When the Balloon Goes Up

High-Altitude for Military Application

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The potential for change is much greater than our appetite for it.
—Garry Kasparov

Isaac Newton first theorized in 1687 that a projectile shot with enough force would break free of Earth's gravity, subsequently falling into continuous orbit.[1] It would be over two hundred years before the Soviets would begin to harness this aspect of the space domain theorized by Newton with the first satellite, Sputnik, igniting the space race that produced manned spaceflight and today's ubiquitous orbiting satellite capabilities.

For the United States, conquering the space domain with its own satellites required political will, deliberate

targeted government investment, and incremental technical progress. This same grit and persistence is necessary to master the high-altitude domain with other vehicles adapted to the task. This article characterizes the high-altitude domain, explains recent scientific advances that are finally enabling the technology, and identifies the risks of pursuing high altitude for military use.

The High-Altitude Domain

Also called "near space," high altitude most commonly refers to the upper stratosphere roughly from sixty thousand to one hundred thousand feet above the ground, and there are two starkly different designs competing for dominance: heavier than air (HTA) and lighter than air (LTA).

The HTA crafts are closer to a classic aircraft design, dependent on long wingspans, commensurately long solar arrays, and propellers to maintain sufficient speed to prevent stalling.[2] The LTA design is a balloon-centric vehicle containing an altitude-controlling expansive element (usually helium or hydrogen) that provides lift.

While each design presents unique engineering and operational opportunities, the balloon design is the focus of this essay.[3] Intuitively, balloons at such heights could perform missions such as intelligence, surveillance and reconnaissance, communications, missile warning, and precision navigation and timing. As the space domain becomes increasingly precarious, balloons offer resilience and redundancy against overhead capability shortfalls. In regard to the operational and tactical levels of war, this technology could allow commanders to surge mission-tailored effects on demand, augment network capacity, quickly reconstitute lost assets, and integrate payloads into dedicated mission architectures—and do it at a fraction of the cost of satellites. But while we may have crossed a technological threshold that greatly increases the viability of high-altitude balloons, harnessing the power of this inhospitable domain will depend in part on conquering meteorology and physics.

Perhaps the most important aspect of this domain is that at roughly sixty-five thousand feet there is relatively less wind, which theoretically allows for a platform to maintain semigeosynchronous station keeping (the ability to maintain relative presence at a specific altitude) with minimum energy expenditure. In other words, there is a "sweet spot" in the atmosphere that should allow for long overhead-loitering capability.

But winds are diminished at high altitude, not absent, and as balloons are objects in flight, they are at the mercy of physics and basic aeronautical engineering. The large surface area of these vehicles mean high drag, even in the reduced atmosphere of high altitude. Without active means to resist, the natural tendency for balloons is to move with the prevailing winds. This lack of geostationary presence is their major operational shortcoming. Stratospheric weather is variable, dependent on season and latitude, with some regions being relatively inhospitable to high-altitude operations, especially in certain tumultuous latitudes (such as those above the Balkans and North Korea).[4]

Alas, maintaining relative position against the wind is not the only obstacle high-altitude balloons must overcome. High altitude is fraught with environmental dangers. Surging wind gusts are especially dangerous and can threaten the structural integrity of the craft. Also, elevated ultraviolet (UV) radiation and ozone concentrations at altitude have a tendency to weaken materials, shortening available loiter time.[5] Additionally, severe temperature swings in the stratosphere also impact both the payload and platform operations.

Without the ability to maintain location and overcome the natural forces found at high altitudes, the capability of these platforms to replicate space capabilities is severely limited.

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Previous page: Flying near the edge of space, a NASA Ultra-Long Duration Balloon (*shown*) broke the flight record for duration and distance. The balloon, almost as large as one and one-half football fields, soared for nearly forty-two days, making three orbits around the South Pole. The U.S. military has periodically explored the practicality of employing high-altitude balloons and other similar vehicles for a range of applications including using them as cost-effective platforms to launch other flight vehicles into space. (Artist rendition courtesy of NASA)

Luckily, with new designs and operational techniques, the high-altitude industry seems to be advancing in the face of these inhospitable conditions.

New Advances in High-Altitude Balloons

Significant advances in material science and navigation techniques have invigorated the potential for balloons as a viable military technology. One of the world's most innovative firms, Google, has been developing high-altitude balloon technology to deliver the internet to less-connected regions such as Sri Lanka, Puerto Rico, and parts of South America.[6] Google's high-altitude division, called Loon, also plans on delivering internet access via balloon to Kenya in 2019.[7] Other companies, such as Arizona-based World View, have also made serious advances in high-altitude balloons.[8] Based on the commercial interest alone, the technology should be piquing the U.S. military's interest.

The basics of evaluating high-altitude vehicles are rather straightforward. The engineering requirement is to optimize the trade spaces of size, weight, and power of the platform.[9] The total weight of the platform is linear in terms of the size, which means the heavier the total weight of the system, the larger the balloon needed. In contrast, the platform size is exponential in terms of the altitude desired. In other words, the higher the altitude, the greater the external pressure, and thus the stronger the balloon needs to be (in terms of material, size, and shape).[10] This is why some of these balloons expand to enormous size. For example, while blimps commonly found at sporting events are considered large, the same blimps at high altitude would be massive, some larger than a football field.[11] Again, an increase in overall aircraft weight (platform and payload) causes a linear increase in its volume, but increases in altitude require a corresponding *exponential* increase in volume. So the heavier and higher the balloon, the larger it is.

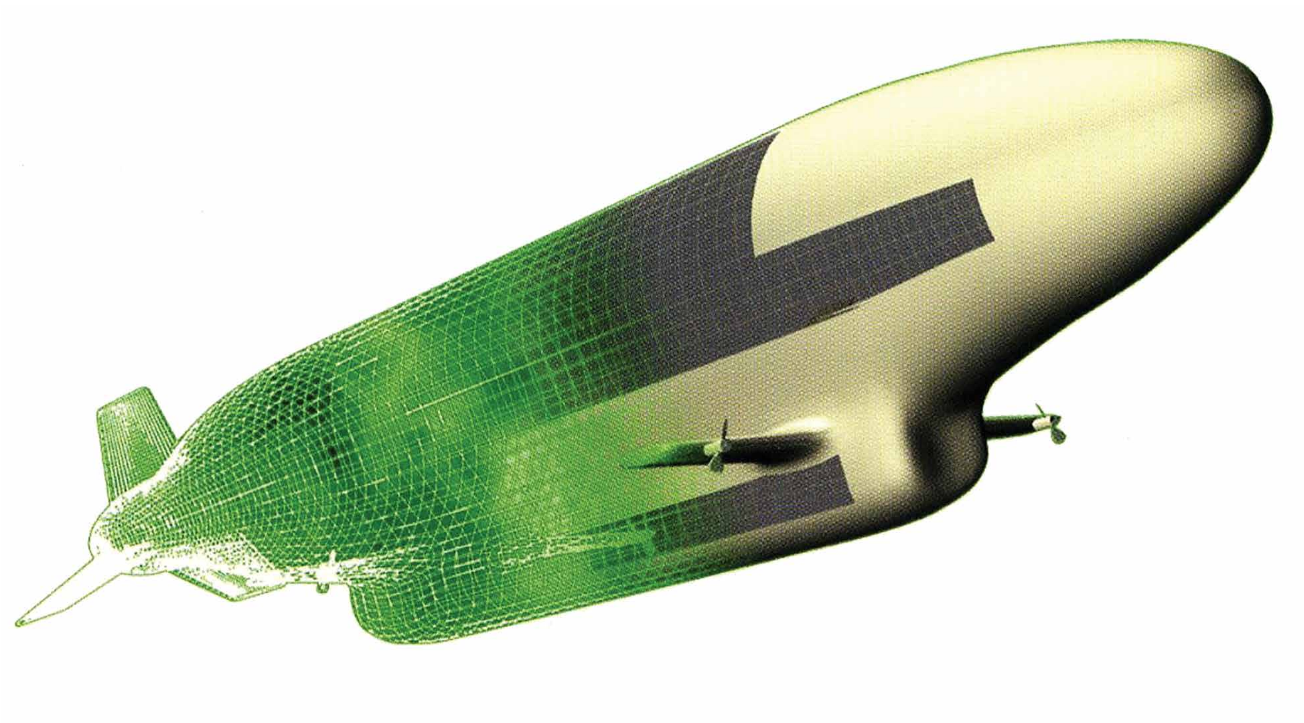
The third major design characteristic is power, and it encompasses both strength and weight. For a majority of high-altitude designs, solar energy is currently the predominant source of power. Unfortunately, available solar energy fluctuates by season and latitude.[12] Throughout the day, the average position of the craft's solar array relative to the sun does not allow for optimal solar collection. Additionally, the weight and size restriction of energy storage systems are limiting. In seasons of favorable solar collection, the added weight of robust energy storage is a liability to the overall system.[13] Solar power technology in the near future is unlikely to be capable of effectively powering the maneuverability of high-altitude aircraft, even in the most favorable range of latitudes and the calmest of seasons.[14] These variations in winds and solar availability are frequently unsynchronized, meaning those times when power is least available may be when it is most needed.

Balloon Construction

Balloons are only as good as the materials that compose them. The state-of-the-art balloon material is an extremely thin and relatively lightweight film of polyurethane blends.[15] Only a few microns thick, these plastics-based materials are able to withstand extreme temperature changes in the stratosphere and the increased solar radiation and ozone effects, all while expanding many multiples of its original (ground level) inflated size.[16] While these balloons have recently maintained altitude for over 180 days, staying aloft is a necessary but insufficient component in providing a useful capability.[17]

To make use of high altitude, it is necessary for these balloons to maintain a presence relative to a location on the earth. The winds in the stratosphere tend to move relatively horizontally and in different directions based on altitude.[18] The ability to change altitudes enables a vehicle to take advantage of this meteorological phenomenon and navigate to maintain a semi-stable presence. Basically, the balloon rises or falls to get into the wind current moving in the desired direction. Current balloon technology accomplishes this change in altitude by increasing or decreasing the balloon's mass by pumping ambient air into and out of a separate section of the balloon called a *ballonet*. At altitude, this minor change in mass causes a corresponding rise or fall in the balloon, enabling it to change direction based on the wind patterns. It follows then that the operational problem now becomes discerning these high-altitude wind directions.

Until recently, science and industry have largely neglected high-altitude weather patterns. Although there has been plenty of scientific examination of the winds and temperature within the stratosphere, the application of these data to balloon maneuvers has not been a major consideration.[19] And although some weather data exists, archival data may be as useful to high-altitude flight as almanacs are to sailing. The extreme variance in stratospheric winds will necessitate more real-time weather



In 2001, the U.S. Army Space and Missile Defense Command began to explore the concept of a lighter-than-air High Altitude Airship (HAA) that could operate for extended periods at an altitude of sixty-five thousand feet. Equipped with an infrared sensor and a steel-track or related radar and data relay equipment, the proposed concept could address both National Reconnaissance Office and ballistic missile defense missions. With a persistent surveillance capability that could range from fifty to four thousand kilometers depending upon the final sensor configuration, the areas of consideration for the unmanned airships ranged from border patrol, counterterrorist, and drug smuggling operations to theater air and missile defense, cruise missile defense, and national missile defense missions. Though a number of tests were conducted to validate the feasibility of the project, the HAA has to date not been built. (Artist rendition of a HAA courtesy of the U.S. Army)

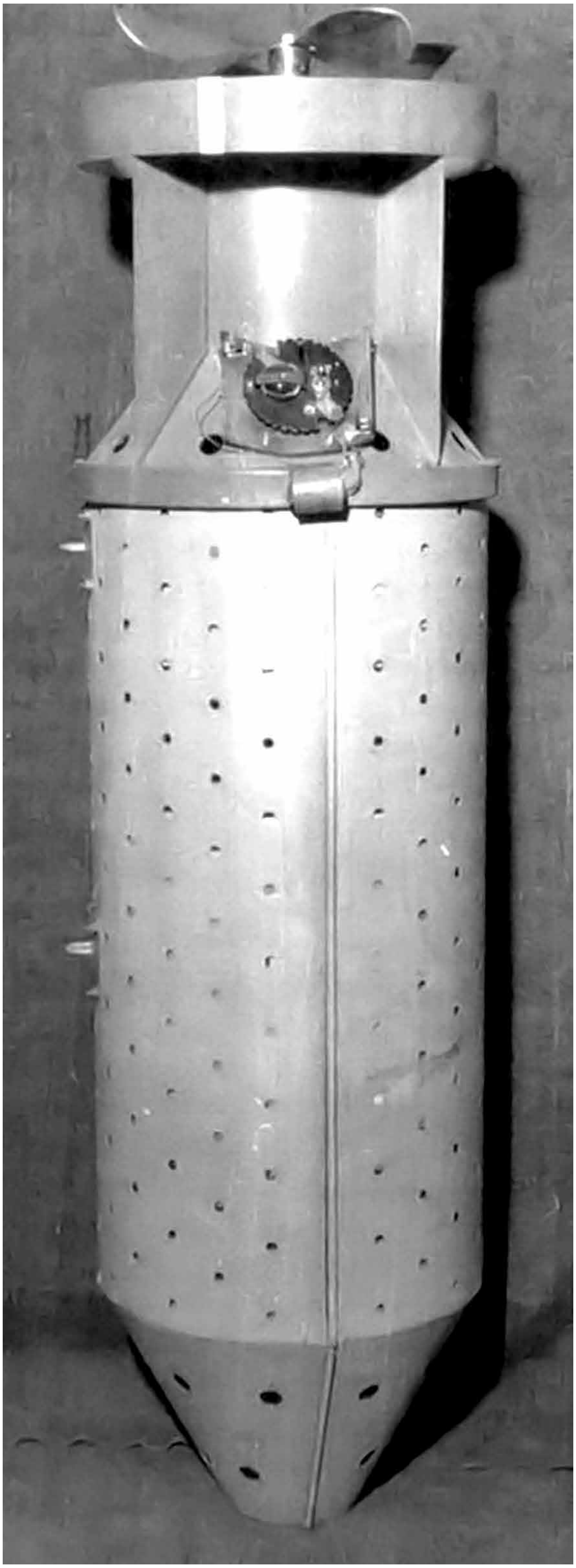
evaluation. In other words, balloon pilots will most likely need to gather a vast majority of wind data during actual operations. The inclusion of new data science techniques, including artificial intelligence and deep learning, may also increase the viability of balloon navigation.

Moving Forward

Like cicadas emerging from hibernation, the scientific community cyclically revives and then summarily dismisses the quest for high altitude. Because the design of this technology encompasses such broad criteria (size, weight, and power), almost any advancement to modern science applies to its development. Consequently, any marked advance in material seems to spur an investigation into the renewed promise of near space. For example, motivated by advances in Kevlar—a lightweight fiber commonly used in body armor—a 1977 U.S. Navy study into high-altitude vehicles determined that advances in "modern materials, structural concepts, methods of analysis, and fabrication techniques will surely make airship structures lighter, stronger, and more efficient."[20]

How can we determine if balloon technology is ready for serious consideration as a viable military technology? New technology is often wrought with information asymmetries (information about the performance of the device or procedure known to only the inventors or developers), the existence of which often makes technology evaluation difficult. One of the fortunate characteristics of high altitude is that the performance criteria are rather straightforward. The vehicle must carry a payload of a specified weight at a certain height, stay aloft for a predetermined amount of time, maintain position relative to a point on the earth, and provide sufficient power to the payload. The vehicle either accomplishes these simple criteria or it does not.

Although the evaluation criteria may be intuitive, the Department of Defense must avoid knee-jerk research funding of extravagant programs, the kind that have



failed extravagantly in the recent past. Periodic resurgence of interest in the high-altitude domain seems to cause periods of irrational exuberance and enthusiastic spending. Convinced that the technology is suddenly viable, government agencies pursue large research-and-development undertakings, and these programs often make unreasonable demands with untested technologies and inexperienced developers, resulting in inevitable failure. These acquisition debacles embarrass the responsible organizations, but even worse, they stagnate high-altitude research-and-development spending.[21]

Perhaps the military needs to start small but continue steadily. For example, the Manhattan Project cost the United States $22 billion in current dollars.[22] At the same time, for roughly $20 million, the military was conducting another secret research project using bats to incinerate Japanese structures.[23] The project called for releasing the bats with tiny incendiary devices attached to their legs over a Japanese city, wherein they would instinctively find refuge in the decorative awnings and structural under-hangings. Once safely ensconced, a timer would detonate the attached devices, burning buildings and consequently the city. The "bat bomb" tests conducted on mock cities were successful, perhaps too successful, as one of the tests almost burned down the historic Carlsbad Army Airfield Base in Carlsbad, New Mexico.[24]

High-altitude balloons are similar to the bat bomb in that they are relatively cheap and effective. But the government must be careful not to incinerate the opportunity to replicate space capabilities just because these balloons are, compared to satellites, inexpensive. In discussion with the author, one high-altitude balloon manufacturer estimated the initial development and operating costs for one balloon at $100,000; compare this to the $1.6 billion each space-based infrared satellite

A "bat bomb" developed circa 1942. The concept called for each canister to hold one thousand bats equipped with small incendiary devices. The bombs, slowed by parachutes, would open at one thousand feet and release the bats, which would seek refuge under wooden building overhangs and covered roof tops in Japanese urban and industrial areas. The incendiary devices would be primed to explode simultaneously, creating thousands of concurrent fires where the bats roosted. Though tested, the bat bombs were never employed outside the United States. (Photo courtesy of the U.S. Army Air Forces) costs.[25] Like the Manhattan Project, a majority of the recent government programs that have attempted to use high altitude have been extravagant, costly undertakings. However, in the near term, these simple balloons present less technical risk, and they may be ready to populate the stratosphere now. If recent civilian operations are telling, these balloons are sufficiently advanced to maintain a long-endurance presence in the stratosphere while carrying and supplying power to a functional payload. As the space domain becomes more difficult to maintain, our government needs a viable alternative. Given the possibility of a much publicized "impending war in space," should the Department of Defense not entertain relatively inexpensive solutions to this space dilemma?[26]

Conclusion

Recent advances in diverse technological frontiers such as materials and information sciences have reignited hope in harnessing the high-altitude domain. But before balloons can supplant satellites, the technology has to overcome some serious limitations. The solution to maintaining balloon presence is mastering the winds. And although balloon navigation is still in its nascent stages, archival data, experimentation, preoperational flights, and predictive algorithms could eventually allow a functional geostationary presence at most latitudes and in most seasons.

Most importantly, our government must avoid wasteful mistakes that tarnish the idea of using high altitude. Past enthusiasm in high altitude has been akin to the clairvoyant financial "guru" who adamantly proclaims that the stock market is going to crash, although history dictates it will crash eventually. Likewise, it is inevitable that technology will eventually enable high-altitude vehicles to replicate much of the current space capabilities. In the future, advanced algorithms, weather sensors, autonomous flight, advanced artificial intelligence, and data science should help improve station keeping and enhance the viability of the balloon concept. But for the military to develop and implement these technologies will require incremental investment, learning, and patience. ■

Notes

Epigraph. Garry Kasparov, *Deep Thinking: Where Machine Intelligence Ends and Human Creativity Begins* (New York: Hachette Book Group, 2017).

1. Isaac Newton, *A Treatise of the System of the World (1728)*, trans. Andrew Motte (Whitefish, MT: Kessinger, 2010), 5. Motte's version is the first English translation of Newton's 1687 publication, *Philosophiæ Naturalis Principia Mathematica*, or *Principia*.

2. Some heavier than air (HTA) designs use hydrogen-powered engines or a hybrid of hydrogen and solar. For examples of HTA craft, see "NASA Armstrong Fact Sheet: Helios Prototype," NASA, 28 February 2015, accessed 7 December 2018, http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-068-DFRC.html; "Phantom Eye," Boeing, accessed 7 December 2018, http://www.boeing.com/defense/phantom-eye; Mark Zuckerburg, "The Technology behind Aquila," Facebook, 21 July 2016, accessed 7 December 2018, http://www.facebook.com/notes/mark-zuckerberg/the-technology-behind-aquila/10153916136506634.

3. Another rising and relevant technology includes nanosatellites, which promise to supplement and complement current on-orbit satellite capability at costs that could be comparable to lighter than air (LTA) platforms.

4. Michael S. Smith, "A New Tool for Estimating Atmospheric Conditions in Four Dimensions" (paper presentation, AIAA [American Institute of Aeronautics and Astronautics] Balloon Systems Conference, Denver, 2017), 3285.

5. Lewis Jamison, Geoffrey S. Sommer, and Isaac R. Porche III, *High-Altitude Airships for the Future Force Army* (Santa Monica, CA: RAND Arroyo Center, 2005); see also Rebecca J. Tobin et al., "Measuring Radiation in the Stratosphere: A High Altitude Balloon Journey" (paper presentation, AIAA Balloon Systems Conference, Denver, 2017), 3788.

6. Uditha Jayasinghe, "Google's 'Project Loon' Balloon Internet Experiment Floats Into Sri Lanka," *The Wall Street Journal* (website), 16 February 2016, accessed 7 December 2018, http://blogs.wsj.com/indiarealtime/2016/02/16/googles-project-loon-balloon-internet-experiment-floats-into-in-sri-lanka.

7. Matt Reynolds, "Facebook and Google's Race to Connect the World is Heating Up," Wired, 26 July 2018, accessed 7 December 2018, https://www.wired.co.uk/article/google-project-loon-balloon-facebook-aquila-internet-africa.

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9. Thomas A. Ozoroski, Craig L. Nickol, and Mark D. Guynn, *High-Altitude Long-Endurance UAV Analysis Model Development and Application Study Comparing Solar Powered Airplane and Airship Station-Keeping Capabilities*, Report 2015-218677 (Hampton, VA: NASA, 2015), accessed 10 December 2018, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150001258.pdf.

10. Jamison, Sommer, and Porche, *High-Altitude Airships*.

11. W. J. Hennigan, "Army Lets Air out of Battlefield Spyship Project," *Los Angeles Times* (website), 23 October 2013, accessed 10 December 2018, http://articles.latimes.com/2013/oct/23/business/la-fi-blimp-fire-sale-20131023.

FUTURE WARFARE WRITING PROGRAM

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Military Review calls for short works of fiction for inclusion in the Army University Press Future Warfare Writing Program (FWWP) for 2019. The purpose of this program is to solicit serious contemplation of possible future scenarios through the medium of fiction in order to anticipate future security requirements. As a result, well-written works of fiction in short-story format with new and fresh insights into the character of possible future martial conflicts and domestic unrest are of special interest. Detailed guidance related to the character of such fiction together with submission guidelines can be found at https://www.armyupress.army.mil/Special-Topics/Future-Warfare-Writing-Program/Future-Warfare-Writing-Program-Submission-Guidelines/. To read previously published FWWP submissions, visit https://www.armyupress.army.mil/Special-Topics/Future-Warfare-Writing-Program/.

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12. David Schmidt et al., "Station-Keeping Performance Analysis of a Notional Airship for Near-Space Application" (paper presentation, SANS [Space and Near-Space] Research Group, University of Colorado at Colorado Springs, CO, 2005).

13. Craig Nickol et al., "High-Altitude Long-Endurance Air Vehicle Analysis of Alternatives and Technology Requirements Development" (paper presentation, 45th AIAA Aerospace Sciences Meeting and Exhibit, Reno, NV, 2007), 1050.

14. Ibid.

15. Jeremy Straub and Ronald Fevig, "Formalizing Mission Analysis and Design Techniques for High Altitude Ballooning" (paper presentation, Proceedings of the 3rd Annual Academic High Altitude Conference, Memphis, TN, 2012). Latex is also one of the possible materials for LTA vehicles, although the industry needs to further investigate the longevity of these balloons in the difficult environment of high altitude.

16. Honglian Zhai and Anthony Euler. "Material Challenges for Lighter-Than-Air Systems in High Altitude Applications" (paper presentation, AIAA 16th Lighter-than-Air Systems Technology Conference and Balloon Systems Conference, Arlington, VA, 2005), 26–28.

17. Dave Lee, "Google Owner Alphabet Balloons Connect Flood-Hit Peru," BBC News, 17 May 2017, accessed 10 August 2018, http://www.bbc.com/news/technology-39944929.

18. James Holton, ed., *The Dynamic Meteorology of the Stratosphere and Mesosphere*, vol. 15 (New York: Springer, 2016).

19. Ibid.

20. Department of the Navy Technical Memorandum VT-TM-1891, "Structures Technology for Lighter-Than-Air Vehicles" (Warminster, PA: Naval Air Development Center, 2 March 1977), 26.

21. Examples of costly government LTA programs include the Long Endurance Multi-Intelligence Vehicle (LEMV) program and the Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System (JLENS) program.

22. Both the Manhattan and "bat bomb" project figures are in 2008 dollars; Deborah D. Stine, *The Manhattan Project, the Apollo Program, and Federal Energy Technology R & D Programs: A Comparative Analysis* (Washington, DC: Congressional Research Service, Library of Congress, 2008).

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26. Emily Taft, "Outer Space: The Final Frontier or the Final Battlefield?," *Duke Law & Technology Review* 15 (2017): 362.