WeRobotics Report
Cargo Drone Field Tests in the Amazon

In collaboration with the Peruvian Ministry of Health
and Becton, Dickinson and Company (BD)

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Executive Summary

Transporting anti-venom, blood samples and other medical supplies is slow and expensive in the Amazon Rainforest. River boats are often the only means of transportation. This means that it can take up to 6 hours for new anti-venom to be transported from a small town to a remote village, for example. In contrast, a small cargo delivery drone can cover this distance in just 35 minutes as demonstrated during two initial flights in December 2016. This demo used a re-purposed, low-cost mapping drone. Two longer distance flights were carried out in February 2017. In June 2017, WeRobotics field tested the use of locally affordable and repairable cargo drones in the Peruvian Amazon Rainforest over the course of 2 full weeks. These tests were carried out in direct partnership with Becton, Dickinson and Company (BD), the Ministry of Health, regional and local doctors and clinics, UAV del Peru and Peru Flying Labs.

The purpose of these field tests was to better understand the opportunities and limitations of using affordable solutions for the rapid delivery of essential supplies in the Amazon. As such, the field tests sought to better understand the failure points and failure rates of the technology while developing streamlined workflows to enable the safe and regular delivery of essential items in the rainforest. Understanding failure points and rates is essential to developing a preventive maintenance strategy. The latter serves to increase the reliability and longevity of aircraft. In addition, understanding the limitations of affordable solutions in relevant social, geographical and environmental contexts was one of the overarching goals of the field tests. In addition, the field tests serve as a capacity building opportunity for our Peru Flying Labs.

The field tests were carried out using a fleet of 9 cargo drones including a VTOL (Vertical Takeoff and Landing) prototype. A total of 44 complete flights were logged (not counting shorter test flights). The types of cargo transported included food, mail and diagnostic test supplies, for example. The distances covered by the cargo drones ranged from 10km to 120km. Three technical failures were experienced and exhaustively investigated.

The growing healthcare needs in the Peruvian Amazon Rainforest coupled with expensive and slow cargo delivery options makes it clear that alternative solutions are needed. Our recent field tests confirm that cargo drones can be part of the solution. That said, the price point of the cargo drone is a big factor. We need an affordable drone that can be easily operated and repaired locally. Affordable, of course, is relative. We're after a reliable cargo drone that is well under USD 10,000 and preferably closer to the USD 5,000 mark. From a business case standpoint in the Amazon, it will be virtually impossible to break even with a cargo drone that costs over USD 10,000 unless the cargo on each delivery is priced at thousands of dollars or there is *verifiable* performance data to prove sufficient reliability that demonstrates an amortization point. Still, more extensively-tested and robust drones currently available tend to be more expensive and sophisticated, which also means they are not necessarily locally repairable because of the specialization and specific spare parts required.

So while our technology partner continues working on a low-cost VTOL prototype, we are continuing to scope the market and startup space for other platforms that fit the needs of the use-cases we've identified in the Amazon Rainforest. We plan to return to the Amazon in 2018 to carry out actual cargo delivery services for a 2-month period. To do this, we will setup a small Droneport in Contamana to service smaller towns and villages within a 100 kilometer radius.

Pictures and videos of the field tests are available at werobotics.org/blog.

Acknowledgements

We sincerely thank the Peruvian Ministry of Health as well as regional and local doctors and clinics in Pucallpa, Masisea, Tiruntan and Contamana for their partnership and invaluable support. We also express our very kind thanks to the Peruvian Civil Aviation Authorities (DGAC) and the airport authorities in Pucallpa for granting us permissions for the field tests. Sincerest thanks to Becton, Dickinson and Company (BD) for their partnership and support for the field tests and to the whole team at UAV del Peru for making these field tests possible. Big thanks as well to all the volunteers at Peru Flying Labs for the countless hours they put into the field tests. We'd also like to thank our technology partner, Oriol Lopez, and the missionaries in Pucallpa who lent us their airfield in San Jose.

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Introduction

WeRobotics is field testing the use of locally affordable and repairable cargo drones in the Peruvian Amazon Rainforest. The purpose of these field tests is to better understand the opportunities and limitations of using affordable solutions for the rapid delivery of essential supplies in the Amazon. As such, the field tests seek to better understand the failure points and failure rates of the technology while developing streamlined workflows to enable the safe and regular delivery of essential items in the rainforest. Understanding the limitations of affordable solutions in relevant social, geographical and environmental contexts is thus one of the overarching goals of the field tests. In addition, the field tests serve as a capacity building opportunity for our Peru Flying Labs. Our research has been concentrated in the region around Pucallpa, a city of around 200,000 people on the Ucayali River (one of two main tributaries of the Amazon) that is the end-point of the 846 km-long Lima-Pucallpa expressway. Pucallpa acts as the last road-accessible populated area inside the Amazon rainforest, and is a main transportation hub for the villages deep within the Amazon that use the river as their main mode of transportation.

Map: Pucallpa and surrounding region, including the villages of Contamana, Tiruntan and Masisea from which WeRobotics performed drone deliveries

Our Peru Flying Labs team has been researching challenges related to public health and supply chains across Peru since early 2016. This research included extensive discussions with the Ministry of Health as well as fact finding missions to meet with local hospital and regional health centers. This primary research was also complemented with secondary research. The research revealed that snakebites are a real issue across the Amazon Rainforest and in particular in the Pucallpa area. Local clinics often run out of anti-venom and other essential medicines. In talking with local doctors, we also learned about the needs for transportation of blood samples from small villages to regional medical centres for testing. While in Pucallpa and Contamana, we also learned about the need to transport diagnostic testing supplies to both remote villages and clinics.

Transporting anti-venom and blood samples is expensive, and river boats are often the only means of transportation. This means that it can take up to 6 hours for new anti-venom to be transported from the small town of Contamana to the remote village of Pampa Hermosa only about 40km away, for example. In contrast, a cargo delivery drone can cover this distance in just 35 minutes as demonstrated during our initial field tests in December 2016 using a re-purposed, affordable (~$3,000) mapping drone. During these tests we demonstrated the delivery of anti-venom between Contamana and Pampa Hermosa, and the return delivery of a blood-sample during a night time cargo flight.

Given the potential from these preliminary tests, we decided to plan further field tests in the region. In February 2017, our Peru Flying Labs used a longer range fixed wing mapping drone (costing $4,600) to deliver about 500 grams of saline solution (to simulate blood samples) between Contamana and the remote village of Tiruntan (75km south). The flight took just over an hour. From Tiruntan, the batteries of the drone were replaced, and the drone was sent on to Pucallpa about 50km away. Due to a battery issue (which has since been resolved), the cargo drone landed 2km before Pucallpa without incident. It was subsequently retrieved.

While very informative, doing these one-off tests or demos can only provide so much insight. What we needed next was to carry out several dozen flights over several weeks, not just 2 flights in 2 days. Only then would we begin to better understand the possibilities and, more importantly, the limitations of using affordable cargo delivery drones. In other words, we wanted to understand what the failure points of this technology are when operated in the hot, humid and wet environments of the Amazon Rainforest. We could then document the failure rates and then develop what is known in the commercial manned aviation industry as a "preventative maintenance" strategy. Only if we know which parts fail and how often they fail can we develop a preventive strategy to have select parts verified or replaced after a select number of flights or landings. A preventive maintenance strategy thus serves to extend the longevity and reliability of aircraft, whether these be manned or unmanned.

Photo: Assembling and field testing the Amelia cargo delivery drone outside of Lima

This explains why we returned to the Amazon in June 2017 for our most recent field tests, which were carried out in collaboration with Becton, Dickinson and Company (BD), the Ministry of Health and local doctors, Peru Flying Labs, UAV del Peru. The field tests were co-financed by WeRobotics, BD and UAV del Peru. BD is a leading, multi-billion dollar medical technology company that manufactures and sells medical devices, instrument systems and reagents

The first 2 weeks were focused on assembling and testing the cargo drones near Lima, enabling our Peru Flying Labs team to get trained on the technology and workflows. As detailed in the “Cargo Drones” section below, we also worked with our technology partner (Oriol Lopez) to customize two additional cargo drone platforms using the SkyHunter airframe. The reason for this was to carry out longer distance field tests and to also carry a larger and heavier payload. In addition, one of the SkyHunters was turned into a quadplane or hybrid vertical takeoff and landing (VTOL) platform. This means that this VTOL platform can take off and land like a helicopter but then fly like a plane. This is particularly advantageous when having very limited space for takeoff and landing.

Photo: Field testing cargo drones just north of Pucallpa in the Amazon Rainforest

Once the drones were built we relocated to Pucallpa for 2 weeks of field tests, between June 19 -29, 2017. Cargo drones were flown to/from Pucallpa, Masisea, Tiruntan and Contamana. The purpose of this report is to present our findings from these field tests and to document the learnings along with our next steps. Unlike our previous field tests in the Amazon, this time we had the opportunity to work directly with one of the leading medical technology companies in the world, BD. The company already has operations in Peru, so BD was particularly interested to learn more about our community-based approach to robotics and to learn-by-doing with us to better understand the opportunities and limitations around using more affordable cargo drones to deliver a range of cargo between clinics and remote villages.

The BD team's deep understanding of the public health space made these field tests far more relevant for everyone involved. Their partnership was an invaluable opportunity for us and our Flying Labs team to better understand the health care challenges in the region and how cargo drones could potentially address some of these challenges and thus make a very real and meaningful difference for the lives of many in the Amazon.

Healthcare Challenges

Our partner BD had the opportunity to carry out a number of fact finding missions during the cargo drone field tests. These included several discussions with healthcare professionals in Pucallpa, Contamana, Masisea and Tiruntan. The purpose of these interviews was to better understand the full range of health care challenges that local communities face in this region of the Amazon. The interviews also sought to provide a better understanding of the actual status of the health care systems already running in the region. The following documentation was kindly shared by BD for inclusion in this report.

> To assess the clinical needs of the region, 7 healthcare facilities were visited in 4 communities along the Ucayali River in Peru (from Pucallpa: Masisea, 35 km South; Tiruntan, 55 km North; and Contamana, 130 km North). The visits focused on evaluating the existing infrastructure and interviewing healthcare professionals to discuss local health burdens, standards of patient testing and care, currently available resources, financial arrangements, and unmet needs.
>
> Two examples from the visits illustrate the desperate and consistent need for improved transport of patient samples and medical supplies, both of which cargo drones could potentially help address. Individuals with HIV in the region must travel to Contamana, the nearest town with an airport, to have blood drawn for CD4 testing. The trip from Tiruntan to Contamana (~70 km by air) takes around 6 hours by boat. The blood is then flown first to Pucallpa, aggregated with other specimens, and then flown to a centralized testing facility in Lima. Unfortunately, due to time delays in transport, samples reaching Lima for testing often are no longer valid. The process is a burden to patients and the healthcare system overall in terms of time, cost, and lost productivity. Not surprisingly, many individuals do not follow through with care. Drones could potentially enable collection of blood samples in local communities, followed by drone transport of the samples to Contamana. More patients would have access to testing, and it could be provided at lower cost. Drones could also potentially be used to transfer the samples from Contamana to Pucallpa.
>
> The second example relates to the delivery of supplies from regional clinics to smaller health posts. While in Contamana, the BD team met a woman who had arrived the night before from an outlying community following serious complications in childbirth. Since drugs for treatment weren't available in her community, she had traveled for 5 hours (3 hours walking and 2 hours by boat) while enduring postpartum hemorrhaging, to reach the hospital in Contamana. The use of a drone would have allowed emergency supplies

> to be delivered within 30-60 minutes directly to the remote community where the woman gave birth.
>
> Our conversations with the clinicians, patients, national health officials, and community members indicated a clear unmet need for transporting medical supplies and, almost more importantly, patient specimens to allow for appropriate diagnosis.

WeRobotics also identified clinical needs and transportation challenges when cargo drone delivery field tests were carried out between Pucallpa and Tiruntan (55km North). There are only two ways to reach Tiruntan: 1) Amphibious plane and 2) Riverboat. To get to Tiruntan, the WeRobotics team took an amphibious plane (costing USD 270) and taking approximately 20 minutes. (It is worth noting that getting to the airfield in Pucallpa from central Pucallpa takes at least half an hour. And after landing in the river near Tiruntan, it takes an additional half an hour walk or 10 minute motor taxi ride to get to Tiruntan). It was only coincidence that the amphibious plane was actually available that morning. The reason the team traveled to Tiruntan was to meet with the local mayor and local hospital before delivering essential medicines by drone from Pucallpa. On the way back, WeRobotics had to charter a "fast" boat which took well over 3 hours to return to Pucallpa (not counting the transportation time to/from each docking port). This fast boat cost USD 300. In contrast, the drone delivery took 40 minutes.

The local hospital in Tiruntan was particularly impressive--fully equipped with numerous examples of high-tech medical equipment. The hospital compound itself would make for an excellent small drone landing pad (or "Droneport") for VTOL drones as these could land directly within the fenced-off compound. We also learned whilst speaking with doctors at this hospital that they have very frequent cargo delivery needs between Tiruntan and Pucallpa (55km away) and Tiruntan and Contamana (75km away) given that the hospital serves many communities in the region. Based on further discussions with the doctors and officials, it became clear that there is a strong business case for situating a small Droneport directly at the hospital. What's more, not only did the hospital have access to electricity (not continuous), they also had good WiFi connectivity and spare rooms to store the drones along with relevant equipment.

Drones and Cargos

A total of 9 cargo drones were used during the field tests this past June. These are listed in the table below. More details on each platform and cargos transported is provided in Appendix 1 and 2 respectively.

Name	**Units**	**Type**	**Model**	**Practical Range w/ max cargo**	**Cargo Volume (L), Weight (g)**	**Price** (approx)
Frankie	3	Fixed Wing	Event 384	30km	1.65 L, 800 g	$3,000
Laura	2	Fixed Wing	Event 384 Long Range	70km	1.06 L, 300 g	$5,000
Amelia	2	Fixed Wing	SkyHunter Airframe	80km	4.14 L, 700 g	$5,000
Jacques	2	Quad Plane	SkyHunter Airframe	30km	4.14 L, 700 g	$5,000

Table 1. List of cargo drones field tested in the Amazon Rainforest

The Amelia and Jacques drones were assembled and initially field tested in Lima during the first half of June. As such, they were (and still are) highly experimental platforms. This is in contrast with the Frankies and Lauras which are commercially available platforms that have been flown across the United States and a dozen other countries for a host of projects ranging from disaster response to agriculture.

A total of 44 complete flights (not counting short testing flights) were carried out during the 2-week period. The cargo drones were field tested with a range of cargo types, volume and weight. These are summarized in Table 2 below. In some cases, drones carried different types of cargos in the same cargo bay. Note that sensors are not included in the table below. Please see Appendix 2 for the list of sensors included in the cargo drones.

Pictures of various types of cargo are displayed in Appendix 2.

Communities & Permissions

Community outreach and raising of public awareness were carried out the weekend prior to the cargo delivery field tests. This was done in person with relevant government officials, doctors and community representatives. The outreach was also carried out via radio and a newspaper article (in Pucallpa). We followed a dedicated Code of Conduct for all WeRobotics projects.[1] This Code of Conduct was developed by the Humanitarian UAV Network (UAViators) in close collaboration with dozens of leading humanitarian and development organizations. Before cargo drones were flown to the selected destinations (Masisea, Tiruntan and Contamana), each was first visited by WeRobotics, Peru Flying Labs and/or UAV del Peru in order to ask the local authorities and communities there for permission.

Photo: Hand-launching cargo drones near Pucallpa in the Amazon Rainforest

While the cargo drones used for the field tests were not carrying cameras, one community expressed concerns based on local superstitions that the drones would "steal their faces". Our Peru Flying Labs team therefore continued their awareness raising to explain to communities that the drones were only being used to transport medical supplies. Another local community, known in the region for being fiercely independent, were particularly unpleased with our

[1] http://werobotics.org/codeofconduct

request to use a nearby area for takeoffs and landings. We obviously complied with their request. Other than these two incidents, all other communities we engaged with responded very positively and with great interest.

Photo: Air traffic control for our cargo drone delivery flights in the Amazon Rainforest

Official written permissions for the flights were secured by our Peru Flying Labs team from the Peruvian Civil Aviation Authority, DGAC. The permissions required us to fly below 400 feet and at least 5 kilometers away from any airport. For one of our flights (from northern Pucallpa to Masisea), the shortest flight path of the drone would literally have the drone fly directly across the runway of the international airport of Pucallpa. The alternative was to fly well around the airport but this would then require traveling further and taking longer. The latter was still an option but we were curious to find out whether the local airport authorities would be amenable to coordinating manned and unmanned aircraft. Thanks to one of our Peru Flying Labs volunteers, a retired Air Force General from the Peruvian Air Force, we were able to liaise directly with the airport authorities and ask their formal permission to fly over the runway. To our surprise, the response was positive. Pucallpa Airport has a dozen or so flights per day and we were granted a 3 hour window to cross the runway (although we only needed 30 minutes even with a safety margin). Though we did not perform any flights above the airport during this round of testing, the exercise demonstrated the willingness of airport authorities to support and coordinate with future drone delivery flights and operations.

We already had the strong backing from the Peruvian Ministry of Health for these field-tests thanks to their previous support during the initial field tests in December 2016 and February 2017. Indeed, in a formal letter of support, the Ministry of Health referred to our field tests as being "in the national interest of the country."

Photo: Engaging with local communities in the remote village of Tiruntan

In terms of insurance, the WeRobotics team and drones are insured for all projects outside the United States. The UAV del Peru team and their drones were also insured.

Testing Methodology

The flight tests were carried out by two teams. Team 1 from Peru Flying Labs and UAV del Peru field tested the cargo drones using the Frankie and Laura platforms while Team 2 from WeRobotics field tested the prototypes Amelia and Jacques. A customized checklist was developed for the field tests and shown in the figure below.

	Drone Mission Sheet - Peru Cargo Tests June 2017			
	Date		**Drone**	
	Manual Pilot		**Copilot**	
A. In office - Pre-flight	**Equipment to bring: sending team**	Drone: ☐ Fuselage ☐ Wings ☐ Tail ☐ RC remote ☐ Rubber Bands (Laura and Frankie)	☐ Propeller x2 ☐ Batteries ☐ Telemetry radio with USB cable ☐ Charger ☐ ToolBox ☐ Laptop	☐ Voltage meter ☐ Log sheets ☐ Spot satellite tracker ☐ Scale (for cargo) ☐ Water, sunscreen
	Equipment to bring: reception team	☐ Telemetry radio - secondary ☐ RC remote - secondary (Laura, Amelia) ☐ Laptop ☐ Usb cable - telemetry ☐ Rubber bands	☐ Spare Propeller ☐ Charger ☐ ToolBox ☐ Batteries ☐ Voltage meter	☐ Generator ☐ Gas/Oil
	Checklist before leaving office	☐ Authorities informed (mayor / local leaders) ☐ Batteries charged (drone, controler, tablet) ☐ Flight plan prepared and saved and shared ☐ Tablet and drone software updated and ready ☐ Background maps loaded for entire route		
B. In field - before first flight	**Checklist before first flight**	☐ Propellers in good condition ☐ Well fixed propellers ☐ Cleaned engines ☐ GPS Satellites acquired > 8 ☐ Drone battery > 90% ☐ Controller battery > 50% ☐ Tablet/laptop battery > 50% ☐ Takeoff area free of obstacles ☐ Observers being kept at distance ☐ GPS Tracker (SPOT) enabled	**Weather**	☐ Rain ☐ Ground Wind speed: .... ☐ Temperature: .... ☐ Birds ☐ ....
			Takeoff/ Landing Location status	☐ Dusty ☐ Dry ☐ Wet ☐ ....
	Arrival time in field		**Time ready for first flight**	
D. In field - after last flight	**Checklist after last flight**	☐ Check state of drone ☐ Copy flight logs to laptop ☐ Copy payload logs to laptop ☐ Pack up all equipment	**Comments on mission**	
D. In office - Post Mission	**Checklist**	☐ Flight and cargo logs saved in a folder 2017-XX-XX_(Location)_(Mission) ☐ SD card cleaned and re-inserted in the Drone ☐ Drone, controller and tablet batteries set to recharge ☐ Drone stowed and ready for the next flight		
	Maintenance description		**Maintenance time**	
	General Observations			
	Copilot Signature		**Pilot signature**	

Figure: Checklist used by pilots for the cargo delivery field tests in Peru

Team BD were focused on understanding the unmet healthcare needs and the potential for drones to help address them. Taken together, WeRobotics, Peru Flying Labs, UAV del Peru and BD brought together 15 members for the field tests in the Amazon.

In addition to the checklist, the flight log sheet in the figure below was also developed for the tests. Both the checklist and log sheet were printed out and given to all the pilots and copilots.

Mission Sheet - Peru Cargo June 2017		Date:		
	Flight 1	Flight 2	Flight 3	Flight 4
	Sending of drone	Sending of drone	Sending of drone	Sending of drone
Drone name *(Frankie I, Laura II)*				
Pilot & Copilot - sending team *(Juan & Jose)*				
Cargo weight *(250g)*				
Cargo description *(blood, bags)*				
Weather (takeoff location) *(5km/h wind, light rain)*				
Takeoff location *(dirt field, airstrip)*				
Destination *(dirt field, airstrip)*				
Expected flight distance and time *(15km, 25min)*				
Number/type of batteries *(2xTitan 14Ah)*				
Battery voltage at takeoff *(16.8V, 100%)*				
Time at takeoff *(11.25 am)*				
Reception team contacted and ready? *(YES)*				
Communication lost - max distance *(3440m)*				
Special notes *(bad takeoff, etc)*				
	Reception of drone	Reception of drone	Reception of drone	Reception of drone
Pilot & Copilot - receiving team *(Marco & Elena)*				
Sending team contacted? *(YES)*				
Communcation detected distance *(1532m)*				
Time at landing *(11:46am)*				
Battery voltage BEFORE landing (read on screen) *(14.5V, 56%)*				
Battery voltage AFTER landing *(14.5V, 56%)*				
Distance flown *(18km)*				
Landing OK? *(YES)*				
Drone OK? *(YES)*				
Payload OK? *(YES)*				
Special notes				

Figure: Log sheet used by pilots for the cargo delivery field tests in Peru

Both the checklist and log sheet are [available here] as Google Spreadsheets for anyone to use (and improve). Anyone is welcome to insert comments directly to the respective spreadsheets to help improve the documents.

Pucallpa was selected as the base of operations because the small city represents an important regional hub in this part of the Amazon Rainforest. Pucallpa has good facilities and infrastructure, an international airport, fully equipped hospital and a number of small hotels to choose from. Three sites in Pucallpa were identified for takeoff and landings prior to the field tests, one in the north of Pucallpa at a small airstrip (grass) with hangar, which provided shelter, electricity, work tables, chairs and even intermittent WiFi. The other two locations were south of Pucallpa and more exposed. One was in a large seemingly abandoned football field, the other was off the beaten track about a kilometer from a main road. This customized map provides more information on the locations and also the various flight plans.

Photo: The airfield and hangar used just north of Pucallpa for the cargo delivery field tests

Masisea, Tiruntan and Contamana were each selected as destinations based on the public health use-cases that had already been identified through previous field-tests and in discussions with the Ministry of Health as well as regional health centers, local doctors and BD. Each site was visited before any flights were carried out in order to secure permissions from the local authorities and local communities.

A daily debrief and planning meeting was organized every evening between 6pm and 8pm. The purpose of this meeting was first to review the day's operations and to document lessons learned in order to improve on both workflows and technology the following day. The second half of the meeting focused on defining and preparing operations for the next day and remaining field-testing days.

Photo: Running pre-flights check at local airfield before long distance cargo drone flights

Flight Descriptions

A total of 44 complete flights (not counting a dozen short test flights) were carried out during the 2-week period. Various routes were tested to demonstrate the limits of the different platforms, medical use cases and workflows.

The first series of tests were run between the towns of Pucallpa and Masisea, at a distance of 36-40km (using two separate sites in Pucallpa). The goal of these flights was to test a real-world use case for Frankie- and Laura-type drones that are limited in flight distance. The two towns are only accessible via boat on the river and the voyage can take between 2-4hrs, depending on the boat being taken. Regular boat services only run once or twice a day. Several types of cargo, including medical supplies and food were transported between these two towns.

The second series of tests was performed between two sites around Pucallpa (the Airstrip and the Dirt Field) that were separated by 9.5km. The goal of these tests was to test workflows related to loading, launching, landing and recovering cargo from the drones.

The third tests involved testing the advantages of the Amelia drone compared to Frankie and Laura drones. A package was delivered from Pucallpa to Tiruntan, a village 51km away that's only accessible by a slow commuter boat connection that runs 4-6hrs. The Amelia drone was tested with a heavier and larger payload than what can be carried by Frankie/Laura drones.

The fourth test series was testing the performance of a custom-designed gas-powered drone, the Plan-H. The drone was flown between Pucallpa and Contamana, a distance of 126km, with a cargo of 1kg and still having a good safety margin of remaining fuel on landing (around 30%). Such a payload weight and distance combination remains significantly longer than what can be flown by the small electric-powered drones that were being trialed.

The table on the following page summarizes the different flight tests that were performed. Appendix 3 contains a description of the flight routes, whereas Appendix 4 includes more detailed information on select flights that were performed.

Route	# of flights	Dist. (km)	Drones	Cargo type	Notes
Pucallpa - Masisea	5	36-40	Frankie and Laura	Medical cargo	On second day, 1 Frankie had technical failure after takeoff
Airstrip - Dirt Path	8	10	Frankie and Laura	Medical cargo	High winds, 1 Laura had technical failure after takeoff
Pucallpa - Tiruntan	2	51	Amelia	Medical cargo	
Pucallpa - Contamana	2	126	Gas-powered fixed wing	Food, letter	Takeoff and landing from local airport in Contamana
Pucallpa - Airstrip Loop	14	2km, mult. loops	Frankie, Laura & Amelia	Medical Cargo	Flights were performed around airstrip for line of site
Loops Airstrip & Dirt Path	6	50-120	Amelia 1 & 2	Medical Cargo	120km with double battery and high margin. 80km done with standard battery and margin
Jacques test flights	5	1-2	Jacques 1	Empty	Early stage flights in assisted mode testing transition

Table 3. List of drone flights carried out during the field tests

Technical Failures

While 93% of the flights were successful, three technical failures were experienced during the field tests. The first involved one of the Laura platforms which failed a few minutes after takeoff. The manufacturer is still investigating the cause of the technical failure but the root cause may be related to preventive maintenance issues. In any event, Laura was subsequently retrieved thanks to the very kind help of the local community and Peruvian authorities including the former head of Peru's national disaster management organization, who served as a volunteer with our Peru Flying Labs.

The second failure involved one of the Frankie drones, which failed a few minutes after takeoff. The cause of this failure is still being investigated as well but may also be due to preventive maintenance issues. In any case, Frankie failed over a part of the rainforest that is dangerous due access on foot due to snakes, spiders and jaguars. Even without these hazards, the area is difficult to access on foot due to to thick forest, swamps and rivers. To make matters worse, due to an error in communication, the standard GPS tracker was not added to Frankie's carbo bay per the pre-flight checklist requirements. So multiple search parties were sent out in the days and weeks following the disappearance but could not venture far out for the reasons just described. The search thus included the use of two multi-rotor drones with live video feeds to search larger areas that were not accessible by foot. Before departing from the Amazon, UAV del Peru kindly offered a generous reward to local communities should they come across any information about the location of the drone. The drone is clearly labeled though, with a contact name and phone number taped to the front of the platform and Peru Flying Labs stickers in multiple places (like all the drones that were field-tested in June). At this point, we believe that Frankie is most likely underneath a dense thicket of trees.

The technical failures with the Frankie and Laura platforms were surprising and certainly a very stressful setback given how many flight tests were successfully carried out with both drones outside of Lima during the first half of 2017. Unlike Amelia and Jacques, which are very much prototype platforms, the Frankie and Laura platforms are commercially available drones that have been used extensively in the US and other countries. This is what leads us to believe that the root cause may of these failures may ultimately have been due to preventive maintenance issues, e.g., not replacing servos after 30 landings. In any event, as a result of these technical failures, all remaining Frankies and Lauras were immediately grounded for a minimum of 24 hours so that UAV del Peru and Peru Flying Labs could fully inspect each platform. No technical problems were identified and the remaining Frankies and Lauras did not experience any technical failures for the remainder of the field tests. As a precaution, since the earlier failures had occurred shortly after takeoff, UAV del Peru and Peru Flying Labs programmed the drones to circle directly overhead for several minutes before proceeding with their cargo delivery.

The third important failure involved the Amelia platform. The failure was provoked by a combination of factors including a sudden change in wind direction and a climbing pitch that was set too high for the heavier cargo that Amelia was carrying for that particular set of tests. These effects resulted in lower lift during the initial takeoff procedure and Amelia unable to clear the tall grass at the end of the runway. This was in part a controlled failure given the experimental settings used for the takeoff. In any event, because the failure took place during takeoff Amelia was quickly recovered and the cargo was intact. After this incident, an airspeed sensor was installed. Banking was reduced and the takeoff altitude was increased to gain more of a safety margin. During the next takeoff and in all subsequent field tests since, Amelia has not encountered any major technical failures. Note that sensors like airspeed sensors are a double-edged sword. When they work, they are invaluable. But when they don't (due to dust, sand, etc.), they can provoke serious technical failures. Fortunately, there are ways to avoid this issue using software. This explains why we are looking at alternative firmware options that protect the airplane from airspeed sensor blockages by discarding those sensor readings and flying with GPS and airspeed estimation.

Besides these failures, there were very minor (controlled) failures in the hand-launching of Amelia as various flight parameters were adjusted to optimize the takeoff portion of the flights. Some flights were aborted due to weather conditions and high winds. Other than that, all the other flights were completed as planned without incident.

Discussion

The field tests provided us and BD with the opportunity to learn about more health related use-cases for the delivery of medical supplies by drone. Given the high costs and many hours that it takes to transport essential medicines, diagnostic tests and patient samples across this part of the Amazon Rainforest, the use of cargo drones is particularly compelling. In addition, there is strong interest from the Ministry of Health and local doctors to continue exploring this alternative transportation solution.

Frankie and Laura drones are commercially available platforms that have been used extensively in the United States and other countries around the world for mapping purposes. Their affordability and positive track record made them a good fit for our continued field tests. That being said, they are stock common airframes assembled with hobby grade components running an open source firmware and ground control. Given their cargo volume constraints, the technical failures experienced with both platforms, some observations regarding the quality of components[2] and the fact that the cause of the failures have not been identified with any certainty, our preference in fixed wings of this price range is to select platforms that are better optimized for cargo with higher grade components and designed with local maintenance in mind.

From an operational perspective, our focus is moving towards a deeper evaluation of VTOL quad planes. VTOL technology required an armada of engineers and programmers just a few years ago, not to mention many failed prototypes. Today, thanks to solutions integrated in standard flight controllers, VTOL technology is becoming relatively easy to implement. In the last campaign, we had to spend a considerable amount of time to find appropriate takeoff and landing areas for Frankie, Laura and Amelia. These locations were often outside the main urban areas, i.e., nowhere close to the hospitals or clinics. Transportation times to/from these places and the takeoff/landing areas took at least half an hour on average. The advantage in moving forward with quadplane solutions like Jacques instead is that the platform could takeoff and land at the hospitals or clinics, making those areas more secure and the cargo delivered directly. Another advantage of a quadplane or VTOL cargo drone is that the takeoffs and landings are easier and less prone to damage. Automatic takeoffs, unlike the handlaunch of fixed-wing drones, reduces the chances for crashes while automatic, vertical landings are much softer on the hardware than the landings of fixed-wing aircraft that tend to wear the hardware after few dozens of flights.

[2] Note that higher quality and thus more durable versions of these components could be used instead. The tradeoff is simply cost.

Photo: Showing children in the Amazon Rainforest how to program cargo delivery flights

The field tests also revealed important opportunities for improving the workflows around the use of cargo drones for medical deliveries. A related issue was the actual use of the designated checklists and the filling out of the log sheets. On several occasions, checklists were not followed and log sheets were not completed. As a result, GPS trackers were not included in each drone flight, for example. What's more, if flights were not logged, they were not included in the total number of flights documented above. Obviously, this is problematic. We are exploring various ways to integrate the use of checklists and make the logging of flights less burdensome. Ultimately, the more tasks that can be automated through software and intelligent sensor checks, the less prone the process will be to human error.

From an economic standpoint, the cost of the platform (both acquisition and maintenance) is currently the major limiting factor to a sustainable drone cargo delivery service. The cargo drone industry is still in its infancy; low-cost drones (USD 5,000 - 10,000) are typically unreliable and ill-suited for long-term operation, whereas high-end drones can easily run upwards of USD

40,000 and are not easily serviced locally due to specialized parts. And although they are built with higher quality parts and more rigorously tested, there is still limited data available on long-term reliability to define an accurate amortization point. For comparison, a used single-propeller Cessna, the current workhorse of aerial delivery in hard-to-reach places, can be bought for around USD 100,000. The Cessna also has decades of use cases and reliability data available and can typically be maintained locally. Of course, the use of manned aircraft comes with relatively high variable costs in terms of pilots and fuel, for example. They are also grounded due to weather conditions including dense fog, which is not uncommon in the Amazon. In fact, during our field tests, Air Traffic Control at Pucallpa Airport grounded all flights for half a day due to fog. We were still able to fly our drones through the fog during this time.

Photo: Drone carrying medical supplies comes in for landing in the remote village of Tiruntan

The Peruvian Ministry of Health is particularly interested in Contamana providing a centralized medical cargo service due to its growth capacity and its current position as health services hub for the region. Based on our findings over the past year, we believe that the expected frequency of flights between Pucallpa, Tiruntan and Contamana will range around 3 to 6 return flights per week. We envisage having 4 cargo drones with 2 dedicated drones for each destination (Contamana - Tiruntan; Contamana - Pampa Hermosa) based at a small Droneport situated in Contamana. Only one cargo drone would be used for each leg, with the other used in case the primary drone needs to be serviced, thus building redundancy into the delivery network.

Selecting a USD 40,000 cargo drone for this project would require USD 160,000 for the technology alone. Spare parts and maintenance costs can add easily add tens of thousands in costs per year, bringing the cost of each delivery into the hundreds or even thousands of dollars. In addition, the need for specialized training and skills for piloting and maintenance of the platform and the difficulty of getting spare parts can also create significant downtime in the network.

Such high costs are not affordable nor sustainable; in order for the network to be viable, the cost of acquisition must be reduced to less than USD 50,000, operations costs should be reduced to a few thousand dollars a year, reliability must be greatly increased, and maintenance should be localized.

Photo: Loading cargo into a hybrid cargo drone before a long distance flight in the Amazon

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Conclusion

In conclusion, our continued experiences in the Amazon Rainforest compels us to continue stressing that the ultimate cargo drone does not exist. Rather, the real questions are: what type of drone is most appropriate based on the specific problems that need to be solved? What drone, based on the specific circumstances, types of partners, funding constraints, regulatory restrictions, nature of the cargo, frequency of flights, etc., actually makes the most sense for the social, economic, geographical and environmental context in which these drones are to be used? Equally importantly, are there any realistic and compelling alternatives to using cargo drones? Finally, what potential negative (or positive) impact might the use of cargo drones have on the local economy?

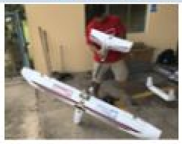
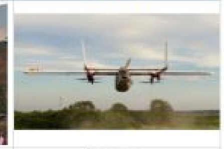
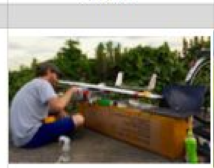
Photo: Cargo drone selfie over the Amazon Rainforest during sunset.

In the case of the Peruvian Amazon Rainforest, the experience we have gained from our three field tests and the insights we have gained thanks to Peruvian health professionals lead us to suggest that an affordable cargo drone is needed and one that can be easily operated *and* repaired locally. Affordable, of course, is relative. We believe that a far more affordable platform is required, priced well under USD 10,000 and preferably closer to the USD 5,000 mark, in order to make the price of each delivery competitive with the price of riverboats and amphibious planes. In terms of cargo capacity, a platform that at minimum should be able to carry 500 grams in a standard biohazard box across 100 kilometers -- preferably 120 kilometers.

The Jacques platform still needs some serious work and additional field testing before we can bring that model back to the Amazon. Together with our technology partner, we drafted a 2 year roadmap for the further development and improvement of the Jacques platform. One of the priority design parameters that our partner will continue to follow throughout this process is affordability and cargo optimization. We plan to return to Peru in June 2018 to carry out 2 months' worth of actual cargo deliveries between Pucallpa, Tiruntan and Contamana. By "actual" we mean deliveries based on actual demand from the various clinics and hospitals. These deliveries will not include patient samples but rather medicines and diagnostic tests as needed.

While our technology partner continues working on Jacques (2.0) we are continuing to scope the market and startup space and pro-actively reach out to companies developing promising cargo delivery solutions that fit the needs of the use-cases we've identified in the Amazon Rainforest. We look forward to returning to the Amazon Rainforest in 2018 to continue our work with the Ministry of Health, local doctors and other partners to help improve the public health supply chain in the region.

Appendix 1: Drone Specifications

Specifications	Manufacturer	Manufacturer	Theoretical	Theoretical
Image				
Nickname	**Frankie**	**Laura**	**Amelia**	**Jacques**
Model	E384	E384 Long-range	Custom-built Skyhunter-frame	Custom-built quadplane, heavily modifed Skyhunter
Manufacturer	Event38	Event38	Oriol	Oriol
Type	Fixed-wing	Fixed-wing	Fixed-wing	Quadplane
Cost (USD) - approx	$3,000	$5,000	$4,500	$5,500
Website	https://event38.com/fixed-wing/e384-mapping-drone/			
Dimensions				
Wingspan (cm)	190	210	180	180
Length (cm)	130	130	130	130
Weight (kg)				
Airframe only	1.50	1.60	1.60	2.10
Empty (no payload, with batteries)	2.41	3.20	2.80	3.10
Max Takeoff	3.50	3.50	3.50	3.80
Batteries			Titan Power	Tattu
Battery weight (kg)	0.46	0.80	1.20	0.94
Battery voltage (V)	14.80	14.80	14.80	14.80
C-rating	15	15	2	15
Capacity (Ah)	8	14	21	10
Max discharge current (sustained) (A)	120	210	43	10
Capacity (Wh)	118	207	311	148
Transport in carry-on?	Only 2	No	No	No
Cost (USD)	$50	$100	$200	$120
Number per drone	2	2	1	1
Cargo				
Max Payload weight (kg)	0.80	0.30	0.70	0.70
Cargo bay dimensions (cm)	14x10x6 (front) + 23x10x3.5 (above battery)	10x8x6 (front) + 29x10x2 (above battery)	23x18x10	23x18x10
Cargo bay volume (L)	1.65	1.06	4.14	4.14
Endurance (minutes)				
No payload, no wind (min)	90	120	126.67	46.15
Max payload, no wind (min)	40	60	106.67	34.62
Speed				
Stall speed (km/h)			32	38
Cruise Speed (km/h)	47	47	45	52
Range				
No wind (km)	70	94	95	40
High wind (km)			80	30
Operating conditions				
Ceiling (m MSL)	3,960	3,960	TBD	TBD
Ceiling auto-takeoff (m MSL)	3,100	3,100	TBD	TBD
Max sustained wind speed (km/h)	36	36	36	20
Telemetry Range (km)	5	5	5-10km	5-10km
Packaging				
Image				
Packaging size			27x29x120	27x29x120
Notes		Laura is a modified version of Frankie with a longer wingspan	Wings and body disassemble for easy transport	Wings, body and quad disassemble for easy transport

Appendix 2: Cargo Specifications

Various types of cargo were transported during the trials, including medical supplies, practical items (letters, food, etc) and sensors.

Figure: Example items that were shipped during the trials. Clockwise from top left: empty BD Vacutainer® blood collection tubes, various medical supplies, and a local fizzy drink.

Cargo Bay Size

Frankie- and Laura-type drones have a cargo volume of 1 to 1.6 L and of an inconvenient shape, whereas Amelia- and Jacques-type drones have a larger cargo bay of 4 L in a rectangular shape. The images below show the size of packages that could be transported in each type of drone.

Figure: A small cardboard box that fits inside Frankie- and Laura-type drones

Figure: a plastic bag full of test vials, fit loosely within a Frankie-type drone.

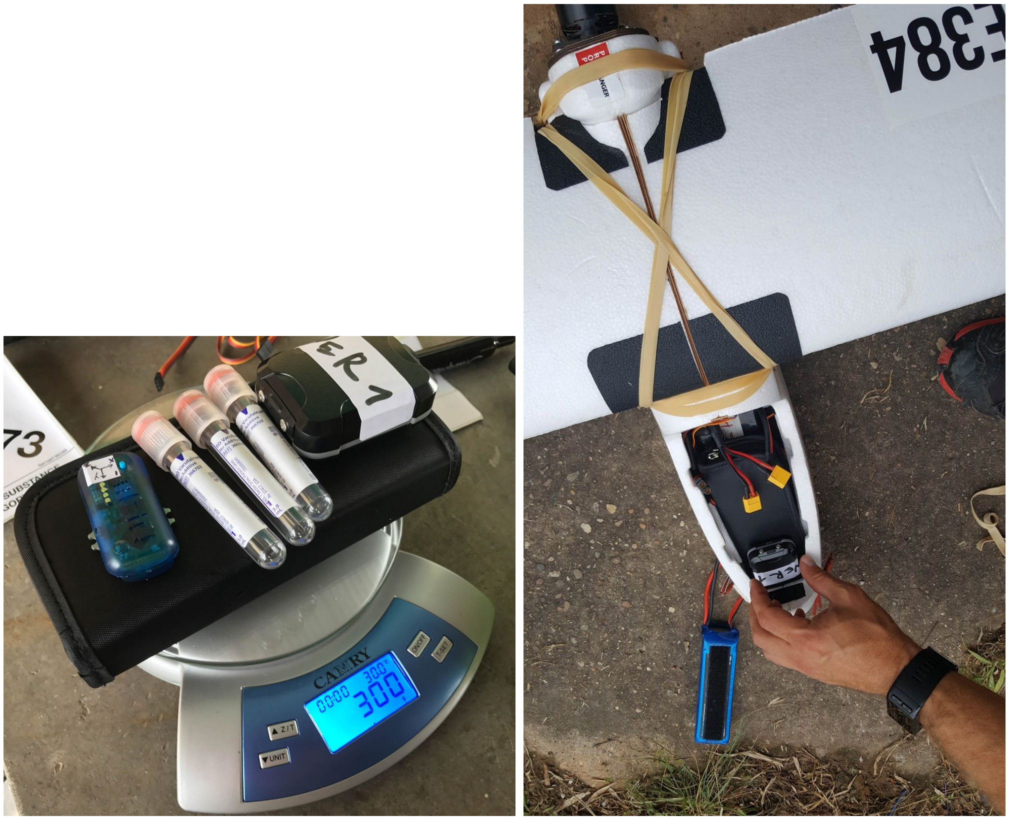


Figure: a small refrigeration pack, fit inside of a Frankie-type drone.

Figure: Large, standard-sized cardboard SAFTPAK box, used with Amelia and Jacque drones.

Cargo Bay Sensors

Several sensors were included as part of the cargo in order to measure the position and environmental conditions within the cargo bay. The images below show (from left to right)

- A SPOT satellite position tracker, for keeping track of the drone even if it loses connection to the ground station
- A LogTag temperature tracker, for long-term temperature measurements within the cargo bay
- A MSR acceleration sensor for detecting the shocks that occur to the cargo during takeoff and landing

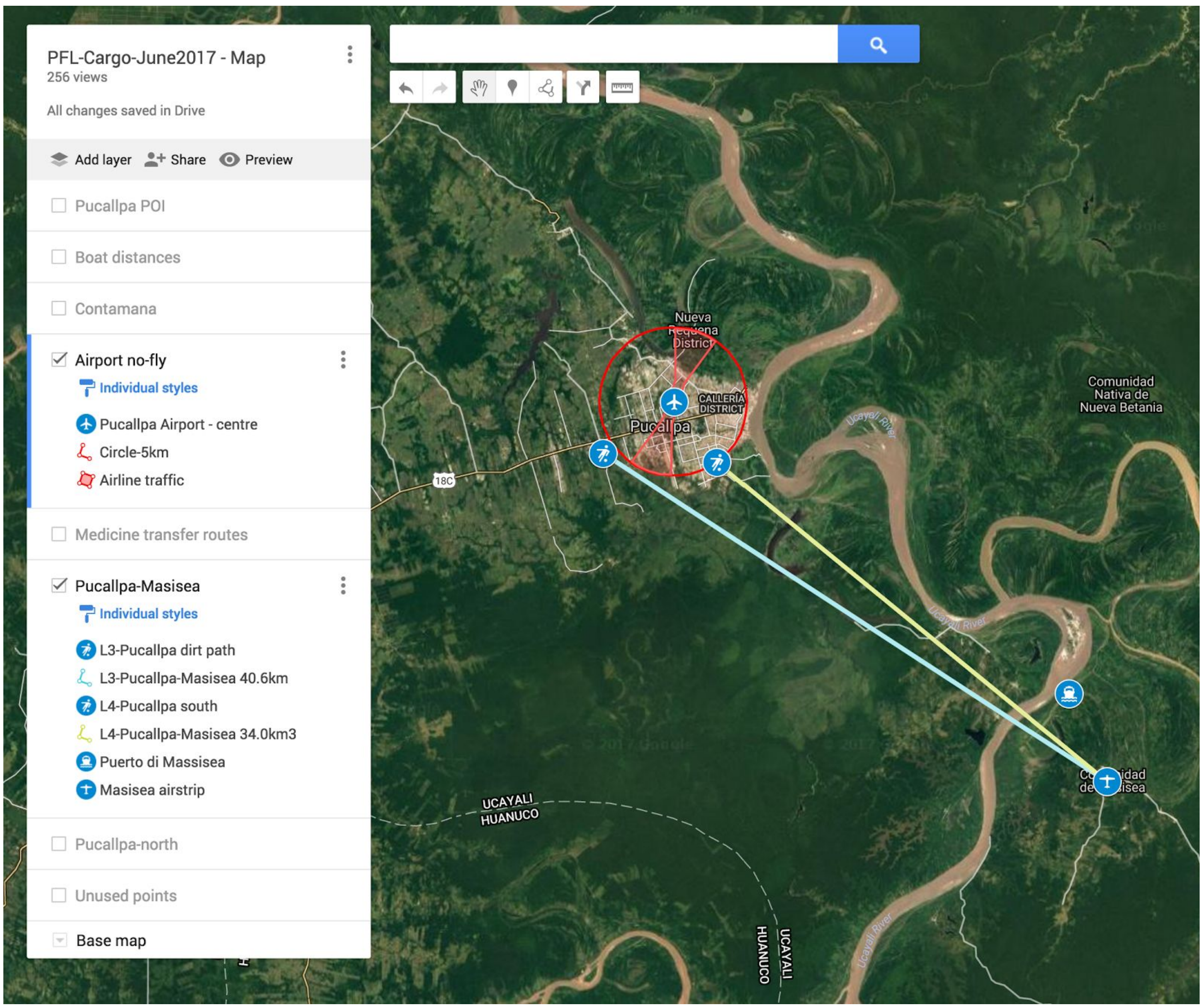
Figure: From left to right, a SPOT satellite tracker, a LogTag temperature sensor and a MSR acceleration sensor.

Appendix 3: Maps of Select Routes

Several routes were used to test various distances, takeoff and landing zones and use cases.

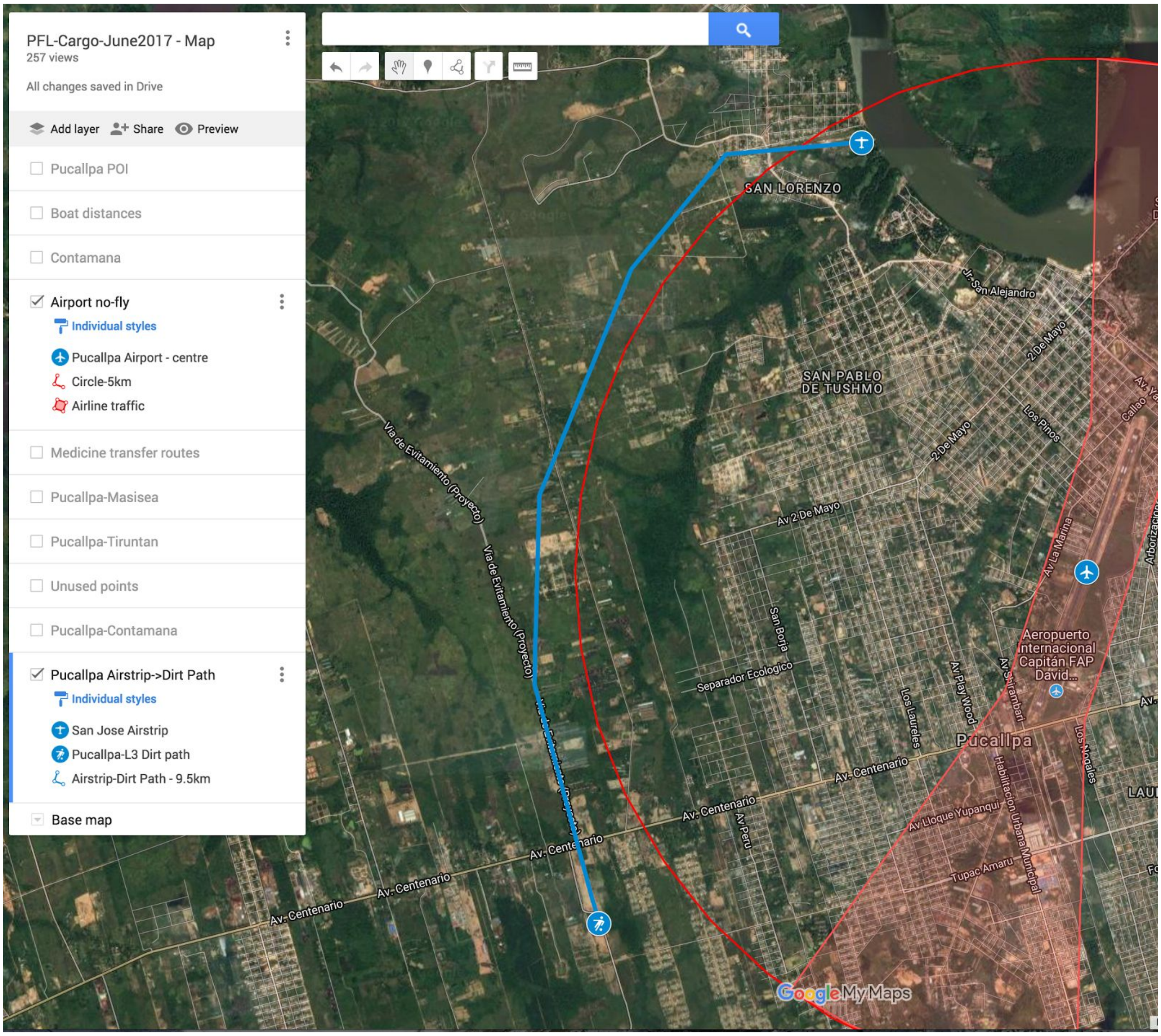
Route 1: Pucallpa (Dirt Path and South) to Masisea

Distance:
Pucallpa (South) to Masisea: 34.0 km
Masisea to Pucallpa (Dirt Path): 40.0 km



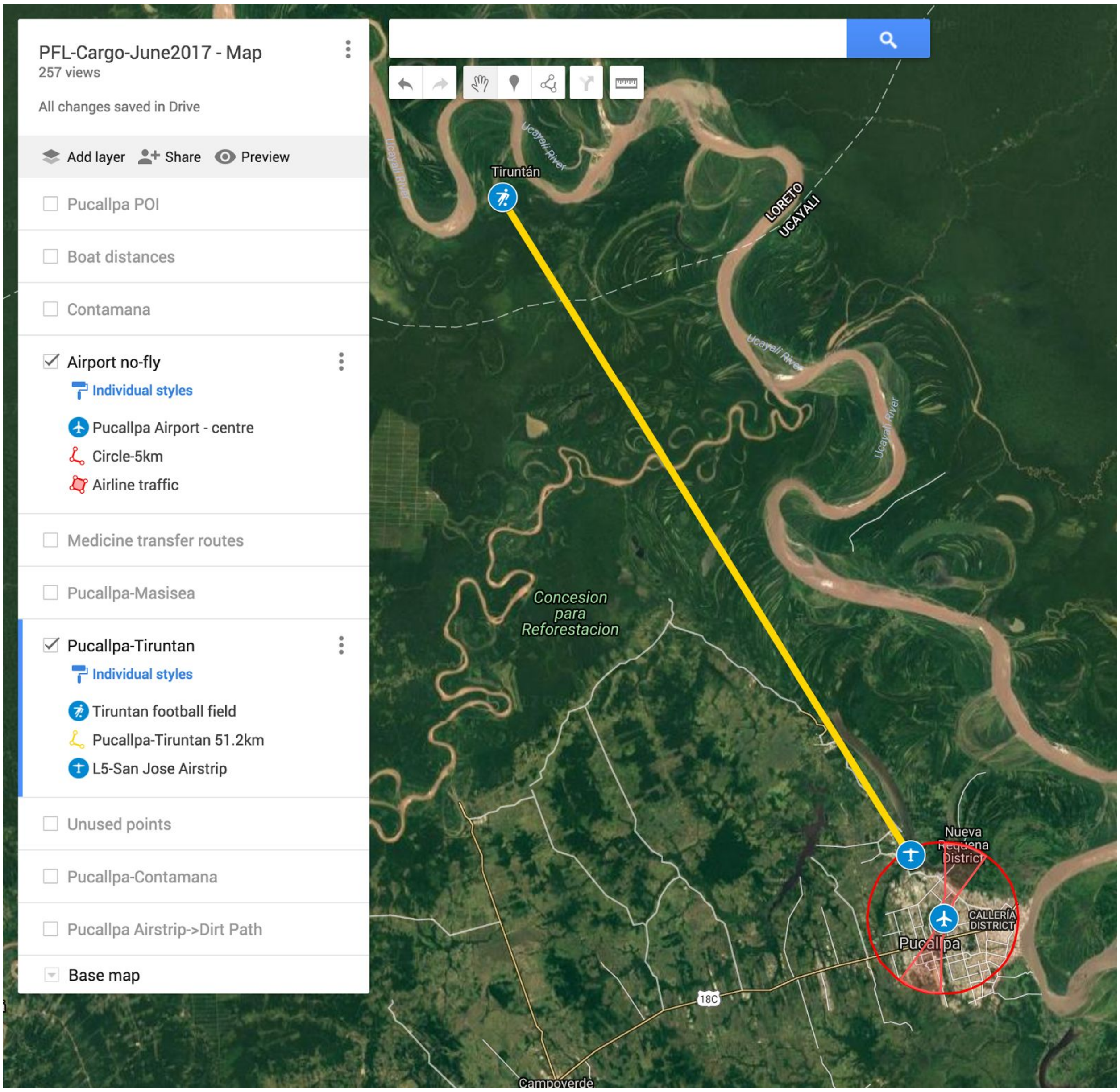
Route 2: Pucallpa (San Jose Airstrip) to Pucallpa (Dirt Path)

Distance:
Pucallpa (San Jose Airstrip) to Pucallpa (Dirt Path): 9.5km

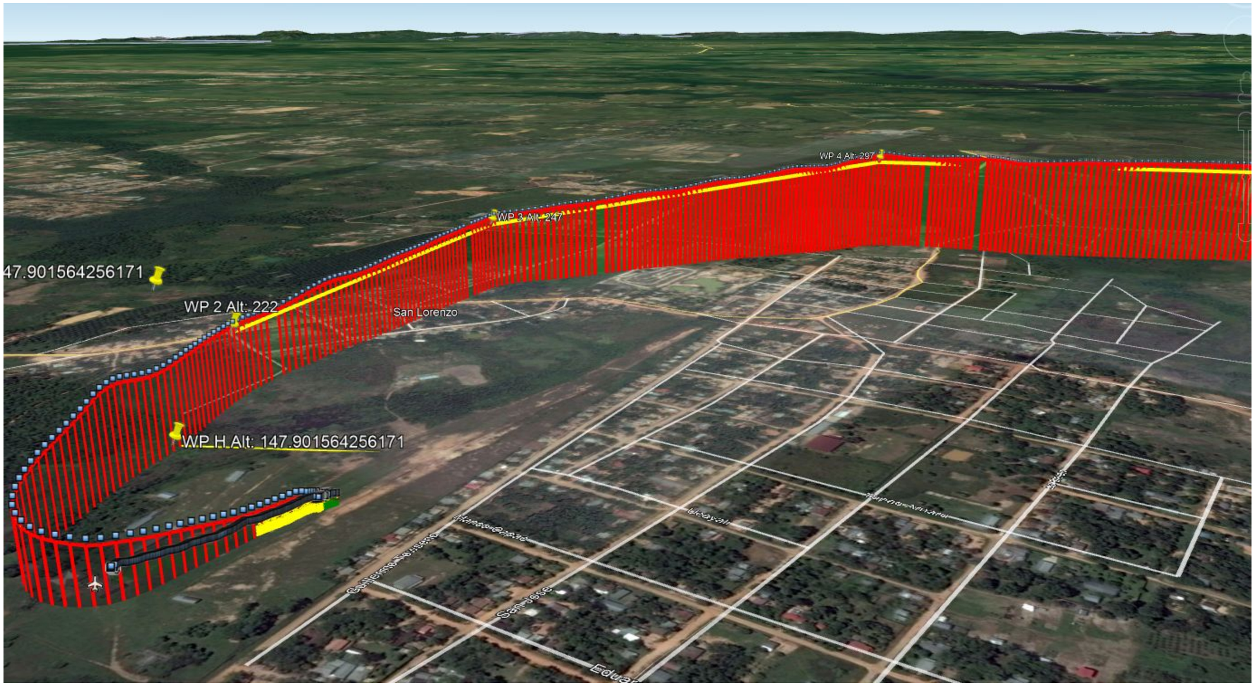


Route 3: Pucallpa (San Jose Airstrip) to Tiruntan

Distance:
Pucallpa (San Jose Airstrip) to Tiruntan: 51.2 km



Tiruntan to Pucallpa (San Jose Airstrip): 51.2 km. Graphic belows shows landing in Pucallpa.



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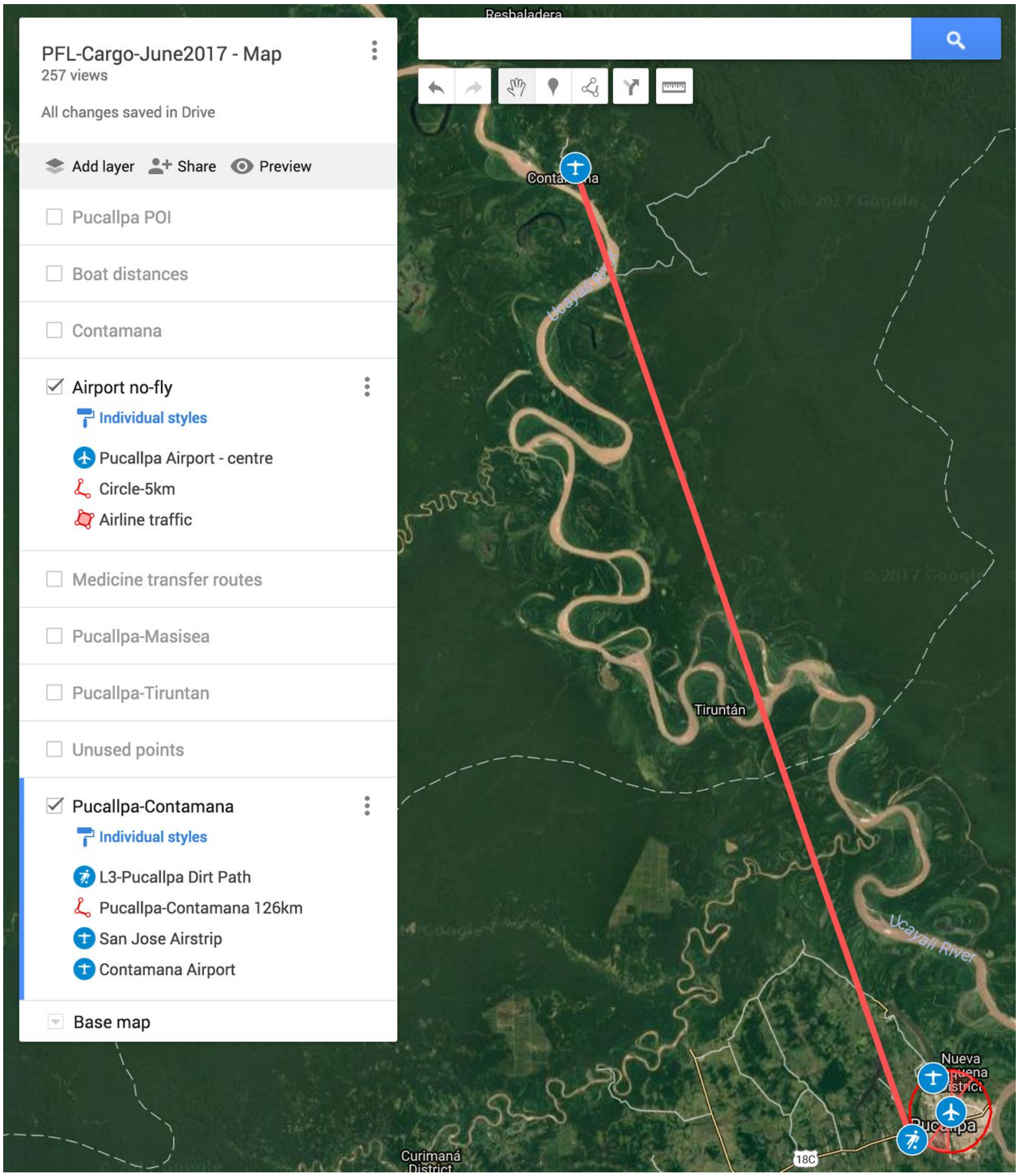
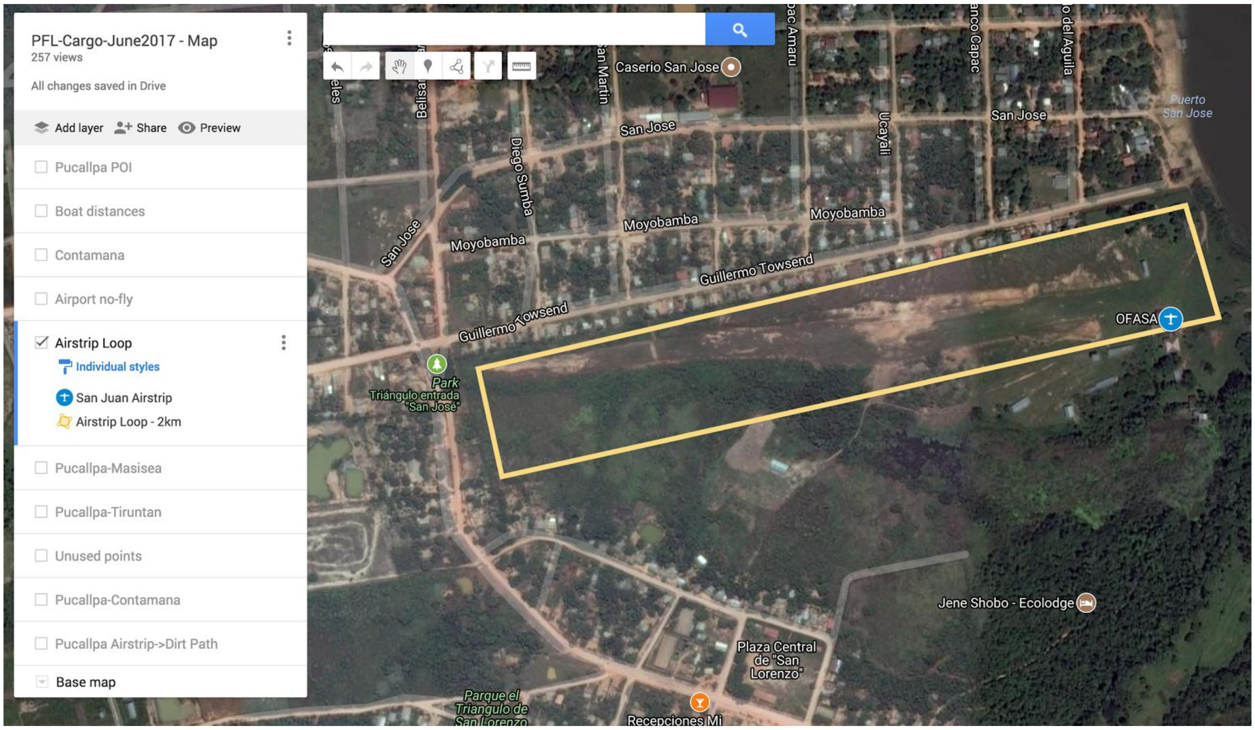
Route 5: Pucallpa (Dirt Path) to Contamana

Distance:
Pucallpa (Dirt Path) to Contamana: 126 km



Route 6 - San Juan Airstrip Loop

Distance:
San Juan Airstrip Loop: 2 km per loop



Appendix 4: Telemetry, Weather Data & Flight Stats

Our telemetry and weather data, as well as the detailed statistics on individual flights that were part of this study are available via this public Google Drive folder : https://goo.gl/XJ7gY8 .