth through intense friction and pressure. However, the boundary between space and terrestrial climates has become more tenuous as humankind has expanded its domain into the nearest regions of the cosmos. Even anthropogenic climate change has impacted the near-Earth ecosystem: Burgeoning carbon dioxide emissions have caused the planet’s thermosphere to contract, thereby reducing the altitude at which atmospheric

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<sup>19</sup> Paul N. Edwards, “Infrastructure and Modernity: Force, Time, and Social Organization in the History of Sociotechnical Systems,” in *Modernity and Technology*, ed. Thomas J. Misa, Philip Brey, and Andrew Feenberg (Cambridge, MA: MIT Press, 2003), 185.

<sup>20</sup> Historians Gregory Good and Dagomar Degroot are currently developing research projects that examine the history of space weather, from the study of sunspots during the 19th century to current space-based research. For more on the effects of space weather on orbiting artifacts, see Chapter 4 of this dissertation.

drag brings space junk out of orbit and diminishing the resilience of this ecosystem.<sup>21</sup>

These exchanges suggest that the planetary borderlands consist of an interactive continuum of natural and anthropogenic exchange in what anthropologist Valerie Olson calls “the extended ecological heliosphere.”<sup>22</sup>

In 1961, four years after the Soviet Union launched Sputnik 1 into orbit, some 380 trackable anthropogenic objects circled the planet. By the end of 1963, that number had mushroomed to 685—though this number only included objects large enough to be seen from the ground. Among the byproducts of human-driven change to the orbital environment during these years were objects too small to be detected by space surveillance technology at the time. At most recent count, the Space Surveillance Network estimates that nearly seventeen thousand objects large enough to be tracked orbit the planet. Of these, 77% have been confirmed as objects with no designated use or purpose—space junk.<sup>23</sup> Another approximately 500,000 pieces of debris between one and ten centimeters in diameter, and over 100 million anthropogenic particles smaller than one centimeter, round out the system of waste in near-Earth space.<sup>24</sup>

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<sup>21</sup> J. T. Emmert et al., “Observations of Increasing Carbon Dioxide Concentration in Earth’s Thermosphere,” *Nature Geoscience* 5, no. 12 (November 11, 2012): 868–71.

<sup>22</sup> Valerie A. Olson, “NEOecology: The Solar System’s Emerging Environmental History and Politics,” in *New Natures: Joining Environmental History with Science and Technology Studies*, ed. Dolly Jørgensen, Finn Arne Jørgensen, and Sara B Pritchard (Pittsburgh, Pa.: University of Pittsburgh Press, 2013), 195–211.

<sup>23</sup> U.S. Space Surveillance Network, “Satellite Box Score,” *Orbital Debris Quarterly News* 19, no. 1 (January 2015): 10.

<sup>24</sup> *Ibid.*



These minute, largely invisible bits of anthropogenic material orbit alongside the empty rocket bodies, dead satellites, and other large objects speeding overhead.<sup>25</sup>

Awareness of the potential dangers of accumulating debris drove the first international debates in the late 1950s over how to define and control pollution in outer space. As soon as the first satellites reached orbit, both the United States and the Soviet Union sought to use this new environment for both peaceful and nefarious purposes. Both superpowers carried out high altitude and exoatmospheric nuclear weapons tests beginning in 1958 and ending in 1963 with the Partial Nuclear Test Ban Treaty. New kinds of satellites—from giant, shiny inflatable balloons to a ring of hundreds of millions of tiny copper fibers—tested the use of space for communications while spurring controversy over whether such satellites could interfere with astronomy, crowd the electromagnetic spectrum, or present a collision hazard to other spacecraft.<sup>26</sup> Just as outer space became a site of political prestige and technological utility during the Cold War, scientists around the world came to embrace Earth orbit as a valuable subject and site of investigation, and rapidly abandoned the idea of a physically isolated Earth.

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<sup>25</sup> All objects in orbit are in constant motion, but the speed of these objects depends on altitude. Objects in low-Earth orbit (between approximately 160 and 2000 kilometers above the surface of the Earth) can travel at speeds up to 7.8 kilometers per second. Objects at higher altitudes move more slowly, but still at speeds that would cause catastrophic damage in a collision with another object. In an analogy used by NASA, a piece of debris smaller than half an inch in diameter traveling at about six miles per second would hit as hard as a bowling ball moving at 300 mph.

<sup>26</sup> Current geoengineering proposals intended to correct atmospheric change by “seeding” orbital space with reflective material recall some of these early controversies, and could spur similar debate over the environmental protection of near-Earth space. For analysis of historical and contemporary weather control, see Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (MIT Press, 2010); James Rodger Fleming, *Fixing the Sky: The Checkered History of Weather and Climate Control*, Columbia Studies in International and Global History (New York: Columbia University Press, 2010); Clark A. Miller and Paul N. Edwards, eds., *Changing the Atmosphere: Expert Knowledge and Environmental Governance*, Politics, Science, and the Environment (Cambridge, Mass: MIT Press, 2001).

As the Space Age wore on, the larger objects became a threat—not just to other objects in orbit, but to people, property, and environments on the ground. The natural geophysical ecosystem of the Earth-Sun environment experienced particularly stormy periods of space weather during the first peaks of the eleven-year solar cycle to take place after the launch of *Sputnik*. As the atmosphere expanded, uncontrolled objects succumbed to friction and fell back to Earth through the destructive upper atmosphere. With no control over where surviving fragments might land, orbital space became a site from which pollutants could cross geographic boundaries and extraterritorial regions. In cases such as the nuclear-powered satellite *Cosmos 954*, which fell over the Northwestern Territories of Canada in 1978, such reentries raised a very real specter of radioactive contamination of ground, sea, and sky—originating not out of geopolitical antagonism but rather the caprice of the natural geophysical forces of the Sun. From the first space nukes to the reentry of *Cosmos 954*, the circulating imprint of what Will Steffen calls the “Great Acceleration” extended from underground to outer space.<sup>27</sup> As the first byproducts of the fledgling space industry circled the planet, newly minted space scientists reached the consensus that the physical influence of our planet extended dozens of kilometers into a physically interactive solar system. Just as the Great Acceleration coincided with the rise of mainstream environmentalist movements around the world, concern over

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<sup>27</sup> The Great Acceleration describes the postwar period, or more accurately the world without analog that began after the detonation of the first atomic weapon. Steffen et al. argue that the Anthropocene began concurrently with the Great Acceleration, in contrast to other suggested starting points like the Neolithic Revolution or the Industrial Revolution. See Will Steffen, Paul J. Crutzen, and John R. McNeill, “The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?,” *Ambio* 36, no. 8 (December 2007): 614–21; Will Steffen et al., “The Trajectory of the Anthropocene: The Great Acceleration,” *The Anthropocene Review* 2, no. 1 (April 2015): 81–98.

environmental risk extended into the nearest reaches of outer space from the first moments of the Space Age.

Representations of outer space as the final frontier permeated popular culture during the Cold War—particularly in America, where the heady rush to the Moon replicated a mythology of American exceptionalism rooted in the conquest of the West.<sup>28</sup> However, despite the appearance of unregulated orbital prospecting by the United States and the Soviet Union, the conquest of near-Earth space did not occur in an absence of authority. As during the colonization of the American West before it, state governments played a large role in facilitating and regulating the expansion of empire in yet another expansive frontier.<sup>29</sup> Scientific, industrial, and state actors of spacefaring and non-spacefaring nations alike competed to exercise control in the planetary borderlands during the Cold War Space Race. I will show that in the early days of the satellite age, the built environment in orbit was constructed atop a web of international governance driven in part by an early worldwide understanding of near-Earth space as an environment at risk. Concurrent with the rise of mainstream environmentalism, the material and rhetorical matter of space junk undergirded a multivalent, wide-reaching dialogue about cosmic environmental morality at the dawn of the space age—far earlier than recognized in most current space policy research.

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<sup>28</sup> Asif Siddiqi, “Spaceflight in the National Imagination,” in *Remembering the Space Age*, ed. Stephen J. Dick (Washington, DC: National Aeronautics and Space Administration, 2008), 26-27.

<sup>29</sup> Brian Balogh, *A Government Out of Sight: The Mystery of National Authority in Nineteenth-Century America* (Cambridge ; New York: Cambridge University Press, 2009).

## The Envirotechnical History of Near-Earth Space

This dissertation brings together the histories of science, technology, and the environment to trace the mutual influences and interactions of humankind, terrestrial environments, and orbital environments over the first decades of human access to outer space. It breaks new ground in space history by highlighting the role of the geophysical world of outer space as a historical actor of equivalent importance to astronauts, engineers, governments, and publics. Historians of space technology examine the emissaries that humankind has sent into the alien beyond, but not how these artifacts in their afterlives interacted with the orbital ecosystem—with profound consequences for Cold War geopolitics.<sup>30</sup> Roger Launius has noted that to date the extensive space history scholarship has given little more than passing notice of the space environment itself as an important feature in the history of space technology and politics.<sup>31</sup>

Since the late 20<sup>th</sup> century, environmental historians have sought to represent the natural world as a significant force in human history—a priority often neglected in the

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<sup>30</sup> For examples of history of space technology, see Dwayne Day, *Eye in the Sky: The Story of the CORONA Spy Satellites* (Smithsonian Institution, 2015); Constance McLaughlin Green, Milton Lomask, and Charles A. Lindbergh, *Vanguard, A History: The NASA Historical Series* (Washington: NASA: Scientific & Technical Information Division, 1971); Pamela Etter Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System*. (Cambridge, Mass.: MIT Press); David A. Mindell, *Digital Apollo: Human and Machine in Spaceflight* (Cambridge, MA: The MIT Press, 2008); Asif A. Siddiqi, *Sputnik and the Soviet Space Challenge*, 1st edition (Gainesville: University of Florida Press, 2003); Simone Turchetti and Peder Roberts, *The Surveillance Imperative: Geosciences during the Cold War and Beyond* (Palgrave Macmillan, 2014); David J. Whalen, *The Origins of Satellite Communications, 1945-1965*, Smithsonian History of Aviation and Spaceflight Series (Washington, D.C: Smithsonian Institution Press, 2002).

<sup>31</sup> Roger D. Launius, “Writing the History of Space’s Extreme Environment,” *Environmental History*, July 1, 2010, 526–32.

preceding decades of historical scholarship.<sup>32</sup> This study of the history of human interactions with the near-Earth ecosystem takes up Martin Melosi's call to reframe this priority to include a more expansive definition of nature and the natural. In his critique of Donald Worster and those historians who isolate "the natural world" as a narrow, necessarily miniscule category of spaces and assemblages devoid of any human intervention, Melosi argues that environmental historians ought to focus instead on "the role and place of the *physical environment* in human life."<sup>33</sup> The physical environment of near-Earth space encompasses naturally occurring phenomena and the built environment, growing over the course of the Cold War into an exemplary combination of what Bill Cronon calls "first nature" and "second nature." In Cronon's take on Hegelian and Marxist rhetoric, first nature represents the natural world that existed before humans, and second nature the artificial structures that human societies construct upon first nature. When first and second natures merge into a landscape made up of geophysical, material, and economic forces they become all but invisible, indistinguishable from one another. Just like the flow of commodities and capital through the markets and hinterlands of Chicago, the second nature of the satellite infrastructure quickly became as invisible, and

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<sup>32</sup> J. R. McNeill, "Observations on the Nature and Culture of Environmental History," *History and Theory* 42, no. 4 (December 1, 2003): 5–43.

<sup>33</sup> Martin V. Melosi, "The Place of the City in Environmental History," *Environmental History Review* 17, no. 1 (Spring 1993): 1–23; In this article, Melosi responds to Donald Worster's appendix to *The Ends of the Earth: Perspectives on Modern Environmental History* (Cambridge University Press, 1988).

its technological and economic momentum as unstoppable as any natural force (with notable exceptions that will be covered in the chapters that follow).<sup>34</sup>

Second nature not only turns creatures, plants, and things into market commodities—it also collapses the distance between the point of production and the point of consumption. Most consumers of the products of modern capitalism do not see the origins of these products, nor do they reside in proximity to the byproducts of this consumption.<sup>35</sup> Scholars of waste and discard studies also emphasize the temporal and geographic discontinuity between sites of consumption and the transformation and spatial relocation of byproducts. Susan Strasser, Joel Tarr, Martin Melosi, and Carl Zimring represent a few among many historians who examine the afterlives of waste. Other social scholars of waste and discard have emphasized the global pathways of refuse, including Anna Davies on the geographies of waste circulation, Marisa Cohn on the decay of global technological systems, and Joshua Reno on waste at social and spatial peripheries.<sup>36</sup> In studies of the byproducts of similarly high-tech, invisible information infrastructures, Phaedra Pezzullo, Josh Lepawksy, and Nathan Ensmenger examine the high-technology wasteways of electronics production.<sup>37</sup> Like these terrestrial wastes, space junk that

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<sup>34</sup> William Cronon, *Nature's Metropolis: Chicago and the Great West* (W. W. Norton & Company, 1991).

<sup>35</sup> *Ibid.*, 266–267.

<sup>36</sup> Anna Davies, *The Geographies of Garbage Governance: Interventions, Interactions, and Outcomes* (Aldershot, Hampshire, England; Burlington, VT: Ashgate, 2008); Marisa Cohn, “Lifetimes and Legacies: Temporalities of Sociotechnical Change in a Long-Lived System” (Dissertation, University of California, Irvine, 2013); Joshua O. Reno, *Waste Away: Working and Living with a North American Landfill* (Oakland, CA: University of California Press, 2016).

<sup>37</sup> Phaedra C. Pezzullo, “What Gets Buried in a Small Town: Toxic E--Waste and Democratic Frictions in the Crossroads of the United States,” in *Histories of the Dustheap: Waste, Material Cultures, Social Justice*, by Stephanie Foote and Elizabeth Mazzolini (Cambridge, MA: MIT

remains in orbit or falls back to Earth nearly always winds up in regions far removed from the state of origin, and far from the communities that use the information produced using the technologies of the space industry.

This analysis of environmental change in near-Earth space both contributes to and expands upon recent historical scholarship in environmental history which connects the acceleration of global environmental change during the Cold War to the shifting environmental politics of the era.<sup>38</sup> By illuminating how Cold War spacefaring humanity shaped, and was shaped by, the orbital geophysical environment, this dissertation for the first time situates the history of near-Earth space within a burgeoning historiography that analyzes the interactions of Cold War politics, technology, and environmental change.<sup>39</sup> During this period, the global scale of the conflict between the United States and its allies and the Soviet Union translated into an imperative to know the enemy by way of knowing the Earth, as evidenced by the rise of federal funding for geosciences and Earth

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Press, 2012), 119–46; Josh Lepawsky and Charles Mather, “From Beginnings and Endings to Boundaries and Edges: Rethinking Circulation and Exchange through Electronic Waste: From Beginnings and Endings to Boundaries and Edges,” *Area* 43, no. 3 (September 2011): 242–49; Josh Lepawsky and Chris McNabb, “Mapping International Flows of Electronic Waste,” *The Canadian Geographer / Le Géographe Canadien* 54, no. 2 (June 2010): 177–95; Nathan Ensmenger, “Dirty Bits: An Environmental History of Computing” March 24, 2015.

<sup>38</sup> See for instance J. R. McNeill and Corinna R. Unger, *Environmental Histories of the Cold War* (Cambridge University Press, 2010); Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism*, (Oxford ; New York: Oxford University Press, 2013); Joshua P. Howe, *Behind the Curve: Science and the Politics of Global Warming* (University of Washington Press, 2014).

<sup>39</sup> For recent histories of Cold War politics, technology, and environmental change, see Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (New York: Oxford University Press, 2013); J. R. McNeill and Corinna R. Unger, *Environmental Histories of the Cold War* (Cambridge University Press, 2010).

surveillance in the postwar period.<sup>40</sup> With the boon of state support, scientific disciplines from geophysics to ecosystem ecology served the double purpose of controlling the enemy and controlling the environment. Like global-scale ecosystems within the biosphere, the near-Earth space environment proved difficult to control, and the objects placed into the environment did not always stay where they were placed—much like the circulation of pollution at the poles or the consolidation of plastics in ocean gyres. Like garbage patches circling within the gyres, gravity wells in orbit tend to attract and pool objects whose position in orbit can no longer be actively maintained.<sup>41</sup>

However, as in the burgeoning field of Anthropocene studies, most existing efforts stop at the arbitrary line of the atmosphere. My dissertation explores the historical permeability of this demarcation, demonstrating how Cold War environmental discourse spatially extended humankind's ecological impact beyond the biosphere. The history of humankind's technological presence in the nearest reaches of outer space suggests a broader, more nebulous reality in which terrestrial and extra-terrestrial environments intertwine in a natural, cultural, and technological continuum with the cosmos. During the first decades of the Space Age, changing scientific and popular understanding of the outer space environment, rising transnational awareness of invisible pollution, and

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<sup>40</sup> Simone Turchetti and Peder Roberts, eds., *The Surveillance Imperative: The Rise of the Geosciences during the Cold War* (New York, NY: Palgrave Macmillan, 2014).

<sup>41</sup> In geosynchronous orbits, debris gathers at two points on opposite sides of the planet due to irregularities in Earth's gravitational field. See S. Valk, A. Lemaître, and F. Deleflie, "Semi-Analytical Theory of Mean Orbital Motion for Geosynchronous Space Debris under Gravitational Influence," *Advances in Space Research* 43, no. 7 (April 2009): 1070–82; Peter B. de Selding, "Debris-Control Report Card Cites Improvement by Geo Sat Owners," *SpaceNews*, October 25, 2013, <http://spacenews.com/37861debris-control-report-card-cites-improvement-by-geo-sat-owners/>.



material evidence of real or anticipated mismanagement of orbital resources led to near-Earth space becoming the subject of the earliest international debates about the “global environment.”

This dissertation diverges from an American environmental history literature that has largely overlooked what Steve Pyne calls “extreme environments”: remote, uninhabited, and unruly natural places that nonetheless constitute compelling sites of human practices and politics.<sup>42</sup> Near-Earth space resembles Antarctica, the deep sea, and the atmosphere in its illegibility, unruly boundaries, and remoteness.<sup>43</sup> As Steve Pyne has argued, these extreme environments represent places where humans can go, but only by using life-sustaining technologies, and only temporarily. In these places life either does not exist, or exists only at the microbial level and at the margins. Pyne argues that a lack of other humans and even biota to resist or conquer has translated to a lack of urgency in examining the environmental histories of extreme environments. As the first historical study to assess the history of outer space itself as a natural environment, this dissertation pushes historiographical boundaries by spotlighting the environmental history of a non-

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<sup>42</sup> Steve Pyne, “Extreme Environments,” *Environmental History*, July 7, 2010, 509–13.

<sup>43</sup> For historical studies of extreme terrestrial environments, see Helen M. Rozwadowski, *Fathoming the Ocean: The Discovery and Exploration of the Deep Sea*, (Cambridge, MA: Belknap Press of Harvard Univ. Press, 2008); Adrian Howkins, *The Polar Regions: An Environmental History* (Cambridge, UK ; Malden, MA: Polity, 2015); James Rodger Fleming, *Fixing the Sky: The Checkered History of Weather and Climate Control* (New York: Columbia University Press, 2012); Samantha K. Muka, “Working at Water’s Edge: Life Sciences at American Marine Stations, 1880-1930” (Dissertation, University of Pennsylvania, 2014); Rachel Emma Rothschild, “A Poisonous Sky: Scientific Research and International Diplomacy on Acid Rain” (Dissertation, Yale University, 2015); Jacob Darwin Hamblin, *Poison in the Well: Radioactive Waste in the Oceans at the Dawn of the Nuclear Age* (Rutgers University Press, 2009); Helen M. Rozwadowski and David K. Van Keuren, *The Machine in Neptune’s Garden: Historical Perspectives on Technology and the Marine Environment* (Science History Publications/USA, 2004).

terrestrial ecosystem.<sup>44</sup> By dismantling the discontinuous planetary boundary of environmental studies scholarship, I demonstrate a new way of seeing the history of the Space Age inextricably bound up in larger questions about environmental governance in an increasingly globalized world.

As an extreme environment that humankind may only access by direct or virtual technological mediation, this dissertation balances environmental history with the history of technology. My analysis of the evolving discourse of environmental risk employed by different communities to control the extreme orbital environment heeds the call by Nelly Oudshoorn and Trevor Pinch to keep users at the center of histories of technology.<sup>45</sup> However, in order to explore how the politics and practices of early space technology users shaped an inchoate orbiting information infrastructure, I take an interdisciplinary approach which prioritizes not only how users matter, but also how nature matters—even in environments so extreme and illegible as to push the limits of our understanding of the natural. In addition to treating the satellite network as an infrastructure, I examine the ways that the evolution of technological systems in an extreme, remote, illegible, and physically complex environment both illustrate, and require the expansion of, existing theories of technological development. In particular, the construction and decay of an orbiting infrastructure calls for a closer look at the social construction of technology and

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<sup>44</sup> Roger Launius has noted a significant absence of attention to the outer space environment itself within the literature of space history. He suggests that space historians may assume the hostility of outer space, and humankind's triumph over it, to be universally understood as part of the heroic narrative of space exploration. Roger D. Launius, "Writing the History of Space's Extreme Environment," *Environmental History*, July 1, 2010.

<sup>45</sup> Nelly Oudshoorn and Trevor Pinch, eds., *How Users Matter: The Co-Construction of Users and Technology* (Cambridge, Mass.: The MIT Press, 2005).

the ways that the geophysical world participates in the shaping of technologies and waste.<sup>46</sup> This analysis of the mutual shaping of space environment and space technology over the course of the Cold War contributes to envirotech scholarship—interdisciplinary studies that highlight the mutually shaping interrelationships between the nonhuman natural world and technology.

Finally, this dissertation also explores how Cold War scientific politics factored into broader cultural understanding of near-Earth space as natural environment. By examining the ways that astronomers, orbital physicists, and other space scientists sought to use and protect the planetary borderlands, I show how the interactions between specialist and lay communities inflected a discourse of environmental protection of outer space. I also demonstrate the pathways by which communities of scientists sought to position themselves as the ideal arbiters of safe activity in outer space. The analysis of internal and external conflicts among astronomers during the earliest moments of human access to space contribute to the historiography of Cold War physical sciences and the unique cultural space carved out by American and European astronomers as separate from their physicist colleagues.<sup>47</sup>

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<sup>46</sup> The conceptual framework of the social construction of technology, particularly interpretive flexibility, plays a key function both in the history of the early development of satellite technology and a coinciding perception of space as a pollutable natural environment. Many of the foundational texts on the social construction of technology apply to the history of space objects. See Donald MacKenzie and Judy Wajcman, eds. *The Social Shaping of Technology: How the Refrigerator Got Its Hum*. (Milton Keynes, UK: Open University Press, 1985); Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History? The Dilemma of Technological Determinism* (Cambridge, Mass: The MIT Press, 1994); Wiebe E. Bijker et al., eds., *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, anniversary edition (Cambridge, Mass: The MIT Press, 2012).

<sup>47</sup> See for instance W. Patrick McCray, *Giant Telescopes: Astronomical Ambition and the Promise of Technology* (Cambridge, MA: Harvard University Press, 2004); Ronald E. Doel, *Solar*

### **Anthropocene Without Borders**

In the decade and a half since Paul Crutzen and Eugene Stoermer published the first printed use of the term “Anthropocene” to describe the current epoch of human-driven geophysical change, environmental scientists, social scientists, and humanists have debated its temporal limits.<sup>48</sup> Some argue that the era began with the industrial revolution in the late 18<sup>th</sup> century, others millennia earlier at the Neolithic Revolution in crop and livestock domestication—and still others argue that such an epoch should not be recognized at all as a formal geological period separate from the Holocene.<sup>49</sup> In 2015, climate scientist Will Steffen suggested a dramatically recent start to the Anthropocene: the post-war period that he, Crutzen, and John McNeill previously named the “Great Acceleration.”<sup>50</sup> Claiming that records of large-scale environmental change prior to the Second World War could be attributed to the natural variability of the Holocene, Steffen

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*System Astronomy in America: Communities, Patronage, and Interdisciplinary Science, 1920-1960* (Cambridge: Cambridge University Press, 1996); Daniel Kevles, *The Physicists: The History of a Scientific Community in Modern America*, Revised edition (Cambridge, MA: Harvard University Press, 1995); Zuoyue Wang, *In Sputnik's Shadow: The President's Science Advisory Committee and Cold War America* (New Brunswick, NJ: Rutgers University Press, 2009); Allan A. Needell, *Science, Cold War and the American State: Lloyd V. Berkner and the Balance of Professional Ideals* (London: Harwood Academic, 2000).

<sup>48</sup> The first published use of the term briefly mentions that humans have stepped on the moon, but otherwise limits the scope of human ecological impact to the biosphere. See P.J. Crutzen and E. F. Stoermer, “The ‘Anthropocene,’” *Global Change Newsletter* 41 (May 2000): 17–18.

<sup>49</sup> William F. Ruddiman, “The Anthropocene,” *Annual Review of Earth and Planetary Sciences* 41, no. 1 (2013): 45–68.; Giacomo Certini and Riccardo Scalenghe, “Is the Anthropocene Really Worthy of a Formal Geologic Definition?,” *The Anthropocene Review* 2, no. 1 (April 1, 2015): 77–80.

<sup>50</sup> Will Steffen et al., “The Trajectory of the Anthropocene: The Great Acceleration,” *The Anthropocene Review* 2, no. 1 (April 2015): 81–98; Will Steffen, Paul J. Crutzen, and John R. McNeill, “The Anthropocene: Are Humans Now Overwhelming the Great Forces of Nature?,” *Ambio* 36, no. 8 (December 2007): 614–21.

and his co-authors poignantly describe the current state of planet Earth as “a no-analogue world.”<sup>51</sup>

The Great Acceleration marked an exponential increase in atmospheric greenhouse gases and large-scale environmental degradation that resulted from the exploding human population and resource use. The first atomic bomb was exploded over New Mexico at the cusp of the Great Acceleration, unleashing an unprecedented quantity of radioactive material into the atmosphere which became one of the hallmarks of this period as the nuclear arms race unfolded. At the same time that nuclear weapons and the first intercontinental ballistic missiles annihilated the time and space of annihilation, humankind used these same technologies to irrevocably and incontrovertibly expand the spatial dimensions of anthropogenic change beyond the atmosphere. Starting with the launch of Sputnik in October 1957, the environment of *anthropos* expanded into outer space. In the midst of the Great Acceleration, humans began to play a major, measurable role in the evolution of natural environments beyond the tenuous boundaries of the terrestrial biosphere.<sup>52</sup> Valerie Olson and Lisa Messeri recently took steps to break down the discursive boundaries between “inner” and “outer” environments in theorizing the

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<sup>51</sup> Steffen et al., “The Trajectory of the Anthropocene,” 94.

<sup>52</sup> Outer space has merited passing mention in Anthropocene studies. In their instigating article, Crutzen and Stoermer briefly note that humankind has extended its reach to the Moon but do not engage with outer space as Anthropocene environments. Bruno Latour brings cislunar space into the Anthropocene in portraying the 2013 Hollywood film *Gravity*—in which angular momentum and space junk are the primary villains—as an indication of an inward, Earthward cosmological shift during this period of profound, global-scale connection between human and biosphere, but once again the environment of near-Earth space does not feature into the analysis. Crutzen and Stoermer, “The ‘Anthropocene,’” 17; Bruno Latour, “Telling Friends from Foes at the Time of the Anthropocene,” in *The Anthropocene and the Global Environmental Crisis: Rethinking Modernity in a New Epoch*, ed. Clive Hamilton, Francois Gemenne, and Christophe Bonneuil, Routledge Environmental Humanities (New York: Routledge, 2015).

spatial parameters of the Anthropocene.<sup>53</sup> As anthropologist Alice Gorman has argued, the Anthropocene cannot truly be understood without considering the place of outer space in geophysical change.<sup>54</sup>

As difficult as it may be to imagine human-caused global change, thinking about the Anthropocene also requires shaking up a more basic, seemingly innate set of assumptions about the world around us. It requires reimagining our ideas about nature and the natural, and redrawing the limits of the human environment to include even those places most alien, empty, and seemingly antithetical to nature as most understand it. The Earth of the Anthropocene is a much larger world than can be bounded by biology, geology, or atmosphere. Through the production, use, and discarding of spacecraft and space junk, humanity has broadened the boundaries of Earth into the universe. Our use and disuse of the nearest regions of space rendered our species materially and virtually cosmopolitan, in the earliest meaning of the word espoused by the Cynics and Stoics of Ancient Greece. A cosmopolitan rejects loyalty to a particular polity in favor of being a citizen of the universe.<sup>55</sup> This effective cosmopolitanism, arising in the midst of the deeply stratified Cold War Space Race, represented a deeply paradoxical new identity for spacefaring societies.

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<sup>53</sup> Anthropologists Valerie Olson and Lisa Messeri recently suggested the necessity of a broader spatial reckoning of the Anthropocene in “Beyond the Anthropocene: Un-Earthing an Epoch,” *Environment and Society: Advances in Research* 6, no. 1 (September 1, 2015): 28–47.

<sup>54</sup> Alice Claire Gorman, “The Anthropocene in the Solar System,” *Journal of Contemporary Archaeology* 1, no. 1 (August 22, 2014): 87–91.

<sup>55</sup> Kwame Anthony Appiah, *Cosmopolitanism: Ethics in a World of Strangers (Issues of Our Time)* (W. W. Norton & Company, 2010), xiii–xv.

### **Silent Spring / Sullied Space**

In September 1962, Rachel Carson's groundbreaking book *Silent Spring* hit bookshelves across America and rapidly became a worldwide best seller. *Silent Spring* introduced an international mainstream readership to an unseen biological threat, the gravity of which Carson likened to nuclear fallout—but not as broadly recognized, understood, or resisted by affected communities at the time. Carson criticized *en masse* the authoritarian government officials that she deemed responsible for indiscriminately dispensing chemical pesticides in an effort to selectively eliminate specific unwanted organisms, but ultimately harming entire ecosystems and human bodies. *Silent Spring* articulated failures of visibility, consent, authority, and education as key social factors underpinning dangerous chemical pesticide use around the world. Should these practices continue unabated, Carson argued, humanity could face a shocking ecological apocalypse—from the loss of cherished birdsong insinuated in the book's title, to the destruction of soil productivity and subsequent conquest by the very organisms targeted for eradication.<sup>56</sup>

The same month that *Silent Spring* was released, newly knighted British radio astronomer Bernard Lovell published an article in *Nature* detailing a similarly grave, similarly invisible environmental threat. In this article and a simultaneously published book—neither of which accrued the same broad readership as *Silent Spring*—Lovell extolled recent advances in satellite-facilitated knowledge about the outer space

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<sup>56</sup> While the famous introductory chapter to *Silent Spring* portrays a bleak future drawn from allegory rather than factual possibility, its apocalyptic rhetoric resonated with publics around the world and served as an effective point of entry to the rigorous science writing that followed. Linda Lear, *Rachel Carson: Witness for Nature* (Houghton Mifflin Harcourt, 2009), 430, 573; Rachel Carson, *Silent Spring*, 40th anniversary ed., 1st Mariner Books ed. 2002 (Boston: Houghton Mifflin, 1962).

environment that had totally transformed scientific understanding of Earth's place in the cosmos. Not yet five years after Soviet engineers launched Sputnik into orbit, a rapidly coalescing international community of space scientists discovered a complex topography of magnetism, radiation, energy, dust, and atmospheric and trapped solar particles extending tens of thousands of kilometers from Earth into space. Lovell lauded these discoveries as early as 1960, noting that the "earth's environment" now dominated its own cosmic neighborhood to a distance of some ten Earth radii.<sup>57</sup> In *The Exploration of Outer Space* he warned, however, that the near-Earth space environment—new to human access and study—had already been polluted beyond repair by the same faceless authorities that drenched an unconsenting society with chemical pesticides.<sup>58</sup> Lovell argued that in a jingoistic race to technological supremacy, Cold Warring states had taken egregious risks by launching dangerous materials—including nuclear devices—into a poorly understood, fragile environment that scientists could no longer study in its natural state. Without proper oversight, Lovell anticipated the imminent militarization of outer space and the apocalyptic destruction of entire scientific disciplines, whose practitioners believed themselves to be standing on the cusp of revolution predicated on future access to outer space.<sup>59</sup>

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<sup>57</sup> A.C.B. Lovell, "The Exploration of Outer Space," *Journal of the Royal Society of Arts* 108, no. 5047 (June 1960): 503.

<sup>58</sup> Bernard Lovell, *The Exploration of Outer Space* (New York: Harper and Row, 1962), 11–16; Bernard Lovell, "The Challenge of Space Research," *Nature* 195, no. 4845 (September 8, 1962): 935–939.

<sup>59</sup> Should spacefaring nations not comply with scientific oversight, Lovell warned that they "may bear the awful responsibility of having started a chain of events leading to the militarization of space and the destruction of astronomy on Earth." *Ibid.*



While many in the chemical industry vilified Carson as anti-science, her text proclaimed otherwise. She argued that pesticide programs required oversight by scientists, many of whom could lose the ability to study organisms and ecosystems in an unaltered, chemical-free state.<sup>60</sup> Likewise, Lovell also anticipated that invisible contamination, abuses of authority, and insufficient consent of affected communities could lead to irreparable destruction of the mythical final frontier as an object of analysis. Both Carson and Lovell claimed that, in American suburbs and thousands of kilometers overhead, moral scientific governance provided the only hope of reversing the dire fates they announced. Hope for salvation could be found only by giving regulatory power to those specialists “guided by the purest of scientific motives,” as put by Lovell.<sup>61</sup>

Both Carson and her astronomer contemporaries sought to educate concerned citizens and promote a specific kind of specialist as the most qualified and morally equipped individuals to serve as clairvoyant environmental watchdogs against Cold War state authorities. Lovell’s writings exemplify surging dissent among transnational networks of American, European, and Soviet astronomers that emerged during the early 1960s against American military space activities. Just as chemical pesticides threatened the work of zoologists and biologists, these astronomers feared that an increasing amount of artificial material launched into orbit threatened the contemporary and anticipated research practices of astronomers around the world. Lovell and many of his colleagues

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<sup>60</sup> Carson did not presume that all scientists could be trusted with the moral responsibility of industry oversight, and after the publication of *Silent Spring* chemists working in the commercial sector were among Carson's most vocal critics. See Lear, *Rachel Carson*, 428–456; Priscilla Coit Murphy, *What a Book Can Do: The Publication and Reception of Silent Spring* (Amherst, MA: University of Massachusetts Press, 2007), 89–118.

<sup>61</sup> Lovell, “The Challenge of Space Research,” 939; Carson, *Silent Spring*, 16, 79.

promoted astronomers as the best line of defense against potential ethical and moral disasters wrought by poorly informed bureaucrats in positions of unchecked power.<sup>62</sup> Like Carson, they enrolled the metaphor of nuclear resistance to garner popular and legislative support for the protection of an invisible environment. Attaining regulatory authority over outer space activities required engaging new opponents and forging new alliances—particularly with those outside the astronomy community who might have the power to affect policy change. Astronomers’ efforts to manage environmental risk in space gave shape and meaning to invisible orbital pollutants. Outer space itself became real, tangible, and vulnerable in the hands of mainstream journalists who employed proto-environmentalist language legible to lay communities that would never directly encounter the environment—and unlike the pesticides of *Silent Spring*, would not likely experience bodily encounters with the pollution in question.

The confluence of publications by Rachel Carson and Bernard Lovell—both of which called for similar forms of expert governance to avoid ecological destruction—suggests that at this moment, widely considered a germinal moment in the subsequent

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<sup>62</sup> At the same time that astronomers debated the environmental protection of outer space, practitioners of the new biological subdiscipline of exobiology organized to discuss another environmental threat to outer space that they hoped to prevent by developing rules for spacecraft sterilization. In what would become known as the planetary containment program, exobiologists aimed to protect both types of biological contamination: “back contamination,” or the incursion of potentially destructive alien microbes into the biosphere; and “forward contamination,” or the seeding of space and other worlds with Earthly organisms and organic material, thereby eradicating or intervening in the development of extant or potential extraterrestrial life. For the history of early exobiology and planetary containment, see Steven J. Dick, “Origins and Development of NASA’s Exobiology Program, 1958–1976,” *Acta Astronautica* 65, no. 1–2 (July 2009): 1–5; Steven J. Dick and James Edgar Strick, *The Living Universe: NASA and the Development of Astrobiology* (New Brunswick, N.J.: Rutgers University Press, 2000); James E. Strick, “Creating a Cosmic Discipline: The Crystallization and Consolidation of Exobiology, 1957–1973,” *Journal of the History of Biology* 37, no. 1 (Spring 2004): 131–80; Audra J. Wolfe, “Germs in Space,” *Isis* 93, no. 2 (June 2002): 183–205.

expansion of mainstream environmentalism, the very definition of the natural environment itself had begun to expand beyond the boundaries of the biosphere.<sup>63</sup> Like chemical pesticides released into watersheds, chemical fuels, fission particles, and metal fragments shed by spacecraft in orbit could not be guaranteed to stay put, or disappear without consequences. These material and rhetorical parallels suggest that the discourses of invisible environmental threat, destruction of nature broadly defined, and the politics of scientific morality and authority of *Silent Spring* extended well beyond the elm-lined streets of suburbia, farmlands of the Midwest, and marine estuaries of the eastern seaboard. Aptly, if coincidentally, the frontispiece to Chapter 10 of *Silent Spring* features a drawing of a nuclear family gazing into a night sky dotted with stars. At the same time that communities around the world confronted the prospect of a silent spring, many also came face to face with the prospect of a crowded sky.

### **Chapter Overview**

Rather than conducting a chronological examination of a single institution, group, or cultural movement, this dissertation will present four intersecting case studies which together reveal the formation of an international environmental consciousness of outer

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<sup>63</sup> The impact, influence, and response to the publication of *Silent Spring* and Rachel Carson have been widely covered in historical and literary scholarship. For example, see Lear, *Rachel Carson*; Lisa H. Sideris and Kathleen Dean Moore, eds., *Rachel Carson: Legacy and Challenge* (Albany, NY: SUNY Press, 2008); Ralph H. Lutts, "Chemical Fallout: Rachel Carson's Silent Spring, Radioactive Fallout, and the Environmental Movement," *Environmental Review: ER* 9, no. 3 (October 1, 1985): 211–225; Thomas R. Dunlap, "Review Essay: Before, During, and After Silent Spring," *Environmental Review: ER* 2, no. 6 (1977): 34–40; Mark Hamilton Lytle, *The Gentle Subversive: Rachel Carson, Silent Spring, and the Rise of the Environmental Movement* (New York: Oxford University Press, 2007); Murphy, *What a Book Can Do*; Craig Waddell, *And No Birds Sing: Rhetorical Analyses of Rachel Carson's Silent Spring* (Carbondale, IL: Southern Illinois University Press, 2000).

space during the Cold War. The five substantive chapters demonstrate how different communities attempted to control an environment that few had directly encountered, and how early perceptions of environmental risk in orbit shaped the material and discursive contours of the planetary borderlands.

Chapter one, “‘Sputnik’s Companion’: 1957α1 as Global Boundary Object,” begins with a case study of the rocket that launched Sputnik and accompanied it into orbit. Most Americans who reported seeing Sputnik cross the night sky actually glimpsed the much larger, shiner core of the rocket. Different communities around the world understood and used this globally mobile artifact as a scientific instrument, political tool, and intelligence commodity, among many other interpretations. With the mythical final frontier opened, the United States and the Soviet Union launched greater numbers of satellites into orbit. These early space artifacts took multiple forms, from passive to active, and the shape, materiality, and institutional home of each contributed to a deep interpretive flexibility during the first few years of the Space Age.

In a geopolitical reality in which high-altitude nuclear devices could be used to disable radio systems across an entire continent, the United States military sought new ways to communicate in case the Cold War turned hot. Chapter two traces the history of Project West Ford, a United States Air Force experiment that culminated in the launch of hundreds of millions of tiny copper needles into space for use in long-range radio communications. In “Under the Copper Curtain: Project West Ford and the Roots of Outer Space Environmentalism, 1958-1964” I follow an international community of astronomers—no strangers to environmental conflict after a century spent battling the

sky-obscuring effects of urbanization— which protested the project in an attempt to halt the extension of the industrial atmosphere into orbit.<sup>64</sup> Astronomers’ disciplinary fight against West Ford transformed in popular presses around the world into a prohibition on “littering,” “trashing,” and “dumping” in outer space. This rhetoric was consistent with an emergent zeitgeist of proto-environmentalist anxiety heralded by the concurrent publication of *Silent Spring*. While project designers saw the needles as valuable information infrastructure, news items and letters from concerned citizens in America and abroad suggest that some interpreted these artifacts alongside fallout and pesticides as invisible environmental threats imposed upon a non-consenting society.

Chapter three focuses on what happens when what goes up comes back down. Subjected to punishing friction, objects that reenter the atmosphere typically break into fragments. In passing through the planetary borderlands, these artifacts change materially, but also ontologically—particularly in legal discourse after space junk falls where it should not. In “‘Terror in the Skies:’ Falling Space Junk, Space Weather, and International Environmental Liability During the Long 1970s” I argue that falling space junk becomes a perilous kind of boundary object, bringing states, legal regimes, and bodies into unexpected and dangerous proximity, principally in instances where the reentry causes real or anticipated environmental damage.<sup>65</sup> Such reentries, particularly of

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<sup>64</sup> On the struggle of 18<sup>th</sup> and 19<sup>th</sup> century astronomers against urbanization, see David Aubin, “The Fading Star of the Paris Observatory in the Nineteenth Century: Astronomers’ Urban Culture of Circulation and Observation,” *Osiris*, 2nd Series, 18 (January 1, 2003): 79–100.

<sup>65</sup> Valerie Olson has reimagined the boundary object as presented by Star and Griesemer to describe natural space objects that force a redefinition of the environmental. Susan Leigh Star and James R. Griesemer, “Institutional Ecology, ‘Translations’ and Boundary Objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology, 1907-39,” *Social Studies of Science*

artifacts containing radioactive materials, evoked Cold War apprehensions of nuclear terror coming from the skies. Whether unintentional delivery vehicles for toxic waste or alien pathogens (as feared by some American biologists at the dawn of the space age), the fear of invasion by our own out-of-control technologies punctuated popular responses to high profile reentries. This anxiety also surfaced in mass culture from novels to films that portray existential disaster delivered by falling space junk.

Finally, chapter four illuminates how economic concerns about space junk factored into a temporary turn away from the single-use culture of the American space industry. This shift occurred during the development and operation of the Space Shuttle and Space Station programs, when NASA faced a shrinking budget under the guidance of an administrator with deep personal environmental commitments. In “Salvaging Space: Refuse, Reuse, and the Pursuit of Orbital Economy, 1968-1986” I examine the Space Shuttle itself—partially reusable and initially expected to facilitate retrieval and reuse of damaged or dead satellites. I have also rediscovered a largely forgotten space station proposal, called the Space Operations Center, which was championed by its designers as an on-orbit salvage and recycling facility. As in postwar American civic recycling programs, these priorities fell away when the cost of reuse surpassed that of single-use operations, and space commerce returned to the throwaway ethos of the early sixties.<sup>66</sup>

The history of the first space shuttle, christened *Columbia* in a hopeful and unintentionally ominous reference to another historical moment of exchange between

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19, no. 3 (August 1989): 387–420; Olson, “NEOecology: The Solar System’s Emerging Environmental History and Politics.”

<sup>66</sup> For American consumer culture and patterns of use and reuse during the 19<sup>th</sup> and 20<sup>th</sup> centuries, see Susan Strasser, *Waste and Want: A Social History of Trash* (Macmillan, 1999).

“old” and “new” worlds, serves as a tragic but apt coda: its early intended use for orbital cleanup, its unique capability to provide safe passage for space artifacts through the destructive planetary borderlands, and its ultimate transformation during the final passage, along with its human passengers, into falling space junk. This final analysis synthesizes the ways that the technologies nations have fashioned, sent aloft, and ceased to control, have brought us into jarring contact with the near-Earth space environment, and with each other.

## CHAPTER 1

### “Sputnik’s Companion”: 1957a1 as Global Boundary Object

On October 4, 1957, the Soviet Union launched the first artificial satellite into orbit around the planet. American citizens picked up newspapers and tuned their radios and televisions to breathless reports of nationwide agitation and fear: The Communists—whose economic system and social backwardness should, by contemporary American jingoist logic, have kept them on the ground—had beaten the United States to outer space.<sup>67</sup> In the days following the spectacular achievement, illustrations and eventually photographs of the so-called “red moon” presented Americans with an idea of the object’s physical appearance. News programs reproduced the sound emitted by the radio beacon aboard Sputnik, diffusing a taunting, now-iconic “beep-beep” through the radios of a nation that had nearly four months to go until it would successfully launch its own artificial moon. These visual and aural indices of the first artificial satellite became symbols of a new chapter in the Cold War that began with Sputnik—an era known as the Space Age.<sup>68</sup>

Though these mediated encounters with the satellite through photos and sounds in mass media constituted most Americans’ first exposure to the first satellite, many

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<sup>67</sup> Howard E. McCurdy, *Space and the American Imagination*, Second (Baltimore: Johns Hopkins University Press, 2011), 70.

<sup>68</sup> For an overview of Western reactions to the first artificial satellite, see Rip Bulkeley, *The Sputniks Crisis and Early United States Space Policy: A Critique of the Historiography of Space* (Indiana University Press, 1991); International Affairs Seminars of Washington, “American Reactions to Crisis: Examples of Pre-Sputnik and Post-Sputnik Attitudes and of the Reaction to Other Events Perceived as Threats,” October 15, 1958, U.S. President’s Committee on Information Activities Abroad (Sprague Committee) Records, 1959-1961, Box 5, A83-10, Dwight D. Eisenhower Library, Abilene, Kansas, <http://www.history.nasa.gov/sputnik/oct58.html>.



subsequently attempted to view the Russian moon with their own eyes. Regional, local, and national news outlets printed schedules of when readers could expect the satellite to pass overhead in the hours immediately following dusk and preceding dawn, when the light of the sun from below the horizon illuminated the shiny object against a dark sky. Interested individuals went outside and looked up, hopeful that they would catch a glimpse of something that no one had ever seen before—perhaps not knowing exactly what they might find.

Those who looked in the right place at the right time, under the right weather conditions, saw a point of light moving rapidly across the night sky, reminiscent of a tiny star traversing the familiar spread of fixed constellations and planets.<sup>69</sup> Hundreds of thousands of people on either side of the Iron Curtain viewed the same bright object. Some 4% of Americans reported seeing Sputnik overhead during its short months in orbit.<sup>70</sup> The Sputnik-watching experience has been memorialized in memoirs, historical literature, Hollywood movies, and the personal recollections of multitudes. However, the tiny moving star that shone twice as bright as the North Star was not what it seemed.<sup>71</sup>

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<sup>69</sup> Associated Press, “Baby Moon’s Rocket: Seen In U.S. Satellite Keeps To Schedule,” *The Times of India*, October 11, 1957.

<sup>70</sup> International Affairs Seminars of Washington, “American Reactions to Crisis: Examples of Pre-Sputnik and Post-Sputnik Attitudes and of the Reaction to Other Events Perceived as Threats,” October 15, 1958, U.S. President’s Committee on Information Activities Abroad (Sprague Committee) Records, 1959-1961, Box 5, A83-10, Dwight D. Eisenhower Library, Abilene, Kansas.

<sup>71</sup> Desmond King-Hele, *Satellites and Scientific Research* (London: Routledge & Paul, 1960), 37.

The object that the newly minted cosmopolitans of Earth breathlessly tracked through the night sky was not Sputnik, but part of the rocket that had sent it aloft.<sup>72</sup>

This strange, obscure, largely forgotten object received the official designation of “1957α1” in the official catalog of orbiting objects now maintained by the US Department of Defense (DOD). It continues to occupy the first entry in a list that has now grown to over 39,000 since October 1957.<sup>73</sup> Sputnik itself comes in second, as “1957α2.”<sup>74</sup> The round spherical satellite with the trailing “whiskers” or “mustaches” received a proper name and occupies a hallowed place in history as the first artificial satellite. However, Sputnik was only one of a trio of human-made objects that first orbited Earth on October 4, 1957: the named satellite, the core of the rocket that launched it into space, and an uncatalogued object that some believed to be the nose cone that protected Sputnik during launch. These objects, of drastically different sizes and shapes, chased each other around the planet until one by one each reentered the atmosphere and plummeted back to Earth. By early January 1958, the last of the artifacts fell from orbit.

Like more familiar discarded things on the ground, space artifacts such as the rocket core do not always fit into neat binary categories of product and byproduct.<sup>75</sup>

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<sup>72</sup> Matt Bille and Erika Lishock, *The First Space Race: Launching the World's First Satellites* (College Station: Texas A&M University Press, 2004), 103–104.

<sup>73</sup> The official NORAD list of orbiting and decayed objects may be found through several publicly available outlets, including CelesTrack, Space-Track.org, and Jonathan McDowell's master satellite list at planet4589.org.

<sup>74</sup> Early satellite classification ordered objects by year, launch order, and brightness. Therefore, the rocket core received the first designation because it appeared at a brighter magnitude than Sputnik 1. See G. F. Schilling, “Introduction,” *Smithsonian Contributions to Astrophysics* 2, no. 10 (1958): 189–90 and Desmond King-Hele, *Satellites and Scientific Research* (London: Routledge & Paul, 1960), 34.

<sup>75</sup> For an excellent recent examination of the slippery definition of product and byproduct, see Daniel Schneider, “Purification or Profit: Milwaukee and the Contradictions of Sludge,” in

Rather, this particular object meant a variety of different things to different communities during the few short months it circled the Earth. Most waste products are mobile in some way—from the transportation of municipal solid waste to the circulation of carbon emissions in the atmosphere. Unlike these out-of-sight, out-of-mind wastes, which never truly disappear even when rendered invisible at the point of consumption, 1957a1 remained both visible and mobile, passing over most populated regions of the planet and visible to everyone regardless of access to technology. The global, visible mobility of 1957a1 contributed to its exceptional array of uses and user communities, and heralded a new form of technology that would be subject to a high level of interpretive flexibility during the early years of the Space Age.

The many identities imposed upon Sputnik's empty rocket core illustrate how the politics of different communities on the ground determine the meaning and value of space technologies along a slippery, shifting dialectic of utility and waste.<sup>76</sup> From the very beginning of the satellite age, the potential for multiple, coexisting, contrasting definitions of objects transiting through outer space and returning to Earth influenced the design, purpose, and use of space technologies themselves. The stories of how these objects came to be valued or discarded also reveal how state actors, scientific

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*Histories of the Dustheap: Waste, Material Cultures, Social Justice*, by Stephanie Foote and Elizabeth Mazzolini (Cambridge, Mass.: MIT Press, 2012), 171–97.

<sup>76</sup> For more on the interpretive flexibility of artifacts and the social construction of technology, see Trevor J. Pinch and Wiebe E. Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other,” in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass.: MIT Press, 2012), 11–44.

communities, and ordinary citizens across the world confronted a new and illegible environment as the Cold War extended beyond the tenuous boundaries of the biosphere.

### **The Many Identities of 1957a1**

The brief history of Sputnik's rocket core reveals how the first artifacts that would come to be known to some observers as "space junk" became broadly flexible, heterogeneous boundary objects, collapsing vast geographical distances and political divides both while in orbit and after returning to Earth through the atmosphere. Multiple communities used and interpreted this first broadly visible space artifact in a variety of sometimes contradicting ways, from space waste to space craft. Beyond constituting the first encounter with outer space as a human environment for thousands of untrained individuals around the world, this artifact also became a range of other artifacts, from political tool to scientific instrument to intelligence commodity. The meaning of the artifact was contingent on the identity of the user and the location of the rocket core relative to the user.

The rocket core artifact in many ways fits the categorization of a "boundary object" as initially described by Star and Griesemer. A boundary object must have a strong identity that nevertheless can be stretched to meet the local needs of different communities, thus serving as a unifying point of translation between divergent social worlds. Unlike the atlases, museums, forms, and state boundaries at play for the different communities of the Museum of Vertebrate Zoology that Star and Griesemer use as a case study, 1957a1 appeared on the world scene as something entirely novel and different, an artifact that drew together new communities of unaffiliated users. Different groups

collaborated to produce representations of outer space and spaceflight using an artifact that turned out to be both elastic in meaning and robust in identity.<sup>77</sup> The rocket core meant different things within different social worlds, but remained recognizable as a Soviet-built piece of space technology. In addition to representing different meanings and uses to different communities, the global motion and visibility of the orbiting artifact redrew the boundaries of what could be considered a “boundary”—between communities, environments, and worlds.

Valerie Olson has argued that near-Earth objects (NEOs) such as asteroids and meteors act as boundary objects that tack between astronomy and environmental and national security communities, as well as between Earthly and extraterrestrial environments.<sup>78</sup> As naturally occurring objects, however, NEOs boast a much longer presence in geophysical and human history, with records of terrestrial boundary crossing in abundant evidence through geological impact features and texts ranging from Chinese folklore to the Bible.<sup>79</sup> Olson and Lisa Messeri group NEOs alongside solar radiation as

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<sup>77</sup> Susan Leigh Star and James R. Griesemer, “Institutional Ecology, ‘Translations’ and Boundary Objects: Amateurs and Professionals in Berkeley’s Museum of Vertebrate Zoology, 1907-39,” *Social Studies of Science* 19, no. 3 (August 1989): 387–420.

<sup>78</sup> Valerie A. Olson, “American Extreme: An Ethnography of Astronautical Visions and Ecologies” (Rice University, 2010), <http://gradworks.umi.com/34/21/3421439.html>.

<sup>79</sup> One NASA study, cited in Chapter 4 of this dissertation, used the fall of meteoroids as a natural analogy to reentering space junk. In surveying past meteoroid casualties, this study includes tentative evidence of ancient meteoroid casualties from verse 10:11 from the Book of Joshua: “...as they fled from before Israel, and were in the going down to Bethhoron, that the Lord cast down great stones from heaven upon them unto Aezkah, and they died:...” V. J. Drago and D. S. Edgcombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs” (Columbus, OH: Battelle Memorial Institute, Columbus Laboratories, March 7, 1974), D-6, Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection. Lincoln LaPaz, “The Effects of Meteorites Upon the Earth (Including Its Inhabitants, Atmosphere, and Satellites),” in *Advances in Geophysics*, vol. 4 (Elsevier, 1958), 226.

objects that gain significance through cultural interpretations of their crossing between Earth and space. Olson and Messeri look at how these cosmic transitory objects challenge acts of discursive boundary drawing through which different communities separate the planet from the rest of the cosmos.<sup>80</sup> The transit of early space artifacts like the Sputnik rocket core through and from space challenges this distinction between the planet and the rest of the universe further, particularly due to the anthropogenic nature of these objects. Designed and built by humans, 1957α1 retained the initial inscriptions from its creators, which then influenced the proliferation of alternate meanings and uses beyond its primary use as the means by which the named first artificial moon reached orbit. It was simultaneously familiar and strange: Though human-made, it inhabited a space external to any that humankind had directly encountered—an uncanny alien artifact that sat astride environments and eras.

In what follows, I identify eight discrete interpretations of the Sputnik rocket core by different communities of users during its short few months in orbit and immediately after its plunge to Earth in December 1957. This wide variety of meanings and uses was echoed in the subsequent development and deployment of the first communications and scientific satellites during the following decade. I then compare Project Echo and Project West Ford<sup>81</sup>—two passive satellite systems with common material attributes imbued with widely varying cultural meanings. The divergent interpretation of these two systems illustrates the persistent material and social flexibility of space artifacts during the years

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<sup>80</sup> Valerie Olson and Lisa Messeri, “Beyond the Anthropocene: Un-Earthing an Epoch,” *Environment and Society: Advances in Research* 6, no. 1 (September 1, 2015): 28–47.

<sup>81</sup> For a full evaluation of Project West Ford as the subject of one of the first debates about environmental governance in outer space, see Chapter 2 of this dissertation.

following the launch of the first space boundary object. Before the form of the satellite settled into the active, electronics-laden version that we currently understand to be the archetypal satellite, the first flexible space artifacts further blurred the distinction between satellite and space junk. As the interpretive flexibility of satellites subsided—as a particular form of active satellite became successful and as a result became “black boxed”—the expanse of communities and uses for these boundary objects also narrowed.<sup>82</sup> Before anyone could fear space junk, they first had to know what space junk could be. This chapter shows how the category of “space junk” emerged within a range of many possible interpretations of the same space artifact: propaganda tool, scientific instrument, diplomatic offering, intelligence object, and environmental pollution.

### **First Satellite**

The rocket core reached orbit at the same time as Sputnik, separating from the sphere 314.5 seconds after the full R7 rocket assembly lifted off from the windswept plains of Kazakhstan. The Soviet engineers responsible for designing the version of the R-7 ballistic missile that launched Sputnik gave it the nickname “Article 8K71PS,” following the Soviet practice of labeling classified technology with deliberately neutral, obscure descriptions and by extension leaving it open to the manufacture of unlimited meanings beyond its initial designed purpose.<sup>83</sup> In contrast, the planned Soviet satellite itself gained

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<sup>82</sup> Bruno Latour describes black boxing as referring to “...the way scientific and technical work is made invisible by its own success. When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become.” Bruno Latour, *Pandora’s Hope: Essays on the Reality of Science Studies* (Harvard University Press, 1999), 304.

<sup>83</sup> Asif Siddiqi, “Iskusstvennyy Sputnik Zemli,” *Spaceflight*, 2007, 431.

the relatively specific moniker *prosteyshyy sputnik*, or Simplest Satellite.<sup>84</sup> An aluminum sphere with a radio transmitter aboard could be seen as simple indeed; and yet, Article 8K71PS, also made of metal and containing a transmitter that was, in the words of an eminent Soviet engineer, “so basic that it would be a snap for any group of young hobby technicians to reproduce it,” could have been described by the same name.<sup>85</sup>

Appropriately, Russians today typically refer to the rocket launcher as “Sputnik,” the name most Westerners use for the satellite itself.<sup>86</sup>

Even as the image of the named satellite graced news reports around the world, the core became the object that most observers, knowingly or unknowingly, assumed to be the first artificial satellite. Many American news outlets neglected to note the true identity of the moving star, while some explicitly identified the naked-eye visible object as the rocket core. The *Los Angeles Times* claimed that 1957a1 “stole the show” from Sputnik as the more spectacular of the two objects, to which Sputnik received second billing in other articles as its “companion” in space.<sup>87</sup> Many Americans had easy access to information identifying the object as the rocket body. However, few memoirs and oral

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<sup>84</sup> Mikhail K. Tikhonravov, “A Report on an Artificial Earth Satellite” (Scientific Research Institute No. 4 (NII-4), May 26, 1954).

<sup>85</sup> B. E. (Boris Evseevich) Chertok, “Rockets and People,” NASA SP; 4110 (Washington, D.C: NASA, 2005), 384.

<sup>86</sup> Siddiqi, “Iskusstvennyy Sputnik Zemli,” 432.

<sup>87</sup> “Rocket Steals Space Show from Sputnik,” *Los Angeles Times*, October 14, 1957; Associated Press, “Baby Moon’s Rocket: Seen In U.S. Satellite Keeps To Schedule”; Associated Press, “Sputnik Timetable Set,” *The Christian Science Monitor*, October 18, 1957; “Rocket 100 Miles Below Sputnik, Pictures Show: Smithsonian Camera Takes 190 Photos of Shell but Fails to Get Shot of Satellite,” *Los Angeles Times*, October 19, 1957; “Sighters May See Sputnik’s Rocket,” *Washington Post & Times Herald*, October 21, 1957, sec. A; Staff Writer, “Sputnik Spotters Given Direction,” *The Christian Science Monitor*, October 22, 1957; Associated Press, “Alert Slated Soon To Watchers On Sputnik’s Plunge,” *The Christian Science Monitor*, October 25, 1957.



histories of Americans who recalled seeing Sputnik mention realizing the true identity of the moving star. In popular memory, the rocket body has become Sputnik itself. During its time in space, the rocket core, together with reproduced images and sounds of and from the named satellite, made up the Sputnik Experience for those who looked into the dawn and dusk sky in October and November of 1957.<sup>88</sup>

The rocket core served as a visual index that enabled a direct, unmediated connection with the first human-made moon. Except among certain communities of specialists and the amateur astronomer networks enrolled to track the first satellites, this artifact has been all but subsumed under the identity of its more famous companion.<sup>89</sup> In hindsight, even some specialists seem to have forgotten the existence of the rocket core. Engineer Homer Hickam, who would pen the best-selling memoir *Rocket Boys* that inspired the 1999 Hollywood film *October Sky*, recalls the moment in which he first saw Sputnik crossing over his West Virginia coal mine town as the motivation behind his entering a career designing spacecraft for NASA.

I stared at it with no less rapt attention than if it had been God Himself in a golden chariot riding overhead. It soared with what seemed to me inexorable and

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<sup>88</sup> Fred Whipple of the Smithsonian referred to the two components as one satellite under the moniker “1957  $\alpha$ ” in presenting the collective research conducted by Smithsonian Astrophysical Observatory physicists during the autumn of 1957. Fred L. Whipple, “Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta,” *Smithsonian Contributions to Astrophysics* 2, no. 10 (1958): v.

<sup>89</sup> For the definitive historical account of the amateur astronomers who made up Operation Moonwatch, see W. Patrick McCray, *Keep Watching the Skies!: The Story of Operation Moonwatch and the Dawn of the Space Age* (Princeton University Press, 2008).

dangerous purpose, as if there were no power in the universe that could stop it...in less than a minute, it was gone.<sup>90</sup>

Had 17-year-old Homer known that this powerful, dangerous, inexorable, nearly divine object had been a piece of a rocket rather than the Russian moon, perhaps he would still have built a career in rocket engineering. However, for most Americans, a satellite was something remarkably different from the rockets that, until October 4 1957, had only served to lift warheads into globe-crossing trajectories. The named satellite attained lofty cultural status as an artifact of value and meaning due to a combination of socially constructed realities including its having a legible name, novel purpose, and a sound that could be heard indirectly by anyone with a radio receiver or television. In spite of ample contemporary news reporting that clarified the true identity of the moving star, the rocket core has disappeared in a worldwide act of collective forgetting. As something designed to place the named satellite into orbit and then to be discarded, the small moving star would mean little more than waste if defined solely by its planned use. In seeing the rocket core with their own eyes and identifying it as the first satellite, communities around the world first experienced outer space as a real, tangible place through a messy visual encounter with an artifact that was simultaneously spacecraft and something else entirely new: space waste.

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<sup>90</sup> Homer Hickam, *Rocket Boys* (New York: Delacorte Press, 1998), 32.

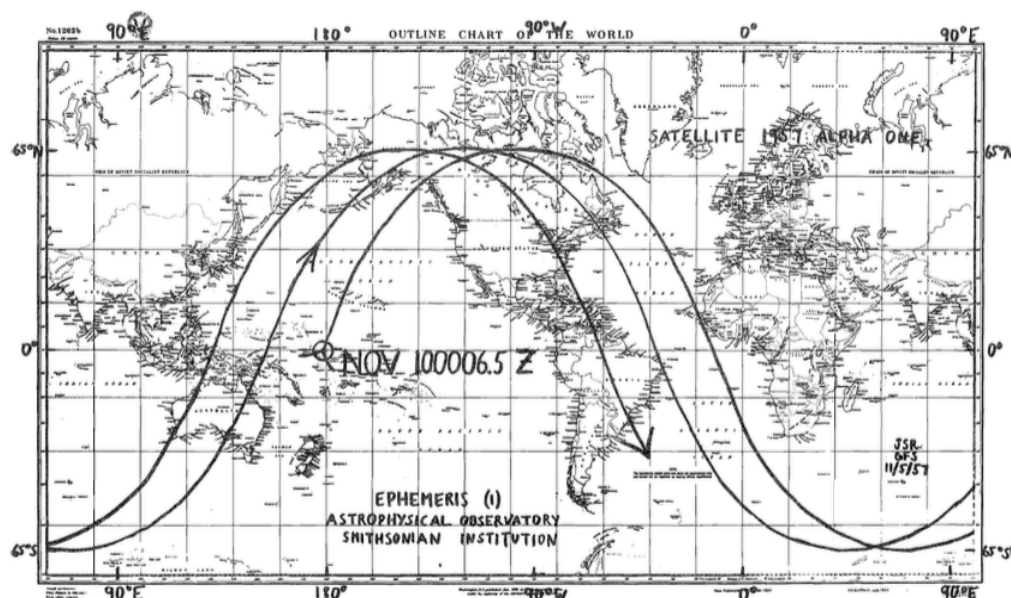


FIGURE 3.—Earth track of Satellite 1957  $\alpha$ 1 plotted on Mercator projection of world.

**Figure 1.1:** Researchers at the Smithsonian Astrophysical Observatory put together this map of the path of the rocket core as it traced a path across the globe. Note that the caption refers to the core by its catalog name, and identifies it as a satellite.<sup>91</sup>

### First Space Junk

Unlike those who looked up into the sky with the naked eye, many specialists with access to the equipment and information necessary to view Sputnik would have been aware of the rocket core as a separate object entirely. Soviet engineers designed the rocket core to provide the final push that sent Sputnik into its path around the planet. To those who acknowledged the rocket's primary function, 1957 $\alpha$ 1 could be best understood as a discarded industrial byproduct in an environment that humankind could now claim as part of its domain. Professional and amateur scientists and radio operators who could see the actual satellite or used the radio signal to signify its existence were aware of the

<sup>91</sup> J. S. Rinehart and G. F. Schilling, "Additional Orbit Information for U.S.S.R. Satellites 1957  $\alpha$ 1 and  $\beta$ 1," *Smithsonian Contributions to Astrophysics*, Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta, 2, no. 10 (1958): 201.

difference between the two artifacts. American astrophysicist Alan Hynek called the rocket core “a traveling junk pile in the sky.”<sup>92</sup> To many of those who could identify and encounter Sputnik through technologically mediated means, 1957α1 became little more than useless space junk—the very first of a highly mobile, illegible, uncontrollable form of waste that would grow in quantity and complexity as the Space Age progressed.

Nothing about the construction of 1957α1 rendered it more space junk than space craft, particularly given its many material similarities to 1957α2. In spite of its high level of visibility, in intentionally or unintentionally subsuming the identity of the rocket core within that of its named companion, an array of observers, by omission, relegated 1957α1 to the category of invisible waste. Like all artifacts that humankind sends into space, the rocket core would eventually fall back to Earth. 1957α2 would follow a month later. Upon passing through the nebulous borderlands between Earth and outer space, 1957α1 became the first example of a different kind of space junk—the kind that replicated a distinctly Cold War cultural anxiety of technological destruction delivered from afar and above.

### **Political Tool**

The mistaken identity of the rocket core as Sputnik proper did not come about entirely by accident. The very first Soviet press release announcing the successful launch noted that some form of equipment would be required to view the simplest satellite as it circled the planet:

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<sup>92</sup> “Travelling ‘Junk Pile’ In The Sky Forecast,” *The Times of India*, October 13, 1957.

At the present time the satellite is describing elliptical trajectories around the earth, and its flight can be observed in the rays of the rising and setting sun with the aid of very simple optical instruments (binoculars, telescopes, etc.).<sup>93</sup>

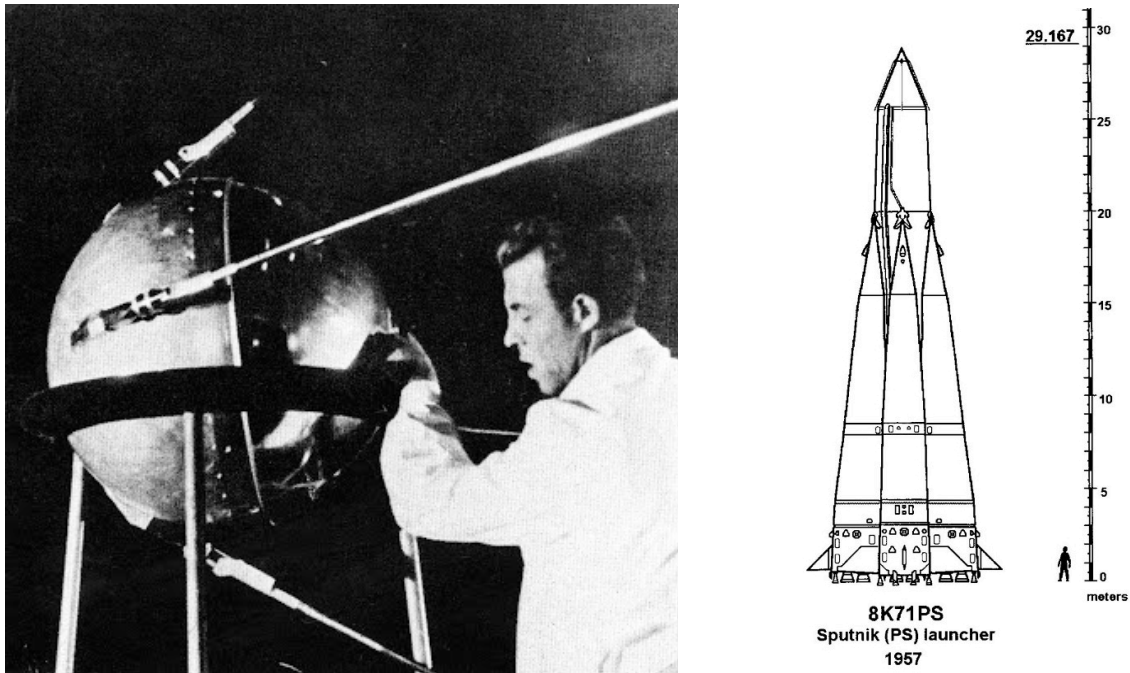
At only 58 centimeters in diameter, roughly the size of a beach ball, Soviet engineers realized that the sphere would be too small to view from the ground with the naked eye, so they planned to make the much larger rocket core a more easily visible substitute.<sup>94</sup> Following orders issued via the Soviet Academy of Sciences, they outfitted the 20-meter-long rocket core with reflective prisms designed to deploy when it reached orbit so that Soviet radars could more easily track it.<sup>95</sup> Beyond this officially stated purpose, the core performed the perfect Sputnik impersonation. Because it was much larger and designed to catch and reflect more sunlight, anyone on the ground with the ability to see, regardless of education or access to specialized equipment, could spot the rocket core and confirm for themselves that the notoriously secretive Soviet Union had indeed put a new moon into orbit.

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<sup>93</sup> Tass, "Announcement of the First Satellite," *Pravda*, October 5, 1957, Historical Reference Collection, NASA History Division, NASA Headquarters, Washington, DC.

<sup>94</sup> Chertok, "Rockets and People," 386; Matthew Brzezinski, *Red Moon Rising: Sputnik and the Hidden Rivalries That Ignited the Space Age* (Macmillan, 2007), 176.

<sup>95</sup> Siddiqi, "Iskusstvennyy Sputnik Zemli," 432.



**Figure 1.2:** Sputnik 1 alongside a technician, compared to the R7 rocket used to launch the satellite. Note that the central core of the rocket is shorter than the entire assembly prior to launch, as pictured here with an average person for scale.<sup>96</sup>

Such a sight had public relations benefits beyond the expectations of Sputnik's designers: Ordinary viewers saw the object and felt pride or terror, anticipation or anxiety, depending on their political inclinations and nationality. The Soviet engineers intentionally crafted the rocket core to be more than waste: They shaped the material form of the object so that, even in what some might determine to be a state of disuse, it yet served a valuable technical and political purpose. By providing a visible index for the Soviet achievement, Soviet engineers ensured that their achievement would become

<sup>96</sup> *Sputnik 1 Satellite Handled by a Technician*, 1957, <http://grin.hq.nasa.gov/ABSTRACTS/GPN-2002-000166.html>; Peter Gorin, *Evolution of Soviet Space Launch Vehicles*, n.d., <http://grin.hq.nasa.gov/ABSTRACTS/GPN-2002-000184.html>.

incontrovertibly understood as the instigating moment of what would unfold into over a decade of proxy conflict known as the Space Race.<sup>97</sup>

In order to capitalize further on this additional use of the rocket core, the Soviet government released information about the revolutions, distances traveled, and apogee heights of each component of the Sputnik system. The Kremlin continued to publish such information over the next few launches, including predictions of where and when specific satellites might be visible to observers on the ground.<sup>98</sup> For the second Sputnik launch, Soviet engineers decided not to separate the spacecraft from the core stage of the launching rocket.<sup>99</sup> As a result, Sputnik 2 would be just as visible from the ground as the unnamed rocket core launched weeks prior. The Kremlin continued to release viewing information for this most recent satellite, privileging information about the more visible artifacts over the orbital viewing times of Sputnik 1.

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<sup>97</sup> Roger Launius has suggested that the triumphalist tale of American pursuit of the Soviet Union through space to an ultimate victory at the Moon comprises one of four “master narratives” of the American space program during the Cold War. Each way by which the American public “saw” Sputnik contributed to the “initial shock to the system” that set the Space Race in motion. Roger D. Launius, “American Spaceflight History’s Master Narrative and the Meaning of Memory,” in *Remembering the Space Age*, by Steven J. Dick, vol. 2 (Washington, D.C.: National Aeronautics and Space Administration, 2008), 353–72.

<sup>98</sup> G. F. Schilling, “Soviet Orbit Information for Satellites 1957  $\alpha$ 1 and  $\beta$ 1,” *Smithsonian Contributions to Astrophysics*, Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta, 2, no. 10 (1958): 282.

<sup>99</sup> Chertok, “Rockets and People,” 388.

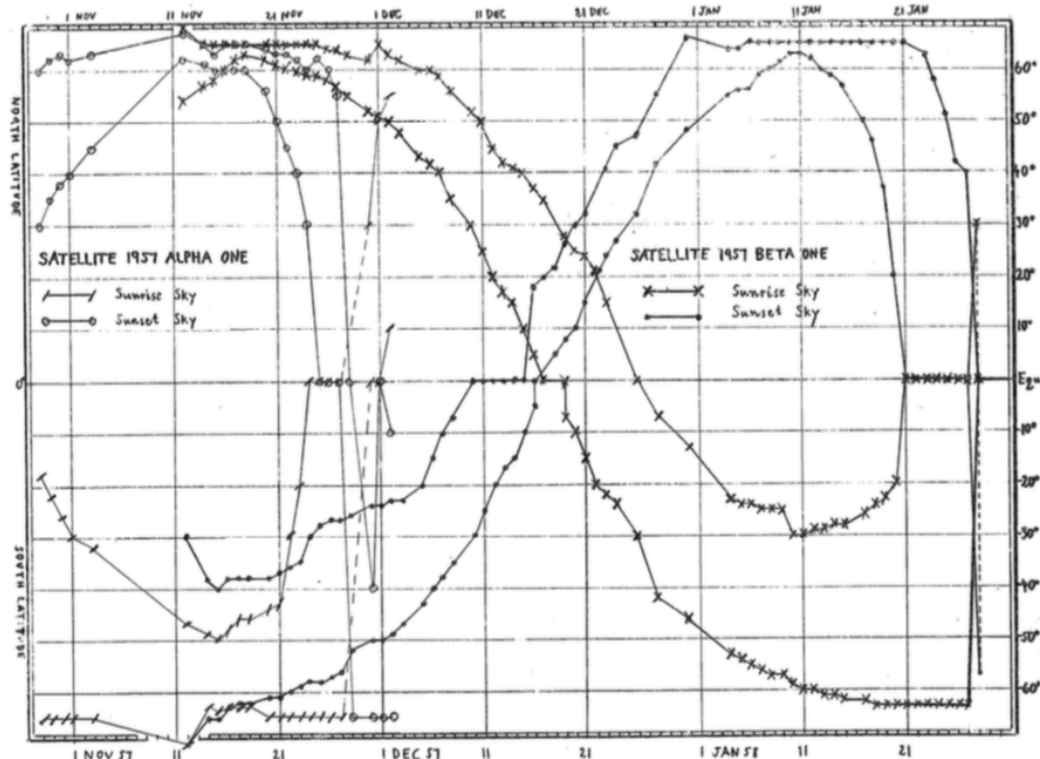


FIGURE 1.—Soviet predictions of zones of visibility.

**Figure 1.3:** This graph, released by the Smithsonian Astrophysical Observatory to illustrate Soviet predictions of when 1957 $\alpha$ 1 (the core of the Sputnik R-7 rocket) and 1957 $\beta$ 1 (Sputnik 2) would be visible from different latitudes at dawn and dusk. Note that both featured artifacts are R7 rocket cores, and this information was not provided for the much smaller Sputnik 1.<sup>100</sup>

### Scientific Instrument

Although they had access to the optical and radio equipment necessary to “see” Sputnik, some specialist communities in the West found the discarded rocket core to be more useful than the named satellite. American and British physicists found an additional use for the object as an unprecedented opportunity to study the upper atmosphere. A group of

<sup>100</sup> G. F. Schilling, “Soviet Orbit Information for Satellites 1957  $\alpha$ 1 and  $\beta$ 1,” *Smithsonian Contributions to Astrophysics*, Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta, 2, no. 10 (1958): 282.



British physicists, who would soon take on the new professional identity of “orbital analysts,” used the rocket core as a research instrument that they did not have to design, order, operate, or pay to use. Tracking the object as it tumbled end over end in its path around the planet, orbital analysts at the Royal Aircraft Establishment (RAE) and the Smithsonian Astrophysical Observatory (SAO) examined the motion of the rocket core to study its interactions with atmospheric particles at high altitudes.<sup>101</sup> These particles exerted drag on the object, causing its orbit to “decay,” or dwindle in altitude far more quickly than it would in a vacuum.<sup>102</sup> During its over eight weeks on orbit, 1957α1 revealed entirely new information about the wind currents and density of the upper atmosphere and the shape of the Earth itself.<sup>103</sup>

The calculations made by RAE and SAO researchers using the tumbling rocket core represented the first *in situ* data about the material dimensions of near-Earth space that would subsequently reveal a complex physical landscape of interacting gravitational forces, radiation, and energy. Earth’s atmosphere and geophysical influence constituted neither a thin, fragile shell around the planet, nor a “vast region of emptiness,” as Bernard Lovell put it.<sup>104</sup> Using the rocket core to measure high altitude wind currents and particle density, physicists on the other side of the Iron Curtain from the launching state took enormous first steps towards a new understanding of the natural environment of planet

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<sup>101</sup> King-Hele, *Satellites and Scientific Research*, 50–53.

<sup>102</sup> R. J. Stirton, “The Upper Atmosphere and Satellite Drag,” *Smithsonian Contributions to Astrophysics* 5, no. 2 (1960): 9–15; Desmond King-Hele, *A Tapestry of Orbits* (Cambridge: Cambridge University Press, 1992), 23.

<sup>103</sup> Desmond King-Hele, *A Tapestry of Orbits* (Cambridge: Cambridge University Press, 1992), frontispiece.

<sup>104</sup> A.C.B. Lovell, “The Exploration of Outer Space,” *Journal of the Royal Society of Arts* 108, no. 5047 (June 1960): 504.

Earth that extended far beyond the biosphere, tens of thousands of kilometers into space, where planetary forces shape natural processes and human-made objects alike.<sup>105</sup>

The early research produced using the rocket core changed contemporary understanding of the orbital environment. Before the Sputnik, RAE physicist Desmond King-Hele called scientific understanding of the atmosphere “abysmally inadequate.”<sup>106</sup> However, once the Soviet press revealed details on the dimensions of the rocket core, physicists could then observe the motion of the rocket and determine how friction and gravity interacted to bring the object back to Earth. Research conducted using the rocket core fostered SAO researchers’ claim that the atmosphere at altitudes of 220 kilometers and 233 kilometers was far denser than initially thought.<sup>107</sup> The first orbital analysts themselves attached great value to 1957 $\alpha$ 1. As King-Hele noted in 1960, most upper atmospheric data used for these revolutionary studies came from tracing the paths of the first rocket bodies to orbit the planet, rather than from native instruments designed for the specific purpose of measuring particle density. Sputnik 3, which the Soviet Union launched in May 1958, would be the first satellite to fly with direct atmospheric measuring devices on board.<sup>108</sup> Thus, American and European physicists made some of the first measurements of the near-Earth space environment indirectly, using an

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<sup>105</sup> For an overview of SAO upper atmospheric research using the first Soviet satellites, see Fred L. Whipple, “Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta,” *Smithsonian Contributions to Astrophysics* 2, no. 10 (1958): 189–347.

<sup>106</sup> King-Hele, *Satellites and Scientific Research*, 81.

<sup>107</sup> T. E. Sterne and G. F. Schilling, “Some Preliminary Values of Upper Atmosphere Density from Observations of USSR Satellites,” *Smithsonian Contributions to Astrophysics*, Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta, 2, no. 10 (1958): 207–210.

<sup>108</sup> King-Hele, *Satellites and Scientific Research*, 107.

improvised scientific instrument unintentionally provided by a foreign, hostile power.<sup>109</sup>

Although the named satellite fulfilled multiple roles in scientific and political arenas, to King-Hele and his cohort of orbital analysts the empty rocket was “more important than the satellite itself.”<sup>110</sup> Some saw it as waste; the Soviets turned it into propaganda; orbital scientists used it as an instrument.

### **Diplomatic Gift**

Unlike the data gathered by Soviet scientists using instruments aboard satellites like Sputnik 3 and the first American satellite Explorer 1, the rocket core’s motion and its global visibility rendered the technology non-proprietary and free to use by observers in any nation regardless of political or national affiliation.<sup>111</sup> The relatively simple rocket core and its successors provided cost-effective means of atmospheric and space research during the 1960s, when funding for European space science remained remarkably low, and before and during the unprecedented state spending bonanza that would soon

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<sup>109</sup> I define this use as a “scientific instrument” based on Deborah Jean Warner, “What Is a Scientific Instrument, When Did It Become One, and Why?,” *The British Journal for the History of Science* 23, no. 1 (March 1, 1990): 83–93.

<sup>110</sup> Desmond King-Hele, *A Tapestry of Orbits*, 31.

<sup>111</sup> Explorer 1 launched into orbit on January 31, 1958. A team led by James van Allen developed a radiation experiment initially for the Vanguard mission that shifted to Explorer when Vanguard fell behind the Army satellite program. The United States National Committee for the IGY’s Technical Panel on the Earth Satellite Program granted Van Allen \$169,225 to develop the experiment — considerably less money than the overall price tag of the satellite, but also much more than the free cost of the Sputnik rocket bodies. The Explorer instruments detected the radiation belts around the planet, thus further expanding the already exponentially shifting understanding of the near-Earth environment. Bille and Lishock, *The First Space Race*, 135–138. For more on Van Allen and the radiation instrument, see James Rodger Fleming, “Iowa Enters the Space Age: James Van Allen, Earth’s Radiation Belts, and Experiments to Disrupt Them,” *Annals of Iowa* 70, no. 4 (Fall 2011): 301–324.

characterize the American space program.<sup>112</sup> In stark contrast to the \$110 million that the US federal government spent on the early Vanguard satellite program, those who studied 1957α1 generated groundbreaking, prestigious scientific research at a price tag of \$0 to taxpayers in America and the UK.<sup>113</sup>

Desmond King-Hele of the RAE wrote an entire popular book to justify the expense of satellite research to the British public—and noted that many of the discoveries made through such research essentially cost nothing to said public.<sup>114</sup> By “stealing a look at satellites launched by other nations,” orbital researchers like King-Hele reformed models of the upper atmosphere without having to pay for satellite development and launch. King-Hele and his cohort at the RAE gave effusive public thanks for the foresight, ingenuity, and unintentional generosity displayed by the Soviet engineers for providing a free, non-proprietary instrument for learning about the orbital environment. He even expressed some degree of guilt over the RAE’s uncompensated use of 1957α1, referring to British study of the rocket core as “piratic.”<sup>115</sup> However, a subsequent meeting between British orbital analysts at the RAE and Soviet astronomer Alla Masevitch to discuss and exchange information about the decay of 1957α1 forged new links between Western European, American, and Soviet scientific communities. As part of this exchange, the Smithsonian-sponsored Operation Moonwatch shared its observational

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<sup>112</sup> John Krige, “Building Space Capability Through European Regional Collaboration,” in *Remembering the Space Age*, by Steven J. Dick, vol. 1 (Washington, D.C.: National Aeronautics and Space Administration, 2008), 46; Walter A. McDougall, ...*The Heavens and the Earth: A Political History of the Space Age*, Reprint. (The Johns Hopkins University Press, 1997).

<sup>113</sup> Bille and Lishock, *The First Space Race*, 98, 167–168.

<sup>114</sup> King-Hele, *Satellites and Scientific Research*, xi.

<sup>115</sup> Desmond King-Hele, *A Tapestry of Orbits*, 56–57.

data with Massevitch, who in turn provided analogous Soviet data and feedback on the equipment used by the amateur astronomer network as compared to Soviet satellite tracking technology.<sup>116</sup>

The launch of Sputnik set off a new, antagonistic proxy front in the Cold War between the United States and the Soviet Union. The existence of the satellite itself posed a challenge and a taunt to the US from across the world, and the subsequent American effort to catch up with and surpass Soviet space achievements would yield harsh exchanges between the two states and cost billions of dollars. However, at the same time the forgotten rocket core became the focus of a brief, nearly anomalous reprieve in these tense relations during the Sputnik crisis. At the outset of the Space Race, 1957α1 became a peacemaking object and a diplomatic tool, bringing together kindred amateur and professional scientists on either side of the contentious Cold War conflict in peaceful collaboration. This was the first instance of an ebbing and flowing relationship between Soviet and Western scientists that often followed its own amicable route independently of the temperature of the Cold War as the Space Race progressed.<sup>117</sup>

### **Telemetry Test**

Compared to Sputnik and its beeping radio signal, which quickly became an aural icon of

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<sup>116</sup> Emile Tavel, "US, Soviets to Swap Moonwatch Reports," *The Christian Science Monitor*, October 14, 1957; AP, "RUSS, U.S. SCIENTISTS TO TRADE 'MOON' DATA: Watchers to Reveal Findings," *Los Angeles Times*, October 15, 1957; Gordon Brown, "U.S. and Soviet Arrange To Swap Satellite Data," *The Washington Post and Times Herald*, October 15, 1957; AP and The Times of India News Service, "FACTS ABOUT SATELLITE: U. S.-Soviet Exchange," *The Times of India*, October 15, 1957.

<sup>117</sup> Audra J Wolfe, *Competing with the Soviets: Science, Technology, and the State in Cold War America* (Baltimore: Johns Hopkins University Press, 2013).

the Space Age, the orbiting rocket cores appeared to be “dumb, deaf, and blind.”<sup>118</sup> However, in the context of British orbital analysts’ research, 1957α1 was far from silent. Soviet engineers installed an early version of the new *Tral* telemetry system into the rocket core that remained active throughout its time on orbit. Telemetry systems like *Tral* provide a constant stream of data regarding the rockets’ operation, altitude, and position. Before they could acquire Sputnik’s radio signal, the signal emitted by *Tral* aboard the rocket core provided Soviet engineers with the first confirmation that both the rocket and satellite had successfully reached orbit. Sputnik itself would not reveal its location until completing a second arc around the planet.<sup>119</sup>

So successful was this telemetry system test that when the Soviet Union began to make plans to launch its second Simplest Satellite, they determined that the rocket core’s *Tral* provided enough data to dispense with a separate detachable satellite with a native radio transmitter like the one on Sputnik 1. Rather than outfit Sputnik 2 with its own radio, the *Tral*-equipped rocket core itself would remain attached to the named satellite, with its canine passenger, Laika, ensconced in the cabin.<sup>120</sup> During this second Soviet space flight, the rocket core once again provided an easily visible visual index for the named satellite and emitted a series of signals to confirm its place in orbit around the planet. The talkative 1957α1 served as a test article for *Tral*, which the Soviet space program would use as a primary telemetry system throughout the Sputnik and Vostok programs, and which would serve as the basis for subsequent ground tracking

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<sup>118</sup> Desmond King-Hele, *A Tapestry of Orbits*, ix.

<sup>119</sup> Anatoly Zak, “Russia’s Space Command and Control Infrastructure,” *Russian Space Web*, accessed September 18, 2015, <http://www.russianspaceweb.com/kik.html>.

<sup>120</sup> Chertok, “Rockets and People,” 388.

technologies.<sup>121</sup> The otherwise silent rocket core spoke volumes to those who had the means to listen.

### **Intelligence Commodity**

Soviet engineers and orbital analysts around the world tracked the rocket body until its orbit fully decayed.<sup>122</sup> After 882 trips around the planet, the object began to spiral into the atmosphere on November 30, 1957, ultimately falling back to Earth on December 2, 1957.<sup>123</sup> As it plunged into denser regions of the atmosphere, punishing heat and pressure caused it to fracture into pieces. Some of these pieces dissipated into the atmosphere; and some of the larger fragments survived intact. In its return to *terra firma*, 1957α1 transformed into the first of a different kind of space junk—the kind that falls to Earth, often far from the launching state, with the potential to threaten the safety of people, property, and ecosystems.

Upon hitting the ground the artifact transformed once again, offering new value to a different set of communities. The American intelligence community valued the rocket core as a potential source of information about the design and production capabilities of the Soviet space industry. Soviet officials sought to uncover any surviving fragments with equal urgency, driven by the inverse objective of preventing such information from

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<sup>121</sup> “Soviet Space Tracking Systems,” *Encyclopedia Astronautica*, accessed July 12, 2016.

<sup>122</sup> L. Campbell, Jr. and J. Allen Hynek, “Visual Observations of Satellite 1957α1 Made by Moonwatch Stations,” *Smithsonian Contributions to Astrophysics*, Orbital Data and Preliminary Analyses of Satellites 1957 Alpha and 1957 Beta, 2, no. 10 (1958).

<sup>123</sup> Anatoly Zak, “Sputnik’s Mission,” *RussianSpaceWeb.com: News and History of Astronautics in the Former USSR*, accessed July 12, 2016, [http://www.russianspaceweb.com/sputnik\\_mission.html](http://www.russianspaceweb.com/sputnik_mission.html).

falling into enemy hands. Observers on either side of the Iron Curtain tracked the rocket body as it fell from the sky, but disagreed about where the object landed. Soviet scientists and officials claimed that it landed in Alaska, and that the American government had covered up its retrieval of exploitable debris. The Americans in turn argued that the object had landed in Mongolia, well within Soviet territory.<sup>124</sup> The matter eventually faded from public view, and the final resting place of the rocket body fragments remains unknown.<sup>125</sup> However, the debate over its landing site initiated several decades of tense exchange between the Cold Warring super powers in which space junk like 1957α1 became intelligence commodities—critical political currency of the Space Race. Where traditional intelligence methods failed, the natural geophysical environment of near-Earth space provided occasional insight by delivering falling space junk across geographic boundaries and geopolitical divides.<sup>126</sup>

### **The Matter of Early Satellites**

The multiple interpretations of 1957α1 foreshadowed the interpretive flexibility of the first artificial satellites launched after Sputnik. While the material attributes of the rocket core remained static over months on orbit and on the ground, different, dispersed user communities found varying meanings and uses for it. As will be discussed in further detail in the following chapter, during the earliest days of the satellite age engineers in the US and USSR considered multiple forms that communications and science satellites

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<sup>124</sup> Max Frankel Times, “American Rebuts Soviet on Sputnik: Figures Prove First Satellite Fell Over Outer Mongolia, He Tells I. G. Y. Session,” *New York Times*, August 5, 1958.

<sup>125</sup> James David, “Was It Really ‘space Junk’? US Intelligence Interest in Space Debris That Returned to Earth,” *Astropolitics* 3, no. 1 (April 1, 2005): 43–65.

<sup>126</sup> For more on falling space junk, see Chapter 3 of this dissertation.



might take. The stuff of satellites mattered greatly during the design phases of each satellite program, as the shape and makeup of passive satellites determined how that satellite functioned, who could use it, and perhaps just as importantly, whether the satellite would be accepted as a technological benefit or technological threat. In a broad field of potential satellite technologies, the matter, shape, size, and quantity of objects sent into space during the first five years of the satellite age deeply impacted how astronomers and other concerned groups interpreted the safety of space artifacts. The material configuration of satellites played a large role in how those on the ground determined a satellite's scope of use, its designers' intent, and its modernity—an important attribute in the early days of the Space Age.<sup>127</sup>

Two passive satellite projects developed in the United States during the late 1950s and early 1960s resulted in deeply divergent outcomes on this last point. Project West Ford, a space communications system designed by the MIT Lincoln Laboratory and funded by the US Air Force, launched twice—in 1961 and again in 1963. West Ford consisted of a field of hundreds of millions of tiny copper fibers orbiting at an approximate altitude of 3500 kilometers, tuned for use with microwave signals sent from a powerful transmitter on the ground. NASA launched two versions of Project Echo—Echo 1 in 1960 and Echo 2 in 1964—sending inflatable Mylar “satelloons” into orbit, also for use as a reflector of microwave signals. Both West Ford and Echo served similar purposes in relaying signals sent from one point on the ground to another point without

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<sup>127</sup> For more on the stylistic attributes of the Space Age, including in fashion and architecture, see Emily S. Rosenberg, “Far Out: The Space Age in American Culture,” in *Remembering the Space Age*, by Steven J. Dick, vol. 2 (Washington, D.C.: National Aeronautics and Space Administration, 2008), 157–184.

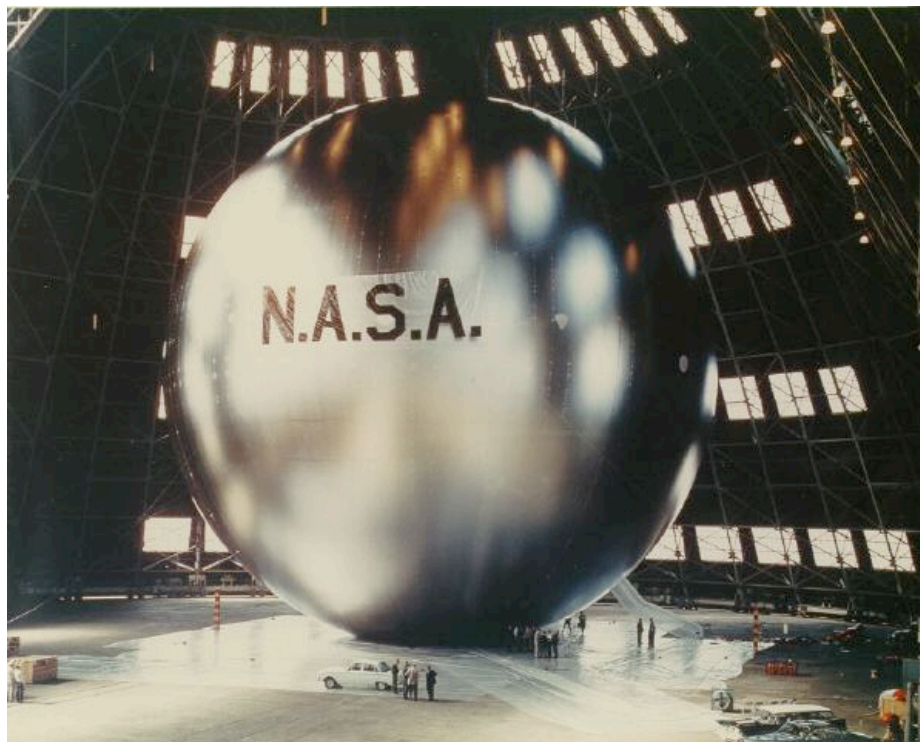
using any electronics installed aboard the satellite themselves. The space components of both satellite systems coexisted in orbit, and both received attention in open literature and popular presses before, during, and after their primary missions. However, West Ford ultimately inspired a furor from astronomers, diplomats, and journalists who interpreted the copper fibers as dangerous space pollution, whereas Echo became known to most communities as useful, anomalously friendly satellites in a largely hostile night sky.<sup>128</sup>

During the International Geophysical Year (IGY) of 1957 to 1958, American atmospheric researchers working under the auspices of the National Advisory Committee for Aeronautics (NACA) designed a small inflatable sphere that could be launched into the upper atmosphere, where its movements would allow researchers on the ground to determine air density at high altitudes, primarily for use in aircraft design. After the Soviet Union provided 1957a1 free of charge for this purpose, the project evolved into a balloon satellite, or “satelloon,” of exponentially larger diameter to be used primarily to test experimental communications methods. After the Sputnik experience touched thousands of people around the world, NACA officials hoped that a satelloon could also serve similar nationalist purposes. Like the rocket core, an American space object that would be visible to the naked eye could yield pride and a sense of accomplishment among American citizens who might have experienced the inverse upon seeing the first Russian moon. Under the name Project Echo, the fledgling National Aeronautics and

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<sup>128</sup> For a complete explication of Project West Ford and its international political outcomes, see Chapter 2 of this dissertation.

Space Administration launched the first of these satelloons into orbit in August 1960, followed by the launch of Echo II in January 1964.<sup>129</sup>



**Figure 1.4:** An Echo satellite undergoes static testing at a facility in Weeksville, NC on June 28, 1961.<sup>130</sup>

Echo and West Ford had plenty of material attributes in common. At the most basic level, both were passive satellites constructed out of shiny, metallic materials, and both were intended to test novel radio communications methods. The designers of each project hoped that their satellites would yield new information about the near-Earth space environment. West Ford's designers hoped that their project would test the hypothesis

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<sup>129</sup> For a definitive history of Project Echo, see James R. Hansen, "The Odyssey of Project Echo," in *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo* (Washington, D.C.: National Aeronautics and Space Administration, 1995), <http://archive.org/details/spaceflightrevo100hansrich>.

<sup>130</sup> NASA Langley Research Center, *Static Inflation Test of 135 Ft Satellite in Weeksville, NC; Image # EL-1996-00052*, Photograph, June 28, 1961.

that sunlight pressure could be relied upon to bring down objects with low mass-to-area ratios from relatively high orbits.<sup>131</sup> Echo’s designers anticipated that the motion of the satelloons over time would reveal how solar energy affects the expansion, contraction, dormancy, and decay of large objects in low orbits.<sup>132</sup> Both West Ford and Echo reflected signals sent and received by MIT equipment on either side of the continental United States. Supporters of both West Ford and Echo celebrated the inherent universal accessibility of each satellite form as communications devices—for those who had the resources and capital to use them. On the negative side, astronomers and astrophysicists anticipated likely interference to their observations by both passive satellite systems. This specialist community initially opposed satellites of all forms, including the active (containing an electronic repeater) type. Bernard Lovell anticipated that West Ford, Echo, and active satellites like Telstar all posed possible threats to astronomical research.<sup>133</sup> Astronomers affiliated with the National Academy of Sciences (NAS) conducted studies of what impact an Echo or West Ford system would have on their research should either type of passive satellite become a permanent part of the orbital infrastructure.<sup>134</sup>

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<sup>131</sup> I. I. Shapiro, interview by the author, June 26, 2014; I. I. Shapiro and Harrison M. Jones, “Lifetimes of Orbiting Dipoles,” *Science* 134, no. 3484 (October 6, 1961): 973–79.

<sup>132</sup> Hansen, “The Odyssey of Project Echo,” 170–175.

<sup>133</sup> Bernard Lovell, “The Challenge of Space Research,” *Nature* 195, no. 4845 (September 8, 1962): 939.

<sup>134</sup> “Effects to Observational Astronomy of a Large Number of Echo-Type Balloons Simultaneously in Orbit” (Space Science Board, National Academy of Sciences, September 1, 1961), Space Science Board, 1958-1974; Space Science Board Committees; Optical & Radio Astronomy: 1961-1962, National Academy of Sciences; “Draft, Multiple Echo: Consensus” (National Academy of Sciences, May 24, 1961), Space Science Board, 1958-1974; Space Science Board Committees; Optical & Radio Astronomy: 1961-1962, National Academy of Sciences.

However, in spite of these similarities in construction, method of use, and alarm among astronomy communities, the response to Echo among scientists, politicians, and general publics worldwide was generally positive in stark contrast to the battle that raged around West Ford. Even in the admittedly hostile audience of the Soviet popular press, which pilloried West Ford as a “criminal act,” Echo earned the nickname “the Friendship Sputnik.”<sup>135</sup> At the Eleventh Meeting of the International Astronomical Union (IAU), during which the assembled passed anti-West Ford resolutions, the daily programs distributed to attendees listed where and when Echo 1 would pass over their Berkeley location each night, in English and in French.<sup>136</sup> Echo was emblazoned on commemorative postage stamps issued by states and local governments around the world, from Paraguay to Kazakhstan to Qatar.<sup>137</sup> Besides being photographed next to a generic postage stamp to illustrate the small size of the dipoles, West Ford never received such philatelic honors.

The sponsoring institution may have been part of the reason for this disparity. Both military and civil science communities considered potential applications of balloon satellites—in a defense context, an Echo type satellite might pose as a decoy to trick enemy spacecraft detection systems, much like West Ford’s World War II radar foil

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<sup>135</sup> “No Justification for Arbitrariness in Outer Space,” Press release (Union of Soviet Socialist Republics Mission to the United Nations, July 15, 1963), Folder 579, MIT Lincoln Laboratory Archives, Lexington, Massachusetts; Special to the New York Times, “Russians Label Echo 2 The Friendship Sputnik,” *New York Times*, March 2, 1964.

<sup>136</sup> “IAU News Bulletin - August 1961 Berkeley, California,” August 1961, Series HUG FP 83.17 Leo Goldberg International Astronomical Union (IAU) Correspondence, 1948-1979; Box 6; IAU Berkeley 1961, Harvard University Archives.

<sup>137</sup> Don Hillger and Garry Toth, “Echo-Series Satellites,” accessed March 19, 2015, <http://rammb.cira.colostate.edu/dev/hillger/Echo.htm>.

ancestor Project Chaff.<sup>138</sup> However, the newly formed NASA—a civilian agency—ultimately funded Echo.<sup>139</sup> West Ford was funded by the United States Air Force, and launched atop an Air Force missile as a secondary payload to a classified military satellite. In 1960 the Space Science Board (SSB) of the NAS advised the Lincoln Laboratory to consider NASA sponsorship instead. In a report to the general board, members of a West Ford review committee included an appendix addressing the issue of public perception of the project should it remain attached to a branch of the armed forces. The committee strongly suggested that sponsorship by a civilian agency might go far to ward off popular assumptions at home and abroad that, however benign in practice, the project had a malicious purpose.<sup>140</sup> However, the *New York Times* reported that due to the U2 incident the preceding year, NASA declined to take over West Ford in order to avoid any appearance of military engagement within the agency—though the US delegation to the United Nations chose a representative from NASA to defend West Ford against critics who accused the United States of military aggression after the second launch in May 1963.<sup>141</sup>

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<sup>138</sup> “Space Handbook: Astronautics and Its Applications. Staff Report of the Select Committee on Astronautics and Space Exploration” (Washington, D.C.: 86th Congress, 1st Session, 1959), 205–206, <http://history.nasa.gov/conghand/spcover.htm>; see “Project Window” and “Project Chaff” in Robert Buder, *The Invention That Changed the World: How a Small Group of Radar Pioneers Won the Second World War and Launched a Technological Revolution* (New York: Simon & Schuster, 1996), 207–208.

<sup>139</sup> Even though NASA sponsored Echo, publicity materials also celebrated the potential military applications of the satelloons. Jerry Fairbanks, *The Big Bounce*, 1960.

<sup>140</sup> “Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board,” June 6, 1960, National Radio Astronomy Observatory - Director’s Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory.

<sup>141</sup> Walter Sullivan, “Science Vs. Defense: Opposition to Orbiting Band of Needles Poses Dilemma for the Administration,” *New York Times*, August 21, 1961, Series HUG FP 83.17 Leo

In comparing the material attributes of each system, the West Ford and Echo projects most drastically diverged in the shape of the orbital components. Both projects were designed to launch a small container that released the reflective payload once it reached the intended orbit. The West Ford dispenser, which bundled hundreds of millions of copper fibers into a cylinder smaller than a coffee can, would slowly release the dipoles into a widely dispersed band that surrounded the planet at an altitude of about 3500 kilometers. Each dipole would be separated by about 400 meters.<sup>142</sup> In contrast, the Echo “shot-put” mechanism, about a meter in diameter, jettisoned and instantaneously inflated a single satelloon to a diameter of over 30 meters (Echo I) or over 40 meters (Echo II). Echo I and Echo II orbited at under half the altitude of West Ford, reaching a perigee of approximately 1600 kilometers.

The shape and size of these two satellite systems largely determined who could use the satellites, and how. The primary purpose touted by Echo and West Ford managers—a test of passive satellite communications—could not be undertaken without specialized equipment. However, NASA touted several ancillary uses for the Echo satelloons, including their accessibility as a “worldwide laboratory tool” for both radio communications and for measuring high altitude air currents. NASA welcomed independent communications researchers to use the satellite at will, offering to provide

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Goldberg International Astronomical Union (IAU) Correspondence, 1948-1979; Box 6; IAU Berkeley 1961 Press, Harvard University Archives; Special to the New York Times, “U.S. Assures World Scientists Space Needles Are Harmless: NASA Official Tells U.N. Study Group No Significant Radio Interference Will Result From Launching,” *New York Times*, May 17, 1963.  
<sup>142</sup> Carl F. J. Overhage and William H. Radford, “The Lincoln Laboratory West Ford Program-- An Historical Perspective,” *Proceedings of the IEEE* 52, no. 5 (May 1964): 452.

any interested parties with tracking data to facilitate such experimenting.<sup>143</sup> The first radio transmission sent via Echo I carried a voice message from President Eisenhower inviting all nations to use the satellite for its own communications interests.<sup>144</sup> The SSB West Ford committee envisioned similar public relations benefits from the non-proprietary nature of the proposed dipole system, noting in its April 1960 report that “properly handled, the Project might even be made into an asset in the realm of international cooperation in space activities, since it is the type in which scientists of any country can participate independently.” They suggested that the belt be used to transmit signals to the Soviet Union and to Western Europe in order to demonstrate its universal accessibility. Otherwise, the project might be open to negative interpretations—the dipoles could be seen as the dangerous waste byproducts of a wanton, unchecked American military.<sup>145</sup>

Neither Echo nor West Ford were particularly “useful” in the primary purpose for which they were designed for any users outside of the state-funded research organizations that had the powerful transmitters and receivers on the ground to send and receive signals from the satellites. This did not preclude others from trying to use them, however. Following the successful second West Ford launch, a British amateur radio operator wrote to the Lincoln Laboratory to express his support of the project in contrast to the

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<sup>143</sup> “Project Echo Payload and Experiment,” press release (Washington, D.C.: NASA, n.d.), LYNDON BAINES JOHNSON ARCHIVES 1931—1968, Box 15G, Science - Space and Aeronautics Satellite, ECHO August 12 1960, LBJ Library.

<sup>144</sup> Hansen, “The Odyssey of Project Echo,” 188.

<sup>145</sup> R. W. Porter, A. Shapley, and O. Jr. Villard, “Report to the Chairman of the Space Science Board on the International Relations Aspects of Project NEEDLES” (Space Science Board, National Academy of Sciences, April 15, 1960), 14.B Outer Space 14.B.19 Project Needles 1960; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 347, National Archives at College Park, MD.



vocal opposition among the professional radio astronomers in his country. Curious about how the Lincoln Laboratory and ham operators might mutually support each other, the letter writer requested information about how amateurs like him might use the belt in order to attain the prestige of long-distance communication. The chief designer of West Ford personally responded with the requested information, but noted that ham operators likely would not transmit at the correct frequency, or with enough power, to be able to use the dipoles.<sup>146</sup>

Of course, as with Sputnik's rocket core, the primary designated use of orbiting artifacts was not always the sole, or even most important, use in practice. Particularly during the early years of the Cold War Space Race, a satellite that could be clearly seen from the ground served important political purposes. Unlike West Ford, which designers planned to install in an orbit so far away and diffusely dispersed as to be all but invisible even through powerful telescopes, Echo's designers built them to be seen from the ground. One of the primary goals of Project Echo was to put an American satellite into orbit that would demonstrate to even the least educated citizens of the world that the United States had reached outer space.<sup>147</sup> An object so large and shiny could be seen with the naked eye, by anyone who knew when and where to look. Journalists who had viewed Echo with their own eyes described the satellite as "a tiny traveling star" or a "small

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<sup>146</sup> "Richard Winters to Walter E. Morrow, Jr.," May 14, 1963, History of West Ford, MIT Lincoln Laboratory Archives, Lexington, Massachusetts; "John A. Kessler to Richard Winters," June 10, 1963, History of West Ford, MIT Lincoln Laboratory Archives, Lexington, Massachusetts; "Richard Winters to John A. Kessler," June 14, 1963, History of West Ford, MIT Lincoln Laboratory Archives, Lexington, Massachusetts.

<sup>147</sup> James R. Hansen, *Spaceflight Revolution: NASA Langley Research Center from Sputnik to Apollo* (Washington, D.C.: National Aeronautics and Space Administration, 1995), 170–175.

bright starlet.”<sup>148</sup> Regional newspapers published schedules listing when local viewers might see Echo passing overhead, and when Echo would be invisible while in the Earth’s shadow.<sup>149</sup> Echo watchers buzzed about a mysterious “companion” to the satellite later attributed to Air Force pilots attempting to get a better look at the satellite while in flight.<sup>150</sup> Three years into the orbital lifetime of the first mission, one American journalist likened Echo-watching to other popular trends like hula hoops, 3D movies, and the twist. NASA reported receiving twenty to thirty calls per week about Echo in 1963, and those who regularly followed its path through the sky described it as a mathematical puzzle, backyard science game, and evidence of American ingenuity visible from anywhere in the world, from American backyards to the Nile River. Echo took on an anthropomorphic identity to some, who described the satelloon as a “sentimental friend.”<sup>151</sup> One Echo-watcher wrote a letter to the SAO upon Echo I’s demise, lamenting: “I shall greatly miss seeing ‘him’ float by.” By the time Echo I reentered the atmosphere in 1968, the New York Times claimed that more people in more countries had seen the satelloon than any other human-made spacecraft.<sup>152</sup> The exact opposite could be said of the West Ford dipoles. Even long-exposure photographs taken by the highly sensitive Baker-Nunn

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<sup>148</sup> Associated Press, “Gemini Difficult to See Even With Telescopes,” *New York Times*, June 5, 1965; Harry Schwartz, “Soviet Praise for Echo I: Seen by Many Russians,” *New York Times*, February 27, 1962.

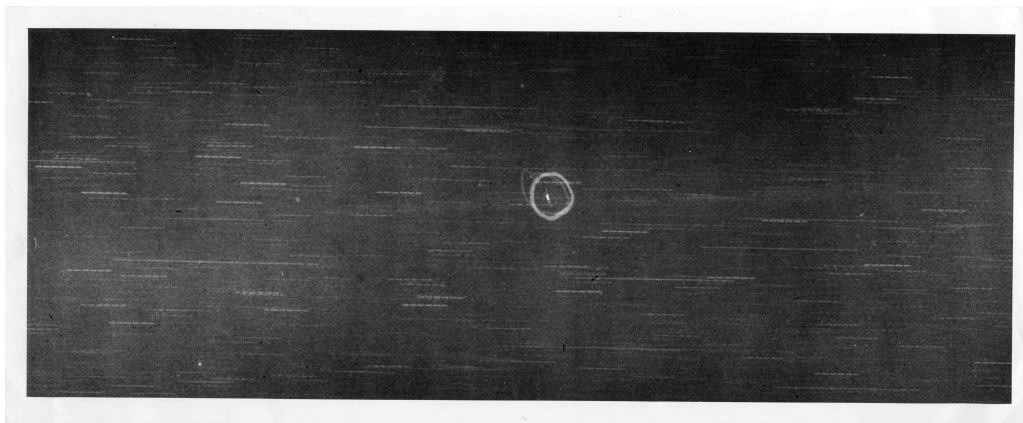
<sup>149</sup> Roy Gibbons, “ECHO WILL TAKE EVENINGS OFF FOR SIX WEEKS: So, Bid It Au Revoir Friday Night,” *Chicago Daily Tribune*, September 23, 1960; “Times to See Satellite,” *Chicago Daily Tribune*, August 30, 1960; “Echo Visits Chicago Twice--on Schedule,” *Chicago Tribune*, January 28, 1964.

<sup>150</sup> Warren Kornberg, “Sightings Here and Elsewhere Note Echo Satellite Has Fast Companion,” *The Washington Post*, August 31, 1960.

<sup>151</sup> Loren Ghiglione, “Wrinkled Old Gasbag (Echo 1) Still Lovely to Local Admirers,” *The Washington Post, Times Herald*, July 14, 1963.

<sup>152</sup> John Noble Wilford, “Echo 1 Is Expected to Fall From Space This Week,” *New York Times*, May 19, 1968.

camera space tracking system could only detect the dispenser mechanism and the faintest fuzzy band inclined approximately three degrees to the surrounding star field.<sup>153</sup>



**Figure 1.5:** This long-exposure photograph demonstrates the faintness of the West Ford system. Taken on September 17, 1963 at the San Fernando station of the Smithsonian Astrophysical Observatory in Spain using a 20-inch Baker-Nunn satellite tracking camera, the dipole field barely appears as a faint, fuzzy line extending from either side of the dispenser (circled), inclined several degrees relative to the star field.<sup>154</sup>

Echo and West Ford also diverged in material composition. While both satellite forms represented innovative products of the Space Age in function and design, they were not both “Space-Age” in construction. In order to attain the enormous size and reflectivity necessary for the proposed satelloon, Echo’s designers chose to build the body of the spacecraft out of Mylar, an aluminized polyester compound newly developed by DuPont for use in the manufacture of recording tape and food packaging.<sup>155</sup> Mylar provided the requisite combination of strength and incredible thinness—about half as thick as the

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<sup>153</sup> D. Tingle, *Photograph of the Project West Ford Copper Dipole Belt*, Photograph, May 14, 1963, National Radio Astronomy Observatory - Director’s Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 3, NAS-SSB - Project West Ford - West Ford Observatories, National Radio Astronomy Observatory.

<sup>154</sup> Ibid.

<sup>155</sup> Hansen, *Spaceflight Revolution*, 167.

cellophane wrapper on a pack of cigarettes, extolled a NASA press release and promotional film distributed in advance of the first Echo launch.<sup>156</sup> Project Echo yielded the first use of Mylar in the spaceflight industry. Soon, the compound would become culturally bound to the space program, as NASA engineers incorporated Mylar into the construction of all Apollo-era spacecraft, as well as the enduringly popular outdoor product spinoff known as the “space blanket.”<sup>157</sup> Touted as a miracle product of space-age chemistry, Mylar soon became a fixture in the silver, streamlined fashion design of the late 1960s.<sup>158</sup>

In contrast, the West Ford dipoles were made out of an ancient, mundane element: copper. If aluminum alloys and shiny silvery materials typified space-age design and consumer culture, copper represented an earlier, bygone age. Space-age alloys were innovative, high-tech, and post-industrial; copper a product of industrial production that most Americans would recognize in their homes, businesses, and in the pennies in their pockets. During the 1960s this industrial substance did not align with the silver, platinum, and white symbols of modernity made most famous by fashion designer André Courrèges.<sup>159</sup>

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<sup>156</sup> “Project Echo Payload and Experiment,” 3; Jerry Fairbanks, *The Big Bounce*.

<sup>157</sup> Hansen, “The Odyssey of Project Echo,” 170–175.

<sup>158</sup> A 1968 advertisement for Lane Bryant titled “Moonlit Silver Orbited in Black” capitalizes on the “space-age blend” of Mylar, cotton, and acrylic to sell garments that evoke the drama of spaceflight: two dresses described respectively as “flouncy-skirted with a striped countdown” and “A-shaped and launched in a silver streak.” “Display Ad 171 -- No Title,” *Chicago Tribune (1963-Current File)*, March 31, 1968, sec. 7.

<sup>159</sup> Copper-infused fabric is currently becoming fashionable, particularly for its purported antimicrobial properties. Laura Johannes, “Silver Lining to Fighting Germs,” *Wall Street Journal*, July 19, 2011, sec. Health and Wellness; Valerie Steele, *Paris Fashion: A Cultural History* (Oxford University Press, 1988).

Together, the shape, size, and composition of Echo and West Ford combined to create a vastly divergent landscape of acceptance. Managers of both projects saw benefit in sending samples of project components to those with the influence or power to lend legitimacy to a new and potentially controversial technology. NASA sent samples of Mylar to space program advocates in the federal government, demonstrating the remarkable attributes of the new material and lauding Echo as a breakthrough in materials and communication technology.<sup>160</sup> The Lincoln Laboratory also circulated material samples from West Ford to potential allies, but for a different purpose. When John Kessler, the publicity manager of the West Ford project, sent around packets of dipoles to journalists, diplomats, and lawmakers, he did not intend to demonstrate anything revolutionary about plain old copper. Rather, he hoped to showcase its banality—boring, ordinary, and inoffensive, copper was not the stuff of military aggression or revolution.<sup>161</sup>

The Lincoln Laboratory often accompanied press releases and other informational materials with a photo of several dipoles arranged next to cat whiskers, or on an unidentified human finger. With the fingerprints as clearly visible as the dipoles themselves, such an image demonstrated the short length and minute diameter of the

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<sup>160</sup> NASA sent then-senator and Vice Presidential candidate Lyndon B. Johnson a sample of Mylar on August 12, 1960. Johnson was the most vocal advocate of the fledgling American space program in the US Senate, and the material sample, accompanied by a written description of its manufacture, was likely intended to drive the point that Echo would be a revolutionary technology. “Sample of Mylar Material Sent to the Office of Senator Lyndon B. Johnson,” August 12, 1960, LYNDON BAINES JOHNSON ARCHIVES 1931—1968, Box 15G, Science - Space and Aeronautics Satellite, ECHO August 12 1960, LBJ Library.

<sup>161</sup> J. A. Kessler, “Letter from J. A. Kessler to Watson Davis, Director Science Service,” May 22, 1963, History of West Ford, MIT Lincoln Laboratory Archives, Lexington, Massachusetts.

copper fibers. By allowing individuals such as the delegates present at a United Nations Committee on the Peaceful Uses of Outer Space meeting held two days after the second launch to see and handle dipoles directly, the circulation of West Ford samples provided an unparalleled method to demonstrate objectively the size of the dipoles, and by extension their harmlessness.<sup>162</sup> Kessler also hoped that this material encounter might also help spur a creative rebranding of the embattled Lincoln Laboratory endeavor. Recognizing the damage that the enduring nickname “needles” seemed to be inflicting upon public opinion of the project, Kessler circulated dipoles to journalists in order to solicit suggestions for how to rename the project one more time, hoping that a softer moniker would render its composite parts both popularly legible and rhetorically innocuous. Suggestions such as “space fluff,” “space hair,” and “space halo” softened an otherwise sharp intrusion into the outer space environment—though none of these suggestions found official or popular traction.<sup>163</sup> Those who did not encounter the dipoles themselves had free range to imagine—they imagined needles raining from the sky, or falling into their gardens.

Compared to the highly visible, widely celebrated Echo I and Echo II, West Ford’s invisibility proved a double-edged sword. The fact that the belt could not be seen by anyone, including professional astronomers who had vocally opposed its potential effect on their research, was a triumph for the Lincoln Laboratory. However, the visibility

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<sup>162</sup> Special to the New York Times, “U.S. Assures World Scientists Space Needles Are Harmless”; Oswald Schuette, “Letter from Oswald F. Schuette to J. A. Kessler,” May 20, 1963, History of West Ford, MIT Lincoln Laboratory Archives, Lexington, Massachusetts.

<sup>163</sup> Kessler, “Letter from J. A. Kessler to Watson Davis, Director Science Service”; Schuette, “Letter from Oswald F. Schuette to J. A. Kessler.”

of the Echo satellites made them familiar and even lovable to certain communities on the ground. While astronomers opposed both Echo and West Ford, they did not raise an international incident over Echo as they did with West Ford. In remarks that inverted Western praise for 1957's 1 years earlier, Soviet physicist Alla Masevitch publicly thanked the United States for providing scientists around the world with a free scientific instrument that could be used to study the effects of sunlight pressure of orbiting objects—and at the end of the same remarks condemned West Ford.<sup>164</sup> During the first years of the Space Age, those artifacts that, like Sputnik's rocket core, could be seen and accessed around the world for multiple uses earned admiration, even from hostile audiences, while invisible orbiting artifacts were not flexible enough to serve as global boundary objects and thus earned fewer defenders. Visible artifacts like satelloons and rocket cores could be interpreted as friendly and useful. Invisible artifacts could be menacing matter out-of-place—in spite of the utility professed by their designers, objects such as the West Ford dipoles could easily be interpreted as dangerous waste.

## **Conclusion**

Whether space waste, satellite, political tool, scientific instrument, diplomatic olive branch, test facility, or intelligence commodity, Sputnik's rocket core played multiple critical roles in the history of humankind's first steps into outer space. When visible and accessible to multiple communities, artifacts like 1957's 1 and the Echo satelloons became expansive boundary objects, bringing specialist and lay communities around the world into contact across ideological, political, and geographic divides. West Ford's largely

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<sup>164</sup> Schwartz, "Soviet Praise for Echo I."

invisible dipoles could not fulfill this mediating function. As a result, many communities interpreted them as dangerous weapons or potentially disastrous waste, without redemptive secondary uses. The strange mobility, remoteness, variable visibility, and ephemerality of these flexibly defined objects undergird the elastic boundaries between utility and waste, particularly in a technological system in which byproducts typically go unnoticed by the majority of users. The divergent interpretations of these early space artifacts suggests that on Earth and in space alike, one user's tool is another user's garbage.



## CHAPTER 2

### **Under the Copper Curtain: Project West Ford and the Roots of Outer Space Environmentalism, 1958-1964**

#### **Talking Over the Bomb**

Thirteen minutes before midnight local time on July 31, 1958, an Army Redstone missile carrying a nuclear device lifted off from Johnston Island in the South Pacific. Its intended target was a patch of upper atmosphere 76.8 kilometers above and approximately 10 kilometers south of the launch site, but a programming error in the missile's guidance system led the missile straight up instead.<sup>165</sup> Upon detonation three minutes after launch, the weapon unleashed a 3.8 Megaton yield directly above the island and the roughly 175 souls that remained on site for the test. The resulting debris cloud rose one and a half kilometers per second, spreading to a diameter of nearly 30 kilometers in three and a half seconds. The night sky over Johnston Island turned bright as daylight for a few seconds, and observers in Samoa reported spectacular aurora displays—a phenomenon rarely seen in that region of the world.<sup>166</sup>

Sensors mounted on sounding rockets launched alongside the nuclear device returned data that indicated the presence of a layer of fissile debris in the upper atmosphere. This debris disrupted Earth's ionosphere, the layer of the atmosphere used as a reflector for long-distance middle and high frequency radio communications. For several hours, radio operators could no longer use the ionosphere to transmit signals

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<sup>165</sup> Lookout Mountain Laboratory USAF, *Operation HARDTACK High Altitude Tests* (Hollywood, CA: Lookout Mountain Laboratory USAF, 1958).

<sup>166</sup> Christian Brahmstedt, ed., *Defense's Nuclear Agency: 1947-1997* (Washington, D.C.: U.S. Department of Defense, 2002), 140.

across the region below the blast zone. A blackout of trans-Pacific high-frequency communications lasted for nine hours in Australia and two or more hours in Hawaii.<sup>167</sup> Certain radio frequencies in Honolulu also went silent for several hours until the debris dispersed and the ionosphere returned to its natural state. On Johnston Island itself, communications systems shut down for the rest of the night. While civilian observers 1300 kilometers away in Honolulu remarked upon the stunning visual display as the unannounced explosion turned the sky from black to yellow to orange to red, military personnel on nearby ships desperately attempted to reach their colleagues at the test site. The blast had so comprehensively disrupted Johnston Island's communications systems that outsiders worried the island itself had been obliterated. The first communication to get through to island personnel in the morning hours following the event was a frantic "Are you still there?"<sup>168</sup>

This nuclear test, codenamed Hardtack-Teak, was the second of three high-altitude blasts set off as part of the series of 35 nuclear demonstrations comprising Operation Hardtack. Each detonation provided experimental data to test the hypothesis of physicist Nicholas Constantine Christofilos that high-altitude electromagnetic pulses (EMPs) might be used to black out communications and electronic systems over a large area, a potentially valuable countermeasure against incoming missiles, enemy satellites, or even hostile cosmonauts. A strategically placed nuclear detonation in the upper atmosphere launched from the Indian Ocean might even cause Moscow to fall silent for a

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<sup>167</sup> Ibid.

<sup>168</sup> H. Hoerlin, "United States High-Altitude Test Experiences" (Los Alamos Scientific Laboratory, October 1976), 17–19.

few hours without causing any material damage on the ground—an appealing tactical advantage in the age of mutually assured destruction.<sup>169</sup> Teak, and the subsequent Operation Hardtack-Orange, clearly demonstrated the validity of Christofilos’s hypothesis. A nuclear explosion in the upper atmosphere could critically disable local and international communications over a particular geographical area. The tests not only confirmed a potential weapon for the United States military, but also identified a possible weakness in the American military communications infrastructure. What could be done if the Soviet Union used this tactic against America in conjunction with cutting transatlantic cable, destroying the president’s ability to maintain contact with forces and nuclear arsenals deployed across the world should the Cold War turn hot?<sup>170</sup> The demonstrated vulnerability of the natural ionosphere motivated several branches of the United States military to consider more robust alternatives to contemporary radio and cable communications systems.

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<sup>169</sup> James Rodger Fleming, “Iowa Enters the Space Age: James Van Allen, Earth’s Radiation Belts, and Experiments to Disrupt Them,” *Annals of Iowa* 70, no. 4 (Fall 2011): 314-315.

<sup>170</sup> An assessment of the need for an invulnerable space-based military communications project to defend against new forms of attack introduces a DOD white paper released in 1961, following the first attempt to launch such a system. “Department of Defense White Paper on Project West Ford,” White Paper (Department of Defense, September 1961), 1, National Radio Astronomy Observatory - Director’s Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory.

<b>Event Name</b>	<b>Location</b>	<b>Date</b>	<b>Altitude (km)</b>	<b>Yield</b>
Hardtack-Yucca	Eniwetok	4/28/1958	26.2	Low
Hardtack-Teak	Johnston Island	8/1/1958	76.8	Megaton range
Hardtack-Orange	Johnston Island	8/12/1958	43	Megaton range
Argus I	South Atlantic	8/27/1958	200	1-2 kilotons
Argus II	South Atlantic	8/30/1958	240	1-2 kilotons
Argus III	South Atlantic	9/6/1958	540 ± 100	1-2 kilotons
Starfish Prime	Johnston Island	7/9/1962	400	1.4 Megatons
Checkmate	Johnston Island	10/20/1962	Tens	Low
Bluegill	Johnston Island	10/26/1962	Tens	Submegaton
Kingfish	Johnston Island	11/1/1962	Tens	Submegaton
Tightrope	Johnston Island	11/4/1962	Tens	Low

**Table 2.1.** American high-altitude nuclear tests, 1958-1962.<sup>171</sup>

Alongside the high-altitude nuclear tests conducted under Project Argus in 1958, the spectacular Hardtack explosions incontrovertibly showed that the reach of the American military and its weapons now extended to space—even as governments on

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<sup>171</sup> Adapted from Hoerlin, “United States High-Altitude Test Experiences.”

either side of the Cold War debated how to define where space begins.<sup>172</sup> Though cloaked under a veil of scientific justification, these tests strained the definition of the militarization of space that President Eisenhower condemned in speeches and national security policy reports.<sup>173</sup> However, these dramatic, catastrophic moments of martial might did not inspire significant backlash among those who hoped to preserve near-Earth space from human alteration. Rather, a seemingly benign attempt by the American military to address this perceived weakness in communication infrastructure sparked the first heated international discussions about what constituted environmentally dangerous activity in outer space. Astronomers in particular spoke out about changes in the orbital environment caused by military operations in space. Few responded during the first volley of high altitude nuclear tests in 1958. Not until 1960, when the United States Air Force announced the details of a space communications system that would come to be known as Project West Ford, did astronomers on both sides of the Iron Curtain become the first advocates for pollution control in orbit. Their response to Project West Ford instigated a broad-reaching worldwide debate about what rules would ensure the safe, long-term use of near-Earth space. This debate led to the codification of environmental protection measures in incipient international space law. While Project West Ford and the maelstrom of controversy that surrounded it have fallen out of popular memory, the questions it inspired about how best to protect a strange, isolated, globally shared natural

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<sup>172</sup> Walter A. McDougall, ...*The Heavens and the Earth: A Political History of the Space Age*. (The Johns Hopkins University Press, 1997), 177–194.

<sup>173</sup> *Ibid.*, 195–209.

environment—and who should be the guardians of this environment—continue to inform current policy discussions about orbital sustainability.

### **A Passive Solution: Project Needles, 1958-1960**

On October 4, 1957, the Soviet Union launched the first artificial satellite, Sputnik, into orbit around the planet, ushering in the cultural and aesthetic era known as the Space Age, and the sociotechnical order more accurately called the Satellite Age.<sup>174</sup> Space Age visionaries predicted that once space became a place that humans could regularly reach, albeit indirectly, satellites would become integral to societies on the ground as conveyers of information. The idea of using high-orbiting satellites to enable nearly instantaneous communications across the globe had been anticipated as early as 1945 by science fiction author Arthur C. Clarke.<sup>175</sup> Sputnik and America's first satellite Explorer, however, were not communications satellites. They contained radio transmitters that emitted signals, but could not relay information sent from the ground to another point on the ground as proposed by Clarke and other early satellite communications proponents.<sup>176</sup> The iconic beeping of Sputnik's radio beacon could strike pride or terror into the hearts of listeners—depending on their political affiliations—and anticipated the increasingly

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<sup>174</sup> Cultural theorist Lisa Parks argues that much of humanity currently lives in a “satellitarian order”—a sociotechnical reality structured and bounded by the satellites to which a growing number of practices on the ground have become inextricably tied. Lisa Parks, “When Satellites Fall: On the Trails of Cosmos 954 and USA 193,” in *Down to Earth: Satellite Technologies, Industries, and Cultures* (New Brunswick, NJ: Rutgers University Press, 2012), 232–233.

<sup>175</sup> Arthur C. Clarke, “Peacetime Uses for V2,” *Wireless World*, February 1945.

<sup>176</sup> Explorer 1 contained instruments that measured radiation in near-Earth space, confirming James Van Allen's predictions that the Earth was surrounded by radiation belts and prompting debate among Western scientists about where the ionosphere ends and space begins—many began to see the Earth's atmosphere and cislunar space as part of one enormous continuum of energized particles.

complex on-board electronics that became standard for satellites in the late twentieth century. However, the design and function of communications satellites was anything but predetermined. The first true communications satellite predated Sputnik, contained no electronics, and had not even been fashioned by human hands. In 1946 the US Army Signal Corps conducted the first radar astronomy experiment code named Project Diana, during which they bounced radio signals off the Moon and set the stage for the so-called “passive” artificial satellites that would follow in subsequent years.<sup>177</sup> As the United States and the Soviet Union launched greater numbers of satellites that incorporated new technologies produced simultaneously by the electronics and synthetic materials industries, satellite designers considered multiple potential forms that communications spacecraft might take.<sup>178</sup>

By the summer of 1958, only six artificial satellites orbited the planet, and the design of satellite technology remained subject to broad interpretive flexibility.<sup>179</sup> The vulnerability of ground-based communication systems revealed by the 1958 high-altitude

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<sup>177</sup> For more on Project Diana, see Andrew J. Butrica, *To See the Unseen: A History of Planetary Radar Astronomy*, The NASA History Series, NASA SP-4218 (Washington, DC: NASA History Office, 1996), 6–10.

<sup>178</sup> For example, the development of lightweight and shiny Mylar was crucial to the design of the ECHO balloon satellite, the first passive satellite used for communications, launched in August 1960. Incidentally, ECHO suffered none of the same public relations problems as Project West Ford, largely due to its easy visibility, culturally valuable space-age material properties, and affiliation with the civilian space agency.

<sup>179</sup> The previous chapter of my dissertation presented a case study of the first orbiting artifacts, and the high level of interpretive flexibility with which different communities designed, encountered, and used the empty rocket casing that accompanied Sputnik into orbit. For more on the interpretive flexibility of artifacts and the social construction of technology, see Trevor J. Pinch and Wiebe E. Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other,” in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, MA: MIT Press, 2012), 11–44.

weapons tests of Operation Hardtack led several branches of the U.S. military to push for new, resilient ways to maintain open communication lines in case of nuclear war. Eight months after the launch of Sputnik and two months after the first American high-altitude nuclear test, the United States Army Signal Corps funded an MIT Lincoln Laboratory summer study in Cape Cod. Participants in what came to be known as the Barnstable Study considered how space technology could be used for military communications, and discussed ways to make such critical remote infrastructure invulnerable to high-altitude EMPs triggered by nuclear detonations—or at least to have an emergency system ready to deploy in case of such an attack.<sup>180</sup> They considered two main forms that a military communications satellite might take, and debated the merits and disadvantages of each.<sup>181</sup> The “active” satellite type incorporated electronics that could receive and store a signal sent from the ground, then amplify that signal upon sending it to another point on the ground. The “passive” satellite form—like its natural cousin the Moon—did not incorporate onboard electronics. Instead, the body of the satellite itself served as a resonant reflector for powerful signals tuned to the satellite’s shape and size.<sup>182</sup>

Two Barnstable study participants, Harold F. Meyer of the Ramo-Wooldridge Corporation and Walter E. Morrow Jr. of the Lincoln Laboratory, devised a system based on the latter, passive form of satellite. Morrow and Meyer’s design called for a simple but

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<sup>180</sup> Delbert R. Terrill, *The Air Force Role in Developing International Outer Space Law* (Maxwell Air Force Base, Alabama: Air University Press, 1999).

<sup>181</sup> Carl F. J. Overhage and William H. Radford, “The Lincoln Laboratory West Ford Program-- An Historical Perspective,” *Proceedings of the IEEE* 52, no. 5 (May 1964): 452.

<sup>182</sup> The ground equipment developed for Project West Ford would also be used in subsequent tests of lunar radio reflection. “Project West Ford – Report on the ‘Needles in Space’ Program,” *Microwave Journal* 5, no. 10 (October 1962): 76.



cost-effective method of radio communications that would reliably replicate the properties of the natural ionosphere. Instead of a single, expensive active satellite with EMP-vulnerable electronics on board, Morrow and Meyer's model called for a ring of simple copper dipole antennas, called "chaff" or "needles," diffused into a an orbiting ring. The dipoles would ideally be established in two belts—one polar, and one equatorial—to ensure worldwide coverage. Such a system could be used to complete multiple communications circuits from any point on the globe using no more than one ground transfer point.<sup>183</sup> The design specified that the dipoles should be cut into short, thin, oblong threads tuned for use with a specific radio frequency, a technique rooted in World War II radar countermeasures and tropospheric scatter telecommunications already in use at remote military installations, including the United States Air Force's White Alice network within the DEW Line aircraft early warning system.<sup>184</sup>

After struggling to find financial support to build and test the Morrow and Meyer model under the code name Project Needles, the Lincoln Laboratory found a funder in

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<sup>183</sup> Allen S. Richmond, "Orbital Scatter Communication," September 9, 1960, Satellites: West Ford 1960-1986 Folder 11429, [hereafter, West Ford] NASA Headquarters Historical Reference Collection, Washington, DC. [hereafter, NASA].

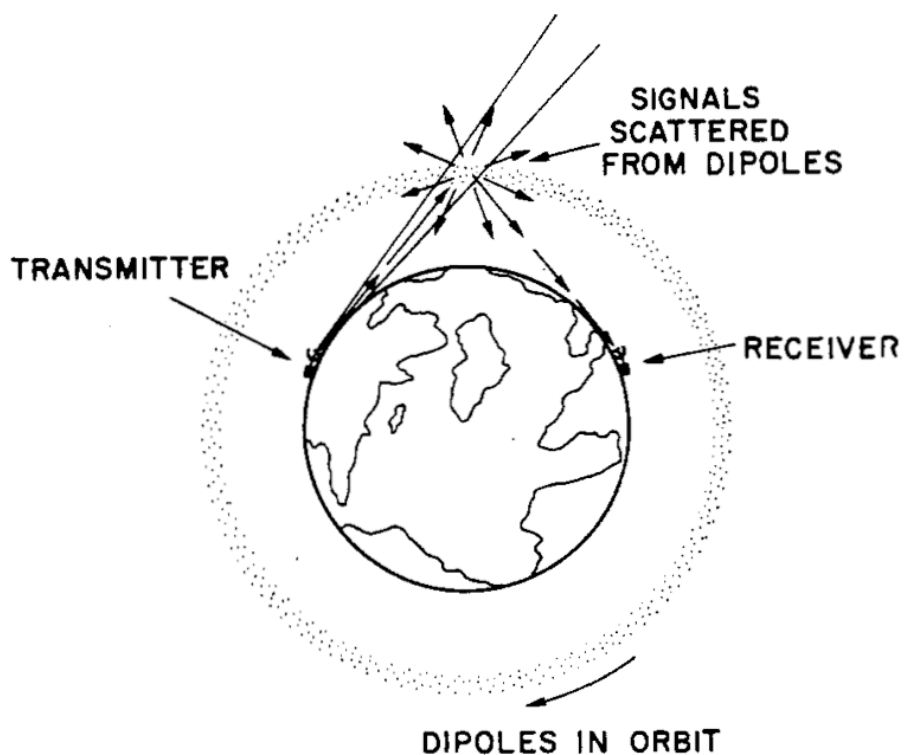
<sup>184</sup> For the World War II countermeasure ancestor to Project Needles, see "Project Window" and "Project Chaff," in Robert Buder, *The Invention That Changed the World: How a Small Group of Radar Pioneers Won the Second World War and Launched a Technological Revolution* (New York: Simon & Schuster, 1996), 207–208. The Air Force's White Alice system used tropospheric scattering across remote regions of Alaska in service of the DEW Line radar network. The DEW Line was built to detect incoming Soviet aircraft—but in practice it mostly detected incoming migratory birds. F. Robert Naka and William W. Ward, "Distant Early Warning Line Radars: The Quest for Automatic Signal Detection," *Lincoln Laboratory Journal* 12, no. 3 (2000): 181–204. Walter E. Morrow, Jr. '49, SM '51, Director, Lincoln Laboratory 1977-1998, interview by Toby A. Smith, June 17, 2010.

the U.S. Air Force.<sup>185</sup> Under military sponsorship, MIT researchers revised the theoretical plan presented at Barnstable and specified the material and spatial parameters of a test system: a field of several hundred million dipoles orbiting in two diffuse rings at about 3600 kilometers above the Earth's surface, positioned along polar and equatorial orbits. Two large ground terminals—one in Camp Parks, California and one in Westford, Massachusetts—would be constructed to send and receive signals using the belts. A powerful microwave signal sent from one terminal would hit the charged dipoles and scatter in multiple directions, enabling the receiver at the other terminal to intersect one of the scattered signals. This mechanism mimicked the natural ionosphere that had temporarily fallen prey to the first high-altitude nuclear tests, but with greater consistency over longer distances. It also enabled the use of higher frequency transmissions than could be reliably reflected by the natural ionosphere.<sup>186</sup>

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<sup>185</sup> R. Joyce Harman, "History of West Ford" (West Ford Project Office, MIT Lincoln Laboratory, n.d.), History of West Ford, MIT Lincoln Laboratory Archives, Lexington, MA [hereafter, MITLL].

<sup>186</sup> W. E. Morrow Jr. and D. C. MacLellan, "Properties of Orbiting Dipole Belts," *The Astronomical Journal* 66, no. 3 (April 1961): 107.



**Fig. 1—Long-range communication by means of radiowave scattering from dipoles in orbit about the earth.**

**Figure 2.1:** A diagram created by one of the original designers illustrates the simplicity of the orbiting chaff model of microwave communications.<sup>187</sup>

By using dipole belts in space as an ionosphere-like scatter medium, Lincoln Laboratory researchers envisioned an economical, durable communications system that would span the globe. All complex, expensive technology would be constructed on the ground, where repairs could be conducted—in stark contrast to the complex technology of active satellites, which could not be retrieved and repaired once launched into orbit. Space components would be made of simple industrial materials easily and cheaply

<sup>187</sup> W. E. Morrow Jr. and T. F. Rogers, "The West Ford Experiment-- An Introduction to This Issue," *Proceedings of the IEEE* 52, no. 5 (May 1964): 462.

installed as a secondary “piggyback” payload on a single Air Force rocket launch.<sup>188</sup> A 1961 white paper on the model lauded its “singular nature of being the cheapest of all communications satellite systems studied to date.”<sup>189</sup> The redundancy of a field of tiny reflectors made the system more resilient against direct or large-scale attack than active satellites. At 3600 kilometers above the surface of the Earth, the belt would be situated significantly higher than the highest recorded altitude of a nuclear explosion, protecting the system from a known method of sabotage. Even if a high-altitude nuclear weapon were to be detonated in the same orbit as the belt or belts, the remaining millions of dipoles would coalesce and fill the gap in short order, rendering any communications outages temporary.<sup>190</sup> Such an open access system yielded additional promise in the form of nearly unlimited circuits, a potentially valuable provision for military applications around the planet.<sup>191</sup> Although the dipoles would be placed in a relatively high orbit, Irwin Shapiro of the Lincoln Laboratory calculated that sunlight pressure would bring them down within a maximum period of five years. Shapiro emphasized that testing the effect of sunlight pressure on low mass-to-area ratio objects—a primary purpose of Project Needles in the minds of a few of those who designed the system—would yield new, valuable information about the near-Earth space environment and the physical forces at work between the Sun and the Earth.<sup>192</sup> Researchers at the Lincoln Laboratory

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<sup>188</sup> Allen S. Richmond, "Orbital Scatter Communication", September 9, 1960, West Ford, NASA.

<sup>189</sup> “Department of Defense White Paper on Project West Ford,” 5.

<sup>190</sup> *Ibid.*, 4.

<sup>191</sup> R. Joyce Harman, “History of West Ford” (West Ford Project Office, MIT Lincoln Laboratory, n.d.), MITLL.

<sup>192</sup> I. I. Shapiro, “Last of the West Ford Dipoles,” *Science*, New Series, 154, no. 3755 (December 16, 1966): 1445–48.

believed that testing Project Needles *in situ* would contribute significantly to applied physics, national security, and the American space industry. With the Air Force footing the bill and providing passage to orbit, these contributions would come about in secret, invisible to the majority of citizens on the planet below.

### **Sniffing Out a Watchdog: The Space Science Board and Risks to Astronomy**

In September 1959, as plans for a test launch proceeded apace, Lincoln Laboratory administrators determined that the project would benefit from external consultation on the possible impact of the proposed project on space research. Given its classified status, the Lincoln Laboratory requested assistance from the Space Science Board (SSB) of the National Academy of Sciences in vetting the safety of the system, particularly to radio astronomy, optical astronomy, and current and future orbiting spacecraft.<sup>193</sup> In January 1960 the SSB convened a small group of astronomers and engineers from its ranks to form an ad hoc committee that would weigh the potential outcomes and risks of the proposed test belts.

The SSB charged the committee, chaired by radio engineer O. G. “Mike” Villard, with the task of evaluating how Project Needles might alter and be altered by the outer space environment at the proposed altitude, and to assess any danger of the proposed experimental dipole belts to scientific research. The committee also planned to gauge how information about the project as designed would be received by scientists and the

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<sup>193</sup> Leo Goldberg, “Project West Ford-Properties and Analyses: Introduction,” *The Astronomical Journal* 66 (April 1961): 105.

public at home and abroad.<sup>194</sup> In his initial invitation to a group of ten astronomers that he hoped would join the committee, Villard enthused about the project that they would shortly gather to evaluate, stating: "I am sure the view is shared by many that Project "Needles" represents one of the most important developments in the communications field which has come to hand in recent years." He closed with a promise that participation on the committee would yield "an interesting and rewarding experience."<sup>195</sup>

On April 14, 1960, after several months of collaboration, the SSB ad hoc committee on Project Needles met with representatives of the Lincoln Laboratory and liaisons from the National Science Foundation (NSF), the Advanced Research Projects Agency (ARPA), and NASA. The following day, the SSB committee issued a confidential report to the general board. In this report, committee members stated that they were "deeply disturbed by the project...because of what appears to be a serious threat to radio astronomy observations in the short-wave end of the radio spectrum."<sup>196</sup> While the committee predicted that the test system as proposed should not adversely affect optical or radio astronomy in the long run, they anticipated that the success of a prototype would likely spur the United States and the Soviet Union to each establish its

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<sup>194</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960, National Radio Astronomy Observatory - Director's Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory

<sup>195</sup> O. G. Villard Jr., "Formation of 'Needles' Committee; First Meeting on January 8 1960," Memorandum, (December 29, 1959), National Radio Astronomy Observatory - Director's Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory.

<sup>196</sup> "Memo on the April 15th 1960 Meeting of the Space Science Board Ad Hoc Committee on Project NEEDLES," April 15, 1960, 14.B Outer Space 14.B.19 Project Needles 1960; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 347 [hereafter Project Needles Records], National Archives at College Park, MD [hereafter, NARA].

own fully functional, denser, longer-lived set of dipole belts, thus crowding Earth orbit with reflective material.<sup>197</sup> Should other nations follow suit in the future, the night sky could soon be replete with shimmery obstructions and errant radio signals, with dire, inescapable consequences for practitioners of radio and optical astronomy.

The committee predicted widespread negative reaction to the proposed project among scientists from around the world, particularly if it continued to be conducted under a veil of secrecy. They recommended that the Air Force publicize some details of the classified test through a series of articles published in an open academic journal and by actively soliciting feedback from the international astronomy community. Most importantly, they stressed that the Lincoln Laboratory must ensure that all dipoles would safely reenter the atmosphere within two years so as to limit the duration of any unforeseen negative effects to observational astronomy that might arise from their presence in orbit.<sup>198</sup> The committee also suggested that certain material details of the project should be communicated to the general public through international news media so as to ward off negative publicity. They contemplated possible reactions by everyday American citizens, including protests that the dipoles would cause climate changes, collide with spacecraft, or rain down on the heads of unsuspecting victims. While

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<sup>197</sup> Or, as one Swedish astronomer noted, every spacefaring nation might soon want its own dipole belts (in spite of the non-proprietary nature of the system as proposed). The space industry has been and continues to be a technological game of keeping up with the Joneses. William H. Littlewood, *Swedish Press Reaction to Project West Ford*, Foreign Service Despatch (Stockholm: American Embassy, October 26, 1961), West Ford - Communications Experiment 1961 - 1961; Records of the U.S. Information Agency, 1900 - 2003, Record 306 Box 13 [hereafter, West Ford Communications], NARA.

<sup>198</sup> "Memo on the April 15th 1960 Meeting of the Space Science Board Ad Hoc Committee on Project NEEDLES." Project Needles Records, NARA.

acknowledging that falling copper space needles posed no real threat to individuals on the ground, the committee accounted for the possibility that some citizens might harbor fears of personal injury or property damage and blame the Air Force for unintentionally bombarding its own soil.<sup>199</sup> Although several space artifacts had fallen back to Earth by the time of this report, none had been recovered as would happen with some regularity in subsequent years. The SSB committee's prediction of fallout from falling space junk shows that even before the first highly publicized reentries of the long 1970s, fear about falling space junk among specialist and lay communities alike originated at a much earlier, much quieter moment.<sup>200</sup>

The committee ended its report on an optimistic note. Although worried that the project might be seen as a unilateral military invasion of the new global resource of near-Earth space, committee members suggested that such a blow might be tempered by emphasizing the system's universal accessibility to scientists, governments, and the lay public. Scientists of any nationality could conceivably use the dipole belts, suggesting possible international relations benefits. Beyond its use as a military system, Project Needles might even yield public relations benefits as a tool for civilian space science

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<sup>199</sup> R. W. Porter, A. Shapley, and O. Jr. Villard, "Report to the Chairman of the Space Science Board on the International Relations Aspects of Project NEEDLES" (Space Science Board, National Academy of Sciences, April 15, 1960), Project Needles Records, NARA.

<sup>200</sup> In a 1966 article published in *Science*, Irwin Shapiro concluded that some of the dipoles did survive reentry and floated back to Earth. However, it is unlikely that they will ever be found. Chuck Perkins, who worked on the West Ford design as a graduate student at MIT, later gathered samples from a region of Antarctica where the needles were likely to have fallen. These samples showed no evidence of dipole detritus. Additionally, Shapiro claims that there would have been a density of 1 dipole per tenth of a mile, making recovery all but impossible. Irwin Shapiro, in conversation with the author, June 26, 2014; Shapiro, "Last of the West Ford Dipoles."



research.<sup>201</sup> However, these suggestions did not negate the report's overall recommendation that the Air Force put an end to Project Needles. The risks to optical and radio astronomy appeared too grave to outweigh the military need and minimal secondary benefits.

After the completion and initial general board review of this report, committee astronomers including Fred Whipple of the Smithsonian Astrophysical Observatory demanded further analysis of the possible physical and material outcomes of the test project. Whipple had missed the April 14 meeting, and wrote urgently to Leo Goldberg, a prominent optical astronomer and chair of the SSB Committee on Astronomy, to inform him of Whipple's misunderstanding of the planned altitude for the dipoles—rather than being satisfied that the dipoles would come down within the predicted two years, he now expected them to stay up forever, diffused into a cloud that would in time cover the whole sky.<sup>202</sup> Over the following weeks, members of the committee prepared studies of expected interactions between Needles components and the near-Earth space environment, and how the physical properties of orbital space itself might affect the structural integrity and longevity of the dipoles, individually and in aggregate.

Less than two months after the committee issued its first, explicitly negative set of recommendations regarding Project Needles, a second version of the report dated June 6,

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<sup>201</sup> R. W. Porter, A. Shapley, and O. Jr. Villard, "Report to the Chairman of the Space Science Board on the International Relations Aspects of Project NEEDLES" (Space Science Board, National Academy of Sciences, April 15, 1960), Project Needles Records, NARA.

<sup>202</sup> Fred Whipple to George Derbyshire," May 12, 1960, 14.B Outer Space 14.B.19 Project Needles 1960; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 347, National Archives at College Park, MD; Leo Goldberg to Lloyd Berkner, April 19, 1960, 14.B Outer Space 14.B.19 Project Needles 1960; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 347, National Archives at College Park, MD.

1960 opened with a stark reversal. The introduction lauded the test project as an “exciting and interesting...opportunity for doing important basic research in several scientific fields.” The general recommendations of the previous report were preserved, including a call for radio frequency allocation for astronomy, declassification and publication of project details, and reassurances that an operational set of dipole belts would not be launched. However, the change in overarching sentiment about Project Needles in the report’s introduction from deeply wary to enthusiastic dramatically altered the overall thrust of the committee’s recommendations from discouragement to outright support.<sup>203</sup>

Among members of the small committee, opinions on Project Needles ranged from ambivalence to outright dissent, a reality unchanged, if not worsened, in the intervening weeks between reports. The abrupt change of official position—from deep opposition to support—for the Needles project as a whole did not accurately reflect the convictions of the board membership in full. It did, however, comply with SSB Chairman Lloyd V. Berkner’s belief that SSB astronomers ought to work *with* Lincoln Laboratory to adjust the project so that it would not harm astronomy, rather than working *against* the Lincoln Laboratory (and its powerful military funders) in an attempt to cancel the project outright. Berkner, himself an ionospheric researcher, argued that taking a collegial position would “go much farther in safeguarding the unquestionable rights of

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<sup>203</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960, 1, NRAO - Director’s Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford [hereafter SSB West Ford], Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory [hereafter NRAO].

astronomers<sup>204</sup>.” Berkner brought several decades of experience in building relationships between the United States military and the nation’s scientists to bear in adopting a newly conciliatory approach.<sup>205</sup> Berkner understood that the U. S. military would likely launch the experiment regardless of scientific dissent, given its potential importance to national security. Indeed, the Air Force had already set a date for a Needles launch in December of that year. The second ad hoc committee report reflects Berkner’s strategy of cooperation and critical support to ensure that astronomers would maintain some level of control over the parameters of the project.

Adhering to the strategy meant expressing general support of Needles overall, alongside more detailed analyses of potential dangers that the experiment might pose and how best to avoid them. In addition to the newly added optimistic window dressings, the June report differs from the April report in the inclusion of overviews of the committee members’ studies of how the Needles belt might affect different areas of scientific research, as well as how the dipole package would impact, and be impacted by, the physical and material environment of Earth and near-Earth space.<sup>206</sup> A brief study of how Project Needles might affect radio astronomy merited a separate appendix, and included projections of how the dipoles might be detected by radio sensors of different sizes and

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<sup>204</sup> L. V. Berkner to Leo Goldberg, January 1, 1961, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>205</sup> Allan A. Needell, *Science, Cold War and the American State: Lloyd V. Berkner and the Balance of Professional Ideals*, Routledge Series in the History of Science, Technology, and Medicine (New York: Routledge, 2001).

<sup>206</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960, 3–5, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

sensitivity; these calculations were completed by John W. Findlay of the National Radio Astronomy Observatory (NRAO), who would remain an active participant in international discussions of the project in the years to come. The committee predicted that radar research would likely not be impacted by Needles, and the dipole belt's effects on optical observations would likely be variable—optical astronomers' exposure times might be limited by an increase in background illumination caused by the belts, but auroral and air glow researchers could find the belt an interesting tool for studying atmospheric phenomena. Mercury spacecraft would not be threatened by the experimental belt, as the dipoles were expected to orbit at a much higher altitude than the first astronauts' spacecraft; however, the NASA researcher who contributed the spacecraft collision analysis warned that future space stations and other high-flying spacecraft could be threatened by speedily orbiting dipoles should Needles remain aloft for a longer period than predicted. The committee's analysis of the effects of the space environment on the dipoles themselves was sunnier: The report suggests that meteorites and micrometeorites would likely have negligible effects on the orientation of the needles, as would corpuscular radiation, sputtering, and Van Allen radiation. Solar radiation pressure, however, would likely reduce the perigee, or minimum altitude, of the dipoles' orbit by 1000 kilometers per year, resulting in a 1.5 year orbital lifetime, a prediction that satisfied the committee's demand that the belt come down within two years.<sup>207</sup>

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<sup>207</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960, 3–5, NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

The committee also evaluated the inverse of this environmental impact—noting not only the ways that the space environment might affect the dipoles but anticipating the ways in which Project Needles might alter Earth’s atmosphere and the near-Earth space environment. This attention to how human actions could transform space represented an early, novel shift in thinking about outer space: an explicit discussion of how technologies change the space environment. The committee predicted that the effects of decreased insolation—the obscuring of solar energy—would be insignificant because the belt would only occupy a sliver of space covering a tiny fraction of Earth’s total area. Ionization of the needles upon reentry would also likely have little to no effect upon the total composition of the atmosphere: The 70 to 75 pounds of dipoles that would fall back to Earth over the course of weeks or years paled in comparison to the 10,000 tons of micrometeorites that reenter each day at far greater velocity. In a subsection titled “contamination,” a group of four committee members suggested that the dipoles should not make any significant changes to the chemical composition of the nearest regions of space, given that the copper fibers would be essentially analogous to micrometeorite material. They warned that the naphthalene binder material used to package and dispense the dipoles would likely increase the amount of particulate matter at that altitude by “many orders of magnitude” with possible photochemical results visible to those with specialized equipment. However, they agreed that this effect would likely be short-lived, and negligible against a background of heavy emissions produced by as-yet hypothetical deep-space rockets or the thrusters of space probes.<sup>208</sup>

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<sup>208</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board,*

In a landmark statement in the conceptualization of near-Earth space as a vulnerable environment, the committee included a pointed statement about the likelihood of “future contamination of space” in the June 1960 report. In spite of the overarching recommendation that the project “should be done” as “a useful scientific experiment” that would not in and of itself obstruct research or destroy the physical and chemical environment in orbit, the committee issued a caveat. The committee evaluated the test system as presented by the Lincoln Laboratory. However, the ever-present specter of an operational system—denser, with a longer orbital lifetime, and possibly consisting of multiple belts—prevented committee members from issuing what might otherwise have been a net positive recommendation in favor of carrying out the test. This motivated the committee to issue a pointed statement about the likelihood of “future contamination of space” in the June 1960 revised report. Considering the possibility that, should Project Needles prove successful, dipole belts might become the wave of the future, the committee recommended that “the Board...consider whether it is desirable at this time to urge the formation, at the international level, of what might be termed a ‘Space Pollution Control Agency.’”<sup>209</sup> Although such a formal group did not imminently form following the publication of this report, this suggestion not only constituted one of the earliest arguments for orbital preservation against pollutants. It also foreshadowed imminent attempts by astronomers in America and Europe to appoint themselves as international environmental watchdogs for outer space.

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June 6, 1960, 3–5, SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>209</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960, 2.

Not all astronomers on the ad hoc committee were in favor—or even aware of—the change from condemnation to support in the June 6, 1960 revised report. Some appeared to be taken by surprise by the update. Fred Haddock, a radio astronomer serving on the ad hoc committee, sent an urgent Telex to chairman Villard claiming that he and the majority of other members of the committee strongly disagreed with the updated position and asking that the top-level recommendations revert back to the April 15 version in which the committee refused to endorse Project Needles.<sup>210</sup> Later that month the committee drafted a third revised report for distribution to the SSB membership. Its modified four-point position on Project Needles drew from both reports, and the overall conclusion on the advisability of the experiment split the difference between the outright condemnation of the April 15 version and the enthusiasm of the June 6 version. The first point concluded that the initial Needles experiment should not adversely affect any branch of science, followed by the caveat that any plans for an operational belt must protect the interests of astronomical research and “science in general.” The remaining points called for declassification and release of information through international channels, the establishment of globally protected frequency bands for radio astronomy, and the creation of a committee of radio astronomers who would serve as advisors to the Lincoln Laboratory to prevent interference to radio astronomy.<sup>211</sup>

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<sup>210</sup> Fred T. Haddock to O. G. Villard Jr., June 21, 1960, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>211</sup> *Space Science Board Position Re: Project Needles* (Space Science Board, National Academy of Sciences, June 30, 1960), NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

A larger wave of dissent followed the delivery of this final version of the report to SSB Chair Berkner and its distribution to the general board. Optical astronomers in particular felt that their interests were inappropriately subsumed under the priorities of radio astronomers. Leo Goldberg voiced some of most strident disapproval within the SSB. While Goldberg did not serve on the ad hoc Needles committee, he conducted his own independent calculations predicting the nature and lifetime of the belt and went directly to Berkner to lodge his complaints. Goldberg argued that the committee's report had underestimated the myriad possible damages that the belt could inflict on optical astronomy. He emphasized that the June 6 report that undergirded the final, cautiously positive SSB position on Needles relied on the calculations and opinions of two astronomers whose overall positive conclusions about the potential benefits of the dipole belt only served a small subset of optical researchers. Goldberg complained that the conclusions of two minority voices constituted "sheer nonsense as far as astronomers are concerned" and did not faithfully represent the position of the entire SSB.<sup>212</sup>

Attempting to allay Goldberg's concerns, Berkner reiterated his belief that a positive approach would yield the best results for astronomers as a larger group, supporting the conclusions and suggestions provided by the ad hoc committee and arguing that most dissent by general SSB membership stemmed from "unsubstantiated

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<sup>212</sup> Leo Goldberg to L. V. Berkner, November 25, 1960. NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1. NRAO.



fears of damage.”<sup>213</sup> Since the participants in the ad hoc committee had carefully determined the first experiment to be unobtrusive to astronomy, Berkner argued that the burden of proof now shifted to those who disagreed with their collective conclusions. He suggested that, as part of his preferred positive approach, apprehensive astronomers in Goldberg’s camp should instead view Project Needles as a carefully controlled experiment that could enable the United States to test and define the safe limits of such a system and set international protocol to police those limits—before some other, unscrupulous country tried it first. Berkner called for an end to what he considered to be nothing more than bewildering “grumbling” by Needles dissenters, but hedged in his commitment to the final committee report by suggesting to Goldberg that the opposition engage in a “true scientific study”—whether or not said study would comply with the ad hoc committee’s positive recommendation or result in the cancellation of the project. Regardless of outcome such an endeavor, Berkner believed, would “go much farther in safeguarding the unquestionable rights of astronomers.”<sup>214</sup>

While clearly irked by the accusation of baseless complaining, Goldberg agreed that a broader study ought to be arranged—though this would require declassifying sensitive information on Project Needles. Stating his doubt “that any single committee is capable of supplying all of the answers to a problem that has so many unknowns,” Goldberg called on the entire population of American astronomers to serve as watchdogs.

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<sup>213</sup> L. V. Berkner to Leo Goldberg, January 1, 1961, 1, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>214</sup> L. V. Berkner to Leo Goldberg, January 1, 1961, 3, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

If Berkner wished the burden of proof to be placed on their shoulders, all relevant Needles data must be widely published in the open scientific literature and astronomers given enough time to evaluate every detail before a decision could be made on whether or not the Air Force should be allowed to launch the project. Otherwise, Goldberg argued, “astronomers have a right to grumble.”<sup>215</sup> Berkner and Goldberg agreed that the time had come to publish the ad hoc committee’s studies and information on Needles in the open literature, in a journal that would be widely read by astronomers at home and abroad.<sup>216</sup>

In the meantime, the Secretary of the SSB met with several Lincoln Laboratory officials—including Needles designer Morrow—to discuss the SSB’s position. They eventually agreed that a more established SSB Needles committee could be useful “not only in safeguarding the Needles experiment from unjustified criticism but also in keeping the Board informed of significant aspects which may affect areas of basic research as the Needles project develops.”<sup>217</sup> The SSB disbanded the ad hoc Needles committee and organized a formal “watchdog” committee composed of three radio astronomers and one optical astronomer that would stand for the duration of the

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<sup>215</sup> Leo Goldberg to L. V. Berkner, January 3, 1961, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>216</sup> Shortly after his epistolary exchange with Berkner, Goldberg took the questions about next steps posed by Berkner to the membership of the SSB Committee on Astronomy. Optical astronomers on the committee expressed sympathy to Goldberg’s position, resentment at the implied responsibility forced upon them to prove the project as unsafe, a belief that even a small increase in background radiation could destroy observations of faint celestial objects, and the imperative that the project be assessed through “full and free discussion within [the] astronomical community.” Leo Goldberg, handwritten notes, n.d., Series HUG FP 83.18 Leo Goldberg National Academy of Sciences (NAS) Correspondence, 1956-1987, Box 6, Folder “Project Westford,” Harvard University Archives.

<sup>217</sup> R. C. Peavey to J. W. Findlay, July 29, 1960, NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

project.<sup>218</sup> This committee would serve as a liaison between the SSB general board and the Lincoln Laboratory, as well as an information conduit for members of the international radio and optical astronomy communities once the journal articles detailing Project Needles were published.<sup>219</sup> The four astronomers came together in their new roles for the first time in August 1960. In preparation to present the project publicly to potentially hostile audiences, the Lincoln Laboratory changed the experiment's name from Project Needles to the less-provocative "Project West Ford," after the town in which the Lincoln Laboratory built one of the ground terminals to be used to communicate using the dipole belt.<sup>220</sup>

Lincoln Laboratory staff and members of the SSB committee moved forward with a program of public information about the upcoming experiment. In September 1960,

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<sup>218</sup> At first, the watchdog committee was made up of three radio astronomers—John W. Findlay, Fred Haddock, and Arthur E. Lilley. Upon Goldberg's contention that this committee did not adequately reflect the concerns of other subdisciplines, optical astronomer William Liller was added to the roster. Leo Goldberg to L. V. Berkner, November 25, 1960. NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1. NRAO; R. C. Peavey to J. W. Findlay, July 29, 1960, NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO. L. V. Berkner to J. W. Findlay, December 26, 1960. NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1. NRAO.

<sup>219</sup> *Space Science Board Position Re Project Needles* (Space Science Board, National Academy of Sciences, June 30, 1960), NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO; *Space Science Board Position Re Project Needles* (Space Science Board, National Academy of Sciences, June 30, 1960), NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1, NRAO.

<sup>220</sup> In a memo to an Operations Coordinating Board official issued mere days after the revised SSB committee report, Raymond Courtney of the State Department detailed the necessity of public support for Project Needles and suggested methods to spread that support. His final recommendation: that the name of the project be changed to something "less ominous" than "Needles." His suggestions include "Sugar Candy" and "Cobweb." Memorandum from Raymond F. Courtney to Richard Hirsch, June 16, 1960, 14.B Outer Space 14.B.19 Project Needles 1960; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 347, National Archives at College Park, MD.

Walter Morrow presented his brainchild to the general assembly of the International Union of Radio Science.<sup>221</sup> Subsequently, researchers from the Lincoln Laboratory and the SSB published a series of papers in the April 1961 issue of the *Astronomical Journal* describing the projected properties of West Ford, though some details, such as the launch date and design of the dispenser mechanism, remained classified.<sup>222</sup> The *Astronomical Journal* articles predicted dipole lifetimes of one to two years before reentry. Although they would be placed in a relatively high orbit, the low mass-to-area ratio of the dipoles meant that sunlight pressure would in theory bring them all down within five years at maximum. In his article, Morrow insisted that the ethereal dipoles—less than an inch long and thinner than a human hair—would cause only minor surface scratches in the highly unlikely event that any of them should collide with other objects in space.<sup>223</sup>

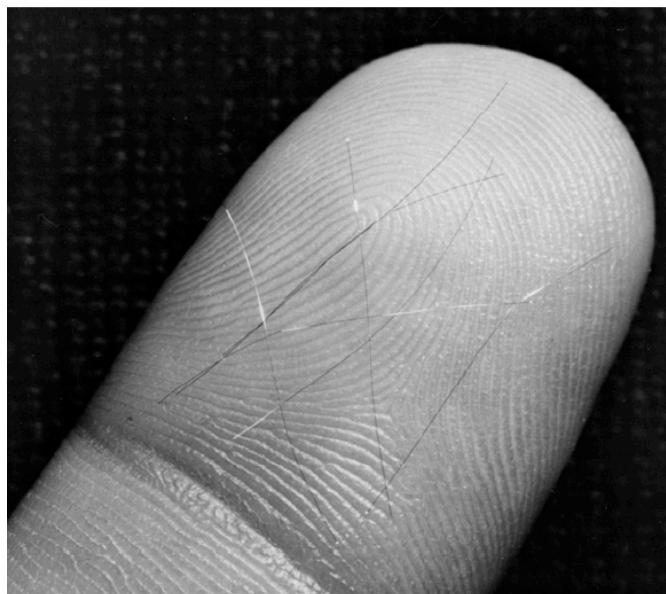
Hoping that this unusually high level of transparency for a military project would foster good will, West Ford's managers and the SSB West Ford Committee awaited response from the broader scientific community.

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<sup>221</sup> Morrow would later characterize his involvement in West Ford as reluctant, stating that he had been “dragged into this business as sort of the leading person,” and calling his various international travels to discuss West Ford as “fairly stressful.” However, Morrow also received awards for his work on West Ford, and was elected to the National Academy of Engineering in recognition of his work on orbital scatter communications and military communication satellite technology. Walter E. Morrow, Jr. ’49, SM ’51, Director, Lincoln Laboratory 1977-1998, interview by Toby A. Smith, June 17, 2010; “Lucky, Morrow, and Viterbi Elected to National Academy of Engineering,” *IEEE Communications Society Magazine* 16, no. 4 (July 1978): 7–8.

<sup>222</sup> William Liller, “Report on the Effects of Project West Ford on Optical Astronomy,” *The Astronomical Journal* 66, no. 3 (April 1961): 114.

<sup>223</sup> Morrow and MacLellan, “Properties of Orbiting Dipole Belts.”



**Figure 2.2:** Several West Ford dipoles displayed against an unidentified finger for scale.<sup>224</sup>

### **Expanding the Industrial Exosphere: West Ford and the Astronomers, 1961**

On October 22, 1961, a *New York Times* article conveyed a dire prediction by Dr. Harold Weaver, founder and director of the Radio Astronomy Laboratory at the University of California, Berkeley. Weaver did not mince words in criticizing Project West Ford. “This is a very bad omen for the future of astronomical research,” he prophesied. “It could mean the start of the demise of one branch of knowledge—astronomy.” Dr. Weaver’s opinion echoed that of a large number of optical and radio astronomers the world over who concurred with what they saw as, in Weaver’s play on Cold War political imagery,

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<sup>224</sup> W. W. Ward and F. W. Floyd, “Thirty Years of Research and Development in Space Communications at Lincoln Laboratory,” *The Lincoln Laboratory Journal* 2, no. 1 (1989): 5–34.

the act of “drawing a copper curtain over the Earth.”<sup>225</sup> The day before, the Air Force had made its first attempt to deploy Project West Ford.

In the months between the publication of the special issue of the *Astronomical Journal* in April and the West Ford launch in October, similarly apocalyptic visions of the end of an ancient discipline reverberated in local and international presses, in epistolary exchanges between individual astronomers, and among memberships of national and international scientific organizations determined to put a stop to the Air Force’s space needles project—or at least delay it until they were satisfied that the project would be safe for astronomy in the present and into what many astronomers predicted would be an imminent revolutionary future.

As one of the most prominent dissenters within the SSB, Leo Goldberg welcomed critique from a broadening scope of specialists from different astronomical disciplines, anticipating that the distribution of the heavy burden of proof assigned to him by Berkner across thousands of shoulders like Weaver’s would reinforce his position that West Ford should be prohibited. He bristled at the thought that the SSB had adorned West Ford with “a cloak of scientific respectability” in spite of the beliefs held by Goldberg and his optical astronomer associates that dipole belts would be “a menace to science.” In the interim between the final SSB report and the publication of the April 1961 *Astronomical Journal*, Goldberg issued a grave warning to Berkner on the likely outcome of the search

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<sup>225</sup> Special to The New York Times, “American Is Gloomy,” *The New York Times*, October 22, 1961.

for proof outside the ranks of the SSB, noting: “The reaction from the scientific community we represent is sure to be adverse and angry.”<sup>226</sup>

This prediction proved prescient. Almost immediately following the publication of the special issue of *The Astronomical Journal*, irate responses from astronomers began to roll in, both to the SSB and to the Lincoln Laboratory. The SSB general board’s imperative to publish details in a scientific journal yielded two concrete outcomes: Astronomers from around the world were indeed not adequately convinced that West Ford would not adversely affect their research; and the SSB ad hoc committee’s suggestion that transparency could yield international relations benefits proved almost comically over-optimistic. In the following months, individual astronomers and memberships of American and international scientific organizations united behind the collective opinion that the Air Force’s space needles project must be stopped, or at least delayed until those most likely to be impacted by the dipole belts were satisfied that the project would be entirely safe for current and future astronomical practices.<sup>227</sup>

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<sup>226</sup> Leo Goldberg to L. V. Berkner, January 3, 1961, National Radio Astronomy Observatory - Director’s Office - Professional Organizations/Committees - NAS Space Science Board - Project West Ford, Box 1, NAS-SSB - Project West Ford - File 1, National Radio Astronomy Observatory.

<sup>227</sup> Some astronomers imagined a practical use for the dipole scatter communications system in visions of a future colonized Moon. Czech astronomer Zdeněk Kopal and British amateur astronomer and science popularizer Patrick Moore wrote an article and a series of letters (respectively) to *New Scientist* promoting this idea. The Moon has no ionosphere, and a shorter horizon than Earth due to its small diameter, complicating long-range communications between points on the surface using tower transmitters and receivers. However, Moore also noted that the same concerns voiced by astronomers concerned about contamination of Earth orbit might also be replicated on the Moon—some Cold War futurists imagined the Moon to be a perfect potential site to build an observatory, unimpeded by atmosphere and light pollution. Zdeněk Kopal, “Communications on the Moon,” *New Scientist*, June 14, 1962, No. 291: 572-573; Patrick Moore, “‘Space Needles’ around the Moon?,” *New Scientist*, May 10, 1962, No. 286: 307.

In the second half of 1961, a flood of resolutions against the project issued forth from scientific organizations around the world. The International Union of Radio Science, the French and Belgian National Academies of Science, the Royal Astronomical Society, the American Astronomical Society, the Committee on Space Research of the International Council of Scientific Unions, and the International Astronomical Union (IAU) adopted resolutions against what the IAU unequivocally called the “contamination of space.” The IAU resolution framed orbital space as part of “Earth’s environment,” charging that no individual group or entity had the right to alter the conditions of what amounted to an international common pool resource without multilateral scientific consultation.<sup>228</sup> The same organization would reiterate its resolution a year later, employing similar rhetoric, following the resumption of high-altitude nuclear tests on both sides of the Iron Curtain. Renowned American and European astronomers such as Fred Whipple, Jan Oort, Lyman Spitzer, and Bernard Lovell registered their concern about West Ford through correspondence with the Kennedy Administration, the SSB, and the popular presses of their respective countries.<sup>229</sup> Many requested delays to the project so that apprehensive astronomers might better predict negative effects of the project and

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<sup>228</sup> William H. Littlewood, *French Academy of Science Resolution on Project Westford*, Foreign Service Despatch (Paris: American Embassy, November 27, 1961), West Ford Communications, Record 306 Box 13, NARA; American Astronomical Society, “Resolution Adopted by the Society at Its Annual Business Meeting, Nantucket, Mass., June 20, 1961,” June 20, 1961, 1 of 2 14.C Satellites 14.C.7m Project West Ford (Needles) 1961-62 [hereafter West Ford 1961-62]; General Records of the Department of State, 1763 - 2002, Record Group 59 Box 362, NARA; “Summary Record of the Ninth General Assembly of the International Council of Scientific Unions,” September 1961, West Ford 1961-62, NARA; *IAU News Bulletin of the XIth General Assembly of the International Astronomical Union Held in Berkeley, CA, August 15-24, 1961*, August 24, 1961, West Ford 1961-62, NARA.

<sup>229</sup> Lyman Spitzer to W. E. Gathright, July 3, 1961, Project West Ford, NARA; From Fred Whipple to George Derbyshire, May 12, 1960, Project Needles Records, NARA; From Jerome Weisner to J. H. Oort in Response to Cable, June 14, 1961, Project West Ford, NARA.



suggest changes.<sup>230</sup> The volume and intensity of these reactions prompted the Presidential Science Advisory Committee and the State Department to enter the fray in order to mediate the dispute, with one State Department official observing in private bewilderment: “Astronomers seem to be a remarkably noisy and parochial group!”<sup>231</sup>

Astronomers had several reasons for raising their voices against West Ford in 1961. One reason concerned the possibility that new types and quantities of industrial products and byproducts would further overtake and obscure the night sky, to an even greater extent than had already occurred over decades of burgeoning industrialization. Optical astronomers as a group were historically no strangers to environmental conflict, engaged as they were in what historian David Aubin has characterized as a century-long effort to preserve the skyward gaze in the face of instrument-disrupting vibrations and what we now call light pollution resulting from urbanization and industrialization.<sup>232</sup> Optical astronomers feared that the reflective dipoles could raise the brightness of the sky in a “Milky Way effect,” impeding their ability to obtain images of celestial objects even on the clearest nights.<sup>233</sup> Radio astronomers, practitioners of a relatively new discipline operating at a wavelength unencumbered by the natural and artificial obscuring properties

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<sup>230</sup> Cedric W. Jr. Tarr, *Summary of Scientific Reaction to Project West Ford* (Department of Foreign Affairs, May 27, 1963), Folder 579, MITLL.

<sup>231</sup> Handwritten note attached to letter from Lyman Spitzer to W. E. Gathright, July 3, 1961, Project West Ford, NARA.

<sup>232</sup> For more on the 19<sup>th</sup> century dialectic between observatory and city, see David Aubin, “The Fading Star of the Paris Observatory in the Nineteenth Century: Astronomers’ Urban Culture of Circulation and Observation,” *Osiris*, 2nd Series, 18 (January 1, 2003): 79–100; David Aubin, Charlotte Bigg, and Heinz Otto Sibum, eds., *The Heavens on Earth Observatories and Astronomy in Nineteenth-Century Science and Culture*, Science and Cultural Theory (Durham [NC]: Duke University Press, 2010).

<sup>233</sup> Tarr, *Summary of Scientific Reaction to Project West Ford*, MITLL; I. S. Bowen to Jerome Weisner, June 8, 1961, Record Group 359 Box 114 Folder Space - Satellite - Westford 1961, NARA.

of the atmosphere, struggled with a different kind of pollution—that of the radio spectrum. Radio astronomers had already begun to agitate for legal allocation of specific frequencies for observation—a proposed panacea that came up in many of the anti-West Ford resolutions.<sup>234</sup> For radio astronomers, the dipoles could raise the background noise of the night sky, making it difficult to differentiate their objects of study from an excess of surrounding information. Worse yet, radio astronomers anticipated that a high volume of reflective copper could yield a spectacular rise in false signals, which might indicate the existence of a distant celestial object when in reality the signal came from a proximate anthropogenic object. A permanent, dense set of belts—ostensibly the end game of a successful Project West Ford in astronomers’ understanding—would drastically compound the concealing qualities of the industrial atmosphere with dire consequences for both extant forms of observational astronomy.

Plans for new observational tools and practices that promised to revolutionize the discipline of astronomy as a whole were also at stake. At roughly the same time that the West Ford controversy raged, the initiative led by prominent American astrophysicist Lyman Spitzer to develop the first generation of Orbiting Astronomical Observatories to observe the cosmos in ultraviolet wavelengths began to gain favor within the ranks of the National Academy of Sciences.<sup>235</sup> Spitzer led the American Astronomical Society in its

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<sup>234</sup> David P. D. Munns, *A Single Sky: How an International Community Forged the Science of Radio Astronomy* (The MIT Press, 2013), 3–4; R. L. Smith-Rose, “Protection of Radio Frequencies for Scientific Research,” *Proceedings of the IEEE* 52, no. 5 (May 1964): 451; American Astronomical Society, “Resolution Adopted by the Society at Its Annual Business Meeting, Nantucket, MA, June 20, 1961.”

<sup>235</sup> Robert W. Smith, *The Space Telescope: A Study of NASA, Science, Technology, and Politics* (Cambridge [England] ; New York: Cambridge University Press, 1989), 30.

anti-West Ford resolution, which specifically condemned the project as a threat to orbiting space observatories scheduled to be operational within two to three years.<sup>236</sup> The IAU resolution similarly emphasized the risk to future astronomical practices both anticipated and as yet undetermined, indicating an international expectation that collecting astronomical data from outer space would become an indispensable practice in the coming decades.<sup>237</sup>

Aspiring space astronomers anticipated that space telescopes would open entire unseen parts of the electromagnetic spectrum that could not be observed from the ground, including light in gamma ray, X-ray, and ultraviolet wavelengths. At such an early stage of planning, advocates of space astronomy were unsure which orbital altitudes or inclinations different types of space observatories might occupy. Should the West Ford belt (or future West Ford-type belts) inhabit the same environs as a space telescope, the dipoles might collide with and damage the spacecraft. More importantly, some astronomers expressed concern about the high altitude of the proposed West Ford belt. At 3600 kilometers above the ground, a cloud of dipoles would be above the supposed altitude limit for exoatmospheric nuclear weapons; but it could also effectively extend the obstructive effects of the atmosphere so high as to force future orbiting observatories to be launched to even higher—and thus more expensive and riskier—altitudes. Optical astronomer William Liller of the SSB West Ford committee, one of a small number of West Ford moderates in 1961, noted these concerns as his ultimate apprehension about

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<sup>236</sup> American Astronomical Society, “Resolution Adopted by the Society at Its Annual Business Meeting, Nantucket, Mass., June 20, 1961.”

<sup>237</sup> “IAU News Bulletin of the XIth General Assembly of the International Astronomical Union Held in Berkeley, CA, August 15-24, 1961.”

the project, warning that the opportunity to observe extremely faint objects from the unparalleled darkness above the atmosphere might be permanently destroyed by a fully functional dipole system.<sup>238</sup> Astronomers opposed to West Ford anticipated the latest environmental threat to their practices in a new form of pollution made of a common industrial material, redolent of the changes that had plagued previous generations of their profession. However, unlike the Industrial Age atmosphere, the Space Age atmosphere could not be escaped by observing from an isolated, high-elevation location. Space Age industry would be truly global, and therefore unavoidable. These formal resolutions highlighted the possibility that the foreseen revolution in astronomy would die before it could take off. Given the highly charged anxiety about threats to both ground-based and space-based astronomy evidenced in these official collective pronouncements, it is perhaps no wonder that some astronomers believed West Ford to be, in the words of British astronomer Fred Hoyle, an “intellectual crime” committed by the United States government against science as a whole.<sup>239</sup>

However, not all American astronomers were united in favor of space telescopes. In the midst of the post-war surge in federal funding for scientific research, a long-standing rivalry between astronomers living in the American West and those living on the Eastern seaboard sparked anew. Many on the West Coast argued that federal funds allocated to a space telescope could be better spent building more telescopes in regions of the American west that had the high, dry conditions necessary for optical and radio

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<sup>238</sup> William Liller, “Report on the Effects of Project West Ford on Optical Astronomy,” *The Astronomical Journal* 66, no. 3 (April 1961): 114.

<sup>239</sup> Howard Simons, “Missing or Not, Needles Point Up U.S. Intention,” *Washington Post*, October 29, 1961.

observation—known as “good seeing.” No big telescopes had been built on the east coast for decades, and some astronomers on the West coast claimed that the embrace of federal funding and plans for a space telescope among East coast astronomers was part of a plan to wrest power and capital from western research institutions, many of which continued to receive private funding. In 1963 Allan Sandage of the Palomar Observatory vehemently rejected calls by his East Coast colleagues for an orbiting observatory, calling support for such a project “space propaganda.”<sup>240</sup>

However, even Sandage united with his east coast rivals and space telescope advocates in condemning West Ford. Irwin Shapiro, one of West Ford’s chief designers at the Lincoln Laboratory, recalls receiving a phone call from Sandage during which he argued that the artificial ionosphere was a conspiracy by East Coast astronomers to put West Coast astronomers—and their mountaintop observatories—out of business. Should the West Ford needles block the view from the ground, federally funded space telescopes would be the only legitimate sensors available to astronomers, and leadership in American astronomy would shift back east to space telescope control rooms in Washington. According to Sandage, his colleagues on the East Coast could even be conspiring with the Lincoln Laboratory to force this power shift, their protests a deliberate, Janus-faced act to obscure their true support for West Ford.<sup>241</sup> In this mindset, a cloud of copper fibers in orbit would serve an insidious political purpose beyond those stated by the American military, promoting a shift in the power hierarchy of American

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<sup>240</sup> W. Patrick McCray, *Giant Telescopes: Astronomical Ambition and the Promise of Technology* (Harvard University Press, 2004), 45–49.

<sup>241</sup> Irwin Shapiro, in conversation with the author, June 26, 2014.

astronomy. Whether for or against space telescopes, many American astronomers expected West Ford to change their professional lives for the worse.

Western astronomers who opposed West Ford in its design phases expressed their dissent as self-defense against a looming disciplinary crisis over which they appeared to have little authority or sway. Unsurprisingly, the reaction of Soviet scientists revealed similar resistance. Academician Mstislav Keldysh, president of the Soviet Academy of Sciences, wrote a letter to the president of the American National Academy of Sciences that took the language of space contamination perpetuated in other anti-West Ford pronouncements a step further, admonishing what he called a precedent that could lead to “serious pollution of space near the Earth.”<sup>242</sup> These rhetorical characterizations of outer space as an environment at risk in late 1961 mirror the language of the lab—“pollution” and “contamination” reflect multiple, context-bound connotations. However, the choice of these words in particular would later serve a different purpose in the hands of the mainstream press in America and overseas under a different cultural context. For the time being, most popular newspapers across the world that picked up the story in 1961 focused on astronomers’ disciplinary complaints, the growing number of American government and diplomatic mediators brought into the fray, and the inflammatory response of Soviet presses to what they characterized as unacceptable military activity in orbit. For the time being, the potential destruction of a site of real or imagined scientific practice represented

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<sup>242</sup> “Soviet Scientists Oppose American ‘West Ford’ Project - Letter from M.V. Keldysh, President of the U.S.S.R. Academy of Sciences,” *The Current Digest of the Russian Press*, October 18, 1961, No. 38, Vol. 13 edition.

a compelling enough story to transmit to lay audiences in media markets from Brussels to Bombay.

Days in advance of the classified launch date, John Findlay of the SSB West Ford committee visited Europe in an attempt to gauge the general feelings about the project among astronomers across the Atlantic. After discussing the expected properties of the belt and its estimated lifetime, Findlay reported back to the SSB that the majority of British astronomers that he met were in agreement that the impact of the project as proposed on radio and optical astronomy would be negligible. He noted that the biggest concern among astronomers continued to be a long orbital lifetime for the dipoles and future dense belts. Findlay concluded that the best solution to allay these concerns would be to conduct the experiment and solicit *in situ* test feedback from the larger international scientific community.<sup>243</sup>

The Air Force moved ahead with the launch on the strength of Findlay's recommendation and the advice of the Presidential Science Advisory Committee's panel on Project West Ford.<sup>244</sup> A West Ford package launched on October 21, 1961, piggybacked atop an Atlas-Agena expendable rocket alongside a classified military reconnaissance satellite.<sup>245</sup> However, the dispenser mechanism failed to operate as designed, emitting clumps of dipoles in nonfunctional clusters. The SSB distributed data

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<sup>243</sup> John W. Findlay, "Notes on a Visit to England on West Ford," October 19, 1961, Folder 3427, MITLL.

<sup>244</sup> "West Ford Statement" (Space Science Board, National Academy of Sciences, August 11, 1961), West Ford - Communications Experiment 1961 - 1961; Records of the U.S. Information Agency, 1900 - 2003, Record 306 Box 13, National Archives at College Park, MD; "Department of Defense White Paper on Project West Ford."

<sup>245</sup> Karl-Heinz Bockstiegel, Marietta Benko, and Stephan Hobe, eds., *Space Law: Basic Legal Documents*, vol. 1 (Utrecht: Eleven International Publishing, 2005), A.IX.1.

on the failure of the project, and the expected orbital properties of the dipole clumps, although neither the Lincoln Laboratory nor outside astronomers could establish visual or radio contact with the deployed objects.<sup>246</sup>

West Ford appeared to be only temporarily grounded by this setback. The Air Force immediately began working on a new dispenser that would not only disperse the dipoles as directed, but would incorporate concerned astronomers' requests that the mechanism be activated manually by a signal from the ground rather than deploy automatically. With these modifications, the dipoles would only disperse if the package reached a "resonant" orbit—one that ensured that solar pressure would force the dipoles to reenter the atmosphere after a short orbital lifetime.<sup>247</sup> To all outward appearances, the Air Force and Lincoln Laboratory had catered to astronomers' demands, altering the West Ford mission accordingly in the lead up to a second launch attempt.

However, a new wave of controversy would surround West Ford before and after this second launch. A pronounced shift in worldwide popular media coverage of the second West Ford attempt took radio and optical astronomers' 1961 resolutions and refashioned their invocations of celestial contamination in proto-environmentalist terms. By referring to the dipoles as invisible waste, these journalists rendered the threat identified by astronomers recognizable to a broad lay audience increasingly aware of, and

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<sup>246</sup> John W. Findlay, "Memorandum for Members of the West Ford Committee of the International Astronomical Union" (National Academy of Sciences Space Science Board, March 8, 1962), Science Service Astronomy and Astronautics Files Box 72 Folder 14 Space Communications - Project West Ford, Smithsonian National Air and Space Museum Archives.

<sup>247</sup> John W. Tukey et al., *Steps Taken by U.S. Government and Lincoln Laboratory with Regard to Consultation and Information Exchange with Foreign and Domestic Scientists on Project WEST FORD* (Washington, DC: Office of Science and Technology, June 7, 1963), Folder 579, MITLL.



concerned about, local terrestrial pollution. The “space pollution” feared by some astronomers in 1961 represented a new kind of hidden environmental hazard imposed by the United States government, military, and industry upon a nonconsenting society. In newspapers and radio programs, dipoles fit neatly alongside chemical pesticides and nuclear fallout into an increasingly publicly maligned category of invisible dangers to life and property. Rather than an esoteric threat to astronomers’ present and future practices, the real threat of West Ford transformed in the hands of mainstream journalists and newspapers editors into a global environmental crisis with moral ramifications for all humankind.

### **Litterbugging Space: West Ford and Emerging Environmentalism, 1963**

Both the United States and the Soviet Union resumed conducting atmospheric nuclear tests after a brief moratorium collapsed in 1961. The 1962 American exoatmospheric nuclear test codenamed Starfish Prime exploded at an altitude of 400 kilometers, well beyond the 100-kilometer high Karman line widely, if unofficially, considered to be the boundary between the terrestrial atmosphere and outer space. Not only did Starfish Prime disable radio and television systems 700 miles away in Hawaii; it also damaged or permanently disabled eight of the twenty-four active communications satellites in orbit at the time of detonation. The groundbreaking, iconic telecommunications satellite Telstar eventually went silent due to the Starfish Prime blast. The grave results of this test meant that the conditions that initially suggested using a field of passive reflectors for a nuclear-proof military communications backup in 1962 had become even more serious, and justified the need for a second West Ford test.

The Air Force moved forward with plans for a second launch in late 1962. As urged by the SSB committee, details of changes to the experiment were released to astronomers, largely through the SSB committee and major scientific unions. By this time, many individual astronomers who had once protested the project as dangerous and shortsighted had tempered their tone. In early May of 1962, the IAU committee on West Ford overwhelmingly voted to stand down. After further study of the first test launch, and continuing research on the effects of reflective satellites on astronomical research, members of the committee were satisfied that the test project itself would not pose an immediate threat to optical or radio astronomy. They were also encouraged by ongoing communication from the Air Force and the Presidential Science Advisory Committee about changes to the payload that would safeguard against a long orbital lifetime for the dipoles, such as the inclusion of a device that would only deploy the dispenser upon a signal from the ground, thus assuring that the dipoles would not dispense unless they had reached the correct orbit from which they would decay on the proposed 2-year schedule. The IAU as a group elected to adopt a wait-and-see approach to West Ford and agreed to conduct tests on the belt should the second launch attempt succeed, and committed to sharing collected data with the Lincoln Laboratory and the SSB after the dipoles deployed.<sup>248</sup>

However, some individual astronomers, particularly in the United Kingdom, remained vocal in their opposition. British radio astronomers, who saw themselves as

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<sup>248</sup> D. H. Sadler, "D. H. Sadler to J. van Miegheem," May 10, 1962, Series HUG FP 83.18 Leo Goldberg National Academy of Sciences (NAS) Correspondence, 1956-1987, Box 6, Folder "Project Westford," Harvard University Archives.

leaders in their nascent field, were notably vociferous.<sup>249</sup> A few short months after publishing multiple journal articles criticizing Soviet and American high-altitude nuclear tests, the newly knighted radio astronomer Bernard Lovell once again loudly voiced opposition to what he saw as the “unforgiveable contamination of space.”<sup>250</sup> When asked about his opinion towards West Ford in the intervening time between the 1961 failed launch and the anticipated second attempt, Lovell stated: “My attitude to this experiment has not changed one scrap. I deplore it.”<sup>251</sup> He interpreted the test as a unilateral incursion into space by the United States military without adequate consultation with the international astronomical community—an opinion shared by Lovell’s British comrades in radio astronomy but not the majority of astronomers represented by the IAU who had reacted favorably to the information shared by the SSB before and after the first launch. Lovell and his allies dominated press coverage of the second West Ford launch attempt. While the 1961 launch had spurred a flurry of press critical of the project’s potential impact on astronomy research—an issue of romantic if not urgent interest to nonspecialists—the imminent second launch transformed in the hands of a vocal minority of astronomers and mainstream journalists into much larger problems of appropriate consultation, consent, and contamination of a delicate natural environment.

The minority opinion that the Air Force had insufficiently solicited astronomers’ advice about space pollution resonated with an international mainstream population

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<sup>249</sup> Robert C. Cowen, “West Ford ‘Needles’ Sift Safely Earthward: Criticism Persistent,” *The Christian Science Monitor*, December 23, 1966.

<sup>250</sup> Bernard Lovell, “The Challenge of Space Research,” *Nature* 195, no. 4845 (September 8, 1962).

<sup>251</sup> Peter Fairley, “Millions of Needles in Space,” *Evening Standard*, May 1963.

increasingly aware of invisible contamination of ecosystems and bodies. The “almost invisible” needles that had caused such uproar among scientists in the preceding years corresponded with growing cultural anxiety about unseen pollutants following the publication of Rachel Carson’s bestselling book *Silent Spring* during the 1962 leadup to the planned second launch.<sup>252</sup> Popular outrage over nuclear fallout increased in the United States and abroad as atmospheric nuclear tests resumed following the end of a short moratorium. 1962 saw the highest number of nuclear weapons tests in history, including several record-breaking high altitude and exoatmospheric tests that damaged active satellites and generated new global fallout patterns.<sup>253</sup> With the increasing regularity of nuclear detonations and evidence of radiation sickness in those proximate to weapons tests, anxiety over nuclear fallout—a largely invisible, insidious bodily threat—had already worked its way into American popular consciousness and culture. Themes of bodily contamination from an unseen source, imposed upon millions of people who had not sanctioned or consented to its use, showed up in a wide array of popular media from movies to novels.<sup>254</sup>

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<sup>252</sup> “Project West Ford – Report on the ‘Needles in Space’ Program,” *Microwave Journal* 5, no. 10 (October 1962): 69. For a brief overview of the Presidential Science Advisory Committee’s reactions to environmental threats including nuclear fallout, pesticides, and West Ford, see Wang, *In Sputnik’s Shadow*, 200–202.

<sup>253</sup> “SIPRI Yearbook of World Armaments and Disarmament.,” *SIPRI Yearbook of World Armaments and Disarmament.*, 1969.

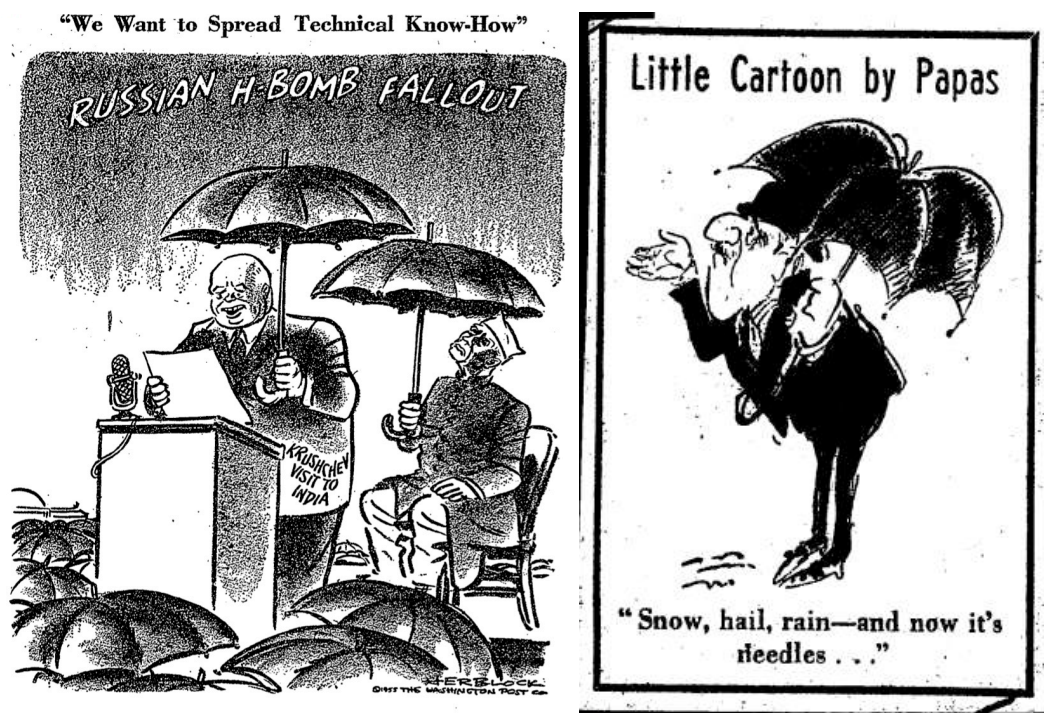
<sup>254</sup> Joshua David Bellin, “Us or Them!: *Silent Spring* and the ‘Big Bug’ Films of the 1950s,” *Extrapolation* 50, no. 1 (March 22, 2009): 145; Ralph H. Lutts, “Chemical Fallout: Rachel Carson’s *Silent Spring*, Radioactive Fallout, and the Environmental Movement,” *Environmental Review: ER* 9, no. 3 (October 1, 1985): 211–25.

In *Silent Spring*, Rachel Carson used nuclear fallout as a clarifying metaphor to reify the invisible threat of chemical pesticides to a general readership.<sup>255</sup> As this groundbreaking book rose to cultural currency, fallout and pesticides together came to serve as a convenient referent for any unseen military or industrial threat—space experiments included. Political cartoons satirically featuring umbrellas as protection against nuclear fallout and copper space needles alike suggest continuity between popular responses to the atmospheric nuclear tests of the late 1950s and early 1960s and the specter of mismanagement of near-Earth space. Through the symbol of an umbrella as meager localized shelter, these images illustrated the futility of individual defense against the global actions of a faceless military-industrial complex that appeared to operate against the moral guidance of scientists and the consent of citizens. The ascendance of *Silent Spring* between the two West Ford missions likely eased the way for a shift in journalistic focus during the second launch.<sup>256</sup>

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<sup>255</sup> Ralph H. Lutts, “Chemical Fallout: Rachel Carson’s *Silent Spring*, Radioactive Fallout, and the Environmental Movement,” *Environmental Review: ER* 9 (October 1, 1985): 211–225.

<sup>256</sup> Ralph H. Lutts, “Chemical Fallout: Rachel Carson’s *Silent Spring*, Radioactive Fallout, and the Environmental Movement,” *Environmental Review: ER* 9 (October 1, 1985): 211–225.



**Figure 2.3:** Political cartoons about nuclear fallout (left) and West Ford (right) both use an umbrella to signify the futility of resistance against global-scale military pollution.<sup>257</sup>

Unlike Cold War physicists, whom Ron Doel and Alison Kraft have described as taking on “outsider” roles to combat the moral and environmental impacts of nuclear weapons in the mid-1950s, astronomers at first did not deliberately attempt to translate their political concerns into moral imperatives that would resonate with environmentally aware lay communities.<sup>258</sup> While they might not have explicitly agitated for the environmental protection of outer space in their exchanges with popular media outlets,

<sup>257</sup> Herblock, “Editorial Cartoon 1 -- No Title,” *The Washington Post and Times Herald*, November 3, 1955; William Papas, “Little Cartoon by Papas: ‘Snow, Hail, Rain, and Now It’s Needles...,’” *The Sunday Times*, May 19, 1963.

<sup>258</sup> Ronald E. Doel, “Scientists as Policymakers, Advisors, and Intelligence Agents: Linking Contemporary Diplomatic History with the History of Contemporary Science,” in *The Historiography of Contemporary Science and Technology*, ed. Thomas Söderquist, 1st ed. (Routledge, 1997), 226; Alison Kraft, “Bombs, Blood, Borders: Radiostrontium – a Biography” (presented at the Symposium Honoring Ruth Schwartz Cowan, Philadelphia, May 3, 2013).

American astronomers serving on the SSB internally expressed firm belief in the great esteem in which the lay public held scientists in general, and astronomers in particular—especially in the Soviet Union, where the SSB West Ford committee claimed that astronomy has “great stature in the public mind.” These astronomers suggested that a lay populace would side with rebelling astronomers, even if it did not fully understand the purpose of their protest.<sup>259</sup> The language of their concern about correct and conservative activities in space found traction with journalists and newspaper editors across the world. The cultural archetype of the moral American scientist as celebrated by Rachel Carson clashed with shifting postwar public opinions about the integrity of physical scientists; however, astronomers actively fashioned a professional identity entirely separate from their physicist counterparts.<sup>260</sup> Conflated with growing public awareness of invisible large-scale contamination and backlash against unilateral military action on Earth and beyond, astronomers’ words against Project West Ford—processed through the writings of mainstream journalists—provided damning arguments against the Air Force in foreign and domestic popular presses.<sup>261</sup>

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<sup>259</sup> *Project Needles: An Evaluation Report by an Ad Hoc Committee of the Space Science Board*, June 6, 1960. NRAO - Director’s Office - Professional Organizations/Committees - SSB West Ford, Box 1, NAS-SSB - Project West Ford - File 1. NRAO.

<sup>260</sup> For more on the disciplinary identity of Cold War astronomers as physical scientists and their resistance to federal patronage, see McCray, *Giant Telescopes*; Doel, *Solar System Astronomy in America*.

<sup>261</sup> For more, see: Zuoyue Wang, *In Sputnik’s Shadow*; Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993); Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (New York: Oxford University Press, 2013); Audra J Wolfe, *Competing with the Soviets: Science, Technology, and the State in Cold War America* (Baltimore: Johns Hopkins University Press, 2013).

When the Air Force launched a second West Ford package on May 8, 1963, the dipoles successfully dispersed into a single polar-orbiting belt. The SSB West Ford Committee solicited feedback from interested astronomers about whether or not they had been able to detect any of the dipoles, or whether the experiment had negatively affected their research.<sup>262</sup> When the Air Force announced the launch, this particular detail of information sharing went unremarked in mainstream news reports. Instead, a firestorm of criticism surrounded the announcement, with some American and European newspaper editorials arguing that the United States military had willfully ignored the advice of morally engaged, environmentally conscious astronomers to cancel the launch.<sup>263</sup>

The Soviet government saw this clash as an opportunity. Academician Keldysh, who had called West Ford “unscientific” in 1961, saw his criticism amplified by the more famous and charismatic voice of cosmonaut Gherman Titov, the second person to orbit the Earth. Titov publicly lambasted the experiment as a subversive capitalist act of sabotage against progress and science—a cynical attempt by “American monopolists” to wrest access to Earth orbit from superior Soviet engineers. He suggested that the American government would rather use copper needles to make space impassable—a place where no man, including an American, could go—than allow cosmonauts to claim

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<sup>262</sup> J. A. Kessler, “Background Material on Project West Ford,” May 6, 1963, History of West Ford, MITLL.

<sup>263</sup> “Space Dirt,” *Daily Worker*, May 8, 1963; John Leroy, “Background Commentary,” *Daily Mirror*, May 14, 1963; “Rubbish Round the Earth,” *The Guardian*, May 17, 1963; Iain Ferguson, “Stars May Be a Memory by 1984,” *Manchester Evening News*, May 16, 1963, MIT Lincoln Laboratory Archives, Lexington, MA



near-Earth space for Communism.<sup>264</sup> The ongoing, highly publicized international condemnation of West Ford sparked terse interactions between the United States and foreign delegations at the United Nations, and led American Ambassador Adlai Stevenson to go before the UN General Assembly less than a month after the second launch to defend the United States' decision to move forward with the test.<sup>265</sup>

While some news items of this period mention astronomers' concerns about their research, the majority of critical articles and editorials from 1963 represent scientific dissent to West Ford as more concerned with preventing the "serious pollution" in space predicted by Academician Keldysh two years prior.<sup>266</sup> One such editorial, published in the *New York Times* on the day of the second launch and cited by newspapers across the world, declared "there is no United States right unilaterally to make changes in the space environment of this planet." The editorial does not mention the change in IAU policy regarding West Ford, arguing instead that the project had not received sufficient scientific vetting.<sup>267</sup> This editorial and many more of its kind published worldwide characterized West Ford within the same military lineage as Rachel Carson's chemical pesticides and the high-altitude nuclear tests that created new radiation belts and threatened the bodies of non-consenting citizens below. Each of these developments came about with the assurances of an unreliable government public relations machine that they would be safe;

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<sup>264</sup> "Speech by Comrade G. S. Titov, USSR Cosmonaut, Moscow Province Party Organization," *The Current Digest of the Russian Press*, February 28, 1962, No. 5, Vol 14.

<sup>265</sup> Adlai E. Stevenson, "Letter from Ambassador Adlai E. Stevenson, United States Representative to the United Nations, to Secretary General U Thant," June 6, 1963, Folder 579, MIT Lincoln Laboratory Archives, Lexington, Massachusetts.

<sup>266</sup> "Soviet Scientists Oppose American 'West Ford' Project - Letter from M.V. Keldysh, President of the U.S.S.R. Academy of Sciences."

<sup>267</sup> "More Needles in Space," *The New York Times*, May 8, 1963.

and each came to be seen as the potential source of unintended, catastrophic environmental change. In these critical articles, West Ford set a “dangerous precedent” by allowing the American military to embark on unilateral activity in space.<sup>268</sup> Should projects like West Ford continue unchecked, these journalists argued that the United States government would proceed with unmitigated power. The military could subsequently unleash forces of environmental destruction that would go beyond the dramatic spectacle of nuclear bombs. Though West Ford involved relatively mundane copper filaments they, like fallout, could quickly and easily prove a destructive problem too difficult to solve.

This journalistic narrative of local and global pollution from West Ford supplanted astronomers’ disciplinary anxieties as the primary focus of popular news outlets. Whereas articles on West Ford at the time of the first launch took a neutral position on the project, focusing mainly on the existential crisis anticipated by astronomers, by the time the second launch attempt came around, American and foreign newspapers referred to the project as “rubbish,” “litter” and “cluttering;” the dispersal of dipoles as “dumping” in space.<sup>269</sup> An editorial in the *Providence Rhode Island Journal* accused the Air Force of “litterbugging the sky” and the *San Francisco Chronicle* issued a jeremiad mourning a “space environment cluttered with litter.”<sup>270</sup>

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<sup>268</sup> “Protests Continue Abroad,” 1961.

<sup>269</sup> “Rubbish Round the Earth,” *The Guardian*, May 17, 1963; “Space Litter,” *Oldham Evening Chronicle*, May 17, 1963; “Project Needless?,” *The Evening Star*, May 14, 1963.

<sup>270</sup> “The New Fight Over the Space ‘Needles,’” *Providence RI Journal*, May 9, 1963. “Messing Up Space,” *San Francisco Chronicle*, May 9, 1963.

Many popular news reports of West Ford clung to the “needle” pejorative in describing waste that was not only dangerous in aggregate, but individually perilous, imbued with a sharp shape with commonplace analogs familiar from suburban mothers’ sewing kits—a pollutant more easily visualized than the contemporary invisible menaces of pesticides and nuclear fallout.<sup>271</sup> Tiny copper filaments in space might not otherwise seem like much of an environmental threat on the ground. Translating the shape of the project rendered the dipoles material and therefore more easily comprehended by a range of non-scientist audiences. Although the Lincoln Lab attempted to comply with the SSB’s suggestion of a thorough public information campaign three years prior, the series of press releases distributed in advance of each launch apparently did not ward off all fears of the dipoles coming home to roost. For instance, a columnist with a local British paper pondered if metallic debris recovered from his neighborhood cabbage gardens might have fallen from space, and invited anyone with relevant expertise to examine and authenticate the artifacts.<sup>272</sup>

In contrast, Lincoln Laboratory staff sought to use the same material attributes of the dipoles to combat their portrayal in the popular press as environmental pollutants. As mentioned in Chapter 1, John Kessler of the Lincoln Laboratory Office of the Director circulated samples of the dipoles to American journalists, foreign diplomats, and others who might help change the mainstream conversation about West Ford. Packets of dipoles that could be seen and handled directly confirmed their minute size, familiar composition, and apparent harmlessness. Unlike chemical pesticides or nuclear fallout, a person could

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<sup>271</sup> “Satellite Punctures Space with Millions of Needles,” *Associated Press*, May 13, 1963.

<sup>272</sup> Whiffler, “‘Space Needles’ in Norwich?,” *Eastern Evening News*, May 24, 1963, MITLL.

safely and repeatedly encounter a copper dipole. The dipoles themselves resembled fine hair, lending them natural, almost human qualities. Kessler's attempts to solicit a kinder, gentler name and material identity for the project found little official or popular traction in the spring of 1963.<sup>273</sup>

Those who directly worked on the design of Project West Ford had an entirely different view of the same minute copper fibers. Rather than penetrating needles, nonthreatening “fluff,” or careless cosmic clutter, these individuals perceived the West Ford dipoles as innovative space technology, individually and collectively. In the words of one West Ford engineer, each dipole represented a discrete spacecraft—performing a defined function in the space environment for which it was designed. From this perspective, those who worked on Project West Ford had the distinction of designing and manufacturing the largest number of satellites in orbit, a record that they still hold.<sup>274</sup> Yet another community interpreted the dipoles differently: Amateur radio operators expressed interest in using the open-access dipole belt for long-distance transmissions—a hallmark of prestige for many ham radio enthusiasts. Although the high-powered transmitters needed to utilize the dipoles presented a cost obstacle to most operators, at least one active amateur community in the United Kingdom enthusiastically solicited data on the West Ford belt from Lincoln Laboratory and celebrated the 1963 launch as a boon to

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<sup>273</sup> J. A. Kessler to Watson Davis, Director Science Service, May 22, 1963, History of West Ford, MITLL. Oswald F. Schuette to J. A. Kessler, May 20, 1963, History of West Ford, MITLL; Barbara Tufty to J. A. Kessler, May 27, 1963, History of West Ford, MITLL.

<sup>274</sup> Charles W. Perkins, in conversation with the author, January 17 2010.

radio research.<sup>275</sup> The interpretive flexibility surrounding the design of communications satellites at the time of West Ford's genesis persisted even as active satellites settled into the current standard form by the mid-1960s. Questions of interpretation in play in 1963 concerned not what a communications satellite should be, but rather, what constituted a functional satellite and what constituted dangerous space debris. Even a minute, hairlike copper fiber, when placed in orbit and the subject of intense, worldwide public debate over its safety, could be categorized anywhere within a range of ontological possibilities that depended on the political, institutional, and disciplinary location of the interpreter.

In summary, during the months leading up to the first, failed attempt to launch West Ford into orbit, astronomers expressed their concern in terms of disciplinary crisis. Fearing the loss of their contemporary and anticipated future observational practices, West Ford detractors spoke out through professional society resolutions and direct correspondence with the Space Science Board and the Lincoln Laboratory, and in doing so instigated a discourse of contamination and environmental risk that would eventually prove both volatile and enduring. As the second, successful launch attempt neared, fewer astronomers raised their voices in dissent. However, a vocal minority upheld the original collective complaint and, in some cases, amplified their disapproval to a fever pitch—one American astronomer likened non-action on West Ford by the IAU to Chamberlain's policy of appeasement towards Hitler during World War II, and anticipated an inevitable

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<sup>275</sup> Correspondence between Richard Winters, Robert Morrow, and J. A. Kessler, May 1963, History of West Ford, MITLL.

build up of space garbage that would soon make the dipoles look trivial by comparison.<sup>276</sup> In transmitting their disapproval to the public, these lingering dissidents found purchase for their case within a burgeoning, proto-environmentalist ethos spreading throughout the world in the years immediately following the publication of *Silent Spring*. By changing the terms of the debate to resonate with emerging mainstream environmental values, popular news writers brought the West Ford controversy into view of a broader public that had begun to pay attention to and challenge the hegemony of the military-industrial-academic complex of Cold War America. The allegorical umbrella, already opened against nuclear fallout and the chemical industries, pointed spaceward to the as-yet unknown consequences of the military's latest attempt to alter Earth's natural environment.

### **West Ford's Legacy**

One week after the second launch, West Ford operators successfully transmitted teletype and voice data between the two terminals located in Massachusetts and California. Meanwhile, the SSB West Ford committee solicited observational data from optical and radio astronomers provided with the proper ephemerides to test the belt's reflectivity. In a special issue of the *Proceedings of the IEEE* published in 1964, Lincoln Laboratory and SSB scientists announced their conclusion that, as originally predicted, the West Ford dipoles had not caused any significant interference to radio or optical astronomy. The internationally organized Committee on Space Research (COSPAR) agreed with this

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<sup>276</sup> William A. Baum to D. H. Sadler, April 3, 1962, NRAO - Director's Office - Professional Organizations/Committees - SSB West Ford, Box 2, NAS-SSB Project West Ford - IAU Committee on West Ford - Folder #1, NRAO.

conclusion.<sup>277</sup> The practice of astronomy would continue unchecked, the anticipated space telescopes safe from heavenly needles. However, the preservationist arguments initially employed by astronomers and reinterpreted by journalists in the public fight against West Ford yielded concrete political outcomes that extended beyond the lifetime of the project itself. When the UN Outer Space Treaty entered into force in 1967, it included a provision requiring full international consultation prior to any activities that might lead to “harmful contamination” of space, emphasizing that scientists must be made aware of the “nature, conduct, locations, and results of such activities.”<sup>278</sup> As a growing club of spacefaring and aspiring spacefaring nations negotiated a new model of international governance for outer space, astronomers successfully ensured that the final frontier would also be a site of scientific moral authority.

Additionally, the controversy surrounding West Ford led to the creation of a new working group within COSPAR dedicated to vetting the safety of scientific research in outer space. COSPAR formed in 1958, the same year that the dipole scatter model was initially proposed at the Lincoln Laboratory and the Department of Defense conducted the first high-altitude and exoatmospheric nuclear tests. COSPAR established the Consultative Group on Potentially Harmful Effects of Space Experiments in 1962, in direct response to calls from astronomers to protect the space environment from further experiments like West Ford.<sup>279</sup> This group would eventually transform into what is now

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<sup>277</sup> “Scanning the Issue,” *Proceedings of the IEEE* 52 (May 1964): 449.

<sup>278</sup> *UN Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, 1967.

<sup>279</sup> John W. Finney, “New Science Panel to Screen Space Experiments: International Group Will Attempt to Bar Projects That Could Be Harmful,” *The New York Times*, May 10, 1962; Edward

the Panel on Potentially Environmentally Detrimental Activities in Space (PEDAS).

PEDAS provides a forum for COSPAR members to discuss matters relating to the creation and mitigation of orbital debris and the environmental impact of space technologies, both in space and within the atmosphere.<sup>280</sup>

In an undated press release following the successful second launch, Lincoln Laboratory referred to the “practical objective” of the project as a test to determine if the orbiting dipole scatter communications model could be instituted without damage to science or space activities.<sup>281</sup> In retrospect, project managers have represented West Ford as a feasible method of testing the resilience of the space environment, in particular whether solar radiation and the Earth’s outer atmosphere could be relied upon to remove objects of a certain mass-to-area ratio.<sup>282</sup> Lincoln Laboratory saw this objective as having been perfectly fulfilled, in addition to more widely broadcast mission objectives. West Ford enabled cheap, reliable, easily accessible radio communications between two points using a scattering medium in orbit, without the obstruction to optical and radio astronomy predicted by its fiercest opponents. By these measures, West Ford was a resounding success.

And yet, the Air Force terminated West Ford eight months after its successful second deployment, and a fully operational system was never implemented. Depending on the source, the reason for this concurrent success and failure could have been the more

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R. Dyer, Jr. to J. W. Findlay, December 18, 1963, SSB West Ford, Box 2, NAS-SSB Project West Ford - IAU Committee on West Ford - Folder #1, NRAO.

<sup>280</sup> “West Ford Needles: Where Are They Now?,” *Orbital Debris Quarterly News*, October 2013.

<sup>281</sup> “The Project WEST FORD Experiment” (MIT Lincoln Laboratory, n.d.), History of West Ford, MITLL.

<sup>282</sup> Irwin I. Shapiro, in conversation with the author, June 26 2014.



general trend in space communications toward active satellites rather than passive reflectors, as suggested in a 1989 Lincoln Laboratory retrospective.<sup>283</sup> The Partial Nuclear Test Ban Treaty of October 1963 outlawing the testing of atomic weaponry in the atmosphere and in outer space may have lessened the urgency for such a system.<sup>284</sup> Or, as suggested in a 1966 report by astrophysicist Irwin Shapiro of the Lincoln Laboratory, the project may have been doomed by little more than a bad reputation. Claiming that all the dipoles had reentered, with the exception of a few that would fall to Earth within two years, Shapiro lamented the end of West Ford, saying:

Our gratification at having seen experimental results in agreement with predictions is tempered by the realization that little can be done to clear the clouded reputation of Project West Ford. For, as was observed long ago, the (alleged) evil that projects do lives after them; the good is oft interred with their bones. So let it be with West Ford.<sup>285</sup>

In Shapiro's eulogy, the experimental success of dipole scatter communications, and confirmation of his theory of the decaying effect of sunlight pressure on low mass-to-area

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<sup>283</sup> Ward and Floyd, "Thirty Years of Research and Development in Space Communications at Lincoln Laboratory."

<sup>284</sup> For an overview of the context and negotiation of the Partial Test Ban Treaty, see Richard Dean Burns and Joseph M. Siracusa, *A Global History of the Nuclear Arms Race: Weapons, Strategy, and Politics* (Oxford: Praeger, 2013).

<sup>285</sup> Shapiro, "Last of the West Ford Dipoles," 154.

space objects, had been sunk under a reactionary rhetoric of astronomy-killing needles, heavenly litter, and invisible environmental pollution.<sup>286</sup>

Shapiro's claim that all West Ford dipoles had reentered turned out to be premature: Ground-based space surveillance sensors have identified and currently track several clumps of needles from both West Ford launches that remain in orbit—and these represent only those clusters large enough to be detected from the ground.<sup>287</sup> Individual needles themselves may in fact remain in orbit, “almost invisible” indeed to current space surveillance technology that cannot easily detect objects of such small size.<sup>288</sup> Shapiro was perhaps right to mourn a bad reputation, however. In 1985, journalists and orbital dynamics researchers claimed that a clump of dipoles collided with the PAGEOS 1 geodesy satellite in 1975.<sup>289</sup> However, the fragments of PAGEOS and West Ford occupy similar orbital paths and have occasionally been mixed up and cross-tagged in the cataloging process, such that blame for the incident remains disputed.<sup>290</sup> Two of the greatest fears of West Ford's opponents—a long orbital lifetime of fibers from the test

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<sup>286</sup> Lincoln Laboratory itself did not suffer from the bad reputation that befell its first space project. In its own historical materials, the Lincoln Laboratory touts West Ford as being the start of a long, storied reputation as the premier designers of military satellites following a contract with the Department of Defense before the second West Ford package launched into orbit. Walter Morrow, the principle engineer of the project, went on to receive multiple awards for his research on space communications. Donald MacLellan, “Looking Back: Space Needles,” *The Lincoln Laboratory Journal* 18, no. 1 (August 2009); Office of the Under Secretary of Defense For Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Options for Acquisition of the Advanced Targeting Pod and Advanced Targeting FLIR Pod (ATP ATFLIR)* (Washington, DC: Department of Defense, February 2001), Appendix C.

<sup>287</sup> “RAE Table of Artificial Satellites, 1963,” 2014, <http://www.satlist.nl/>. Accessed October 10, 2014.

<sup>288</sup> Mark Garcia, “Space Debris and Human Spacecraft,” *NASA*, September 27, 2013, [http://www.nasa.gov/mission\\_pages/station/news/orbital\\_debris.html](http://www.nasa.gov/mission_pages/station/news/orbital_debris.html).

<sup>289</sup> Thomas O'Toole, “Man-Made Junk Jams Space,” *Space*, March 29, 1985.

<sup>290</sup> Irwin I. Shapiro, in discussion with the author, June 26 2014. Jonathan McDowell, e-mail message to author, October 30 2014.

and a threat to spacecraft—have at least partly come to pass. The negative reputation the test acquired in the early 1960s persists into the present, as evidenced by the 2012 IMAX film *Space Junk 3D*, in which the filmmakers feature a bundle of “West Ford Needles” among common sources of small space debris such as microchips and screws shed from orbiting satellites and rocket bodies.<sup>291</sup> In 2013, on the fiftieth anniversary of the second, successful West Ford launch, several American news outlets published retrospectives on the project, some of which characterized the dipole scatter model as part of a poorly planned and poorly executed scheme to put a Saturn-like ring around the Earth. An echo of Shapiro’s lament appears to have lingered decades beyond the functional lifetime and popular memory of the test itself.<sup>292</sup>

While the project did not impede ground-based observing as some astronomers feared, the concerns of would-be space astronomers about West Ford’s effects on their future practices turned out to be well founded. Optical and radio astronomers spoke out against the contamination of outer space, which has become, as advocates of the first space telescopes predicted, a crucial site of astronomical practice in certain wavelengths. The remnants of West Ford that continue to circle the planet form part of an ever-growing body of speeding orbital debris that indeed threatens space observatories. In 2012, operators of the Fermi Gamma-ray Space Telescope executed a risky maneuver to

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<sup>291</sup> Melissa Butts, *Space Junk 3D* (Melrae Pictures, 2012).

<sup>292</sup> Many articles published about West Ford in 2013 on the 50<sup>th</sup> anniversary of the second launch portray the project in an unflattering light. See, for instance, “6 Insane Schemes Attempted at the Dawn of Space Travel,” *Cracked.com*, accessed October 11, 2014, [http://www.cracked.com/article\\_20661\\_6-insane-schemes-attempted-at-dawn-space-travel.html](http://www.cracked.com/article_20661_6-insane-schemes-attempted-at-dawn-space-travel.html).

nudge the spacecraft out of the intersecting path of a defunct Soviet-era satellite.<sup>293</sup> The Hubble Space Telescope has been bombarded by micrometeoroids and human-made debris over its quarter century in orbit. A small object punched a hole in one of Hubble's antennas, through which the tube of the telescope can be clearly discerned in photographs.<sup>294</sup> The Hubble Wide-Field Planetary Camera 2, retrieved from orbit by astronauts during the final repair mission in 2009 and placed on exhibit at the Smithsonian National Air and Space Museum in 2014, sports a radiator cover that resembles a giant slice of Swiss cheese.<sup>295</sup> Although none of these impacts or close calls ultimately impeded telescope operation, they provide material evidence of the environmental conditions anticipated by astronomers and journalists fifty years earlier during the first debates over what space policy analysts now call the sustainable use of outer space.<sup>296</sup>

This first recognition of near-Earth space as a pollutable environment connected what many communities might have otherwise dismissed as a remote, invisible void to

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<sup>293</sup> "The Day NASA's Fermi Dodged a 1.5-Ton Bullet," *NASA*, April 30, 2013, [http://www.nasa.gov/mission\\_pages/GLAST/news/bullet-dodge.html](http://www.nasa.gov/mission_pages/GLAST/news/bullet-dodge.html).

<sup>294</sup> "Orbital Debris Surface Examinations," accessed February 14, 2014, <http://orbitaldebris.jsc.nasa.gov/measure/surfaceexam.html>.

<sup>295</sup> The decision to place the Wide-Field Planetary Camera 2 on display as-is triggered some controversy between Smithsonian curators and Hubble operators at NASA. Researchers sampled the impact craters on the radiator shield via core removal, thus making the debris impacts appear far more severe than they were. However, the curatorial standard in place at the Air and Space Museum required that the genuine artifact must be displayed. The camera as it flew remains on exhibit with explanatory signage. David DeVorkin, in discussion with author, November 2014.

<sup>296</sup> In 2012 a group of chemists used the decreasing rate of space junk reentry to study how anthropogenic global climate change had affected the upper atmosphere. During periods of high solar activity, the outer layers of Earth's atmosphere expand, dragging a greater cross-section of space junk into the atmosphere. This self-cleaning resilience mechanism has become less efficient in recent years, according to the authors of the paper in question, who concluded that climate change has caused the thermosphere to contract. J. T. Emmert et al., "Observations of Increasing Carbon Dioxide Concentration in Earth's Thermosphere," *Nature Geoscience*, 2012.

terrestrial environments susceptible to destruction by human activity. The debate over Project West Ford gave rise to a new but persistent perception of outer space as an environment at risk, in need of international safekeeping. It also situated scientists—astronomers in particular—as the appropriate stewards to provide the necessary environmental oversight. The breadth and legacy of the West Ford controversy reveals an expansive transnational consciousness of pollution in outer space during the early years of both the Space Age and mainstream environmentalism. A ring of minute, mundane metal fibers brought lasting worldwide attention to a strange, illegible natural environment that rapidly came to be understood as fragile and worthy of protection.

### CHAPTER 3

#### **“Terror in the Skies:” Falling Space Junk, Space Weather, and International Environmental Liability During the Long 1970s**

##### **Cows Over Cuba**

On Sunday, December 4, 1960, approximately 300 protesters, six cows, and one bull paraded past the United States Embassy in Havana in the first government-organized rally since Prime Minister Fidel Castro’s ascent to power. The assembled humans chanted anti-American slogans and demanded that the United States cease its imperialist assault on Cuban sovereignty. The cows wore sandwich board-style placards painted with messages such as “We condemn the use of atomic arms to kill defenseless cows” and “Killing cows will not stop our revolution.”<sup>297</sup> American newspapers reported that the rally lasted about forty-five minutes, and that the bovine contingent left the ground in front of the embassy “thoroughly soiled.”<sup>298</sup>

Four days earlier, on November 30, the United States Navy launched a Thor rocket from Cape Canaveral, Florida. It carried three satellites destined for orbit around the planet. Following an anomaly at the end of the flight, the range safety officer sent a self-destruct signal that destroyed the rocket and its payload. However, several large

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<sup>297</sup> R. Hart Phillips, “CUBANS AND COWS MARCH IN PROTEST: 300 Havana Students Mourn Beast Killed by Pieces of U.S. Space Rocket,” *New York Times*, December 5, 1960; “250 IN CUBA DEMONSTRATE AGAINST U. S.: Use Cows in Protest of Rocket Firing,” *Chicago Daily Tribune (1923-1963)*, December 5, 1960, sec. SECTION ONE.

<sup>298</sup> Associated Press, “Cuba Protests Cow Death By Rocket,” *The Lewiston Daily Sun*, December 5, 1960, Monday Morning edition.

fragments survived the explosion and fell through the atmosphere back to Earth.<sup>299</sup> The Cuban government broadcasted reports of shrapnel raining from the sky, striking and killing an unlucky cow in Oriente Province. American sources claimed that the cow had merely been injured.<sup>300</sup> In the weeks that followed, the U.S. Department of State agreed to pay the Cuban government damages to the tune of two million dollars—quite a lot of money to replace a cow. This inspired critics to call the event “the Cuban Cash Cow” and the “herd shot round the world.”<sup>301</sup> Castro threatened to hand the rocket fragments over to the Kremlin for intelligence use.<sup>302</sup> The cow is said to have received a state burial.<sup>303</sup>

The destroyed spacecraft did not contain nuclear weapons or radioactive material. However, the protesters denounced what they believed to be an act of nuclear aggression by Cuba’s neighboring superpower, in this case destroying a living symbol of pastoral domesticity. Radioactive or not, falling pieces of space hardware materialized a pervasive form of Cold War nuclear anxiety in an increasingly volatile region. The rocket shards delivered fiery, indiscriminate destruction from the sky, sent by a foreign enemy but—depending on the politics of the observer—without the malicious intent behind a nuclear warhead. Whether the cow lived, died, was slightly injured, or never existed in the first

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<sup>299</sup> Daniel Hill Zafren, “Convention on International Liability for Damage Caused by Space Objects: Analysis and Background Data,” Staff Report Prepared for the Use of the Committee on Aeronautical and Space Sciences (Washington, D.C.: United States Senate, May 1972).

<sup>300</sup> “Rocket Fragments Found,” *The Science News-Letter*, August 4, 1962.

<sup>301</sup> In a speech recalling this event, CIA Director George Tenet called it “the first—and last—time that a satellite has been used in the production of ground beef.” George J. Tenet, “Remarks of the Director of Central Intelligence George J. Tenet at the National Reconnaissance Office 40th Anniversary Gala (as Delivered)” (Speech, Central Intelligence Agency, September 27, 2000).

<sup>302</sup> Martin W. Houseman, “Castroites Detain Archbishop,” *The Washington Post, Times Herald*, December 4, 1960.

<sup>303</sup> C. Bullock, “Commercial Space Launches: Liability Questions Resolved at Last,” *Space Markets*, no. Winter (1988): 211–14.

place, the event came to worldwide public attention as one of the first of a new kind of envirotechnical disaster that would test emergent space liability law.<sup>304</sup> It heralded an era in which the geophysical forces that draw space artifacts back to Earth from orbit—in an event known as “reentry”—would come under international scrutiny as geopolitical actors. Scientific understanding of the physical topography of near-Earth space transformed as *in situ* data from satellites and the uncontrolled movement of anthropogenic objects revealed a near-Earth environment that was as active and resilient. Near-Earth space could heal itself of human interventions as thoroughly as could the terrestrial ecosystems that the burgeoning mainstream environmentalist movement sought to protect. During the long 1970s several reentry events collapsed geography and brought geographically and politically disparate states into unexpected, sometimes dangerous, often contentious proximity. During this critical time period, the orbital environment itself became a culpable, uncooperative actor in the legal and environmental history of an increasingly messy, increasingly global Space Age.

The passage of the first international space treaties in the late 1960s and early 1970s, particularly the 1967 Outer Space Treaty, established a common legal language to support the transnational governance of a global environment. However, 91 nations, representing a plethora of languages, cultures, and legal traditions, initially signed a treaty meant to govern a remote, illegible ecosystem that followed its own set of arcane,

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<sup>304</sup> Sara B. Pritchard writes about the interwoven technological and ecological features of disasters in “An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima,” *Environmental History* 17, no. 2 (April 1, 2012): 219–43; see also Scott Gabriel Knowles, *The Disaster Experts: Mastering Risk in Modern America* (University of Pennsylvania Press, 2012); Charles Perrow, *Normal Accidents: Living with High Risk Technologies* (Princeton University Press, 2011).



strict laws. In such a messy mix, the issue of responsibility—in the legal language of the United Nations, the issue of fault—became even more contingent and controversial than the concept of utility at play during the years of West Ford and Echo. Even the addition of the more explicit and expansive Liability Convention of 1972 could not, in advance, fully articulate the complexities of damages wrought by objects passing through, and coming back to Earth from, outer space. This fraught scaffolding of outer space governance was put to the test during the long 1970s, when a confluence of natural and social factors brought about an unprecedented rate of reentry of large space artifacts—including some that did in fact contain radioactive materials.<sup>305</sup> These reentries forced all Outer Space Treaty signatory nations, spacefaring and non-spacefaring alike, to consider who should be at fault for nuclear damage, not through human intent but via the vagaries of the geophysical world. During the long 1970s, questions of how to ascribe culpability to states and the natural world came to the forefront of international political debate when the sky began to fall.

### **Controlling the Reentry Message**

In the years before the first spate of large reentries, NASA officials sought to keep information about reentering debris as unpublicized as possible—even within the lower ranks of the NASA bureaucracy and among space technology contractors.<sup>306</sup> In 1964,

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<sup>305</sup> Here I use the periodization of the long 1970s as 1969 to 1984 as put forward in Bruce J. Schulman, *The Seventies: The Great Shift in American Culture, Society, and Politics* (Da Capo Press, 2002), xvi–xvii.

<sup>306</sup> Leo X. Abernethy, “Briefing Memorandum: NASA’s Interest, Experience and Concern with Space Debris,” February 23, 1968, Orbital Debris Documentation (1951-1979), NASA Headquarters Historical Reference Collection, Washington, DC.

NASA policy regarding the agency's response to inquiries about potential or actual land impact by space fragments required a great deal of evasion. A confidential memo distributed among top NASA officials offered stock responses that personnel should use to address hypothetical public inquiries about the threat of falling debris. The memo instructed officials to dismiss the possible endangerment of human life from reentering hardware fragments as "remote" and "conjectural," and to actively restrict any public discussion of reported debris impacts before the country of origin could be identified.<sup>307</sup> NASA responded to inquiries from citizens that claimed to have found space hardware with a standardized form requesting more information about the landing site, object, and conditions of observation. NASA would arrange to retrieve such objects in the event that the information provided by the individual citizen on the form suggested that the fragment might yield "some scientific or technological value"—a euphemistic way of denoting the intelligence value of recovered space hardware, which could be exploited to learn about Soviet engineering and manufacturing.<sup>308</sup>

By 1966, following the recovery that year of several pieces of reentered American hardware from the Rio Negro district of Brazil, Apollo program administrators suggested developing a public information plan.<sup>309</sup> However, the internal debate within NASA over the benefits and dangers of public education about falling space debris continued into the

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<sup>307</sup> Julian Scheer, Memorandum on Earth Impacts of Fragments, April 7, 1964, Orbital Debris Documentation (1951-1979), Folder 16350, NASA History.

<sup>308</sup> "Letter from Leo X. Abernethy to Stephen E. Bobiak," May 27, 1965, Orbital Debris Documentation (1951-1979), NASA Headquarters Historical Reference Collection, Washington, DC.; James David, "Was It Really 'space Junk'? US Intelligence Interest in Space Debris That Returned to Earth," *Astropolitics* 3, no. 1 (April 1, 2005): 43–65.

<sup>309</sup> J. K. Holcomb, "Orbital Debris," May 13, 1966, Orbital Debris Documentation (1951-1979), Folder 16350, NASA History.

1970s. A classified 1972 NASA Office of Policy Analysis memo reveals that some in the administration harbored “questions of morality”—specifically whether or not NASA was justified in taking the chance that someone might someday be hit by a piece of one of the ever growing number of satellites that would eventually fall to Earth, while NASA also withheld information about this danger from the public. The memo suggests that, by providing useful, modernizing services to the nation and world, NASA had “assumed the moral right to impose that incremental risk on society.”<sup>310</sup> However, recent milestones in national and international policy tempered this recommendation. The 1970 enactment of the National Environmental Protection Act (NEPA) indicated that the United States federal government had begun to take certain environmentalist priorities seriously. Additionally, the 1971 Liability Convention clarified extant rules of responsibility for damage caused by space artifacts in the UN Outer Space Treaty, meaning that any future reentries would be subject to stricter rules and recourse procedures than had previously been in force. Given these recent changes to relevant environmental and space policy, the same memo predicts widespread political fallout—especially among an increasingly environmentally conscious American public and international diplomatic networks—should space debris cause bodily harm to people or animals, or contaminate the soil,

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<sup>310</sup> Cold War historian Sarah Robey writes that American citizens resisted government secrecy about the development of the hydrogen bomb in the early 1950s, protesting that no individual or small group should be granted the moral right to make such momentous decisions without democratic oversight. The rhetoric of morality in calling for greater public knowledge of the hydrogen bomb program directly anticipates claims of moral responsibility by NASA officials two decades later. See Sarah Robey, “The Atomic American: Citizen in a Nuclear State, 1945-1963” (draft dissertation, Temple University, n.d.).

water, or atmosphere.<sup>311</sup> By this time, NASA policy explicitly stated that the movement of fragments from orbit to Earth endangered the “quality of the human environment” as set forth in NEPA, and officials began developing an official national policy on the matter of reentry control and public awareness.<sup>312</sup>

### **The Sky is Falling: Space Junk Comes Back to Earth**

“What goes up must come down”—an adage used to describe everything from fly balls to the stock exchange—also applies to objects that humankind sends into orbit. In his famous cannon thought experiment, Isaac Newton described what would happen to a projectile shot with enough velocity to “escape” the invisible forces that would otherwise bring the projectile back to the ground. A cannonball that reaches this velocity continues to be gravitationally attracted towards the massive planet Earth. However, with no land below to stop it, and therefore no way to land, the projectile will continue to plummet in a path around the planet—a perpetual free fall known as orbiting.<sup>313</sup> Unless the object gains enough velocity to escape from Earth’s gravitational field and move into interplanetary space, gravity continually pulls the object into this cycle of free fall.

What goes up *can* stay up—but only temporarily.

All objects that human beings have launched into orbit will one day come back down to Earth. *When* they return depends on a combination of factors including the mass and area of the object, and external conditions including altitude, atmospheric density,

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<sup>311</sup> Nathaniel B. Cohen, “Memorandum: Orbital Debris,” February 11, 1972.

<sup>312</sup> Jay Holmes, “Memorandum for the Record: Oral Statement to Senate Committee,” March 23, 1971, Orbital Debris Documentation (1951-1979), NASA Headquarters Historical Reference Collection, Washington, DC.; Cohen, “Memorandum: Orbital Debris.”

<sup>313</sup> Sir Isaac Newton, *A Treatise of the System of the World* (F. Fayram, 1728), 5-8.

and solar activity. The higher an object orbits, the thinner the atmospheric density—and therefore the fewer particles to impart drag upon the object. The orbital altitude directly correlates to the length of time it takes for an object to fall back into the atmosphere—in the parlance of orbital mechanics, for its orbit to decay. Some objects’ orbits decay at rates so slow as to defy geological scale. Objects in orbits higher than 1,000 kilometers will take centuries to reenter, and objects in geosynchronous orbit 35,786 kilometers above the ground will take millennia to decay.<sup>314</sup> Unless humankind moves elsewhere into the cosmos, or devises a way to bring high altitude objects back to Earth, the orbital lifetimes of these artifacts will far outlast the human species and the majority of the changes it has wrought on the geophysical world.

However, the vast majority of anthropogenic hardware and debris orbit at lower altitudes, where the atmosphere (although thin) still exerts significant drag. Objects in low-Earth orbit reenter on shorter time scales. Subjected to punishing friction and heat-generating air pressure as it moves through denser and denser layers of the atmosphere, any object—natural or human-made—begins to fall apart. Most objects that fall through the atmosphere without special heat shielding either dissipate entirely or break into fragments that fall into the oceans that cover the vast majority of the planet. NASA, the North American Air Defense Command (now the North American Aerospace Defense Command, or NORAD), and the international mainstream media have long represented marine disposal or atmospheric absorption of reentering artifacts as ideal outcomes,

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<sup>314</sup> National Research Council (U.S.), *Orbital Debris: A Technical Assessment* (Washington, D.C: National Academy Press, 1995), 149–153.

portraying these global terrestrial environments as consequence-free sinks for space debris.<sup>315</sup>

However, on occasion, as in Havana, a piece of space junk will hit *terra firma*, spurring political, diplomatic, financial, and environmental complications. The repercussions of such events do not remain localized at the landing site, but also among a range of geographically dispersed state actors and international organizations with legal, financial, or political stakes in the outcome of a real or potential space junk disaster. The physical properties of the most valuable orbits (and the geographical orientation of launch sites required to send satellites to these orbits using minimal resources) often result in uncontrolled space junk landing far from the state of origin, often in regions of the Global South.<sup>316</sup> The first few such reentries included the Cuban cow incident and the survival of several large pieces of American space hardware retrieved from South Africa following John Glenn's historic orbital spaceflight a year and a half later. Following these events, many more state parties than the Cold Warring superpowers became invested in securing

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<sup>315</sup> I refer here to the idea of the ultimate sink as a consequence-free resting place for transformed waste, as presented by Joel Tarr, *The Search for the Ultimate Sink: Urban Pollution in Historical Perspective* (Akron, OH: University of Akron Press, 1996); "Letter from M. Dale Crubb to the Honorable James B. Pearson, United States Senate," November 4, 1970, Orbital Debris Documentation (1951-1979), NASA Headquarters Historical Reference Collection, Washington, DC.; NORAD Public Affairs Office, "NORAD Fact Sheet: Falling Space Debris," May 10, 1979, Orbital Debris (1960-1988), NASA Headquarters Historical Reference Collection, Washington, DC.; "'WTF' Space Junk: Should We Be Worried? - CNN.com," *CNN*, accessed December 10, 2015, <http://www.cnn.com/2015/11/13/opinions/space-junk-wt1190f-conversation/index.html>.

<sup>316</sup> An in-depth discussion of the political repercussions of the physical reality of space junk from developed nations falling over regions of the Global South is beyond the scope of this dissertation. However, a future iteration of this research will explore how non-spacefaring nations and latecomer spacefaring states treated near-Earth space as a natural resource and a source of alternating danger and value during this time period.

a guarantee of recourse in the event that a piece of falling space junk should strike sovereign ground.

The advent of the satellite age was inextricably entwined with the development of the intercontinental ballistic missile, or ICBM. These missiles descended from V-2 missiles designed by German engineers and built by prison camp labor during World War II. At the end of the conflict, the Soviet Union and United States scrambled to claim both rocket technologies and rocket specialists from Germany in order to build their own rocket programs—a clandestine expertise grab known in the United States as Operation Paperclip.<sup>317</sup> When the Soviet Union launched Sputnik into space aboard an R-7 rocket—the world’s first operational ICBM in one of its first successful flights—the nation demonstrated its powerful, unprecedented ability to access outer space. It also signaled to the rest of the world that the Soviet Union was ahead of everyone in ICBM technology, suggesting that a Soviet missile could, in the near future, deliver nuclear weapons nearly anywhere in the world at the push of a button.<sup>318</sup> Soon, the militaries of both superpower nations developed and maintained arsenals of ICBMs for use in spaceflight, and in anticipation of warfare.

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<sup>317</sup> B. E. Chertok, *Rockets and People*, 4 vols., The NASA History Series 2004-4110 (Washington, D.C: NASA : For sale by the Supt. of Docs., U.S. G.P.O, 2005); Michael J. Neufeld, *The Rocket and the Reich: Peenemünde and the Coming of the Ballistic Missile Era* (New York: Free Press, 1995); Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945-1974*, NASA History Series 2000-4408 (Washington, D.C: National Aeronautics and Space Administration, NASA History Div., Office of Policy and Plans, 2000); Frank H. Winter, *Rockets Into Space*, *Frontiers of Space* (Cambridge, Mass: Harvard University Press, 1990).

<sup>318</sup> Rip Bulkeley, *The Sputniks Crisis and Early United States Space Policy: A Critique of the Historiography of Space* (Indiana University Press, 1991), viii.

The ICBM marked a sea change in munitions technology, shrinking the spatial and temporal scope of warfare. Whereas before the development of the ICBM a large-scale attack would have required mobilization of forces and implementation of invasion and withdrawal strategy, a single disposable long-range missile with a warhead could cross the globe in minutes. Even the relatively recent advances in long-range bomber technology appeared to be destined for imminent obsolescence, replaced by a quicker (if initially less accurate) delivery system that did not rely on an onboard human pilot for success.<sup>319</sup> Warfare became truly global when ICBMs shortened geographical distance and facilitated the ability to launch quick retaliation in case of attack—a major lynchpin upholding the Cold War version of the global military strategy known as mutually assured destruction.<sup>320</sup>

As an integral part of large-scale weapons systems, ICBMs enabled the controlled delivery of destructive materials from the sky above the intended target. As launch vehicles for non-armament space technology, these rockets facilitated a similar outcome—without the control and, in many cases, the synchronicity typified by advanced nuclear ICBMs. Even in the absence of a warhead, ICBMs made it possible for a nation to drop dangerous projectiles onto faraway lands without intent, control, or accuracy, as illustrated by the fate of the hapless Cuban cow.<sup>321</sup> In the first decades in which ICBMs

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<sup>319</sup> Siddiqi, *Challenge to Apollo*, 128.

<sup>320</sup> For more on flight technology and Cold War geopolitics, see Edward Kaplan, *To Kill Nations: American Strategy in the Air-Atomic Age and the Rise of Mutually Assured Destruction* (Cornell University Press, 2015).

<sup>321</sup> Parts of these rockets accompany their cargo into orbit. When extinguished and separated from the payload, these parts come to be known as “rocket bodies,” which comprise some of the most dangerous orbital debris. Any remnant fuel and pressure could cause an explosion, hurtling



were used to launch spacecraft, both expired satellites and pieces of these rockets fell from orbit, generating different kinds of threats to both the state in which the fragments landed and the launching state. Beyond the physical danger of high-speed objects falling from high altitudes, if any fragments were to survive the fall they could be used as valuable currency in the intelligence community on either side of the Iron Curtain. Should fragments land in enemy territory, or in a region within a particular sphere of influence, that fragment could be recovered, examined, and exploited by hostile operators and used against the launching state. The ICBM thus facilitated an expansion of the material and virtual scope of space technology, but also a new way to gather information about the technical knowledge of the enemy's space industry.<sup>322</sup> As much as these technologies collapsed time and space by delivering bombs and then spacecraft further and more quickly than previously imaginable, the unprecedented mobility of byproducts and wastes of the space industry confirmed that the Cold War Space Race had become a truly global phenomenon.<sup>323</sup>

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hundreds or thousands of smaller fragments into ballistic trajectories in the initial body's former orbit. A rocket body explosion accounted for the very first on-orbit anomaly in 1961, which instantaneously expanded the number of tracked debris in orbit exponentially.

<sup>322</sup> For more on the commodification of reentered space junk in the international intelligence community, see Chapter 1 of this dissertation.

<sup>323</sup> A current wave in space history scholarship focuses on destabilizing the myth of the Cold War Space Race as a binary competition between superpowers. See for example Asif Siddiqi, "Departure Gates: Histories of Spaceflight on Earth," recipient of a John Simon Guggenheim Memorial Foundation Fellowship. Other scholars of the social studies of outer space have examined how the technological landscape of orbital space unevenly maps onto terrestrial social and economic landscapes below. See for example Lisa Parks, *Cultures in Orbit: Satellites and the Televisual* (Duke University Press, 2005); Parks, "When Satellites Fall: On the Trails of Cosmos 954 and USA 193"; Peter Redfield, *Space in the Tropics: From Convicts to Rockets in French Guiana* (Berkeley: University of California Press, 2000).

### **Stormy Space Weather: Solar Maximum in the Space Age**

In early October 1957, as the rest of the world reacted to the stunning launch of the first artificial satellite by the Soviet Union atop a modified ICBM, physicists at the Royal Aircraft Establishment (RAE) found themselves deeply enthralled by the motion of Sputnik's rocket core as it tumbled through space. RAE physicists' research revealed that atmospheric particles exerted drag on moving objects at unexpected altitudes, causing its orbit to "decay," or dwindle in altitude. The group of RAE physicists who would soon come to self-identify as "orbital analysts" tracked the motion of the rocket core over the course of its eight weeks in orbit to reveal entirely new information about the wind currents and density of the upper atmosphere.<sup>324</sup> This early orbital research, conducted using the rocket core as a scientific instrument, changed contemporary understanding of the orbital environment that would continue to shift as humankind sent greater numbers of artifacts into orbit around the planet.<sup>325</sup>

This research, as well as newly acquired data about the regions just beyond Earth's atmosphere, shattered physicists' previous perception that a "vast region of emptiness" enveloped our isolated planet.<sup>326</sup> Within five years after the launch of Sputnik, a rapidly coalescing international community of space scientists discovered a complex topography of magnetism, radiation, energy, dust, and transiting plasmas, alongside

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<sup>324</sup> Desmond King-Hele of the RAE includes a memoir of the weeks in which he and his team tracked the orbit and reentry of 1957a1 in *Satellites and Scientific Research* (London: Routledge & Paul, 1960).

<sup>325</sup> The first chapter of my dissertation examines the Sputnik rocket core as a global boundary object, subject to interpretations and uses ranging from visual stand-in for the named satellite among many lay observers to political tool to intelligence commodity—to space junk.

<sup>326</sup> Lovell, "The Exploration of Outer Space," June 1960, 125.

atmospheric and trapped solar particles extending tens of thousands of kilometers from Earth's atmosphere into space. Although the effects of sunspots on terrestrial systems had been a subject of formal study since the mid-19<sup>th</sup> century, the discovery of a web of magnetic and radiation fields above the atmosphere pointed to the likelihood that Earth's geophysical influence extended far further into space than previously imagined.<sup>327</sup> The Sun did not exert its influence upon a wholly passive third planet. Almost overnight Earth had become a power player in a physically and materially interactive solar system.<sup>328</sup>

As the space age progressed, evidence of Sun-Earth interactions manifested most spectacularly within the region of near-Earth space into which humankind sent its first technological envoys. The Sun entered solar maximum—the active peak of its roughly eleven-year-long solar cycle—three times between the launch of Sputnik in 1957 and the mid-1980s.<sup>329</sup> During solar maximum, the Sun's energy output increases to its highest levels. Ultraviolet emissions increase by more than a factor of two, heating the Earth's atmosphere and causing it to expand several hundred kilometers further into outer space.<sup>330</sup> The first solar maximum of the Space Age peaked in early 1958, when only five artificial satellites circled the globe. Over the course of the next two solar cycles,

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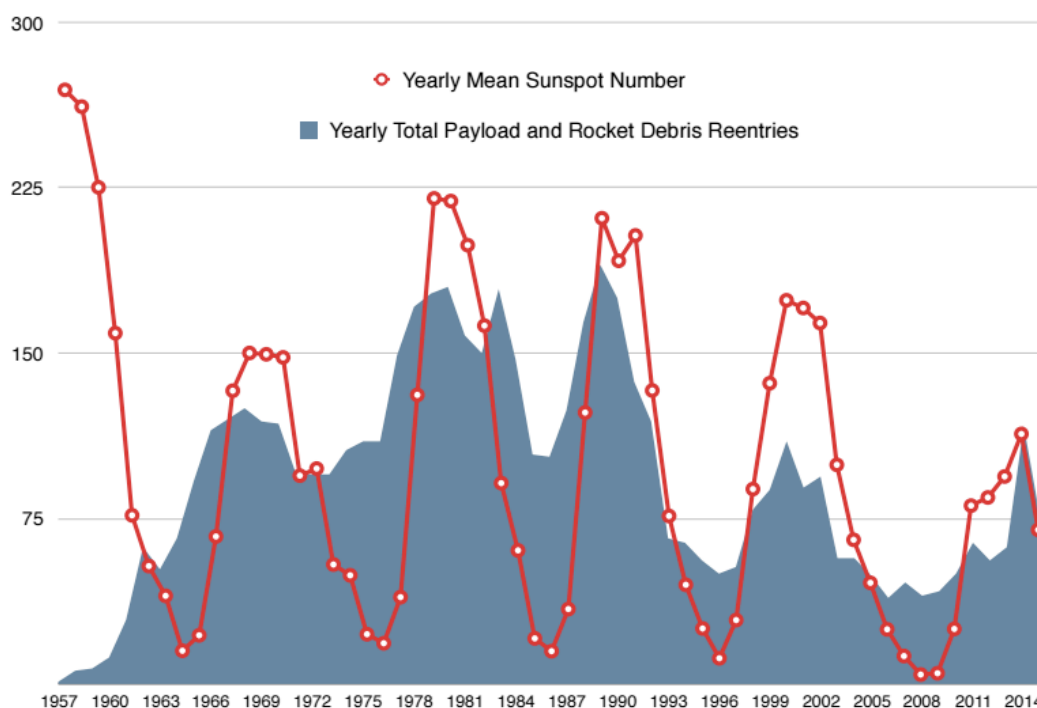
<sup>327</sup> For an overview of early sunspot and solar cycle research in Europe during the mid 19th century, see Wilfried Schroder and Karl-Heinrich Widerkehr, "Geomagnetic Research in the 19th Century: A Case Study of the German Contribution," *Journal of Atmospheric and Solar-Terrestrial Physics* 63 (2001): 1649–1660; For a more comprehensive account by a non-historian, see Stuart G. Clark, *The Sun Kings: The Unexpected Tragedy of Richard Carrington and the Tale of How Modern Astronomy Began* (Princeton University Press, 2007).

<sup>328</sup> Lovell, "The Exploration of Outer Space," June 1960; Fleming, "Iowa Enters the Space Age: James Van Allen, Earth's Radiation Belts, and Experiments to Disrupt Them."

<sup>329</sup> WDC-SILSO, Royal Observatory of Belgium, Brussels, "Sunspot Number," accessed September 22, 2015, <http://www.sidc.be/silso/datafiles>.

<sup>330</sup> Louis J. Lanzerotti, "Space Weather Effects on Technologies," in *Space Weather* (Washington, DC: American Geophysical Union, 2001), 20.

spacefaring nations accelerated the manufacture of the satellite infrastructure and the concurrent production of space junk. At the time of the solar maximum of 1968-1970 and the following solar maximum of 1978-1982, humankind had launched several thousand anthropogenic objects into orbit, including both satellites and the uncontrolled detritus of this construction project.<sup>331</sup>



**Figure 3.1:** The blue area graph illustrates the number of uncontrolled, non-deliberate, “natural” reentries of payloads and empty rocket stages. The red line graph shows the mean number of sunspots per year after Sputnik, with peaks denoting solar maxima. A clear correlation exists between periods of high solar activity and the orbital decay of space debris.<sup>332</sup>

<sup>331</sup> Based on data aggregated by Jonathan C. McDowell, “Satellite Catalog,” *Jonathan’s Space Pages*, accessed October 7, 2015, <http://planet4589.org/space/log/satcat.txt>.

<sup>332</sup> Sunspot data courtesy WDC-SILSO, Royal Observatory of Belgium, Brussels; Reentry data courtesy Jonathan McDowell.

The second and third Space Age solar maxima demonstrated what happens to objects orbiting at low altitudes during periods of stormy space weather: As the layer of the atmosphere known as the thermosphere expands due to ultraviolet heating, atmospheric particles extend further into space and exert drag on a broader subsection of orbiting artifacts, causing their orbits to decay, or decrease in altitude. Eventually, gravity takes hold and the object falls back to Earth through the punishing friction and pressure of the upper atmosphere. This cyclical expansion and contraction of the atmosphere acts as a self-cleaning mechanism, sweeping lower orbital altitudes clear of uncontrolled junk. Like terrestrial ecosystems, the near-Earth space environment demonstrated mechanisms of natural resilience that are both shaped by and resist the effects of anthropogenic activity.<sup>333</sup> The effects of these first Space Age solar maxima on early space hardware reinforced Cold War physicists' claims of an interactive solar system and confirmed that Earth's environment did not stop at an arbitrary layer of the atmosphere.

The combination of turbulent solar activity and the steadily increasing number of satellites sent into space during the long 1970s resulted in some of the biggest pieces of orbital debris to return to Earth. Of the sixteen most massive artifacts to reenter the atmosphere from space since 1957, ten fell to Earth during the period of time from 1969

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<sup>333</sup> In 2012, a group of chemists argued that reentries were on the decline, citing increasing inefficiency of this self-cleaning mechanism due to anthropogenic climate change causing the thermosphere to contract. This research provides contemporary evidence of the interconnectivity of Earth and orbital ecosystems, and that the boundary between Earth and outer space is a social construct. J. T. Emmert et al., "Observations of Increasing Carbon Dioxide Concentration in Earth's Thermosphere," *Nature Geoscience* 5, no. 12 (December 2012): 868–71.

to 1984.<sup>334</sup> This included the fall of the Cosmos 954 satellite over a remote part of Canada in 1978 and the infamous 1979 reentry of the American space station Skylab over rural Australia. Both events received significant attention in the international press. They mobilized both state space programs and State departments to determine the best way to reduce risk from falling objects. They also sought ways to appropriately inform a general public, which reacted along a spectrum of responses ranging from terror to macabre acceptance of an inevitably falling sky.

In addition to an increasing number and size of reentering artifacts, many of the artifacts themselves had changed in a significant way by the 1970s. Starting in 1965 the Soviet Union and the United States began installing nuclear power devices on spacecraft—and continue to do so today, especially on deep space probes. These ranged from simple generators that draw heat energy from the decay of a radioactive isotope to small nuclear generators deriving power from enriched uranium, the latter being more common on Soviet era satellites.<sup>335</sup> Since then, several nuclear-powered satellites have slipped beyond the control of their human operators and fallen to Earth with their generators intact. Nearly all of them have disappeared from view, either in the atmosphere or in water. However, in 1978, a nuclear powered satellite fell to solid ground, with local and international ramifications that would reverberate well after the end of the Cold War conflict that bore it into space. While this was neither the first nor

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<sup>334</sup> The Aerospace Corporation, “Largest Objects to Reenter,” accessed September 22, 2015, <http://www.aerospace.org/cords/reentry-data-2/largest-objects-to-reenter/>.

<sup>335</sup> The United States launched a single nuclear reactor powered satellite in 1965, and has since largely relied on radioisotope thermal generators on spacecraft that cannot make efficient use of solar energy. Steven Aftergood, “Background on Space Nuclear Power,” *Science and Global Security* 1 (1989): 95–97.

the last of what I call “nuclear reentries,” a confluence of material, legal, and ecological factors amplified the ways in which this particular kind of accident uniquely reified and materialized extant nuclear anxiety in the midst of the Cold War arms race.

### **The Nuclear Reentry of Cosmos 954**

In September 1977, the Soviet Union launched an ocean reconnaissance satellite named Cosmos 954 into orbit. By December of that year, the North American Aerospace Defense Command noticed that the satellite had begun to behave erratically, indicating that it was no longer under control. American intelligence efforts suggested that the Cosmos satellites drew power from onboard nuclear reactors. Whether this particular satellite contained a reactor (and if so what kind of reactor), and what kind of emergency failsafes Soviet satellite engineers might have installed, could only be extrapolated from older data. Should a live reactor fall into a populated area, the Defense Intelligence Agency could not fully predict the extent or scale of potential damage. When briefed on the issue, some senior American government officials even wondered if the satellite might detonate upon impact like a nuclear weapon.<sup>336</sup>

When pressed in secret, the recalcitrant Soviet government provided few details beyond admitting that the satellite contained a reactor fueled by uranium-235. The Kremlin insisted that the reactor core would not go critical upon reentry—that it had been designed to fully disintegrate and dissipate into the upper atmosphere. They allowed the faint possibility that pieces of the satellite might survive, arguing that any fragments

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<sup>336</sup> Gus W. Weiss, “The Life and Death of Cosmos 954,” *Studies in Intelligence (U.S. Central Intelligence Agency)*, 1978, 4, note.

would fall in a localized area and therefore pose no risk to communities or environments below following “limited usual measures of cleaning up”—a confusing suggestion given that the impact of a nuclear powered spacecraft on land had no precedent, and therefore no “usual measures” existed. American trackers predicted that Cosmos would fall somewhere over North America, but could give no more specifics about the margin of impact. Under cover of secrecy, the United States government informed allies who might be affected by the reentry, especially the Canadian government. None of the notified nations chose to inform their citizenry of the potential threat.<sup>337</sup>

In the early morning of January 24, 1978, Mounties and night janitors in the Northwest Territories of Canada reported seeing a bright meteor falling over the Great Slave Lake in the vicinity of Yellowknife.<sup>338</sup> Other eyewitnesses determined that some pieces of the satellite had survived and landed in a stretch of mostly frozen tundra in a region commonly known as “the Barren Lands” or simply “the Barrens”—a region that exemplified the definition of wilderness put forth in the American 1964 Wilderness Act: “a place where man himself is but a visitor.”<sup>339</sup> First responders remarked that only those hardy individuals seeking a return to nature braved the elements of the Barrens. Subsequent reports characterized the region as “a most inhospitable place... where flora and fauna must be tough to survive.”<sup>340</sup> In January 1978, the landscape of the Barrens appeared uniformly white under a thick, impenetrable cover of snow and ice—

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<sup>337</sup> Ibid., 3–4.

<sup>338</sup> U.S. Department of Energy, “Operation Morning Light” (National Nuclear Security Administration, August 2013).

<sup>339</sup> Wilderness Act of 1964, 16 U.S.C. 1131-1136, 78 Stat. 890 (1964)

<sup>340</sup> W. K. Gummer et al., “Cosmos 954: The Occurrence and Nature of Recovered Debris” (Hull, Quebec, Canada: Atomic Energy Control Board, May 1980), iv.



inhospitable, tough, and yet potentially endangered by a nuclear reactor inadvertently dropped from above by a foreign, hostile government.

A coalition of American and Canadian nuclear experts and intelligence personnel scrambled an ad hoc search and containment project code-named Project Morning Light. After eight and a half months of careful work, often under survival conditions, the Morning Light team recovered approximately 65 kilograms of debris from a well-defined 600-kilometer path across Great Slave Lake and its vicinity. All but two of the hundreds of pieces of collected debris turned out to be radioactive. The rest of the massive satellite dissipated in the upper atmosphere as predicted by the Soviet engineers. The falling debris didn't hit any people or animals, and nobody witnessed the impact, but six naturalists that stumbled upon one of the largest pieces of debris were promptly evacuated and eventually given a clean bill of health. The more difficult task lay in determining what to do about the dispersal of tiny particulate nuclear fuel over a 100,000 square kilometer area. Some of these particles reached Alberta and Saskatchewan, as well as regions where the 1978 Arctic Winter Games were shortly to be held. Particulate nuclear material posed a significant risk to humans through inhalation or digestion, either directly or by consumption of contaminated flora or fauna. However, after chemical testing revealed the particles to be insoluble, Morning Light managers concluded that no more needed to be done; the particulate matter would be absorbed in lakebeds and permafrost, where the isotopes would decay in safety, peace, and isolation.<sup>341</sup> Those responsible for cleanup assigned the harsh arctic environment itself a crucial role in the

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<sup>341</sup> Ibid., 34–36.

cleanup. After two search phases to account for the spring thaw, Operation Morning Light ended on October 14, 1978. The American and Canadian teams dispersed, satisfied that they had returned the Great Slave Lake area to an adequate semblance of its pre-Cosmos state of nature.



**Figure 3.2:** A radioactive particle shed during the Kosmos 954 crash, next to a penny for scale.

Once word got out about the accident after the fact, the details dominated mainstream international news for several days. Because it had already happened and was not an impending threat, updates in the American press quickly tapered off as news about the Panama Canal, Anwar Sadat, and welfare reform reclaimed center stage. Reactions

among lay citizens in America and Canada varied. A Canadian government official assured a group of 250 concerned Inuit that they were in no danger of ingesting contaminated caribou meat.<sup>342</sup> American editorials lauded the quick work of the international response team, reserving their most pointed critique for the sloppy, nuclear-happy Soviet space program—conveniently neglecting to mention the radioisotope thermal generators regularly used by NASA. Soviet news outlets accused the “bourgeois press” of embellishment, comparing Cosmos 954 favorably to American nuclear weapons accidents on its own soil.<sup>343</sup> Of course, a few public reactions by civilian observers reflected greater alarm.<sup>344</sup> The back cover copy of a journalist’s memoir of the cleanup effort published immediately afterward compared the Cosmos 954 reentry to “all our nightmarish memories of Hiroshima and Nagasaki.”<sup>345</sup> For the most part, those who responded publicly about the accident expressed relief that it had happened in a place seemingly devoid of life—human or otherwise.<sup>346</sup>

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<sup>342</sup> The meeting between Inuit communities and the Canadian government official took place a year and a half before the results of tests to the lichens were published, which suggests a certain level of unsupported placation at work. “Eskimos Reassured On Satellite Radiation,” *New York Times*, January 30, 1978; H. W. Taylor et al., “Cosmos 954: Search for Airborne Radioactivity on Lichens in the Crash Area, Northwest Territories, Canada,” *Science (New York, N.Y.)* 205, no. 4413 (September 28, 1979): 1383–85.

<sup>343</sup> Yuriy Kornilov, “Fears Spread By Some Western Papers Over Cosmos 954 Discounted. Who Is To Profit By This?,” *TASS*, February 7, 1978, *Orbital Debris (1960-1988)*, NASA Headquarters Historical Reference Collection, Washington, DC.; Vladimir Gubarev, “In a Businesslike Manner,” *Pravda*, January 28, 1978.

<sup>344</sup> “The Dangers of Cosmos 954,” *New York Times*, January 27, 1978, 954; “Asides: The Cosmos 954 Affair,” *Wall Street Journal (1923 - Current File)*, February 1, 1978, sec. 1; “The Orbiting Reactors,” *The Washington Post (1974-Current File)*, February 2, 1978.

<sup>345</sup> Leo Heaps, *Operation Morning Light: Terror in Our Skies: The True Story of Cosmos 954*. New York: Grosset and Dunlap, 1978.

<sup>346</sup> This claim recapitulated classic colonialist tropes used to justify the conquest of empty, underused land, as First Nations used the area as a seasonal hunting ground, and a small fishing industry thrived on Great Slave Lake. Kornilov, “Fears Spread By Some Western Papers Over

In the months after Cosmos 954's plunge, several space objects fell to Earth. Many made American news in advance—to the public puzzlement of at least one NASA spokesperson who noted that space junk had been falling for years with similar non-outcomes, and nobody had said a word.<sup>347</sup> This public performance of openness and surprise obscured decades of classified NASA policy on containing and concealing instances of reentering debris and the potential for damage at the site of impact. Private citizens were actively aware of reentering space junk before the rash of late 1970s reentries, most notably members of the Smithsonian-sponsored Operation Moonwatch.<sup>348</sup> Moonwatch enlisted amateur astronomers to track satellites as well as participate in what the Smithsonian called “death watches”—tracking falling debris and aiding in the recovery of fragments that survived.<sup>349</sup> By the late 1960s, reentering space junk became the star of major novels and films. The Michael Crichton novel *The Andromeda Strain*, published in 1969 and adapted into a film of the same name in 1971, features a fallen satellite that has transported a deadly microorganism to a small American town, where officials must contain it before it decimates the entirety of human civilization.<sup>350</sup> The

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Cosmos 954 Discounted. Who Is To Profit By This?"; Gubarev, "In a Businesslike Manner"; From Times Wire Services, "Russ Must Pay Recovery Cost--Trudeau: Otherwise, Leader Says, Canada Will Not Return Cosmos Debris," *Los Angeles Times*, February 5, 1978, sec. PART ONE FINAL.

<sup>347</sup> Barbara Brotman, "Satellite Falling, but Landing Site Still Up in the Air," *Chicago Tribune*, September 16, 1978.

<sup>348</sup> For the definitive history of Operation Moonwatch, see W. Patrick McCray, *Keep Watching the Skies!: The Story of Operation Moonwatch and the Dawn of the Space Age* (Princeton University Press, 2008).

<sup>349</sup> Leo X. Abernethy, "Briefing Memorandum: NASA's Interest, Experience and Concern with Space Debris."

<sup>350</sup> Michael Crichton, *The Andromeda Strain* (New York: Alfred A. Knopf, 1969); Robert Wise, *The Andromeda Strain*, 1971.

groundbreaking 1968 horror film *Night of the Living Dead* portrays a group of civilian and military bureaucrats arguing over whether radiation from a destroyed space probe should be publicly held responsible for an epidemic of reanimated corpses.<sup>351</sup>

### **Ground Testing Liability**

The Cosmos 954 incident briefly influenced broader nuclear negotiations between the Cold War superpowers. On January 30, 1978, President Jimmy Carter held a press conference in which he praised the United States' cooperation with Canada in the Cosmos 954 tracking and cleanup efforts. In his remarks, Carter called for the Soviet Union to join the United States in a bilateral ban on nuclear powered spacecraft, citing the newly demonstrated threat of damage by reentry accidents.<sup>352</sup> The Soviet government roundly rejected this call, as did American space scientists and engineers who understood the utility of nuclear energy on spacecraft with certain energy requirements, or those that cannot use solar energy efficiently due to distance from the sun and other physical obstacles.<sup>353</sup> However, at the international level, the United Nations created a space nuclear power working group within the Scientific and Technical Subcommittee in the summer of 1978.

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<sup>351</sup> George A. Romero, *Night of the Living Dead*, 1968.

<sup>352</sup> "Transcript of President's News Conference on Foreign and Domestic Affairs: OPENING STATEMENT Soviet Satellite Problem Entered the Atmosphere QUESTIONS AND ANSWERS 1. Egyptian Arms Request 2. Handling Marston Case 3. Picking U.S. Attorneys 4. Israeli Settlements 5. Conflict on Marston Replies 6. Reply to Eilberg Request 7. Middle East Solution 8. Coal Strike 9. Nuclear Satellites 10. Status of Satellite 11. Farm Worker Entry 12. Soviet Killer Satellites 13. Nazi March in Skokie 14. Plan to Be Missionary 15. Covert Surveillance 16. 100% Parity Demand 17. Tax Plan Changes," *New York Times*, January 31, 1978.

<sup>353</sup> David Buden, "Satellites: An Overreaction to Reactors: Carter's Call to Ban Orbiting Nuclear Devices Is Wrong--They're Safe, Necessary," *Los Angeles Times (1923-Current File)*, February 9, 1978, sec. PART II; "Soviets Defend A-Satellites," *The Christian Science Monitor (1908-Current File)*, February 16, 1978.

By 1979, the Canadian government put the United Nations' relatively new rules on space liability to the test for the very first time.<sup>354</sup> Recalling the exorbitant payout of the Cuban Cash Cow, national liability in the case of damage by space junk, particularly between two opposite sides of an era-defining geopolitical divide, can be an extremely messy affair. On January 23 1979, exactly within the 1-year limit imposed by the 1972 Liability Convention, Canada filed a claim against the Soviet Union for an amount of \$6,041,174.70 to cover the cleanup expenses alone.<sup>355</sup> The total costs of Operation Morning Light would climb to an excess of \$14 million, but at the time of the claim deadline the full extent of damages were not yet fully known.<sup>356</sup> The claim called for compensation of what the Canadian government had spent so far in order to return the affected region back to the condition in which it had been before the accident occurred—the required outcome for efforts to rectify reentry damage stipulated in the Liability Convention. The Canadian government argued that the introduction of radioactive debris

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<sup>354</sup> This was not the first instance in which a recovered fragment of space technology tested emergent international space law. In 1962 pieces of hardware identified as the remains of Sputnik IV were recovered in Manitowoc, Wisconsin. The following year a local lawsuit by a man who recovered several shards of metal and wished the fragments to be returned to him tested clause 7 of the 1962 United Nations Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space. "Space Law Case Ends," *Washington Post*, February 18, 1963, Orbital Debris (1960-1988), NASA History

<sup>355</sup> Eilene Galloway argues that this figure came from the amount spent on recovery and cleanup of radioactive materials, and excludes "administrative and other types of expense." "Nuclear Powered Satellites: The USSR Cosmos 954 and the Canadian Claim," *Akron Law Review* 12, no. 3 (Winter 1979): 413.

<sup>356</sup> W. K. Gummer et al., "Cosmos 954: The Occurrence and Nature of Recovered Debris," 36. Verbatim Record of the U.N. Comm. on the Peaceful Uses of Outer Space. (180th mtg.) held July 5, 1978, U.N. Doc. A/A.C. 105/P.V.187 (July 13, 1978) 26-27.

into the Barrens rendered a part of Canadian territory unfit for use, which qualified as “damage to property” in the Convention.<sup>357</sup>

As part of this claim, two members of the Dene nation submitted affidavits speaking to the particular utility of the environment in which the Cosmos satellite fell. Georges Erasmus, president of the Dene Nation of the Northwest Territories, contributed sworn testimony in which he expressed deep concern that the radioactive effects of the debris field, as yet unknown, could “cause injury to the Dene and their way of life.” Erasmus described meetings held among the Dene in which many citizens worried about the uncertainty of contamination even after the cleanup—that fishing and hunting, as well as water and land use, could be negatively affected for years.<sup>358</sup> John Marlowe, also of the Dene Nation, obliquely suggested in his affidavit that the cleanup effort might not have taken place with the best interests of First Nations at heart. In relaying his memories of the reentry, Marlowe recalls that the “army” came to clean up, and forced Dene residents to remain in their homes for a day and prevented them from visiting the lake for a week. Noting the importance of fishing in his family for winter subsistence, Marlowe related his habit of visiting his lake fishing nets every two days, yielding over ten trout and whitefish in each haul. During the period of cleanup, no Dene residents of nearby Snowdrift could procure food, even as Marlowe claims they found pieces of satellite debris in town.<sup>359</sup> Erasmus concluded his testimony by noting that the Dene “fish and trap in almost every

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<sup>357</sup> “Canada: Claim against the Union of Soviet Socialist Republics for Damage Caused By Soviet Cosmos 954,” *International Legal Materials* 18, no. 4 (July 1979): 905.

<sup>358</sup> Georges Erasmus, “Affidavit of Georges Erasmus,” May 7, 1980, Library and Archives Canada.

<sup>359</sup> John Marlowe, “Affidavit of John Marlowe,” May 6, 1980, Library and Archives Canada.

square mile of [the] area” in which the debris landed, concluding that “therefore, there is no place where the debris fell which is not used by the Dene.”<sup>360</sup>

Indeed, an official with the Canadian Atomic Energy Control Board concurred in separate testimony that radioactive particles had been found in Snowdrift and other nearby towns, supporting the concerns put forth by Dene citizens.<sup>361</sup> In spite of this supporting evidence from local communities, the idea of utility was just one point of translation difficulty that had plagued the UN space treaties for decades. For example, the French term “responsabilité” contains the English meanings of both “responsibility” and “liability”—very different concepts, particularly in a case like the Cosmos 954 crash in which one of the responsible parties was not human, but rather the natural environment of near-Earth space that brought the satellite down in the first place.<sup>362</sup> The translation was not just linguistic, but also cultural: In the case of the Northwest Territories, the damaged “property” amounted to a seemingly empty snowscape described by its own citizens as barren, lifeless, and inhospitable—arguably a perfect picture of uselessness, even as defined by a defendant nation that governed vast areas marked by similarly extreme arctic conditions. Soviet representatives noted that the small debris had been determined by the claimants themselves to not be a threat to the environment or bodies of humans or animals in the region. The large pieces of radioactive debris represented the only real sources of damage subject to liability, and those had been safely contained and removed

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<sup>360</sup> Georges Erasmus, “Affidavit of Georges Erasmus.”

<sup>361</sup> Geoffrey B. Knight, “Second Supplementary Affidavit of Geoffrey B. Knight,” April 30, 1980, Library and Archives Canada.

<sup>362</sup> Piotr Manikowski, “Examples of Space Damages in the Light of International Space Law,” *The Poznań University of Economics Review* 6, no. 1 (2006): 58–59.



from the environment by the time the Canadian government filed its claim with the United Nations.

In a chapter titled ““When Satellites Fall: On the Trails of Cosmos 954 and USA 193,” in *Down to Earth: Satellite Technologies, Industries, and Cultures*, cultural theorist Lisa Parks argues that Soviet officials pushed back against Canada’s claim by stating that Cosmos 954 had, upon reentry, ceased to be a Soviet satellite. Parks contends that the Kremlin took the official position that Cosmos 954 had transformed into an assortment of undifferentiated metals and substances and, since this diffuse conglomeration could no longer perform the functions of a satellite, it could therefore not be held to the absolute terms of the Liability Convention.<sup>363</sup> This argument suggests that Soviet legal officials imbued the borderlands between Earth and outer space with unique powers of ontological transformation. However, the earliest international space law, which predates Cosmos 954 by fifteen years, declares that passage through the atmosphere does not negate basic liability for damage caused by space objects.

After over two years of wrangling with these translational issues, the Soviet Union relinquished a tidy and even settlement of \$3 million, which the Canadian government accepted.<sup>364</sup> This was the first, and to date the only invocation of the Liability Convention by two signatory nations. Canada would go on to play a leading role in subsequent international negotiations of nuclear space power source regulation. These negotiations snowballed into a decades-long debate in the United Nations as space

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<sup>363</sup> Parks, “When Satellites Fall: On the Trails of Cosmos 954 and USA 193,” 225.

<sup>364</sup> “Canada-Union of Soviet Socialist Republics: Protocol on Settlement of Canada’s Claim for Damages Caused by ‘Cosmos 954,’” *International Legal Materials* 20, no. 3 (May 1981): 689.

industries developed, evaluated, and adopted new power technologies for rockets, probes, and satellites, and as nuclear energy crises unfolded on the Earth below.<sup>365</sup>

While Canada was the third nation to launch an artificial satellite into outer space, it did not have its own launching capabilities and relied on an alliance with America as its launching state. The encounter with hazardous fallen space debris forced the Canadian government into the combative aspects of the Space Race without warning, on the side of its neighbor and ally. The legal fight over the remains of Cosmos 954 highlighted the necessity of further elaboration and codification of an expansive definition of space debris at the international level. Beginning in the 1980s, most state space programs, the United Nations, and international space policy organizations issued formal statements defining “fragments” of space technologies as falling within the legal realm of space debris. This strengthened the legal foundation of space liability law should a future piece of falling space debris cause similar sparring as occurred over Cosmos 954.

Cosmos 954 was not the first object to reenter the atmosphere. It was not the first piece of space junk to hit land, nor was it the first radioactive artifact to fall from orbit. However, it was the first of this kind of phenomenon to happen at the exact confluence of circumstances to create a minor maelstrom: the right space weather, the right antagonists, the right material attributes (i.e. nuclear), and the right location—just safe enough to be a

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<sup>365</sup> United Nations General Assembly, *UN Resolution 33/16 No. 9 Relating to Information to Be Furnished by States about Malfunctioning NPS in Outer Space*, 33/16, vol. 9, 1978; United Nations Outer Space Committee, *Principles on the Use of Nuclear Power Sources in Outer Space*, 1986; Vladimir Kopal, “The Use of Nuclear Power Sources in Outer Space: A New Set of United Nations Principles?,” *Journal of Space Law* 19, no. 2 (1991); United Nations General Assembly, *Principles Relevant to the Use of Nuclear Power Sources in Outer Space*, vol. A/RES/47/68, 1992.

test and not a conflict. The Great Slave Lake area where the visible debris landed occupied a perfect sliver of Western cultural space between empty wasteland and Fragile Arctic at a time when such liminal spaces were only beginning to become visible and precious to mainstream communities around the world.<sup>366</sup> By 1978, a broad Western public was already aware of the potential dangers of nuclear energy production, and as influential space law scholar Eileen Galloway put it at the time, these dangers would soon provide a dependable source of international momentum towards environmental protection in cases of nuclear reentry.<sup>367</sup> Galloway maintained that a mainstream international public had grown increasingly acclimated to the burgeoning discourses of environmentalism, grounded in early resistance to invisible contamination forced upon a non-consenting society by faceless authoritarians. She anticipated that from that point forward an educated populace would demand to be made aware of the sources of said contamination, whether within the atmosphere or hundreds of kilometers overhead.<sup>368</sup>

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<sup>366</sup> In 1985, ecologist M. J. Dunbar questioned the rhetoric used to drum up popular support for Arctic environmental protection. "Ecological stability, diversity, and fragility have been exposed to so much discussion in recent years, both in the scientific press and in the popular press and other 'media,' that a sort of miasmatic atmosphere has been produced, from which it is necessary every now and then to escape into clearer and purer air. The phrase 'the fragile Arctic' appears to have been coined and perpetuated not by scientists but by politicians and newspapermen. It is a catchy phrase and it has been greatly overworked. I can see little reason to suppose that Arctic ecosystems are any more or less vulnerable to human interference than other ecosystems; and it seems from present developments that a really fragile ecosystem can be found in the tropical rainforest." In Franklyn Griffiths, *Arctic Alternatives: Civility of Militarism in the Circumpolar North* (Dundurn, 1992), 117.

<sup>367</sup> Eilene Galloway, "Nuclear Powered Satellites: The USSR Cosmos 954 and the Canadian Claim," *Akron Law Review* 12, no. 3 (Winter 1979): 414.

<sup>368</sup> These discourses abounded following the rise to currency of Rachel Carson's *Silent Spring*, which provided the imagery and allegory that extended to multiple debates about space junk in orbit and reentering the atmosphere. The impact, influence, and response to the publication of *Silent Spring* and Rachel Carson have been widely covered in historical and literary scholarship. For example, see Linda Lear, *Rachel Carson: Witness for Nature* (Houghton Mifflin Harcourt,

While the social and political ramifications of a nuclear reactor-powered satellite crash-landing on solid ground may have been unprecedented, at the atmospheric level the Cosmos 954 accident barely left a mark. If the United States Department of Energy had not detected unique aerosol signatures of 90% enriched uranium-235 in stratospheric samples gathered in the months following reentry, the existence of fissile material from the satellite would have been all but invisible against the mixing and remixing of over thirty years of atmospheric nuclear fallout from weapons tests.<sup>369</sup> Like the caribou that could have transported uranium across the tundra and into human bodies, the biological, geochemical, and geophysical world played an incontrovertible role in rendering humankind's nuclear presence into a uniform continuum from underground to outer space.

### **Skylab Falling**

Mere days after Cosmos 954 fell from the sky, Assistant Secretary of State for Oceans and International Environmental and Scientific Affairs Patsy Mink sent a letter to NASA Administrator Robert Frosch. Mink noted that the recent impact of the nuclear satellite had brought the hazards of satellite reentry to the attention of the international press—

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2009); Lisa H. Sideris and Kathleen Dean Moore, eds., *Rachel Carson: Legacy and Challenge* (Albany, NY: SUNY Press, 2008); Ralph H. Lutts, "Chemical Fallout: Rachel Carson's Silent Spring, Radioactive Fallout, and the Environmental Movement," *Environmental Review: ER* 9, no. 3 (October 1, 1985): 211–25; Thomas R. Dunlap, "Review Essay: Before, During, and After Silent Spring," *Environmental Review: ER* 2, no. 6 (1977): 34–40; Mark Hamilton Lytle, *The Gentle Subversive: Rachel Carson, Silent Spring, and the Rise of the Environmental Movement* (New York: Oxford University Press, USA, 2007); Priscilla Coit Murphy, *What a Book Can Do: The Publication and Reception of Silent Spring* (Univ of Massachusetts Press, 2007); Craig Waddell, *And No Birds Sing: Rhetorical Analyses of Rachel Carson's Silent Spring* (SIU Press, 2000).

<sup>369</sup> P. W. Krey et al., "Atmospheric Burnup of the Cosmos-954 Reactor," *Science (New York, N.Y.)* 205, no. 4406 (August 10, 1979): 583–585.

which had recently switched its focus to another potential reentry disaster. This time, the feared object contained no nuclear fuel, but was several times more massive than Cosmos 954, and American in origin. The American space station, Skylab, had been drifting in orbit for some time since its last crew of astronauts departed in 1974. Mink related a deep concern about what might happen if NASA did not interfere: “It is said that about 50 tons of metal can be expected to survive the Skylab reentry and impact the earth’s surface. This appears to represent a substantial hazard to life.” Fearing the potential international implications and detrimental effect on US foreign policy, Mink concluded by offering the services of her office to NASA in devising both a plan to avoid catastrophe and to address the seemingly inevitable international pressure as Skylab’s orbit continued to decay.<sup>370</sup>

The 1979 reentry of Skylab inspired worldwide space junk mania, and remains the best-known and most-repeated story of falling anthropogenic debris.<sup>371</sup> Launched in May 1973, Skylab was America’s first space station—a spacecraft that remains in orbit for extended periods of time. It hosted three different mission crews from 1974 to 1975, who used Apollo-era spacecraft to arrive and depart from orbit. At the end of the first Skylab program, NASA developed intermediate plans to continue use of the space station in conjunction with the upcoming Space Shuttle program, which was then still in the

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<sup>370</sup> “Patsy T. Mink to Robert Frosch,” Letter, (February 14, 1978), Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

<sup>371</sup> For a thorough overview of the Skylab program from planning through reentry, see Charles Dunlap Benson and William David Compton, *Living and Working in Space: A History of Skylab* (Washington, DC: Scientific and Technical Information Branch, National Aeronautics and Space Administration, 1983). Chapter 19, “What Goes Up...” focuses on NASA’s attempts to save the station during its final years on orbit.

early design and study stage. However, two converging obstacles interfered with these plans—one social and one environmental.

As part of the complex, years-long series of deliberations and decisions that went into the construction of Skylab, engineers compromised on whether to include a rocket engine on the space station. Such an engine would enable astronauts or ground controllers to move the spacecraft to a different orbit or bring it back to Earth in a controlled fashion in the event of orbital decay or other incident; however, it would also require greater spending on this final application of the cash-strapped Apollo program. NASA researchers reasoned that a native engine would not be necessary, considering that a new spacecraft then under development could do the job just as well at no additional upfront cost.<sup>372</sup> The Space Transportation System, of which the Space Shuttle program was to be the keystone technology, had been designed with the retrieval and rescue of satellites in mind as a primary mission. As NASA administrators and engineers struggled against ongoing design conflict, political gridlock, and budgetary overrun, the projected first launch of the Shuttle slipped until it became clear that the spacecraft would not fly until the early 1980s.<sup>373</sup> Before returning the Earth, the final Skylab crew used the propulsion system of the Apollo command-service module, which was docked to the station, to carefully nudge the space station to a higher altitude. At such heights, NASA predicted

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<sup>372</sup> George Alexander, “TONS OF DEBRIS COULD STRIKE EARTH: U.S. Seeks a Safe Death for Skylab,” *Los Angeles Times (1923-Current File)*, January 14, 1979, sec. Part I.

<sup>373</sup> For more on the planning of the Space Transportation System and the rescue and reuse of satellites, see Chapter 4 of this dissertation.

that Skylab would safely orbit for approximately ten years, until 1983, by which time NASA leadership pledged that the Shuttle program would be well underway.<sup>374</sup>

By whim of chance and nature, the Sun entered a period of solar maximum as the end of the decade neared, reaching its peak month of sunspot activity in December 1979.<sup>375</sup> Given the regularity of the solar cycle, NASA researchers and administrators anticipated that the increase in solar activity would likely affect the orbit of the dormant space station. However, the peak of the 21<sup>st</sup> solar cycle turned out to yield a stronger surge in sunspot activity than predicted by astronomers and accounted for by NASA in planning Skylab's orbital lifetime. All objects in low-Earth orbit were affected by the expanded, denser veil of atmospheric particles, but Skylab was one of the most massive objects to succumb to the encroaching sky. By the middle of the decade, NASA and NOAA officials determined that the space station's orbit had already begun a rapid decay

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<sup>374</sup> "Robert A. Frosch to the Honorable Patsy T. Mink," Letter, (March 28, 1978), Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

<sup>375</sup> The sun does not sit quietly when not in a period of solar maximum. A vigorous solar storm occurred in August 1972 that affected communications systems — including a major outage of the AT&T coaxial cable linking Plano, Illinois to Cascade, Iowa. Had an Apollo mission taken place during this storm, it is highly likely that the astronauts would have been seriously injured or killed by the excessive radiation while passing through a region of orbit not as well protected by magnetic fields. Given that the event happened exactly between the final two Apollo moon missions, and not during a period of solar maximum, the timing proved fortunate. In his novel *Space*, first published in the midst of the 21st solar maximum, James Michener imagines what would happen to astronauts on the moon should an unexpected solar storm hit—with fatal results. C. W. Anderson, L. J. Lanzerotti, and C. G. MacLennan, "Outage of the L4 System and the Geomagnetic Disturbances of 4 August 1972," *Bell System Technical Journal* 53, no. 9 (November 1974): 1817–37, doi:10.1002/j.1538-7305.1974.tb02817.x; Louis J. Lanzerotti, "Space Weather Effects on Technologies"; National Research Council (U.S.), ed., *Radiation and the International Space Station: Recommendations to Reduce Risk*, Compass Series (Washington, D.C.: National Academy Press, 2000); James A. Michener, *Space*, 1st edition (New York: Random House, 1982).

into the upper atmosphere, starting a downward plunge earlier than expected.<sup>376</sup> Had the sun produced energy at average solar maximum levels, the space station likely would have remained aloft for the entirety of its initial ten-year predicted orbital lifetime, well beyond the Space Shuttle program's first launch in April, 1981.

The physical realities of the stormy Solar Maximum meant that Skylab would reenter before a Shuttle orbiter—as well as the retrieval and repair spacecraft needed to rendezvous and capture the rapidly moving station—could be mobilized to boost it to a higher orbit. The space station would undergo an uncontrolled reentry—that is, ground controllers could not alter its orbit to ensure that it would fall over a specific part of the Earth below. As it stood, the combination of natural and social obstacles led NASA administrators to concede that Skylab would reenter the atmosphere anywhere from mid-1979 to early 1980.<sup>377</sup>

The problems associated with uncontrolled reentry had concerned program officials before Skylab even reached orbit. In 1970, Skylab mission operators at the Johnson Space Center (JSC) circulated a memo noting the need to take the end of the space station's life into account in the years leading up to its launch. Three years in advance of Skylab's ascent to orbit, JSC commissioned a study of risks presented by reentering debris generated by the Skylab mission, and called for the creation of a public information plan to be released in the event that any such debris threatened populated

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<sup>376</sup> "Sunspot Activity Threat to Skylab Predicted," *Aviation Week & Space Technology*, December 19, 1977.

<sup>377</sup> "Skylab Reuse Program Strawman Plan" (NASA Marshall Space Flight Center, September 14, 1977), Skylab Series, Management Reviews and Presentations (1967-77), Box 744, JSC History Collection; "Robert A. Frosch to the Honorable Patsy T. Mink."



areas in the future.<sup>378</sup> The report that resulted included the probability that each major component of the planned station might hit a human being on the ground upon reentry, focusing on objects massive enough to survive the fall more or less intact. The authors of the study calculated the likelihood of at least one human casualty resulting from the reentry of Skylab at 0.018—or, as one reviewer of the study scribbled in marginalia, one in 55.<sup>379</sup> After detailing potential changes to the Skylab mission that could reduce the risk, the authors of the report concluded that these steps would only take place at great expense and could very well be technically unfeasible. They also noted a low likelihood that such labor and expense would be recouped in subsequent missions. They concluded with a set of simple recommendations for future large unshielded spacecraft that echoed NASA policy on reentry risk from the earliest days of the space program:

We therefore recommend: That NASA accept the Skylab orbital debris risks. That NASA establish orbital debris criteria for future programs. These criteria, for example, may specify acceptable levels of risk and may require that the risks be assessed early in the programs.<sup>380</sup>

Acting NASA Administrator George Low concurred with these conclusions. Upon assessing the report, Low relayed to his staff his decision that NASA should accept the

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<sup>378</sup> Dudley G. McConnell, "Space Orbital Debris," Memorandum, (October 6, 1970), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>379</sup> Dale D. Myers, "Report on Skylab Orbital Debris," Memorandum, (November 24, 1970), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>380</sup> *Ibid.*, 3.

risk associated with reentering Skylab debris. He shifted responsibility for preparation for such an outcome from JSC to the NASA Office of Public Affairs and Office of International Affairs, from whom he requested a comprehensive plan for how to manage public information before reentry three months in advance of the Skylab launch.<sup>381</sup>

By the following year, however, as Space Shuttle engineers contemplated the survivability of the expendable external fuel tank—designed to be discarded over the ocean after each launch—Low reconsidered his stance. In calling for the establishment of predictive protocols to account for fragments of the ET that might survive the fall from orbit, a group of NASA technical officers advised Low that similar studies ought to be undertaken for objects of a certain size and mass that were either slated for launch or already in orbit. In addition to recommending that “all future flight projects... should take into account methods for defending against returning debris,” the group of technical officers also advised Low that the 1971 decision to accept the risk for orbital debris generated by Skylab could yield material hazards down the line.<sup>382</sup> First among the “open issues” that concluded the official memorandum for the record on orbital debris was the

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<sup>381</sup> George M. Low, “Skylab Orbital Debris,” Memorandum, (April 3, 1971), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>382</sup> Those who were concerned about reentry fragments from Skylab in the years before it launched also worried about the reentry of pieces of the Saturn V rocket that would send it into orbit. A separate report concluded that venting additional fuel from these rocket stages at the correct attitude would allow ground controllers to choose where and when to bring these artifacts out of orbit. Dale D. Myers, “Skylab Program, Deorbit of S-IVB,” Memorandum, (November 28, 1972), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

requirement that NASA take steps to notify an unidentified audience of the approximate time and location of space debris impact.<sup>383</sup>

NASA subsequently supported several studies intended to address the potential debris hazard from Skylab as a special case.<sup>384</sup> From this initial effort, NASA researchers and administrators assembled criteria on risk, how to assess the odds of casualty, and reentry assessment protocols for all future massive spacecraft.<sup>385</sup> While other large artifacts had reentered the atmosphere in the preceding two and a half decades, the size and inclination of Skylab's orbit made it different. Researchers calculated that the total weight of Skylab debris that could be expected to survive reentry would likely equal the debris generated by the entirety of the Gemini and Apollo missions; additionally, Skylab would produce half the total fragments that either Gemini or Apollo flights produced in aggregate. However, the size and weight of Skylab fragments would vastly outweigh any single piece of Apollo or Gemini debris, and the inclination of Skylab's orbit meant it covered a much broader area of the ground below. The orbits of the previous program spacecraft constrained the range of a potential debris impact to areas in South Asia, Africa, South and Central America, and Australia. Skylab, as the author of one briefing

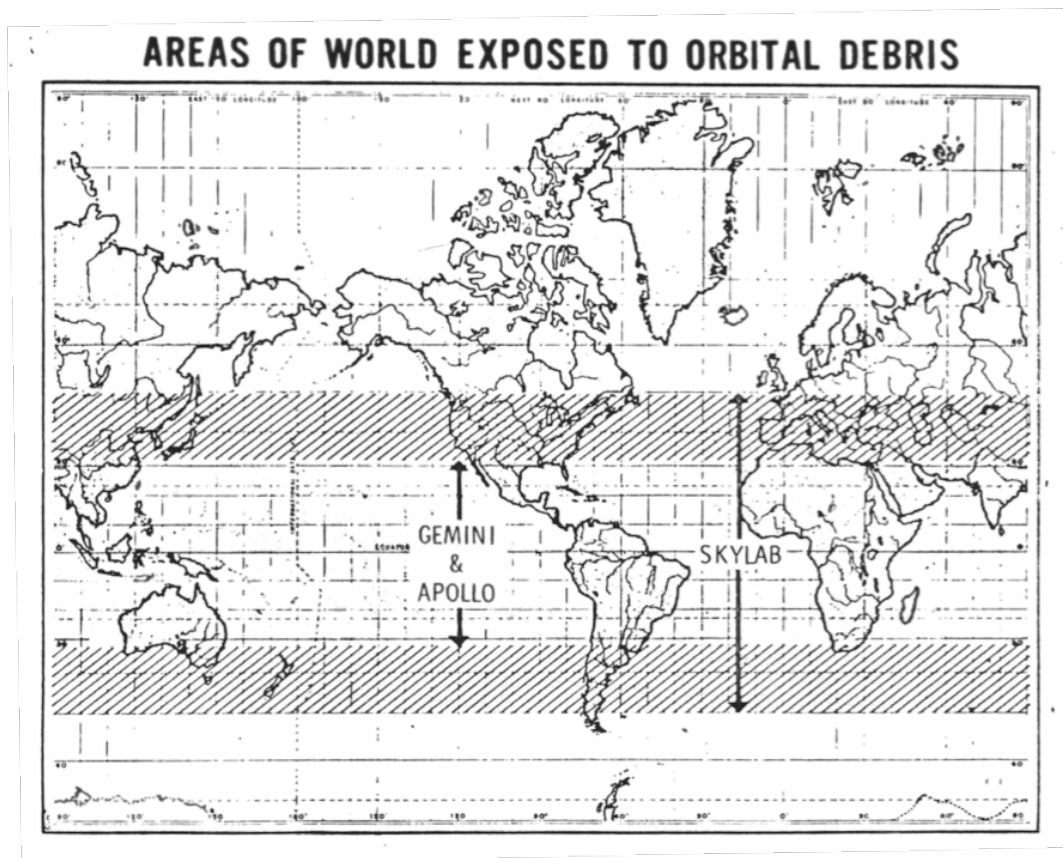
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<sup>383</sup> William A. Fleming, "Decisions, Action Items, and Open Issues Resulting from October 18 Meeting with Dr. Low on Orbital Debris," Memorandum, (October 26, 1972), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>384</sup> W. A. Fleming, "Presentation Slides of Orbital Debris," November 30, 1972, Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>385</sup> William A. Fleming, "Decisions, Action Items, and Open Issues Resulting from October 18 Meeting with Dr. Low on Orbital Debris."

pointed out, could fall over these regions as well as parts of the continental United States, Europe, and Russia.<sup>386</sup>



**Figure 3.3:** This map shows the breadth of latitude over which orbital debris from Gemini and Apollo could land, and the significantly larger corresponding area of potential impact for the Skylab program.<sup>387</sup>

The physical properties of the orbit chosen for Skylab meant that the station would cross over a greater total area of land, though the probability that any debris from its reentry would hit *terra firma* remained minuscule compared to the likelihood that it would land in an ocean. Orbital mechanics affected the potential range of impact, as did

<sup>386</sup> W. A. Fleming, "Presentation Slides of Orbital Debris."

<sup>387</sup> Ibid.

other environmental factors such as atmospheric wind currents and the rotation of the Earth, some of which proved either difficult or impossible to calculate in reentry models.<sup>388</sup> The combination of these natural factors with unknowns such as the aerodynamic properties, velocity, attitude, and path of surviving fragments exceeded researchers' abilities to precisely predict when and where fragments would land—known as the “boundary of dispersion” or “footprint.”<sup>389</sup> Determining hazard to human life required the consideration of yet another factor that had begun to be featured in other assessments of global environmental risk—namely, population growth. In determining whether boosting a potentially dangerous object to a higher orbit could provide an acceptable alternative to hazardous reentry, researchers argued that such a procedure could have the opposite effect. As time goes on and the world population increases, it becomes more likely it becomes that a piece of debris will hit someone. Therefore, boosting the object to a higher orbit from which it would eventually still fall back to Earth could be more likely to yield casualties in a more population-dense future.<sup>390</sup>

In determining the thresholds for human risk, researchers attempted to model debris footprints using different object and environmental variables, including a so-called

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<sup>388</sup> For instance, a 1974 review of debris dispersion studies noted that all documents surveyed calculated debris footprints using the assumption of a nonrotating Earth. V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs” (Columbus, OH: Battelle Memorial Institute, Columbus Laboratories, March 7, 1974), 19, Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>389</sup> V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs.”

<sup>390</sup> *Ibid.*, 46.

“man-radius” that ranged from one foot to one meter.<sup>391</sup> However, one study also suggested that the best way to assess the risk of human casualty from falling debris came from a natural analogy—namely the casualty rates from falling meteoroids. Although the authors of this study recommended a controlled reentry experiment in place of the extant theoretical studies, they argued that the behavior and low casualty rates of meteor impacts suggested that space junk would be similarly benign to human beings. The simple conclusion: "The risk of casualties due to meteorite impact appears to be low. (To date, there have been no verified human fatalities due to meteorite impacts.) Therefore, the risk from NASA activities should also be low."<sup>392</sup> Authors of the study included an overview of meteorite-caused casualties that included interpretations of Biblical passages that suggested a meteor strike. Such a wide stretch of time perhaps best illustrated the rarity of casualties caused by objects falling from space—compared to the mere decades of the space age, in which no people had been struck by space debris, the long term low rate of meteorite casualties provided a hopeful comparison point. An appendix table at the end of the report lists only twenty incidents, each labeled with a “provisional rating” regarding the likelihood that the event happened as recorded, ranging from “doubtful” to “possible” to “probable” to “certain.” Until an in situ test of a reentry experiment, these natural

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<sup>391</sup> J. Lindberg, “Skylab Orbital Debris Risk Assessment” (Marshall Space Flight Center, May 10, 1973), 2, Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection; V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs,” 19.

<sup>392</sup> V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs,” 6.

analog provided the only logical source of data on what might be expected to happen with the reentry of artifacts—and the expectation proved optimistic.<sup>393</sup>

When program parameters changed and Skylab's weight ballooned from 138,743 pounds to 169,635 pounds in the leadup to launch, the possible "lethal area" of reentry footprint increased by 11.7 percent and raised the probability of casualty to 0.0273, above the 0.001 casualty probability threshold designated as "unacceptable" by the Air Force.<sup>394</sup> When NASA officials decided that the program should keep to its planned launch date anyway, program technical researchers contemplated different contingency plans—instead of changing the station before launch to reduce the risk upon reentry, the parameters of reentry itself could be changed or precluded entirely. Before Skylab even reached orbit, one group of researchers proposed sending a crew of astronauts aboard an Apollo spacecraft to dock with Skylab and draw it back to Earth in a carefully planned manner to ensure that it would fall over water. The astronauts would separate their craft from the station before its final plunge and return through the atmosphere themselves, protected from Skylab's fate by the Apollo command module's heat shield. However, such a plan would require changing the structure of Skylab in such a way that could possibly force out valuable components of the program's science mission and cause the launch date to slip further into the future. Risk to the astronauts, expense, labor, limited payload space, and scheduling all doomed the crew-controlled deorbit scenario.<sup>395</sup>

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<sup>393</sup> Ibid.

<sup>394</sup> J. Lindberg, "Skylab Orbital Debris Risk Assessment," 2; W. A. Fleming, "Presentation Slides of Orbital Debris," 17.

<sup>395</sup> Kenneth S. Kleinknecht, "SWS Deorbit," Memorandum, (March 12, 1973), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection; Leland F. Belew and

With direct human intervention off the table, in April, 1973, one month before launch, the Skylab program manager commissioned structural testing to determine whether certain components of the station could be manipulated so that larger fragments would be less likely to survive the eventual reentry.<sup>396</sup> Should the station break into small enough pieces, the possibility that large fragments would remain intact decreased. However, once again, changing critical components of the mission so close to the planned May launch proved to be a dead end due to the political and budgetary necessity of keeping to the launch schedule.<sup>397</sup> In 1974, after Skylab had reached orbit, researchers from the Battelle Institute suggested three categories of reentry damage countermeasures for future spacecraft of similar size and mass. The first, “destructive systems,” involved destroying the station before it began its eventual Earthward plunge. On-board explosives could be triggered from the ground at an optimal moment of decay, breaking large structures into smaller, less resilient pieces. Battelle researchers even suggested that a small nuclear device would do this job well, though perhaps such a method would not be a practical choice due to safety and political concerns.<sup>398</sup> By 1977, after the final crew of astronauts had departed, this idea resurfaced, this time with conventional chemical

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Richard G. Smith, “Saturn Workshop Deorbit” (Huntsville, AL: NASA Marshall Space Flight Center, March 12, 1973), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>396</sup> These studies required extra money and time. A study of one component of the reentry assembly would take 4 weeks and cost approximately \$100K. The other study, of the structural stability of the entire system to deorbit procedures, would take 6 months and cost approximately \$275K. Leland F. Belew and Richard G. Smith, “Saturn Workshop Deorbit.”

<sup>397</sup> Richard G. Smith, “SWS Deorbit,” Telegram, (March 27, 1973), Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

<sup>398</sup> V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs,” 6.



explosives launched in a separate vehicle to destroy Skylab while it remained in orbit.<sup>399</sup>

A second category of countermeasure, “protective systems,” involved building components of spacecraft to survive not only reentry, but impact as well—particularly those components that house hazardous materials, as had been done on spacecraft equipped with radioisotope thermal generators (RTGs).

The final category of reentry countermeasure proposed in 1974 gained favor among Skylab officials as the likely reentry date drew closer. “Orbital control systems” required using a native or external propulsion system to boost the spacecraft to a higher orbit.<sup>400</sup> The first and best option from this category involved using the under-development Space Shuttle to do the job. As an additional perk to this plan, Skylab program managers developed embryonic ideas for ways to reuse the space station. In an attempt to save money as the Space Transportation System development rapidly ran over budget and schedule, researchers at MSFC advocated turning the extant space station into the basis of a much larger, longer-lived orbital outpost and platform for the future Space Shuttle. Reusing the orbital workshop and the Apollo Telescope Mount (ATM), perhaps with the addition of a discarded Space Shuttle external tank, such a system would be made almost entirely out of free materials and scientific apparatus, and could even

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<sup>399</sup> John H. Disher, “Note to JSC/AT-J. Loftus,” May 2, 1977, Skylab Series, General Subject Files, Box 761, Skylab Reboost Documents, JSC History Collection; John H. Disher, “Skylab Review,” Memorandum, (June 27, 1977), Skylab Series, General Subject Files, Box 761, Skylab Reboost Documents, JSC History Collection.

<sup>400</sup> V. J. Drago and D. S. Edgecombe, “A Review of NASA Orbital Decay Reentry Debris Hazard to National Aeronautics and Space Administration Office of Space Science and Applications Launch Vehicle and Propulsion Programs,” 6.

eventually serve as a servicing station to repair failing satellites.<sup>401</sup> In 1977, after the last astronauts departed and the first shuttle had yet to launch, the reuse of Skylab seemed to be an ideal way to both reduce costs for the next generation space infrastructure and diminish the risk of the station causing damage or casualties on the ground upon reentry.<sup>402</sup> However, as the Solar Maximum became more intense and Skylab's decay accelerated, the feasibility of such a solution also declined. As noted earlier, although the final crew had boosted the station to an orbit that, under normal solar conditions should have kept it aloft into the mid-1980s, new estimates suggested it would come down before the end of the 1970s, well before the Shuttle would be operational. One more last-ditch effort to assemble an orbital control method to save Skylab involved sending an uncrewed, automated expendable rocket armed with a teleoperator retrieval system (TRS). However, the TRS had not yet been fully developed and tested by spring 1978.<sup>403</sup> The chief forecaster for the National Oceanic and Atmospheric Administration (NOAA) claimed that NASA had not used the most accurate model for sunspot activity, and predicted that none of these methods would be ready before the station began to

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<sup>401</sup> For more on the roots of the drive towards a reuse economy in the American space industry, including different iterations of a space station intended to be used as a repair and salvage site, see Chapter 4 of this dissertation.

<sup>402</sup> "Skylab Reuse Program Strawman Plan"; Joseph P. Loftus, Jr., "Skylab Reuse," Memorandum, (November 22, 1977), Skylab Series, Management Reviews and Presentations (1967-77), Box 747, JSC History Collection; J. Murphy, B. Chubb, and H. Gierow, "Skylab Reuse Study Presented to Mr. Yardley by MSFC" (NASA Marshall Space Flight Center, November 16, 1977), Skylab Series, Management Reviews and Presentations (1967-77), Box 747, JSC History Collection.

<sup>403</sup> John H. Disher, "Skylab Review"; Bob Allen, "Dr. Lovelace Briefing / Skylab," Briefing (NASA, March 8, 1978), Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

tumble.<sup>404</sup> With the TRS still at an early stage of development, launched atop an automated rocket without a “man in the loop” to facilitate any last-minute changes needed to ensure mission success, the ELV-TRS plan could not continue as a viable rescue option.<sup>405</sup> By December 1978, NASA cancelled the planned orbiter rendezvous mission with Skylab, and with it the possibility of recycling the venerable space station.<sup>406</sup>

With no way to break up the spacecraft into smaller pieces, nor money and time to scramble a rescue mission to move it to a higher, safer orbit, NASA had to determine how best to gain control over a potentially dangerous situation. In the summer of 1978, NASA joined forces with the Department of State, the DOD, and NORAD in forming a Skylab Contingency Working Group (SCWG).<sup>407</sup> Another victim of the active solar maximum provided a test run a few months before Skylab’s predicted reentry. The Pegasus program launched three satellites during the mid-1960s to study the micrometeoroid environment in orbit, yielding early information about what NASA currently calls the Micrometeoroid and Orbital Debris environment (MMOD), the natural and artificial objects that can degrade or destroy functioning payloads.<sup>408</sup> Pegasus 1 fell

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<sup>404</sup> “Sunspot Activity Threat to Skylab Predicted.”

<sup>405</sup> Bob Allen, “Dr. Lovelace Briefing / Skylab.”

<sup>406</sup> Charles S. Harlan, “Summary of Real Time Considerations to Tumble the Skylab Spacecraft for an Entry Target in the Indian Ocean” (NASA, August 10, 1979), Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

<sup>407</sup> William G. Bastedo, “Skylab Final Report” (Washington, DC: NASA, August 17, 1979), Attachment 1, p 2, Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

<sup>408</sup> “Pegasus Satellite,” *Encyclopedia Astronautica*, accessed July 8, 2016, <http://www.astronautix.com/p/pegasussatellite.html>; “Orbital Debris Impacts on Spacecraft,”

from orbit in September 1978, and SCWG used the opportunity to fine-tune their models for estimating reentry footprints and protocols for alerting diplomatic agencies of any potential danger. Shortly after the Pegasus reentry, the working group released its first general Q & A package about the impending Skylab reentry, and sent an accompanying telegram to all American diplomatic posts.<sup>409</sup>

SCWG researchers eventually decided to attempt to change the attitude of the station using dormant thrusters and moveable external components. By changing the orientation of Skylab relative to the rapidly encroaching atmosphere, controllers could influence the amount of drag and friction exerted upon the station and thereby slow or accelerate decay as needed.<sup>410</sup> At the same time that SCWG contemplated potential ways to reduce the debris impact, members also worked to reduce the likelihood of a negative social impact. With the controversy and cleanup of the nuclear-powered Cosmos 954 in recent memory, SCWG began providing information to interested state governments ranging from orbital elements and prediction maps to Q & A documents regarding nuclear power sources aboard Skylab—which, unlike the Soviet satellite, drew power only from solar panels and fuel cells and contained no radioactive materials.<sup>411</sup> While some elements of the reentry plan remained classified, and the SCWG fielded FOIA

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*NASA Orbital Debris Program Office*, accessed July 8, 2016, <http://www.orbitaldebris.jsc.nasa.gov/protect/shielding.html>.

<sup>409</sup> William G. Bastedo, “Skylab Final Report,” Attachment 1.

<sup>410</sup> Charles S. Harlan, “Summary of Real Time Considerations to Tumble the Skylab Spacecraft for an Entry Target in the Indian Ocean”; William G. Bastedo, “Skylab Final Report.”

<sup>411</sup> William G. Bastedo, “Skylab Final Report,” Attachment 1, p 9; Charles Dunlap Benson and William David Compton, *Living and Working in Space: A History of Skylab*, 363.

requests from a handful of newspapers and individuals, the group regularly updated its diplomatic materials during the first half of 1979.

Skylab hysteria hit the entire world before the debris itself hit the ground. The prospect of getting hit by a piece of a former space habitat struck a chord of macabre humor among many communities across the globe. In a media spectacle since repeated, but at smaller scales, individuals speculated about the likelihood of being hit by space hardware falling back to Earth. An undercurrent of jaded acceptance of the reentry as the inevitable result of technological hubris ran through the popular discourse regarding the reentry of Skylab. Vendors hawked shirts and other memorabilia emblazoned with targets, local news outlets held reentry prediction contests, and a San Francisco newspaper offered a \$10,000 reward to the first person to deliver a verifiable piece of Skylab debris.<sup>412</sup> The Massachusetts-based Brookline Psychoenergetics Institute held a “think-in” on May 25 to try boosting Skylab by meditation and telekinesis.<sup>413</sup> Former astronaut John Glenn, by that time a United States Senator, brought a piece of his reentered rocket to his office to demonstrate that while Skylab may have been unusually large, this reentry would be neither new nor something to fear.<sup>414</sup>

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<sup>412</sup> UPI, “Solitary Contestant Waits for Skylab Piece Prize,” *The Washington Post*, July 15, 1979, Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

<sup>413</sup> AP, “Meditators to ‘Fuel’ Skylab,” *The Spokesman-Review*, May 18, 1979, City Edition edition.

<sup>414</sup> An article describing Glenn’s space junk demonstration opens with a phrase that perfectly describes the unstable value of used space artifacts: “‘One man's 'space junk' is another man's space souvenir...” Karlyn Barker, “A Senator’s Space Junk Souvenir,” *Washington Post*, July 12, 1979.

Two computer programmers started a consulting firm called “Chicken Little Associates” that provided localized Skylab viewing times and predictions of where and when the station would land to media and municipal clients who believed that NASA’s predictions about a safe reentry seemed too sanguine.<sup>415</sup> The head of the interagency task group charged with handling mission support and public information about the Skylab reentry blamed Chicken Little Associates for much of what he considered to be a larger than warranted level of international interest in where and when the space station would fall.<sup>416</sup> But it wasn’t just aerospace outsiders who received the blame for inflating Skylab mania. The introductory memo prefacing a NASA-sponsored compilation and bibliography of Skylab debris studies conducted before the reentry critiqued aerospace companies such as Lockheed for using language that some at NASA considered to be inappropriately inflammatory—such as using “lethal” rather than “hazardous” or “capable of causing injury”—and suggesting that the Skylab reentry posed “a very high risk to human life.”<sup>417</sup>

On July 11<sup>th</sup> 1979, Skylab began its final plunge. The trajectory of reentry brought it over land—specifically, a large island in the middle of the Pacific Ocean: Australia. Because Skylab was made up of two main components, the orbital workshop and the ATM, trackers were surprised to observe that the station remained intact throughout most of its plunge through the atmosphere. It finally broke into several fragments that hit the

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<sup>415</sup> Thomas O’Toole, “‘Chicken Little’ Is Looking Up: The Sky May Not Be Falling, but Skylab Will,” *Washington Post*, January 20, 1979.

<sup>416</sup> William G. Bastedo, “Skylab Final Report,” Appendix 3.

<sup>417</sup> Larry K Edwards, “Skylab Debris Documentation” (Washington, DC: NASA, June 20, 1979), Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection.

ground in remote areas in and around the municipalities of Balladonia and Esperance. No casualties—human or animal—were reported. However, in the days after citizens in Perth reported seeing hundreds of glowing pieces falling from the sky, Australian citizens began to recover pieces of hardware that appeared to have been part of the American space station.<sup>418</sup> One resident of Esperance took the American radio station up on its posted bounty, flying to America with a few small pieces of blackened debris in his luggage. Local governments recovered the larger fragments, the largest of which was an intact oxygen tank.<sup>419</sup> A team from MSFC traveled to Australia to observe and collect debris, as per stipulation in the Outer Space Treaty regarding the return of space objects to the launching state.<sup>420</sup> Several pieces of debris remained behind, however. One fragment of the orbital workshop component of Skylab made a publicity circuit around the country, even being featured in the Miss Universe pageant that took place in Perth a few days after it was recovered.<sup>421</sup>

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<sup>418</sup> Bill Curry and Thomas O’Toole, “Skylab Rains Debris Over Ocean, Australia,” *Washington Post*, July 12, 1979.

<sup>419</sup> For more on the popular commodification of Skylab fragments, Alice Gorman, “The Sky Is Falling: How Skylab Became an Australian Icon,” *Journal of Australian Studies* 35, no. 4 (December 1, 2011): 529–46, doi:10.1080/14443058.2011.618507.

<sup>420</sup> William David Compton, “Skylab Reentry Chronology” (Houston, TX, September 24, 1979), 17–18, Skylab Series, General Subject Files, Box 761, Skylab Debris Documents, JSC History Collection; William G. Bastedo, “Skylab Final Report,” Appendix 5.

<sup>421</sup> Megan Garber, “That Time a Space Station Became Part of the Miss Universe Pageant,” *The Atlantic*, August 22, 2013, <http://www.theatlantic.com/technology/archive/2013/08/that-time-a-space-station-became-part-of-the-miss-universe-pageant/278953/>.



**Figure 3.4:** Skylab debris on display at the Miss Universe Pageant 1979 in Perth, Australia.<sup>422</sup>

Comparing the reentry of Skylab to the reentry of Cosmos 954 a year and a half prior reveals some similarities and some stark differences. Like Cosmos 954, Skylab fell over land, into a remote part of a country geographically removed from the launching state. The natural environment of each landing site provided a sink for each field of debris: the muddy lake bed and frigid waters of the Great Slave Lake covered the insoluble particulate matter shed by the Cosmos nuclear reactor, and several pieces of

<sup>422</sup> “Skylab Debris Displayed at Miss Universe Contest Venue. NAA: A6135, K19/7/79/2.” (Photograph, Canberra, 1979 1979), A6135, K19/7/79/2, National Archives of Australia, <http://www.naa.gov.au/cgi-bin/Search?O=I&Number=11648920>.



Skylab debris likely remained undiscovered in the Australian outback and ranch land.<sup>423</sup> However, following the reentry of Cosmos 954 the Canadian government mobilized an international search and cleanup team, for which Canada invoked the Liability Treaty against the Soviet Union to recover money dedicated to the effort; whereas the Australian government opted to waive any claims against the United States. NASA reported that by August of that year, some 13 claims had been filed against Skylab, none of which originated in Australia.<sup>424</sup> The local government in Esperance charged NASA a \$400 fine—for littering. This fine went unpaid until 2009 when a radio disc jockey serving California and Nevada raised money from his listeners and paid the fine on NASA’s behalf. A giant novelty check marked “paid in full” now hangs on the wall of the Esperance Municipal Museum, above display cases housing some of the largest fragments of Skylab collected from the surrounding area.<sup>425</sup>

In the midst of the Cold War, the fall of a nuclear powered Soviet satellite over a sovereign Western nation reified the nuclear threat feared but never realized in the form of atomic weapons use in warfare. Australia and the United States—two nations on the same side of the Iron Curtain with open lines of communication and information—did not have the same substrate of animosity pushing them to invoke legal recourse. The difference between in the two spacecrafts’ nuclearity—a category that Gabrielle Hecht has argued emerges from a complex web of material and social realities—also factored

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<sup>423</sup> Charles Dunlap Benson and William David Compton, *Living and Working in Space: A History of Skylab*, 372.

<sup>424</sup> William G. Bastedo, “Skylab Final Report,” Attachment 5, p 2.

<sup>425</sup> Ben Cooper, “Encountering Skylab: A Visit to the Space Station’s Remains,” *Space.com*, May 13, 2013, <http://www.space.com/21122-skylab-space-station-remains-museum.html>.

into the difference in legal action.<sup>426</sup> The nuclear reentry, seemingly the result of an uncontrolled accident (with neither effort nor information provided by the Soviet space program to the regions threatened by Cosmos debris) stood in stark contrast to the publicized attempts by NASA to prevent, delay, and eventually direct the reentry of the non-nuclear Skylab. Finally, the differences between the two environments—one seen by many in Canada as part of a fragile, critical natural resource, the other as empty land traversed only by the occasional livestock—also factored into the drastic differences in subsequent legal and financial action. These stark contrasts in environmental value, political affiliations, nuclearity, and perceptions of control yielded wholly divergent outcomes in the days and months that followed each reentry.

While both the reentry of Skylab and Cosmos 954 tested new rules of space governance and brought the geophysical world into legal negotiations of liability, the reentry of Skylab also provided a fitting conclusion to a program intended to yield new information about the near-Earth space environment. The Skylab science mission was divided into three primary categories: the medical study of long-duration microgravity on the human body, Earth resource monitoring, and observations of the Sun.<sup>427</sup> The Apollo Telescope Mount (ATM)—one of the two main, massive components of the station that

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<sup>426</sup> Gabrielle Hecht illuminates the many material and social realities that together make up a nuclear thing, whether an object, a place, a state, or a legal regime. See *Being Nuclear: Africans and the Global Uranium Trade* (Cambridge, Mass: The MIT Press, 2012).

<sup>427</sup> The Skylab program description begins with the emphasis on solar studies and learning more about the Earth-Sun system: “Basic objectives of the [Skylab] program are: 1) To increase man’s knowledge of the sun and its effect on man’s earthly environment...” “Environmental Impact Statement - Skylab Program” (Washington, DC: Office of Manned Space Flight, NASA, February 4, 1971), 1, Skylab Series, General Subject Files, Box 760, Skylab Debris, JSC History Collection.

program controllers feared might present a reentry hazard—constituted the first crewed space observatory.<sup>428</sup> It housed eight discrete instruments for studying different aspects of solar activity in wavelengths spanning the electromagnetic spectrum, including wavelengths that cannot be observed from the ground due to atmospheric absorption.<sup>429</sup> Two scientist-astronauts flew aboard Skylab, and were chosen for these flights so that astronomers on the ground might benefit from their expertise in ionospheric and solar physics.<sup>430</sup> Astronomers revised their models of the structure of the Sun's corona after definitively proving, using ATM-gathered data, that the stream of energetic particles

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<sup>428</sup> During the planning of the Apollo Telescope Mount, some of the same astronomers who struggled with administrators for influence in the design and control of space experiments found themselves in a familiar predicament. Many felt that George Mueller, the NASA associate administrator responsible for Apollo Applications and Skylab programs, regularly ignored scientific rigor in favor of budgetary and engineering considerations and failed to consult adequately with project scientists before making changes to the ATM mission. For more on these exchanges, as well as the planning and execution of the Apollo Telescope Mount project, see Charles Dunlap Benson and William David Compton, *Living and Working in Space: A History of Skylab*, 166–181.

<sup>429</sup> For more on atmospheric absorption and the promise of space astronomy—as well as how the idea of space telescopes influenced astronomers' participation in early negotiations about the environmental protection of near-Earth space—see Chapter 2 of this dissertation.

<sup>430</sup> Owen Garriott (Skylab 3) and Edward Gibson (Skylab 4) specialized in ionospheric physics and solar physics, respectively. Astronomer Leo Goldberg, who was one of the most vocal opponents of Project West Ford in the early 1960s, initially opposed a crewed space telescope. However, after the astronauts rescued Skylab after an initial error in deployment rendered the entire station unusable, and subsequently gathered immense quantities of data about the Sun by operating the ATM on site, Goldberg publicly effused about the benefits of direct, hands-on human involvement in space astronomy. Goldberg concluded a paper summarizing new discoveries about solar physics with the following: “By their rigorous preparation and training and enthusiastic devotion to the scientific goals of the mission they have proven the value of men in space as true scientific partners in space research.” Leo Goldberg, “Research with Solar Satellites,” *The Astrophysical Journal* 191 (July 1, 1974): 37. For more on the tensions between scientists and astronauts during the first decades of the Space Age, see Matthew H. Hersch, *Inventing the American Astronaut* (New York: Palgrave Macmillan, 2012).

known as the solar wind originates in phenomena known as “coronal holes.”<sup>431</sup>

Astronomers were astonished to learn just how active the Sun could be even during solar minima. So perhaps when this activity accelerated, and the solar wind buffeted the near-Earth environment, expanding the exosphere and bringing the ATM crashing back to Earth, it provided a fitting end to the study of the Earth-Sun environment. While in operation, Skylab had revealed new information about our star; on its death, it revealed just how much we had yet to learn—both about the Sun and about its interactions with the near-Earth environment and the artifacts transiting through it.

### **Global Fallout: Space Junk in the Anthropocene**

Following the reentry of Skylab, the Chief of International Program Support International Affairs at NASA expressed his fervent hope that “we will not have to repeat such an exercise in the foreseeable future.”<sup>432</sup> Yet, the Sun continues to shine, it continues its cyclical energetic pulsing—and it continues to push our out-of-control technologies back home to roost. Two solar cycles have passed since the fall of Cosmos 954 and Skylab at the peak of cycle 21. During each subsequent solar maximum, massive Cold War era artifacts have fallen back to Earth, with varying degrees of popular attention. In the spring of 2001, during the 23<sup>rd</sup> solar maximum, the 140-ton Soviet Mir space station began a slow tumble into the atmosphere when funding ran out to maintain its place on orbit. While the Kremlin emphasized that Russian engineers had carefully controlled the

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<sup>431</sup> Charles Dunlap Benson and William David Compton, “Results,” in *Living and Working in Space: A History of Skylab* (Washington, DC: Scientific and Technical Information Branch, National Aeronautics and Space Administration, 1983), 339–60.

<sup>432</sup> William G. Bastedo, “Skylab Final Report.”

reentry to fall over the Pacific Ocean, some echoes of Skylab reverberated through popular culture worldwide.<sup>433</sup> Not only did early estimates indicate a landing near Australia, but displays of macabre humor conveyed a similar popular response, ranging from targets mowed into golf courses to an advertising ploy by the fast food chain Taco Bell. The company deployed a 40-foot-square floating target within the predicted reentry footprint and promised a free taco to every American should the main body of Mir hit the bull's eye.<sup>434</sup> The debris missed the target, instead streaking massive plumes of smoke through the skies over Fiji and landing far off shore.<sup>435</sup> Taco Bell offered a “consolation” deal of two tacos for 99 cents.<sup>436</sup>

The most recent solar cycle, which reached a relatively benign maximum in 2014, brought several artifacts into the atmosphere. In June 2016, denizens of the Canadian arctic once again found themselves asking questions about a reentering spacecraft of Soviet origin with hazardous fuel aboard. Local officials from the Inuit hamlet of Grise Ford—considered one of the coldest inhabited places on Earth—expressed fear that a

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<sup>433</sup> Robert C. Cowen, “Splash Down!: TO STEER THE FALLING MIR SPACE STATION SAFELY BACK TO EARTH, RUSSIA AND THE US ARE UNDERTAKING A CRASH COURSE IN COOPERATION,” *The Christian Science Monitor*, March 8, 2001; AP, “Russians Trying to Steady Mir as She Dies,” *New York Times*, March 22, 2001.

<sup>434</sup> Agence France-Presse, “Mir Parts to Splash Down Near Australia,” *New York Times*, January 27, 2001; For this and other gallows humor related to the reentry of Mir, see *Other News - Mir and Present Danger*, The Daily Show with Jon Stewart (New York, NY: Comedy Central, 2001), <http://www.cc.com/video-clips/zyagu9/the-daily-show-with-jon-stewart-other-news---mir-and-present-danger>; Shawn Donnan, “Mir Gazers Ready to Duck and Cover,” *The Christian Science Monitor*, March 21, 2001; Brandon Dean, “Mir Hits Taco Bell, Kills Four,” *BBspot*, March 21, 2001, [http://www.bbspot.com/news/2001/03/taco\\_mir.html](http://www.bbspot.com/news/2001/03/taco_mir.html).

<sup>435</sup> Anatoly Vereshchagin, “Mir’s Odyssey Ends in a Watery Grave,” *The Times of India*, March 24, 2001.

<sup>436</sup> Taco Bell took out an insurance plan valued at \$10 million in case Mir did in fact strike the floating target. Chief Marketer Staff, “MIR MISSES TACO BELL’S TARGET,” *Chiefmarketer*, March 29, 2001, <http://www.chiefmarketer.com/mir-misses-taco-bells-target/>.

falling hydrazine-laden rocket body could contaminate a valuable cod fishery and refuge for beluga whales, narwhals, walrus, seals, polar bears, and seabirds.<sup>437</sup> While the government of Nunavut released a public service announcement reassuring citizens that the falling rocket would be a “very low risk event” and that the debris would land outside Canadian territorial waters, locals reacted with indignation that a foreign power would use sensitive Arctic waters as a toxic space junk dump, as characterized by University of British Columbia political scientist Michael Byers.<sup>438</sup> A World Wildlife Fund official working in the region defended the Baffin Bay region as “the most productive...in the Arctic,” and “not an empty wasteland. It's a place that Inuit have lived around and use.”<sup>439</sup> An Arctic campaigner from Greenpeace raised a legal analogy, claiming that “dumping these chemicals from a ship would be a clear violation of international and Canadian law, and it is no more acceptable when it is dumped from the air.”<sup>440</sup> In sharp contrast, Nunavut Minister of Community and Government Services Joe Savikataaq expressed a

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<sup>437</sup> “Russian Space Junk, Believed to Be Toxic, Set to Splash down in Canada’s Arctic,” *CBC News*, June 1, 2016, <http://www.cbc.ca/radio/asithappens/as-it-happens-wednesday-edition-1.3610810/russian-space-junk-believed-to-be-toxic-set-to-splash-down-in-canada-s-arctic-1.3610817>.

<sup>438</sup> Kris Mullaly, “Russian Rocket Impact Area,” Public Service Announcement (Iqaluit, Nunavut: Government of Nunavut, June 2, 2016), <http://www.gov.nu.ca/eia/news/russian-rocket-impact-area>; Michael Byers, “Michael Byers: Canada — Russia’s Toxic Waste Dump,” *National Post*, May 18, 2016, <http://news.nationalpost.com/full-comment/canada-russias-toxic-waste-dump>.

<sup>439</sup> CBC, “Danger of Russian Rocket Debris Downplayed by Officials, but Arctic Locals Fear It,” *Yahoo! News*, June 3, 2016, <https://ca.news.yahoo.com/danger-russian-rocket-debris-downplayed-050100554.html>.

<sup>440</sup> Bob Weber, “Potentially Toxic Russian Space Debris Set to Drop on Canadian Arctic,” *Toronto Star*, May 31, 2016, <https://www.thestar.com/news/canada/2016/05/31/potentially-toxic-russian-space-debris-set-to-drop-on-canadian-arctic.html>.

healthy measure of defeat in contemplating potential environmental disaster. “It’s a Russian rocket,” he opined to the local press. “We have very little control over it.”<sup>441</sup>

As these parallel events demonstrate, reentry of space junk has become a regular, material attribute of the solar cycle, as reliable as an increase in energetic activity at Solar Maximum. They also demonstrate that questions of consent, control, responsibility, and even the definition of toxic waste continue decades after the first tests of space liability.<sup>442</sup> The most optimistic predictions of low casualty rates from falling debris generated by Skylab personnel endure; to date, only one person has been struck by a piece of space debris, a light piece of mesh that did not cause injury. However, the seemingly random, dangerous contact between sea, space, sky, and land facilitated by falling space junk continues to raise alarm among those concerned about human health and environmental integrity alike. Ancient principles of *terra nullius* endure into the Space Age, when even ultimate sinks turn into political flashpoints in the face of a falling sky. The movement of space junk continues to break down geographical boundaries, with waste from one extraterritorial region transforming upon arrival in other extraterritorial and sovereign places.

The history of reentering space junk during the long 1970s demonstrates the expanding role of the geophysical world of near-Earth space on Cold War geopolitics. It

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<sup>441</sup> Jim Bell, “NEWS: Inuit Org: We’re Not a Dumping Ground for Space-Borne Waste,” *Nunatsiaq Online*, June 3, 2016, [http://www.nunatsiaqonline.ca/stories/article/65674inuit\\_org\\_were\\_not\\_a\\_dumping\\_ground\\_for\\_space-borne\\_waste/](http://www.nunatsiaqonline.ca/stories/article/65674inuit_org_were_not_a_dumping_ground_for_space-borne_waste/).

<sup>442</sup> For more on toxicity and invisibility of waste in extraterritorial regions, see Simone Müller, “Move It Offshore! On the International Governance of Ocean Dumping in the Long 1970s” (European Society for Environmental History Biennial Conference, Versailles, France, 2015).

also destabilizes the common historiographical narrative of the Space Race as a binary battle between super powers and their spheres of influence. Rather, in being unwillingly and unintentionally conscripted into legal, political, and diplomatic exchanges over space junk reentries, even the governments and citizens of countries that had not yet or barely become spacefaring themselves were drawn by conditions within the orbital environment into early debates over safe environmental governance in and through near-Earth space. This was one of the first instances in which, as an assistant to the Secretary of Defense during the Carter Administration put it in the spring of 1978:

The ‘opposition’ was Newton’s Law of Gravitation, later compounded by Bernoulli and the physical effects of aerodynamic drag on the satellite. The game was against nature rather than against conscious intelligence.<sup>443</sup>

An expanded definition of the natural world had become a player in a spatially broadening Space Race. Exceeding Cold War binaries, nature inhabited the roles of both primary antagonist and primary victim, both in the guise of familiar and strange terrestrial environments and in the alien ecosystem of near-Earth space. There, the circulating products and byproducts of the space industry inspired new questions of utility and liability on the ground as well as in orbit. From Cuban cows to Canadian cleanups, falling space junk opened a different extraterritorial front in the Cold War: not among human antagonists but with the strange material and physical ecosystem of orbital space.

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<sup>443</sup> Gus W. Weiss, “The Life and Death of Cosmos 954,” 1.



## CHAPTER 4

### Salvaging Space: Refuse, Reuse, and the Pursuit of Orbital Economy, 1968-1986

#### **Introduction: The Rarest of Beasts**

On a clear day in November 2015, commercial aerospace company Blue Origin launched its reusable New Shepard rocket. The rocket dipped into the nearest reaches of outer space before safely nailing a vertical landing at the Blue Origin test facility in the plains of West Texas. Blue Origin's owner, Amazon founder Jeff Bezos, celebrated the accomplishment by breaking his seven-year silence on Twitter with his very first tweet:

The rarest of beasts – a used rocket. Controlled landing not easy, but done right, can look easy.<sup>444</sup>

A used rocket is a rare beast indeed—until 2015 all standalone space rockets could only be used once. Since the end of the space shuttle program in 2011, single-use rockets have provided the only way off the planet. After sending people or satellites into space, these massive artifacts effectively disappear. They are large, complex, expensive, and strangely ephemeral. In order to reach orbit, large rockets fly in stages. As each stage runs out of fuel, it detaches, yielding a lighter, more manageable load for the remaining stages to propel. After delivering their payloads into space, these stages of so-called expendable launch vehicles (ELVs) either remain in orbit or fall back to Earth and burn up in the

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<sup>444</sup> Jeff Bezos, Twitter post, November 24, 2015, 6:14 AM, <https://twitter.com/JeffBezos/status/669111829205938177>

intense heat and pressure of the atmosphere. In some cases, pieces of these artifacts survive the fall, typically landing in the oceans that cover the majority of the planet.<sup>445</sup>

Whether in orbit or falling back to Earth, these objects become invisible to the majority of those who consume information products from outer space—whether this information materializes in the form of advanced weather reports, time-sensitive banking transactions, air travel, or a myriad other technological practices involving satellite technology. This impermanence and invisibility connects the consumption practices of the American space program to broader cultural patterns of discard. Susan Strasser has argued that a conspicuous, even joyous culture of disposability defined postwar American modernity. Once primarily the domain of the rich, single-use products marketed towards the growing middle class became symbols of freedom from the drudgery of reuse.<sup>446</sup> By the beginning of the Space Age, an increasing number of Americans—particularly white Americans—regularly exercised their right to a life physically and visually separated from the trash they produced.<sup>447</sup> Early Cold War space technologies could be seen as the high-tech pinnacles of this postwar culture of disposability. With the exception of the very occasionally visible space artifact that survives the fall from orbit—such as, perhaps most famously, the reentry of the Skylab space station in 1979 which shed several

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<sup>445</sup> For more on reentering space debris, see Chapter 3 of this dissertation.

<sup>446</sup> Susan Strasser, *Waste and Want: A Social History of Trash* (Macmillan, 1999).

<sup>447</sup> Nigel Whiteley, “Toward a Throw-Away Culture. Consumerism, ‘Style Obsolescence’ and Cultural Theory in the 1950s and 1960s,” *Oxford Art Journal* 10, no. 2 (January 1, 1987): 3–27; In the thick of this postwar transformation, John Atlee Kouwenhoven defined waste as the result of democracy and abundance. John Atlee Kouwenhoven, “Waste Not, Have Not: A Clue to American Prosperity,” *Harper’s Magazine*, March 1959; For more on the racial dimensions of American consumption, see Carl A. Zimring, *Clean and White: A History of Environmental Racism in the United States* (New York: NYU Press, 2016).

retrievable fragments—single-use satellites and rockets disappear from the view of those who use space information facilitated by these objects.<sup>448</sup> Even the enormous, expensive Saturn V moon rocket all but vanished after each single-serve flight—the emptied hulks of the multi-stage rocket either burned up in the atmosphere, fell into the ocean, hit the moon, or went into orbit around the Earth or around the Sun. Reusable rockets have been considered a possibility for decades, from as early as the 1920s. Rocket engineering pioneers such as Robert Goddard, Konstantin Tsiolkovsky, and Wernher von Braun each recorded ideas for a rocket that could be safely landed and relaunched.<sup>449</sup> However, the industry standard from the beginning of the Space Age embraced multistage, single-use rockets for reasons of physical and economic expediency.<sup>450</sup>

The current private industry initiative to construct a reusable spaceflight paradigm distantly follows on the heels of a period during the Cold War Space Race during which reusability and recycling became key goals of an increasingly austere public American space industry.<sup>451</sup> After the spectacular success and economic excess of the Apollo moon program, three presidential administrations alongside leadership in civilian and military space programs set out to normalize spaceflight as a common form of transportation. For

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<sup>448</sup> For more on the reentry of space debris, including Skylab, see Chapter 3 of this dissertation.

<sup>449</sup> Marcia S. Smith, *United States Civilian Space Programs, 1958-1978: Report*, vol. 1 (Washington: U.S. Government Printing Office, 1981), 446; American Institute of Aeronautics and Astronautics, “New Space Transportation Systems, an AIAA Assessment,” January 9 1973.

<sup>450</sup> Andrew J. Butrica, *Single Stage to Orbit: Politics, Space Technology, and the Quest for Reusable Rocketry* (Baltimore, MD: Johns Hopkins University Press, 2003).

<sup>451</sup> For a comprehensive overview of the first drive towards a reusable, single stage to orbit rocket within the American aerospace industry from the 1920s to the beginning of the 21st century, see Butrica, *Single Stage to Orbit*; For other attempts to reduce the cost of spaceflight, see Howard E. McCurdy, *Faster, Better, Cheaper: Low-Cost Innovation in the U.S. Space Program* (Baltimore, MD: Johns Hopkins University Press, 2001).

a prolonged but limited time the vanguard of the American space industry focused on re-materializing a deeply illegible, ephemeral form of waste into a key component of a tangible reuse economy. Rather than designing old rockets and satellites to disappear into space, atmosphere, or ocean after use or failure, NASA made efforts to invest in developing new technologies that would save money in the long term. However, in order to achieve true economy, Cold War advocates of reusability advocated the reuse of all components of the space infrastructure, not just launch and landing vehicles. The primary means of savings would come through comprehensive revision of spacecraft design that privileged the three Rs: not reduce, reuse, recycle; but retrieve, refuel, repair. The unique environment of orbital space presented challenges that forced space policymakers and engineers to rethink and retool an entire technological system already in place and in use. During the long 1970s, Presidents and NASA engineers alike envisioned near-Earth space becoming part of the human environment. As Senator Adlai E. Stephenson put it in 1979, “the United States plan[ned] to make space an extension of life on the Earth’s surface.”<sup>452</sup> In contrast to the high adventure of 1960s frontier exploration, space would become a place where people would live and work, a place of industry, and perhaps as importantly, a place where we clean up after ourselves; a place that we ought to keep clean.

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<sup>452</sup> Stephenson summarized the shift from Apollo era exploration mania to mundane space activities as follows: “We will go into space not just to meet the challenge of exploration but to do many useful and productive jobs, at reduced cost, returning again and again. We are initiating an era of “routine utilization” of space, and it signifies a new epoch in the history of the planet...the United States plans to make space an extension of life on the Earth's surface.” From the forward to H. Allaway, “The Space Shuttle at Work,” January 1, 1979.

### **“Very Much Like a Modern Airplane”**

Less than a month after the Blue Origin success, Elon Musk’s aerospace company SpaceX accomplished a similar feat, returning the first stage of a Falcon 9 rocket from orbital space to land in Cape Canaveral, Florida. A media ruckus unfolded around which tech millionaire had first achieved true reusability first: whether the launch and landing of New Shepard or of Falcon 9 would go down in history as the revolutionary moment, after which spaceflight would become as cheap and commonplace as commercial air travel.<sup>453</sup> The SpaceX website uses just this analogy to assert the necessity of its rocketry labors: SpaceX rockets costs as much to manufacture as a 747 jumbo jet airplane, but a 747 can be used multiple times a day, for tens of thousands of flights. On the company website, SpaceX asks readers to imagine the cost of air travel if each transatlantic aircraft could only be used once before being destroyed, and a new jet manufactured for each subsequent flight.<sup>454</sup>

At the beginning of 1972, then-NASA Administrator James Fletcher asked American citizens to consider the same question. Fletcher released a statement supporting President Nixon’s announcement that NASA would begin developing a next generation of human spacecraft that would be the first of its kind to be used more than once. He employed a broadly recognizable analog, noting that in air transportation “we don’t throw

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<sup>453</sup> “When Elon Musk And Jeff Bezos Clash Over Reusable Rockets, We All Win,” *Popular Science*, accessed March 13, 2016, <http://www.popsci.com/elon-musk-and-jeff-bezos-clash-over-reusable-rockets-but-in-end-were-all-winners>.

<sup>454</sup> Hannah Post, “Reusability: The Key to Making Human Life Multi-Planetary,” Text, *SpaceX*, (June 10, 2015), <http://www.spacex.com/news/2013/03/31/reusability-key-making-human-life-multi-planetary>.

away an airplane after its first trip from Washington to Los Angeles.”<sup>455</sup> The next year, a final group of American astronauts visited the moon aboard a massive, disposable Saturn V rocket that weighed the same as a C-5A military aircraft and cost twice as much to manufacture.<sup>456</sup> A few months later, Fletcher persuaded the US Senate Committee on Aeronautical and Space Sciences to consider plans for the reusable space shuttle, a craft that he believed would change the space industry in the same way that the DC-3 had revolutionized civil aviation.<sup>457</sup> In 1976, the editors of the *New York Times* predicted a new age of reusable spacecraft that would open the way to an economic and technological revolution, rendering spaceflight as routine, affordable, and accessible as a ride on a modern jumbo jet.<sup>458</sup> An even more optimistic journalist suggested that perhaps even space junk could someday be designed to land in the same manner as commercial airlines.<sup>459</sup> The Space Age had followed closely on the heels of the Jet Age, and to Fletcher and supporters of the American space program it seemed likely that the space

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<sup>455</sup> James C. Fletcher, “Statement by Dr. Fletcher,” January 5, 1972, NASA Technical Reports Server (NTRS).

<sup>456</sup> George E. Mueller, “The New Future for Manned Spacecraft Developments,” *Aeronautics & Astronautics*, March 1969.

<sup>457</sup> James C. Fletcher, “Spaceship Earth, A Look Ahead to a Better Life,” March 1973, <http://eric.ed.gov/?id=ED093601>.

<sup>458</sup> “...and Space,” *New York Times*, December 28, 1976, sec. Technology Review, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>459</sup> In a news article about the reentry of the Pegasus 1 spacecraft in 1978, a journalist opined that someday even space junk would be able to land on a pad, revolutionizing spaceflight very much like the standardization of landing infrastructure revolutionized the airlines. Barbara Brotman, “Satellite Falling, but Landing Site Still Up in the Air.”

industry might continue to follow to the same trajectory to eventual normalization and economy.<sup>460</sup>

This veneer of technological enthusiasm obscured the grittier realities of an increasingly squeezed federal spaceflight budget during and after project Apollo. The desire expressed by Fletcher and Nixon to set the US space program on the path to build a reusable spacecraft largely grew out of a changing political climate, as legislative support for the space program waned following the successful first moon landing in July 1969.<sup>461</sup> Indeed, beginning that same year, NASA consulted with airline companies while developing the initial designs for what would become the space shuttle, with the explicit aim of emulating the volume, quick turnaround, and most importantly, the economy that the American commercial air industry had achieved in a short half-century since the first

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<sup>460</sup> The physical constraints that affect airplanes differ greatly from those of an orbital rocket, and advocates of a cheap, reusable space shuttle were well aware of these differences. In a 1969 article in *Aeronautics and Astronautics* in which he argued that reusable spaceflight could be achieved immediately, Francis Clauser (a primary champion of the winged form of space shuttle vehicle) acknowledged that first stages of rockets tend to be shed because the dramatic drop in weight makes the rest of the flight easier on the remaining stages. Staged rockets end up being cheaper than single-stage rockets because it would cost more to haul around the weight of empty machinery. "We now see why space vehicles get thrown away after only one use, with the largest and most expensive stage being the first to go. Everyone is so glad to get rid of the expended weight that few mourn the tens and hundreds of millions of dollars of equipment that falls into the sea."

Clauser championed a single-stage-to-orbit reusable shuttle, suggesting that, just as widespread concerns about the damaging force of wind in the early years of aviation had been assuaged with the normalization of air travel, Americans would someday wonder what all the fuss over the challenge of developing single stage orbital launch vehicles was about. In reality, such an engineering feat has proven enduringly complicated; no single-stage-to-orbit launch vehicle has ever been successfully flown. Francis H. Clauser, "No Law Says Space Must Be Expensive," *Aeronautics & Astronautics*, May 1969, 36-37.

<sup>461</sup> Robert Dallek, "Johnson, Project Apollo, and the Politics of Space Program Planning," in *Spaceflight and the Myth of Presidential Leadership* (Champaign, IL: University of Illinois Press, 1997), 68-91.

powered flight.<sup>462</sup> The form that the space shuttle took in 1972 not only looked like an airplane, in stark contrast to the blunt, small capsule-shaped human spacecraft of the Mercury, Gemini, and Apollo programs. George Mueller, then the NASA Associate Administrator for Manned Space Flight, also called for the next generation of spacecraft to be integrated into the existing air control and maintenance infrastructure, sharing launch and landing facilities with the civil aviation industry.<sup>463</sup> In 1968, well before NASA officials agreed upon a final design of the Shuttle, Mueller predicted that the new spacecraft would eventually even fly out of major American airports, generating savings through volume of flights and using a system already in regular, reliable operation. “By building a launch-vehicle shuttle for multiple usage,” he argued in a speech before the British Interplanetary Society that year, “we can achieve a breakthrough in costs.”<sup>464</sup>

However, Mueller noted that the launch vehicles would not be the sole path to making

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<sup>462</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle*, The NASA History Series, NASA SP-4221 (Washington, D.C.: National Aeronautics and Space Administration, 1999), 253.

<sup>463</sup> While the space shuttle was under development, NASA put out the official legal position that the new craft was a space craft, not an aircraft. By explicitly defining the space shuttle this way, NASA avoided the strictures of FAA regulation. In the memorandum for the record that lays out the reasoning behind the classification, NASA Assistant General Counsel for General Law Gerald J. Mossinghoff refers to the Liability Convention and its application to any future accidents involving the Shuttle. The space shuttle would be bound by international law as a spacecraft, particularly should it fail to operate as planned: “Under our interpretation of the Convention on International Liability for Damage Caused by Space Objects, the space shuttle would clearly be a ‘space object’ so as to impose absolute liability upon the United States for ‘damage caused [by it] on the surface of the earth or to aircraft in flight.’” Gerald J. Mossinghoff, “Classification of the Space Shuttle as a ‘Space Vehicle’ and Not an ‘Aircraft,’” Memorandum for the Record, (September 25, 1975), NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>464</sup> George E. Mueller, “Address by Dr George E Mueller, Associate Administrator for Manned Space Flight, National Aeronautics and Space Administration before the British Interplanetary Society, University College London, England,” August 10, 1968, NASA Headquarters Historical Reference Collection, Washington, DC.; George E. Mueller, “The New Future for Manned Spacecraft Developments,” 27.



spaceflight affordable; rather, a multicomponent space transportation system made up of a reusable shuttle, space station, and reusable satellites would be key to making orbital space truly airline-like in efficiency and price.<sup>465</sup>

In this sense, the current race to a reusable rocket waged between billionaire entrepreneurs only partially recapitulates the earlier effort to make spaceflight more like air flight.<sup>466</sup> Air infrastructure does not simply consist of airplanes and runways, but requires sustainable fueling supply lines, communications networks, maintenance facilities, and storage at key points of departure and arrival.<sup>467</sup> During the long 1970s, those who advocated a reusable space industry paradigm promoted practices that required not only a reusable launch vehicle but also the infrastructure necessary to reuse, refuel, and repurpose the satellites these rockets launched into space. Given the range of altitudes at which America operated its satellites—from low orbits of several hundred kilometers to high orbits of tens of thousands kilometers above the planet’s surface—building this infrastructure would require comprehensive changes beyond simply building a new human spacecraft that could reach low-Earth orbit (LEO) over and over again. Beginning in the late 1960s, NASA commissioned studies that reached the overall conclusion that, for the economics of reuse to yield concrete benefits in the post-Apollo

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<sup>465</sup> George E. Mueller, “The New Future for Manned Spacecraft Developments,” 26.

<sup>466</sup> “Aircraft-like operation of such future systems will increase the safety of the launch process.” Heribert Kuczera and Peter W. Sacher, *Reusable Space Transportation Systems* (Berlin, Heidelberg: Springer Berlin Heidelberg, 2011), ix–x.

<sup>467</sup> On rise of airports and airline infrastructure in America, see David T. Courtwright, “The Routine Stuff: How Flying Became a Form of Mass Transportation,” in *Reconsidering a Century of Flight*, ed. Roger D. Launius and Janet R. Daly Bednarek (Chapel Hill: UNC Press Books, 2015), 209–22; Martin Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog: A History of the Software Industry* (MIT Press, 2004), 41–50; Janet Rose Daly Bednarek, *America’s Airports: Airfield Development, 1918-1947* (Texas A&M University Press, 2001).

era, all of orbital space—not just the nearest reaches—would need to be governed under an ethos of recycling and salvage.<sup>468</sup> In order to attain a truly austere, sustainable economy of reuse into the 1980s and 1990s, all parts of the space infrastructure would need to be designed with reuse in mind from the outset—from design and construction through launch, use, and reuse.

### **Imagining Reuse**

I believe that the exploitation of space is limited in concept and extent by the very high cost of putting payload into orbit, and the inaccessibility of objects after they have been launched.

—NASA Associate Administrator for Manned Space Flight George E. Mueller, 1968<sup>469</sup>

As more and more countries and private industries sought information services provided by orbiting satellites, the American and Soviet space industries produced a burgeoning supply of spaceworthy rockets during the first two decades of the Space Age. Many of these vehicles started out as ICBMs, and in America the different branches of the armed

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<sup>468</sup> Ad Hoc Subpanel on Reusable Launch Vehicle Technology, “Report for Presentation to the Supporting Space Research and Technology Panel” (Aeronautics and Astronautics Coordinating Board, September 14, 1966), NASA Headquarters Historical Reference Collection, Washington, DC; Supporting Space Research and Technology Panel, “Final Report, Ad Hoc Subpanel on Reusable Launch Vehicle Technology” (Aeronautics and Astronautics Coordinating Board, September 22, 1966), NASA Headquarters Historical Reference Collection, Washington, DC; “America’s next Decades in Space: A Report for the Space Task Group” (NASA, September 1, 1969), <http://ntrs.nasa.gov/search.jsp?R=19710002945>.

<sup>469</sup> George E. Mueller, “Address by Dr George E Mueller, Associate Administrator for Manned Space Flight, National Aeronautics and Space Administration before the British Interplanetary Society, University College London, England.”

services modified them to carry benign payloads and human spacecraft aloft. From a very early moment, these rockets became known as expendable launch vehicles, their single use-ness built into the name of the technology itself.

The payloads launched atop these ELVs, however, do not factor significantly into the current NewSpace race as they once did during the 1970s.<sup>470</sup> Each satellite was (and is, with some notable exceptions) purpose built to a specific set of specialized functions, carefully tested to ensure functionality, and then launched at a high premium per pound into orbits ranging from a few hundred kilometers above the surface of the earth to several thousand kilometers high.<sup>471</sup> When satellites malfunctioned, ran out of fuel, or became obsolete, they could not be revived or upgraded. Without the ability to send astronauts to each satellite to safely repair or refuel these technologies, spacefaring entities had to replace satellites wholesale and at high cost should any of the above conditions render it unusable for the designated purpose. Once they ran out of fuel necessary to maneuver or lost contact with operators on the ground, satellites would essentially become waste—objects discarded, invisible, and useless.

From soda bottles to diapers, the luxury of single use consumption and living out of sight of waste has signified wealth over centuries of American history. Those with disposable income dispose of the products they buy, never to see their discarded waste

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<sup>470</sup> The competition between commercial aerospace companies is typically called “NewSpace.” Jeff Foust, “Current Issues in NewSpace,” *The Space Review: Current Issues in NewSpace*, March 5, 2007, <http://www.thespacereview.com/article/823/1>.

<sup>471</sup> For an overview of low-mass satellites employed over the last half century, including the currently popular “cubesat,” see Henry Helvajian and Siegfried W. Janson, eds., *Small Satellites: Past, Present, and Future* (El Segundo, Calif. : Reston, Va: Aerospace Press ; American Institute of Aeronautics and Astronautics, 2008).

again; those who do not must use and reuse.<sup>472</sup> As Carl Zimring has demonstrated, recycling in America grew from the nineteenth-century networks of scrappers, collectors, and brokers—many of them immigrants—who transformed the landscape of consumption and set the stage for current large-scale recycling systems.<sup>473</sup> Before the 1890s, discarded things represented not waste, but the potential for future value through reuse and remaking.<sup>474</sup> However, as Donald Worster has noted, the frugality of reuse and the value of consumption have not cohabited well under the capitalism of the past half-century.<sup>475</sup> Although space infrastructure, as a publicly funded project, did not arise from individual consumer choice in the same direct manner as the purchase of a newspaper or glass jar, this uneasy tension of postwar American capitalism was evident even in the high technology industry of space technology over the political transitions from the Nixon to Reagan eras.<sup>476</sup> Those who imagined the next steps in space as crafting near-

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<sup>472</sup> Strasser, *Waste and Want*.

<sup>473</sup> Carl A. Zimring, *Cash for Your Trash: Scrap Recycling in America* (New Brunswick, N.J.: Rutgers University Press, 2005).

<sup>474</sup> Martin V. Melosi, *Garbage In The Cities: Refuse Reform and the Environment* (University of Pittsburgh Press, 1981).

<sup>475</sup> Donald Worster, “Can History Offer Pathways to Sustainability?,” in *Cycling and Recycling: Histories of Sustainable Practices* (New York: Berghahn Books, 2015), 215–18.

<sup>476</sup> For more on the history of waste and recycling in America, see for example Adam S. Weinberg, David N. Pellow, and Allan Schnaiberg, *Urban Recycling and the Search for Sustainable Community Development* (Princeton University Press, 2000); *Histories of the Dustheap: Waste, Material Cultures, Social Justice, Urban and Industrial Environments* (Cambridge, Mass: MIT Press, 2012); R. Friedel, “American Bottles: The Road to No Return,” *Environmental History* 19, no. 3 (July 1, 2014): 505–27, doi:10.1093/envhis/emu061; Ruth Oldenziel and Helmuth Trischler, *Cycling and Recycling: Histories of Sustainable Practices* (New York: Berghahn Books, 2015); For an excellent primer on theories of waste and reuse, see Juliana Mansvelt, *Geographies of Consumption* (SAGE, 2005).

Earth orbit into “an extension of life on the Earth's surface” echoed these terrestrial politics in reimagining a future in space based on reuse.<sup>477</sup>

Squeezed from all sides by legislative and popular pressure to do more with less as Apollo wrapped up, NASA leadership looked to reuse as a way of making ends meet.<sup>478</sup> At the height of its funding support in 1965, NASA enjoyed an annual operating budget of \$5.25 billion. This windfall covered the costs of developing new spacecraft, purchasing expendable launch vehicles from the US Air Force, Army, and Navy for crewed and uncrewed spacecraft, and constructing a proprietary moon rocket. With the ongoing conflict in Vietnam bleeding the US budget into a \$29 billion deficit by 1967, the Johnson administration repeatedly cut funding to NASA during the years leading up to the first moon landing.<sup>479</sup> By the autumn of 1968, the NASA budget lost more than \$1.25 billion from its 1965 peak, spurring the standing NASA administrator to resign.<sup>480</sup>

Polls showed that the American public continued to support the space program, but also

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<sup>477</sup> H. Allaway, *The Space Shuttle at Work* (Washington, DC: Scientific and Technical Information Branch and Division of Public Affairs, National Aeronautics and Space Administration, 1979).

<sup>478</sup> Roger D. Launius, “A Western Mormon in Washington, D.C.: James C. Fletcher, NASA, and the Final Frontier,” *Pacific Historical Review* 64, no. 2 (May 1995): 217–41; Kim McQuaid, “Selling the Space Age: NASA and Earth’s Environment, 1958-1990,” *Environment and History* 12, no. 2 (May 2006): 127–63.

<sup>479</sup> The idea of integrating a reusable launch vehicle into the American space infrastructure first came about during and immediately after the peak of funding in 1965. By 1966, the Aeronautics and Astronautics Coordinating Board (AACB), which served as the liaison between NASA and the DoD, put together an ad hoc research panel to determine whether the technology for a reusable launch vehicle would be immediately feasible. Their main conclusions suggested that a stronger economic study would be required to determine whether such a vehicle ought to be developed, and whether it would provide real savings over expendables—particularly to be achieved by reducing the launch cost per pound of payload. Ad Hoc Subpanel on Reusable Launch Vehicle Technology, “Report for Presentation to the Supporting Space Research and Technology Panel”; Supporting Space Research and Technology Panel, “Final Report, Ad Hoc Subpanel on Reusable Launch Vehicle Technology.”

<sup>480</sup> Dallek, “Johnson, Project Apollo, and the Politics of Space Program Planning,” 84–88.

demanded that NASA operate on a greatly diminished share of public funding.<sup>481</sup> When Richard Nixon ascended to the presidency at the height of Apollo, he immediately set his administration to work establishing a future direction for the space program that would reflect his agenda. Nixon prioritized the creation of a plan for future space activity that emphasized cooperation, rather than competition, with the Soviet Union, and, above all, economic austerity.<sup>482</sup> Nixon established a Space Task Group, to be chaired by Vice President Spiro T. Agnew, upon which he bestowed the responsibility of assessing the next directions that the civilian space sector should take in order to move towards the goal of achieving a kinder, cheaper American space program.<sup>483</sup>

With the knowledge that the windfall of the mid-1960s would not return, particularly under the new administration and growing public resistance to government spending on big technology projects, NASA commissioned its own series of studies to determine how best to reduce costs and keep the American space program competitive among the growing roster of spacefaring nations.<sup>484</sup> One such report, issued by Nixon's Space Task Group mere weeks after Neil Armstrong and Buzz Aldrin rode a disposable \$185 million Saturn V to land on the lunar surface, argued that developing a new multi-

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<sup>481</sup> Howard E. McCurdy, *Space and the American Imagination*, Second (Baltimore: Johns Hopkins University Press, 2011), 118; Joan Hoff, "The Presidency, Congress, and the Deceleration of the US Space Program in the 1970s," in *Spaceflight and the Myth of Presidential Leadership* (Champaign, IL: University of Illinois Press, 1997), 92–95.

<sup>482</sup> Joan Hoff argues that for Nixon, defense spending and space spending comprised the same budgetary category. In decreasing military presence in Vietnam and cutting military spending, Nixon adopted the cautious defense stature of his Republican predecessor, Dwight D. Eisenhower. However, it also meant that the civil space sector also suffered from defense cuts in contrast to Eisenhower's enthusiasm for space following Sputnik. Hoff, "The Presidency, Congress, and the Deceleration of the US Space Program in the 1970s," 100–101.

<sup>483</sup> *Ibid.*, 97–99.

<sup>484</sup> Edgar Ulsamer, "The Shuttle: US's Airline Into Space," *Air Force Magazine*, September 1971.

vehicle system of transportation would constitute “the next natural step for us to take in space.”<sup>485</sup> The report laid out a three-pronged set of priorities that its authors believed should govern the development of the new space transportation infrastructure: commonality, or the use of only a small number of flexible technologies for a wide variety of missions; reusability, or the ability to use the same systems over multiple missions and a long time period; and economy, particularly through the simplification of hardware and the reduction of “throw away” technologies used in any given mission. These priorities would, the study’s authors argued, facilitate vastly cheaper operating costs for spaceflight than the contemporary use of non-reusable launch vehicles and satellites, and eventually lead to the hoped-for acquisition of airline-level efficiency in transporting people and materials between the surface of the Earth and outer space.<sup>486</sup>

These three priorities—commonality, reusability, and economy—would become central to a new ethos in the American space industry that persisted through three presidential administrations and two new large-scale space vehicle projects. These three terms made up a refrain that punctuated discussions of how best to develop a more robust orbiting infrastructure, particularly one that would also incorporate astronauts as necessary participants in recycling outer space technology. Human astronauts’ flexibility, adaptability, and bodily dexterity would allow them to puzzle out potentially complex repair problems. Including humans as a central component of the next generation space

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<sup>485</sup> Adjusted to 2016 dollars, the price tag for each Saturn V would reach \$1.23 billion. T. A. Heppenheimer, *The Space Shuttle Decision: NASA’s Search for a Reusable Space Vehicle*, 48.

<sup>486</sup> “America’s next Decades in Space: A Report for the Space Task Group,” 45–46.

program served an additional political purpose, however.<sup>487</sup> Although some studies of remote and robotic repair technologies took place during this time, few in American space policy circles argued against including astronauts in this new age of reusable spaceflight.<sup>488</sup> As Joan Hoff has argued, the astronaut in orbit represented the only truly compassionate symbol of space exploration, and provided a legible point of reference for the average American of the 1970s whom Nixon and his Space Task Group hoped to gratify with these changes.<sup>489</sup> By investing in the development of a large, maneuverable, reusable spacecraft to shuttle people and cargo to and from orbit alongside a permanent orbiting outpost and agile orbital maneuvering vehicles, the authors of the 1969 Space Task Group report expected a large, stable return on an admittedly substantial initial investment. By standardizing the size of satellite payloads to fit the parameters of such a system, and allowing astronauts to return to faltering or failed satellites to make repairs or bring them back to Earth for salvage, NASA saw the potential for an expanded customer base that would also save money in the long run by launching and maintaining longer-lived space assets that could be reliably maintained by human hands.<sup>490</sup>

The shape and scale of proposed standardized, reusable space vehicle systems varied, and different NASA centers favored different approaches to the challenge of

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<sup>487</sup> For previous decisions on what role human astronauts should serve in spacecraft control systems, see Mindell, *Digital Apollo*.

<sup>488</sup> See for instance “NASA Studies Satellite Repair Satellite,” *Space Business Daily*, July 19, 1968, Satellite Repair Satellite (SRS) 6345, NASA Headquarters Historical Reference Collection, Washington, DC. and “NASA Funds GE Satellite Repair Satellite Study,” *Space Business Daily*, July 29, 1968, Satellite Repair Satellite (SRS) 6345, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>489</sup> Hoff, “The Presidency, Congress, and the Deceleration of the US Space Program in the 1970s,” 109.

<sup>490</sup> “America’s next Decades in Space: A Report for the Space Task Group.”



coming up with the next grand space endeavor. Nixon's ambitions for reelection in 1972 motivated him to balance two contradictory campaign initiatives: to scale back funding for military and big technology projects in favor of domestic programs, while also maintaining large-scale space program planning in several key battleground states. He hoped to leverage support with local space industries that would stand to benefit economically from the development of a post-Apollo human space project.<sup>491</sup>

With the Apollo program winding down and the election looming, the Nixon administration called on NASA to devise a next generation launch vehicle which would set a new tone for America's future in space in accordance with the 1969 task group report.<sup>492</sup> Shepherding the goal set by John F. Kennedy through the finish line would not be the legacy of President Nixon, whose interest in outer space policy was limited compared to his two Democratic predecessors.<sup>493</sup> Instead of announcing a race to a new finish line—such as Mars, as suggested by some of his contemporaries—President Nixon planned to focus his administration's space policy on making near-Earth space into a site of commerce. Supporters of this approach, including George Mueller, argued that in order to make space an extension of the human environment, the cost of transportation to

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<sup>491</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle*, 73; Hoff, "The Presidency, Congress, and the Deceleration of the US Space Program in the 1970s," 108–109.

<sup>492</sup> Other spacefaring nations at this time also attempted to implement reusable space transportation systems. The Soviet Union developed the Mikoyan MIG-105 in 1965, and the Buran spaceplane (which resembled the American space shuttle in many respects) during the 1980s. Japan, the European Space Agency, and the UK each studied reusable spacecraft, as well. However, none of these systems came to full fruition beyond a single, uncrewed test flight of Buran in 1988. For an overview of different national reusable spacecraft development programs during and after the Cold War, see Kuczera and Sacher, *Reusable Space Transportation Systems*.

<sup>493</sup> Hoff, "The Presidency, Congress, and the Deceleration of the US Space Program in the 1970s," 96–98.

orbit must be reduced through an initial upfront investment in new technologies of reuse yielding substantial savings over time and regular use.<sup>494</sup> Such a commonplace presence in outer space would not only yield industrial benefits, but would also foster the first steps towards humankind achieving a true understanding of what Mueller called “the nature of space.”<sup>495</sup>

### **Technological [Angular] Momentum**

The nature of space that Mueller hoped to know by way of normalizing the nearest reaches of the cosmos included both the “first nature” and “second nature” that together made up the orbital infrastructure. As put forward by Bill Cronon, these two terms describe the enmeshed networks of human and non-human entities, structures, and processes that together become equally invisible and inevitable to the societies that encounter them.<sup>496</sup> In order to reshape the second nature of near-Earth space, Mueller and his colleagues faced an uphill battle.

The state of the orbital infrastructure during the early 1970s represents a remarkable example of a large technological system that has reached what Thomas Hughes calls “technological momentum.” A compromise between technological determinism and the social construction of technology (SCOT) approaches to understanding the development of technological systems, the concept of technological momentum takes additional factors such as environmental forces and time into account to

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<sup>494</sup> George E. Mueller, “The New Future for Manned Spacecraft Developments.”

<sup>495</sup> George E. Mueller, “Address by Dr George E Mueller, Associate Administrator for Manned Space Flight, National Aeronautics and Space Administration before the British Interplanetary Society, University College London, England.”

<sup>496</sup> Cronon, *Nature's Metropolis*.

consider the ways in which society and technology mutually shape one another. Although human beings fashion technology and continue to do so through early stages of interpretive flexibility, with time, use, and integration into larger technological systems, artifacts can become so deeply settled into a particular form that they become “black boxed.” Human beings may more easily adapt to black boxed technologies rather than change the material characteristics of the technology itself.<sup>497</sup> Those who sought to create an affordable, economically sustainable reuse paradigm in outer space believed such a massive shift would require more than simply changing the ways we get to orbit. Rather, America would have to take the lead in refashioning nearly all aspects of the vast, expensive, complex technological system already in place.<sup>498</sup>

During the early days of the Space Age, engineers built satellites that ranged in form from passive satellites like the Echo satelloon and West Ford dipoles, to the active satellites that we think of today as the standard form of space communications technology.<sup>499</sup> As a web of social conditions led to the prevalence of the active form of satellite in the Soviet and American space programs, each national industry

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<sup>497</sup> Thomas Parke Hughes first laid out his theory of technological momentum in *Networks of Power: Electrification in Western Society, 1880-1930* (Baltimore, MD: Johns Hopkins University Press, 1993) and further extrapolated it in “The Evolution of Large Technological Systems,” in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, by Wiebe E. Bijker, Thomas Parke Hughes, and Trevor J. Pinch (Cambridge, Mass.: MIT Press, 1989), 51–82.

<sup>498</sup> Hughes’s essay on technological momentum appears in an edited volume that addresses historical approaches to technological systems from a SCOT perspective. Wiebe E. Bijker, Thomas Parke Hughes, and Trevor J. Pinch, *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass.: MIT Press, 1989).

<sup>499</sup> For more on passive vs. active satellites, particularly Echo and West Ford, see Chapters 1 and 2 of this dissertation.

simultaneously constructed additional components of a vast technological system to further grow the new space-facilitated globalism of the late twentieth century. Expendable launch vehicles carried satellites and human spacecraft into orbit. The satellites themselves, destined for altitudes ranging from a few hundred to thousands of miles above the surface of the planet, would never be seen or touched by human hands again. Engineers did not design them with the expectation that they could be retrieved once they left the atmosphere. Whether through anomaly, fuel depletion, or eventual orbital or material decay, these artifacts could not be reused. The considerable momentum of expendability permeated all aspects of the space infrastructure from Sputnik through the early 1970s.<sup>500</sup>

The attempt by Nixon, his advisors, and leadership at NASA to push a change in momentum—and the subsequent challenges faced by those who attempted to fulfill the initial charge—represents a unique case study in technological momentum. The idiosyncratic attributes of the orbital environment further complicate the interplay between social and technological forces that make change difficult to enact once momentum builds. The combination of physical and temporal illegibility and remoteness of the space environment itself, the extreme mobility of orbiting objects, as well as the highly visible risk to human life required for substantial change to occur, intensified the

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<sup>500</sup> The first chapter of this dissertation presents a case study of the first orbiting artifacts, and the high level of interpretive flexibility with which different communities designed, encountered, and used the empty rocket casing that accompanied Sputnik into orbit. For more on the interpretive flexibility of artifacts and the social construction of technology, see Trevor J. Pinch and Wiebe E. Bijker, “The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other,” in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology* (Cambridge, Mass.: MIT Press, 2012), 11–44.

momentum at an early stage of technological system-building. Without the ability to materially modify components of the system already in space, and with the high cost associated with launching new spacecraft generating resistance among funding decision makers, enforcing a shift would require monumental change among all stakeholders in the space industry. Given the paramount role of the geophysical world of outer space in stabilizing the initial paradigm, the attempt to strong-arm a change from expendability to reusability could perhaps be stylized as a fight to overcome “technological angular momentum.”

When nonhuman nature occupies a position of such dominance—even a dominance that lacks the intentionality that critics of actor-network theory defend as unique attributes of human beings—it becomes a force on par with, or even stronger than, social construction and technological determinism.<sup>501</sup> When human actors, from Nixon to NASA administrators to engineers, attempted to change the direction of the technological momentum of the space system, the strangeness, inaccessibility, and intractability of the orbital environment presented obstacles to reuse that arguably equaled political factors and the economic climate on the ground below. As the history of the space shuttle program demonstrates, changing one component of the system in space does not accomplish enough to foster comprehensive change in the infrastructure as a whole. Interested social groups that wished to change one or more components of a

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<sup>501</sup> Bruno Latour, one of the creators of Actor Network Theory (ANT), addresses some of the most compelling critiques of this approach in “On Recalling ANT,” *The Sociological Review* 47, no. S1 (May 1, 1999): 15–25.

technological system must change the entire system and create an entirely new vector of momentum.

NASA would make several attempts to foster a change in momentum by changing one major component of the infrastructure, namely the shift from using ELVs to using the reusable space shuttle to launch all American space technologies. Political coalitions driven by the promise of a reuse economy supported this drastic change in protocol. For example, in 1971, the US Air Force agreed to cease design and production of new ELVs in deference to using the space shuttle to launch DOD payloads.<sup>502</sup> Buying into the new reusable civilian spacecraft in advance promised to yield savings in the long run, particularly if the high cost of development could be shared between government agencies. With such a complex system, developed over the course of decades, the forces undergirding these political coalitions shifted. As the Air Force used up its store of extant ELVs and the Shuttle schedule slipped into the early 1980s, President Ronald Reagan stepped in to ensure the enduring solidity of the DOD-NASA partnership. In a November 1981 National Security Directive, the Reagan administration designated the Shuttle—which was in the midst of its second crewed test flight—as the exclusive delivery mechanism for all spacecraft, by all space users. Any exceptions to this policy would have to be made directly through the president's office.<sup>503</sup>

However, the continuous motion of satellites through space and the complexities of operating in a microgravity vacuum meant that single-use technology would be

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<sup>502</sup> Thomas H. Johnson, "The Natural History of the Space Shuttle," *Technology in Society* 10 (1988): 419.

<sup>503</sup> Reagan Administration, "Space Transportation System," National Security Decision Directive, (November 13, 1981), Federation of American Scientists.

difficult to replace. During the long 1970s, as the typical form of communications satellites firmly settled into complex multifunction units with active electronics on board, those at NASA who advocated the adoption of reusable spacecraft attempted to introduce some flexibility into this momentum. NASA and its contractors proposed—and in a few rare cases designed, built, and launched—a radically new form of satellite: one that we could see, touch, and alter after its initial ascent into orbit. NASA and its contracted organizations attempted to redirect industry priorities in such a way as to predict the afterlives of products and reanimate them. Instead of building new satellites at great expense, with the possibility that failure or accident would mean a complete loss of investment, the change in momentum would mean long-lived satellites that could be repaired, refueled, or even salvaged to make new technologies. In addition to saving money in the long run, this would also minimize the impact on the near-Earth space environment by reducing the amount of non-functioning material in orbit—a priority that Fletcher emphasized as an important benefit towards investing in a wholesale shift in the way that humans occupied the nearest regions of outer space.<sup>504</sup>

As the movement towards a paradigm of reuse in space gained ground, the environment of outer space remained simultaneously a central problem and resource to those who hoped to relinquish single-use technology. In a yearly report on national aeronautics and astronautics activity put out by the Ford administration, the phrase “unique environment of outer space” occurs some five times, denoting its value for scientific research and commercial and industrial production, particularly with respect to

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<sup>504</sup> Fletcher, “Spaceship Earth, A Look Ahead to a Better Life.” 21.

microgravity conditions that cannot be replicated on the ground.<sup>505</sup> The strange environment itself was laden with value due to its unique gravitational properties; however, these same properties also generated greater technological momentum that would deeply hinder incremental steps towards reuse. In combination with intransigent political forces and the ever-present priority of austerity after Apollo, the strange space environment presented an enormous obstacle to those who sought to change the direction of an entrenched technological angular momentum.

### **Building A Reusable Space Transportation System**

Space historians have spilled plenty of ink on the development of the space shuttle and the different reusable designs considered before NASA settled on the partially reusable (and therefore cheaper to build) spaceplane and booster system.<sup>506</sup> However, few have illuminated the extent and scope of the reuse paradigm heralded by the late 1960s flurry of studies, speeches, and articles that preceded the Shuttle program. In addition to designing a vehicle that could move people and payloads to and from orbit over and over again, many within NASA believed that the space infrastructure in its entirety must undergo a comprehensive redesign that would include reusable satellites. NASA Administrators from James C. Fletcher in the early 1970s to James Beggs in the mid

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<sup>505</sup> In one of the yearly reports put out by the Ford administration, the phrase “unique environment of space” occurs five times to describe the reasons why greater and cheaper access to space must become the norm. “Aeronautics and Space Report of the President, 1974 Activities” (NASA, 1975).

<sup>506</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA’s Search for a Reusable Space Vehicle*; Butrica, *Single Stage to Orbit*; T. A. Heppenheimer, “Economics and the Shuttle,” in *The Space Shuttle Decision: NASA’s Search for a Reusable Space Vehicle*, The NASA History Series, NASA SP-4221 (Washington, D.C.: National Aeronautics and Space Administration, 1999).



1980s emphasized the economic and political necessity of fostering a new way of building standardized, repairable satellites that met the commonality, reusability, and economy criteria of NASA's 1969 Space Task Group study.

The space shuttle represented only the most visible part of a much larger system that American space leadership hoped would make outer space accessible and affordable. As a launch and landing vehicle, the space shuttle orbiter would provide the critical link between Earth and space. The full Space Transportation System (STS), as it came to be known moving into the 1970s, included several components that most Americans would never have a chance to see should the various proposals come to fruition. From plans for a reusable Space Tug, space-based nuclear shuttle, Spacelab, upper stage rockets, and space stations, the early, ideal STS required multiple vehicles that would remain in space for the entirety of the technologies' useful lives.

In its earliest design iterations, the space shuttle was intended to be fully reusable. More than that, it was meant to facilitate the launch and operation of reusable, long-lived satellites. Shuttle supporters argued that the shape of the vehicle itself would yield greater economy in satellite production and performance. Should satellite builders be constrained to the spatial dimensions of a shuttle payload bay, NASA engineers predicted that a standard satellite form would emerge. Instead of a fleet of satellites built to individual specifications and matched to the appropriately sized expendable rocket, a standardized satellite form would enable mass production and economy of scale. If standardization also included uniform handholds, docking apparatus, and other features necessary for capture, refueling, and refurbishing, the space program would save time and money that

would otherwise be spent training astronauts for specific, non-generalizable repair missions. Additionally, if satellite companies designed their products with the possibility of cheap servicing and repair, they might be able to eschew some measure of expensive pre-launch ground testing.<sup>507</sup>

The shuttle would serve as a garbage truck and salvager, both directly and indirectly. By removing the need for disposable rockets, fewer rocket bodies and other mission debris would litter near-Earth space. And by bringing back dead satellites and other payloads that could not be refurbished in space, the Shuttle would remove more potentially dangerous large debris and safely transport the satellite through the heat and pressure of the upper atmosphere, potentially to be refurbished and used again. Fewer large pieces of debris would be left to reenter the atmosphere and potentially threaten people, property, and environments on the ground—a threat that increased as the Solar Maximum of the late 1970s drew large dead spacecraft back to Earth to the chagrin of concerned publics and governments alike.<sup>508</sup> Rather than littering near-Earth space with pieces of empty single-use rockets and dead satellites, NASA and its contractors attempted to build a vehicle that would allow the United States to clean up its own messes in space, and perhaps even clean up after others.

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<sup>507</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle*, 261–262.

<sup>508</sup> Editorial, “Falling Satellites Pose Growing Threat,” *Today*, September 20, 1978. For more on Solar Maximum and the threat of reentry, please see Chapter 3 of this dissertation.

The space shuttle constituted “the major element,” or the “key element,” but certainly not the only piece of the reuse-based Space Transportation System.<sup>509</sup> In two studies, produced for NASA in 1971 and 1972, Mathematica, Inc. projected significant savings for state and commercial space customers, to the tune of nearly half the direct costs of the expendable launch vehicle paradigm. However, Mathematica researchers emphasized that this savings would not come about through the launch and successful operation of the shuttle alone. Only with additional components and clearly defined reuse objectives firmly in place would the STS yield the projected savings.<sup>510</sup> Even as evolving shuttle designs conducted by different organizations considered varying degrees of reusability and partial expendability, the need for such additional components as a reusable Space Tug and reusable satellites persisted throughout the design stages of what would eventually become the partially reusable space shuttle that NASA and the DOD would use from 1981 to 2011. STS designers planned that this combination would facilitate the refurbishment and reuse of satellite payloads, both in space and by bringing obsolete or complex systems back to Earth for repair via the Shuttle.<sup>511</sup> By the mid-1970s,

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<sup>509</sup> Barbara A. Luxenberg, “Space Transportation System,” in *United States Civilian Space Programs, 1958-1978*, vol. Volume I, Serial D (Subcommittee on Space Science and Applications of the Committee on Science and Technology, US House of Representatives, Ninety-seventh Congress, First Session, 1981), 638; “Aeronautics and Space Report of the President, 1975 Activities” (NASA, 1976), 18.

<sup>510</sup> “Economic Analysis of the Space Shuttle System, Volume 1,” January 31, 1972; K. P. Heiss and Oskar Morgenstern, “The MATHEMATICA Economic Analysis of the Space Shuttle System” (Symposium on Space Shuttle Payloads, Washington, DC, 1972).

<sup>511</sup> “The major economic potential identified for Space Transportation Systems in the 1980's is the lowering of space program costs due to the reuse, refurbishment, and updating of satellite payloads. The fully reusable, two-stage Shuttle is the major system considered in the May 31, 1971 report, but not the only system to achieve reuse, refurbishment and updating of payloads. Payloads were assumed to be refurbished on the ground, with refurbishment costs varying

as engineers began to design the space shuttle vehicle, NASA continued to field studies on how to implement satellite servicing using the proposed Space Transportation System.<sup>512</sup> Those who pitched the STS to lawmakers and the public emphasized that the greatest cost of the system would come in upfront development expenses. The overall system would see the most savings in implementation and operations.<sup>513</sup> All of the pieces would be necessary in order to get the American space industry to reach a sustainable economy.

The most enduring proposed components of the Space Transportation System included the space shuttle, the Space Tug, a Space Station, and satellites designed to be retrieved, repaired, refueled, and redeployed. The economics, promise, and arguable failure of the space shuttle may be gleaned from the significant historical and policy literature. In the remainder of this section, I will examine each of the less well-known components of the original plans for the STS, each of which would see some level of implementation but not in a coordinated fashion that would yield the economy promised by a fully reusable space infrastructure. For each of these components, the technological

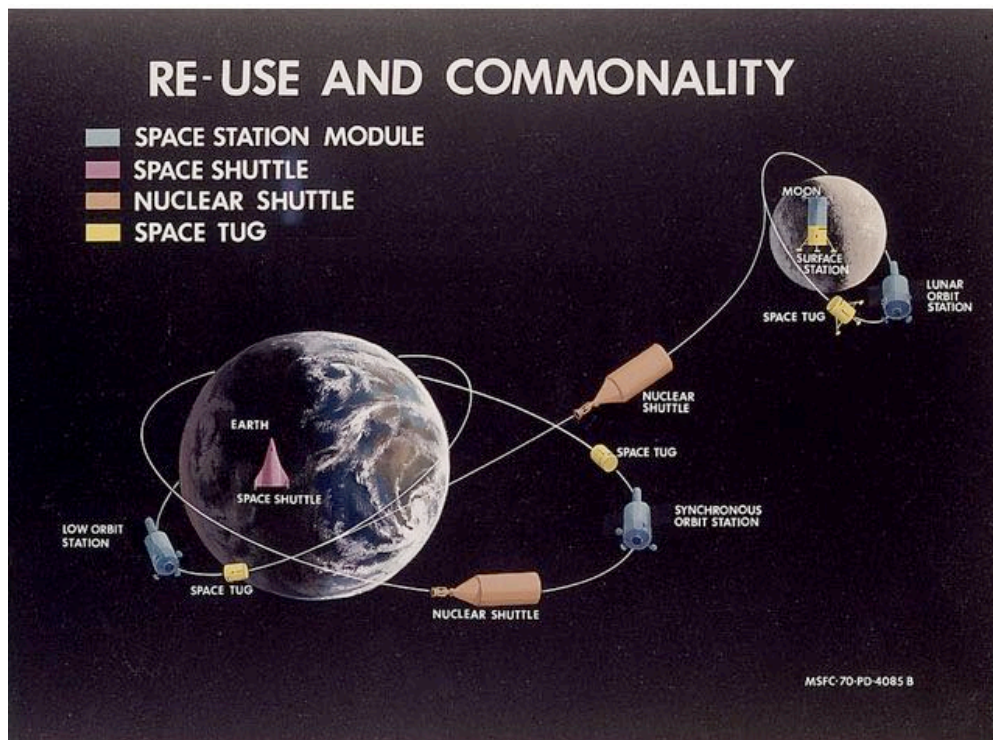
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between 30% and 40%. The launch costs of the space shuttle and Space Tug needed to recover and place the refurbished payloads are also allowed for. We strongly recommended in May that other systems be studied to determine the extent and the cost at which they can achieve reuse, refurbishment, and updating of payloads.” Heiss and Morgenstern, “The MATHEMATICA Economic Analysis of the Space Shuttle System,” p 0–4.

<sup>512</sup> “NASA Continues to Look at STS Orbital Servicing,” *Defense / Space Daily*, March 24, 1975, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>513</sup> C. J. Donlan and E. J. Brazill, “The Space Transportation System. Space Shuttle-Spacelab-Space Tug System,” in *Proceedings of the Thirteenth Goddard Memorial Symposium* (Future Space Activities, Tarzana, CA, 1975), 3–17; see also the many speeches by NASA Administrator James M. Beggs in 1984, in which he made the point about in-use costs over and over. For example, see “Suggested Remarks: National Space Club, Washington DC,” January 25, 1984; “Suggested Remarks: American Bar Association’s Section on Public Contract Law, Washington, DC,” June 12, 1984; “Suggested Remarks: Metropolitan Club, Washington, DC,” April 23, 1984.

momentum resulting from political immobility, failed coalitions, and the intransigence of the outer space environment impeded the implementation of each. Rather than representing the vanguard of technological innovation, the Shuttle instead indicated the limitations of changing only one part of a system in use.



**Figure 4.1:** An artist's concept from 1970 shows an integrated system consisting of a space shuttle, Nuclear Shuttle, and several Space Tugs that could expand humankind's access to space from low orbit to the lunar surface. Marshall Space Flight Center engineers studied these concepts in response to the Space Task Force's 1969 call for commonality, reusability, and economy.<sup>514</sup>

<sup>514</sup> *Spacecraft Reuse and Commonality*, January 1, 1970, NASA NTRS.

## Space Tug

In January 1961, Joseph McGolrick of the NASA Office of Launch Vehicles privately proposed an idea for a reusable orbital vehicle that he called the “space tug.” In a note to self, McGolrick imagined a small, reusable craft, either crewed or uncrewed, whose versatility would allow the United States to maintain a vast future infrastructure in outer space over the next decade. McGolrick’s vision of the space tug supported several different missions that, if implemented, would go a long way towards keeping space safe, affordable, and clean:

One space tug mission would be to correct the orbit of earth satellities [sic]. This could prolong the life of some satellites, which would otherwise prematurely enter the earth's atmosphere. Satellities [sic] requiring precise positioning could be made simpler, cheaper and more reliable if their final positioning was made by a space tug. It could even come back from time to time to make minor corrections or move the satellite to a new position. A space tug could afford a means of cleaning junk out of space by directing it at the earth's atmosphere. It could...bring friendly satellites to orbiting space stations for repair.<sup>515</sup>

Written when only a few dozen artificial satellites circled the planet, months before the first human flew into space, and years before the cost overruns of the moon project and the subsequent downturn in the American aerospace industry of the 1970s, this memo

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<sup>515</sup> J. McGolrick, “Idea,” Memorandum, (January 5, 1961), Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

suggests that some at NASA had already considered the ramifications of the single-use economy from an early moment in the Space Age. McGolrick primarily emphasized the importance of developing space technology that could support longer-lived, less-expensive satellites, which made up the largest percentage of the total cost of space launches.<sup>516</sup> The form of the tug itself does not matter much in this memo; what matters is the ways in which it might enable a new way of saving money and maintaining order in a forbidding environment that would not make such efforts easy. In closing, McGolrick claims that human presence and space would not become routine until such satellite servicing and removal practices became the norm.

The 1969 Space Task Group report specified that the next generation space transportation system should include just such a vehicle. In April 1970, the NASA Manned Space Center put out a request to the American aerospace industry for preliminary studies of a reusable Space Tug, formalizing the name that McGolrick speculated a decade earlier. The call for proposals specified that such a vehicle should be versatile enough to operate from low-Earth orbit to the moon, and be capable of boosting spacecraft to high altitudes, supporting construction projects, and rescuing and repairing disabled spacecraft. It should be designed to operate autonomously or with an onboard

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<sup>516</sup> Satellites continue to make up the largest percentage of mission costs. United Launch Alliance, which currently provides ELVs for DOD, NASA, and commercial missions, lists the per-launch price \$225 million, which pales in comparison to the “multi-billion dollar” satellites that ride into space aboard these disposable rockets. However, the current trend towards mini satellites and so-called “cubesats” has made this cost breakdown more complicated. While multiple cubesats may be launched on a single rocket as a secondary payload, they are typically less complex, perform fewer functions, and spend less time on orbit than their larger cousins. “Launch Costs - United Launch Alliance,” *ULA - America’s Ride to Space*, accessed July 22, 2016, <http://www.ulalaunch.com/faqs-launch-costs.aspx>.

crew. The Marshall Space Flight Center (MSFC) published a press release the following month that highlighted the tug as an important component of a larger, multi-vehicle Space Transportation System—relatively small and mundane in purpose but no less crucial than the “larger and more publicized” shuttle and space station.<sup>517</sup> The Space Tug would also be at the core of STS self-maintenance, keeping all other components in working order to preclude expensive replacements for any piece of the system that should fail. Marshall engineers proposed that the tug would have particular value in its capacity as a “satellite repair shop”:

Arriving at a satellite, for example, powered by a propulsion module, two astronauts in a crew module could use manipulator arms to grasp and insert the satellite into the cargo module. The module could then be pressurized, the crew could enter it and repair or service the satellite (without going outside the craft). The satellite could also be taken inside the cargo module to a space station for extensive repair.<sup>518</sup>

The following year, North American Rockwell completed a preliminary, pre-Phase A study for NASA that pitched significant savings based on a projected ten-year span of Tug use. Noting that the failure rate of satellites after reaching orbit hovered between 5 to

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<sup>517</sup> “News Release,” News release (Houston, TX: NASA Manned Spacecraft Center, April 6, 1970), Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>518</sup> Maurice Parker, “NASA Press Release,” May 26, 1970, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.



10 percent, Rockwell researchers claimed that retrieval, repair, and relaunch of satellites—particularly those from GEO—would yield some \$15000 per pound of satellite in savings over wholesale replacement. They projected that over the course of ten years, payload recovery and repair would eventually yield \$250 million in savings, a figure that would all but recoup the initial outlay to develop, test, and operate the Space Tug.<sup>519</sup> In addition to paying for itself, Marshall researchers argued the next year that the Tug would make the difference in whether or not the STS project as a whole would meet the primary goal of bringing down the cost of spaceflight. The Shuttle, while planned to be maneuverable, would not be capable of reaching orbits beyond several hundred kilometers in altitude. The ability to retrieve payloads from very high orbits, which could only be achieved using a versatile hypothetical tug, would be the key to making the shuttle itself “economically feasible.”<sup>520</sup> Two other American companies, including Boeing and the Aerospace Corporation, as well as the European Launcher Development Organization, conducted pre-Phase A studies on the Space Tug in 1970 and 1971. Each study inextricably tied the Tug to Shuttle costs: Both must be developed and used in efficient conjunction for the economy of reuse to be truly successful over the course of a decade of operations.<sup>521</sup>

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<sup>519</sup> Space Division, North American Rockwell, “Pre-Phase A Study for an Analysis of a Reusable Space Tug. Volume 1 - Management Summary Final Report” (NASA Manned Spacecraft Center, March 22, 1971), NASA NTRS.

<sup>520</sup> Public Affairs Office, “Space Tug” (Huntsville, AL: NASA Marshall Space Flight Center, November 2, 1971), Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>521</sup> A. S. Kiersarsky, H. S. London, and D. Macchia, “Pre-Phase A Tug Studies” (Washington, DC: Bellcomm, Inc., June 30, 1971), Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

The Tug would effectively increase the diameter of space access on the order of several thousand kilometers. Without the Tug to reach higher altitudes in order to launch and retrieve malfunctioning satellites, the STS would fall far short of the economies suggested by its advocates. The Mathematica studies of 1971 and 1972 also put forward the necessity of a Space Tug to make the STS system cheaper than the extant expendable launch regime.<sup>522</sup> By April 1972, Marshall put out a call for a more intensive, nine-month study of a Space Tug that would be “an efficient, compact system designed exclusively for delivery and retrieval of space payloads” to and from the Shuttle, thus providing a seamless transit link from high, geosynchronous orbits to the surface of the Earth.<sup>523</sup> As MSFC and the Johnson Space Center (JSC) generated in-house studies and solicited external reviews of potential Tug design capabilities, each description and call for proposals emphasized that any Space Tug must become available for use at the same time as the space shuttle in order to ensure that the STS could be used immediately to retrieve and service satellites—and by extension, to set the accumulation of savings in motion as soon as possible. Although the Space Transportation System would go through several conceptual design changes—dropping the nuclear shuttle, gaining a shuttle-based Spacelab, the rise and fall of different space station concepts—the Space Tug remained a constant requirement of STS proposals throughout the 1970s.<sup>524</sup>

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<sup>522</sup> “Economic Analysis of the Space Shuttle System, Volume 1”; Heiss and Morgenstern, “The MATHEMATICA Economic Analysis of the Space Shuttle System.”

<sup>523</sup> Charles Kurtz, “Space Tug Operations Study Planned,” *NASA News*, April 4, 1972, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>524</sup> The space tug also appears in promotional materials featuring artistic representations of STS proposals, including those that supposed a full circuit between Earth and moon. See for example

However, even as NASA studies compartmentalized the Tug and the Shuttle together in co-development and readiness, the less flashy component of the STS did not garner enough of a spotlight to merit the same level of steadfast internal and external support in the midst of setbacks. From the outset of the Shuttle project in 1972, Fletcher acknowledged that expendable orbital rocket stage would be necessary to fill any gaps in development between Shuttle and Tug.<sup>525</sup> By 1974, the DOD agreed to develop a “kick motor” upper stage for use by both NASA and military projects that required payload placement in high orbits.<sup>526</sup> Called the “Interim Upper Stage” (IUS), this expendable rocket would not have the capacity to retrieve payloads; it would simply provide a stopgap until the NASA-developed reusable Tug could be called into service.<sup>527</sup> After over two years of competition, the DOD contracted Boeing to develop a solid rocket concept for the IUS that could deploy from either the Shuttle or extant expendable rockets to deliver payloads to high orbits, then maneuver into a different orbit for disposal so as not to present a collision risk to the newly activated satellite.<sup>528</sup> By 1975, the DOD had committed to providing IUS units beginning in 1980, until the mid-80s

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*Earth Orbit Cargo Transfer*, January 1, 1969; *Mission Evolution Through Hardware Commonality*, January 1, 1970; *Spacecraft Reuse and Commonality*, January 1, 1970.

<sup>525</sup> “James C. Fletcher, Administrator, NASA to Senator Walter F. Mondale,” April 25, 1972, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>526</sup> In addition to the IUS and the SSUS, Martin Marietta also developed a disposable upper stage known as the Transfer Orbit Stage (TOS) which was used to deploy a satellite during STS-51. “Space Shuttle Mission STS-51 Press Kit,” Press Kit (NASA, July 1993), -51, NASA Johnson Space Center History Portal.

<sup>527</sup> “Aeronautics and Space Report of the President, 1974 Activities,” 25.

<sup>528</sup> “Inertial Upper Stage,” *Federation of American Scientists*, accessed June 22, 2016, <http://fas.org/spp/military/program/launch/ius.htm>; “Space Launchers - IUS,” accessed June 22, 2016, <http://www.braeunig.us/space/specs/ius.htm>.

when NASA projected that the tug would be ready for use.<sup>529</sup> As the IUS development also began to slip, McDonnell Douglas developed a similar single-use kick motor for use on expendable rockets and modifiable for Shuttle use. Built by a private company for primary use by commercial customers, the Spinning Solid Upper Stage (SSUS) would not cost the federal government any development money, with the added benefit of providing a unique ability to deploy spinning payloads.<sup>530</sup> The SSUS would eventually become known as the Payload Assist Module (PAM).<sup>531</sup> Each of these technologies was expendable—they could only be used once. In spite of being designed to deploy from a partially reusable spacecraft, these kick motors reinforced the existing single-use paradigm.

Because neither the IUS nor the PAM were being designed to retrieve payloads, when the Skylab space station began to fall from orbit towards the end of the decade, the Tug and an accompanying mechanism referred to as the Teleoperator Retrieval System (TRS) once again became a top priority at NASA. Many at the agency hoped that the imminent first launch of the space shuttle alongside completion of the Tug and TRS would allow astronauts to either boost the station to a higher orbit, or bring it back to Earth. However, as the development schedule for the Shuttle slipped, the Tug and TRS project went over budget and had to be temporarily abandoned. Skylab fell from orbit as

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<sup>529</sup> Responsibility for contracting and operating the IUS came with increased DOD involvement in and responsibility for the Shuttle program beginning in the mid-1970s. “Aeronautics and Space Report of the President, 1975 Activities,” 18.

<sup>530</sup> “Aeronautics and Space Report of the President, 1976 Activities” (NASA, 1977), 16.

<sup>531</sup> One such PAM motor would reenter the atmosphere and land in a sparsely populated desert area of Saudi Arabia in 2001. See Chapter 3 of this dissertation for more on reentering debris. “PAM-D Debris Falls in Saudi Arabia,” *The Orbital Debris Quarterly News*, April 2001.

expected, and in the without the immediacy of a potential reentry disaster the focus on a reusable high orbit booster solution shifted in short order. By 1981, the Space Tug was no longer on the table, though space technology reports from that year onward continued to gesture to “low level efforts” to build a Space Tug at some future date.<sup>532</sup>

The expendable rocket stages that served a smaller subset of the planned Tug’s functions effectively extended the reach of the Shuttle from its low-Earth orbit operational ceiling, boosting satellites to GEO and in some cases sending space probes such as Galileo, Magellan, and Ulysses on their way to other planets and the Sun.<sup>533</sup> Fifteen IUS units launched aboard space shuttles, including one that was destroyed during the ill-fated Challenger’s final flight.<sup>534</sup> An IUS unit that never launched currently hangs above the payload bay of the Shuttle habitability trainer in the Boeing-sponsored Museum of Flight in Seattle, Washington. An explanatory sign notes that Boeing designed the stage only to fill in for the planned reusable Space Tug before it could enter service, but after budget cuts the IUS became the “permanent solution” for high orbit missions.<sup>535</sup> At this point, the word “interim” no longer described this technology; to preserve the in-use acronym, it became known as the “Inertial Upper Stage”—a less

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<sup>532</sup> For a comprehensive overview of the planning and failure of the reusable Space Tug initiative circa 1981, shortly after “interim” became “inertial” in the official name of the expendable vehicle used to deploy high orbit satellites from the space shuttle, see Charles S. Sheldon II, “Launch Vehicles and Propulsion,” in *United States Civilian Space Programs, 1958-1978*, vol. Volume I, Serial D (Subcommittee on Space Science and Applications of the Committee on Science and Technology, US House of Representatives, Ninety-seventh Congress, First Session, 1981), 265.

<sup>533</sup> “Space Transportation System Payloads,” in *NSTS News Reference Manual* (NASA, 1988).

<sup>534</sup> “Inertial Upper Stage.”

<sup>535</sup> Boeing Inertial Upper Stage. (Seattle, WA: The Museum of Flight, n.d.). Museum exhibit label.

ethereal name for a less than ideal fix.<sup>536</sup> The name shift along with the preserved acronym illustrates another attribute of the unswayable technological momentum of space technology: even as the intended use shifted in profound ways, the in-use acronym proved so entrenched as to remain in place even as the underlying words changed.

As the STS program limped along in development and ran over budget, it became more difficult to justify the price of developing such a reusable ancillary vehicle. As a 1982 study of potential orbital transfer vehicles indicated, none of the necessary component technologies for such a vehicle existed yet. The procedures and technologies would require extensive *in situ* development and testing at considerable cost and human hours. Terrestrial testing could not provide the necessary conditions to fully test and develop methods to construct, operate, and maintain such a vehicle. A particular challenge came in the need to safely transfer and store fuel in a microgravity vacuum, which would be necessary for a reusable Tug.<sup>537</sup> By contrast, an expendable upper stage like the IUS and PAM would not require refueling, and could be based largely on extant rocket technologies that had already been extensively tested in space during the Apollo program. While the reusable Space Tug promised to revolutionize the American satellite infrastructure, the necessary wholesale overhaul of the rest of the transportation system and the challenges of the space environment proved too big an obstacle for Tug designers to bring their plans to fruition in the midst of the stable, settled single-use paradigm.

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<sup>536</sup> Charles S. Sheldon II, "Launch Vehicles and Propulsion," 263.

<sup>537</sup> "Evolutionary Space Platform Concept Study. Volume 1: Executive Summary," May 1, 1982, NASA NTRS.

### Space Operations Center

SOC: We've got a bunch of satellites coming in for servicing close to your arrival time, but we'll hold them for you.

Tanker 3: Thanks....we have a full load of cry[ogenics] for you....an extra 11,500 pounds from the ET. Looks like the boost engines were better than nominal on today's run. That ground crew is doing a great job!<sup>538</sup>

Relative to the small, agile Space Tug, plans for a continuously operated Space Station inspired a more visible debate and controversy within and outside NASA.<sup>539</sup> With the space shuttle ferrying people and cargo from Earth to orbit and a versatile Space tug providing the link to higher orbits, this third piece of infrastructure rounded out early conceptions of the reusable Space Transportation System. Robert R. Gilruth, the first director of the Manned Spacecraft Center (later renamed the Lyndon B. Johnson Space Center) argued in 1968 that to achieve true economy in space flight, America would need to first achieve a permanent presence in orbit.<sup>540</sup> While a space station of some sort featured in nearly every STS proposal from the late 1960s through the 1980s, the size, shape, and purpose of such a station varied widely from person to person and among staff at different NASA centers. The initiative to reuse space technology showed up in the proposed form and function of several space station ideas studied by NASA and its contractors during the 1970s and 1980s.

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<sup>538</sup> Howard L. Myers, "SOC - Spaceport of the Future" (Eleventh Intersociety on Environmental Systems Conference, San Francisco, CA: Rockwell International Space Operations and Satellite Systems Division, 1981).

<sup>539</sup> Maurice Parker, "NASA Press Release."

<sup>540</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle*, 72.

At the time that the NASA centers began developing STS space station concepts, they had a single reference point for permanent American presence on orbit. The Skylab space station launched atop (and was made of pieces of) a spare Saturn V moon rocket. For two years three different crews of three astronauts used Skylab as an orbital laboratory, conducting mostly medical and astronomy experiments within the station and undertaking spacewalks to fix the station itself when automated systems failed. In NASA terminology, Skylab was a Space Laboratory. The station did not have the thrusters necessary for maneuverability and could not be used as a base from which to construct or retrieve satellites. At first, Skylab mission operators hoped to reuse the station after its final crew departed, reviving the derelict vessel and repurposing it for use as an extension of the Shuttle during missions that would require roomier accommodations.<sup>541</sup> Plans for such reuse imagined the second iteration of Skylab as extra laboratory space, relatively spacious quarters for less hardy astronauts, and even eventually as the backbone to a manufacturing and repair center in orbit.<sup>542</sup> Once it became clear that the Shuttle would not be ready in time to boost Skylab to a high enough orbit to prevent it from reentering the atmosphere, NASA officials realized that they would need to start from scratch on a new form of orbital platform. In exchanges between administrators and researchers, three clearly delineated types of station emerged as the most appropriate applications of limited funds and research resources during the upcoming STS era: a station that would support

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<sup>541</sup> J. Murphy, B. Chubb, and H. Gierow, "Skylab Reuse Study Presented to Mr. Yardley by MSFC."

<sup>542</sup> "Skylab Reuse Program Strawman Plan"; Joseph P. Loftus, Jr., "Skylab Reuse."



Space Industrialization, an Operational Base, or another Space Laboratory.<sup>543</sup> Different NASA centers, from Goddard Space Flight Center in Maryland to the Manned Space Center in Texas, each backed one of these primary station functions depending on the mission strengths of the institution. However, many Space Laboratory models such as those advocated by NASA Goddard personnel during the mid 1970s included satellite servicing and operations in the overall mission.<sup>544</sup> Satellite servicing became a consistent refrain in many station concepts as the most important factor in justifying and recouping the cost of STS development.<sup>545</sup>

As part of an ideal Space Transportation System, a continuously occupied space station would provide the on-demand access to space technology that the STS was intended to facilitate. The form and purpose of the space station—and the degree of its autonomy as a separate component of the larger STS—vacillated widely under the tenure of different presidential administrations and NASA administrators.<sup>546</sup> Regardless of the

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<sup>543</sup> “Space Station” (Washington, DC: NASA Headquarters, March 8, 1976), Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>544</sup> Despite its overall focus on Earth-Observing satellites, Goddard personnel remained invested in satellite servicing possibilities well beyond most other interested communities gave up on the prospect. In June 1987, Goddard hosted the third Satellite Servicing Workshop, intended to facilitate information exchange and stimulate new technical ideas. Leon N. Perry and David W. Thomas, “NASA/Goddard to Host Satellite Servicing Workshop,” *NASA News*, May 22, 1987, Orbiting Servicing System 6280, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>545</sup> “Space Station Mission Classifications” (Washington, DC: NASA Headquarters, March 8, 1976), Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>546</sup> The term “platform” as used to describe a particular kind of orbiting space station arose during the Carter administration. President Carter was staunchly opposed to funding new large space engineering projects reminiscent of Apollo, as emphasized at the outset of his 1978 presidential directive on national space policy: “It is neither feasible nor necessary at this time to commit the US to a high-challenge, highly-visible space engineering initiative comparable to Apollo. As the resources and manpower requirements for Shuttle development phase down, we will have the

intended primary use of the space station, the role of the station to facilitate space technology reuse showed up in several early proposals. One early idea for an orbiting platform, proposed by Fletcher and later supported by Beggs, demonstrated the feasibility and challenges of building a spacecraft quite literally upon reuse.<sup>547</sup> This proposal suggested using discarded space shuttle external tanks (ET) for purposes ranging from equipment storage to crew quarters.<sup>548</sup> Each large ET by design fell back into the atmosphere after feeding liquid fuel to the orbiter's main engines—a disposable component of the otherwise reusable space shuttle system. What could be cheaper, Fletcher's space station team argued, than building the foundations of a necessary piece of infrastructure using an expensive technology that otherwise immediately went to waste?<sup>549</sup> This plan would not move beyond an early, informal proposal, though it recurred periodically throughout the Skylab and Shuttle programs, cropping up as part of the Skylab reuse study of the mid-1970s and in studies conducted as recently as the early

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flexibility to give greater attention to new space applications and exploration, continue programs at present levels, or contract them. An adequate Federal budget commitment will be made to meet the objectives outlined above." "Presidential Directive/NSC-42, Civil and Further National Space Policy," October 10, 1978. As a result, those within NASA, including administrators Fletcher and Robert Frosch, advocated simpler "platforms" that would not be fully autonomous from the Shuttle nor continuously occupied; and for better or for worse (depending on the administration and the political climate over ensuing decades) rhetorical distance from the term "space station." The difference between space platforms and space stations is fully explicated in Howard E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice* (Baltimore, MD: JHU Press, 2010) and John M. Logsdon, *Together in Orbit: The Origins of International Participation in the Space Station*, Monographs in Aerospace History 11 (Washington, DC: NAS History Division Office of Policy and Plans, 1998).

<sup>547</sup> James Vedda, "The Changing Purpose of the Space Station," *Quest: The History of Spaceflight* 13, no. 3 (August 2006): 35, 38.

<sup>548</sup> J. R. Dossey and G. Trotti, "An Investigation of the Needs and the Design of an Orbiting Space Station with Growth Capabilities," January 1, 1977, NASA NTRS.

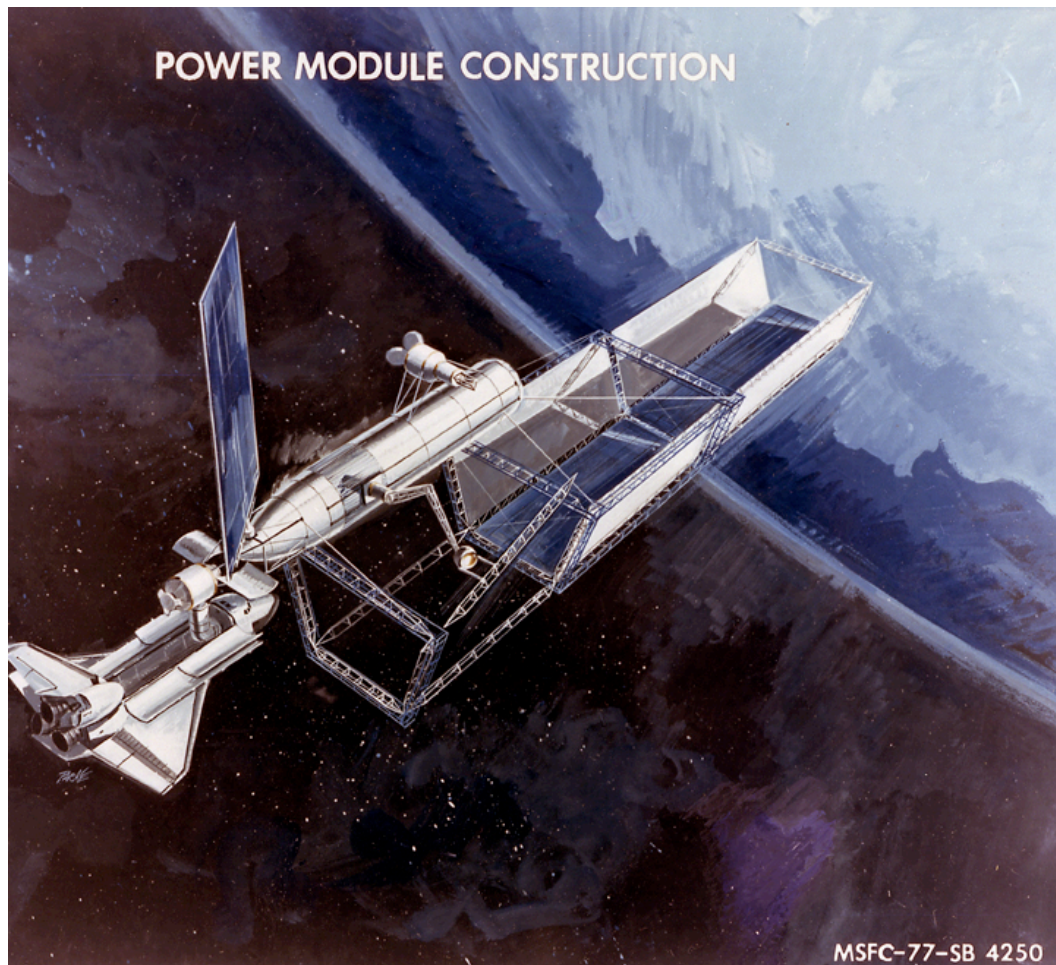
<sup>549</sup> Howard E. McCurdy, *The Space Station Decision: Incremental Politics and Technological Choice* (Baltimore, MD: JHU Press, 2010), 82–84.

years of the International Space Station program.<sup>550</sup> The authors of one such proposal acknowledged the likely material difficulties of using an ET to build a space station, noting: “The alchemists of the Middle Ages who sought to transform lead into gold would feel quite at home with space designers seeking to transform expended rocket propellant tanks into useful space payloads.”<sup>551</sup> In imagining a second life for expendable launch technology, those who supported an ET-based space station took the reuse initiative to the next level, transforming an artifact designed to be disposable into a utility-laden object of value.

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<sup>550</sup> See for example Dossey and Trotti, “An Investigation of the Needs and the Design of an Orbiting Space Station with Growth Capabilities”; “Use Found for Shuttle Fuel Tank,” *Starlog*, October 1977, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.; Barbara A. Luxenberg, “Space Transportation System,” 445–639; W. D. Kelly, “Stabilization of the External Tank for Use as a Large Space Platform” (High Frontier Conference, Princeton, NJ, 1997); For a concept of the ET as part of an expanded space platform built upon the reuse of Skylab, see J. Murphy, B. Chubb, and H. Gierow, “Skylab Reuse Study Presented to Mr. Yardley by MSFC.”

<sup>551</sup> W. D. Kelly, “Stabilization of the External Tank for Use as a Large Space Platform.”



**Figure 4.2:** This artistic conception portrays one potential reuse for the expendable shuttle external tank, as part of an orbital construction facility.<sup>552</sup>

In another study sponsored by NASA and actively researched by aerospace subcontractors from the late 70s to early 80s, the space station itself became a critical part of the reuse economy, serving as the neighborhood salvage and recycling center for low-Earth to geosynchronous orbits. The Space Operations Center (SOC) station proposal grew out of an idea by researchers at the Johnson Space Center in the late 1970s. Those at

<sup>552</sup> *Space Station Systems Analysis Study (SSSAS)*, January 1, 1977, NASA NTRS.

NASA, Rockwell, and Boeing that executed studies of the proposed SOC aimed to design an orbiting depot where astronauts and automated vehicles could undertake satellite repurposing, refurbishing, and salvage on a daily basis. Contributors to the planning of the SOC did not intend the station to be a scientific lab like Skylab and the spacecraft that would eventually become the International Space Station. As the name implies, its primary purpose was to support operational missions—run-of-the-mill construction projects, maintenance, and transportation that would keep the space infrastructure running cleanly and cheaply for government and commercial space consumers.<sup>553</sup> The SOC model provided a permanent, consistently occupied, *in situ* berth for the space shuttle, a Space Tug, and an orbital maneuvering vehicle like the ill-fated TRS. Using the SOC as a home base, astronauts could manipulate satellites as high as geosynchronous orbit or even the moon.<sup>554</sup> As one NASA press release argued, the SOC would provide the cheapest way to maintain the growing satellite infrastructure through upgrading and repairing faltering satellites rather than the expensive contemporary—and continuing—practice of launching replacement satellites in the event of failure or obsolescence.<sup>555</sup>

Johnson Space Center researchers rallied around the Operational Base model of the space station at the end of the 1970s and the early 1980s, and the SOC became a

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<sup>553</sup> Some space station studies presented a teleological “evolutionary” set of steps for development of an orbital platform—typically starting with a laboratory craft, then a site for technology testing, and then, in its most evolved form, an operations base. See for instance “Evolutionary Space Platform Concept Study. Volume 1,” 19–22.

<sup>554</sup> *Mission Evolution Through Hardware Commonality; Planetary Mission Evolution*, January 1, 1970; *Spacecraft Reuse and Commonality*.

<sup>555</sup> “Unique STS Services” (NASA, n.d. ca 1984), Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

favored option for implementing this mission.<sup>556</sup> Sam H. Nassif of the Program Development Office of the NASA Engineering and Development Directorate noted that the SOC would provide “a logical extension of the operationally oriented space capability that began with the space shuttle.”<sup>557</sup> With the space shuttle providing space customers with cheap, reliable ways to extend the functional lives of satellites, the SOC would provide greater working and storage space, particularly for unfixable satellites that could then be brought back to Earth for salvage upon the next returning Shuttle.<sup>558</sup> With retrievable satellites in service and an agile Space Tug, or even an expendable orbital maneuvering vehicle, JSC personnel and affiliated researchers at Rockwell International expected the SOC to provide the key to access to all orbital altitudes and the reduction of necessary Shuttle flights, which had already become more expensive than initially hoped.<sup>559</sup> While none of the SOC designs made use of discarded Shuttle fuel tanks as part of the material infrastructure, researchers sought to reduce the amount of waste generated

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<sup>556</sup> The issue of whether NASA ought to support operational missions instead of only running research and development programs came up several times during the Phase A SOC studies. Then-Deputy Administrator-designate Hans Mark responded to such a question posed by a member of the House Space Subcommittee by claiming that “experimental” projects of all kinds fall under NASA purview—thus including the unprecedented SOC as an experimental project. “Mark Sees Space Station as Next Goal After Shuttle,” *Defense Daily*, May 18, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>557</sup> Sam H. Nassiff, “Space Operations Center: The Next Step in Manned Space Flight (draft),” n.d., Center Series, Samuel H. Nassiff Papers, Box 4, SOC Study Planning Charts 1981, JSC History Collection.

<sup>558</sup> Space Transportation & Systems Group, “Future Space System Operational Concept” (Rockwell International, October 1981), 12–13, Space Flight - Human Space Flight; Space Stations; Space Platform Concepts (I) 9342, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>559</sup> Space Transportation & Systems Group, “Future Space System Operational Concept”; J. P. Loftus, “Advanced Missions Briefing for Administrator” (Houston, TX: NASA, July 20, 1981), Space Flight - Human Space Flight; Space Stations; Space Platform Concepts (I) 9342, NASA Headquarters Historical Reference Collection, Washington, DC.

with each jettisoned ET.<sup>560</sup> For instance, in the Rockwell SOC study, each Shuttle flight would end with the ET accompanying the orbiter to the station, whereupon any excess fuel therein would be transferred to a holding tank. Instead of dissipating in atmosphere or ocean with the rest of the disintegrating ET, this fuel could then be used to power the orbital transfer vehicles, and perhaps even refuel satellites.<sup>561</sup>

By May 1981, acting NASA Administrator Alan Lovelace came out with his support for the SOC, calling for an operational station by 1984.<sup>562</sup> Astronauts John Young and Robert Crippen, who flew the first space shuttle mission the previous month, also supported the SOC concept, calling it “the next logical step to our exploration of space.”<sup>563</sup> The DOD concurred, with officials expressing their desire to save money through regular refurbishing of defense payloads.<sup>564</sup> The following month, Representative

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<sup>560</sup> An analysis of the potential environmental impact of the SOC concluded the station would cause negligible effects to the biosphere because it would not significantly increase the total number of annual shuttle launches—the only direct terrestrial byproducts of station construction. However, the SOC Program Plan also considered how the SOC might change the orbital environment, and called for a concrete assessment of debris accumulation, waste gas venting, liquid dumps, etc. “Mark Sees Space Station as Next Goal After Shuttle.”

<sup>561</sup> Space Transportation & Systems Group, “Future Space System Operational Concept,” 10.

<sup>562</sup> “NASA Endorses Space Station Development,” *Aviation Week & Space Technology*, May 25, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.; “Lovelace Pushes Space Operations Center,” *Defense Daily*, May 22, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>563</sup> “Young, Crippen Lobby for Space Operations Center,” *Aerospace Daily*, May 21, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.; Associated Press, “Space Heroes Lobby For Orbiting Station,” *Daily Press*, May 21, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>564</sup> “Stafford Proposes Air Force Takeover of Shuttle,” *Defense Daily*, September 24, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.; “DOD Use of Shuttle to Build Large Structures in Space Seen,” *Defense Daily*, December 21, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

Bill Nelson publicly called for the Reagan Administration to commit to putting the SOC in orbit by 1989.<sup>565</sup> However, NASA never devoted funds to the development of the SOC beyond the initial Phase A concept. The NASA budget for fiscal year 1982 allocated only \$1 million for continuing SOC studies.<sup>566</sup> At the end of November 1981, Reagan's assistant director for national security at the Office of Science and Technology Policy argued that the SOC should not be America's next step in space, and that if such a spacecraft should become necessary then the private sector would fill the void—a charge that would prove prescient of future launch vehicle policy positions taken by Reagan in subsequent years. Such directives would adversely shift the American space industry away from reuse.<sup>567</sup>

By 1990, plans for Space Station Freedom (which would eventually turn into the International Space Station program) were already in motion, with the station explicitly defined as a laboratory for scientific research. Initially, Freedom would also be used as a home base for the construction and servicing of spacecraft—but specifically human spacecraft intended for Mars and the moon, rather than Earth-orbiting satellites.<sup>568</sup> By the time the first modules of the space station reached orbit, the construction and servicing component fell away, and the International Space Station (ISS) of today primarily

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<sup>565</sup> “Congressman Suggests SOC By 1989 As Space Goal,” *Defense Daily*, June 30, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>566</sup> “Lovelace Pushes Space Operations Center.”

<sup>567</sup> “Official Doubts Space Station Need,” *Aviation Week & Space Technology*, November 30, 1981, Space Station (1972-1981) 009347, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>568</sup> Barry D. Meredith et al., “Space Station Freedom Accommodation of the Human Exploration Initiative,” in *Proceedings of the Twenty-Seventh Space Congress (90's: Decade of Opportunity*, Cocoa Beach, FL, 1990).



operates as a scientific research facility. The ISS's shape was determined by the size of the Shuttle's payload bay, as anticipated by those who hoped that the payload bay would shape a cheaper standardized satellite. The ISS does not have the facilities to serve as an orbital repair shop, and for the most part its thrusters are only used to move it out of the way of space junk that might have been cleaned up using the Space Transportation System in its original form.

NASA and its international partners used the space shuttle as the primary workhorse to build the ISS, which has been continuously occupied for a decade. The ISS took a shape determined by the size of the Shuttle's payload bay, and serves as an orbiting science laboratory rather than an operations center.. Early cost projects of the SOC and ISS suggested that a similar investment would be necessary to build a permanent structure in space. In 1981, JSC staff estimated the cost of developing and operating an SOC in conjunction with a Space Tug would come to some \$1.5 billion per year initially, tapering down after 3 years.<sup>569</sup> A separate estimate brought the total SOC cost to \$6.99 billion including the cost of seven shuttle launches over the two years budgeted for building the station.<sup>570</sup> In 1993 NASA adjusted the American contribution to ISS construction to around \$1.3 billion per year from 1994 to 2005, rising to over \$2

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<sup>569</sup> J. P. Loftus, "Advanced Missions Briefing for Administrator."

<sup>570</sup> Sam H. Nassiff, "Space Operations Center: The Next Step in Manned Space Flight (draft)"; Space Operations Center Program Office, "Space Operations Center Program Plan" (Houston, TX: NASA, November 23, 1981), Space Flight - Human Space Flight; Space Stations; Space Platform Concepts (I) 9342, NASA Headquarters Historical Reference Collection, Washington, DC.

billion during peak years of construction.<sup>571</sup> While this figure parallels the projected costs for the SOC, the ISS required 40 total construction launches, including 36 shuttle flights over the course of twelve years.<sup>572</sup>

Although the actual costs of the SOC had it been approved cannot be calculated, and the total costs of the ISS including Shuttle launches also cannot be easily determined, in the planning stages the ISS and SOC models diverged in terms of cost recouping through satellite recycling. As a laboratory with no equipment to capture or refurbish satellites, cost estimates for the ISS did not incorporate any additional projected savings through providing a platform for satellite repair and reuse. In contrast, 1981 budget projections for the SOC included millions of dollars in savings by the year 2000, particularly if the station operated in conjunction with an upgraded Shuttle and reusable Space Tug.<sup>573</sup> With the loss of the SOC in favor of a second Space Laboratory to succeed Skylab, another important piece of the reusability paradigm fell by the wayside.

### **Reusable Satellites**

Planning for the space shuttle began in earnest in 1970, but was not without its enduring skeptics. For instance, Democratic senator Walter Mondale consistently resisted the expenditure of such large sums of federal money that would be required as an initial

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<sup>571</sup> “International Space Station (ISS) Response to the Cost Assessment And Validation Task Force on the ISS,” June 15, 1998, [NASA.gov](http://www.nasa.gov).

<sup>572</sup> NASA considers forty missions to have been dedicated to the construction of the International Space Station, including those that used the Shuttle as well as missions launched atop expendable Russian rockets. “International Space Station Assembly - Past Flights,” [NASA.gov](http://www.nasa.gov), accessed June 2, 2016, [http://www.nasa.gov/mission\\_pages/station/structure/iss\\_assembly.html](http://www.nasa.gov/mission_pages/station/structure/iss_assembly.html).

<sup>573</sup> J. P. Loftus, “Advanced Missions Briefing for Administrator.”

outlay, no matter the projected eventual savings.<sup>574</sup> Fletcher addressed these concerns by emphasizing that the Shuttle would provide over a billion dollars in savings compared to expendables once it became operational. He cited studies by the Aerospace Corporation and other external organizations that demonstrated the monetary payoff of repairing and maintaining satellites, even if some would be lost to obsolescence. However, Fletcher also clearly delineated the need to provide other “essential future elements” that would make it truly reusable—including the Space Tug, and perhaps most importantly, satellites that had been built from the outset to be retrievable and repairable. Rather than requiring a staggering research and development expenditure, Fletcher argued that “repair and maintenance of satellites in orbit is technically and practically feasible when the satellites have been designed with this in mind.”<sup>575</sup>

As part of STS development, NASA dedicated resources to developing a new satellite design called the multimission modular spacecraft (MMS). Initially developed for scientific research satellites, the MMS streamlined manufacturing costs by incorporating standardized modules for power, attitude control, communications, and data management, thereby fulfilling the “commonality” priority from the original 1968 Space Task Group report. In addition to saving money by manufacturing these components in bulk rather than building them to spec for individual missions, MMS designers expected that standardized modules would save money by enabling easier on-orbit repairs to failing satellites. Because all MMS satellites used the same components,

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<sup>574</sup> John M. Logsdon et al., *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program. Volume 4; Accessing Space* (Washington, DC: National Aeronautics and Space Administration, 1999), 256, <http://ntrs.nasa.gov/search.jsp?R=19990116994>.

<sup>575</sup> “James C. Fletcher, Administrator, NASA to Senator Walter F. Mondale.”

replacement parts would be easy and cheap to both procure and install. In 1981, NASA projected that some 75 percent of space science missions of the 1980s could be achieved using the MMS. The first tests of the MMS model came with the Solar Maximum Mission and two Landsat satellites. NASA anticipated that other astronomical, geophysical, climatological, and defense missions could be fulfilled by the MMS at greatly reduced costs to the customer.<sup>576</sup>

Additionally, NASA developed several larger satellites that would be retrievable from orbit, some of which used the MMS system. The candidates for such design supported science research that would benefit from regular servicing and upgrades. Four such satellites went into service: the Hubble Space Telescope (HST), Compton Gamma Ray Observatory, Extreme Ultraviolet Explorer, and the Upper Atmosphere Research Satellite.<sup>577</sup> Of these four, only the Hubble received visits from the Shuttle—five over a span of seventeen years, most infamously in 1993 to correct the telescope’s faulty optics.<sup>578</sup> Both the MMS and larger research satellites required specific features in order to be considered “man-rated,” or safely manipulated by astronauts. These features included hand holds and safety locks, and required larger overhead to include—which

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<sup>576</sup> Barbara A. Luxenberg, “Space Transportation System,” 629–630.

<sup>577</sup> The Upper Atmospheric Research Satellite (UARS) reentered the atmosphere in 2011, to much hoopla about its potential survival and threat to inhabited areas. It ultimately landed in the Pacific Ocean with no reported damage or casualties. “NASA’s UARS Re-Enters Earth’s Atmosphere,” Press Releases (Washington, DC: NASA, September 24, 2011), NASA.gov, [http://www.nasa.gov/home/hqnews/2011/sep/HQ\\_11-350\\_UARS\\_Re-entry.html](http://www.nasa.gov/home/hqnews/2011/sep/HQ_11-350_UARS_Re-entry.html).

<sup>578</sup> Rob Garner, “Hubble Servicing Missions Overview,” Text, *NASA*, (2015), [http://www.nasa.gov/mission\\_pages/hubble/servicing/index.html](http://www.nasa.gov/mission_pages/hubble/servicing/index.html).

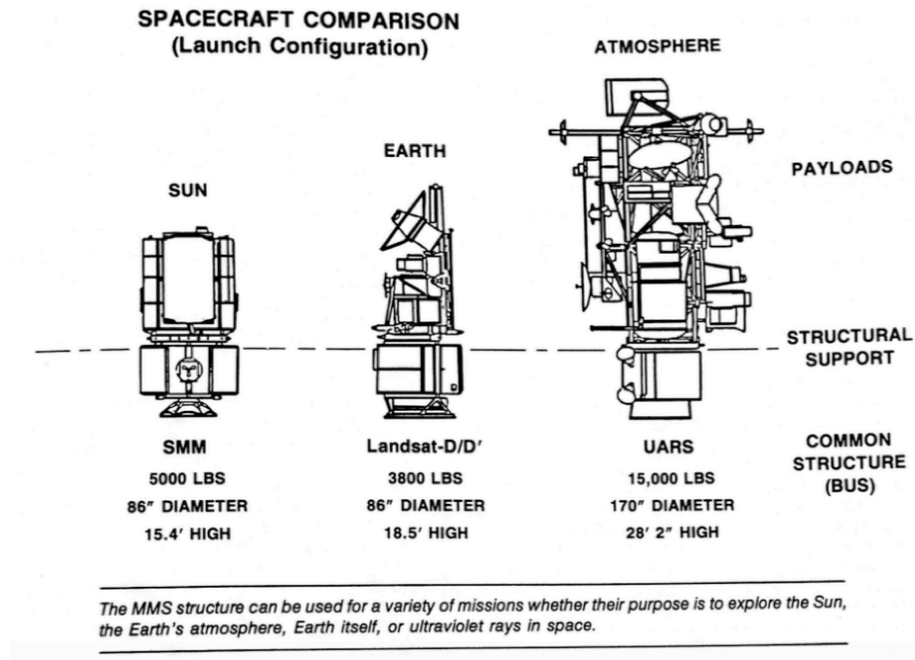
some satellite customers found onerous.<sup>579</sup> However, not just any satellite could be retrieved by Shuttle astronauts, as NASA demonstrated in several initial satellite rescue missions during the mid-1980s. The high speeds at which satellites orbit in microgravity conditions, as well as the risk inherent in sending astronauts into a lethal environment, rendered repair nearly impossible without safety and manipulation devices that astronauts could be adequately trained to use.<sup>580</sup> In published materials intended to describe the latest space technology to the American public, the NASA public affairs department described the HST as “a test-bed for satellite repair work.” Lockheed designed the HST to be serviced in space, and occasionally brought back to Earth for more complicated upgrading and refurbishing.<sup>581</sup>

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<sup>579</sup> Doyle McDonald, “Overview of the Report of the Group Task Force on Satellite Rescue and Repair” (NASA, November 16, 1992), 3, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>580</sup> McDonald, “Overview of the Report of the Group Task Force on Satellite Rescue and Repair.”

<sup>581</sup> Allaway, *The Space Shuttle at Work*; Dave Dooling, “DIY in a Space Suit,” *New Scientist*, December 1983.



**Figure 4.3:** The Multimission Modular Spacecraft (MMS) served as the basis for several different satellites across a wide variety of science missions. Two of the featured spacecraft have reentered the atmosphere, and one continues to orbit the planet following its decommissioning in 2001.<sup>582</sup>

In addition to putting up the development costs from the outset in an austere budget environment, NASA also ran into obstacles of compliance with its intended satellite customer base. In 1982, JSC researcher Gordon Rysavy lamented NASA management's lack of attention to the need for a coordinated set of rules and regulations for retrievable satellites, like the technical manuals provided by the FAA to military and civilian jet manufacturers. Rysavy claimed that commercial satellite customers especially had clamored for such defined parameters, and that NASA's failure to provide them may have set satellite servicing back by five years—at a cost of some \$1.5 billion in estimated

<sup>582</sup> "Service Calls in Space," NASA Facts (Greenbelt, MD: Goddard Space Flight Center, n.d.), Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.

savings to be achieved through reuse.<sup>583</sup> A Grumman Aerospace Corporation estimated that the cost of repairing a satellite in orbit represented only 5 to 10 percent of the cost of building a new satellite.<sup>584</sup> However, in order to achieve these savings satellite customers had to comply with man-rating standards that NASA did not have the resources to distribute and regulate.

The strange physical environment of orbital space precluded any simple, one-point solution to replace expensive single-use space infrastructure with reusable technologies. Most satellites launched into orbit would never be seen again, and no spacecraft existed that could reach artifacts at orbits above a few hundred kilometers. Therefore, they were not designed in such a way as to make capture or repair possible. Catching a satellite in a microgravity environment in which objects move at speeds of upwards of 7 kilometers per hour presented a design challenge. Like the airline industry of the preceding decades, satellite designers would need to adhere to a set of specifications in order to qualify for access to outer space.<sup>585</sup> Advocates of the reusability paradigm saw greater economy in a more standardized form of satellite that they believed would take shape dictated by the rest of the technological system in which it would be

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<sup>583</sup> Space World Staff, "Satellite Servicing NASA Holds Back," *Space World*, October 1982, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>584</sup> J. Mockovciak, "Servicing Costs for Representative Service Missions," vol. 2 (NASA Johnson Space Center Satellite Servicing Workshop, Houston, TX, 1982), 11, <http://ntrs.nasa.gov/search.jsp?R=19830002935>.

<sup>585</sup> One skeptic of the reusable satellite paradigm criticized the difficulty in standardizing forms for multiple customers: "They want a danged book that looks like MilSpec or MilStandard that's just like the book that folks use in building a military jet or civilian aircraft. I think we can establish baseline equipment and reasonable interfaces and they'll work to it. If NASA builds gear that there's no requirement for, that's not very smart." Space World Staff, "Satellite Servicing NASA Holds Back."

embedded. Constrained in size by the payload capacity of the proposed space shuttle orbiter, commercial and government satellites would become part of a larger, integrated system of reuse.

### **Compromises and Cuts**

Those who advocated the development of the reusable Space Tug, Space Operations Center, and serviceable satellites as the components of a reusable space transportation infrastructure argued that the United States ought to work on making space a place for industry, rather than solely a place for conducting science. While on the surface this perhaps runs counter to the uses of space advocated by astronomers and biologists during the early years of the Space Age, the operational model of Space Transportation System nonetheless would support the overall goals of those who sought to protect the nearest regions of outer space for scientific research.<sup>586</sup> Not only would the large space telescope be designed from the outset to be serviceable by astronauts or brought back to Earth for full upgrading; but the ability to reach a wide breadth of near-Earth space to retrieve nonfunctional satellites would mean a less cluttered place, a site of scientific research that would be protected from potential collisions and obstructions.<sup>587</sup>

As the Shuttle slipped in schedule and rose in costs, each additional piece of the Space Transportation System fell victim to the vagaries of legislative and presidential

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<sup>586</sup> See Chapter 2 of this dissertation for more on astronomers' self-assigned role of space pollution watchdog.

<sup>587</sup> For more on the incremental decisions that made up the final form and serviceability of what would become the Hubble Space Telescope, see Robert W. Smith, *The Space Telescope: A Study of NASA, Science, Technology, and Politics* (Cambridge [England] ; New York: Cambridge University Press, 1989).



support. The nuclear shuttle dissipated in the face of contemporary anti-nuclear politics; the reusable Space Tug gave way in the face of skyrocketing Shuttle expenses and competitive expendable launch vehicles; and the operations model of Space Station yielded to a more competitive laboratory version. Soon, the space shuttle was all that remained from the heady proposals for an integrated, highly reusable space transportation system of the 1970s.<sup>588</sup> The name “Space Transportation System” eventually became a synonym for the space shuttle.<sup>589</sup> As physicist Thomas Johnson argued six years after the first Shuttle launch, the Shuttle program ultimately failed because it was “expected to do the impossible”—in Johnson’s framing, to provide an economy of scale that would financially justify the program without cutting corners that would lead to catastrophes like Challenger in 1986.<sup>590</sup> It failed to deliver on its promises, which were willfully sustained in order to maintain support from presidents and other branches of government.

In its 1981 report, Rockwell researchers laid out the ideal elements of an operational system in orbit: Shuttle, man, SOC, orbital transfer vehicle, and serviceable satellites.<sup>591</sup> By that time, the first two of those elements had flown together and returned safely to the Earth, with plans underway for a second launch the following month. The second two elements continued to be debated among NASA personnel as the Space Station program evolved and private enterprise developed expendable kick motors for

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<sup>588</sup> T. A. Heppenheimer, *The Space Shuttle Decision: NASA’s Search for a Reusable Space Vehicle*, 394.

<sup>589</sup> Although the Shuttle was initially intended to be but one component of the Space Transportation system rather than the entire system in and of itself, the acronym “STS” endured in the numbering of each space shuttle mission—e.g. STS-106, STS-41-D.

<sup>590</sup> Thomas H. Johnson, “The Natural History of the Space Shuttle,” 421–422.

<sup>591</sup> Space Transportation & Systems Group, “Future Space System Operational Concept.”

interim use. The final component—satellites that were designed to be serviceable by the other components of the system—would be the next test of the reusability. Even as the operational Shuttle proved pricier than hoped, and the Space Tug that would provide efficient access to higher orbits remained in limbo, many at NASA anticipated that the most expensive part of the single use economy could still be replaced with more affordable, standardized, reusable technologies. By the third year of the Shuttle program, several critical trials would test the ultimate feasibility of the reuse economy.

### **Testing the Limits of Reuse**

After the Shuttle went into service, and in the midst of debates over what form the proposed space station should take, NASA demonstrated the feasibility of each of the capabilities promised by a reusable space transportation and operations platform. As a servicing station for satellites, such a system must be able to provide the ability to achieve, with regularity and reliability, the three Rs of a reusable space technology ethos: retrieve, repair, refuel. Each of these capabilities would be necessary in order to maintain a longer-lived, and therefore more economical satellite. If any one of these tasks could not be completed on budget and on time, the extant paradigm of expensive, single-use, multipurpose satellites would continue into an indefinite future.

Within nine months in 1984, NASA astronauts tested all three Rs using the space shuttle. In April of that year, astronauts maneuvered the *Challenger* within range of the malfunctioning Solar Maximum satellite. An astronaut used a remote jet pack to reach and grapple the Solar Maximum satellite, then used the orbiter's remote manipulator arm

to bring the satellite into the payload bay for the astronauts to assess and repair.<sup>592</sup> After replacing a faulty electronics box, they returned the satellite to orbit to continue its mission of collecting data about the sun for an additional five years before it reentered the atmosphere. The astronauts filmed the retrieval, repair, and redeployment of Solar Max using the then-new IMAX film camera, immortalizing their activities in the movie *The Dream is Alive*. On the same mission, astronauts deployed the Long Duration Exposure Facility (LDEF), which would reveal the mixture of micrometeoroids, and anthropogenic debris in low-Earth orbit over the course of its six years in orbit after a different mission retrieved it in 1990.<sup>593</sup>

Later that same year, in October 1984, astronauts tested a refueling system that could be used to revive satellites that had used up propellants—once a satellite consumes its maneuvering fuel, it can no longer maintain its orbit and as a result often cannot fulfill mission objects. On the STS-41-G mission, astronauts transferred hydrazine fuel from one spherical bladder tank to another using the experimental Orbital Refueling System. Although they did not retrieve and refuel any extant satellites, this demonstration showed that volatile fuel could be safely transferred from one tank to another in microgravity using pressurized nitrogen as the propelling force.<sup>594</sup> Should such a practice become

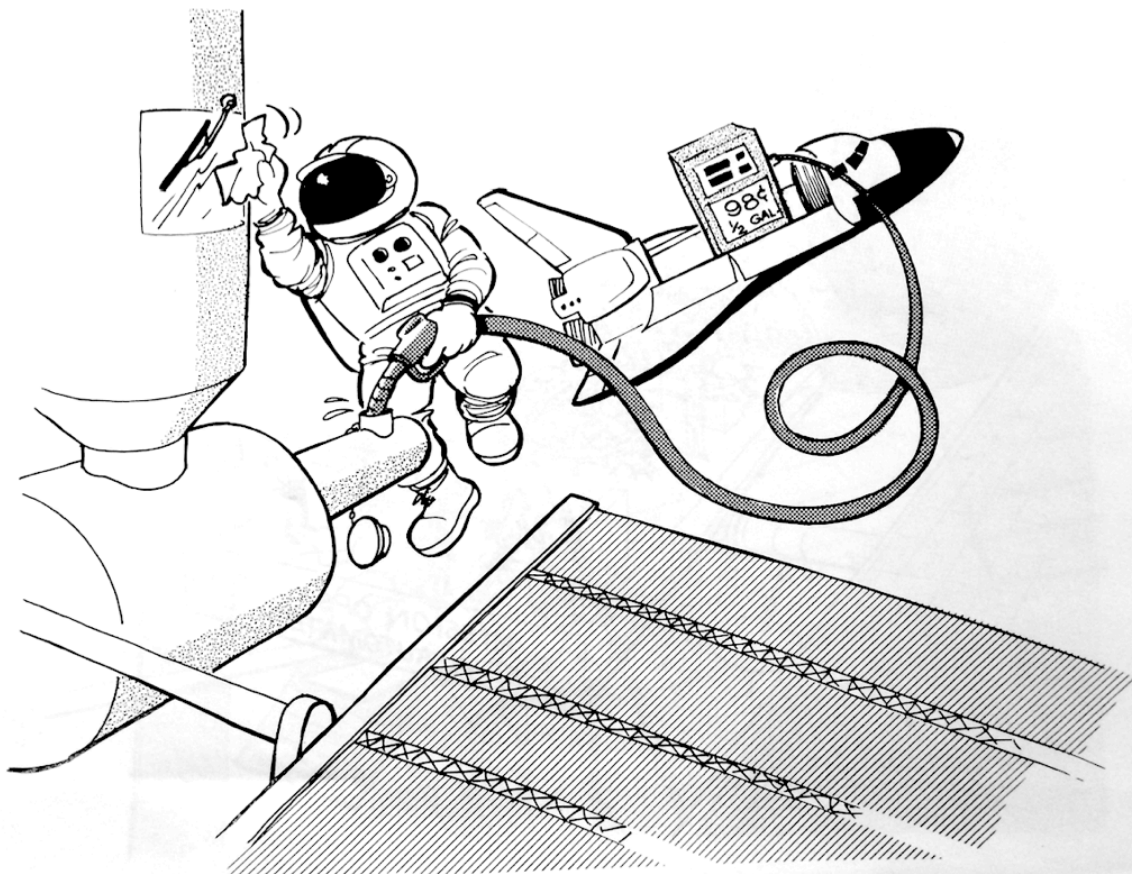
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<sup>592</sup> "Routine maintenance of satellites in orbit will become a reality next year when the space shuttle makes a service call for the crippled Solar Maximum Mission." Dooling, "DIY in a Space Suit."

<sup>593</sup> "Space Shuttle Mission STS-41C Press Kit," Press Kit (NASA, March 1984), NASA Johnson Space Center History Portal; "Space Shuttle Mission STS-32 Press Kit," Press Kit (NASA, December 1989), NASA Johnson Space Center History Portal.

<sup>594</sup> D. Kauffman, "An Analysis of Ullage Heat Transfer in the Orbital Refueling System," 1986.

common, then satellites that continued to provide useful services could spend longer in orbit, requiring fewer expensive replacements using entirely new satellites.



**Figure 4.4:** This image from a briefing on the Space Operations Center space station model demonstrates high hopes among NASA researchers at the Johnson Space Center for the future ability to refurbish and refuel satellites *in situ* and at low cost.<sup>595</sup>

The following month, NASA demonstrated the feasibility of accomplishing a third lynchpin of the reuse economy using the space shuttle. When the *Challenger* deployed the Westar and Palapa communications satellites earlier that year, the single-use

<sup>595</sup> “Space Operations Center: A Concept Analysis” (Space Operations Center Conference, Lyndon B. Johnson Space Center, Houston, TX, November 29, 1979).

PAM-D orbital maneuvering vehicle intended to boost the satellites to geosynchronous orbit failed to function correctly. They remained stuck in an orbit too low to provide the services for which they were designed. The companies that had insured the Westar and Palapa satellites made a deal with NASA: The insurance companies would pay for astronauts to retrieve and return the satellites to Earth for refurbishment and eventual resale. After an extensive training period in which they practiced the customized rescue plan devised for this particular mission, the team of astronauts that flew aboard the *Discovery* that November first deployed two new satellites from the orbiter's payload bay, leaving room for the drifting Westar and Palapa satellites. Satellite controllers first had to use the satellites' thrusters to move them to a lower altitude and reduced spin for easier manual capture. Because both satellites had been designed to be deployed using the space shuttle, their size and shape made it possible to return both artifacts safely to the ground. However, they had not been designed to be serviced, as both satellites were destined for geosynchronous orbit far above the Shuttle's highest functional altitude. In order to bring the satellites back to Earth, astronauts had to manually grapple each using a specially designed device meant to be inserted into the empty motor casing on one end of the satellite, then use the thrusters of the newly designed manned maneuvering unit to slow the spin of both satellite and astronaut so that the Shuttle's remote manipulator arm might then attach to the newly inserted grapple device. The lack of pre-installed servicing features on the satellites complicated their rescue. The astronauts themselves expressed doubt that the mission would succeed. According to astronaut Joseph Allen,

mission commander Rick Hauck exclaimed that “it would be a fucking miracle” to get both satellites back to Earth as planned.<sup>596</sup>

After struggling to follow the training plan and improvising new techniques, the astronauts successfully retrieved the satellites. Upon safely securing them into the payload bay, astronaut Dale Gardner posted a “for sale” sign on one to indicate its intended future reuse. The Westar 6 satellite would eventually be sold to Chinese company AsiaSat, which refurbished and launched again in 1990 atop a single-use Long March rocket. Westar/AsiaSat represents the only instance of successful salvage and reuse of a flown satellite. Whether the insurance company recouped its losses through the sale to AsiaSat remains a proprietary matter.

These three demonstrations of each the three Rs of space economy appeared to be the culmination of over a decade of negotiations with three different presidential administrations. NASA had met the goal set by Fletcher and Nixon a decade earlier, and as one space policy analyst claimed in 1985, the “era of ‘throw away’ space activities is coming to an end.”<sup>597</sup> Riding on the success of these missions, the future seemed bright for a reuse economy in space. In an open letter to NASA in the magazine “Space World,” space journalist David Leonard called for NASA to use these abilities to do even more than revitalize the orbiting infrastructure on the cheap. He suggested that the Shuttle

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<sup>596</sup> Joseph P. Allen, Joseph P. Allen Oral History, interview by Jennifer Ross-Nazzal, November 18, 2004, NASA Johnson Space Center Oral History Project, [http://www.jsc.nasa.gov/history/oral\\_histories/AllenJP/AllenJP\\_11-18-04.htm](http://www.jsc.nasa.gov/history/oral_histories/AllenJP/AllenJP_11-18-04.htm).

<sup>597</sup> Lawrence Aronovitch, “Satellite Servicing: The Center for Space Policy Inc. Explains How It Views the Future of Satellite Repair and Retrieval,” *Satellite Communications*, February 1985, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

could be used to save a select number of orbiting artifacts that had historic or cultural value; the shuttle could bring back such treasures as the first weather satellite. In addition to preserving priceless historical artifacts, this practice would serve an ancillary benefit, clearing orbital regions and making more room for functioning technologies while giving space junk a second life in a museum.<sup>598</sup>

### **A Return to Disposability**

In the end, the shuttle itself would become one of the only spacecraft of its era to enjoy this form of retirement. When the space shuttle program ended in 2011, its three remaining orbiter spacecraft went on to second lives as popular artifacts in museums around America.<sup>599</sup> NASA dedicated one of the final missions of the Shuttle program to servicing the storied Hubble Space Telescope. Over its 26 years on orbit, the Hubble has hosted five crews of visiting astronauts and persisted alongside the Shuttle as a rare relic of the paradigm of reuse envisioned during the long 1970s. During a final Hubble

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<sup>598</sup> Leonard David, "An Open Letter to NASA," *Space World*, May 1985, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>599</sup> The three remaining retired Shuttle orbiters, Discovery, Atlantis, and Endeavour, now reside in museums around the country. The California Science Center, which received Endeavour in 2012, also successfully petitioned NASA to receive the single remaining flight-qualified expendable external tank, designated ET-94. In 2016, the tank shipped from the Michoud Assembly Facility in Louisiana where it was built, passed through the Panama Canal, and arrived in Marina del Rey, California. It then made the rest of the trip over land to the Science Center where it will be displayed upright as if ready for flight alongside Endeavour. As a technology built to be disposed after use, this artifact is perhaps an even greater rarity than its venerable exhibit-mate. Rong-Gong Lin II and Raoul Ranoa, "NASA Gives California Science Center Museum Last Remaining Space Shuttle Fuel Tank," *Los Angeles Times*, May 28, 2015, <http://www.latimes.com/local/lanow/la-me-ln-space-shuttle-20150528-story.html>; Hailey Branson-Potts, "Giant Space Shuttle Tank Arrives in L.A. by Sea," *Los Angeles Times*, May 18, 2016, <http://www.latimes.com/local/lanow/la-me-space-shuttle-tank-arrives-20160518-snap-story.html>; "External Tank," *California Science Center*, accessed July 14, 2016, <http://californiasciencecenter.org/exhibits/air-space/space-shuttle-endeavour/external-tank>.

servicing mission in 2009 astronauts installed several new instruments in the telescope and retrieved the instruments that groundbreaking optical corrections equipment installed during the 1993 repair.<sup>600</sup> Given how rarely NASA used the space shuttle in its initial planned role as a salvager, these space-flown artifacts are a true rarity. They now reside at the Smithsonian National Air and Space Museum in a display that teaches about the handful of repair missions achieved using the Shuttle—also a true rarity in the history of space technology.<sup>601</sup>

The economy of reuse envisioned during the long 1970s fell victim to the same combination of social and environmental factors that made the shift an uphill battle from the outset. The proliferation of STS planning studies generated by NASA and American aerospace companies during the mid-1970s predicted an economy of scale that would eventually follow the wholesale implementation of a reusable space infrastructure. The sticker shock that legislators suffered in response to the anticipated outlay needed to develop the brand-new space shuttle system proved difficult for its supporters to counteract. After this struggle, studies for the SOC model of space station emphasized a lower initial investment required for research and development, given that such a station would be built entirely out of “off-the-shelf” technology. However, the one-two punch of

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<sup>600</sup> “Team Hubble - Servicing Missions,” *HubbleSite*, accessed May 27, 2016, [http://hubblesite.org/the\\_telescope/team\\_hubble/servicing\\_missions.php](http://hubblesite.org/the_telescope/team_hubble/servicing_missions.php).

<sup>601</sup> Most of the satellites and uncrewed spacecraft on display are not the genuine article because they disappeared into the strange ultimate sinks of space, sea, or sky. The Hubble itself is an artifact of incontrovertible cultural significance. But now that the space shuttle is a museum display itself, there is no way to save Hubble from its eventual fate. In 2009 final repair mission astronauts outfitted it with a grappling hook so that some future, as yet undesigned space tug might carefully draw it into the atmosphere over an ocean at the end of its life—as yet another piece of ephemeral waste.



the upfront sticker shock needed to develop, build, and test the space shuttle and its planned STS counterparts, and the eventual skyrocketing costs of the Shuttle program itself doomed the dream of a fully reusable space infrastructure that many at NASA had hoped would come to fruition by the 1990s and 2000s. While the success of such an economic ethos would undeniably save money in the long run, a publicly funded space program required the kind of investment and legislative support that no number of dramatic satellite rescues could inspire. As seen in subsequent and continuing legislative fights over other large-scale civilian satellite programs, garnering enough financial support for the construction of new, expensive spacecraft presents a battle by those who hope to use the space environment.<sup>602</sup>

Although it remained in use for thirty years, the space shuttle is considered by many historians and amateur space junkies alike to have been a failure.<sup>603</sup> Its skyrocketing costs, proportionally high rate of failure, irregular launch rate, and inability to move beyond the close confines of low-Earth orbit seem to some to have accomplished the opposite of its stated purpose of routinizing space travel on the road to Mars and beyond; rather, many argue it closed America out of the final frontier through demonstrating the

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<sup>602</sup> Roger Launius has argued that the cost alone has kept space travel the nearly sole domain of the US federal government and other state governments, with the exception of a few “high-end” communications satellite companies. In spite of government attempts to foster new, cheaper launch technologies, the cost per pound for space payloads remains high—a problem that SpaceX hopes to address with the Falcon 9 reusable rocket.

<sup>603</sup> John Logsdon, “Was the Space Shuttle a Mistake?,” *MIT Technology Review*, accessed March 25, 2016, <https://www.technologyreview.com/s/424586/was-the-space-shuttle-a-mistake/>; Roger D. Launius, “Assessing the Legacy of the Space Shuttle,” *Space Policy* 22, no. 4 (November 2006): 226–34.

considerable material and economic limits of routinely inhabiting space.<sup>604</sup> As the one part of the Space Transportation System that did come to full fruition, the Nixon through Reagan administrations accepted the upfront cost for the Shuttle. Unfortunately the in-use costs for the program ballooned well beyond the economy that was promised to follow after that investment. By 2011 each launch cost approximately \$450 million. Shuttle flights became too expensive to justify using the spacecraft for routine satellite launches.<sup>605</sup> Building one-off expendable launch vehicles, while akin in cost to wasting a 747 after each transatlantic flight, still amounted to fewer overall expenditures than required to launch, land, inspect, and refurbish a crewed spacecraft, which cost more than any airplane in existence—in stark contrast to the promise of a revolution in space travel to match that of civil aviation decades earlier.

The price of flights constituted only one component of the technological momentum that sent the American space industry back to a single use culture. The geophysical properties of the near-Earth space environment factored into the failure of another component of the STS infrastructure. Different orbital angles and altitudes require launches from different latitudes. For instance, vehicles that take off from Cape Canaveral, Florida fly in an easterly direction to take advantage of an extra boost provided by the Earth's rotation. Florida-launched spacecraft reach orbital inclinations

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<sup>604</sup> Bruno Latour, "Telling Friends from Foes at the Time of the Anthropocene," in *The Anthropocene and the Global Environmental Crisis: Rethinking Modernity in a New Epoch*, ed. Clive Hamilton, Francois Gemenne, and Christophe Bonneuil, Routledge Environmental Humanities (New York: Routledge, 2015).

<sup>605</sup> John Logsdon, "Was the Space Shuttle a Mistake?"

from 28.5 degrees to 57 degrees relative to the equator.<sup>606</sup> Due to this physical reality, as well as the need to adhere to air space sovereignty and safety concerns, spacecraft that require a polar orbit cannot be launched from the subtropical Florida site. A second, Air Force-sponsored space shuttle launch facility planned for Vandenberg Air Force Base, the departure point for many DOD space launches destined for polar orbits, fell victim to design conflict and the post-Challenger drive to consolidate all Shuttle launch activities at Cape Canaveral.<sup>607</sup> The Vandenberg site would have enabled the Shuttle to serve a broader range of orbital inclinations.<sup>608</sup> While the DOD did sponsor its own classified Shuttle missions, the reusable spacecraft could not serve all national defense space needs. After the cancellation of the California launch site and the Reagan Administration's support of commercial rockets, the DOD changed its policy and launched a majority of defense satellites aboard single use, expendable launch vehicles, to live out their useful lives and then turn into uncontrolled, potentially hazardous, often expensive pieces of space junk.

The necessary presence of astronauts to fly the Shuttle and repair satellites ultimately became one of the most intransigent obstacles to the paradigm of reuse envisioned as the end goal of the STS. After the Challenger accident in 1986, NASA brought in a committee of engineers, scientists, former astronauts, and administrators to

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<sup>606</sup> McDonald, "Overview of the Report of the Group Task Force on Satellite Rescue and Repair," 9–10.

<sup>607</sup> Roger D. Launius and Dennis R. Jenkins, *To Reach the High Frontier: A History of U.S. Launch Vehicles* (Lexington, KY: University Press of Kentucky, 2002), 393–395.

<sup>608</sup> For full details on space shuttle launch site decisions and the DOD role in sponsoring the California Shuttle launch site, see T. A. Heppenheimer, *The Space Shuttle Decision: NASA's Search for a Reusable Space Vehicle*, 233, 423–427.

review what had gone wrong and make recommendations for how to reduce the risk to astronauts' lives once the Shuttle program went back online. In the comprehensive report delivered by the so-called Robinson Commission, but also in reports written by former astronauts and NASA leadership, the regularity of Shuttle launches received particular attention as an underlying cause of the tragedy. The commission report pointed to the Shuttle's status as the principle launch technology in America as forcing "relentless pressure on NASA to increase the flight rate" that exceeded the resources available to sustain safe operations.<sup>609</sup> One of the results of the Robinson Commission report came about in the revision of the official NASA policy on when to use the space shuttle for satellite launches. The commission recommended that the Shuttle manifest be subjected to strict controls to ensure that those payloads that did not require human tending for mission success would not make the trip to orbit aboard the Shuttle.<sup>610</sup>

The Reagan Administration concurred with this conclusion. The president reversed his 1981 position that the STS be made available to "all authorized space users"<sup>611</sup> in a policy statement decreeing that all commercial payloads would from then on fly into space aboard ELVs. Andrew Butrica has argued that Reagan's early support

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<sup>609</sup> Presidential Commission on the Space Shuttle Challenger Accident, "Report at a Glance," June 6, 1986, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>610</sup> In a brief overview of the larger report, the so-called Rogers Commission argued that NASA and the DOD needed to work together to reduce what they saw as a dangerously over-scheduled Shuttle flight rate—largely wrought by an over-reliance on the Shuttle to deliver payloads rather than relying more regularly on ELVs to do the job when possible. "The nation's reliance on the Shuttle as its principal space launch capability created a relentless pressure on NASA to increase the flight rate. Such reliance on a single launch capability should be avoided in the future. NASA must establish a flight rate that is consistent with its resources. A firm payload assignment policy should be established. The policy should include rigorous controls on cargo manifest changes to limit the pressures such changes exert on schedules and crew training." Ibid.

<sup>611</sup> Reagan Administration, "Space Transportation System."

for the STS program stemmed from an ideology that favored the commercialization and industrialization of space. Even in the immediate aftermath of the Challenger accident, the President urged lawmakers to support the development of the next reusable spacecraft, one that would truly fulfill the airline efficiencies and safety initially desired.<sup>612</sup> However, the president had also furthered policy positions intended to foster private sector development of ELVs as early as 1983.<sup>613</sup> A 1986 policy announcement supported Reagan's proven preference for free enterprise over government spending, couched within appropriately presidential expressions of mourning for lives lost and reassurances against future accidents:

The private sector, with its ingenuity and cost effectiveness, will be playing an increasingly important role in the American space effort. Free enterprise corporations will become a highly competitive method of launching commercial satellites and doing those things which do not require a manned presence in space... The greatest tribute we can pay to those brave pathfinders who gave their lives on the Challenger is to move forward and rededicate ourselves to America's leadership in space.<sup>614</sup>

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<sup>612</sup> Ronald Reagan, "Address Before a Joint Session of Congress on the State of the Union" (State of the Union address, Washington, DC, February 4, 1986), <http://www.presidency.ucsb.edu/ws/?pid=36646>.

<sup>613</sup> Andrew J. Butrica, "The 'Right' Stuff: The Reagan Revolution and the US Space Program," in *Remembering the Space Age*, by Steven J. Dick, vol. 1 (Washington, D.C.: National Aeronautics and Space Administration, 2008), 121–34; "Expendable Launch Vehicles: Presidential Policy Announcement," May 16, 1983, NASA.gov.

<sup>614</sup> "Expendable Launch Vehicles: Presidential Policy Announcement."

A National Security Decision Directive issued by the White House at the end of the year formalized the new requirement that all commercial space users launch payloads aboard ELVs, unless a mission absolutely required the attention of astronauts. This directive pushed the US space industry back in the direction of single-use production that had been the rule since 1958. The tension between the austerity of reuse and the consumption of free market capitalism embraced by Reagan saw an uneasy articulation in the aftermath of the Challenger accident.<sup>615</sup>

The promise of a reuse economy was compromised by the larger-than-expected costs of Shuttle use, but ended definitively with the demise of Challenger and her crew. Saving money or the space environment could not outweigh the risk to human life inherent in each crewed launch. Six weeks after the Challenger accident, veteran astronaut and chief of the astronaut office John Young—who had vigorously campaigned for the SOC as the first Shuttle commander—summarized this accusation in an unintentionally evocative statement that reversed the lofty optimism of Shuttle advocates two decades prior: “Our space shuttle machinery is not airline machinery.”<sup>616</sup> By 1986, the airline-like safety and economy of scale expected in 1968 had clearly not borne out in the American space industry.<sup>617</sup> With the exception of a few necessary payloads, and the

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<sup>615</sup> Donald Worster, “Can History Offer Pathways to Sustainability?”

<sup>616</sup> “John W. Young to Director, Flight Crew Operations,” Memorandum, (March 4, 1986), NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>617</sup> Young was not the first astronaut to speak out about safety problems with the Shuttle; several veteran astronauts provided interviews before the program began expressing concern that a lack of Congressional and presidential support for the Shuttle during its development gave them low confidence in the program as a whole. See for example UPI, “Solitary Contestant Waits for Skylab Piece Prize.”

servicing of the Hubble Space Telescope, NASA returned to its earlier policy of throwing away the equivalent of a 747 jet after each orbital flight.

Of the thousands of satellites launched by America since the start of the space shuttle program in 1981 only 180 were brought into orbit aboard the space shuttle. Only 7 satellites were retrieved from orbit, repaired, and placed back into orbit. Only two were brought back from orbit to be refurbished and reused.<sup>618</sup> Some eight years after the 1984 satellite refurbishment test flights, very few candidates for further repair seemed to be in sight. In 1992, NASA Administrator Daniel Goldin asked his staff to devise clear criteria and pricing for rescues.<sup>619</sup> In the autumn of that year, NASA assembled a Group Task Force on Satellite Rescue and Repair. The group compiled a list of total American satellite failures that took place over the preceding 22 years, and assessed whether these failures might have been corrected by astronaut intervention via the space shuttle. Of 42 satellite failures, the group concluded that 15 could have been salvaged on orbit. 5 failures did benefit from repair missions.<sup>620</sup> Planning and training for the first, unplanned Hubble repair mission took place at the same time that the task force conducted its research and potentially influenced its conclusions. The first Hubble repair mission

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<sup>618</sup> Statistics drawn from a press kit released in advance of the final space shuttle launch in July 2011. In this retrospective on the Shuttle program as a whole, NASA states that 52 total payloads have been returned by the shuttle, including “satellites, space station components.” For the purposes of this paper, I am only counting standalone satellites rather than pieces of the ISS, given the initial hope that satellite salvage would be a primary use of the Space Transportation System, rather than primarily a space station construction vehicle. “STS-135: The Final Mission,” Press Kit (NASA, July 2011), 32, 100.

<sup>619</sup> “Mission Review Group Fact Sheet,” *NASA Facts*, 1992, Satellite Retrieval from Space 20226, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>620</sup> McDonald, “Overview of the Report of the Group Task Force on Satellite Rescue and Repair,” 17.

required nearly three years from initiation to completion—hardly the simplicity and routine access provided by civil aircraft. The group task force used the Intelsat VI repair aboard *Endeavour*'s maiden voyage as a prime example of the overruns that plague planning, training, and funding satellite rescues.<sup>621</sup> The Intelsat rescue demonstrated several discouraging realities: that such repair missions tended to be non-generalizable, requiring highly specific planning and training that could not be extrapolated forward to other rescues; that simulating all contingencies in a microgravity environment could not be fully accomplished on Earth beforehand; and that the difficulty of routinizing rescues and the loss of institutional memory through staff attrition meant that such missions resulted in a net loss of knowledge about how to undertake space operations.<sup>622</sup>

The task force concluded that regular rescue, repair, and salvage of faltering or failed satellites would not be the best use of NASA resources moving forward, particularly given the increased assumption of risk that accompanied each shuttle flight in the immediate post-Challenger years. Even if the occasional satellite commercial customer were to invest in the expensive overhead necessary to man-rate their satellites for future servicing, if the full price of a Shuttle launch were to be considered part of the rescue bill, such a cost would more than cancel out the economic benefit of satellite

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<sup>621</sup> Office of Media Relations, Space Systems Division, "STS-49 Press Information," Press Kit (Rockwell International, May 1992), NASA Johnson Space Center History Portal, [http://www.jsc.nasa.gov/history/shuttle\\_pk/1984.htm](http://www.jsc.nasa.gov/history/shuttle_pk/1984.htm); "Space Shuttle Mission STS-49 Press Kit," Press Kit (NASA, May 1992), NASA Johnson Space Center History Portal, [http://www.jsc.nasa.gov/history/shuttle\\_pk/1984.htm](http://www.jsc.nasa.gov/history/shuttle_pk/1984.htm).

<sup>622</sup> "Report of the Group Task Force on Satellite Rescue and Repair" (Washington, DC: NASA, September 29, 1992), 3, 24–26, Satellite Repair 16204, NASA Headquarters Historical Reference Collection, Washington, DC.



refurbishment.<sup>623</sup> Without a significant customer base willing to commit to sharing the load, such expenditures would fall on the habitually cash-strapped NASA. The task force declined to fully close the door on repair missions, however, particularly given the popularity that such successful missions seemed to generate among American citizens—though they cautioned that the definition of “success” for rescue missions ought to be more carefully communicated to the public to preclude negative publicity should any part of extremely complex repair missions not go perfectly to plan. With this caveat, the task force concluded that only some one percent of total satellites to be launched in the future would be candidates for rescue and repair, and recommended that the majority of satellites should be initially launched via uncrewed rocket rather than investing in a launch via the expensive and risky shuttle.<sup>624</sup>

### **Conclusion: The Future in Reuse**

The hoped-for austerity of reuse proposed and supported by NASA, the Nixon Administration, and others in the aerospace industry failed in an additional respect. With only single-use rockets and satellites that have not been built to be retrievable, the current model of space use has contributed to a mess in orbit that intensifies already considerable technological angular momentum. Although state space programs and private companies have proposed a variety of space debris removal technologies, most suggest novel ways to dispose of technologies at the end of their useful lives. These ideas range from using large nets in orbit to ground-based lasers that can nudge debris into a reentry trajectory.

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<sup>623</sup> Ibid., 4.

<sup>624</sup> Ibid., 1–5.

Some exceptions to this trend exist. DARPA has developed a few theoretical models of flexible spacecraft that can remotely and robotically repurpose old hardware *in situ*.<sup>625</sup> Project Phoenix is currently developing small “satlets” that can be launched to geosynchronous orbit, attach to expensive expired payloads, and commandeer mirrors, antennae, and other features for new uses.<sup>626</sup> The MDA Corp and Vivisat companies are also currently developing satellite-servicing technologies that have been reported as a potential “end to space trash.”<sup>627</sup> A 2013 fuel test aboard the ISS demonstrated that an automated system might be able to revive even those satellites not initially designed to be serviced.<sup>628</sup> Such a technique would remove one component of the technological angular

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<sup>625</sup> Pamela Melroy, “Space Technology Is Changing - How Will Space Policy Change Too?” (Space Policy and History Forum #10, Smithsonian National Air and Space Museum, Washington, DC, December 5, 2013); DARPA tv, *Port of Call at 36,000 Km (DARPA “Wait, What?”)*, 2015, [https://www.youtube.com/watch?v=wYnz4\\_OHks](https://www.youtube.com/watch?v=wYnz4_OHks); Timothy J. Seppala, “DARPA Thinks It Has the Solution to Satellite Longevity,” *Engadget*, March 25, 2016, <https://www.engadget.com/2016/03/25/darpa-rsgs/>; “Darpa Reports Progress on GEO Satellite Recycling Concept,” *Aviation Week Aerospace Daily & Defense Report*, January 25, 2013, Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>626</sup> Graham Warwick and Gary Norris, “Space Salvage,” *Aviation Week & Space Technology*, August 20, 2012, Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.; Graham Warwick, “Orbital Recycling,” *Aviation Week & Space Technology*, February 4, 2013, Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>627</sup> Peter B. de Selding, “Intelsat Signs Up for MDA’s Satellite Refueling Service,” *SpaceNews*, March 18, 2011, <http://spacenews.com/intelsat-signs-mdas-satellite-refueling-service/>; Frank Morring, Jr., “An End To Space Trash?,” *Aviation News Releases Magazine*, March 22, 2011, <http://www.aviationnewsreleases.com/2011/03/end-to-space-trash.html>; Peter B. de Selding, “Satellite Servicing Venture Jockeys for US Government Business,” *Space News*, October 17, 2011, Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.

<sup>628</sup> Stephen Clark, “Satellite Refueling Testbed Completes Demo in Orbit,” *Spaceflight Now*, January 25, 2013, <http://www.spaceflightnow.com/news/n1301/25rrm/#.V2A5BuYrK9a>; Rachel Kraft and Dewayne Washington, “NASA’s Refueling Demonstration Proves Viability of Satellite-Servicing Technologies,” Press Release (Washington, D.C.: NASA, February 8, 2013), Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.; Frank Jr. Morring, “NASA May Test Refueling of Satellites on Space Station,” *Aviation Week*

momentum that plagued the STS program—human risk. The test was conducted under the auspices of the Satellite Servicing Capabilities Office at NASA's Goddard Space Flight Center, the continued existence of which suggests that satellite reuse remains at least a nominal priority at NASA even in the absence of an infrastructure to support such endeavors. Benjamin Reed, the deputy manager of the Goddard program, expressed his belief that the successful experiment signaled an upcoming paradigm shift. "I don't want to sound overly dramatic," he enthused in a NASA TV interview, "but it is, or it might be, the start of what could be a revolution or a new era in how satellites are built and flown in space."<sup>629</sup>

While recycling and reuse programs tend to be a hallmark of austerity at the level of the individual consumer, even civic recycling programs fail when expenses outweigh savings. The American space industry did not differ from local recycling efforts in this sense; much like communities that cease recycling used glass in spite of user desire for such programs, environmental politics or attempts at conservation alone cannot sustain a recycling program that costs more than single-use consumption.<sup>630</sup> However, the attempts by legislators and the space industry to adopt reuse in space appears to have been forgotten by those seeking to replicate it today. For the foreseeable future, however, what

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*Aerospace Daily & Defense Report*, January 12, 2010, Repair in Space 20276, NASA Headquarters Historical Reference Collection, Washington, DC.; NASA Goddard, *NASA | Teaming Up to Test the Future of Satellite Refueling*, accessed March 31, 2016, [https://www.youtube.com/watch?list=PLXzOMEex7adehd9TPi0VkdKwYg8\\_j2QRd&time\\_continue=39&v=CSErB9H5-qY](https://www.youtube.com/watch?list=PLXzOMEex7adehd9TPi0VkdKwYg8_j2QRd&time_continue=39&v=CSErB9H5-qY).

<sup>629</sup> Stephen Clark, "Satellite Refueling Testbed Completes Demo in Orbit."

<sup>630</sup> On the economics of recycling networks, see Finn Arne Jørgensen, *Making a Green Machine: The Infrastructure of Beverage Container Recycling* (Rutgers University Press, 2011); Friedel, "American Bottles"; Zimring, *Cash for Your Trash*.

was then perceived as the most expensive way to deal with broken satellites, namely total replacement, remains the only way to go. Without the ability to repair and salvage, the number of dead spacecraft in orbit continues to grow, to the perennial consternation of many in international space policy circles. Gaining the political capital to foster this shift continues to be as difficult as it was during the 1970s. A group of engineers writing about the history and future prospects of a new reusability paradigm have expressed the hope that current mainstream political attention to recyclability and reusability may yield support for sustainability in outer space, though the trickiness of demonstrating threats to an invisible environment persisted from the early days of mainstream environmentalism through the green politics of the present day.<sup>631</sup>

Since the end of the partially-reusable space shuttle program, NASA has relied upon the Russian space program to provide human spacecraft to bring astronauts to and from the International Space Station. The most recent designs for a next generation crewed vehicle to come out of NASA have returned to an earlier version of a relatively small crew capsule aboard an expendable rocket. The human spacecraft designed by SpaceX, Blue Origin, and Virgin Galactic all fit the definition of “reusable.” However, the latter two are intended only for recreation uses, not research or operations. Arguably, opening space to leisure visitors could be seen as a major step towards the routinization of space as originally envisioned by Nixon and Fletcher, but for a different purpose. The SpaceX Dragon capsule, while intended for flexible use by NASA to conduct a variety of missions, does not have the same capability as the Shuttle to retrieve, repair, and refuel

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<sup>631</sup> Kuczera and Sacher, *Reusable Space Transportation Systems*, 85.

faltering or aging satellites. While much of the rhetoric of the long 1970s initiative to construct and maintain a reusable space infrastructure endures in the current race to a reusable rocket, the end goals set by private aerospace are far narrower than the early design and planning years of the space shuttle and Space Operations Center.

The stark parallels between the post-Apollo era and these most recent stories from the private space sector confirm that private aerospace companies are chasing a white whale that has tormented the American space industry and government for decades. The latest attempt to return to the reuse ethos of the long 1970s American space program has yet to bear out. Both Bezos and Musk have the advantage of not being bound by federal money—and therefore legislative approval—in the same way that NASA answered to Washington in developing the Shuttle. Both have represented reusability and economy as inseparable outcomes in celebrating their technological achievements. And while both CEOs fight for bragging rights, neither can predict whether the economy of scale they anticipate will bear fruit where others have failed. Perhaps most importantly, this latest attempt to forge an era of reusability only addresses waste on the front end, so to speak. Expensive satellites, whether launched on reusable or expendable rockets, still have shelf lives. Rather than repairing, retrieving, refueling, these artifacts either quietly decay in their decaying orbits, or are nudged by nature or automated thrusters into the atmosphere. Once this happens, these multi-million dollar satellites must be replaced *de novo* and at full price in order to prevent a lapse in service.

On the morning of June 19, 2016, Blue Origin relaunched the same New Shepard rocket it sent into suborbital space the preceding November. This would be the rocket's

fourth successful flight and landing.<sup>632</sup> CEO Jeff Bezos provided live commentary through all stages of the eight-minute flight. Upon safe touchdown of both the booster and a test crew module, Bezos signed off with a celebratory comment: "Any day with a rocket landing is a fantastic day."<sup>633</sup> As a rocket intended for suborbital space tourism flights, New Shepard will not contribute to the same sector of the space economy addressed by plans for the space shuttle, Space Tug, SOC, and reparable satellites. However, the aerospace private sector for which Bezos's company is at the vanguard has combined the Reagan call for commercial ELV development with the NASA hope for a reusability economy. Should the success of these new reusable private rockets coincide with future success in automated satellite capture, a second wave of reuse in space may yet succeed. The 1970s dream of making near-Earth space an extension of life on Earth—economically, routinely, and tidily—may be in reach, but without a robust coalition and commitment by all invested space users, such an ethos may yet not be strong enough to counter the previously insurmountable forces of technological angular momentum.

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<sup>632</sup> Stephen Clark, "Blue Origin Flies Reusable Suborbital Rocket for Fourth Time," *Spaceflight Now*, June 19, 2016, <https://spaceflightnow.com/2016/06/19/new-shepard-flight-4/>.

<sup>633</sup> Blue Origin, "Flight 4 Live Webcast," Webcast (West Texas, June 19, 2016), <https://www.blueorigin.com/#youtubeEI-tGVFg7PU>.

## CONCLUSION

Early on the morning of February 1, 2003, the Space Shuttle orbiter *Columbia* turned homeward after nearly sixteen days in orbit. As it began its journey through the upper atmosphere, the protective thermal tiles on the underside of one wing began to crumble.<sup>634</sup> Shortly before 9AM, a final truncated transmission from the mission commander came through to Mission Control in Houston, followed by an eerie silence. Observers outside Dallas, Texas reported hearing a loud series of booms, and watching smoking trails of debris streak through the clear morning sky. By mid-morning, citizens of the small town of Nagadoches, Texas started recovering pieces of charred metal in their backyards, farmlands, parking lots, and roadways. Some residents discovered human remains among the fragments.<sup>635</sup> Moments after crossing through the planetary borderlands, space junk was all that remained of the *Columbia* and her crew of seven.

The venerable vessel performed many firsts in its more than twenty years of service. The first of the shuttle orbiters to fly into space, *Columbia* was also the first

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<sup>634</sup> After a lengthy investigation, it was determined that several pieces of foam had become dislodged from the external tank at launch, falling and hitting the trailing edge of Columbia's left wing and damaging the thermal tiles. The sister tank to the one that doomed Columbia is currently on display at the California Science Center—one of the few remaining artifacts of its kind. "External Tank," *California Science Center*, accessed July 14, 2016, <http://californiasciencecenter.org/exhibits/air-space/space-shuttle-endeavour/external-tank>.

<sup>635</sup> ABC News, "Remains From All Columbia Astronauts Found," *ABC News*, February 2, 2003, <http://abcnews.go.com/US/story?id=90896&page=1>; CNN, "Astronauts' Remains Being Studied," *CNN.com*, February 3, 2003, <http://webcache.googleusercontent.com/search?q=cache:GZwrGMNnsWcJ:www.cnn.com/2003/TECH/space/02/02/shuttle.debris/&num=1&hl=en&gl=us&strip=1&vwsr=0>; David M. Halbinger and Richard A. Oppel Jr, "Loss of the Shuttle: On the Ground"; "First the Air Shook With Sound, And Then Debris Rained Down," *The New York Times*, February 2, 2003, sec. U.S., <http://www.nytimes.com/2003/02/02/us/loss-shuttle-ground-first-air-shook-with-sound-then-debris-rained-down.html>.

airplane-style winged orbital spacecraft, the first spacecraft to fly more than once, and the first to fly using solid rocket fuel. As would be the case for each of the additional four orbiters subsequently built, the new ship received a name that honored a historic sailing vessel. *Columbia* had two namesakes: the first American-built ship to circle the globe, and the Apollo 11 command module that took astronauts to the Moon for the first lunar landing mission.<sup>636</sup> However, the name “Columbia” also unintentionally evokes another dangerous moment of exchange earlier in American history. The Columbian exchange between “old” and “new” worlds transformed peoples, ecosystems, and landscapes previously separated by an uncrossable divide—a moment of exchange that echoed over rural Texas as a technology built to brook safe passage between Earth and space instead brought both environments into perilous, destructive proximity.

In addition to heralding the end of the Space Shuttle program—and with it hopes for safe, routine, and cheap spaceflight that had been in decline since the *Challenger* accident—the *Columbia* disaster serves as a fitting if tragic coda to this environmental history of near-Earth space. When the orbiter transformed from a winged spacecraft to falling space junk, it rendered the space infrastructure visible for a brief, terrifying moment. Texas residents looked into the sky to find something they had not seen before—not the moving star of Sputnik’s rocket nor the friendly twinkle of Echo, but the fiery debris of destroyed machine and human bodies. Instead of pride, fear, or wonder, the pieces of *Columbia* inspired horror and sorrow. Although pieces of debris hit cars and homes, no humans on the ground were harmed—though one news article reported that a

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<sup>636</sup> “Space Shuttle Overview: Columbia (OV-102),” *NASA.gov*, January 31, 2005, [http://www.nasa.gov/centers/kennedy/shuttleoperations/orbiters/columbia\\_info.html](http://www.nasa.gov/centers/kennedy/shuttleoperations/orbiters/columbia_info.html).



Nagodoches farmer spent the afternoon of the accident searching for a dead cow that a neighbor suspected had been struck down by a piece of the orbiter in the second reported but unconfirmed bovine death from falling space hardware.<sup>637</sup> In its final, failed crossing through the planetary borderlands, the *Columbia* transformed from spacecraft to falling space junk, spurring potential legal consequences among the citizens below whose lands and livelihoods may have been threatened by the unexpected, unsanctioned fallout.<sup>638</sup> The survival of nematodes that flew aboard the shuttle as part of an experiment on muscular dystrophy prompted scientists to reaffirm longstanding appeals to police and protect the planetary borderlands against passage by more robust organisms.<sup>639</sup> The *Columbia* accident tragically illustrated the dangerous permeability of the tenuous borderlands between Earth and space. While this region is capable of self-healing and cleaning up human-made messes, the ecosystem of near-Earth space can also cast our creations and our selves back at the ground.

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<sup>637</sup> Toby Harnden, "Searchers Stumble on Human Remains - Telegraph," *The Telegraph*, February 3, 2003, <http://www.telegraph.co.uk/news/worldnews/northamerica/usa/1420965/Searchers-stumble-on-human-remains.html>.

<sup>638</sup> While NASA solicited legal claims from those who may have suffered property loss during the *Columbia* disaster, according to some space law experts a clause of the Liability Convention precludes any recourse should the claimant be a citizen of the launching nation. Andrew W. Murnane and Daniel Inkelas, "Liability Issues Associated with the Space Shuttle Columbia Disaster," CRS Report for Congress (American Law Division, Congressional Research Service, The Library of Congress, February 12, 2003); Charles R. Lucy and Skip Smith, "The Space Shuttle Columbia and the Legal High Frontier: Possible Claims and Defenses," *Proceedings on the Law of Outer Space* 46, no. 1 (2003): 28–36.

<sup>639</sup> Astrobio, "Columbia Survivors," *Astrobiology Magazine*, January 1, 2006, <http://www.astrobio.net/topic/origins/extreme-life/columbia-survivors/>; Cassie Conley, "Foreword," in *When Biospheres Collide: A History of NASA's Planetary Protection Programs*, by Michael Meltzer, vol. NASA SP-2011 4234 (Washington, D.C.: National Aeronautics and Space Administration, 2010).

In his 2004 critique of critique, Bruno Latour points to the *Columbia* accident to demonstrate the catastrophic disbanding of an object into a thing (in the Heideggerian sense of the word). Latour notes the multiple transformations at play when “here, suddenly, in a stroke, an object had become a thing, a matter of fact was considered as a matter of great concern.”<sup>640</sup> Latour describes the perfect mastery of the space shuttle assemblage—an object simultaneously so complex, yet so banal as to have been utterly forgotten by the news media and the American public until it transformed into something else.<sup>641</sup> As part of an invisible space infrastructure and a system of material and capital exchange, the shuttle represented an exemplar of Cronon’s “second nature.” After it transformed into debris, it became a failed piece of infrastructure, no longer invisibly supporting the practices of satellite users but rather raining down on the heads of a small fraction of them.

Ten years after the *Columbia* accident, a major Hollywood movie brought space junk as a bodily hazard back to broad cultural currency. In Alfonso Cuarón’s action thriller *Gravity*, astronauts played by Sandra Bullock and George Clooney discover that a Russian antisatellite mission has accidentally set off a chain reaction of collisions that all but instantaneously destroys the entirety of the satellite infrastructure. While the scenario as presented in the film would be physically impossible in the universe inhabited by the worldwide moviegoing public, it illustrates an extreme, accelerated version of the Kessler syndrome and its potentially disastrous outcomes. The social ramifications of losing all

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<sup>640</sup> Bruno Latour, “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern,” *Critical Inquiry* 30, no. 2 (January 2004): 235, doi:10.1086/421123.

<sup>641</sup> Latour, “Why Has Critique Run out of Steam?”

satellites in the blink of an eye merits only brief mention in the film—instead, Cuarón materializes a space junk crisis in a form far more legible to the average moviegoer. Rather than losing a virtual commodity—information—the swirling space junk that obliterates the fictional space shuttle and non-fictional Hubble Space Telescope featured in the film instead poses a bodily hazard to the astronauts moving through a ruined near-Earth space environment.<sup>642</sup> Loss of life, not loss of information, typifies the plot points of most successful summer action films.

As with the *Columbia* accident, Bruno Latour also responded to *Gravity* as heralding a major transformation. In this case, Latour sees the transformation of perfectly mastered objects into things as indicative of a symbolic turning inward in a moment of global environmental crisis. Even as, once again, human beings turn from objects into things, “debris among the debris” of the international orbital infrastructure, the main tragedy of *Gravity* comes in what it tells us about life on the planet Earth during the Anthropocene. Without outer space as an escape route, the borderlands between Earth and space materialize and constrain humanity within the finite bounds of a shrinking planet.<sup>643</sup> When Sandra Bullock’s character Dr. Ryan Stone utters an angry “I hate space,” she rejects the idealistic American frontierism that sent her into orbit and spends

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<sup>642</sup> In 2014 I published a general audience article that playfully imagines what might have happened on the ground at the moment of satellite infrastructure loss, portrayed as a sequel to *Gravity*. Lisa Ruth Rand, “Gravity, the Sequel: Why the Real Story Would Be on the Ground,” *The Atlantic*, February 28, 2014, <http://www.theatlantic.com/technology/archive/2014/02/-em-gravity-the-sequel-em-why-the-real-story-would-be-on-the-ground/284139/>.

<sup>643</sup> Bruno Latour, “Telling Friends from Foes at the Time of the Anthropocene,” in *The Anthropocene and the Global Environmental Crisis: Rethinking Modernity in a New Epoch*, ed. Clive Hamilton, Francois Gemenne, and Christophe Bonneuil, Routledge Environmental Humanities (New York: Routledge, 2015).

the rest of the film attempting to find safe passage back through the borderlands to the safe embrace of *terra firma*. However, as Latour briefly notes in passing, during the Anthropocene Earth has transformed from a planet bounded by its atmosphere into a “sub-lunar Gaia”—an expanded realm of human activity and human consequences.<sup>644</sup>

In 1997, *Launchspace Magazine* published an article in which an engineer and space policy analyst described recent evasive maneuvers taken by the space shuttle to avoid space junk, describing near-Earth space as a “300-mile deep, omni-directional dump moving at 18,000 mph.” Noting the success that Rachel Carson achieved in spurring social action and legislative attention to chemical pollutants, the author asks: “Why is there no ‘Rachel’ currently calling attention to what’s being done above our atmosphere?”<sup>645</sup>

In terms of cultural visibility, perhaps even the fictional Dr. Ryan Stone of *Gravity* could have fit the bill. Her body, the main victim of space pollutants, provides a somatic grounding for an otherwise illegible environmental threat. However, in expressing her hatred of space, Stone turns back to Earth as a refuge from the collapsed orbital environment. In Latour’s take, this return to a ruined Earth from ruined space signifies a profoundly traumatic, ultimately futile attempt to locate a safe haven in the midst of an unforgiving anthropogenic crisis. Rachel Carson did not abandon the pastoral landscapes threatened by invisible chemical pesticides; she did not respond to a fearful future with expressions of hatred or a turning away, but rather with a concerted effort to

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<sup>644</sup> Latour, “Telling Friends from Foes at the Time of the Anthropocene,” 2.

<sup>645</sup> Robert J. Kuntz, “Where Is RACHEL?,” *Launchspace Magazine*, March 1997, Center Series, Michael Reynolds Files, Box 27, Space Station Orbital Debris, JSC History Collection.

make broadly legible the previously invisible networks of knowledge, power, and capital that made up both the source and possible solution to the perceived environmental crisis.

This dissertation has demonstrated that there have been many would-be Rachels for space, from Carson's time through the present. Their accomplishments have not inspired the same mainstream cultural transformations and concrete changes to relevant sanctioned practices as Carson achieved through the publication of *Silent Spring*. However, the actions of communities of Rachels within specialist and lay communities have influenced the forging of agreements and precedents for how best to manage a global, extraterritorial environment, simultaneously in everyone's backyard and in nobody's backyard—even if no hard and fast rules for debris removal or reduction exist at the international level. For the time being, the orbital infrastructure functions as it should, its invisibility the hallmark of its success. If we have indeed passed the tipping point, however, moments of orbital decay will likely become more common and more visible—either directly in moments like the *Columbia* accident, or in the virtual, incremental diffusion of a once-global world.

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