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High Altitude Pseudo-Satellites

A Technology Primer

BY PEDRO JUNIOR VICENTE VALDEZ AND PAULINA WHEELER

TYPE Unmanned Aerial Vehicle (UAV)	**CHARACTERISTICS** Speed, Vantage, Persistence, Precision, Resilient/Reliable	**RISK FACTORS** Predictive, Preemptive, Dual-Use
DOMAIN Air	**COUNTRY** United States	

Introduction

Over the last 60 years,[1] government and the private sector have made significant progress in different types of aerospace technologies, including the areas of operation, payloads, and capabilities. This primer focuses on multi-mission military unmanned High Altitude Pseudo-Satellites (HAPS). HAPS fill an existing gap between lower-altitude UAVs and conventional satellites that are unable to loiter in place, and have applications that include reconnaissance, damage assessment, and remote sensing.[2] Pseudo-satellites are high-altitude air vehicles or airships characterized by their ability to both maintain a fixed position over a single area of interest for extended periods of time (with time horizons in the days and weeks). HAPS provide multiple payload capabilities (within the size, weight, and power limitations of the platform).[3] Long endurance and fixed positioning mean that pseudo-satellites provide flexible and persistent ISR capabilities that satellite systems cannot provide. HAPS are designed to fly above commercial air traffic at altitudes of approximately 65,000 feet, or 20km. This altitude, referred to as the stratosphere, is high enough for sensor payloads to cover areas of interest without interfering with commercial aviation.[4]

The most common type of HAPS platforms are forms of unmanned airplanes, airships, and balloons, and as such have low mass and high surface area.[5] These characteristics make it possible for a single HAPS,

[1] The launching of USSR's Sputnik 1 in 1957 marked the start of the Space Age.

[2] Benkuan Wang, Datong Liu, Wenjuan Wang, and Xiyuan Peng, "A hybrid approach for UAV flight data estimation and prediction based on flight mode recognition," Microelectronics Reliability84 (March 2018): 253–262, https://doi.org/10.1016/j.microrel.2018.03.032.

[3] Anthony Colozza, "Initial Feasibility Assessment of a High Altitude Long Endurance Airship," NASA Cent. Aerosp. Inf, December 1, 2003, https://ntrs.nasa.gov/search.jsp?R=20040021326.

[4] David Grace and Michael Mohoric, "Broadband Communications via High-Altitude Platforms," 2010.

[5] Mark Altaweel, "High Altitude Pseudo-Satellites," GIS Lounge, February 22, 2018. https://www.gislounge.com/high-altitude-pseudo-satellites/; Jesús Gonzalo, Deibi López, Diego Domínguez, Adrían García, and Alberto Escapa, "On the capabilities and limitations of high-altitude pseudo-satellites," Prog. Aerosp. Sci. 1–20 (2018).

depending on model and type, to carry up to several hundred kilograms of equipment and provide up to 800 watts of constant power.[6] This means that it is possible for HAPS to carry anything from imagers, voice and data communications, to radio detection and ranging (RADAR), light imaging detection and ranging (LIDAR), and electronic support measure/electronic intelligence (ESM/ELINT) payloads.[7] These technologies, leveraged on a high-altitude platform, enable monitoring of an area without putting the platform directly over it, allowing for less intrusive spying.

HAPS systems remain experimental, but advancements in structural materials and solar panel technologies have led to recent advances. The Airbus Zephyr, a solar-powered aircraft with a design and function similar to a UAV, set a continuous flight record of more than two weeks in 2010.[8] The Zephyr system has already been tested with high-resolution imagery and video equipment with up to 15 cm resolution with a 400 km sight horizon, and with communications payloads with coverage up to 1,000 square kilometers.[9] Although most of the existing and proposed HAPS systems are designed and built to operate under solar power, there are a variety of systems being developed by other companies that use other fuel types. For example, Boeing's Phantom Eye uses liquid hydrogen to power flight.

HAPS can provide capabilities and services that complement or in some cases replace those offered by airplanes, satellites, and terrestrial networks.[10] These capabilities can be divided into telecommunications, Earth Observations, GNSS (Global Navigation Satellite System), or scientific applications.[11] In terms of telecommunications, HAPS platforms offer several advantages over satellites, including faster deployment and flexibility. Since these systems can be brought back to the ground and deployed again, their payloads are upgradable and even replaceable without the need to build a new HAPS system. Furthermore, shorter distances from HAPS platforms to the Earth's surface (relative to satellites) reduces latency (the delay between input to system output) to levels similar to terrestrial networks (around 0.26 ms vs 30 ms for LEO satellites and 250 ms for GEO satellites).[12]

Theoretically, HAPS platforms will require fewer system operators and will cost less to deploy than a satellite or less to fly over long periods of time than a conventional UAV. Several factors account for these estimated cost savings: the system is completely autonomous in its operation (including flight and power management); it does not need rockets to place the vehicle into orbit (e.g., the Zephyr system is a lightweight carbon fiber, launch-by-hand system); it does not need radiation-hardened electronics (since systems operate within the atmosphere); some do not have fuel costs (because of the use of solar energy); and it carries terrestrial payload technology that has already been developed (contrary to satellites which need special equipment). However, these

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[6] Ibid.

[7] "Airbus Zephyr Solar High Altitude Pseudo-Satellite Flies for Longer than Any Other Air-craft during Its Successful Maiden Flight," Airbus Defense and Space, August 8, 2018. https://www.airbus.com/newsroom/press-releases/en/2018/08/Airbus-Zephyr-Solar-High-Altitude-Pseudo-Satellite-flies-for-longer-than-any-other-aircraft.html.

[8] "High-flying Bird: Zephyr Remains in the Vanguard of Solar-powered Flight," Jane's International Defense Review, 2017, https://www.janes.com/images/assets/459/72459/High-flying_bird_Zephyr_remains_in_the_vanguard_of_solar-powered_flight.pdf.

[9] "Airbus Zephyr Solar High Altitude Pseudo-Satellite Flies for Longer than Any Other Air-craft during Its Successful Maiden Flight," Airbus Defense and Space.

[10] Kendall Russell, "High-Altitude Pseudo Satellite Market to Grow 15% Over 5 Years," Via Satellite, October 9, 2017, https://www.satellitetoday.com/innovation/2017/10/09/high-altitude-pseudo-satellite-market-grow-15-5-years/.

[11] Classification according to: Gonzalo et al., "On the capabilities and limitations of high altitude pseudo-satellites." Progress in Aerospace Sciences 98 (2018): 37-56.

[12] For a definition of latency, see: Margaret Rouse, "Latency," WhatIs.com, https://whatis.techtarget.com/definition/latency; Phillip Olla (ed.), Space technologies for the benefit of human society and earth (Springer Science & Business Media, 2009).

estimated cost savings will likely be offset by production costs during the initial development and deployment of these exquisite HAPS systems. Moreover, most of these cost savings are largely predicated on the HAPS systems being able to achieve extremely long endurance flights, in the scale of one or two years, which is not yet feasible.

State of Play

Thus far, HAPS technology for continuous monitoring has been demonstrated in the prototype phase and a number of companies are now fulfilling orders to manufacture, mainly from the defense industry. For example, Airbus Zephyr, whose system has already gained military and commercial flight clearance, received orders for three HAPS systems from the UK Ministry of Defense in 2016.[13] In July 2018, Airbus Zephyr conducted a successful full-scale test, breaking the record for longest continuous unfueled flight at just under 26 days (this is about 18 times longer than the Global Hawk's continuous flight record, and about five times longer than that of Vanilla VA001).[14] This comes as an indication of technology readiness for the Zephyr system. It will not be long before this and other HAPS platforms are used around the globe for commercial and military applications. Because of all the potential applications of HAPS, interest from several companies and governmental organizations has risen over recent years. Airbus, Boeing, Thales, Lockheed Martin, Tao Group, Alta Devices, RosAeroSystems, and Northrop Grumman are some of the primary companies pursuing active ventures in this type of platform (see Table 1).

Solar Airplanes Project Name	Status	Solar Airship Project Name	Status
NASA HELIOS	Inactive	**US Army HISENTINEL**	Inactive
KARI EAV-3	Active	**JAXA SPF**	Active
Facebook AQUILA	Active	**KARI KSAP**	Active
Airbus ZEPHYR	Active	**US Army HAA**	Inactive
CAAA CH-4	Active	**Thales STRATOBUS**	Active

Table 1. Status on several Airplanes and Airship projects.[15]

[13] "United Kingdom orders additional Zephyr," Airbus Defense and Space, August 18, 2016, https://www.airbus.com/newsroom/press-releases/en/2016/08/united-kingdom-orders-additional-zephyr.html.

[14] "Airbus Zephyr Solar High Altitude Pseudo-Satellite Flies for Longer than Any Other Air-craft during Its Successful Maiden Flight," Airbus Defense and Space. For more information about Global Hawk and Vanilla VA001 flight times, see: "RQ-a Global Hawk," U.S. Air Force, October 27, 2014, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104516/rq-4-global-hawk/; David Szondy, "Vanilla VA001 sets new drone endurance record after five days aloft," New Atlas, October 28, 2017, https://newatlas.com/vanilla-va001-record/51952/.

[15] Gonzalo et al., "On the capabilities and limitations of high altitude pseudo-satellites."

HAPS can theoretically operate at a low cost because of their lightweight low-cost propulsion systems and ability to meet payload energy requirements with solar technology. HAPS systems are projected to be up to two orders of magnitude cheaper than conventional satellites. This is largely because of the launch system (carrier rockets are not required) and the electronics platform (radiation-hardened technologies are not needed). Furthermore, HAPS platforms can provide cost savings because they are easy to retrieve, repair, and re-equip for different missions.

According to several market research agencies, the market for HAPS systems can reach revenues of $1 billion each year toward 2020, with a targeted annual growth rate of 12 percent from 2020 to 2030.[16]

Effects on Situational Awareness

HAPs have the potential to fill a void between the situational awareness capabilities currently provided by satellites and UAVs. Satellites are nonintrusive and can provide information about large geographic areas. However, they cannot provide information continuously because they are limited to collecting high-quality information during "usable passes" over the target of interest.[17] UAVs can provide more persistent and higher resolution coverage of a target within their fuel limitations, but most are easily detectable and intrusive.

HAPS can improve on satellite surveillance by increasing the speed[18] with which information is transmitted to analysts or operators. Satellites experience a propagation delay—a signal delay because of the distance it must travel.[19] Because they operate at lower altitudes, within the stratosphere, HAPS experience shorter propagation delay. As such, HAPS platforms can contribute to real-time mapping, communication, and surveillance. HAPS improve on drone capabilities primarily by increasing endurance and thus persistence. Drones have much shorter maximum flight times, with the maximum flight time of individual systems more dependent upon battery or fuel systems as opposed to HAPS systems that rely primarily on solar power.

HAPS also improve situational awareness by providing a different vantage from which to surveil adversaries. HAPS platforms' high altitude provides a greater slant range, allowing them to collect information on a target without having to be directly over it and could potentially surveil another country from outside its borders. For example, Zephyr can capture images of objects up to 35 km away, and radar returns of objects up to 70 km away. It can scan the horizon up to 400 km away.[20] Furthermore, HAPS systems can provide imagery, video,

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[16] "High-Altitude Pseudo Satellites (HAPS) - Global Market Outlook 2017-2023," Cision PR Newswire, October 3, 2017, https://www.prnewswire.com/news-releases/high-altitude-pseudo-satellites-haps---global-market-outlook-2017-2023-300530083.html.

[17] Keir Lieber and Daryl Press define a "usable pass" to be any pass of a satellite over a target area where the angle of incidence between the satellite and the target area is between 22 and 74 degrees. This angle of incidence would allow a satellite to provide 90 percent coverage of the target area. Satellite passes outside of this angle of incidence could still provide information, but with a diminishing amount of coverage. See Keir Lieber and Daryl Press, "Appendix for Keir A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," International Security Vol. 41 No. 4 (Spring 2017), 9-4." Harvard Dataverse, V1, https://doi.org/10.7910/DVN/NKZJVT, 8.

[18] To learn how this project defines the term speed, please visit the On the Radar website glossary, https://ontheradar.csis.org/glossary.

[19] Zixuan Zheng, Jian Guo, and Eberhard Gill, "Onboard mission allocation for multi-satellite system in limited communication environment," Aerospace Science and Technology 79 (2018): 174–186, https://doi.org/10.1016/j.ast.2018.05.022.

[20] All three distances are measured along the ground from the point directly beneath the HAPS to the location of the target. See: "Airbus Zephyr: Unique Contribution to Decision Superiority," Airbus Defence and Space, 2017,

and communication in geographical areas where the terrain normally interferes with conventional equipment (e.g., mountain regions in Afghanistan) or in rural areas where communication infrastructure is lacking, resulting in enhanced global ISR.[21]

Generally speaking, these systems are detectable—especially when fixed for extended periods of time—but this attribute greatly depends on the specific HAPS technology. For instance, earlier Zephyr models were transparent, which made it more difficult for forces on the ground to spot the HAPS. However, most HAPS systems would be easily detected by ground-based radar. The detectability of a HAPS also depends on the type of sensor or sensors it is equipped with. Active sensors, such as radar, can be identified by an adversary because of the signal it transmits; passive sensors, such as EO/IR cameras, are unable to be identified by an adversary.

HAPS also can increase the resiliency of the U.S. communications, command, control, computers, intelligence, surveillance, and reconnaissance (C4ISR) architecture. HAPS can provide the same capabilities as satellites but can more easily avoid adversary attempts to destroy or disable them because they can quickly be moved. If U.S. satellites were targeted during a conflict, HAPS could help fill the gap. Furthermore, deploying HAPS could discourage adversaries from targeting satellites in the first place because doing so would not significantly hinder U.S. C4ISR capabilities.

Overall, HAPS systems provide services at significant altitude for payloads to cover an area of interest and with enough endurance to provide continuous information. HAPS systems can be used to monitor air space (e.g., air traffic, missile defense and tracking), land (e.g., high resolution imagery and video of adversary forces and nuclear facilities), sea (e.g., tracking piracy and maritime border control), and cyber (e.g., bringing communications like internet connectivity to forces deployed in rural areas).[22] Employing HAPS systems will not only increase situational awareness; it also will enable faster responses by government agencies in emergency management scenarios.

Impact on Strategic Stability

HAPS provide resilient, persistent, and *precise* surveillance capabilities with broad geographic coverage that may allow countries to significantly improve their situational awareness. The ability to have persistent ISR capabilities at any fixed point, however, may be perceived to reduce the survivability of an adversary's strategic assets and thus decrease strategic stability. For example, North Korea or China could find persistent surveillance of their mobile missiles very threatening, causing them to use these assets early in a crisis or change their force posture. On the other hand, a state's knowledge that it is being surveilled may deter it from attacking, which would be stabilizing.

Furthermore, HAPS ability to enhance predictive situational awareness may have implications for stability. Having persistent surveillance on any area of interest means that a country can predict, with high confidence, adversary actions or movements. Access to platforms like HAPS can provide information that otherwise would not be available because of the constraints of other monitoring technologies (e.g., satellites are not able to maintain a fixed position and UAV have limited endurance causing intermittence on its ISR information). This

https://www.airbus.com/content/dam/corporate-topics/publications/brochures/0612_17_zephyr_datasheet_e_horizontal_a4_lowres.pdf.

[21] AIRBUS Defence & Space. Zephyr Focus of an aircraft. Endurance of a satellite. (2017).

[22] Fightersweep staff, "Airbus Zephyr Solar Powered Aircraft Purchased by British Defence Military," January 31, 2017, https://fightersweep.com/6946/airbus-zephyr-solar-powered-aircraft-purchased-british-defence-ministry/.

type of highly confident, uninterrupted monitoring information also potentially allows for preemptive reactions to adversaries' actions (e.g., ballistic missile launch detection). Although potentially desirable, predictive situational awareness is not conducive to stability, since an act of preemptive defense toward an adversary may be perceived as an attack and cause escalation. HAPS systems could be intrusive depending on how they are employed. Because of their high altitude, HAPS can theoretically collect information about an adversary without entering its airspace. Used this way, HAPS systems would be particularly effective for surveilling smaller countries that cannot use their geographical depth to protect sensitive military assets from surveillance. However, if a country wanted to use a HAPS to collect information in the interior of a larger country, it would have to deploy the HAPS within adversary airspace. However, even when operating in adversary airspace, HAPS may be perceived to be less intrusive (compared to low- or even medium-altitude aircrafts) because of their high altitude.

As mentioned before, HAPS are dual-use platforms that surveil both conventional and strategic targets. HAPS can provide different services that can complement, compete with, or replace those offered by airplanes, satellites, and terrestrial networks in both military and civilian scenarios.

HAPS is not a clandestine capability. As mentioned previously, adversaries would be able to detect HAPS systems using radar or if the HAPS platform was equipped with active sensors. In the case of detection, the system and information are at risk of being compromised, which can leave the system vulnerable to anti-aircraft weapons or jamming.

Conclusion: Risks Versus Reward

Reliable, redundant, and resilient information gathering and communication capabilities are high priorities for providing situational awareness. HAPS systems are close to becoming operational given the level of technological maturity achieved in terms of materials, solar panel efficiency, energy storage technologies, and propulsion systems. However, before implementing this technology, decisionmakers should consider the potential impact of HAPS use on situational awareness and strategic stability.

M.R. Endsley's definition of situational awareness includes three layers: the perception of elements in a current situation, comprehension of these elements, and the projection of future status.[23] For the user, HAPS system capabilities enhance each of these three layers by providing uninterrupted ISR information. However, when these systems are detected by adversary forces, then tensions between the spying and the spied-upon party may increase, affecting the escalation ladder and even the existent deterrence calculus. This is similar to the stability risks posed by UAV systems.

It is also worth noting that the impact of HAPS on strategic stability will be greatly influenced by the payload with which a HAPS system is equipped. Although there are no disclosed efforts to weaponize HAPS platforms in the open source, there exists the potential for adversaries to misperceive the mission of the platform.

[23] Mica R. Endsley, "Situation awareness misconceptions and misunderstandings," Journal of Cognitive Engineering and Decision Making, 9(1), 2015, 4–32. https://doi.org/10.1177/1555343415572631.

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