The HAP Shack: An Investigation into the Infrastructure Necessary to Commercially Operate High Altitude Long Endurance Uncrewed Aerial Systems

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The commercial aviation industry devotes an enormous amount of energy into the logistics of their operations and ground activities. In the case of HAPS, the proposed vehicles have enormous wing spans comparable to passenger jets, but due to endurance goals, will be extremely light and comparatively delicate. This requires more thought on the types of facilities necessary to launch, recover, and maintain these drones. More than the facilities are the systems of personnel, ground support equipment and tools needed to actually conduct the maintenance. These systems will also require pilots and dedicated command and control infrastructure on the ground for some portion of their missions. HAPS operations have been reserved for bespoke research missions, but what is required when HAPS reaches Technology Readiness Level (TRL) 9? What logistics networks will need to exist when HAPS go from exotic one-off flights to perpetually orbiting above? Commercial HAPS performing imaging missions in the United States of either 1 week, 3 months, or 1 year duration will require a system of systems of support infrastructure and personnel, otherwise known as a HAP Shack.

The HAP Shack requirements outline the key requirements in terms of covering its location, operational capabilities, facilities, and personnel. These requirements were constructed using a mixture of current FAA requirements, UAS historical data, and regulatory studies with the goal of making the most flexible and effective HAP Shack possible. The location must be road accessible and situated in sparsely populated areas to facilitate launch and recovery operations, with additional emphasis on avoiding restricted airspace. Operational capabilities include enabling launch and recovery operations, maintaining line-of-sight communications during operations, and providing support for vehicle systems. Facilities must meet stringent standards for ground station certification and include provisions for assembly/disassembly, climate-controlled storage, security, and rest areas for pilots. Personnel requirements encompass certified UAS pilots, maintainers with relevant certifications, ground personnel familiar with HAPS systems, and analysts for mission support. All personnel must be US citizens with some having the capability of obtaining security clearances, facilitating potential government contracts.

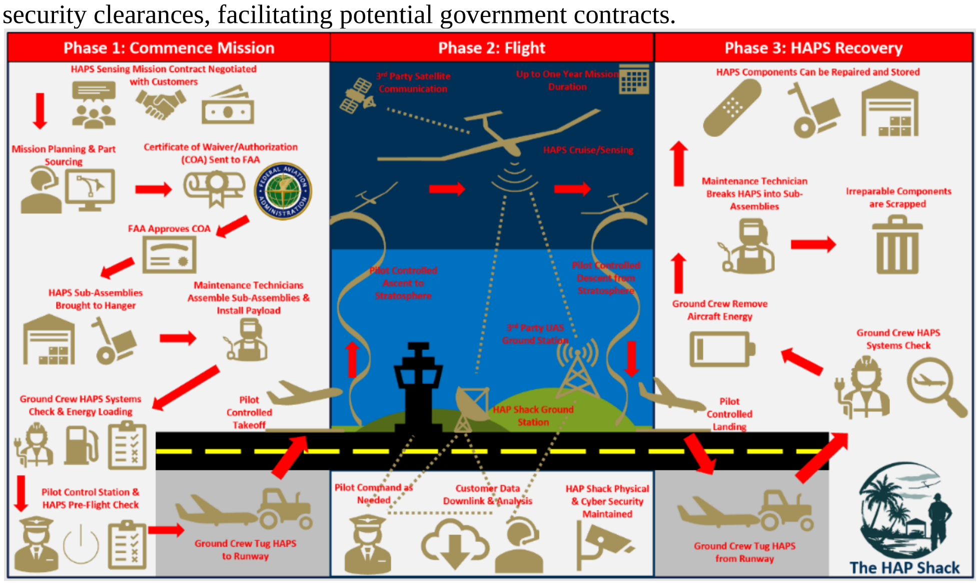

Figure 1. HAP Shack CONOPs

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For a future HAP Shack, 3 distinct phases in the CONOPs were conceived in this study. Phase 1 of the HAP Shack mission involves customer engagement and mission planning, requiring coordination with the FAA for regulatory approval. Assembling the HAPS just in time for flight optimizes hanger ownership and reduces operational overhead, allowing for flexible leasing arrangements and cost-effective maintenance strategies. Once fully assembled, the HAPS undergoes system verification testing before launch, with pilots interfacing with air traffic control and ground crew for final preparations. Phase 2, the flight stage, entails launch/recovery procedures, communication network transitions, and mission operations in the stratosphere, including data transmission and pilot rotations. Phase 3 focuses on HAPS recovery, assuming landing at the departure facility unless alternative options prove more economical. Recovery efforts prioritize safety and include thorough maintenance inspections, with decisions made regarding potential repairs or upgrades based on cost-effectiveness and mission readiness.

With the requirements and CONOPS in hand, the rest of the research focused on optimizing the physical location of a HAP Shack in the United States. The Shack Selector tool considered state taxes, disruptive and extreme weather, population density, airport performance, and runway infrastructure conditions. Additionally, the study included each state's perceived readiness for UAS operations in terms of jobs, if there were any UAS sandboxes available, and if the state had task forces formed to help ease UAS legislation. This criterion was all equally weighted and then applied to the 8,000 DOT tracked runways in the US. Around 2,000 airports met all the HAPS requirements and the overall best airport for a HAP Shack was determined to be ELY in Nevada. This airport performed well due to its mild weather, high state readiness for drones, sparse population, and state taxes. ELY is also a glider hub, near US military airspace for potential special testing, and offers affordable leasing terms. Beyond ELY, California and Washington state stood out as states with many top contender airports and legacy aerospace facilities that could provide the contract workforce needed to sustain HAPS.

One of the biggest impacts on HAPS Operations will be having to submit a COA for every mission with the mission details laid out explicitly. Comparing the maintenance program of a HAPS to a typical commercial airline or even a small UAS does not seem to bring much value. HAPS maintenance programs/component life limits will need to be built up from operational experience and component testing or the HAPS will have to be considered attritable after a year of high-altitude UV exposure. The HAP Shack will likely only require a single pilot working at a time, with a group of pilots sufficient to cover 24/7 operations, and 24/7 security. The security can be outsourced or perhaps the airport's own security would be sufficient for HAPS' needs. Pilots cross-trained as analysts would allow the HAPS staff to be further streamlined and give the pilots a variety of work. It is important to note that one HAPS pilot will likely be able to manage multiple HAPS in the cruise portion of their missions. It is really the launch and recovery that becomes personnel intensive. A pilot may need to be solely focused on HAPS launch/recovery and ground staff could be contracted to support each launch/recovery. Maintenance personnel could also be contracted on as needed to assemble and repair HAPS or shared with another company at the HAP Shack airport. The cost of acquiring, certifying, inspecting, and maintaining all the HAP Shack Power, Communication, and Control equipment will be substantial, but require deeper study.

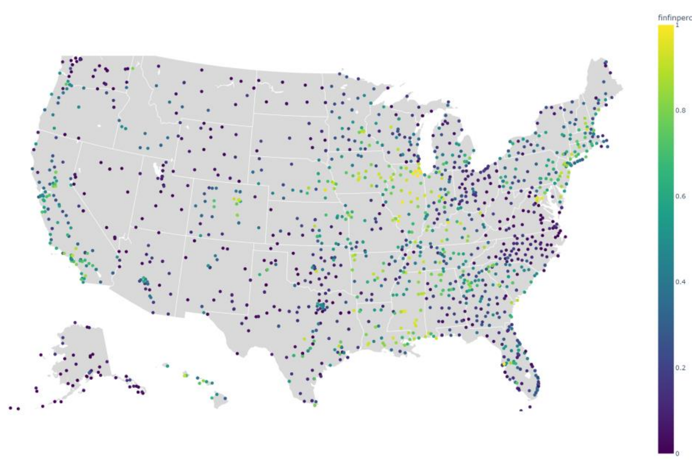

Figure 2. Best Airports in the U.S. for a HAP Shack (lower scores/darker colors indicate better suited airports.

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The HAPS Shack: An Investigation into the Infrastructure Necessary to Commercially Operate High Altitude Long Endurance Uncrewed Aerial Systems

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Commercial High Altitude Platform Stations (HAPS) have diverse applications in surveillance, communication, and environmental monitoring. While there have been decades of military and research missions with HAPS, there have yet to be reoccurring commercial operations. Many companies and academia are focused on the design of HAPS vehicles, but the key enabler to commercial operations will be the supporting infrastructure. The HAP Shack is a literature study to develop the requirements for personnel, equipment, infrastructure, and communications governing a commercial HAPS airport. The HAP Shack will then couple developed requirements with evaluation criteria and open-source data to create a data visualization dashboard to determine the optimal location for a HAP Shack in the United States.

Nomenclature

ARC = FAA's BVLOS Advisory and Rulemaking Committee
ATC = Air Traffic Control
BVLOS = Beyond Visual Line of Sight
COA = Certificate Of waiver Application
DoT = U.S. Department of Transportation
FAA = Federal Aviation Administration
HAPS = High Altitude Platform Station
LOS = Line of Sight
TRL = Technology Readiness Level
UAS = Uncrewed Aerial System

I. Introduction

The past decade has seen an explosion of commercial uncrewed systems, or drone, activity. Higher charge density batteries, lightweight powerful processors, and material advancements have fueled technological progress. Once reserved for hobbyists, researchers, and the military, an unimaginable number of businesses are trying to enable commercial operations of everything from burrito delivery to apple picking with drones. In turn, many countries are developing new regulations to support autonomous, beyond visual line of site, or extreme high altitude drone operations [1]. Companies such as Google, airbus, and BAE are looking to blur the line between aircraft and satellite with a new vehicle class: High Altitude Platform Stations (HAPS) as in Figure 3. These vehicles are uncrewed, intended to fly in the stratosphere, utilizing solar power to enable extremely long duration missions. This is made possible by high aspect ratio wings with lightweight high efficiency solar panels [2]. Some of the most popular proposed missions are for these vehicles to serve as communications relays, weather monitoring stations, or in earth imaging roles.

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Figure 3. BAE HAPS 'Phasa 1' flew for the first time beyond 66,000ft. in October 2023 [1]. This is a technology demonstrator and BAE has been working on this particular model since 2018.

Imagine you are sitting in the window seat of a Boeing 787 at ATL waiting for takeoff. Looking to the tarmac, you will see it is abuzz with fuel trucks, luggage trains, taxiing aircraft and support personnel. But that is only what you can see from your seat. The aircraft you are flying on is a complex machine of millions of components that depend on rigorous maintenance procedures, global supply chains, and dedicated facilities to ensure cost effective operations. Everyone from the pilots to the cabin crew to the engine mechanic will have a minimum required set of certifications set out by the FAA. Commercial aviation has managed to bring the time between flights to minutes at an affordable cost because they have developed detailed sets of requirements governing their operations. Fulfilling these requirements takes 10% to 14% of an airline's operating cost and results in a $100 Billion per year market. [3,4]

While there has been a lot of excitement and research around the design, missions, and manufacturing of uncrewed systems, there has been comparatively little around the ground logistics of such systems. Some smaller drones are intended to be attributable, and can thus ignore the rest of this research, but that is unlikely for HAPS. For the focus of this research, our sponsor ---------- has provided some requirements, rough outlines for what their intended HAPS will look like, and how it will operate. The commercial aviation industry devotes an enormous amount of energy into the logistics of their operations and ground activities. In the case of HAPS, the proposed vehicles have enormous wing spans comparable to passenger jets, but due to endurance goals, will be extremely light and comparatively delicate. This requires more thought on the types of facilities necessary to launch, recover, and maintain these drones. More than the facilities are the systems of personnel, ground support equipment and tools needed to actually conduct the maintenance. These systems will also require pilots and dedicated command and control infrastructure on the ground for some portion of their missions. HAPS operations have been reserved for bespoke research missions, but what is required when HAPS reaches Technology Readiness Level (TRL) 9? What logistics networks will need to exist when HAPS go from exotic one-off flights to perpetually orbiting above?

II. Problem Definition

Commercial HAPS performing imaging, weather, or research missions in the United States of either one week, three months, or 1 year duration will require a system of systems of support infrastructure and personnel. The HAPS in consideration is based on input from ----------. The HAPS will have an 80 ft. long wingspan, weigh around 300 lbs., is capable of transiting 1000 nm/per day, fly Beyond Visual Line of Sight (BVLOS), above 60,000 ft., and is capable of being disassembled into 4 main sub-components. Through discovering the high-level requirements relating to the system of personnel, facilities, equipment, and communications necessary to commercially operate HAPS in the present or near future world, the research will form the ground level for more detailed study and design into HAPS airports and maintenance infrastructure. After defining top-level requirements, this research will provide evaluation criteria to determine the optimal location in the United States for a commercial HAP Shack. With the Shack Selector, the main objectives are to gather publicly available data related to optimal shack criteria, combine it in a meaningful way, build a dashboard that allows the customer to compare various locations, and select the best site in the United States for a commercial HAPS airport.

III. Literature Study

The first sweep on the literature study focused on HAPS companies and anything related to ground operations they have released. Coincidentally, after this research was already underway two different HAPS organizations released relevant information. First, the Airbus spinoff responsible for the Zephyr, Aalto Haps, announced that they are racing towards commercial operations in 2025 and will start with their “Aalto Port” located in Kenya [5]. The company stated they selected Kenya due to its equatorial location and clear weather as they plan to build five more ports around the world. Second, an industry group focused on HAPS, the HAPS Alliance, released a whitepaper discussing the certification pathways for HAPS [6]. This paper covered some of the ways current regulations are at odds with HAPS vehicle designs and intended operations, but also discussed FAA issue papers that could provide a path to initiating operations. Some of those mitigations are based on starting operations in sparsely populated areas, focusing on not loitering over dense population centers, and designing the HAPS to be more frangible. This stance is not much different from what the FAA required in 2007 for some of the first NASA MQ-9 missions over the Western United States for wildfire monitoring [7]. To conduct that mission, NASA and the FAA worked together to generate Certificate of Waiver Applications (COA) which spelled out the mission area, lost-link plans, and keep-out zones which were areas of high population. Specifically, areas defined as high population were designated as no go zones, whereas the UAS was permitted to enter areas defined as medium density when the pilot was in active control and the aircraft was in “good health”.

One aspect that references 5, 6, and 7 echo is that HAPS, and UAS in general, need to achieve the same level of safety as other aircraft when operating in the national air system. The HAPS Alliance and a prior UAS regulatory case study both point to the ground systems being a part of UAS safety considerations [8]. Even looking to the military, who has far more operational UAS experience, both MIL-HDBK-516-B and the NATO Standardization Agreement STANAG 4671 go to great lengths to put forth ground station and maintenance criteria for UAS [9,10]. Some estimates place the development of the UAS ground stations at 20% of the R&D costs for the UAS itself, with the final ground station acquisition consuming up to 50% of the UAS acquisition cost [4].

UAS operations are still in their infancy, so there is not much hard data on what their operations might cost, but a typical crewed vehicle requires up to 17 labor hours per flight hour, with the RQ-2 Pioneer UAS at the low end requiring 5.87 [4]. The extreme mission duration of the HAPS will be incomparable to current maintenance planning tool kits, but it can be expected that spending hundreds if not thousands of hours flying will result in extreme maintenance. While the HAPS may benefit from its overall smaller weight and electric motors in maintenance burden, it will introduce new personnel difficulties. Experienced aircraft mechanics expressed concern that their training had not prepared them to deal with electric motors, high voltages, or hundreds of batteries that may be found in a UAS [11]. The RQ-9, a US large UAS, required nine experienced, cross-trained personnel to enable remote operations, not including the pilots [4]. The ground support equipment and maintenance requirements for the RQ-9 meant that a full hangar needed to be dedicated to each vehicle [4].

While the FAA is still working on releasing regulations to support UAS activity, we can look at what studies they have released so far. The FAA’s BVLOS Advisory and Rulemaking Committee (ARC) put out a comprehensive UAS report in March of 2022 [12]. The ARC’s discussion on risk should be of particular interest for any HAPS operator. The general sentiment is that UAS operations should align with general aviation in terms of safety/risks. The population density of an area is not an accepted means of solely defining safety, as this does not consider how many people are inside vs. outside or transiting through areas. The focus should be on the overall “Risk profile, not use cases”, which would consider not only the area of operations, but also the planned vehicle maneuvers, design, and overall kinetic energy. This discussion acknowledged that there is growing public acceptance for UAS operations and that there is an overall information gap, but they were focused on UAS with kinetic energy less than 800,000 ft-lbs. For reference, the MQ-9 was classified as around 40,000,000 ft-lbs. of kinetic energy. A 300lbs HAPS in the stratosphere dropping like a rock would have 18,000,000 ft-lbs. of potential energy. It is important to note that the kinetic energy would depend on terminal velocity and could get some alleviation from frangibility or safety measures like a parachute, but a HAPS may still need to be implemented in less populated areas to improve its risk profile.

The ARC also discussed more on the personnel requirements for UAS. It acknowledges that there will need to be more BVLOS specific operator certifications for UAS, but that the medical requirements should be looser than for commercial aviation, expanding the potential pilot pool [12]. This also included the potential for UAS pilots to be managing multiple operations at once as opposed to flying just one aircraft at a time. Maintenance and repair personnel should have certifications in line with 14 CFR 65.107, or the light sport category, until the FAA develops new UAS courses. Facilities and repair programs for UAS should operate under current FAA requirements, but there should be special attention to future regulations on maintaining components of the UAS and ground station that could "result in loss of flight or unrecoverable loss of UAS control" [12]. UAS operations near airports and heliports is of particular concern, but the FAA is encouraged to look at new "drone ports" or integrating specific airports into UAS operations to start. Beyond that, UAS operations near "sensitive areas" or other critical infrastructure may require special certifications or approvals. The DoD releases a map, shown in Figure 4, of sensitive airspaces, and although with the right permissions these could be good HAPS testing grounds, the HAP Shack location should consider its proximity to these regions [13].

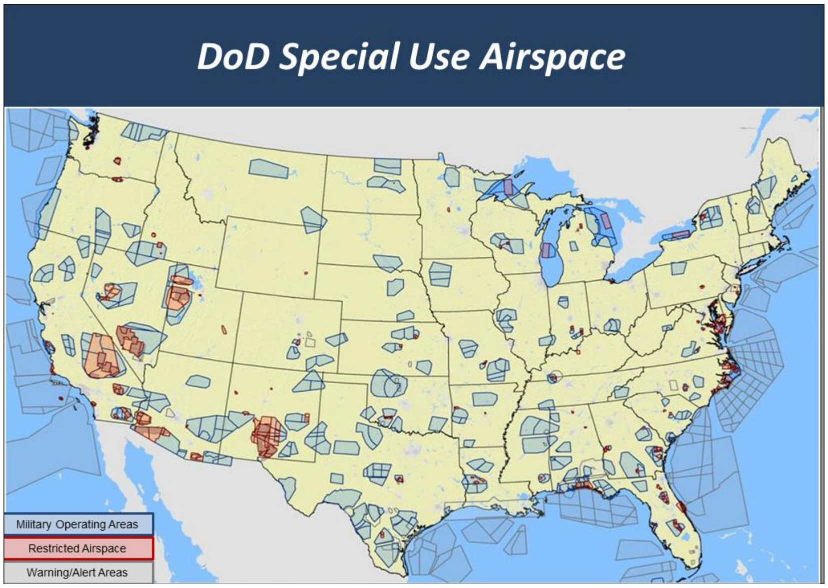


Figure 4. Current map of special DoD airspace from [13]. HAPS operations may be constrained in these regions, but these could also offer special testing areas for HAPS. Either way, the DoD airspace should be considered in HAP Shack location selection.

The FAA and NASA have also been studying Upper Class E Traffic Management, where Class E airspace includes stratosphere and beyond operations and currently does not require coordination with Air Traffic Control (ATC) [14]. There are currently small amounts of air traffic in the stratosphere, but the rise of HAPS, other HALE vehicles, and supersonic commercial transport may start to crowd the airspace. This will require a higher level of operator pre-coordination with the FAA and active surveillance and de-confliction with the operators. Of note for the HAP Shack is that the current recommendation for a HAPS ascending to Class E airspace would be for the vehicle to spiral climb over its launch point while the ATC segregates other air traffic away from the vehicle. A HAP Shack located away from busy air traffic routes or challenging wind patterns could reduce the work burden on ATC and pilots as the ascent portion could have several deconflicting flight changes. Additionally, this report and the ARC's BVLOS report discuss the potential of third-party communication networks and satellite communications for HAPS. The HAP Shack may need to provide provision for multiple communication systems or at least provide enough room to incorporate future systems as the requirements are finalized. Both reports also highlight the need to secure UAS vehicles and ground systems from unauthorized physical and cyber access. This will likely be translated into more specific security regulations, but for now we can look at the security of the ATC systems themselves for the HAP Shack.

IV. Shack Requirements Discovery

This section provides an overview of the HAP Shack requirements. For the full list, see Appendix A: HAP Shack Requirements. The general methodology is to take current customer and regulatory requirements, then expand to include proposed future requirements from FAA/Military/Academic research, and create others deemed beneficial to enable the HAP Shack to take on military R&D missions in addition to commercial missions.

A. Location

The location of the HAP Shack will play a significant role in operations. ----------'s only provided location requirement is that the HAP Shack be located in the US. For operational simplicity, the requirement to be road accessible was added. This will ensure easy logistics for the HAP Shack and the transportation of HAPS to and from alternative launch/recovery locations. The FAA's study in [12] focused on low altitude delivery type drones, but concluded that there should not be a firm requirement for the operational areas/flight paths, but rather a risk-based approach to permissible flight paths. This would consider more than the population density, including the kinetic energy of the vehicle and overall safety analyses. However, as these are not official regulations yet, and the HAPS safety analysis is not complete, it would be best to operate near sparsely populated locations. The HAPS must launch and spiral ascend over a low population area within LOS of the HAP Shack. It is also important to note that each HAPS operation will require a special COA for the time being, so avoiding populated areas may aid in securing approval. An additional requirement was added to stay away from restricted airspace or sensitive locations such as military bases or the D.C. flight region. This is to avoid limitation on HAPS operations or sensors, as well as mitigate any emergencies in the initial testing phases of HAPS.

B. Operations

---------- did not specify that the HAP Shack must be capable of launch/recovery operations and is open to the idea of using multiple sites, but for simplicity and to potentially lower cost, the HAP Shack must be capable of enabling launch and recovery. ---------- is planning for up to sixteen-hour launch operations, so the HAP Shack must be capable of enabling and maintaining LOS communications throughout the entire launch and recovery window. Current FAA regulations do not support BVLOS operation nor third party control networks, so LOS up to the HAPS cruising altitude will allow for more frequent local missions or training missions. Additionally, the HAP Shack must be capable of moving the HAPS to and from the launch/recovery location, and sustaining vehicle systems. Some UAS require avionics cooling ground carts, offboard computers to monitor system status, and engine carts to help startup [4]. We will require these provisions until the HAPS design is finalized. Likely this would end up being a pickup truck or golf cart as the HAPS is a lightweight vehicle with a wingspan close to a Gulfstream G650, but with an MTOW potentially less than a passenger onboard the G650 [1, 2].

C. Facilities

While FAA studies and different military standards have put forward recommendations for UAS ground station certification, there are no official FAA regulations. In generating these requirements, the closest FAA analogue was defined to be the requirements for ATC systems. As the HAPS will physically divorce the pilot from the aircraft, we can expect stringent standards to be applied to BVLOS control stations. It is important the pilots have multiple control stations capable of full HAPS control, and independent from one another, in case of failure. While not a requirement to use this, the MQ-9 ground station could offer the HAP Shack with already flushed out and battle proven pilot control stations. These could be purchased and deployed as two separate trailers, with the potential to back up and move to future testing sites. It is also important that the HAP Shack contains at least primary and secondary means of contacting the HAPS, ATC, and any third-party communication networks. These could include Amazon's UAS ground stations or SpaceX Starlink satellites, but whether or not they are in house, they will likely require future FAA certifications. All of these primary systems will then need to be supported by emergency power systems as per the FAA's policies on ATC power for at least sixteen hours [15]. This duration comes from the longest duration emergency situation for HAPS. This would be if the HAPS launched and then there is a site wide power outage. In that scenario the HAPS will still require pilot input and ATC flight path revisions to de-conflict with commercial traffic until it reaches cruising altitude. By that time power should be restored as the FAA only requires four hours of emergency power for the ATC facilities [15].

The specific maintenance facilities will be heavily dependent on the HAPS design, but ---------- is currently planning on HAPS to disassemble it into four main sub-components. The additional requirement added is that the HAP Shack must be capable of conducting the assembly/disassembly of those four sections in a climate-controlled hangar protected from the elements. Certain carbon fiber components and electronics are sensitive to temperature, humidity, and sunlight so until the HAPS design is finished this should be provisioned for. As with a commercial airline, the HAPS maintainers should have all the tools and equipment they need to conduct systems testing, conduct minor repairs, and swap out line replaceable units without having to send the HAPS off to more intensive maintenance facilities. The design/economics of the HAPS may not require multiple tiers of maintenance facilities, but the HAP Shack will only require this low level of maintenance to enhance operational flexibility.

Beyond this, ---------- requires the HAP Shack to store at least ten HAPS. For optimization purposes, the HAP Shack requirement is to store the ten HAPS either fully assembled or in pieces as the four sub-components in a climate-controlled unit. The HAP Shack will also need forklifts, cranes, or ramps to help with the unloading of HAPS components from trucks. The HAP Shack facilities will require 24/7 security in line with FAA CFR 171.11 and FAA Electrical requirements to ensure there is no physical or cyber tampering of critical HAPS ground systems [15]. Typically, the aircraft itself is of more security concern, but as a light weight UAS, there will need to be more attention paid to protecting HAP Shack ground power, command, and control systems compared to an airline. One more unique facilities requirement will be for the HAP Shack to have an area for pilots to rest/sleep. With long mission durations, the workload will need to be split between at least two pilots, so by allowing them to sleep at the shack, scenarios where the second pilot is unable to reach the HAP Shack for launch/recovery operations can be prevented.

D. Personnel

Starting with the pilots, they will be required to be certified to fly UAS in the United States. There are currently no FAA certifications for BVLOS pilots, but HAPS pilots will be required to meet these when they are released. The good news for potential pilots (and HAP Shack staffing) is that the medical and hands on training requirements for UAS pilots will be much less restrictive than for commercial airlines. For instance, a HAPS pilot would not necessarily need formal crewed vehicle flight training, nor need to have the same personal mobility or eyesight as an airline pilot. This means there should be a wide pool of potential pilots such as student pilots in training, retirees, or off duty pilots. The HAPS maintainers will need FAA CFR 171.11 certifications for airframe and at least one of them will need to be certified on the powerplant rating. There are no specific electrical aircraft certifications right now, but HAP Shack mechanics should be comfortable with high voltage systems, large amounts of stored power, and potentially carbon fiber aircraft [11]. Ground personnel will be responsible for moving the HAPS to and from launch/recovery as well as in performing final checks before launch. There are no specific requirements for this, but they will need to be familiar with HAPS systems, the supporting ground equipment, and be comfortable working outside at any hour of the day. Either the maintenance personnel or the ground operations personnel will be required to start up the HAPS and work through the initial checklists with the pilots. Analysts will support the HAPS via mission planning, data collection, and analysis. There are no formal requirements for this role, but this would also be a good role to cross train a pilot on for ease of FAA COA planning. For all roles and security personnel, it is a requirement that some of them be US citizens and capable of obtaining security clearances. The rationale is that the HAPS could be an excellent intelligence gathering, satellite/aircraft sensor testing, or test monitoring platform for the government. Having proper personnel would enable the HAPS operator to go after a wide variety of government contracts without having to re-hire.

V. HAP Shack CONOPs

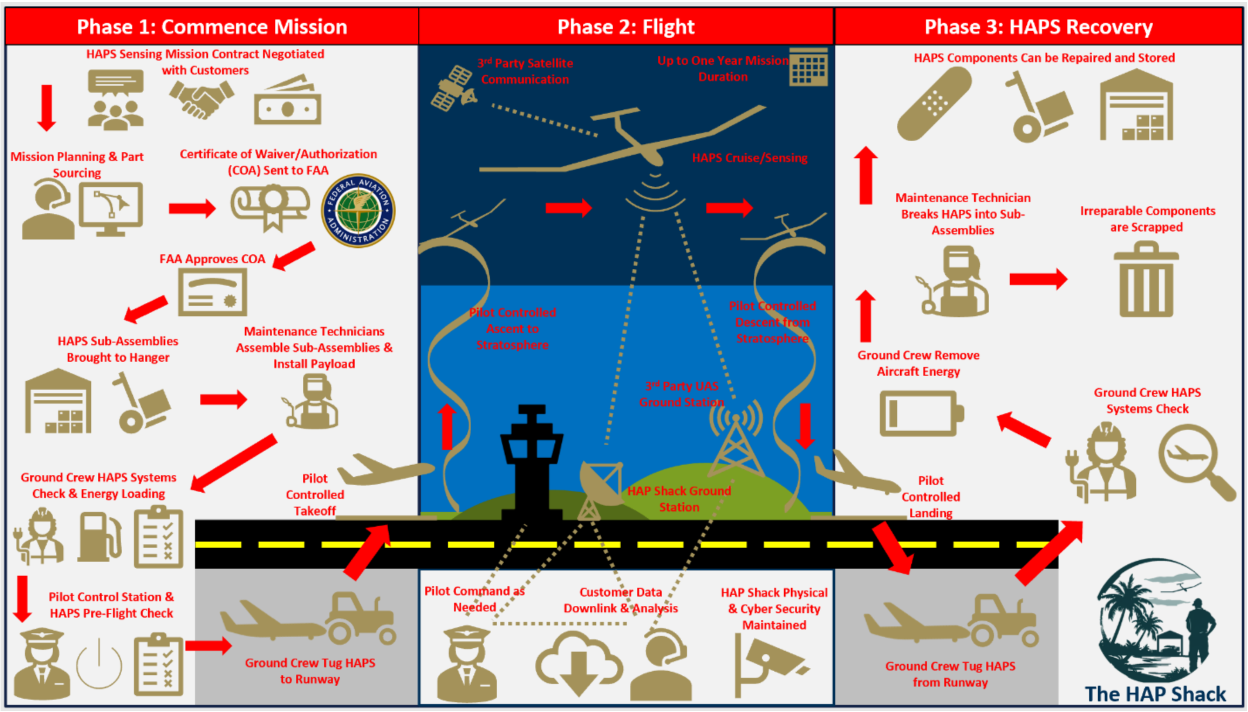


Figure 5. The HAP Shack CONOPs for a yearlong mission. Starting from the pre-launch phase where the mission is planned, coordinated with the FAA, and the HAPS is prepared for flight. The second phase has pilots and analysts monitoring/controlling the HAPS while receiving data. The third phase is recovery, where pilots will land the HAPS and then ground crews will perform system checks, repair whatever is possible, and discard the rest before the HAPS returns to storage.

A. Phase 1: Commence Mission

With the HAP Shack requirements defined in Section IV, we can now dive into what the HAP Shack operations could look like for a year-long mission. Starting off with the most important part: the customer. The HAPS may have some dedicated baseline sensors for imaging or weather scanning, but maintaining the ability to swap out sensor payloads for different customer missions could unlock a large market in testing satellite sensors, aircraft sensors, research missions, or specific customer communications requirements. The customer would approach the HAPS operator with a proposed mission. Once the requirements and negotiations are finalized, the HAP Shack analysts can get to work planning out the mission in terms of flight path, communication infrastructure, sourcing unique components, and gaining regulatory approval. As discussed in [7] and [12], operations beyond BVLOS currently require special COAs from the FAA. In the future, there may be more streamlined operations, where no COA is required to operate HAPS BVLOS, but for now the analysts will need to engage with the FAA to gain a COA for each HAPS mission. The COA will need to detail out the HAPS route, lost-link plans, emergency plans, graphics and latitude/longitude descriptions of the COA application area, and keep-out zones of high and medium density population. For the example in [7], this process took 60 days for the FAA to grant the COA. Once the FAA approves the COA, and this may take several weeks, the maintenance personnel can begin readying the HAPS.

The CONOPS depicted in Figure 5 assumes that there is no HAPS assembled and ready for flight. While it would be possible to keep one HAPS assembled in the HAP Shack, assembling the HAPS just in time for flight enables more flexible hangar ownership, where the HAPS operator leases hangar space as needed, and reduces the burden of keeping an aircraft maintained on the ground. Commercial aircraft have significant work statements to keep their electronics and engines maintained during storage periods [16]. Depending on the tempo of the HAP Shack missions, there may be significant down time between HAPS maintenance. For instance, the HAP Shack could launch all ten aircraft in a short period of time, but then it may not have any aircraft onsite for a year. Assembling HAPS only when they are needed would allow the HAP Shack to lease or share hangar space with another company to reduce operational overhead. Additionally, the same scheme could be applied to the maintenance technicians themselves. HAPS mechanics will require specific knowledge of the system, but it could be expensive to have full-time maintenance employes when there are no HAPS to work on. The HAP Shack operator could optimize costs by either contracting maintenance personnel only when there is work to be done, or by cross-training analysts/pilots with the necessary certifications.

Once the HAPS is fully assembled and the payload is installed, the maintainers or ground crew will need to conduct system verification testing to ensure that everything is operational. This may include engine runs, sensor testing, and communications verification. After the HAPS passes all tests, the next step would be for the ground crew to confirm with the pilots that the weather is suitable for launch. Since the HAPS missions are extremely long duration, the HAPS operator can be more selective with launch conditions to increase safety and lower operational strain by delaying until there is suitable weather. The HAPS may then be fueled/fully charged for flight and the pilots can begin going through their checklists. At this stage, the pilot would begin interfacing with the local air traffic control tower to get clearance for flight and go through his/her final checks of the HAPS and control interfaces. Then, the ground crew can begin moving the HAPS out to the flightline or loading it on a launcher. This may require special ground equipment for electronics cooling or power, but at a minimum, it would be a small golf cart or aircraft tug to get out the HAPS of the hangar and carry support equipment.

B. Phase 2: Flight

Once the ground crew releases the HAPS and proper flight clearance is issued, the pilot can initiate the HAPS launch. This scenario assumes that the HAPS will take off and land like a conventional commercial aircraft, but the final HAPS design could include a specialized launcher or recovery system. The pilot will be in direct control of the HAPS at launch and need to maintain control throughout the ascent phase. The HAPS may be capable of autonomous flight, but the launch phase is the riskiest and the pilots should be ready to take over control as needed. Additionally, ascending to the stratosphere is estimated to take sixteen hours and will require contact with ATC to deconflict the flight path throughout Class A airspace. Sixteen hours is far too long for one pilot to maintain control of the HAPS, so there will need to be at least two shifts of pilots for launch. Having both shifts of pilots at the HAPS Shack for launch would help mitigate any unforeseen weather events or ground travel disruptions, so at the time of launch the next pilot should be sleeping or resting in the ready room. Initial HAPS operations will have a stronger safety justification if they can launch and recover over sparsely populated regions and within LOS [12]. This scenario is assuming that the HAPS would corkscrew its way up to the stratosphere in the vicinity of the HAP Shack to maintain the LOS communications.

The HAPS mission really begins once it reaches the stratosphere. It is at this point that the pilots will be able to rely more on the HAPS automation to navigate to the target area and there is not much air traffic in Class E airspace that the pilots would have to deconflict with. It is also at this point that the HAPS will leave LOS of the HAPS shack. Communications will need to switch from the HAP Shack infrastructure to either dispersed communication towers, third party UAS towers, or to satellite communications. Purchasing access to certified third-party networks could significantly reduce costs as the HAPS operator would not have to set up communications networks across the whole country or deploy special networks for each mission. The BVLOS communication network will be utilized for most of the mission, but the HAPS should remain controlled from the HAP Shack, as this will be the most logistically simple for the personnel and may be the easiest to ensure ground station compliance.

Once the HAPS is at the target area, mission analysts or pilots can work to ensure that the customers data is transmitted in real time. This may be through the same BVLOS network for control of the HAPS or through the customer’s preferred network. Current regulations do not permit the fully autonomous use of drones, so for the remainder of the mission there will need to be HAPS pilots rotating on and off to ensure there is always at least one certified UAS pilot able to take control of the vehicle. The HAPS operator could look at reducing costs by having the pilot serve as the data analyst or having multiple HAPS under the control of one pilot. Additionally, pilots for this stage could be contracted as the operational requirements will be less sensitive. Retired airline pilots or pilots in training could provide a valuable source of labor as the expected requirements for BVLOS operators are much less stringent than for airlines [12]. Throughout all stages of the HAPS mission, there will be a requirement to restrict access to critical HAPS infrastructure. The security requirements may increase for sensitive missions, but for the duration of the HAPS mission, it is expected that at least one pilot and one security person will be at the HAP Shack 24/7. Finally, when the HAPS completes its mission, it transits back to the HAP Shack to begin recovery.

C. Phase 3: HAPS Recovery

If all goes well during the HAPS mission, this CONOPS assumes that the HAPS will land at the same facility it took off from. This is not strictly necessary as the HAPS could be broken back into its four main sub-components and shipped back on the ground from an alternative site, but this is the cheapest and simplest option. Similar to launching, the HAPS will have the luxury of time on recovery. This means that if there are adverse weather conditions, the HAPS could remain orbiting over the HAP Shack until it clears up. LOS communications with the HAPS should be more dependable and cheaper than solely on the BVLOS networks, so this strategy will increase safety and prevent vehicle damage for a slight increase in operational cost. The recovery effort is estimated by ---------- to take eight hours, but could increase due to air traffic in the area. For this reason, it would also be recommended to split the landing between two shifts of pilots. The first would arrive prior to descent to begin interfacing with ATC and running through system checks. The second pilot would come in halfway through, but again should already be resting at the HAP Shack to ensure no ground disruptions will interfere with recovery. It is assumed that the HAPS will land like a typical commercial aircraft, but specialized recovery systems, such as the U-2s chase car to relay instructions to landing aircraft, may be required [17].

The pilot will hand over control of the aircraft to the ground crew after touching down and the ground crew will return the HAPS to the HAP Shack hangar. As discussed previously, a HAPS spending a year in the air is a new realm of maintenance requirements. While there is only one takeoff and landing cycle, it will have thousands of flight hours and potentially much more UV damage than a typical airframe. The ground crew/maintainers will have to spend a significant amount of time inspecting the HAPS. The low-end estimate for UAS maintenance hours per flight hour was 5.87, which would mean the HAPS would have 51,421 hours of maintenance after a year in flight [4]. If that were true, it could be more cost effective to scrap the whole aircraft. On top of this, there may also be significant advances or upgrades for the HAPS after a year of development on the ground. The maintainers/leadership will have to evaluate if it is worth repairing the different sub-components of the HAPS in terms of structural integrity, sensor functionality, battery life, and may have to repair UV damage on carbon fiber components. If the HAPS is in a repairable condition, the maintainers could then prepare the vehicle to return to the sky or to storage. If there are no missions available, the HAPS can be broken down into its four components and returned to storage.

VI. Shack Selection Process and Results

A. Selection Criteria

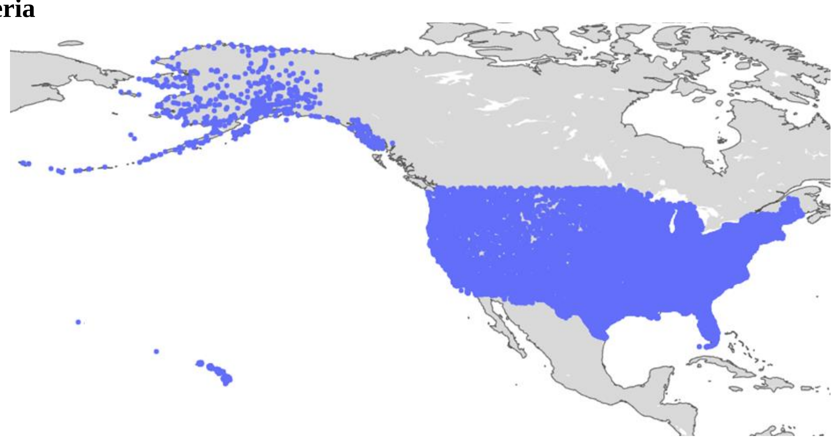


Figure 6. Screenshot of the HAP Shack Selector Dashboard displaying all airports in the United States [18]. On the mouseover, the airport name and current category scoring information is displayed for each airport.

Most small UAS operators and commercial airlines are constrained as to where their operations need to be located. Airlines need to operate out of cities with sufficient demand to justify operations, while delivery drones need to be located in or near neighborhoods. This is not the case for HAPS. ---------- specified that their HAPS could cover up to 1,000 nautical miles a day and would at a minimum perform 7-day duration missions. Given that the United States is only 2,800 miles at its absolute widest, HAPS launching from the middle of the US could be on station at any point within a day and a half [19]. For a week-long mission, that could eat up nearly half of the mission time, but for a longer mission, that transit time becomes almost irrelevant. HAPS capabilities mean that the HAP Shack has geographical location freedom, and there is more room to optimize its operation. The HAP Shack Selection will be narrowed down to only existing runways to reduce startup cost and complexity. To start, the FAA and Department of Transportation have data on over 8,000 runways in the US and its territories, as displayed in Figure 6. Many airports have multiple runways of different caliber, so each runway is considered individually for the HAP Shack Selection.

Figure 7. U.S. Air Force Base Tyndall suffered billions of dollars in damage to infrastructure and aircraft due to Hurricane Michael in 2018 [20]. This included some F-22s that were in a state where they could have been flown out of the base. A future HAP Shack could leverage its location flexibility to avoid hurricanes and tornados.

When comparing locations, the first criterion that comes to mind is weather. While HAPS launches will likely be infrequent, it would still be nice to avoid weather disruptions as much as possible. Example disruptions to HAPS operations could be lightning that prevents ground handling, severe winds that restrict takeoff, or cold weather that requires special ground equipment. Beyond disruptions, the HAP Shack selection should consider extreme weather. HAPS long mission duration means that HAP Shacks will not be optimized to minimize turn time, or the amount of time it takes to get an aircraft ready for flight, so it may be difficult to launch all aircraft away from approaching weather. HAPS are extremely lightweight and have extremely high aspect ratio wings, which may be covered in solar panels and filled with batteries that could be more fragile or sensitive to extreme weather. Particularly in the case of fast-moving weather events with strong winds. Hurricanes and tornados have devastated other air bases, even if there is an advance warning as in Figure 7, as it is still difficult to get all the aircraft in a flight-ready state and off before impact. Both general weather disruptions and extreme weather are likely to prevent HAPS from taking off. Using data from the Federal Emergency Management Agency (FEMA), each US Census County can be compared for expected extreme and disruptive weather conditions [21]. From there, the data can be refined to focus only on HAPS specific disruptive and extreme weather. For both the disruptive weather and extreme weather, the annualized frequency for the listed weather events for each U.S. census county were combined to create the disruptive and extreme weather scores. Disruptive weather is defined as cold waves, hail, lightning, strong wind, ice storms, and winter weather. These weather events will not likely result in major damage to the HAPS or the HAP Shack, but will likely disrupt launch and recovery operations. Extreme weather is defined as hurricanes, tornados, and wildfires. These are all fast-moving disasters that either strike without much warning and/or destroy large areas. For a more detailed description of each type of weather event, see Appendix B FEMA Weather Data Glossary.

For example, Allentown, P.A. is located in Lehigh County (U.S. Census Code 42077). FEMA collected data on hail events in Allentown over 34 years, see Appendix B to see more details on each category, and found Allentown to have an average annual frequency of 2.8 hail events. The annual frequency for hail is summed with the other disruptive weather event frequencies, producing a disruptive weather event sum of 59.3 for Allentown, where the lower the better. While some of the disruptive weather events are more impactful than others, just summing their frequencies together represents the days in a year that a weather disruption is expected. This score is then compared to all other counties/U.S. Census Codes FEMA has data on, to generate a percentile rank for each county. Allentown was overall middle of the pack in terms of weather when compared to all other counties, as it had a lower/better weather disruption sum than 39.6% of all other counties. The same process was applied to extreme weather events to generate a extreme weather percentile rank for each county. Figure 8 shows the results of this method by color coding the airport marker darker to indicate which airports are located in counties with better weather for HAPS. For disruptive weather, the southeastern states performed poorly. This is largely due to the annual frequency of lighting far exceeding the other categories of disruptive weather (some counties had annual lightning frequencies in the hundreds while the highest frequencies for other weather types were no higher than twenty occurrences per year). Extreme weather events, meaningful to HAPS, appear more impactful in the eastern United States and the Midwest. This is due to hurricanes only striking the south and east coast states and tornados far more common in the Midwest. Counties in western states, like California and Washington, scored well in terms of both extreme and disruptive HAPS related weather events.

Table 1. Disruptive weather data for Allentown from FEMA [21]. For each category, lower scores are better as they indicate less disruptive weather events.

	Cold Wave	Hail	Ice Storms	Lightning	Strong Wind	Winter Weather	Disruptive Sum	Disruptive Percentile Rank
Average Annual Frequency	0	2.8	1.5	45.5	6.7	4.8	59.3	39.6%

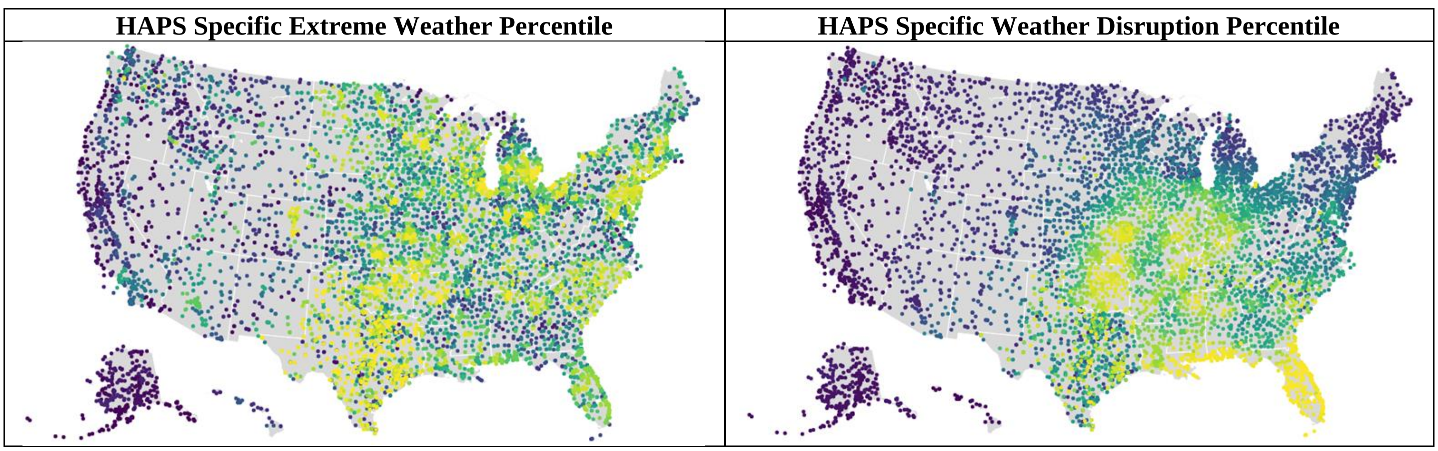


Figure 8. Map of US airports color coded for their HAPS specific extreme weather percentile [21] (left) and HAPS specific weather disruption percentile [21] (right). In both plots, darker colors indicate more favorable weather for HAPS operations. Central and Southeastern states are indicating more disruptive weather, while more extreme weather is distributed along the east coast and up through Texas to the Midwest.

Flight delays are incredibly frustrating for passengers, but can be an even greater headache for the airline itself. Flights that are delayed too long can force the airline to bring on fresh crews, cancelled flights create a large workload for ticketing agents to re-book customers, and diversions drop passengers, crew, and aircraft in unexpected locations. Again, because of the HAPS large range, a future HAP Shack can be built on airports with the least disruptions to maximize the opportunities the HAPS operator will have to launch and recover HAPS. Some of the disruptions to airport operations will be weather-driven, but the airport operational data from the U.S. Department of Transportation (DoT) in Figure 9 also highlights how prepared an airport is for whatever comes its way, how busy it is, and if there are any other operational issues [22]. One important note is that for the HAP Shack Selection, airports with the least number of disruptions (delays, cancellations, or diversions) are favored. The data from the DoT tracks the yearly number of disruptions at each airport from 2014 to 2023 as a percentage of the total amount of flights to that airport. Additionally, airports with the least amount of flight operations are more favorable. Busy airports with crowded airspace can present safety concerns or more pilot strain due to increased Air Traffic Control instructions to deconflict flight path or altitude.

To help normalize the data, a percentile rank is calculated for each type of DOT data by ranking each airport's performance in each category against all the other airports in the DoT dataset. Table 2 shows the example data for Allentown, PA's airport. On average, 17% of Allentown's flight operations per year experienced delays (delays are defined as flights arriving at their gate or departing over 15 minutes behind schedule) from 2014 to 2023. This put Allentown in the top 59% of all U.S. airports for the least number of delayed flights. This process was repeated for cancelled flights and diverted flights, with flight operations using the raw number as the basis for the percentile score. Ther percentile score for each of these four data categories are summed up and the final percentile score is the overall ranking of that airport compared to the other U.S. airports in the DoT data. In the case of Allentown, the combined sum of its percentile ranks was 2.33 (where lower scores are better) which means it performed poorly as it was in the top 73.7% of airports in the U.S. DoT operational data. It is important to note that only airports with operational data in the DoT database were considered for the HAP Shack.

Table 2. Example DoT data for Allentown, P.A. from the DoT from 2014 to 2023 [22]. Each category calculates the percentage of annual flights. The overall score for Allentown was the sum of the percentile scores for each category on the left. A percentile score is then calculated based on the overall performance of U.S. airports.

Airport Operational Data for Allentown, P.A.	Total (Yearly Average over 2014 to 2023)	Percentage (Based on Departures)	Percentile Score
Cancelled Flights	84	2.8%	72.9%
Delayed Flights	569	17.5%	55.9%
Diverted Flights	8	0.25%	45.4%
Flight Operations	3201	X	59.1%
		Total	**2.33**
		Final Airport Operational Percentile	**73.7%**

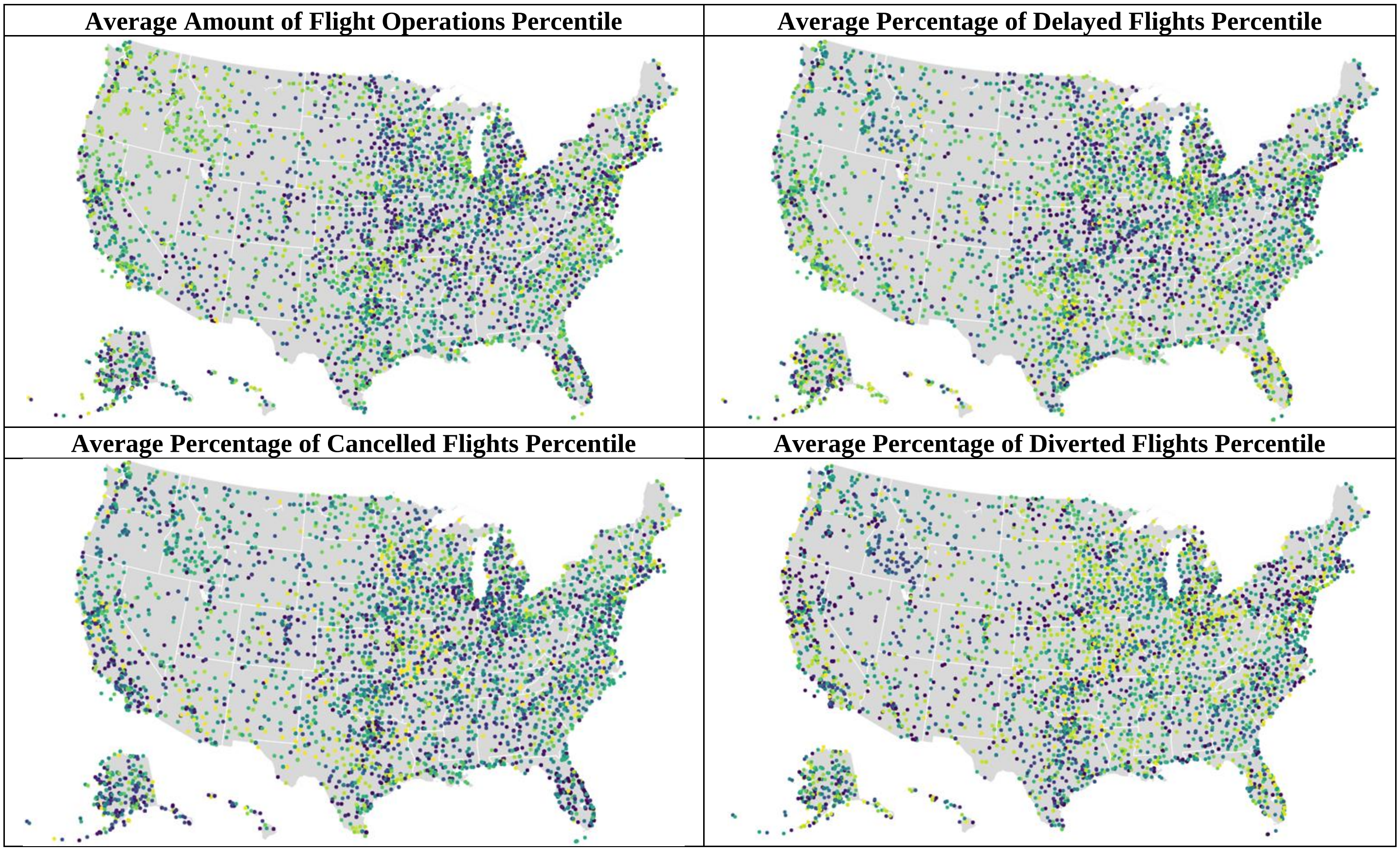


Figure 9. Top left is each airport's percentile of average flight operations. The other three maps display each airports percentile of the average percentage of flights delayed (top right), cancelled (bottom left), and diverted (bottom right). For all four plots, darker colors indicate better suited airports for HAPS (either less flight operations or smoother operations. The data represents the annual average from 2014 to 2023 [22]

The final category of location selection criteria to consider is every engineer's favorite: money. Certain states or cities may be more advantageous to set up shop in from a strictly tax perspective. The Tax Foundation ranked every state in their "Tax Climate Index" in terms of the following equally weighted categories: corporate tax rank, individual taxes, sales tax, property tax, and unemployment taxes [24]. The top three states for overall taxes were Missouri, New Mexico, and Oklahoma, but Figure 10 shows the results for the entire US. Some states are attempting to kickstart commercial drone activity in their backyards by forming drone committees. These committees can work with industry to put forward laws enabling operations, lobbying the FAA, or even forming designated testing grounds [23]. The Mercatus Research Center has released a "Drone Readiness Score Card" for the last two years to rank each state. Their report focuses on lower altitude delivery style or Urban Air Mobility Drones, but the data was re-weighted to make it more applicable to HAPS, and plotted in Figure 10. A cheap, friendly home base state could make all the difference in commercial feasibility of HAPS.

- Airspace Leasing – 10% HAPS Weight
    - Leasing airspace above public roadways for "drone highways". This will not have a significant impact on HAPS operations, but it indicates states are making actual progress in enacting drone legislation.
- Avigation Easement – 10% HAPS Weight
    - Operators can fly their drones as long as they are high enough not to bother landowners and passersby. This will not have a significant impact on HAPS operations, but it indicates states are making actual progress in enacting drone legislation.

- Task Force – 25% HAPS Weight
    - o States that are setting up teams or 'task forces' to start working through potential drone legal issues are favorable for a new novel drone operator, such as the HAP Shack.
- Sandbox – 25% HAPS Weight
    - o Whether or not the state has or is setting up drone 'sandbox' testing grounds and the size of them. Some of the sandboxes are substantial, such as the 1,000 square mile tribal area of the Choctaw Nation in Oklahoma, and could be meaningful for less restrictive HAPS initial testing [23].
- Jobs – 30% HAPS Weight
    - o The amount of drone job postings per 100,000 residents. Having other companies in the HAP Shack area would unlock access to more labor and potential to contract workers as needed, rather than having to hire for the full year. The infrequent landings of the HAPS means infrequent maintenance opportunities. Having dedicated personnel that are paid to move to the middle of nowhere for the HAP Shack could have a drastic impact on its economic viability.

The final category of location. North Dakota, Oklahoma, and North Carolina were the top three states, based on their HAPS Drone Readiness scores. North Dakota in particular has been making a legislative effort to set up more drone sandboxes and attract more industry to the state. North Dakota and Oklahoma scored highly on the jobs category because both states have a high number of drone, aircraft maintenance, or other aerospace jobs relative to their small population size. Combining the UAS readiness with State Policy, shown in Figure 10, it can be seen that there are a fair number of states that are purple, or darker in color, on both the maps. States darker in both are cheaper to conduct business in due to taxes and state governments have indicated that they are open to UAS operations by creating legislation to support the adaption of UAS, which could result in more savings for the HAPS operator.

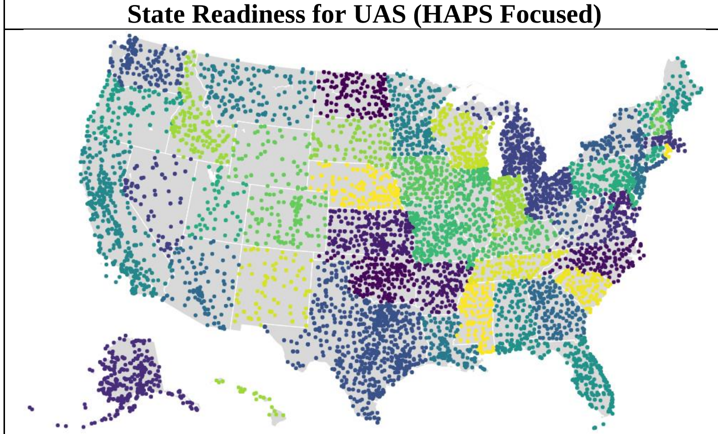
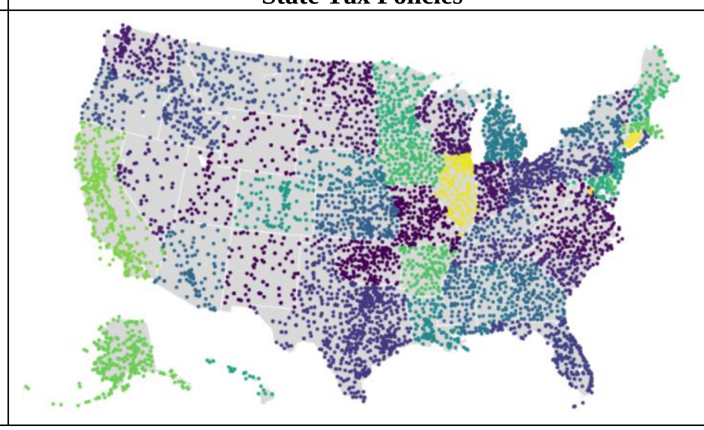
State Readiness for UAS (HAPS Focused)	**State Tax Policies**
	

Figure 10. Map of US airports color coded for the states ranking in the readiness for UAS operations, with a weighting to align with the needs of the HAP Shack [23] (left) and the state's tax friendliness [24] (right). For both plots, darker colors indicate better states for the HAP Shack (less taxes and ready for UAS)

The last data component added was a percentile rank for population density based on the FEMA records, where the lower the population, the better for HAP Shack operations. Although it is not an FAA requirement, nor a proposed requirement, to limit UAS to sparsely populated areas, it is still advantageous for current safety justification arguments. This data only considers the population density in the immediate vicinity of an airport (the US Census Code County) and does not consider neighboring regions or oceanic area. The last data to be taken into account in the Shack Selector is the airport characteristics. The FAA data provides the length of the runway, width of the runway, material, condition, and type of ownership. To ensure the least restrictions on HAPS design, the future HAP Shack is only interested in fair, or better, maintained solid runways (asphalt or concrete). A well maintained, smooth runway will reduce the undercarriage needs of the HAPS and overall conventional takeoff length. For ease of recovery, the minimum runway width is set to the wingspan of the HAPS (80'). Further HAPS design and airport details would be required to understand if that should increase or decrease. There was also a restriction on the runway length to be 3,000' or longer. This is akin to the MQ-9 and again leaves more flexibility in the HAPS design and operational requirements [25]. The last cull was to eliminate any airports under military ownership for reduced HAP Shack access requirements. This ended up reducing the airport pool down to 1,989 eligible airports/runways in the US.

B. HAP Shack Finalists

We have gone through all the candidates and our selection criteria, so there is only one thing left to do: crown a winner. But first we will need to start combining the different data groups into one meaningful score. The final score is a sum of the percentile ranks for overall weather, population density, drone readiness, state taxes, and overall airport operations. All five categories were weighted equally. For overall weather, the disruptive and extreme weather percentiles were combined, and a new percentile rank was calculated. Similarly, the overall airport operations score is the combination of the individual data categories' percentile ranks. Lower scores, or darker colors in Figure 11, indicate airports that are better suited to set up a HAP Shack at. Figure 11 shows that even with the prior filtering based assumed HAPS runway requirements, there is still a good spread of airport across the U.S. that could be considered for the HAP Shack.

Starting with the weather data, there is an equal weighting between the extreme weather and disruptive weather scores. This was done by adding the total annual event percentages and then taking the percentile rank for each airport for an overall weather score. Airport operations got a similar treatment as total flight operations (goal to minimize), delays, diversions, and cancellations were weighted equally and combined into one flight operation percentile rank. State tax ranks and drone readiness ranks were converted to their own, independent, percentile ranks. The overall percentile ranks for weather, total flight operations, state taxes, drone readiness, and population density were added together for Figure 11 to produce a final HAP Shack viability score, where the lower the percentile the better as an airport with a score of 1% would be better suited for a HAP Shack than 99% of other airports considered. Figure 11 shows that even with the prior filtering based on complete data, there is still a good spread of airport in the U.S. that could be considered for the HAP Shack. There is a larger number of airports represented in the east than the west, but this aligns more with the population differences. Many airports are a darker color in Figure 11 as there were outliers in the combined score that created a large range to create percentile scores from.

Table 3. Overall score breakdown for Allentown, P.A. The percentiles from the six categories are summed up and compared to other U.S. airports to generate a percentile rank. Allentown faired middle of the pack overall only ending up in the top 63% of U.S. airports to set up a HAP Shack at.

	Combined Extreme and Disruptive Weather	Population Density	Drone Readiness	State Taxes	Overall Airport Operations	Overall Score	Overall Percentile
Percentile	22.8%	95.7%	50.7%	32.7%	60%	2.620	63%

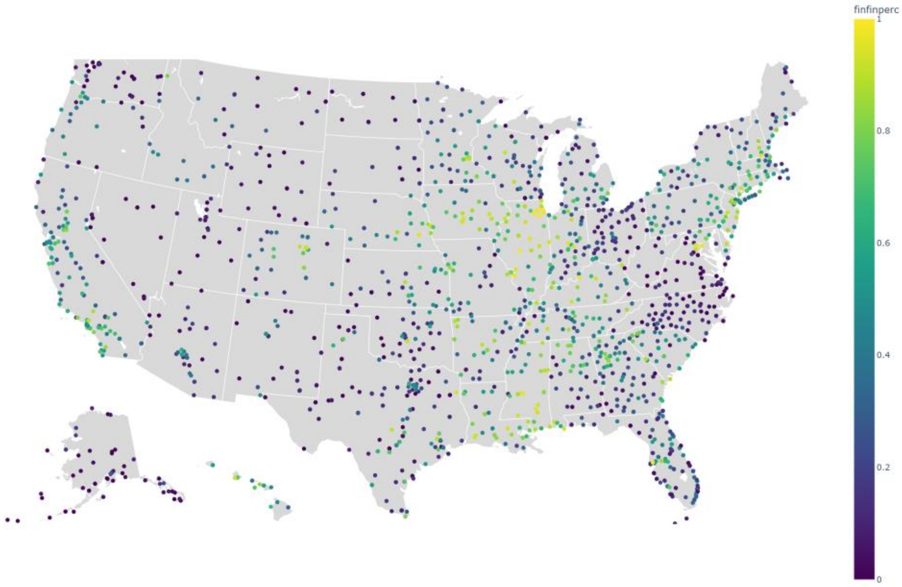


Figure 11. This map represents the final down selection to the 5,627 eligible HAPS runways for which DOT data is available, runways are wider than 80', longer than 3000', are in fair or better condition, and are made out of asphalt/concrete. The runways are color coded with their final score percentile (dark indicating the best locations for HAPS).

Figure 12 displays the top ten airports from several more enlightening categories that vary airport to airport, not just state to state like taxes or drone regulations. Best Airport performance is the most geographically diverse with the overall winner Four Corners Regional Airport in New Mexico. With results all over the US, this spread indicates that there is more than local airport weather driving overall airport performance. For best overall HAPS weather, the winner was San Francisco, but with all the results on the west coast and over half from Washington State. It is a similar story for the least extreme weather as Washington State airports dominated the list. Three of the top four are located around Seattle and around significant aerospace manufacturing facilities. While this may be a busier airspace than HAPS would be interested in, there is access to fly over water or forest areas that could reduce the risk profile. For more general weather disruptions, Central California had all the top spots. The area around San Francisco would have access to over water flights and sparsely populated mountains and desert regions.

	State	Code	City		State	Code	City
Best Airport Performance	NM	FMN	FARMINGTON	Best Overall Weather	CA	SFO	SAN FRANCISCO
	CO	FNL	FORT COLLINS/LOVELAND		WA	PAE	EVERETT
	MI	MOP	MOUNT PLEASANT		WA	BFI	SEATTLE
	CA	MOD	MODESTO		CA	CVH	HOLLISTER
	SC	FLO	FLORENCE		WA	EPH	EPHRATA
	FL	FMY	FORT MYERS		OR	OTH	NORTH BEND
	WA	YKM	YAKIMA		WA	OLM	OLYMPIA
	CA	CIC	CHICO		WA	RNT	RENTON
	OH	YNG	YOUNGSTOWN/WARREN		WA	RLD	RICHLAND
	GA	BGE	BAINBRIDGE		CA	STS	SANTA ROSA
Least Extreme Weather	WA	OLM	OLYMPIA	Least Weather Disruptions	CA	STS	SANTA ROSA
	WA	PAE	EVERETT		CA	WVI	WATSONVILLE
	WA	BFI	SEATTLE		CA	CVH	HOLLISTER
	WA	RNT	RENTON		CA	KIC	KING CITY
	WA	RLD	RICHLAND		CA	SNS	SALINAS
	CA	SFO	SAN FRANCISCO		CA	MRY	MONTEREY
	NV	HTH	HAWTHORNE		CA	SJC	SAN JOSE
	WA	EPH	EPHRATA		CA	NUQ	MOUNTAIN VIEW
	CA	CEC	CRESCENT CITY		CA	CCR	CONCORD
	OR	OTH	NORTH BEND		CA	C83	BYRON

Figure 12. The top ten airports for the following categories: best overall airport performance (top right), best overall weather for HAPS (top left), least number of extreme HAPS specific weather events (bottom left), and least amount of HAPS specific weather disruption (bottom left). Figure 15 geographically lays out the winner from each category, as well as the best overall airports.

The top airport located in the United States of America for HAPS Operations, by final score, is Ely, Nevada's Ely Airport/Yelland Field (ELY)! Ely is a small city of about 3,000 people founded as a stagecoach hub [26]. ELY is a small airport, with one runway, and Figure 13 shows its location between Salt Lake City and Las Vegas. It offers a 150' wide runway with a 6,000' asphalt runway in excellent condition. The airport averages 14,000 flights per year, so it is fairly active (80th percentile for flights) and falls in the top 20% of total airports by operations scores. Where ELY really shines is weather (top 9% overall), drone readiness (top 16%), and state taxes (top 20%) all in a location with the lowest 2% population density. ELY's management team, and a quick review of glider Facebook groups, reveals that this is a sought-after glider location [27]. A crewed glider and a HAPS will have similar aspect ratios, wing spans, and weight. ELY also saw 4% military air traffic and is located near enough to other DoD restricted airspaces that a HAPS could transit from ELY to special testing areas without passing above populated areas [13]. However, Ely, NV is still far from major population centers. A HAP Shack here may have a limited staff pool to hire from or may require crew to temporarily rotate into Ely from Las Vegas to support flight operations for a couple of days at a time. But at $75 per month to rent access to a hangar, and $0.75 per sq. ft. per month for other terminal space, a HAP Shack could be set up at ELY at quite a steal [28]

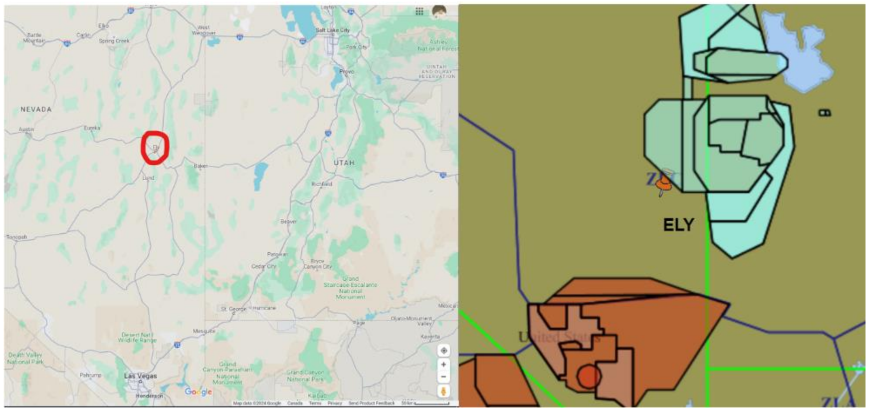


Figure 13. ELY is hundreds of miles from major population centers, but offers attractive UAS operations. Image courtesy of Google Maps (Left). On the right is a map of DoD special use airspace with ELY pinned in the center [13]. The blue indicates Military airspace while the red indicates restricted airspace.

After ELY, there are airports from the Oklahoma/Texas region, Washington State, and North Dakota with the top ten in Figure 14. Some contenders from North and South Dakota were expected due to the states' favorable drone policies and sparse populations. The Texas and Oklahoma airports are also great options for a HAP Shack as there is a significant aviation Maintenance, Repair, and Overhaul presence in these areas. Additionally, there are drone testing sandboxes, low population density, and above all, low taxes. However, it is the Washington airports that could be the most promising, Figure 14 and depicted in Figure 15. Having four of the top ten HAP Shack locations, and two of them within one hour from each other, is an indication that the state deserves some attention (shown in Figure 12). The Yakama airport is not near a major population center, but it borders up the Washington deserts, Yakama Indian Reservation, as well as a National Forest and National Park. This location could offer a variety of test flight conditions over a huge expanse of land. Seattle's Boeing Field and nearby Everrett's Paine Field also topped the list of potential airports, with these two located in the largest population areas. Both of these are in more congested airspace and population centers, but there is still enough water, National Parks, Forests, and Mountainous terrain that a HAPS could wind through to stay within LOS over sparsely populated areas. The legacy aerospace in the area would offer a ready supply of contract workers, engineers, and pilots. The general best airports, those from Figure 12 or Figure 14, are shown laid out in Figure 15.

	State	Code	City
1	NV	ELY	ELY
2	OK	GUY	GUYMON
3	WA	YKM	YAKIMA
4	TX	GVT	GREENVILLE
5	WA	PAE	EVERETT
6	WA	BFI	SEATTLE
7	TX	GGG	LONGVIEW
8	OK	HBR	HOBART
9	ND	XWA	WILLISTON
10	WA	SFF	SPOKANE

Figure 14. The top ten airports in the US, by final score, for HAPS operations

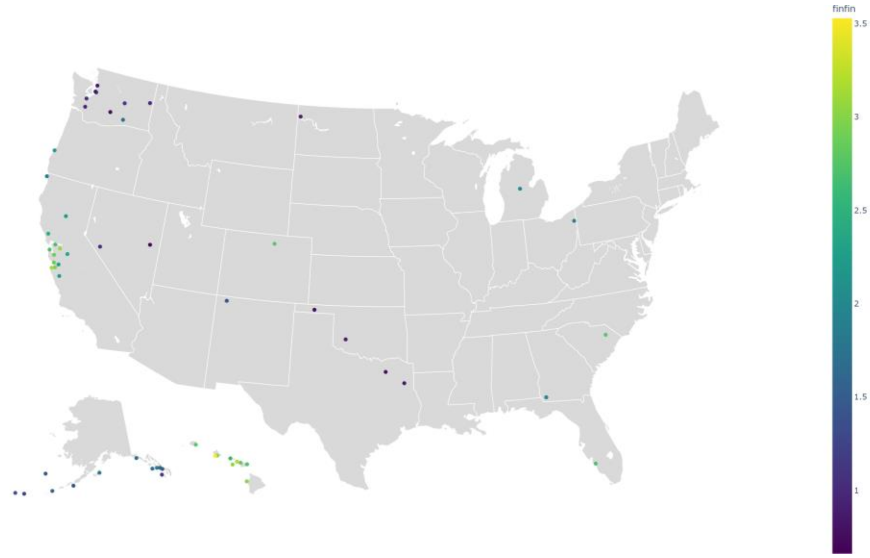


Figure 15. Map view of the top overall airports and the top airports of the four main categories shown colored by their overall final score, with dark indicated the best airports. Note that this view includes Alaskan and Hawaiian airports that would have been finalists in the categories from Figure 12.

VII. Concluding Remarks

The most surprising aspect to come out of this study was around the FAA's COA. Learning that the COA was first developed for HALE use in 2007 [7]. This is both surprising in that very early into the UAS boom, the government was able to make this work to monitor wild fires, but that also there has not been much improvement since then. One of the biggest impacts on HAPS Operations will be having to submit a COA for every mission with the mission details laid out explicitly. The true power of HAPS will be when dozens of vehicles are orbiting, like satellites, and are capable of being tasked with new missions as they arise. At that point, the HAP Shack will be in full swing as HAPS will be regularly landing, undergoing maintenance, and launching. But as the HAP Shack is getting started, there will be a lot of idle time. Idle time waiting for regulation and idle time as the HAPS is in the air. Comparing the maintenance program of a HAPS to a typical commercial airline or even a small UAS does not seem to bring much value. HAPS maintenance programs/component life limits will need to be built up from operational experience and component testing or the HAPS will have to be considered attritable after a year of high-altitude UV exposure.

The cost of setting up and running a HAP Shack will require deeper investigation to estimate and more detailed HAPS design to fully determine. The HAP Shack will likely only require a single pilot working at a time, with a group of pilots sufficient to cover 24/7 operations, and 24/7 security. The security can be outsourced or perhaps the airport's own security would be sufficient for HAPS needs. Pilots cross-trained as analysts would allow the HAPS staff to be further streamlined and give the pilots a variety of work. It is important to note that one HAPS pilot will likely be able to manage multiple HAPS in the cruise portion of their missions. It is really the launch and recovery that are personnel intensive. A pilot may need to be solely focused on HAPS launch/recovery and ground staff could be contracted to support each launch/recovery. Maintenance personnel could also be contracted on as needed to assemble and repair HAPS or shared with another company at the HAP Shack airport. The cost of acquiring, certifying, inspecting, and maintaining all the HAP Shack Power, Communication, and Control equipment will be substantial, but require deeper study.

For the majority of this study, Alaskan and Hawaiian airports have been included amongst the data, but they have been removed from Figure 12. These could both prove to be logistically difficult locations with more significant HAPS transit time retired to get on target. I was curious to see how they would score, so I left them in and unsurprisingly Hawaii dominated the general disruptions weather category. A Hawaiian HAP Shack could be useful for weather monitoring, testing over the ocean, and integrating with government customers, but overall, no Hawaiian airport had a high final score. What was surprising was Alaska. I assumed the weather data would knock Alaskan airports out of consideration due to cold weather and ice storms being included, but Alaskan airports were the top ten for extreme weather airports. This I see as more of a result of the narrow HAPS extreme weather focus on high winds, and I would need to do further work to include more of the winter impacts in the Shack Selector. The success of San Francisco and Seattle area airports in the Shack Selector leads me to believe that air traffic data must be included in the shack selection. I still believe that those airports can be great candidates for a HAP Shack, but I would like to be able to add in some impact from their busy airspace.

VIII. Future Work

This HAP Shack paper is a first glance at the future requirements and planning to run a High-Altitude Platform Station operations hub. Many of the areas touched by this paper have or deserve their own dedicated research and analysis. For instance, the HAPS control stations along with interfacing into third party communications systems and getting that all certified by the FAA will be non-trivial. In the Shack Selector there could be more research into enhanced data or fine tuning the weighting factors. A true HAP Shack location selection would need to narrow down a list of target areas of operations, consider air traffic in the area, and look more closely at the proposed routes HAPS would need to take to access target areas. In the future, the HAP Shack Selector would ideally be a tool others could access on the internet and would include sufficient controls and data such that other UAS or aviation base locations could be discovered. The HAPS maintenance requirements will only be able to be better defined as the first HAPS are designed, built, and achieve more flight hours. For now, we will eagerly await the rise of HAPS from our soon to be leased hangar in Ely.

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Appendices

A. Appendix A: HAP Shack Requirements

a) Location

i) Must be located in the U.S.
  (1) Customer Requirement
ii) Must be located at an already active airport in fair or better condition.
  (1) This is to minimize HAP Shack startup costs. A functioning airport will require the least amount of cash to get ready for HAPS in terms of power, re-paving, and building crew infrastructure.
iii) Must be road accessible.
  (1) This is to ensure easy personnel access, supply planning and for the transportation of HAPS to and from alternate launch facilities.
iv) Must be located near sparsely populated area for HAPS ascent/descent.
  (1) FAA BVLOS proposes some other ways to compensate for the flight operations risk vs. the danger to the local population, but a HAP Shack located near sparsely populated regions will have less risk and less regulatory hurdles.
v) Must not be located within Restricted Airspace or other sensitive locations.
  (1) This is to ensure there will be no restrictions on flight operations, communications, or onboard sensing.

b) Operations

i) Launch & Recovery
  (1) Must be capable of facilitating HAPS Takeoff
    (a) Customer Requirement
  (2) Must be capable of sustaining at least 16-hour launch/ascent missions.
    (a) Customer Requirement
  (3) Must have onsite certified primary and backup systems to enable LOS communication from launch until cruise (Up to the Stratosphere)
    (a) This will enable safety as the ascent/descent is the most communication intensive part of the HAPS mission and the most likely to encounter other air traffic.
  (4) The Launch/Recovery runway must be at least 100’ wide, in good condition, concrete or asphalt, and 3,000’ long.
    (a) Allows for full HAPS wingspan + buffer and similar distance to the MQ-9 [25].

ii) Cruise & Remainder of the HAPS Mission
  (1) Must enable HAPS Missions up to one year in duration.
    (a) Customer Requirement
  (2) Must have access to certified onsite or third-party primary and backup communication systems to enable vehicle control through the entire mission profile.
    (a) After launch, the HAPS will likely travel BVLOS, and the local HAP Shack communication systems may lose LOS with the vehicle. There must be other control stations set up along the mission route or access to third party ground stations or satellites must be negotiated.

iii) Ground Operations
  (1) The HAP Shack must have the means to move unpowered, fully assembled, HAPS from the HAP Shack to the launch location at all times of the day and in all weather conditions.
    (a) The HAPS is anticipated to be under 300 lbs., but the HAP Shack Personnel will need a ground vehicle to assist in moving the unpowered HAPS [4].
  (2) The HAP Shack must have a means to move all necessary equipment for HAPS power up, engine starting, pre-flight computers, and avionics heating/cooling equipment from the HAP Shack to the launch location.
    (a) Depending on the final design of the HAPS, there may be sophisticated start up procedures or standby equipment necessary on the ground. The ground personnel may need to move this with the HAPS up to the launch location [4].
  (3) The HAP Shack must have sufficient portable fire suppression equipment or fire suppression services from a third party.
    (a) The HAPS will start off as an untested vehicle with substantial amounts of batteries and/or fuel. The HAP Shack ground personnel must be able to put out HAPS fires during transit to and at

the launch location. This could either be included in the ground vehicles or be contracted out to a local airport fire department to follow the HAPS on ground.

c) Facilities

i) Command and Control

(1) The HAP Shack must contain all necessary primary and secondary equipment to enable LOS communications.
  (a) The current regulatory state means that without a waiver, HAPS operations will be limited to LOS. Having the ability to fly LOS test or training missions without special regulatory approvals or third-party communication systems will enable more flexible operations. This is also a safety measure for Launching/Recovering HAPS.
(2) The HAP Shack must contain primary and secondary means of contacting Air Traffic Control
  (a) Typical aircraft contain the necessary radios to reach out to ATC, but in the case of the HAPS, the pilots will need that equipment on the ground.
(3) The HAP Shack must contain all necessary primary and secondary means of tracking HAPS within LOS in all weather conditions and times of day.
  (a) The current regulatory state means that without a waiver, HAPS operations will be limited to LOS. Having the ability to fly LOS test or training missions without special regulatory approvals or third-party communication systems will enable more flexible operations. This is also a safety measure for Launching/Recovering HAPS
(4) Must contain primary and secondary HAPS control interface stations capable of fully controlling the HAPS remotely.
  (a) The remote pilot stations will be the only means of flying the HAPS. There should be at least 2 independent stations to ensure control of HAPS during critical mission phases.
(5) Must have primary and secondary access to the internet with sufficient bandwidth and speed to transmit real time HAPS controls inputs and receive HAPS flight data.
  (a) This will enable third party communication interfaces such as Amazon UAS ground station network access or third party satellite network control.
(6) Must contain sufficient intra-airport communication equipment for all HAP Shack Personnel
  (a) HAP Shack personnel will need to be able to reliably communicate information during ground operations.

ii) Maintenance Infrastructure

(1) The HAP Shack must have all equipment necessary to remove from storage, assemble, disassemble, and return to storage all 4 HAPS sub-assemblies and all systems testing equipment to verify correct assembly.
  (a) Customer Requirement
(2) The HAP Shack must have all equipment and tools necessary to replace Line Replaceable Units on the HAPS
  (a) The ground personnel may need to perform light maintenance on the HAPS such as swapping out batteries or sensors.
(3) The HAP Shack must be large enough to allow for the full assembly/disassembly of at least one HAPS in a climate-controlled hangar out of sunlight.
  (a) This will help protect sensitive electronics and protect any carbon fiber components from UV/temperature damage [4].
(4) The HAP Shack must store at least one HAPS worth of spare Line Replaceable Units on site.
  (a) This will ensure smooth flight operations as ground crews can quickly access and replace small components on site.
(5) The HAP Shack must have the tools and equipment necessary to conduct minor structural repairs to the HAPS.
  (a) This would cover events like oversized holes or minor damage to the HAPS material. Depending on the HAPS design, it may require special carbon fiber tools.
(6) The HAP Shack must follow all 14 CFR 171.11 requirements for FAA approved maintenance facilities.
  (a) This is a federal requirement.

iii) Storage

(1) The HAP Shack must provide climate controlled and tracked storage shielded from the elements for at least 10 fully assembled HAPS or 10 HAPS broken into their 4 sub-assemblies.

(a) Customer Requirement

(2) Must include means to load and unload tractor trailers and flatbed trailers for all HAPS sub-assemblies and Line Replaceable Units.

(a) This is to help out with logistics and scenarios where the HAPS must use alternate launch/recovery facilities.

(3) The HAP Shack must have separate special access storage areas to support classified payload storage.

(a) This will enable the HAPS to go after government missions or hardware testing contracts. Ideally, it would be sensor payloads that should be kept securely away from general HAPS storage.

iv) Power

(1) The HAP Shack must be connected to the national power grid.

(a) This ensures smooth operations by not relying on generators or other sources of power from the HAP Shack for everyday operations.

(2) The HAP Shack must provide a backup means to supply instantaneous sufficient power to primary communication, tracking, and control systems for at least 16 hours in the event of a power outage.

(a) This covers the scenario where a HAPS must come in for landing, but the power goes out on the base. This is the longest, most critical scenario for controlling the HAPS and is in line with the FAA's electrical policy for ATC backup power requirements FAA Electrical policy [15].

(3) The HAP Shack shall not launch HAPS on backup power and should not initiate the descent sequence on backup power, unless in the case of emergency.

(a) Given the extremely long mission duration of HAPS, there should not be a need to launch HAPS during a power outage.

(4) The HAP Shack must provide enough backup fuel or power to enable movement of the HAPS to and from the launch location in the event of a power outage.

(a) This is to ensure if a HAPS is being towed to the runway and the power goes out, there are sufficient reserves to enable ground personnel to tow the HAPS back to the hangar.

v) Security

(1) There shall be no unauthorized physical or cyber access to HAP Shack power, storage, control, maintenance facilities, communications equipment, or control equipment at all times.

(a) This is in line with the FAA Electrical requirements, but also prevents malicious actors from hijacking HAPS, HAPS data, or otherwise jeopardizing mission safety [15].

(2) There shall be no unauthorized physical or cyber access to HAPS vehicles on the ground at all times.

(a) During transit to and from the launch location or alternative sites, security will need to ensure that no one is able to jeopardize HAPS onboard systems physically or digitally.

(3) The HAP Shack must have sufficient security to support classified missions.

(a) This requires persistent security and special access areas, but the exact requirements will stem from the specific customer and mission.

vi) Comfort

(1) The HAP Shack must have climate-controlled sleeping areas for at least two personnel.

(a) The ascent and descent portions of the HAPS mission exceed FAA allowable pilot duty times. In the event that these missions go longer than planned, or there are other unforeseen weather events on the ground inhibiting personnel movement, there should be space set aside for pilots to sleep. The climate-controlled requirement stems from US Airforce pilot quarter requirements.

(2) Must have enough food storage, bathrooms, and shelter from the elements for the minimum required amount of ground personnel.

(a) This should be in line with a typical office.

d) Personnel

i) Pilots

(1) All Pilots must be certified to fly UAS in the United States, BVLOS certified when the BVLOS certification is available, and trained on the HAPS.

(a) The FAA is working on BVLOS requirements at this time [12], but in general the HAPS Pilots requirements will be less restrictive than typical commercial airlines. There will be less physical requirements such as eye site or fitness that should enable a wider pool of candidates.

(2) All pilots must be US citizens and at least two pilots must hold, or be capable of obtaining, Top Secret security clearances.
    (a) This would be the minimum crew required to operate a HAPS on a classified mission or with classified payload. Having all HAPS pilots as at least US citizens would reduce security complications for sensitive payloads.

ii) Maintenance Personnel

(1) At least two maintenance personnel are required at a time to enable 2-person lifts and to assist with maintenance.
    (a) This supports ease of maintenance by having assistance, spotters for moves, and loading/unloading shipments.
(2) Maintenace personnel are required to be certified to use all HAP Shack equipment necessary for moving HAPS sub-assemblies to and from storage and on and off of ground transport.
    (a) This will require overhead crane or forklift certification.
(3) All maintenance personnel must have the required FAA Part 147 Airframe certifications and at least one maintainer must also have a Powerplant rating.
    (a) This follows FAA Part 147 requirements, but may need to be refined once more UAS specific maintenance regulations are defined.
(4) All maintenance personnel must be trained and comfortable working on high voltage systems and with substantial amounts of batteries.
    (a) At this time, there is not a specific FAA training certification for electric aircraft, but it is expected that the HAPS will utilize electric propulsion systems for most, if not all, of its mission [11]
(5) Maintenance personnel must all be US citizens and at least two must hold, or be capable of obtaining, Top Secret security clearances.
    (a) This would be the minimum crew required to operate a HAPS on a classified mission or with classified payload. Having all HAPS maintainers as at least US citizens would reduce security complications for sensitive payloads.
(6) Maintenance personnel must otherwise comply with 14 CFR 171.11 requirements.
    (a) This is a federal requirement.

iii) Ground Operations Personnel

(1) All ground personnel must be US Citizens and at least two must hold, or be capable of obtaining, Top Secret security clearances.
    (a) Ground Operations personnel may have to interact with sensitive HAPS payloads. Having all HAPS ground operations personnel as at least US citizens would reduce security complications for sensitive payloads.
(2) Ground personnel must be trained and familiar with local HAPs launch/recovery location operations and be comfortable working outside in all weather conditions.
    (a) It is unlikely that a HAPS will be launched in adverse weather, but emergency situations may drive recovery efforts in adverse weather.
(3) Ground personnel must be trained/certified on all HAP Shack equipment necessary for moving the HAPS and supporting pre/post flight procedures.
    (a) This may require forklift, ground cart, or cooling cart training.

iv) Analysts

(1) Analysts will support HAPS missions planning, data collection, and analysis. They must be US citizens and at least one analyst must hold, or be capable of obtaining, Top Secret security clearances.
    (a) This would be the minimum crew required to operate a HAPS on a classified mission or with classified payload. Having all HAPS analysts as at least US citizens would reduce security complications for sensitive payloads.

v) Security

(1) Security personnel must be US citizens and at least one analyst must hold, or be capable of obtaining, Top Secret security clearances.
    (a) This is to support classified missions and expected security requirements.
(2) Security personnel must be familiar with HAP Shack facilities, comfortable working outside in all weather conditions, and for all hours.

(a) HAP Shack will require a persistent security presence to maintain ground system and aircraft integrity.

B. FEMA Weather Data Glossary

The following information is from the FEMA's data glossary [21]. For the disruptive category, all annualized frequencies are combined to build the disruptive weather score for each U.S. Census County. The extreme weather annualized frequencies were also added together to build the extreme weather score for each U.S. Census County.

- Disruptive Weather
  - Cold Wave
    - A Cold Wave is a rapid fall in temperature within 24 hours and extreme low temperatures for an extended period. The temperatures classified as a cold wave are dependent on the location and defined by the local National Weather Service (NWS) weather forecast office.
    - A Cold Wave annualized frequency value represents the average number of recorded Cold Wave hazard occurrences (event-days) per year over the period of record (16.9 years).
  - Hail
    - Hail is a form of precipitation that occurs during thunderstorms when raindrops, in extremely cold areas of the atmosphere, freeze into balls of ice before falling towards the earth's surface.
    - A Hail annualized frequency value represents the average number of recorded Hail hazard occurrences (events) per year over the period of record (34 years).
  - Ice Storm
    - An Ice Storm is a freezing rain situation (rain that freezes on surface contact) with significant ice accumulations of 0.25 inches or greater.
    - An Ice Storm annualized frequency value represents the average number of recorded Ice Storm hazard occurrences (event-days) per year over the period of record (67.1 years).
  - Lightning
    - Lightning is a visible electrical discharge or spark of electricity in the atmosphere between clouds, the air and/or the ground often produced by a thunderstorm.
    - A Lightning annualized frequency value represents the average number of recorded Lightning hazard occurrences (events) per year over the period of record (22 years).
  - Strong Wind
    - Strong Wind consists of damaging winds, often originating from thunderstorms, that are classified as exceeding 58 mph.
    - A Strong Wind annualized frequency value represents the average number of recorded Strong Wind hazard occurrences (events) per year over the period of record (34 years).
  - Winter Weather
    - Winter Weather consists of winter storm events in which the main types of precipitation are snow, sleet or freezing rain.
    - A Winter Weather annualized frequency value represents the average number of recorded Winter Weather hazard occurrences (events) per year over the period of record (16.9 years).
- Extreme Weather
  - Hurricane
    - A Hurricane is a tropical cyclone or localized, low-pressure weather system that has organized thunderstorms but no front (a boundary separating two air masses of different densities) and maximum sustained winds of at least 74 miles per hour (mph).
    - A Hurricane annualized frequency value represents the average number of recorded Hurricane hazard occurrences (events) per year over the period of record (169.9 years for the Atlantic Basin and 69.04 years for the Pacific Basin).
  - Tornado
    - A Tornado is a narrow, violently rotating column of air that extends from the base of a thunderstorm to the ground and is visible only if it forms a condensation funnel made up of water droplets, dust and debris.
    - A Tornado annualized frequency value represents the average number of recorded Tornado hazard occurrences (events) per year over the period of record (34 years).
  - Wildfire

- A Wildfire is an unplanned fire burning in natural or wildland areas such as forests, shrub lands, grasslands, or prairies.
- A Wildfire annualized frequency value represents the modeled frequency of Wildfire hazard occurrences (events) per year.

C. Shack Selector Code

Note that the following code was modified depending on which value I wanted to display on the U.S. map

```
import dash
from dash import dcc, html
from dash.dependencies import Input, Output
import pandas as pd
import plotly.express as px

# Load data
df = pd.read_excel('final_data_ex.xlsx', sheet_name="useme")

# Initialize the Dash app
app = dash.Dash(__name__)

vals = ['My Drone Compare',
        'State Tax',
        'Flight Operations',
        'Delayed Percentile',
        'Cancelled Percentile',
        'Divert Percentile',
        'Flight Percentile',
        'Rank', 'Static Fips',
        'Extreme Percentile',
        'Disrupt Percentile',
        'Density',
        'Density Percentile',
        'z',
        'TOTWEATH',
        'finscore',
        'finpercent',
        'finfin',
        'finfinperc',]

# Define the layout of the app
app.layout = html.Div([
    html.H1("American Airports"),
    dcc.Graph(
        id='airports-map',
        figure=px.scatter_geo(
            df,
            lat='LAT1_DECIMAL',
            lon='LONG1_DECIMAL',
            hover_name='ARPT_NAME',
            color=vals[18],
            color_continuous_scale='Viridis',
            template='plotly',
            scope='usa',

        ).update_geos(resolution=50, landcolor='rgb(217, 217, 217)', visible=True).update_layout(
```

```
            showlegend=True,
            height=1000,  # Adjust height
            width=1500,   # Adjust width
            geo=dict(
                showsubunits=True,
                projection_scale=1  # Adjust zoom level
            )
        ),
    ),

])

# Run the app
if __name__ == '__main__':
    app.run_server(debug=True)
```

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