Final Report of 31/05/2018

SP 250: produzione di elettricità dal vento in alta quota tramite il prototipo Skypull SP250

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Del contenuto e delle conclusioni del presente rapporto rispondono unicamente i suoi autori.

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Sintesi

Skypull mira a realizzare una soluzione innovativa brevettata per la produzione di energia da fonti rinnovabili: una soluzione con maggiore disponibilità, maggiore densità energetica territoriale, minori costi di installazione, logistica e smantellamento più facili, maggiore capacità produttiva, maggiore e più stabile produzione, impatto visivo e ambientale trascurabile, maggiore scalabilità e infine con un LCOE stimato a CHF 45 / MWh, garantendo al cliente un IRR stimato al 14,95%.

L'obiettivo del progetto è stato quello di realizzare un prototipo di potenza nominale di 3 kW, analizzarne il comportamento per caratterizzare l'elettricità prodotta e definire il modo migliore per integrare la produzione di energia nella rete. Prima dell'inizio del progetto, Skypull aveva completato con successo una prova di volo del primo prototipo su piccola scala (primavera 2016) raggiungendo una prima convalida. Skypull è una nuova soluzione di energia eolica, che sfrutta i venti di alta quota. Consiste di un generatore a terra con un generatore collegato ad un tamburo sul quale è avvolto un cavo in polietilene, leggero ma estremamente resistente, collegato ad un drone (UAV). L'UAV trasforma l'energia eolica tra 200-600 m dal suolo in trazione sul cavo, costringendo il tamburo a ruotare e il generatore a produrre elettricità.

Il programma di lavoro del progetto si è concentrato sullo sviluppo e sull'implementazione di tutte le funzionalità del sistema necessarie per raggiungere gli obiettivi del progetto, realizzando le seguenti attività:

1. Modifiche e test di UAV e del generatore a terra

2. Modifica e test del sistema di controllo di volo del drone

3. Integrazione e test del sistema

4. Gestione di progetto, gestione dei DPI, valutazione della conformità alle normative, preparazione SP2, attività di divulgazione.

Nel corso del progetto sono stati realizzati 8 diversi droni, valutate diverse soluzioni tecnologiche, il sistema completo è stato integrato e testato raggiungendo oltre 300 minuti di volo e circa 30 minuti di volo in modalità cablata, generando con successo energia dal vento di quota. Inoltre Skypull SA è stata incorporata, il brevetto PCT / EP2016 / 000479 è stato esteso a UE, USA, Cina e India e diversi accordi di cooperazione sono stati fatti, aprendo la strada per il completamento del sistema e il suo upscaling fino alla classe dei MW, con un team forte ed impegnato a perseguire la realizzazione di un nuovo sistema di generazione di energia elettrica, efficace, economico e pulito.

Zusammenfassung

Skypull zielt darauf ab, eine patentierte bahnbrechende Lösung für RES-basierte Energieerzeugungssysteme zu repräsentieren: mit größerer Verfügbarkeit, höherer territorialer Energiedichte, geringeren Installationskosten, einfacherer Logistik und Stilllegung, größerer Produktionskapazität, höherer und stabilerer Energieproduktion, vernachlässigbaren visuellen und ökologischen Auswirkungen, größere Skalierbarkeit und schließlich mit geschätzten Stromproduktionskosten von CHF 45 / MWh, wodurch dem Kunden ein IRR von schätzungsweise 14,95% gewährt wird.

Das Projektziel bestand darin, einen Prototyp mit einer Nennleistung von 3 kW zu realisieren, sein Verhalten zur Charakterisierung der Ausgangsleistung zu analysieren und zu definieren, wie die Energieerzeugung am besten in das Netz integriert werden kann. Vor dem Projektstart hatte Skypull erfolgreich einen Flugtest des ersten kleinen Prototyps (Frühjahr 2016) abgeschlossen und eine erste Validierung erreicht. Skypull ist eine neuartige Windenergie-Lösung, die Strom aus Höhenwinden erzeugt. Es besteht aus einem Bodengenerator mit einer Trommelwinde, in der ein sehr zugfestesSeil mit einem Fluggerät (Drone) verbunden ist. Die Drone wandelt die Windkraft zwischen 200-600 m über dem Boden in Zugkraft am Seil um, wodurch die Trommelwinde in Rotation versetzt wird und der Generator Strom produziert.

Der Projektarbeitsplan konzentrierte sich auf die Entwicklung und Implementierung aller Systemfunktionen, die zur Erreichung der Projektziele erforderlich sind, indem folgende Aktivitäten durchgeführt wurden:

1. UAV und Bodengenerator:Anpassungen und Tests

2. Einstellung und Test des Drohnenflugsystems

3. Systemintegration und Test

4. Projektmanagement, Geistiges Eigentum, Bewertung der Einhaltung von Vorschriften, Vorbereitung von SP2, Verbreitungsaktivitäten.

Im Rahmen des Projekts wurden 8 verschiedene Drohnen realisiert, mehrere verschiedene technologische Lösungen bewertet, das Gesamtsystem wurde integriert und getestet, wobei mehr als 300 Minuten Flugzeit und etwa 30 Minuten Flugzeit im gebundenen Modus erreicht wurden, um Energie aus dem Höhenwind zu gewinnen.

Nebstder Gründung der Skypull SA wurde das Patent PCT / EP2016 / 000479 auf die EU, die USA, China und Indien ausgedehnt, und es wurden mehrere Kooperationsvereinbarungen getroffen, die den Weg für eine Komplettierung des Systems und dessen Upscaling bis zur MW-Klasse ebnen könnten.

Abstract

Skypull aims at representing a patented breakthrough solution in RES based energy production systems: with larger availability, higher territorial energy density, lower installation costs, easier logistics and decommissioning, greater production capacity, higher and more stable energy output, negligible visual and environmental impact, greater scalability and finally with a LCOE estimated at CHF 45/MWh, granting to customer's a IRR estimated at 14,95%.

The project goal has been to realize a prototype of 3 kW rated power, analyze its behavior to characterize output electricity and define how best to integrate energy production into the grid. Prior to the project start Skypull had successfully completed a flight test of the first small scale prototype (spring 2016) reaching a first validation. Skypull is a novel airborne wind energy solution, which generates electricity from high-altitude winds. It consists of an on-ground generator with a drum winch hosting a strong light cable connected to a flying device (UAV). The UAV transforms the wind power between at 200-600 m above the ground into traction on the cable, forcing the drum winch to rotate & the generator to produce electricity.

The project working plan has been focused on developing and implementing all the system's features necessary to reach the project goals, by realizing the following activities:

1. UAV and ground generator modification and test
2. Drone flight system control modification and test
3. System integration and test
4. Project management, IPR management, regulation compliance assessment, SP2 preparation, dissemination activities.

Within the project 8 different drones have been realized, several different technological solutions assessed, the full system has been integrated and tested reaching more than 300 minutes of flight time and around 30 minutes flight time in tethered mode, successfully generating energy from altitude wind. Aside that Skypull SA has beenincorporated, patent PCT/EP2016/000479 has been extended to EU, US, China and India and several Cooperation agreements has been made, paving the way for a completion of the system and its upscaling up to the MW class, with a strong team committed to pursue the realization of an effective, cheap and clean energy generation system.

Take-home messages

- Despite the many challenges and difficulties, the Skypull concept has been tested and its potential validated.
- The need for automated flight controls for both safety and continuous operation purposes has been confirmed.
- The collaboration with the relevant stakeholders has been excellent and certainly facilitated by an early inclusion in the project.
- Social acceptance – during these test phases – has been surprisingly good. We did not have any negative remark.
- Switzerland as a testing base for innovative technology has been confirmed as ideal. The collaboration with the involved authorities has been excellent and always goal-oriented.

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Foreground

Energy is the largest market in the world and Renewable Energy Source (RES) based technologies take the lead, especially wind generation. Mankind has been recently enabled to reach the biggest energy reservoir existing on earth: the altitude wind. Standard wind turbines can just "scratch" this reservoir, limited by their intrinsic physical constraints. To overcome these limitations, several Altitude Wind Energy (AWE) concepts has been developed, but still no significant results have been reached worldwide. Skypull aims to representing a breakthrough solution in AWE systems, with a LCOE estimated at CHF 45/MWh, granting to customer's a IRR estimated at 14,95%. Initially targeted to providing generation systems and maintenance services, Skypull's potential positioning fields could range from equipment manufacturing up to energy production and supply.

Skypull, compared to all other existing present and under development wind energy technologies is aimed to enable a system with larger availability, higher territorial energy density, lower installation costs, easier logistics and decommissioning, greater production capacity, economic performance, higher and more stable energy output, negligible visual and environmental impact, greater scalability.

Skypull has a proprietary airframe structure (box-wing) and a high efficiency wing profile, protected by worldwide extended Patent No. ITUD2015A000038 and PCT/EP2016/000479.

Project goals

To realize a prototype characterized by a drone with 3 kW rated power, analyze its behavior to characterize output electricity and define how best to integrate energy production into the grid.

Framework

Skypull, compared to all other existing Altitude Wind Energy solutions, tackles the problem by dedicating great attention to the flying device, a tailored fully autonomous UAV drone with specific features: aerodynamic efficiency, lifting power, low weight, intrinsic resistance, automatic take off, flight and landing, safety, reliability and resilience.The UAV is equipped with propellers & motors used for vertical take-off & landing. They are also used to recharge the batteries of the UAV during flight.

The key element of Skypull system is a highly efficient & fully autonomous drone (UAV) that allows safe, effective & reliable high-altitude wind generation at a low cost.

The Skypull system is estimated to work at rated power up to 55% of the year (compared to 25-30% of traditional wind turbines) with an expected LCoE < 50 CHF/MWh, being potentially competitive with fossil fuel energy generation technologies regardless of public incentive policies.

Prior to the project start Skypull had successfully completed a flight test of the first small scale prototype (1.3m wingspan, spring 2016) reaching a first validation of the aerodynamic design & the flight envelope of the UAV (takeoff, climb, cruise, recovery & landing).

System description

Skypull is a novel airborne wind energy solution, which generates low cost electricity from abundant high-altitude winds. It consists of an on-ground generator with a drum winch hosting a strong light cable connected to a next generation autonomous flying device (UAV). The UAV is linked to the on-ground generator via a drum with a light, super-strong ultra-high-molecular-weight polyethylene (UHMWPE) cable (Figure 1). The UAV transforms the wind power between at 200-600 m above the ground into traction on the cable, forcing the drum winch to rotate & the generator to produce electricity. The duty cycle is automatically & precisely managed by the on-board control system of the UAV & comprises the following steps:

– Take-off;

– Generation phase (the UAV increases altitude);

– Recovery phase (the UAV loses altitude);

– Landing.

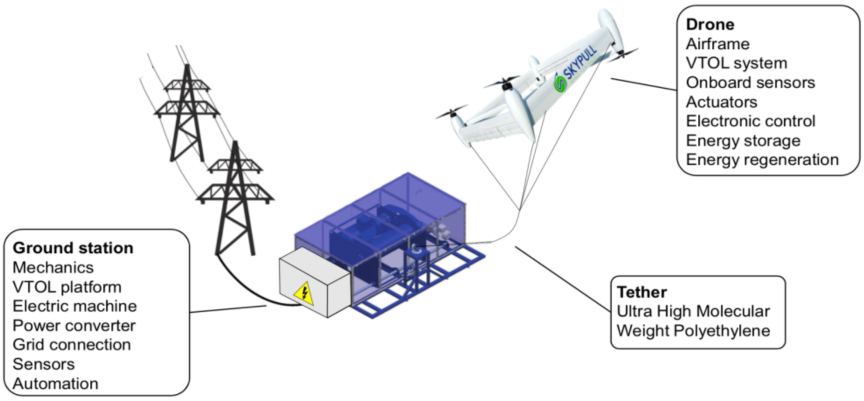


Figure 1 - System schematic

The UAV is equipped with several propellers & motors used for vertical take-off & landing. They are also used to recharge the batteries of the UAV during flight. The UAV uses GPS signals, solid-state inertial navigation systems, weather satellites & atomic clock data for precise device positioning & navigation, predictions of the system's energy output & synchronization with the ground generator's software.

Workplan

Working Plan has been focused on developing and implementing all the system's features necessary to reach the project goals.

From the time plan perspective, the project has been characterized by significant modifications. Time shift has been caused by contemporary multiple events occurring during the project:

1. The need to test control SW updates brought at the beginning to some drone crashes. This made necessary - in order to be able to pursue with the development activities - the realization of several drones (9) and their periodical refurbishing, thus requiring a longer time. The need to have several drones nevertheless allowed experimenting different hardware and aerodynamic solutions, bringing to a deeper and wider knowledge on the UAV characteristics, manufacturing methods and potential optimization.
2. The development of the autonomous control SW system has been previously outsourced to a Dutch specialized company that worked from February until August 2017 without being able to provide a suitable result. Follow to that, the task has been delegated to the Polytechnic of Milan that restarted in September 2017 the work from scratch, extending the delivery of the expected SW out of the project timeframe.

3. The project test site, situate in Alpe del Tiglio (Isone), notwithstanding the initially promising available wind data, eventually appeared to be unfit for the scope, so that a new test site have been set up in September 2017 in Monte Bar (Capriasca). Unfortunately, due to an abnormally long winter and snowy season, the site in Monte Bar has been unreachable for a long period (from October 2017 until April 2018), forcing to the stop of the necessary testing sessions that restarted on April 2018.

Procedures and methodologies

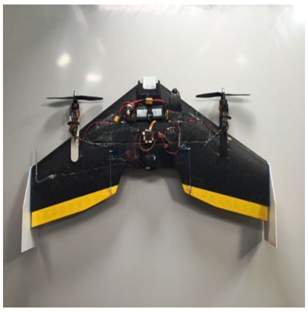
The original Project working plan foresaw the following activities:

1. System development for untethered flight (design optimization, CFD, structural and aerodynamic improvement, SP250 prototype realization, control SW optimization, system's test).
2. System development for tethered flight (structural and aerodynamic improvement, control SW optimization, system's test).
3. System development for electricity generation (structural and aerodynamic improvement, control SW optimization, ground station generator system integration, system tests, electricity generation).
4. Reporting: system's assessment and characterization, technological and economical assessment
5. Dissemination
6. In order to perform the above mentioned work plan, the following activities have been performed:
7. UAV and ground generator modification and test
8. Drone flight system's control modification and test, autonomous flight SW system development
9. System integration and test
10. Other: project management, IP management, regulation compliance assessment, SP2 preparation, and dissemination activities.

(Hardware) UAV and Ground Generator modification and test

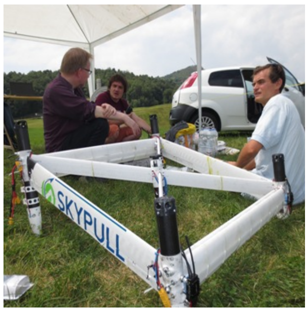
While the UAV wingspan suitable to reach the targeted 3kW power had been initially esteemed to be around 250 cm (this value is mentioned into the project title: SP250), eventually new modeling assessments of the system performed by the Polytechnic of Milan showed that a wingspan of 125 cm was sufficient to reach that order of magnitude of power, while a 250 cm wingspan could have been not compatible (too high power output) with the Ground Station system generator, rated 4kW. The possibility to use a smaller drone made also logistics simpler, due to the possibility to move the drones between laboratory and test site with standard vehicles.

Following the above considerations, several so called "SP1" prototypes, with different characteristics have been realized and tested, ranging from 80 to 130 cm wingspan:

SKP 100	CAIPIRINHA	SKP 125A	SKP 125
Made mostly with on the market components, standard wing profiles, for SW testing purposes	Based on an on the marked drone, duly modified, for SW testing purposes	Wings and structural parts made in 3D PLA printing, tested for free flight	Wings and structural parts made in composite materials, tested for free flight and aerodynamic concept validation

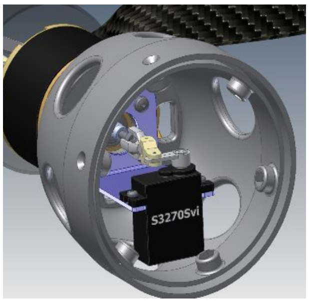


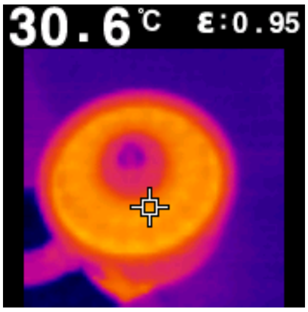


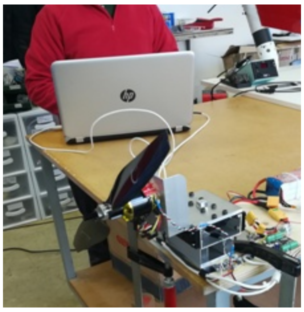
SKP 125 C	SKP 80	SKP 125 B	SKP 90
Wings and structural parts made in 3D polypropylene printing + wood and poly-styrene, tested for tethered flight	Wings and structural parts made in polystyrene + composite, tested for teth-ered flight	Wings and structural parts made in 3D polypropylene printing, tested for tethered flight	Wings and structural parts made with on the market components, for SW test-ing

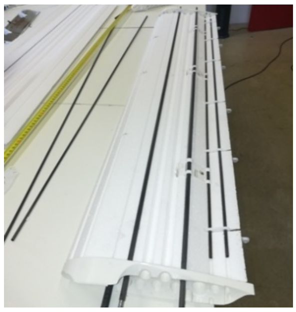
Table 1 - Skypull SP1 UAVs realised

For each one of the above depicted drones the following activities have beperformed:

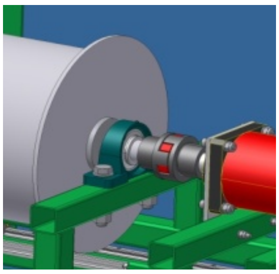


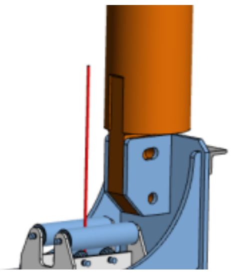






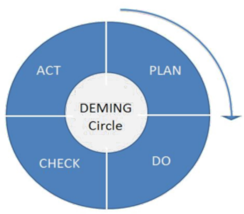
UAV design-redesign	Component choice, assessment and validation	UAV profiles manufac-turing
All UAV drawings have been revised in order to optimize aerodynamic performances, structural lightness and stiffness, manufacturing and assembly easiness. (*above, particular of a servo motor inside a pod*)	All electric & electronic system components have been assessed and purchased. Main components have been submitted to test sessions to better characterize their performances and validate their implementation. (*above left: a thermal analysis of a motor; above right: a session of characterization of a propeller*)	Wings and structural parts have been realized in several different ways, using different materials, specs and manufacturing processes (*above: realization of a polistirene wing with reinforcing carbon fiber struts*)





UAV assembly and preliminary indoor test	Ground Station (GS) redesign / adaptation
Structural elements, wings, cables and components have been assembled. Once the UAV is complete it is tested and trimmed indoor prior to the flight tests. (*above left: UAV cabling; above right: a drone on the indoor test-bench supporting structure*)	GS had been realized for a different AWE concept so that modifications has been made on the layout (frames and geometries), on the generation side (speeds, torques, reaction times) and on the dumping system (to manage excess forces due to UAV accelerations). (*above left: particular of the GS; above right: a particular of the newly adopted dumping system*)

Table 2 - HW improvement activities

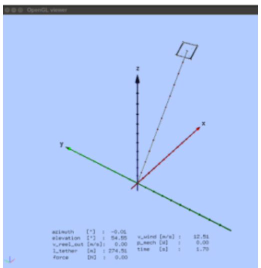


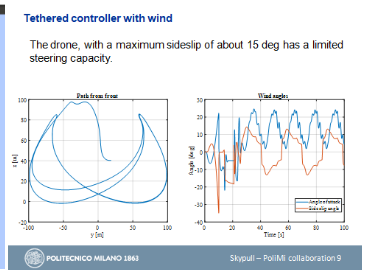
Within the above activities changes and novelties in the system components have been developed and tested, under a PDCA approach, in order to gather the biggest number of information on available choices and solutions in order to improve and optimize the system. Most changes and novelties have been related to aerodynamic profiles changes, structural novelties, materials & manufacturing processes, on board components.

Drone flight system's control modification and test, autonomous flight SW system development

Flight control system adaptation for Skypull UAVs

Other main developing activities performed in the meanwhile have been related to the SW:





On board flight control system adaptation	Ground Station (GS) control system	Autonomous flight control SW development
On board system's SW control, based on PX4 developed by ETH, required to be adapted to Skypull's specific parameters and behavior. Moreover, every change of UAV layout or components required a further SW adaptation. (*above: working on SW parameters during a winter test session*)	Also GS control SW had been to be adapted to the new system's layout and to manage Skypull system components. (*Above: the GUI of the GS control SW*)	Development of the autonomous control SW system previously developed by the dutch supplier then by the Polytechnic of Milan. (*above left: a first system's model; above right: simulations*)

Table 3 - SW improvement activities

Skypull UAVs present an highly nonlinear dynamics which makes the design of a control system a challenging task. The most relevant challenges faced during the development of the autopilot are hereafter resumed:

- Asymmetric weight distribution

  In standard multicopter vehicles the Center of Gravity (CoG) is always located in the geometric center of the frame.In this configuration thrust forces and torques are automatically balanced.

  Even attitude & position algorithms assume that all the accelerations and forces measured by the IMU are applied on the CoG.

Skypull vehicles have instead an unconventionaldesign. To guarantee aerodynamic stability during airplane flights,the CoG and IMUs have been placed fore the geometric center causing an asymmetric weight distribution during hovering.

In order to achieve stable flight in both multicopter and airplane modes, the Flight Control System has been developed by taking into account the particular geometry of Skypull vehicles.

- Different trim conditions depending on flight mode
  Classical PID control architectures are tuned around a particular trim condition (i.e hover or forward flight) and assume small deviations (around +/- 15 degrees) from the operating point. Since Skypull vehicles operate in high dynamic conditions, this assumption does not hold anymore.
  In order to achieve stable flight in all the conditions, the autopilot has been improved with robust tuning techniques guaranteeing flight stability under wider operating conditions.

- Hovering in high wind conditions
  Compared to conventional multicopters, Skypull vehicles present aerodynamic surfaces which increase drag. In windy conditions, torque generated by the rotors is not enough to counteract drag forces generated by the aerodynamic surfaces. Attitude control in hovering became thus a non trivial task. This problem has been faced by developing a Single Input Multiple Output (SIMO) control architecture.The new actuation system introduces aerodinamic control surfaces as auxiliary actuators during hovering flights. In such conditions, thanks to the aerodynamic flux generated by the propellers, rudders and ailerons provide an extra torque which results in augmented control autority.

Ground Station Control

Flight Tests highlighted the difficulty from the operator to properly set the Ground Generator working states by using a Software User Interface.

The problem in this case has been solved by developing a novel hardware User Interface which allowed the operator to operate the machine away from the monitor.

- Inertia of the winch drum
  Generating energy with Skypull vehicles is a dynamic task which require fast responses from the ground generator.

  Generation tests highlighted a lack in the generator’s response due to the inertia of the winch drum.
  This challenge has been faced by improving the generator’s control system with a dynamic feed-forward compensation for winch drum inertia during transients.

  Thanks to this improvement Ground Generator setpoint traking performances increased allowing a better control during generation phases and in case of wind gusts.

Autonomous Flight Control SW development

The most critical challenges faced during the development of the automatic flight control system are highly related to the points presented in 1.2.1.
More in detail:

- Non-linear dynamic model of a tethered aerial vehicle
  In order to design and validate the automatic control system, a non-linear 6DOF model of the Skypull vehicle was mandatory. The model has been obtained starting by deriving the Equations of Motion from Newton's second law. The challenge in this task, due to the particular geometry of the Skypull vehicles, has been to model all the aerodynamic forces that were acting on the vehicle's body (Figure 2). Such forces have been modelled by integrating results obtained from Computational Fluid Dynamics (CFD) analysis of the Skypull vehicle.

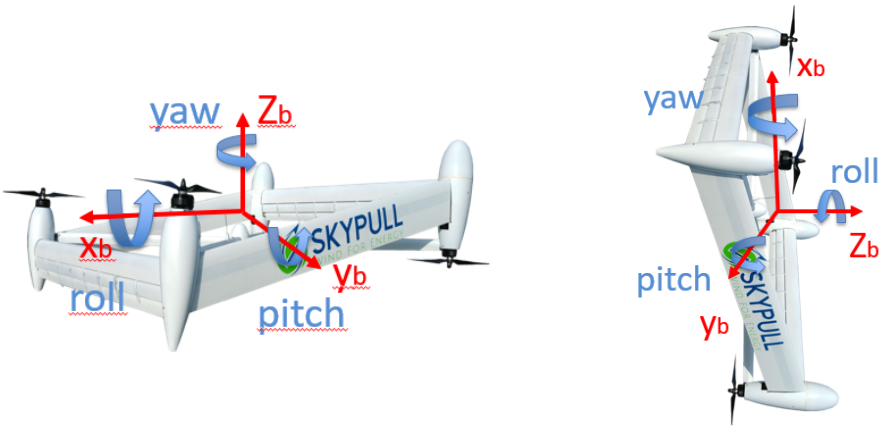


Figure 2 - Aircraft frame references in hovering and forward flight modes

- Controller Switching logic
  Due to different flight conditions that the Skypull vehicles face in an operational cycle (take off, hovering, transition to airplane, transition back to multicopter, landing) different controllers handling one single flight condition have been developed (Figure 3).

  The challenge in this task has been the definition of a state machine that triggers the switch from a controller to another by avoiding drastic changes in the control signal.

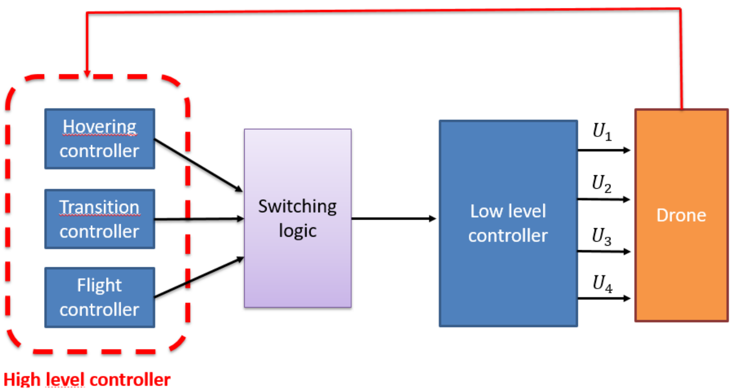


Figure 3 - Control logic architecture

- Trajectory planning
  The design of a Flight Management System (Figure 4) capable of taking into account all the environmental constraints (Wind speed, altitude from ground, tether length,...) has been another challenging task.

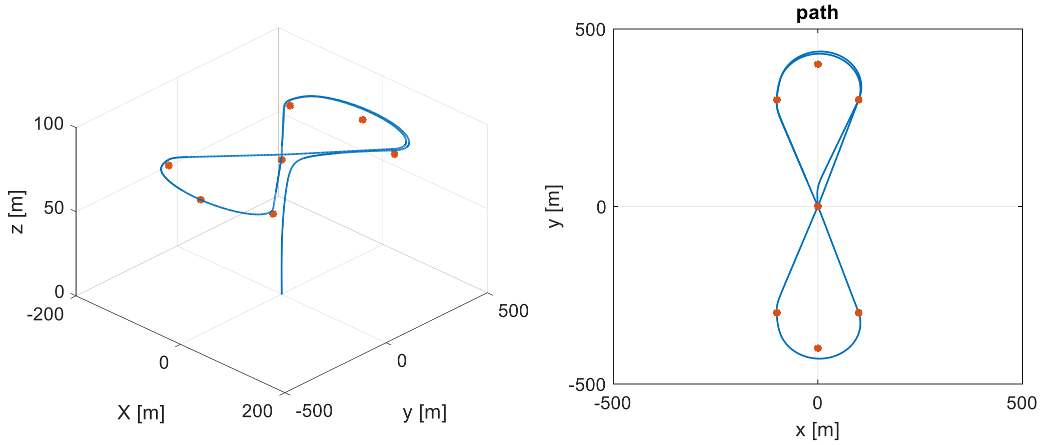


Figure 4 - Trajectory tracking results

System Integration and test

Figure 5 – Site on Monte Bar in late March 2018

Follow to the realization and integration of its components, the system has been extensively tested. Thanks to the different and multiple drones made, dozens of flight hours have been logged in untethered and tethered flight test, manual & semi-automatic mode between Jul 2017- Apr 2018.Due to the above mentioned problems in having access to test site in Monte Bar during the winter period (October 2017 – April 2018; Figure 5) tests have been focused on UAV flight attitudes, with the aim of improving its reliability and predictability.

Flight tests have been performed in Ferrara (ITA), Stabio, Lodrino, Lugano, Zurich, Losone (CH), while generation tests have been performed in Alpe del Tiglio (Isone - Cantone Ticino) and Monte Bar (Capriasca – Cantone Ticino).

Between July 2017-April 2018 the SP1 prototypes served as proof of concept, where the overall concept was tested & validated (Figure 6).

Figure 6 (from left to right) – Flight tests in Isone (July 2017); generation tests in Isone (August 2017); flight tests at Monte Bar (October 2017)

Other activities

Project Management

PM activities have been carried on regularly. The main problems in the PM area have been caused by:

- Uncertainties and technological issues occurred during the development;
- Difficulties in combining the limited availability of suppliers with project needs together with
- Meteorological conditions jeopardizing planned test activities on the test site.

IP management

A preliminary Freedom To Operate analysis has been conducted within a comprehensive IP asset assessment and strategy definition conducted with the support of Giovanni Gervasio (IP expert by P&TS Ltd, Neuchatel-CH).

An international patent WO16150561 has been granted to Skypull SA with a positive acknowledgement of all claims, which are fairly broad. The patent, internationally registered with the n. PCT/EP2016/000479 in September 2017 has been extended to EU (EPO), US, China and India.

Regulation compliance assessment

Regulatory barriers may be related to:

1. Technical compliances of the electricity generation plant with grid specifications
2. Local regulations connected to the construction of an industrial structure
3. Safety issues of the electricity generation plant
4. Environmental impact assessment of the electricity generation plant
5. Aviation related risks.

Barriers numbered from 1 to 4 may assumed to be similar to wind turbines. Some regulations (e.g. environmental impact assessment) can also be considered as less relevant if compared to wind turbines. As far the technical compliances with local grids are concerned, although existing standards can be partially applied to some of the components, such as the low voltage directive (LVD)2006/95/EC for electrical installation, and machine directives 2006/42/EC or IEC61400 for wind turbines, there are no standards for the tether and the flying device. On the contrary, additional considerations are required for managing the aviation risk.

Aviation related risks have been thoroughly analysed over the entire project at various levels. Safety and reliability have to be ensured by both design and procedures. The ultimate goal is to meet specific standards and remain within acceptable risks.

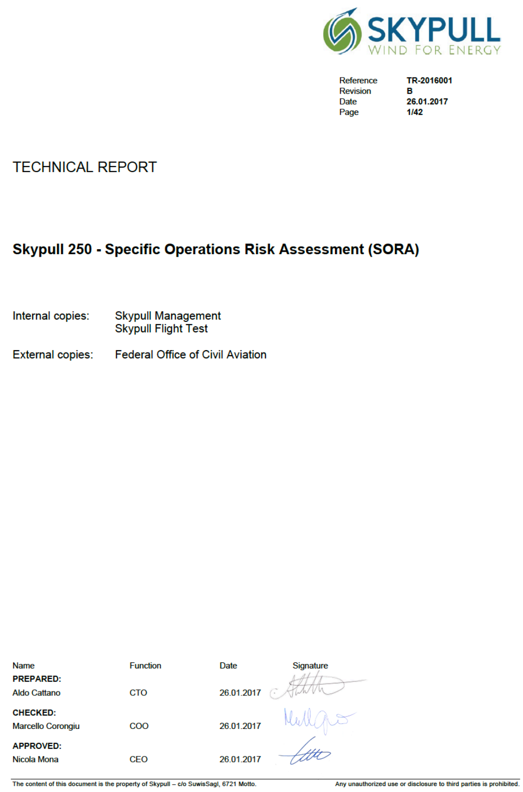
Although there is currently no regulation that thoroughly encompasses systems like Skypull, the forward on how to obtain the necessary flight permits was pretty clear. As for any aircraft, also Skypull has intrinsic risks in the air and on the ground.

Current Swiss regulations allow the operation of drones up to 30 kg (if in constant line of sight and not overflying large crowds). However, if the flying object is tethered it could be considered as a kite or ground-tied balloon. In such a case, the maximum flying altitude would be 60 meters above the ground.

To overcome any misunderstanding and avoid problems, Skypull – in accordance with the Federal Office of Civil Aviation – decided to file for a special permit under a specific operations risk assessment (also known as SORA). Skypull was the first company in Switzerland to compile a SORA and acted as pilot also for FOCA (Figure 7).

The SORA has been developed by the Joint Authorities for Rulemaking on Unmanned Systems. Its aim is to assess the risks of a specific operation for a defined flying vehicle. The adopted methodology is the so-called harmonized risk assessment. The process is pretty straightforward and easy to follow (especially if there is an aviation background in the company). The support by FOCA was excellent and permitted to fulfil all the requirements in about 3 months. More information about the SORA process can be found here: http://jarus-rpas.org/content/jar-doc-06-sora-package

The obtained flight permit has a national validity (Swiss airspace) and allows – if needed – to fly in beyond visual line of sight (BVLOS). To operate our system, a special airspace is been put in place (Temporary Danger Area) communicated through all relevant channels (e.g. aeronautical charts).


SKYPULL
WIND FOR ENERGY

Reference TR-2016001
Revision B
Date 26.01.2017
Page 1/42

TECHNICAL REPORT

Skypull 250 - Specific Operations Risk Assessment (SORA)

Internal copies: Skypull Management
Skypull Flight Test

External copies: Federal Office of Civil Aviation

Name	Function	Date	Signature
PREPARED:			
Aldo Cattano	CTO	26.01.2017	
CHECKED:			
Marcello Corongiu	COO	26.01.2017	
APPROVED:			
Nicola Mona	CEO	26.01.2017	

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Figure 7 - Skypull's SORA

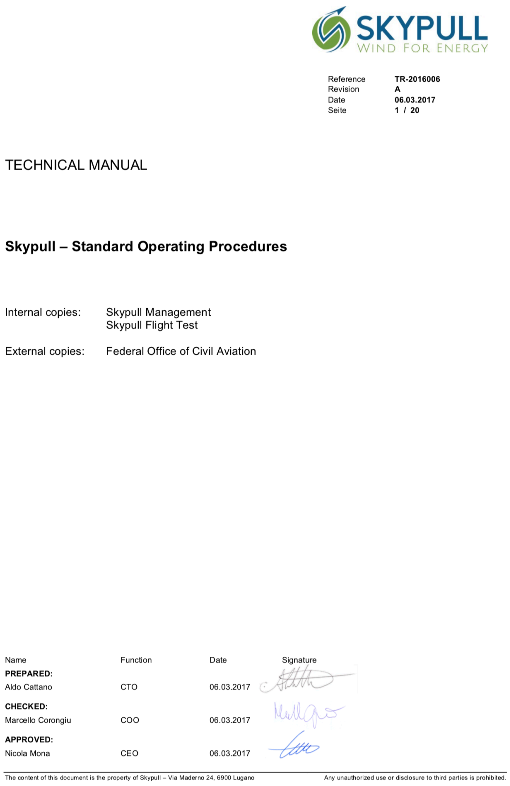
Signalization and operating concepts of AWE systems

As already mentioned above, there is no clear rulemaking for the operation of AWE systems. Within the SORA process, is the responsibility of the operator to assess the risk of the envisioned operation and define mitigation action in order to reduce hazard probability and impact.

This can be done both by design and by procedures. The design of Skypull (UAS and ground station) features risk-mitigating redundancies, which reduce both air and ground risk. In terms of procedures, we defined both Standard Operating Procedures (SOP; Figure 8) and a Standard Operations Manual (SOM; Figure 9) in order to establish and regulate both normal and abnormal procedures. Both documents are part of the SORA.

In terms of signalling the operations, many options were evaluated and assessed. These entailed hardware, software and communication solutions. At the end, in accordance with FOCA, we opted for the adoption of a special airspace to be activated during operation.

To operate our system, a special airspace is been put in place. It is a so-called Temporary Danger Area, which is communicated through a NOTAM to the airspace users and published on the applicable aeronautical charts (Figure 10).



SKYPULL WIND FOR ENERGY

Reference	TR-2016006
Revision	A
Date	06.03.2017
Seite	1 / 20

TECHNICAL MANUAL

Skypull – Standard Operating Procedures

Internal copies: Skypull Management
Skypull Flight Test

External copies: Federal Office of Civil Aviation

Name	Function	Date	Signature
PREPARED:			
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Nicola Mona	CEO	06.03.2017	

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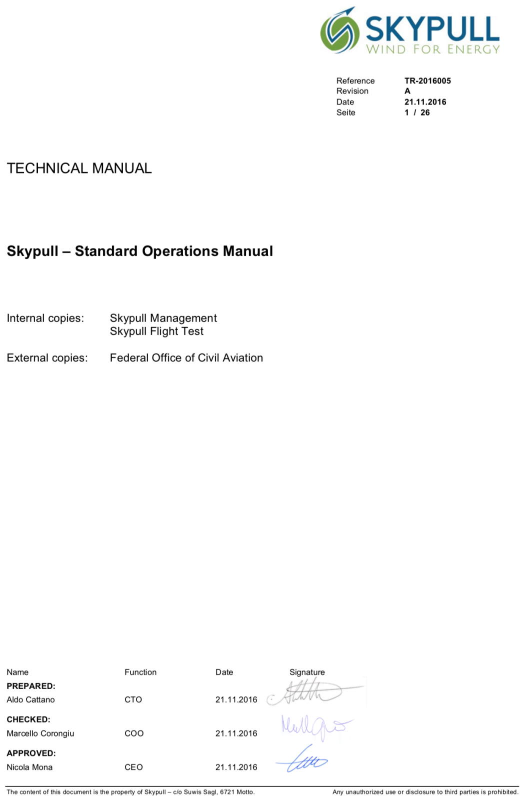
Figure 8 - Standard Operating Procedures



SKYPULL WIND FOR ENERGY

Reference	TR-2016005
Revision	A
Date	21.11.2016
Seite	1 / 26

TECHNICAL MANUAL

Skypull – Standard Operations Manual

Internal copies: Skypull Management
Skypull Flight Test

External copies: Federal Office of Civil Aviation

Name	Function	Date	Signature
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APPROVED:			
Nicola Mona	CEO	21.11.2016	

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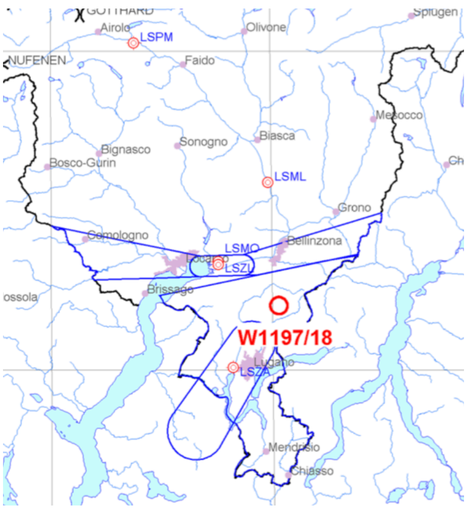
Figure 9 - Standard Operating Manual



W1197/18	0400 - 1900	GND	2450m / 8000ft	460603N 0090054E	0.9 KM / 0.5 NM	TEMPO D-AREA ESTABLISHED 3.9 KM SE ISONE, RADIUS 0.9 KM (460603N0090054E RADIUS 0.5 NM). KITE OPS ATTACHED WITH CABLE TO CENTER COORD, MAX LEN OF CABLE 500M.

Figure 10 - Notice to Airmen (NOTAM) and publication on aeronautical chart

No other special markings (e.g. strobe lights) or signalization (e.g. ground-based or airborne radio beacons) were deemed necessary by the authority; at least not for the intended test operation.

We recognize that this is not a fail-safe solution and that air traffic is legally not forbidden to enter this airspace. So this measure is to be seen as a precautionary measure only and future permanent installations will need other solutions (e.g. intrinsic traffic collision avoidance systems).

For the smooth operation of our test activities, we involved and informed personally all relevant stakeholders (Swiss Air Force, REGA, airport authorities in Lugano and Locarno, air traffic management, Cantonal FOCA delegate, local aero clubs,…) early on. This helped enormously in the awareness raising and acceptance of our project and, ultimately, permitted seamless operation.

AWE regulations at EASA level

As mentioned, the regulatory environment is still to be defined but there are already working groups of airspace regulatory bodies debating the regulation for airborne wind energy in the US and in Europe. In May 2018 a delegation of Skypull met with also at European level with the European Aviation Safety Agency (EASA)in Cologne in order to optimize and boost a comprehensive regulation favourable towards the deployment of the Skypull system.

With EASA we discussed essentially two main topics:

- EU regulatory concepts for UAS
- Current and future process for UAS type certification

In terms of regulatory concepts for UAS, EASA has recently proposed an amendment and extension of its Basic Regulation to encompass all UAS (until now, it is limited to an operating mass above 150 kg. All drones below 150 kg are regulated nationally) and to categorise them into 3 categories (Figure 11).

The major novelties are the definition of three different UAS categories and the adoption of an *operation centric, proportionate, performance-based and risk-based approach* (in analogy to the SORA) for the approval (OPEN and SPECIFIC) or certification (CERTIFIED).

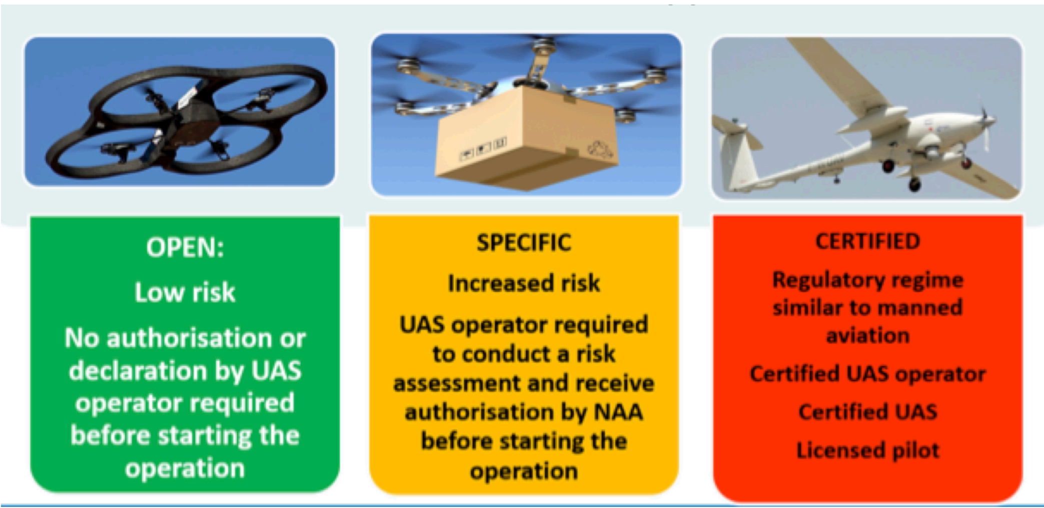


Figure 11 - New UAS categories proposed by EASA

It is certainly clear that AWE systems will not fit into the OPEN category but will find their place in either the SPECIFIC or CERTIFIED category. They have both their pros and cons and the decision for which to apply will depend on a variety of factors driven by the manufacturer and the operator.

This new Basic Regulation is expected to be adopted later this year (2018).

If a certification is pursued, the soon to be published Certification Specification for UAS (CS-UAS) shall be adopted.

The **UAS Type Certification Basis** will typically consist of the following:

- **Certification specifications** selected and tailored from the applicable manned aircraft airworthiness code or codes
- **Special Conditions & interpretative material** related to UAS specifics, where the existing requirements do not contain adequate or appropriate safety standards.

It is both important and interesting to note that the applicable airworthiness code or codes to be used as reference for establishing the type certification basis will be proposed by the applicant.

This is change of paradigm in aviation certification, which is progressively being adopted also for other aircraft types.

SP2 preparation

During the SP1 development phase some preliminary activities related to the preparation of the SP2 system (SP2 is the market demonstrator expected to be realized within 2020, a 60 kW system to be deployed mainly in off-grid or mini-grid contexts) have been realized. Main results of these activities have been the analysis and definition of the SP2 components functions and their relative interactions, in order to define system requirements then go on to the system design and components selection and procurement.

Dissemination activities

In order to boost the project’s communication activities and prior to that, an analysis has been performed by a professional on the communication assets of Skypull, with the aim of define a correct positioning of the Skypull brand/product within the exiting communication competitive landscape.

The results of the study will be adopted as a general framework within guidelines for the definition and structuring of the communication activities (brand and visual identity, contents, channels, com carriers, etc.) will be defined. The analysis has concerned the following items:

- The energy production technologies communication models and their positioning in a value map
- A suggested Skypull communication position and model
- The Skypull technology specs, vision and communication points of strength
- The wind turbine sector communication models
- The AWE sector communication models and their positioning in the specific communication values of wind energy generation

- Recent trends in technology/innovation communication models
- A suggested Skypull communication positioning

Dissemination have been pursued by mean of:

1. Web contents: website, social media (FB, Instagram, Twitter, Linkedin) .

Figure 12 (from left clockwise) - Skypull’s Newsletter, Linkedin Profile, FB profile

2. Appearances on media and delivered press releases:

Media appearances

https://www.alpict.com/far-from-the-conference-format-an-innovative-formula/
http://www.startupticker.ch/en/news/march-2017/skypull-is-ready-for-flight-test-campaign
http://www.startupticker.ch/en/news/may-2017/w-a-de-vigier-awards-five-startups
http://startupticker.ch/en/news/april-2017/ten-startups-in-the-finalists-of-w-a-de-vigier-award
http://www.cpstartup.ch/website/it/news/skypull-fa-parte-delle-10-start-up-svizzere-high-tech-in-ambito-aerospacespace
http://www.cdt.ch/ticino/lugano/176754/una-start-up-luganese-premiata-a-soletta
https://www.aargauerzeitung.ch/solothurn/kanton-solothurn/fuenf-start-ups-freuen-sich-ueber-je-100000-franken-131341992
https://www.derbund.ch/wirtschaft/mit-drohnen-strom-erzeugen/story/16573777

3. Participation to events and conferences in the field of start-ups, renewable energy, new technologies, aviation/space.

2017 03 09 Kickers Camp - LAUSANNE
2017 03 24 Andromeda - CHIASSO
2017 03 28 SICTIC - GENEVA
2017 03 31 SVMS - LUGANO
2017 04 05 Swiss Venture Day - ZURICH
2017 04 27_28 - GENEVA
2017 05 18 De Vigier Award - SOLOTHURN
2017 06 30 Masschallenge - LAUSANNE
2017 08 23 AGIE - FIESCH
2017 08 28 SEIF Awards Live - ZURICH
2017 09 15 Dong Energy – PALO ALTO (US)
2017 09 29 Swiss Engineering - BELLINZONA
2017 10 02 SEIF Awards 2017 - ZURICH
2017 10 03 "Imagine if" Swiss Finals - LAUSANNE
2017 10 06 ESA BIC Switzerland Demo Day - ZURICH
2017 10 24 Swiss Startup Days - BERN
2017 11 08 Inventrix Pitch - ZURICH
2017 11 14 EVC ePitch
2017 11 15 MobLab 2017 - BELLINZONA
2017 11 30 Slush 2017 – HELSINKI (FIN)
2017 12 05 "Imagine if" world finals - OXFORD (UK)
2017 12 12 EVC Final – DUSSELDORF (DE)
2018 01 16 12. Schweizerischer Stromkongress - BERN
2018 03 20 Cleantech Innovate LONDON (UK)
2018 04 09 Swiss Drone Industry Day - ZURICH
2018 04 10 Venture Leaders China Selection - LAUSANNE
2018 04 26 SDG Mashup Impact Hub - GENEVA

Results

Technological results

8 different drones realized

(see above) Par. 1.1.

Several different drone manufacturing solutions assessed

In realizing the different prototypes several manufacturing techniques and materials have been adopted and assessed. Each one characterized by its relative cost, time of delivery and technical performances (quality of the output). Among the solutions adopted we mention CNC milled moulds, sandwich with carbon fibre and epoxy resin, wet lay-up under vacuum pump, standard of the shelf RC models, 3D printed components, pultruded carbon tubes with surfaces in 3D PLA printed parts, sandwich of polystyrene foam core covered by carbon with epoxy resin, balsa wood, mould in polystyrene foam and others.

Electrical circuit development

The Skypull drone is new in its components and flight behaviour, with previously unapplied technological solutions, so that its electric layout and specs has had to be designed from scratch and thoroughy implemented and tested.

- First electrical circuit has been wholly outsourced, without any inner know-how.
- Next electrical circuit has been designed in-house and outsourced for the production. The result was bad due to insufficient internal knowledge on drone applications
- Next electrical circuit was done with an external consultant expert in drone design and assembly for designing the circuit with inner production. The system has been improved but still problems arose, due to the lack of knowledge of the external consultant about the Skypull's peculiarities (notably wing geometry and flight philosophy)
- Next electrical circuit was designed and produced in house. An employee expert in drone design has supervised the production part made by an electronic technician. Results were good, in house know –how has been increased, but company overall cost was higher due to necessity to internal employees.

Electronic components development

- The process has been similar and parallel to the electrical circuit development. In house design and employees were speeding up decisions of which components to use. Better bench testing were lowering problems during flight. A full electronic test equipment set was bought to make all required test before flight. Problems of high voltages, high signal noise, correct data logging have been faced and solved thanks to previous bench (and flight also) testing. The cost was obviously increased though, but that allowed speeding up the reaching of the necessary solutions.

Fully and successful system (UAV, GS) integration and Proof of Concept

UAV flight tests have been performed first in untethered then in tethered mode, with the following steps:

1. Hovering flight in stabilized mode
2. "acro" mode, testing the drone in a flight similar to plane flight mode.
3. Full plane flight mode (fixed wing flight mode, all 4 motors are giving the same thrust)
4. Gliding flight mode (without motors thrust) aimed to characterize aerodynamic efficiency and control surface manoeuvre capabilities. This development part has been quite challenging due to Skypull's specific aerodynamics and geometries.

With untethered tests the drone flight capabilities have been succesfully characterized. After that tethered flight test have been pursued, following the same steps of untethered testing. The tethered flight mode have been previously made with the help of a manual drum, expected to better maintain tether tension during take-off and landing (thanks to human sensitivity), than with the Ground Generator System.

Ground generator System (GS) development, testing, integration and POC

- The ground generator was initially tested using two twins generator, were one was working as a generator and the other simulating a drone in real wind environment (motor mode).

- The generator was then installed outdoor (on-grid) and a kite was attached with a tether. In this way the sensitivity towards change in tether tension has been improved, without risking of drone crashes. Kites of increased dimensions have been tested also to understand the generating capabilities. A small energy production has been realized during this test, due to the fact that tether traction was based on drag and not lift, so that as reel-out speed get higher the drag force lowered.
- The generator was then connected to a small (and low cost) drone to get the system closer to real working operations. Improvement in the system have been required since drone traction is higher in reel-out condition (compared to kite) and also the changes in traction are much more sudden. A dumping system based on a special fishing rod was integrated in the assembly for decreasing the effect of changes in traction on tether due to wind gusts.
- Finally the generator has been connected to bigger drone for real energy production.
- Within the project period more than 300 minutes of flight time has been performed with the 8 different drones.
- Around 30 minutes of flight time have been performed in tethered mode (Figure 13).
- The concept has been successfully proved, by generating energy from altitude wind up to a power of about 400W.

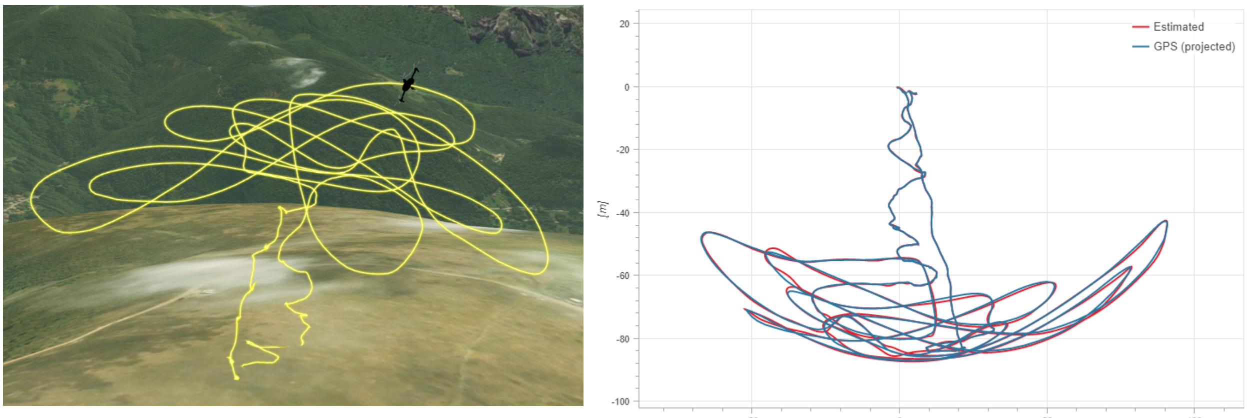


Figure 13 - Plots of a tethered flight test session

Other results

- Skypull SA incorporated. Transformation from Suwis Sagl to Skypull Sagl (July 2017) and then to Skypull SA (September 2017).
- Skypull Patent PCT/EP2016/000479 has been granted in the period. It has also be extended to EU, US, China, India. A preliminary FTO analysis has been performed with positive results
- Cooperation agreements made with Polytechnic of Milan, SUPSI and Venture Kick (currently Skypull's shareholder)

Perspectives, next steps

Even if project goals have not been thoroughly reached, the results obtained proved the concept and paved the way for a complete characterization of the system as well as for its scale up the system (both the UAV and the Ground Station), up to 60 kW in order to deliver a first market demonstrator (so called SP600) as from 2021. Some tenth of SP600 will be delivered, in order to validate the system on the market and prepare the upscale to the 1 MW system (SP1700), which is expected to be marketed around the end of 2023.

In terms of regulations and certification, the herein conducted activities led to some important findings and showed the way forward. For an international sales and deployment, it is of paramount importance that the system has an internationally recognized certification base and meets all the relevant standards. It is quite unrealistic (unless for some very specific cases) that for each system a SORA has to be made.

The soon to be published EASA Basic Regulation will entail an extension to all types of UAS. It will certainly shake the industry quite a bit but ultimately permit safe and regulated operation of UAS. It will also affect the AWE industry, which is somehow still trying to find its own way but eventually will have to confront itself with aviation regulations. In our view, if correctly interpreted, adopted and integrated early on in the design phase, the newly proposed *“operation centric, proportionate, performance-based and risk-based approach”* leaves a lot of manoeuvring space to AWE manufacturers to proactively propose and adopt their solutions on how to obtain an approval or certification. It is, however, important that the AWE manufacturers adopt such an approach already from the design phase. This will facilitate the approval/certification process tremendously.

To conclude, some thoughts about air traffic management and, in particular, about the integration of manned and unmanned air traffic in the same airspace (known also as U-Space). This might indeed remain an open issue not really solveable by the AWE manufacturers as it encompasses a variety of players. This becomes especially true for autonomous operations (as AWE systems are expected to be operated).

Further research and tests on autonomous operations and on the integration into a traffic awareness and management system (which allows traffic detection and avoidance) is of significant importance for a safe and continuous operation of Skypull. There are already some very interesting solutions in testing phase (e.g. INVOLI – low altitude traffic data), which we intend to explore further.

Evaluation

The project goal of realizing a prototype characterized by a 3kW drone able to produce energy by exploiting the altitude wind by mean of a on ground generator connected by a tether has been reached. Nevertheless energy production has not been sufficiently continuous and significant to make it possible an assessment of the system's performances and behavior in the perspective of characterizing the electricity output and its integration within the grid.

This has been mainly due to:

- The failure of the Dutch supplier to delivery autonomous flight control, which led to a **forced adoption of manual piloting.** This made difficult to match pilot and drone availabilities, weather conditions and authorizations, slowing down dramatically the **pace of testing activities**. Moreover, even if computer assisted, human control of the UAV is limited to 5-10 minutes, due to the level of attention required by pilot and implies close to terrain flights (max 60 m agl), with highly turbulent wind conditions.

Coupled with

- The total **lack of wind** during the first full system's test in **July- August 2017 -** due to an abnormal heat wave in Ticino - matched with an abnormally **long and snowy winter** 2017-2018**-** that impeded the access to the test site at Monte Bar **-** reduced to a limited number of hours the conditions suitable for system's generation tests.

Moreover, the following issues have generally affected the project, adding factors that jeopardized the smooth project management and deployment:

- Problems in setting up the **SW control system** on new prototypes, due to technological issues that had to be faced one by one. It took a long time for the system to reach an acceptable and reliable behavior.
- Many test and activities performed in order to select the right **components mix** fit for the application. Every new/different component on board control SW has to be modified accordingly, verified and debugged.
- Big efforts have been devoted in **bug diagnostics**. Several drone crashes has been followed to a long time required to **troubleshooting** (and to drone repairing / refurbishing as well).
- Many solutions assessed for the GS **dumping system**
- A big effort has been required to **customize the driver/inverter SW** in order to make it compliant with the GS operation patterns and specs.
- Several and continuous modifications of the PX4 drone flight control SW in order to adapt it to the (changing) specs of the Skypull's drone, it's behaviour and duty cycle requirements (many crashes have occurred because of that).
- Inability – driven by financial constraints - to **hire on a full-time base** the technicians required. External collaborators working on part-time basis treated often Skypull as **second priority** with regards to their primary occupation/customers.
- Problem in finding the right **competences** in a highly specialized and innovative domain.

- External collaborators and **suppliers scattered** throughout Switzerland, Germany, Netherlands, Swiss, Italy, Ukraine, Slovenia and Spain making the **coordination** and the execution of common activities (e.g. test sessions) quite challenging and effort intensive.

All the above issues can be synthetically represented by the difference between the originally esteemed project budget (around CHF 215,000) and the finally reported project costs (around CHF 340,000).

Conclusion

Even if the expected results have not been thoroughly reached, the project showed the feasibility and potentialities of the Skypull technology. Not a single “no-go items” emerged, while the team has learnt relevant lessons from failures, creating a a solid shared knowledge and experience and constituting abase to build upona project structure suiteable to reach overall project goals in a straitforward and sound way. The team is strong and with a strong commitment to pursue the realization of an effective, cheap and clean energy generation system.