HAPS Alliance

HIGH ALTITUDE PLATFORM STATION

Bridging the Digital Divide with Aviation in the Stratosphere

HAPS Flight Test Results Show Path to Unlock Stratospheric Communications

Introduction

In 2019 and 2020, HAPSMobile Inc. (“HAPSMobile”), a HAPS Alliance member, conducted test flights and communication trials using “Sunglider,” an unmanned aircraft that is planned to be used as a stratospheric communications platform. The tests carried out were very helpful in determining the potential of a High-Altitude Platform Station (HAPS) and the benefits related thereto.

This White Paper is a compilation of the test details, presented with the intention of actualizing the practical application of HAPS. The main body consists of seven chapters. The first chapter is an introductory section describing an overview of HAPS and Sunglider. The second and third chapters discuss the details and results of the Sunglider test flights. Chapters 4, 5 and 6 are devoted to providing the details and results of the communications tests conducted using communications equipment mounted on Sunglider. Chapter 7 gives examples of similar undertakings carried out by other members of the HAPS Alliance, an association of cross-industry players working to enable a HAPS ecosystem and Chapter 8 offers concluding remarks.

In 2020, Loon LLC (“Loon”), a HAPS Alliance member, published a report[1] on its own HAPS project. The companies involved in HAPS projects have been proactively disseminating information, including this White Paper, with the intention of helping the stakeholders better understand the possibilities for HAPS and further increase interest in achieving practical application. At the same time, we are advocating for the support of international organizations and national governments for the improvement of underlying aerospace/telecommunications frameworks for HAPS.

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[1] Loon LLC（2020）THE STRATOSPHERE HIGH ALTITUDE, HIGHER AMBITIONS （https://kstatic.googleusercontent.com/files/700fe7484ef07f5b986715faaa846f183be7e952c65e49bf75256c287cd1721451b2762b327a50f58a3b1589e37e52324767c67796a4b8d9f6139017233c4987）

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Chapter 1. Introduction

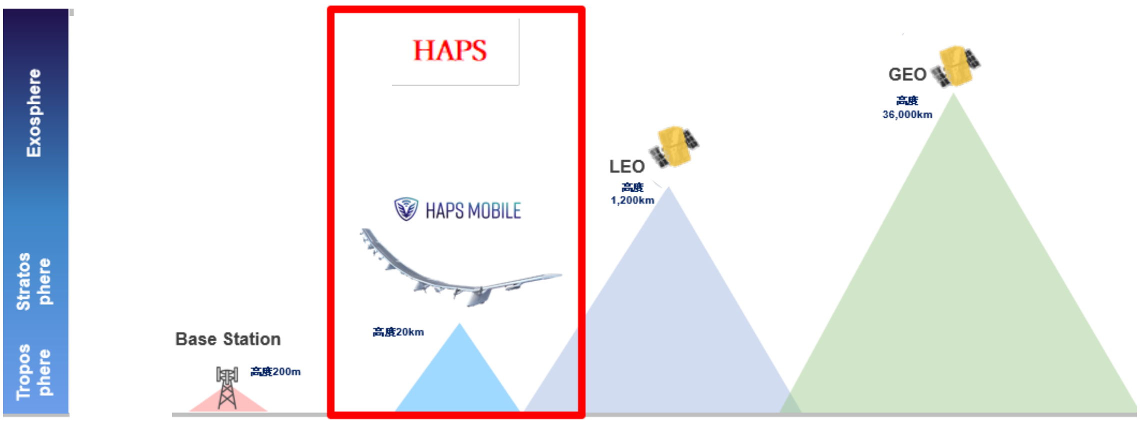
Section 1. About HAPS

HAPS is an acronym for High-Altitude Platform Station, which is a system that utilizes an unmanned vehicle, such as an aircraft, flying in the stratosphere as a communications base station. In doing so, the system is capable of providing communications services over an extensive area. The stratosphere is a layer of the atmosphere far above the clouds. Because of this, it is not affected by rain or snow and air currents have little influence. These characteristics enable the flight of a stratospheric platform to be more stable as compared to flight in other layers of the atmosphere.

HAPS can provide a wide array of services which include connectivity, earth, atmosphere and climate monitoring, disaster response, mapping and humanitarian missions, search and rescue, infrastructure inspection, and more. HAPS can either be stationary (or quasi-stationary), or be mobile across large regions (e.g. for survey missions).

In the field of telecommunications, HAPS is classified as a non-terrestrial network, equivalent to that of geostationary and low-earth-orbit satellites. This new network system is capable of covering a wider area more efficiently when compared to traditional ground base stations. It is also unaffected by damage caused by disasters such as earthquakes and tsunamis.

Non-Terrestrial Networks



Provided by HAPSMobile Inc.

HAPS can be divided in two categories: Lighter-than-Air platforms (LTA) use buoyancy to sustain flight, and Heavier-than-Air platforms (HTA) (e.g. fixed wing aircraft) which use aerodynamic lift forces to remain airborne.

HTA has the strength of high operability during flight. In particular, small- to medium-sized platforms are easy to operate, and hence, currently there are number of companies developing platforms of this scale. On the other hand, larger platforms are more difficult to meet the level of safety. While being more difficult to develop, larger aircrafts are capable of reaching their destinations faster than their smaller counterparts, as well as providing ample electricity to power the communications devices and sensors mounted on the aircraft; this is because the relatively large area of solar panels attached to their wings can generate more power.

Lighter-than-Air-Platforms can generate very large amounts of lift, enabling to carry heavy payloads. Their designs scale-up relatively easily to carry larger payloads, as their buoyancy is proportional to the cube of their dimension, while sustaining level flight does not require any energy (making them inherently safe) LTA platforms have typically higher drag profiles than their HTA counterparts. For this reason, many LTA platforms are wind-driven: they navigate using altitude changes to leverage adequate wind currents, assisted by Assistive Impulse Devices (AID) which can be turned on to provide motion relative to the air.

It is no exaggeration to say that the advancement of HAPS depends on improving the performance of battery cells and solar panels. In recent years, substantial improvements in battery capacity and solar panel power-generation efficiency have enabled aircraft to rise to the stratosphere and fly there longer. Going forward, battery capacity and solar panel power-generation efficiency are expected to continue to improve. In line with these trends, it is anticipated that HAPS systems, too, will make further progress. It is safe to say that the HAPS is guaranteed to become vital infrastructure for humankind.

Section 2. SoftBank's HAPS Project

SoftBank Corp. ("SoftBank") aims to bridge the global information gap by utilizing state-of-the-art technologies under the corporate philosophy of "Information Revolution – Happiness for everyone." The company believes that the Internet of Things (IoT), big data, and artificial intelligence (AI) will be key factors in realizing the Information Revolution.

In order to advance these key technologies, significant improvement in telecommunications network connectivity is required. Furthermore, when electric vertical take-off and landing (eVTOL) vehicles, often referred to as "flying cars," and drones enter practical use, the enhancement of non-terrestrial networks will be needed so that radio waves can be emitted into the air more efficiently than traditional ground base stations are capable of doing. In light of these prospects, SoftBank is promoting HAPS.

It is said that approximately 3.7 billion people have no access to the Internet today[2] , and SoftBank aims to eliminate this kind of digital divide and expand the Information Revolution to every corner of the globe.

In 2017, SoftBank entered into a joint venture with AeroVironment, Inc. (AeroVironment) and established HAPSMobile Inc. HAPSMobile is currently proceeding with the ongoing development and commercialization of Sunglider, a large fixed-wing HAPS.

The aim of the SoftBank HAPS project is to accelerate effort towards commercialization, with the target of beginning the mass-production of aircraft in 2027. The objective is to provide communications network services from the stratospheric HAPS to extensive areas, including sparsely districts, around the world. From the stratosphere, the last frontier for humanity, HAPS is designed to provide communications network services using solar power only. This project can be considered an extremely ambitious undertaking, which happens to also be in line with the Sustainable Development Goals (SDGs) advocated by the United Nations.

[2] Source: Statista "Number of Internet Users Worldwide from 2005 to 2018"

Sunglider

Provided by HAPSMobile Inc.

Section 3. History of Sunglider

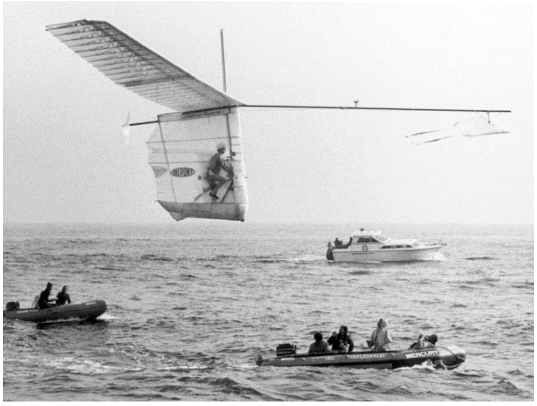
The history of Sunglider that HAPSMobile is developing goes back as far as the 1970s. Dr. Paul B. MacCready, Jr., known as the father of human-powered flight, founded AeroVironment in 1971. His aim was to develop human-powered aircraft capable of highly efficient flight by increasing wingspan and the sincere pursuit of lighter airframes. Since its founding, AeroVironment has become a global leader in intelligent, multi-domain robotic systems and serves a variety of defense, government and commercial customers.

Dr. MacCready successfully developed the “Gossamer Condor,” the first human-powered aircraft capable of being controlled and maintaining flight for a significant period of time. This aircraft successfully performed a figure-eight flight in 1977 and was awarded the Kremer Prize, which honors innovative human-powered aircraft. Then in 1979, the “Gossamer Albatross” was developed and successfully achieved human-powered flight across the English Channel winning the second Kremer prize. It was the Gossamer Albatross that became the benchmark for the basic structure of the airframe.

The Gossamer Albatross further evolved into the “Gossamer Penguin,” a solar-powered aircraft. It was eventually succeeded by a full-scale model, the “Solar Challenger,” which flew across the English Channel in 1981. The basic technologies utilized were passed on, resulting in the development of the “Pathfinder” and “Helios” HAPS aircrafts, flying wings without a tail section, and eventually, the development of Sunglider.

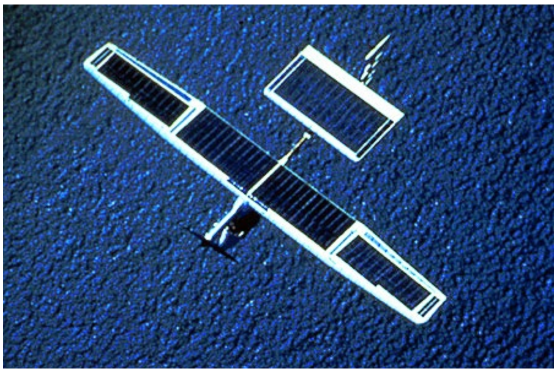
Gossamer Condor

Gossamer Albatross



Gossamer Penguin

Solar Challenger



Pathfinder

Helios

Provided by AeroVironment Inc./Mr. Don Monroe

Section 4. Sunglider Overview

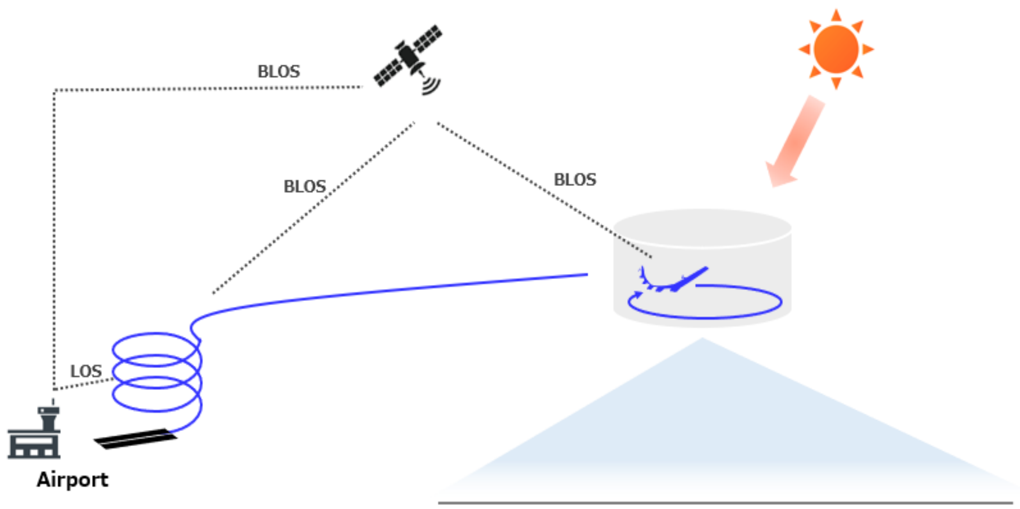
Sunglider is a world-class HAPS unmanned aircraft developed by HAPSMobile. Its major feature is that it has no tail section, like Pathfinder and Helios, which minimizes induced resistance at the wingtips, thus enabling efficient flight.

Additionally, meticulous planning ensued in order to reduce the weight of the airframe. As a result, despite its large size, Sunglider is capable of flight over an extended period of time.

The future use of Sunglider is illustrated below. A ground crew will control it visually when taking off from an airport. It will then gradually climb to the stratosphere while circling over the airport. Once it has reached the stratosphere, operation will be supervised remotely via a satellite command and control link. After reaching the destination, it will remain there circling at a fixed point in the sky. At this point in time, it will begin providing service as a network for terrestrial communications.

Sunglider is powered by solar energy. During the daytime, it generates electricity using the solar panels attached on the top of its wing. Using this solar energy, its propellers turn and communication devices mounted on the airframe are powered. At the same time, any surplus energy is stored in battery cells mounted in the airframe. As the stratosphere is located above the clouds, stable power generation is ensured during the daytime. At night, the propellers are kept turning by consuming the energy stored during the daytime. This is how it is planned to maintain continuous flight in the stratosphere for approximately six months.

Sunglider operation example



Provided by HAPSMobile Inc.

Chapter 2. Sunglider Test Flights

Section 1. Executing Low-altitude Test Flights

On September 11, 2019, after passing strict airworthiness assessments stipulated by the National Aeronautics and Space Administration (NASA), HAPSMobile successfully conducted test flights at the Armstrong Flight Research Center (AFRC) in California, USA, doing so without experiencing difficulties.

During the low-altitude flights, everything proved to work as calculated. Both take-off and landing were also stable, demonstrating that Sunglider experiences no problems during the flight. Later, another low-altitude test flight was carried out. The flight data was later used for various tuning aspects, helping to achieve enhanced stability in later flights.

Provided by HAPSMobile Inc.

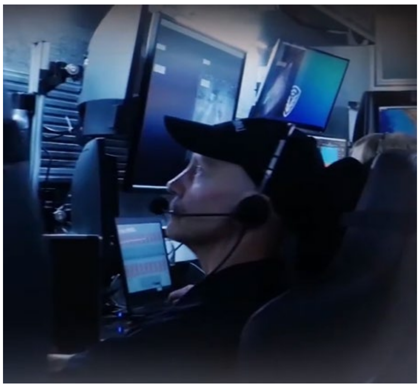
Section 2. Preparations for High-altitude Test Flight

Following the successful low-altitude test flights that verified basic safety, HAPSMobile took the next steps required to prepare for high-altitude test flights. Spaceport America (SpA), located in New Mexico, USA, was chosen as the venue. Ahead of transporting the aircraft, the airport's facilities were reserved and prepared for exclusive use. As a stratospheric flight tends to be a long-hours mission, various facilities were also prepared for the crew, making certain that appropriate measures had been taken and everything was in place.

In particular, the training of the crew was important. Detailed procedures for the entire mission were written down. Flight simulators were used, and all crew members participated in repeated training sessions. Additionally, in the event of an unforeseen situation occurring during the mission, various emergency procedures were formulated, followed by a series of training sessions. A crash-landing site in the case of an emergency was also setup, ensuring everyone was prepared to deal with any problem swiftly.

An attempt was made to be aware of the lower- and upper-air conditions around the airport. Ahead of the flight, a weather balloon and various meteorological observation equipment were used to gain a clear understanding of the unique weather patterns in the region. For example, an attempt was made to learn how strong the jet streams are and where the upper-air temperature is extremely low. We then tried to predict them so that we would be able to cope with such demanding conditions during the forthcoming stratospheric flight.

Additionally, in the wake of the COVID-19 pandemic, we practiced physical distancing inside the Ground Control Station to ensure the safety of the crew, even procuring an additional trailer in order to practice social distancing among operation systems.



Provided by HAPSMobile Inc.

Section 3. Tests Prior to High-altitude Test Flight

In May 2020, HAPSMobile assembled Sunglider that had been transported to SpA for the test flight. After arrival, all ground-based testing of the airframe was successfully carried out, including functional testing, and apron and runway tests. As part of the last series of tests, Sunglider was subjected to an airworthiness assessment conducted by the Airworthiness Review Board (ARB), which it passed.

Prior to the high-altitude flight, another low-altitude test flight was conducted on July 23, 2020. During this flight, in addition to the tests performed previously, basic flight performance and functions for a stratospheric flight were checked and data was recorded throughout the flight. The low-altitude test flight was completed successfully, confirming that Sunglider was an airplane capable of achieving stratospheric flight without a problem.

Provided by HAPSMobile Inc.

Section 4. Successful High-altitude Test Flight

In mid-September 2020, after studying forecasts for near-ground weather and jet streams and atmospheric conditions above, HAPSMobile decided to conduct the first stratospheric flight on September 21. Finishing touches on the aircraft were completed and the crew was prepared for the big day.

On September 21, the weather was exemplary, with no meteorological issues as expected. Accordingly, HAPSMobile proceeded with the planned stratospheric flight. Expecting the aircraft to return on the next day, weather balloons were launched on a periodic basis in an effort to monitor weather conditions continuously and ensure flight safety at all times. Sunglider took off at 5:16 a.m., before beginning the planned test flight system check. As it climbed, the system was checked as it reached every predetermined altitude. At 1:57 p.m. on the same day, Sunglider finished passing through the troposphere and entered the stratosphere. It continued its ascent, reaching a maximum altitude of 62,500ft (approximately 19km). It also achieved the world's first delivery of LTE connectivity while flying a constant pattern in the stratosphere. During the high-altitude test flight, it also completed a mission consisting of approximately 200 requirements, such as a sharp turn, changing speed, and auto-pilot control. Subsequently, it descended out of the stratosphere at 7:35 p.m. and began preparing to land. Throughout the flight, Sunglider was subjected to various demanding conditions, including wind speeds up to 58 knots (30m/s) and temperatures as low as -73°C. Nevertheless, it maintained its course within the planned flight zone and completed the flight safely.

At 1:32 a.m. on September 22, Sunglider landed safely. The total flight time was 20h 16min, and its stay in the stratosphere lasted 5h 38min.
*Time and date are US Mountain Standard Time

Provided by HAPSMobile Inc.

Section 5. Review of Test Results

This test flight confirmed that the airframe is a robust, has sufficient safety margin for unexpected situations.

Additionally, stratospheric flights cannot be made without passing through a very low temperature zone during ascent and decent. During this test flight as well, the aircraft travelled through a zone where the temperature fell to as low as -73°C. Despite the extreme temperatures seen, the design of the aircraft and equipment allowed for the mission to be accomplished and for a subsequent safe return of the aircraft. There were also concerns that strong winds, including the jet stream, may force the aircraft off course. Despite the fear however, in addition to Sunglider's superb flight performance, appropriate steps taken by the operating crew and ongoing computation ensured that the mission was executed within the planned area at all times. Moreover, LTE connectivity was successfully delivered by perfectly maintaining the originally planned flight course.

As reported above, the stratospheric flight was successful and significant results were obtained. Due to the COVID-19 pandemic in 2020, extra time was required for preparations in order to prevent infection. In particular, careful anti-infection measures had to be implemented as a number of people often had to be close to each other during the operation and maintenance of the aircraft. However, the entire mission was accomplished without a single case of infection owing to appropriate anti-coronavirus measures. This is also one of the significant results taken away from the test flight. In the future, when the commercialization phase of Sunglider gathers momentum, these anti-infection measures will be helpful for constructing a flight system that can function properly, even at times of emergencies.

Going forward, we will continue to pursue improvements to the airframe concept for Sunglider. At the same time, we will demonstrate a longer-period flight in the stratosphere, with the aim of contributing to the advancement of technologies required for HAPS, such as those for solar panels and battery systems.

Chapter 3. HAPS Project Flight Challenges and Measures Moving Forward

While HAPS operators have obtained approval for test flights, there are currently no established, internationally recognized, regulatory pathways for HAPS to operate in the stratosphere. In order to achieve the commercial use of HAPS systems in the near future, it is imperative that a regulatory framework, suitable for HAPS operations, be developed. To this end, the HAPS Alliance and its members are partnering with regulators across the world and the International Civil Aviation Organization (ICAO) to develop the multiple elements necessary for HAPS operations at scale:

- An internationally consistent Collaborative Traffic Management concept for Higher Airspace operations.

- A risk-based and performance-based safety framework for HAPS and pathway to operation approval

- A route towards Attended Autonomous Fleet operations

It is also important to analyze and clarify meteorological phenomena in the troposphere and stratosphere as a means of contributing to the safe flight of HAPS aircraft. In our recent high-altitude test flight, almost all of the atmospheric data collected was as we had expected, based on the pre-flight forecasts and additional in-flight data that were obtained. However, in order to better understand the air conditions during decent, it was necessary for us to periodically launch weather balloons after the aircraft had taken off. There is currently a shortage of global meteorological data, as the number of locations that deploy weather balloons on a regular basis is sparse. We recognize that sharing meteorological information is one of the industry-wide issues for those involved in HAPS projects, as well as being required for improving the meteorological observation framework.

In order to address these issues, we are proposing that the analysis and clarification of stratospheric weather conditions be carried out by the HAPS Alliance as a whole. In cooperation with meteorological authorities in respective countries, a global platform should be established for obtaining meteorological data in the troposphere and stratosphere.

Chapter 4. Preparations Prior to Communications Tests

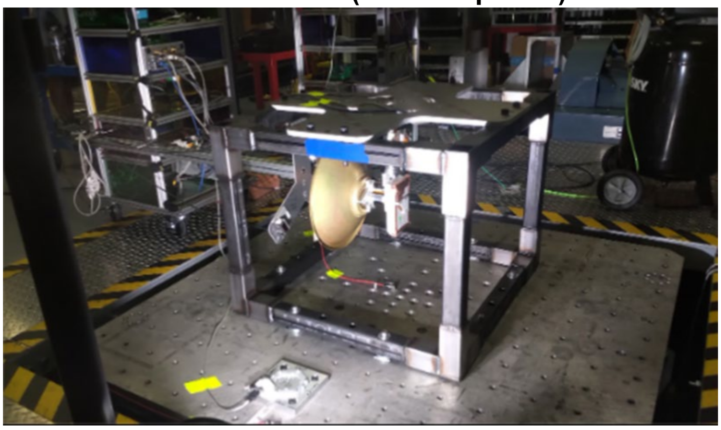
Section 1. Payload Development

Here "payload" collectively means the equipment mounted on an unmanned aircraft, including communications devices, cameras and measuring instruments. In this section, it specifically refers to communications equipment used for a cellular phone network base station.

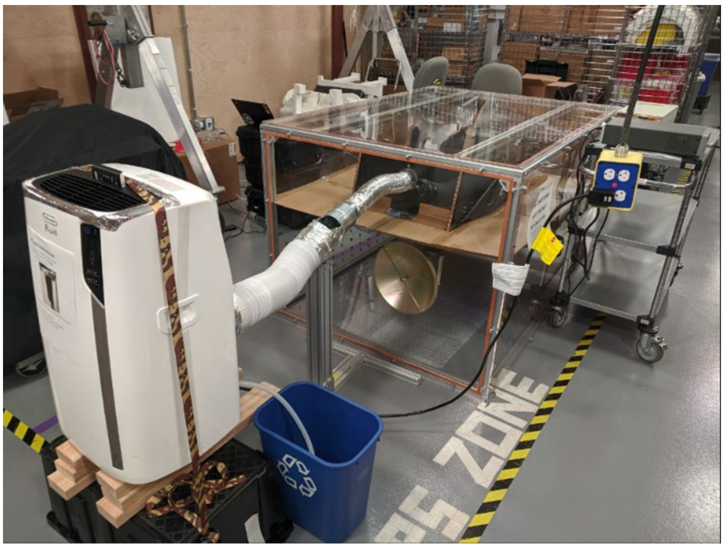
Payloads must be developed based on the assumption of being able to function in all environments from the ground to the stratosphere, the point from which services are delivered. Among all of the requirements, resistance to significant changes in temperature and air pressure is paramount. In addition, as the payload is to be mounted on a lightweight unmanned aircraft powered by solar energy, power consumption and weight need to be minimized. Payloads also need to be resistant to the vibration unique to lightweight unmanned aircrafts in order to provide a reliable signal.

To collect the data used in the development payloads capable of providing commercial services while functioning under various circumstances, HAPSMobile first conducted a variety of different tests on the ground using a prototype payload. (Images below are examples of ground-based tests.)

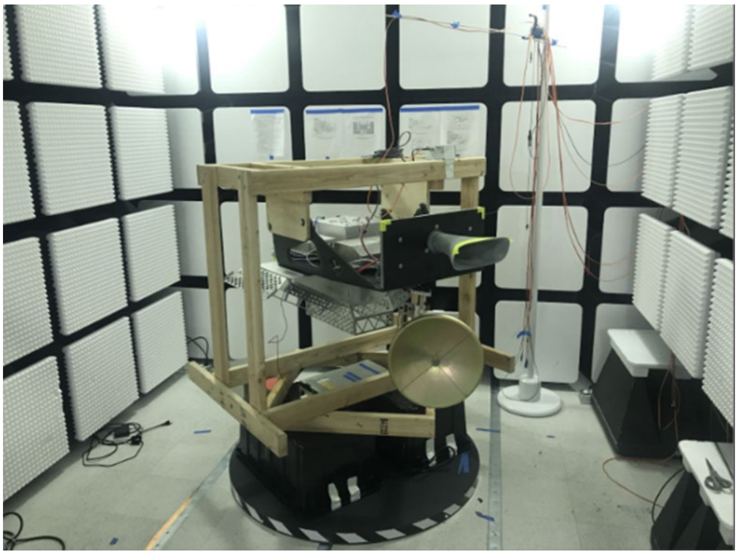
Vibration Test (Follow-up Test)



Heat Resistance Test (Cooling Test)



EMI/EMC Test

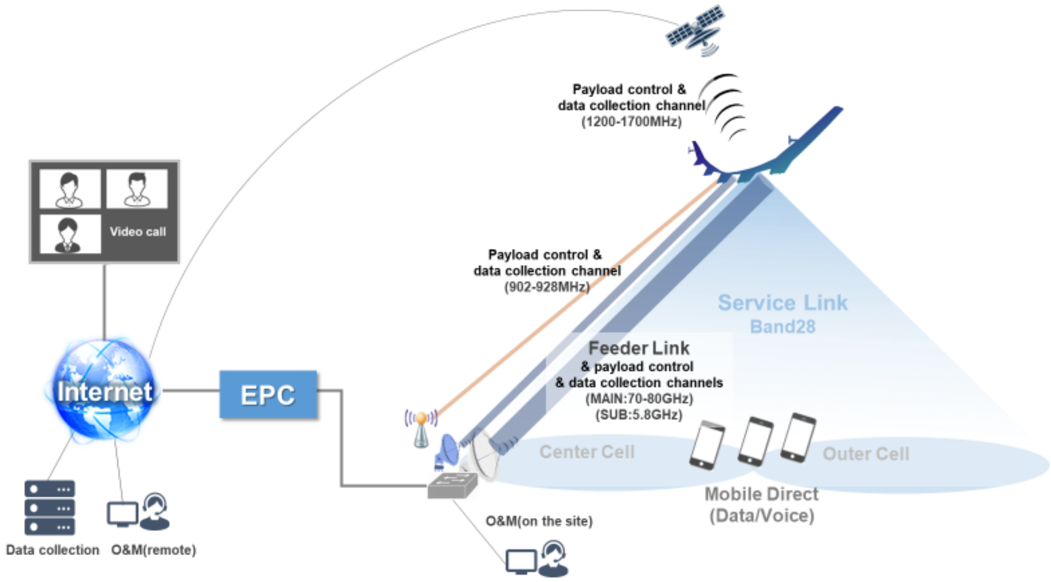


Mounting Test

Provided by Loon LLC/HAPSMobile Inc.

Section 2. Network Structure at Spaceport America

For the test flight at Spaceport America, the payload transmitted service link (LTE) radio waves earthward to be received by smartphones. HAPSMobile secured two frequency bands to be used as the feeder link for transmitting data from the smartphones to terrestrial Internet lines, enabling the feeder link to operate with main and sub-channels and thereby having structure redundancy. Two more frequency bands were allocated exclusively for controlling the payload and data collection.



Provided by HAPSMobile Inc.

Section 3. Terrestrial Gateway Construction

A ground gateway serves as the hub that connects a ground base station and a HAPS. For the test flight at Spaceport America, a shipping container was temporarily transformed into a ground gateway (shown below). Feeder link antennas were installed on the roof of the container to conduct the communications test.

Provided by HAPSMobile Inc.

Section 4. Experimental License (Frequency) Acquisition

In preparing for the payload testing to be conducted during the test flight at Spaceport America, New Mexico, HAPSMobile obtained an experimental license for the service link from the US government (i.e., Federal Communications Commission, FCC). With Spaceport America being located adjacent to the White Sands Missile Range ("WSMR"), a US military installation, all of the frequencies to be used during the test were reported to WSMR authorities, and permission to use them received prior to beginning the test. The frequency bands used are listed below.

• Service Link (Band28 (700MHz band))
After conducting research on mobile network operators (MNOs) who were using Band28 at the time, as well as vacancies in other frequency bands, this bandwidth was chosen after receiving the consent of the MNOs and prior to applying for permission of the FCC.
In order to obtain FCC permission, proof of receiving the prior consent of the MNOs, the possible impacts of frequency interference, and the specifications of the wireless equipment to be used had to be provided.
Spaceport America is located approximately 200km from the US-Mexican border as the crow flies. The FCC was concerned about causing interference in the neighboring country; but following an explanation from a technological perspective proving that there would be no problem, negotiations concluded and a license was granted.

• Feeder Link (70-80GHz band)
This frequency band, which had already been licensed by the FCC to Loon, was utilized.

• Feeder Link (5.8GHz band)
A license-free Wi-Fi frequency band was used.

• Payload Control & Data Collection Channel (902-928MHz)
An ISM band was used.

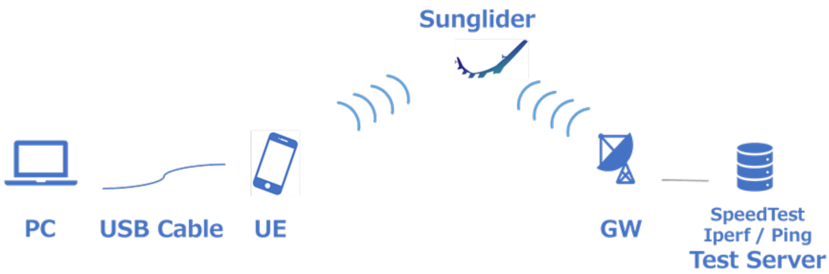
• Payload Control & Data Collection Channel (1200-1700MHz)
Iridium Certus was used.

Chapter 5. Details and Results of Communications Tests

Section 1. Details of Main Communications Tests

HAPSMobile conducted a wide variety of communications tests at Spaceport America in addition to the Sunglider test flight. In this White Paper, a focus is placed on communications speed tests, ping tests, and a video call. For the communications speed tests, the presence of any fading effect was checked by comparing the difference between estimated signal received and that actually measured. The effectiveness multiple-input multiple-output (MIMO) in the HAPS environment was also verified. For the ping tests, messages were sent from a host computer to another computer. Round-trip time (RTT), which is the amount of time it takes for the host computer to receive a reply, was estimated, as well as the amount of delay in commercial use.

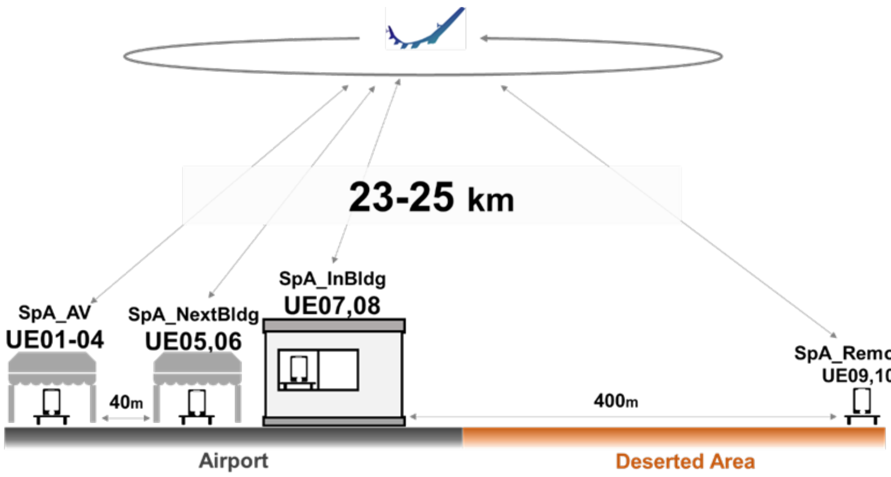
The testing environment for communications speed and ping tests is illustrated below. User equipment (UE) was controlled using personal computer connected via USB cable. Communications speed and pinging were measured using Iperf and a test server on the Internet.



Provided by HAPSMobile Inc.

The distances between each UE and Sunglider during communications testing are shown in the following illustration.

Partly due to the effects of COVID-19 and other restrictions, communications tests were conducted within a restricted range. Each UE was measured multiple times on separate occasions. After reaching the stratosphere (approximately 19km in altitude), Sunglider circled above Spaceport America. As a result, the distance between Sunglider and the same UE may have varied each time, depending on when the measurement was taken. However, direct distances between UEs and Sunglider were generally kept within a range of 23-25km.



Provided by HAPSMobile Inc.

UE data is provided in the table below.

UEs were located in four places. The locations of SpA_AV and SpA_Remote1 were in open space, while that of SpA_NextBldg was outdoors adjoining a building and that of SpA_InBldg was inside a building. When measurements were being taken for one UE, the other UEs were disconnected from the HAPS base station.

Item	Value
UE Model No.	Pixel 3aXL(G020B)
Number of UEs	10
Test Location (Position Name: UE No.)	SpA_AV: UE1～UE4 (Outdoor) SpA_NextBldg: UE5, UE6 (Outdoor NB) SpA_InBldg: UE7,UE8 (Indoor) SpA_Remote1: UE9, UE10 (Outdoor)
Test Application	Speed Test1: Iperf + QXDM(Logging) Video call: Zoom

Section 2. Communications Speed Results

HAPSMobile conducted the tests using one UE connected at time, disconnecting the UE tested before testing the next.

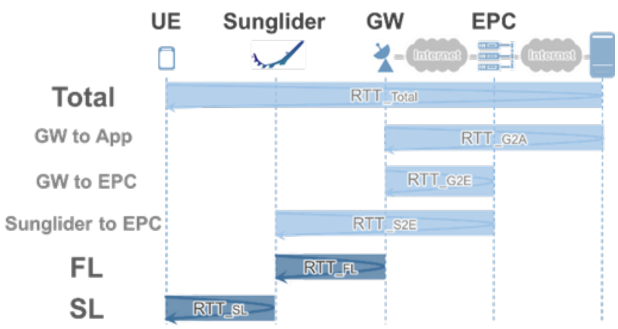
The results confirmed successful connectivity to all of the UEs, including the one located indoors.

Additionally, fluctuation in signal reception was predicted, which would result in fading due to the HAPS being in motion. However, an analysis of the time variation in down-link (DL) reference signal received power (RSRP) obtained during the tests revealed that there was no fading effect.

The analysis of communications speed also indicated that there were many cases in which the Rank Indicator values sent from UEs maintained a value of 2, which means MIMO is possible. There had been regarding MIMO capabilities due to the open-air nature of the HAPS environment; however, the data revealed that MIMO is feasible.

Section 3. Ping Test Results

The right-hand side of the illustration shows from which node to which node verification was carried out during the ping test. The test was performed from a UE to the test server, as well as from the gateway to the test server, from the gateway to the Evolved Packet Core (EPC), and from Sunglider to the EPC. Using the values obtained, the RTTs for the Feeder Link (FL) and Service Link (SL) could be determined.



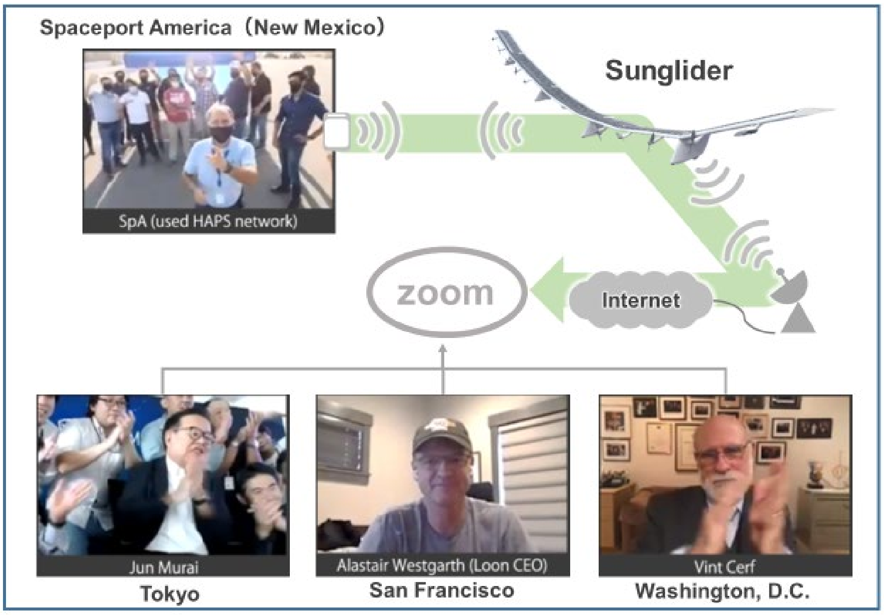
Provided by HAPSMobile Inc

The FL RTT value turned out to be very small. Even if the transmission distance is farther than used in the test at SpA, HAPS systems can achieve RTT values significantly lower than 1ms. On the other hand, for the SL, partly because of the LTE protocols used, the scheduling request transmission cycle and grant allocation negatively affected the amount of delay. In order to expand the application of HAPS, it is imperative to lower the latency. HAPSMobile is also considering the utilization of 5G networks as a solution to reduce latency.

Section 4. Making a Video Call

Using a communications payload resistant to the demanding stratospheric conditions and smartphones equipped with the Zoom video-conferencing application, members of Loon and the AeroVironment team at Spaceport America successfully completed a video call with members of HAPSMobile in Tokyo, Japan.

Vint Cerf, recognized as one of the "Fathers of the Internet" and VP and Chief Internet Evangelist, Google, and Jun Murai, known as the "Father of the Internet in Japan," Faculty of Environment and Information Studies Professor at Keio University, and also HAPSMobile External Director, also joined the video call and discussed HAPS' significance for the future of the Internet.



Provided by HAPSMobile Inc.

Section 5. Review of Test Results

These communications tests, including the video call, confirmed that communications can be properly established from the stratosphere to the ground. They also prove that high-quality mobile communications services can be provided using Sunglider. We are confident that the communications tests provided significant results.

Moving forward, in order to further ensure that communications services can be achieved from high altitudes, we will be working to reduce the weight of the communications payload and demonstrate stratospheric flights having longer durations.

Chapter 6. HAPS Project Communication Challenges and Measures Moving Forward

As discussed previously in the section regarding preparations prior to test flights, considerations regarding neighboring countries may become one of major issues for Telecom regulatory considerations in the future. Since HAPS will provide coverage over extensive areas from the stratosphere, measures will need to be taken for radio-wave interference in the proximity of neighboring nations' borders. Coordination with neighboring countries may take a long time and negatively impact the project such as delaying the roll-out of the HAPS operations. Furthermore, if interference occurs during operation, the continuation of service will depend on negotiations and arrangements made at that time, which could lead to an increase in operating costs.

In order to conduct communications tests and provide smooth, stable services using HAPS at the global level, rules need to be established so that negotiations and arrangements with neighboring countries are conducted under cordial circumstances.

To this end, we hope that HAPS Alliance members and the relevant authorities in respective countries will build good relationships that contribute to the active exchange of views. The public and private sectors should work together to establish rules that resolve the problems in each country.

The establishment of rules will ensure that barriers to HAPS operations are removed prior practical application and facilitate a swift expansion of services and information-sharing in the event of radio-wave interference.

Additionally, for high-altitude communications, it will be necessary to reduce the weight of communications payloads and resolve the issue inherent to moving platforms (i.e., variation in the quality of communications). HAPSMobile is committed to continuing independent research for measures to overcome these challenges.

Chapter 7. Similar Initiatives by Other HAPS Alliance Members

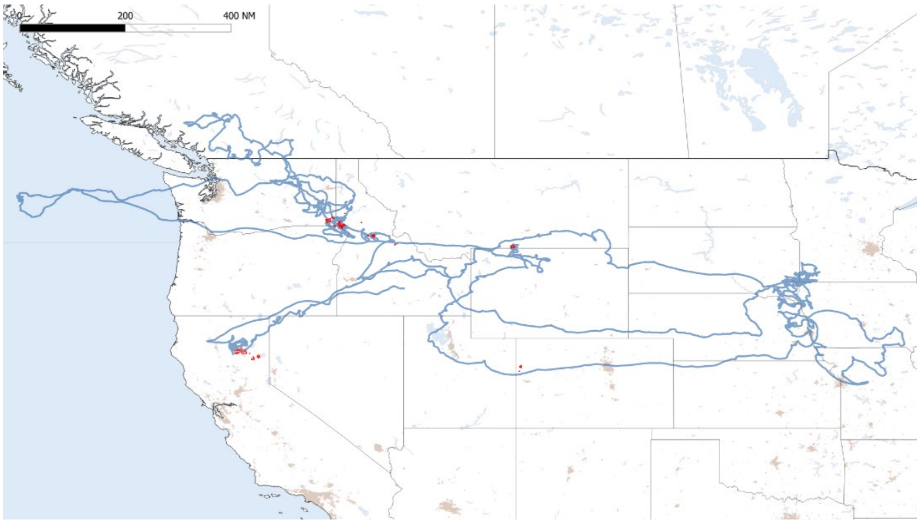
Section 1. Raven Aerostar

Raven Aerostar has been flying balloons in the stratosphere for 65 years and have amassed nearly 50,000 flight days in the stratosphere since 2013 in support of persistent communications platform development and operations. Aerostar's Thunderhead Balloon Systems® are in a high state of technical readiness with a well-developed balloon manufacturing capability and experienced flight operations crews. In the late Summer of 2021, an Aerostar balloon carried a multispectral instrument on a two-month mission over the Western United States. The mission demonstrated the utility of free-flying balloons in the stratosphere in support of firefighting efforts.

Caption1: Thunderhead balloon systems are designed to be launched by a small crew in a variety of conditions. The balloon shown here was flown from Aerostar's Flight Operations Center in South Dakota to persistence waypoints in Eastern Oklahoma and West Texas where it performed station seeking maneuvers to maintain a useful radius from points of interest.

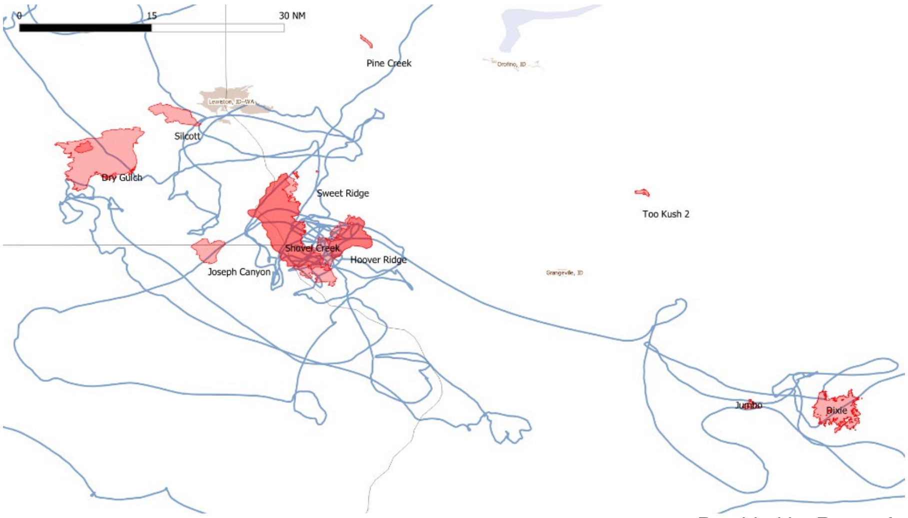
Provided by Raven Aerostar

Caption2: This ground track shows the path of a two-month mission in which an Aerostar Thunderhead Balloon System® was flown over wildfires in the Western United States. The mission demonstrated the utility of stratospheric balloons in support of firefighting operations. The station seeking maneuvers were executed almost entirely by Aerostar's proprietary station seeking algorithms. The algorithms fuse weather model data with balloon flight movements to determine the best path to keep the balloon in a useful range of the target area. After covering a specific area, the system was redirected to other areas of interest. The use of automated navigation and station seeking capabilities has almost eliminated the need for manual piloting of the balloons during persistent coverage missions.



Provided by Raven Aerostar

Caption 3: Close Up of ground track over Snake Creek Complex Fires



Provided by Raven Aerostar

Section 2. Airbus Zephyr

The current Zephyr variant is the 8th generation of a system under continuous evolution and development. Zephyr utilises batteries to drive propellers and solar cells to charge the batteries during daylight hours.

Zephyr utilises an ultra-lightweight airframe and BVLOS command and control utilising a Sat-Com datalink to provide world-wide coverage and extreme endurance targeting up to one-year flights.

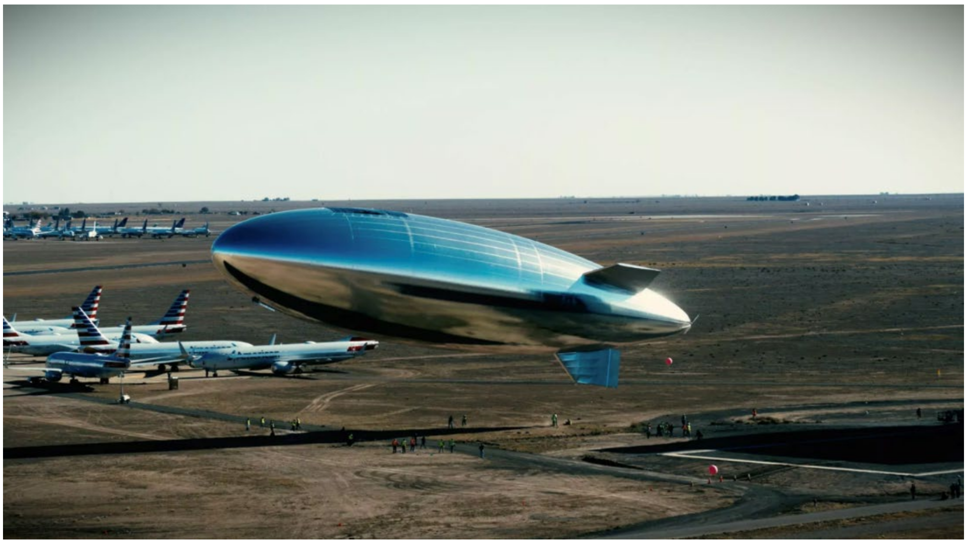
Zephyr has demonstrated extreme endurance (world record of 26 days), maintaining a dawn altitude of FL600 and a world altitude record at FL760.

Section 3. Sceye

Sceye uses a wind-driven lighter-than-air HAPS platform to provide connectivity, earth observation and humanitarian services from the stratosphere. In particular, Sceye recently entered into a partnership with the US Environment Protection Agency (EPA) to study pollution sources and their impacts on climate and air quality.

The Sceye platform is capable of carrying payloads over 150kg into the stratosphere. It is equipped with assistive impulse devices capable of delivering 10-15 meters per second of true air speed capability.

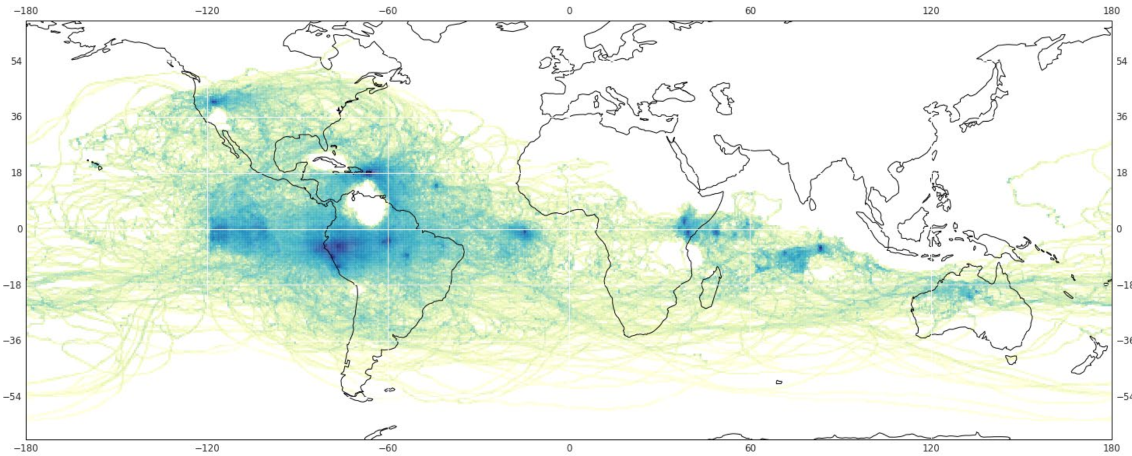
In a recent connectivity test, Sceye demonstrated the ability to connect with LTE devices up to 120km horizontal distance, demonstrating the large potential that HAPS can offer over terrestrial infrastructures.



Caption 1 – Sceye platform test on ascent Provided by Sceye

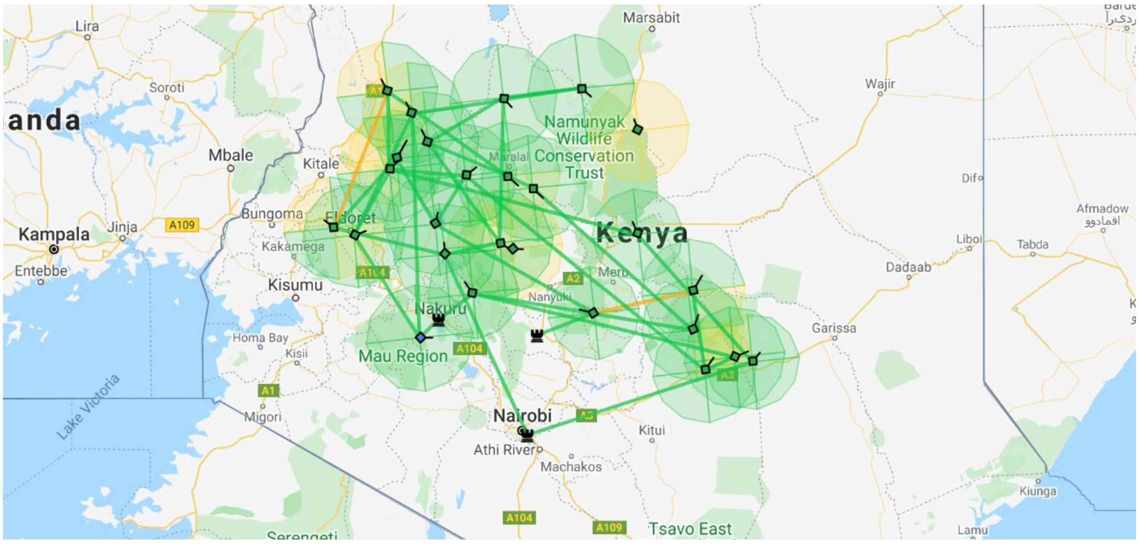
Section 4. Loon

Using wind-driven Lighter-than-Air HAPS, some of which were equipped with assistive impulse devices, Loon provided connectivity to hundreds of thousands of users across Kenya, Peru and Puerto Rico - flying over 1.9 million flight hours and over 70 million kilometers across the globe, and reaching flight durations of 323 days aloft. While Loon's journey ended after over 10 years, the details of its achievements and technological progress can be found here: https://x.company/projects/loon/the-loon-collection/



Caption 1 - Historical Loon Flight Tracks (2018 – 2020) Provided by Loon

Caption 2 - Mesh network over Peru, Bolivia, Brazil and Ecuador Provided by Loon



Provided by Loon

Caption 3 - A mesh network of 25 Loon platforms providing connectivity over Kenya

Chapter 8. Conclusion

In this White Paper, details of the HAPS test flights and communications tests conducted by HAPSMobile in the USA from 2019 to 2020 have been reported. The major objectives of these tests were to achieve stable flight for Sunglider in the stratosphere and execute adequate communications from Sunglider to a fixed terrestrial point during flight. The tests conducted were successful and the desired outcomes have been achieved. Meanwhile, regarding the durability of Sunglider's airframe and communications payload during long-duration flights and other issues, the plan is to address these issues by conducting ongoing tests in the future.

An internationally recognized aviation regulatory pathway for the development and commercialization of HAPS is needed. The HAPS Alliance and its members are partnering with international regulators, resulting in the publication of the first concept of operations published by the Federal Aviation Administration (FAA). An international framework for coordinating negotiations/arrangement of schemes with neighboring nations regarding radio-wave interference also needs to be established. Furthermore, the necessity of a global platform for collecting and sharing meteorological data on the troposphere and stratosphere has been pointed out.

In Chapter 7, similar initiatives implemented by HAPS Alliance members are reported. As indicated in that chapter, there are companies other than HAPSMobile conducting HAPS test flights and communications tests. This fact underlines the increasing industry needs for the commercialization of HAPS. The development of a striving HAPS ecosystem will involve cooperation across industry partners, governments and regulatory agencies across the world.

To that end, the HAPS Alliance is enhancing the cooperation between members, and this coalition will function as a platform. It is vital for the realization of HAPS that the HAPS Alliance acts as the industry's window to collaborate with international organizations and national governments.

As for HAPSMobile, the company will continue to maximize its contribution to the HAPS Alliance as much as possible.