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Laurea Magistrale in Ingegneria Aerospaziale

Master's Degree Thesis

Project INDOOR: Development of a Remotely Piloted Aircraft System for Smart Transport of Transplant Organs and Biological Material

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献给我的爸爸, 齐海平

和妈妈，夏肖玲

永远爱你们

scientia potentia est

Acknowledgments

I would like to dedicate this work to the remarkable people and organizations who made it possible.

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Abstract

The INDOOR project (usINg Drones fOr Organ tRansportation) is an initiative led by the Fondazione D.O.T. (Donazione Organi e Trapianti) in collaboration with PIC4SeR (PoliTo Interdepartmental Centre for Service Robotics). This research explores the feasibility of using UAVs (Unmanned Aerial Vehicle), commonly known as drones, for transporting transplant organs and biological samples between healthcare facilities in an urban environment, specifically within the city of Turin.

The transport of biological material is a fundamental aspect of transplant medicine, ensuring timely accessibility to donated organs. Modern medical logistics require fast, reliable, and safe transport solutions, leading to the exploration of drones for rapid hospital connectivity. This study pioneers the integration of advanced air mobility technologies into healthcare logistics in densely populated areas, aiming to improve operational efficiency while minimizing time and costs. Although the technology already exists and continues to evolve rapidly, key concerns remain regarding safety and ethical implications, while ensuring the security of both the transported payload and the population along the flight path.

The project's primary objectives are to assess the feasibility of operative implementation and ensure compliance with legislative regulations while adopting risk mitigation strategies, as transplant organs and biological samples are classified as "dangerous goods". Adhering to appropriate legal frameworks is essential

for future standardized operations as it requires the establishment of a reliable procedure to connect infrastructures in the same geographical area.
The thesis has been structured as follows:

1. A comprehensive study of the state of the art was conducted to establish a foundation for the field.

2. Vibration simulations were analysed to ensure the integrity of blood samples during transport.

3. A specialized payload capsule has been designed to securely transport delicate biological materials, including blood samples and, eventually, transplant organs.

4. Compliance with recent EASA regulations, particularly MOC Light-UAS.2511, was examined. This regulation mandates the enhancement of drone security through the integration of a flight termination system, a parachute, and designated buffer zones to maintain flight safety.

5. A demonstrative test in extended Visual Line Of Sight (VLOS) was conducted on October 1st 2024, between CTO and Molinette Hospital of Città della Salute. The test flight, which passed over the adjacent Po river, was executed in collaboration with the startup ABzero, which specializes in autonomous systems equipped with smart capsules for the transport of perishable medical goods.

Further experimental trials and additional analysis will be conducted to refine the system and ensure its practical applicability in real-world medical logistics.

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Acronyms

ATR Active Transport Refrigerator

BVLOS Beyond Visual Line Of Sight

CAD Computer Aided Design

CNT Centro Nazionale Trapianti

CSS AOU Città della Salute e della Scienza di Torino

CTO Centro Traumatologico Ortopedico

D.O.T. Donazione Organi e Trapianti

EASA European Union Aviation Safety Agency

ENAC Ente Nazionale per l'Aviazione Civile

ENAV Ente Nazionale per l'Assistenza al Volo

FDM Dused Deposition Modeling

FTS Flight Termination System

GCS Ground Control Station

GPS Global Positioning System

IMU Inertial Measurement Unit

INDOOR usINg Drones fOr Organ tRansportation

LoRa Long Range

MD Medical Doctor

MOC Means Of Compliance

MTOW Maximum Take-Off Weight

NOTAM NOtice To AirMan

PIC Pilot In Command

PIC4SeR PoliTo Interdepartmental Centre for Service Robotics

PLA Polylactic Acid

PVA Polyvinil Alcohol

SAIL Specific Assurance Integrity Level

SORA Specific Operations Risk Assessment

TPU Thermoplastic polyurethane

UAS Unmanned Aerial System

UAV Unmanned Aerial Vehicle

UHF Ultra High Frequency

VLOS Visual Line Of Sight

VTOL Vertical Take-Off and Landing

Chapter 1

Introduction

The INDOOR project, us**IN**g **D**rones f**O**r **O**rgan t**R**ansportation, is an initiative of the Fondazione D.O.T. (Donazione Organi e Trapianti) for the development of a mission using an Unmanned Aerial System (UAS), informally known as a drone, for the transportation of organs and biological material in transplant medicine between healthcare facilities.

Figure 1.1: Project INDOOR

The scope of this thesis is to create a practical procedure with a hands-on approach to ensure that the operation of drone transport of biological cargo is safe and reliable for all the stakeholders involved, including the general population alongside the pathway of the autonomous vehicle. By prioritizing real-world applicability, this study seeks to address both technical and societal challenges, such as public safety concerns, regulatory compliance and ethical considerations, while establishing a standardized protocol for the secure transit of sensitive biological material within urban environments.

The project is concretely focused experimentally on the feasibility study, the design and the execution of a preliminary flight test for the validation of the mission of transporting biological material between healthcare facilities, such as hospitals, analysis laboratories and research institutes in the city of Turin in Italy. A successful implementation demonstrates the viability of using autonomous systems in enhancing urban medical logistics.

For such missions, crucial aspects are the reduction of operating costs, the optimization of the delivery timings, the maintenance and constant monitoring of the temperature and sterility conditions of the organ, as well as the intrinsic improvement of logistics in the transport chain for life-saving transplant organs and supporting biological specimens (20) (1), as well as emergency medical services systems (6).

Context for the birth of the project

The clinical needs that favor the development of this project arise from the need of transplant medicine to use cutting-edge technologies and implement efficient logistical coordination to safeguard both the patient and the donated organs.

The ultimate goal of using drones in this type of mission is to speed up and possibly automate the process of transporting the biological material necessary for organ donation, such as biological samples, tissues, cells and transplant organs, within the clinical time constraints, as it is essential to adhere to the specific ischemia times of the organ for the transplant operation to be successful. The adoption of modern, highly specialized and quality technologies in transplant logistics would therefore allow an increase in the overall efficiency of safe transfer operations, making a more significant number of organs available for transplantation in the long term and, consequently, improving the quality of life of the patients (37).

Figure 1.2: Centro Nazionale Trapianti

The Centro Nazionale Trapianti (CNT) (7) explains that ischemia is the period of time in which organs and tissues have been procured and are not supplied by blood and oxygen, while in transport or awaiting reperfusion, so they cannot be preserved for a long time outside of a proper environment, that could potentially damage the organ itself and increase the risk of organ rejection upon transplant. Moreover, there is a stringent time limit for the ischemia of different organs, as illustrated in the following infographic.

Figure 1.3: Ischemia time for different organs

Consequently, it's fundamental to have a timely transport of the biological material as it is one of the most delicate phases that lead up to the transplant, ensuring that the operation is not compromised by increasing the ischemia time beyond what the medical literature allows.

In most cases, the organs are transported on the road with vehicles and operators of the regional emergency services, that is ambulances or medical cars that deliver the donated organ to the destination in order to proceed with the transplantation. Sometimes, when the destination is far away and the time available is little, organs and medical teams for the organ procurement have to travel by airplane to cover important distances. In some exceptional cases, Italian *Polizia Stradale* uses their high speed Lamborghini cars with some specifically trained pilots to transport organs between locations that are well connected by highway, under a collaboration between the State Police and the CNT.

In Italy, at the moment, drone transport of organs unaccompanied by a medical team is considered only in the case of the human kidney, whereas all other organs usually transplanted, such as the heart, the lungs and the liver require further control of the organ's parameters, so they cannot travel unsupervised.

Figure 1.4: Usual means for the transport of transplant organs

Involved stakeholders

Figure 1.5: Fondazione DOT

Figure 1.6: Centro Regionale Trapianti

Figure 1.7: Città della Salute e della Scienza di Torino

INDOOR is a research project conducted by the Fondazione D.O.T., a non-profit dedicated to advancing organ donation awareness and transplantation therapies created in 2017 by the *Centro Regionale Trapianti del Piemonte e della Valle d'Aosta*. It focuses on funding scientific research, promoting social initiatives, and supporting medical practices related to transplantation to improve patient outcomes and public engagement.

It has been constituted with the following founding members:

- *A.O.U. Città della Salute e della Scienza di Torino*
- *Città di Torino*
- *Regione Piemonte*
- *Politecnico di Torino*
- *Università degli Studi di Torino*

in active collaboration with Politecnico di Torino through PoliTo Interdepartmental Centre for Service Robotics (PIC4SeR), where the majority of the project has been implemented and conducted.

Figure 1.8: PoliTo Interdepartmental Centre for Service Robotics

As a technical and regulatory authority, Ente Nazionale per l'Aviazione Civile (ENAC) is heavily involved to ensure compliance with national and European aviation normative, such as airspace and ground safety protocols, drone certification processes and risk mitigation strategies for urban operations. Other institutional figures such as the Prefecture of Turin and the Municipal Police's drone unit are fundamental partners involved in the successful execution of a demonstrative mission in the urban area of the city of Turin.

Figure 1.9: Ente Nazionale per l'Aviazione Civile

The previously involved industrial partners were MavTech, PRO S3 and LMA, while a collaboration with ABzero is currently ongoing. Other partnerships have also been evaluated, but they didn't have a suitable funded application call to sustain it.

Project timeline

The project started in 2021 with a preliminary phase conducted by researcher Chiara Bosso around a comprehensive evaluation of the current state-of-the-art methodologies and technologies in this category of healthcare related missions, both within Italy and globally. This initial stage aimed to identify best practices, technological and normative requirements, and opportunities for innovation in the field. Following this preliminary research phase, the project proceeded with experimental activities, including tentative vibration analyses on biological samples, which were scheduled for later implementation to assess potential impacts on sensitive biological payloads.

In early 2023, these planned vibration analyses were executed at Molinette Hospital in Turin. The tests focused on evaluating the effects of mechanical vibrations on blood samples obtained from volunteer donors, simulating conditions similar to those encountered during drone flights. Results from these experiments concluded that no statistically significant adverse effects were detected, confirming the feasibility of the proposed transportation protocols for biological materials.

Afterwards, attention was turned to the design and optimization of the mission payload. Multiple configurations were conceptualized, prototyped, and subject to testing to evaluate their compatibility with the project requirements. However, the conclusion was that the existing payload design developed by ABzero, a startup based in Pisa and focused on this exact type of mission, offered the optimal balance of functionality and cost-effectiveness for an organ transport smart capsule.

In parallel, the project has remained responsive to evolving regulations regarding drone operations. In May 2022 EASA published a new MOC Light-UAS.2511 (15) that mandates enhanced safety protocols regarding containment, including the integration of a Flight Termination System (FTS) into drone hardware to ensure fail-safe mechanisms in case of malfunctioning. Adherence with these standards requires extensive certification testing, part of which was conducted in the PIC4SeR laboratories. These tests validated the FTS' s durability under simulated operational stresses, certifying its capability to sustain at least 500 repeated mission cycles without performance degradation.

Finally, on the 1st of October 2024, a full-scale demonstrative test was conducted between the Centro Traumatologico Ortopedico (CTO) and Molinette hospitals, both part of the Città della Salute network in Turin. This trial flight, executed in partnership with ABzero, showcased the integration of their smart capsule technology within the urban scenario in which the test was conducted, demonstrating the validity of the technical readiness for the biomedical payload transport mission and operational safety under real-world conditions.

Overview of the technical aspects of drones

A drone, formally referred to as a Unmanned Aerial Vehicle (UAV), is a remotely piloted aircraft, typically consisting of a carbon-fiber or composite frame equipped with electric motors connected to propellers, or rotors, to enable lift generation and, thus, the ability to fly, hover and maneuver in the air.

Drones are categorized by their configuration, such as multirotor like quadcopters (4 arms) or hexacopters (6 arms), fixed-wing, or hybrid Vertical Take-Off and Landing (VTOL) convertiplane with multirotor systems being commercially predominant due to their agility and stability in diverse environments.

Beyond the main structure, drones are equipped with critical hardware components to ensure operational functionality and safety. These include a Global Positioning System (GPS) module for geolocalization and navigation, IMUs (Inertial Measurement Unit) for attitude control and other sensors for environmental control like altitude and speed. All this information is processed by the autopilot, a centralized flight management system that executes the expected flight plan while stabilizing eventual turbulences along possible dynamic pathways.

Communication between the drone and the pilot is accomplished through a secure radio telemetry system installed on board that communicates bidirectionally with the operator's Ground Control Station (GCS) while receiving commands on the drone's motion.

The power supply for both the motors and the hardware components is provided by an external high-capacity lithium battery inserted in a pouch or compartment under the structure. Usually, based on the size of the transportable weight, the batteries limit the flight endurance of the autonomous vehicle to a maximum of one hour.

Finally, as drones are modular platforms capable of performing a wide variety of missions, the specific payload transported can vary greatly. High-resolution cameras can be used for aerial photography, multispectral sensors for thermal monitoring, LIDAR systems for 3D mapping or commercial payloads for last-mile deliveries, especially for medical purposes.

A schematic figure of a generic drone is present in the figure 1.10 (28).

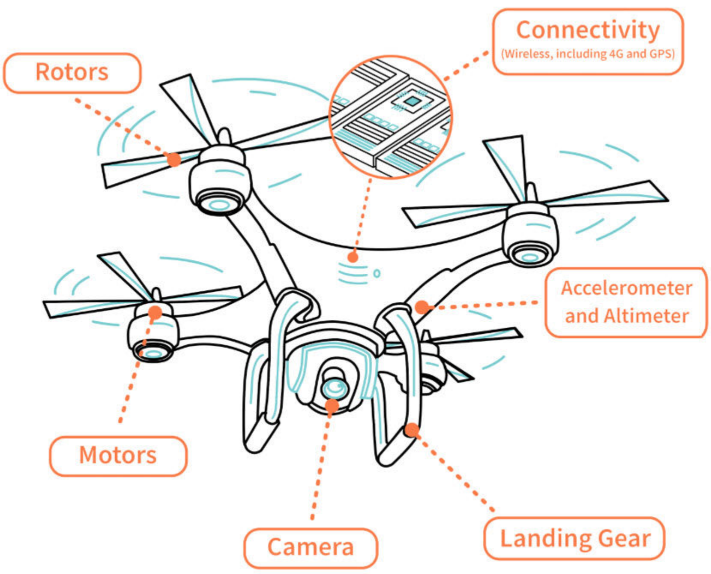

Figure 1.10: Generic drone configuration

Chapter 2

Literature Review

The use of remotely piloted aircraft for the transport of medical and biological material has spread globally, especially in the last decade, in conjunction with the evolution and maturation of drone technologies. This innovation has found resonance in developing countries, where often inadequate or insufficient road infrastructure hinders efficient distribution of essential medical supplies or the execution of timely blood analysis, as well as in industrialized nations aiming to enhance logistical efficiency in densely populated urban environments.

Around the world

In this chapter, a brief chronological overview of innovative projects and studies similar to INDOOR about the application of drones in the healthcare field around the world will be presented. A wide array of initiatives have been conducted globally, ranging from Tanzania's "Deliver Future" and Vayu's drones in Madagascar to Swoop Aero in the Democratic Republic of Congo. Additional documented efforts include UPS Flight Forward in North Carolina, Matternet in Switzerland, Germany and the USA, MissionGO in Nevada and Minnesota, and the Austrian Red Cross partnership with Thales, alongside further initiatives in Malaysia and India.

To maintain conciseness, this literature review will not explore these topics in depth.

In North America

Since the year 2014, Amukele and Scalea, physicians based in Baltimore, Maryland, have conducted preliminary and practical studies on the viability of drones for transporting blood samples (4) (3) across long distances (2), while patenting appropriate technologies also for organ transportation, such as the HOMAL (37) (36) (38), used for kidney control and preservation during transport. These analyses and real-life study cases have emphasized the advantages of using drones for sample transportation, including the rapidity and low cost of such missions, while no relevant variations with regard to the control group have been identified in the tested samples, thus ensuring the safety of using drones for this scope.

Figure 2.1: Amukele testing blood samples on a glided fixed-wing drone

Figure 2.2: Scalea's HOMAL drone system mounted on a DJI M600

Another significant instance has been the transport of transplant lungs that took place in downtown Toronto, Canada, in October 2021, operated by the company Unither Bioeletronics (35). The delivery occurred with a modified DJI M600 drone across 1.5 km in 5 minutes with a custom carbon-fiber transport box with temperature control and vibration dampening. Other safety measures were also present in compliance with aviation regulation.

Figure 2.3: Drone transporting transplant lungs in Toronto

Zipline in Rwanda

Particularly relevant is the case of Zipline (30), project that distributes blood in Rwanda since 2016 and subsequently expanded to other countries in Central Africa, allowing a 63% reduction of wasted blood as the drone assisted deliveries took almost 80 minutes less than road deliveries, achieving a mean time of around 50 minutes to connect 20 facilities to the main center for blood transfusion.

Figure 2.4: Fixed-wing Zipline ejects boxes with a parachute to help the descent

In Europe

In 2020 a study conducted by Beck (5) of the Department of Pharmacy of London King's College evaluated the feasibility of drone delivery of auto-injectable adrenaline to treat anaphylaxis, that could be potentially life-threatening. The laboratory tests on the stability of the chemical reveal that no degradation is detectable, thus validating this way of transport for adrenaline based supplies. The team's research also focused on the healthcare professionals' perception of using UAVs to ensure a gradual acceptance of the technology. Similar results were obtained at the University of Southampton in a study led by Oakey about the stability of insulin transported by drone (31).

In Valencia in 2021, a realistic experimental use case has been developed and tested by the team of Quintanilla (34) by designing a drone delivery network for medical supplies during high-demand scenarios. Three real-world test applications, in urban and controlled airspace zones, showed that drones could deliver payloads without new dedicated infrastructure while complying with EASA safety regulations through the Specific Operations Risk Assessment (SORA) methodology. The performed flights were successful but some challenges required the activation of emergency protocols, emulating realistic scenarios. According to this assessment, further refinement is needed for full automation and to ensure proper safety at scale, but drones are definitely a feasible solution to strengthen healthcare logistics during emergencies.

Figure 2.5: Beck's drone testing on delivery of adrenaline

Figure 2.6: Quintanilla's DJI Matrice 300 RTK fitted with upper cargo bay

In a study conducted in 2021 in Norway, Johannessen (21) evaluated the possibility of using drones to concretely change the transportation logistics of blood samples by modeling the transportation data of 6.5 million annual analyses between two laboratories located 2 km apart. Using the standardized protocol for time-sensitive blood analysis, it was revealed that 15-minute departures of drones with payloads under 3.5 kg were crucial to maintaining the proper flow of the estimated samples, even though there were often delays caused by the laboratories. These findings suggest that drones could outperform ground transport, but proper technological and operational consolidation is needed before implementation. In a subsequent study conducted by the same laboratory, random vibrations and turbulence simulation at a higher g-force than those previously tested have been applied to specimens in order to analyze their integrity. The result of the experiment showed that whole blood had little vulnerability but plasma easily separated by gel was more impacted due to vibration exposure, thus making it less appropriate for drone transport (22).

In the meantime, in Switzerland, the Jedsy system, a platform anchored to windows for the takeoff and landing of a small fixed-wing aircraft, has been designed to enhance urban medical logistics and enable direct delivery of medical supplies to healthcare facilities through automated docking and charging (19).

Figure 2.7: Jedsy drone that docks directly to a station anchored on windows

In Japan

Similar results to those achieved in the North American continent were obtained in a study conducted by the team of Yakushiji at the Tokyo Metropolitan Hospital in Japan, which verified the feasibility of drone transport of blood samples through test flights in simulated disaster conditions at the Fukushima Robot Test Field (43) and its subsequent analysis confirmed the integrity of the specimens (42) that confirms the applicability of this protocol for medical aid in case of heavy natural disasters or crises. There have been other trial flights that covered transoceanic distances between Japanese islands that would provide a solution for providing blood transfusions by connecting even remote locations (44).

Figure 2.8: UAV connected to the ATR with blood

Figure 2.9: Industrial uncrewed autonomous vehicle for the transoceanic flight

In 2023, researchers in Nagasaki, Japan, conducted a groundbreaking experimental study in which they transported rat liver via 30 minutes of six-winged multicopter drone flight and subsequently executed a biopsy on the organ to ensure that no significant cellular degradation or functional impairment with respect to the control group occurred due to the vibrations and the accelerations of the UAV (10). This trial has the potential to validate the scalability of drone transport applied to human transplant organs.

In Italy

In Italy, in October 2020, some experimental flights were carried out by Leonardo and Telespazio in collaboration with the Bambino Gesù Children's Hospital in Rome for the delivery of biological samples and biomedical goods between two hospital facilities (24). In February 2023, the group Cerba HealthCare Italia, that involves also a blood analysis laboratory, conducted a flight demonstration for the transport of biological material between Opera and Rozzano, in the province of Milan, operated by the company Nimbus (8). Also in May 2024, Veneto region unveiled their new hydrogen-powered drone for the safe transport of biomedical material in Venice(23). Another emerging figure in the Italian application of UAS in healthcare is project DragonFly, which executed a maiden flight on Lago d'Iseo, in Lombardy, in January 2025 (32).

Additionally, ABzero, a startup founded in Pisa in 2017, with their smart capsule specifically developed for the transport of biological payloads (29), has a series of collaborations in progress with major healthcare centers in various parts of Italy, including Rome, Sicily and now also in Turin with the project INDOOR.

Concerns about the safe usage of drones

Some parties still hold concerns about the usage of drones for safety reasons (26) while considering the risks that could occur while traveling near inhabited spaces, as emphasized by this database that collects drone crash events since 2007 (9), and the regulations (25).

A survey conducted on transplant surgeons' perspectives on the potential integration of UAS to deliver organs highlighted the skepticism of the direct stakeholders in this innovation, indicating that more in-depth education is required before implementing this technology (39).

Still, Amukele, one of the major pioneers in this sector, defines himself as a ”drone optimist” regardless of the challenges that the actual adoption presents (1), as this technology requires incremental development that progresses at the same pace as the general public's perception acceptance and regulatory framework governing it.

Chapter 3

Analysis of the vibrations of a drone on the transport of biological material

Before proceeding with the operational implementation of missions for the transport of biological payloads, stress tests were carried out in a non-critical environment in order to conduct a preliminary analysis of the impact of drone vibrations on blood samples taken from volunteer donors, representative of the payload that will be transported in potential future missions.

Vibration study

To conduct the drone vibration simulation bench tests in a laboratory, flight test stress analysis data provided by PRO S3 was processed to be used as input signals to the SmartShaker K2007E01 with integrated power amplifier of The Modal Shop, the instrument used to reproduce the vibrations generated during the flight of an UAV. The data considered is the median value of the information processed from three Inertial Measurement Unit (IMU)s, sensors acting as both accelerometers and gyroscopes, installed on the tested drones.

ID	DATA E ORA	FONTI	TimeU	I	GyrX	GyrY	GyrZ	AccX	AccY	AccZ
1577	27/01/2022 14:55:08,145	IMU	1,45E+08	1	0,003329	-0,0003	1,34E-05	-0,71834	-0,03616	-9,82291
1578	27/01/2022 14:55:08,145	IMU	1,45E+08	2	0,001239	-0,0031	0,004565	-0,7113	-0,25684	-9,78472
1579	27/01/2022 14:55:08,179	IMU	1,45E+08	0	0,001751	0,000993	0,001623	-0,41496	-0,56061	-9,91717
1580	27/01/2022 14:55:08,179	IMU	1,45E+08	1	-0,00097	0,000652	-0,00119	-0,73921	-0,04225	-9,81095
1581	27/01/2022 14:55:08,179	IMU	1,45E+08	2	-6,22E-05	-0,00155	0,002972	-0,73976	-0,26332	-9,78375

Figure 3.1: Snipet of the raw data of the log relative to the convertiplane

Specifically, the focus was on the tabulated signals of the convertiplane, as, according to the state-of-the-art evaluation from the previous researcher, fixed-wings have a larger payload cargo and longer hourly autonomy with respect to the multirotor drones configuration considered. Another parameter considered when carrying out the experimental tests concerns the temporal duration of the audio files: the file with the shortest duration was selected in order to conduct a greater number of tests in a limited time and to best calibrate the provided instruments for the evaluation. Subsequently, the same operation was performed on signals of longer duration to evaluate the impact of prolonged vibrations on the biological load in conditions more similar to those of an actual flight.

Figure 3.2: Setup for the SmartShaker configuration in the PIC4SeR lab

An initial calibration setup has been performed on the SmartShaker in order to get acquainted with the hardware and how to properly manage it without damage, as explained in the datasheet that accompanies it (40). In figure 3.3 is the result of one of the different tests performed on the instrument by generating a sin wave at 80 Hz, with the aid of a script that elaborated the data in input and output, and its transfer function.

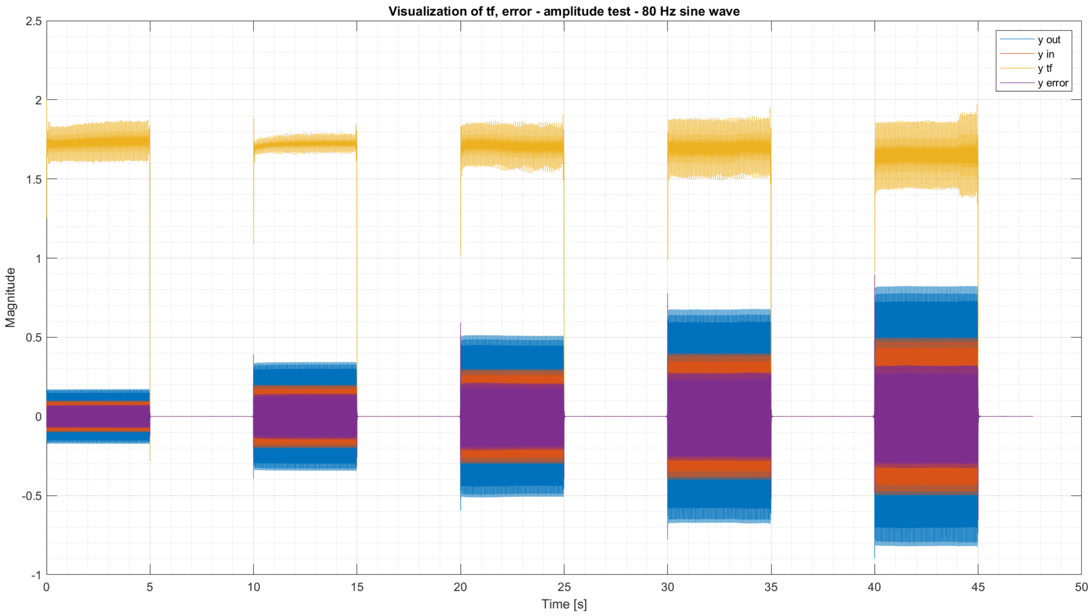

Figure 3.3: Shaker calibration test result

Frequency filtering

The transformation of the provided values was carried out using the MATLAB calculation software, which generated WAV audio files for the control of the SmartShaker through a jack-BNC audio cable. Corrections were made to the files originally imported for the safe and suitable use of the available instrument. Firstly, the sample frequency in [Hz] and the Nyquist frequency (half of the sample frequency) were calculated from the raw data.

Thus, the audio signals emulating the vibrations of the drones present the following modifications:

- They were filtered at 10 Hz with a high-pass filter, which allows the passage of frequency values higher than the considered cutoff value, in order not to damage the instrument with signals that have incompatible wavelengths.
- The sampling frequency was modified to obtain a higher resolution of the transmitted and received signal, especially at lower frequencies, which is of interest for this specific drone application.
- An additional distinct initial peak signal has been introduced to facilitate the search and enable a straightforward point-by-point comparison between the input and output signals obtained.
- The acceleration values, which have a range higher than those acceptable as input to the shaker, have been proportionally resized to the original signal.

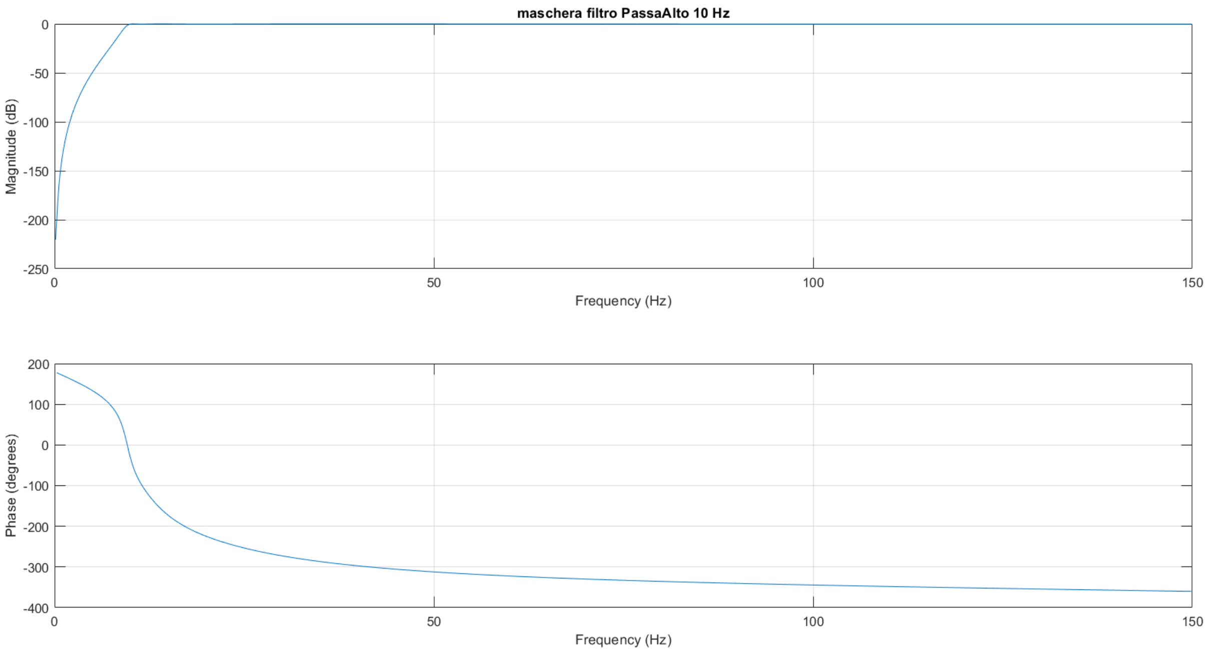

Figure 3.4: 10 Hz high pass filter mask applied to the log

The spectral analysis visualization of the edited wav files originated by the raw log data is shown in figure 3.5.

It can be noted that the band under 10 Hz is completely absent and the initial peak signal is clearly visible around 40 Hz for 5 seconds, while the stress peaks are in accordance with the findings of the drone's vibration analysis conducted by Ge's team in China (17).

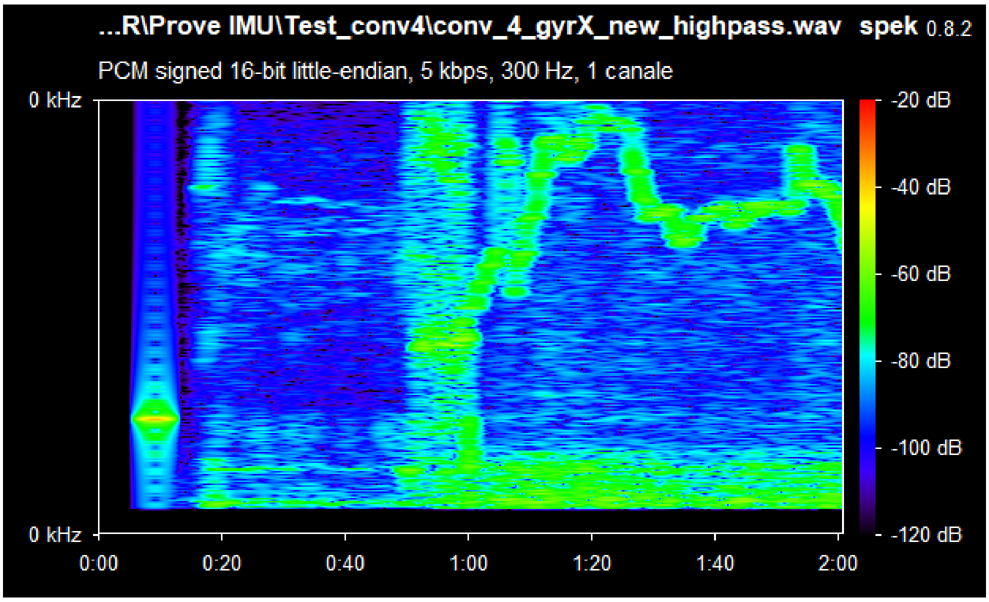

Figure 3.5: Filtered spectrogram of log gyrX conv 4 using Spek

Stress simulations with the MiniShaker

The acceleration files chosen for the final test are related to the fifth log of the convertiplane, with a duration of about 30 minutes, and present the vibration amplitude proportionally resized to the maximum peak value present in each individual audio file. It should be noted that the file related to the Z axis presents a low-frequency (below 10 Hz) filtering problem at certain moments during playback. The payload used is a 3D printed cylindrical container with a conical base, which has a foam element inside to accommodate about 30 test tubes and a container for biological material, shown in figure 3.10. In the center of the conical base there is a threaded hole for connection to the stress test instrument, the accelerometer pictured in figure 3.6.

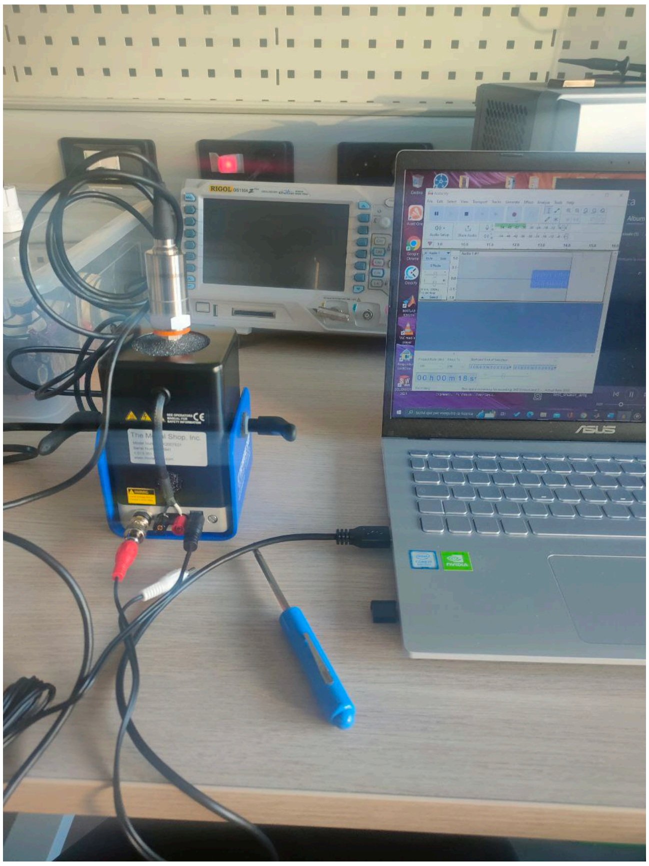

Figure 3.6: MiniShaker with accelerometer

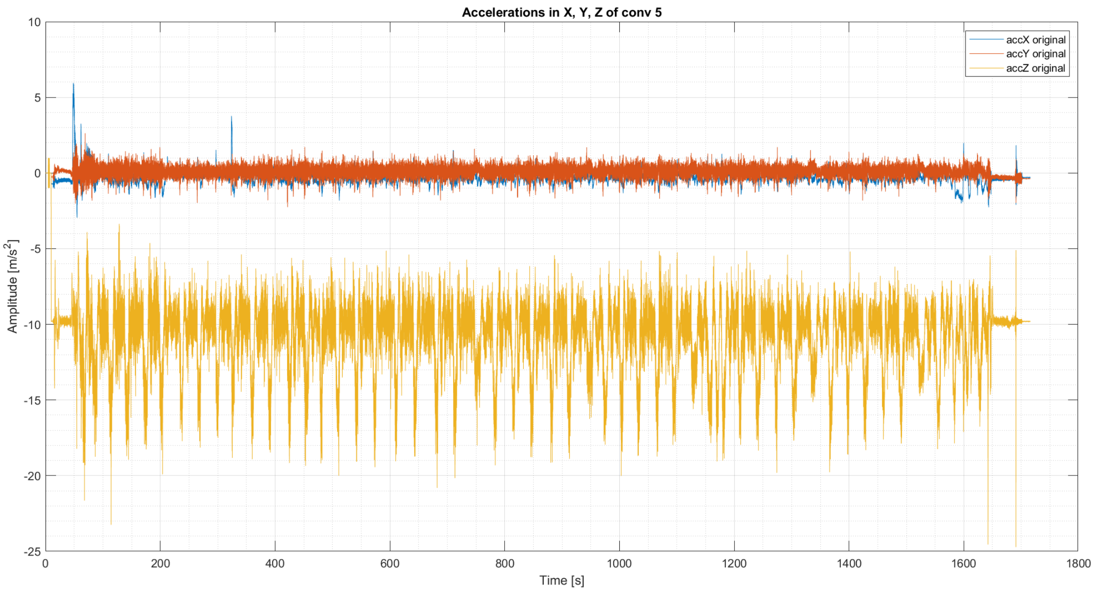

Figure 3.7: Acceleration logs of conv 5 without filtering

First of all, the method of processing the vibration data in WAV format to command the shaker input was integrated and finalized. Specifically, MAT-

LAB scripts for the processing and modeling of generic logs were created and documented, appropriately modifying some parameters depending on the data provided. Finally, the results obtained in output from the shaker were elaborated in a similar way, in order to obtain a consistent comparison with the input data.

For all the tests carried out, the FFT (Fast Fourier Transform) and PSD (power spectral density) graphs derived from the collected data were obtained. The results appear consistent with what is expected from the presence of a payload with its own distributed weight.

Using the data acquisition instrument for the acceleration data produced by the active shaker, the compatible Digiducer 333D01, which is connected to the PC via a USB cable, the resulting frequency signals of the shaker were captured using the Audacity audio editing software. The shaker's output files, after appropriate cuts and transformations, present certain peaks that allow the original signal and the one derived from the shaker to be overlapped, in order to make a precise comparison.

These data, as in the example in the figure 3.8 (gyroscope around the X axis of the fourth file of the convertiplane), can be analyzed in power, observing the deviations of the peaks and any amplifications and attenuations resulting from the use of the shaker, even in the presence of the test tube container.

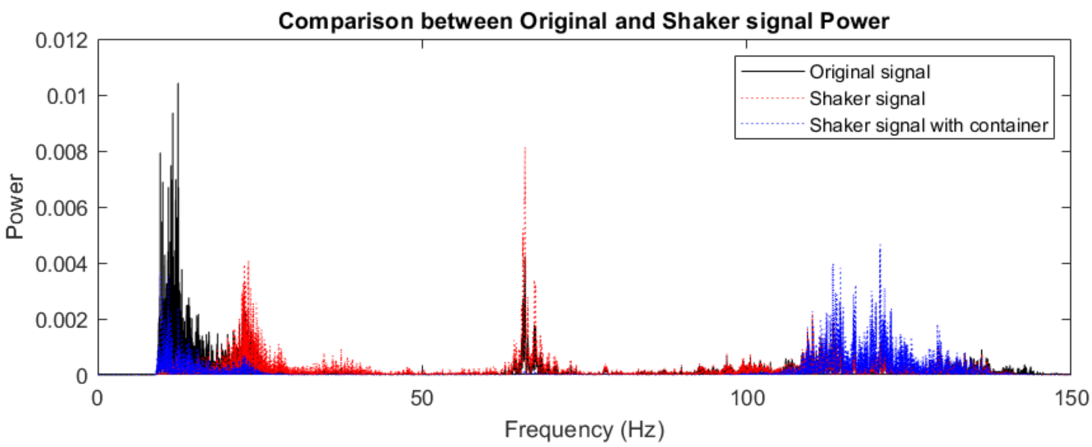

Figure 3.8: Power comparison graph for a conv log

Vibration tests with biological material

The experimental tests with the shaker were carried out both in the laboratory at PIC4SeR, and on-site at the laboratory of the *Centro Regionale Trapianti* located in the *Ceppellini* building of the *Molinette* Hospital, and were carried out with a gradual increase in the complexity of the elements involved in the tested cases, that is:

1. test: in the absence of mounted elements on the instrument, in addition to the accelerometer
   Total weight = 148 g

2. test: in the presence of the 3D printed support and container, inside which the foam test tube holder is positioned
   Total weight = 618 g

3. test: in the presence of test tubes containing blood samples from volunteer donors housed inside the container described in the second test
   Total weight = 845 g.

After the test at the *Molinette*, the blood samples were tested to analyze and compare their hematological, coagulation, chemical and virological characteristics after the simulation of the vibrations with a batch of control blood samples that were not shaken.

From the collected data, there should be no substantial differences in the results between the PRE and the POST shaken tubes. With this information, it can be concluded that the blood transported during a standard drone operation should not undergo significant deterioration of its physical properties. So, it is safe to assume that transporting biological samples with a drone is a valid method of transportation.

In appendix A the complete report (in Italian) of the clinical analysis from a Medical Doctor is present.

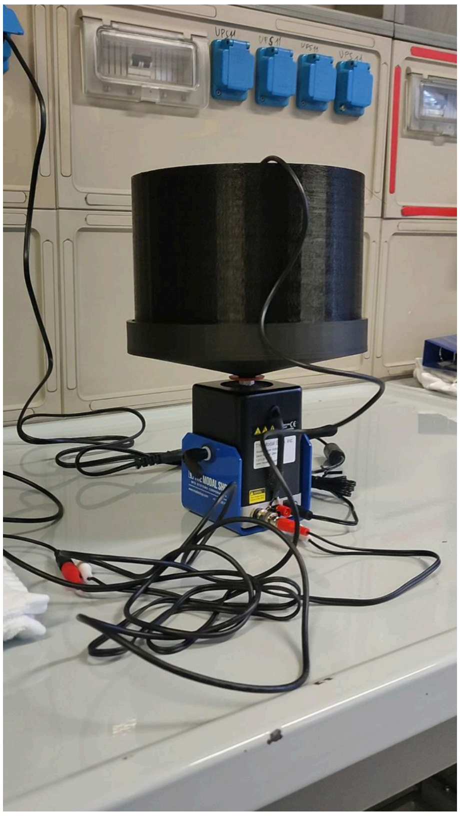

Figure 3.9: Shaker configuration for testing blood tubes

Figure 3.10: View from the top of the experimental configuration

Figure 3.11: Blood tubes collected from voluntary donors for the test

Use of an additional IMU in flight tests

Inside the capsule for the transport of the biological material, a sensor could also be positioned to evaluate the perceived vibrations and accelerations involved in the planned mission profile for the demonstration flight.

Specifically, the ProMove MINI IMU from Inertia Technology has been evaluated, a sensor with small dimensions and equipped with wireless and USB connectivity for data transmission after recording on an embedded flash memory, or viewable in real-time on the compatible platform provided by the manufacturer.

Figure 3.12: Promove IMU

The data processing will take advantage of the considerations already made in the vibration tests and a comparison with the internal IMU log of the drone could be performed to quantify the realistic difference between the measured vibrations and the ones perceived from the payload.

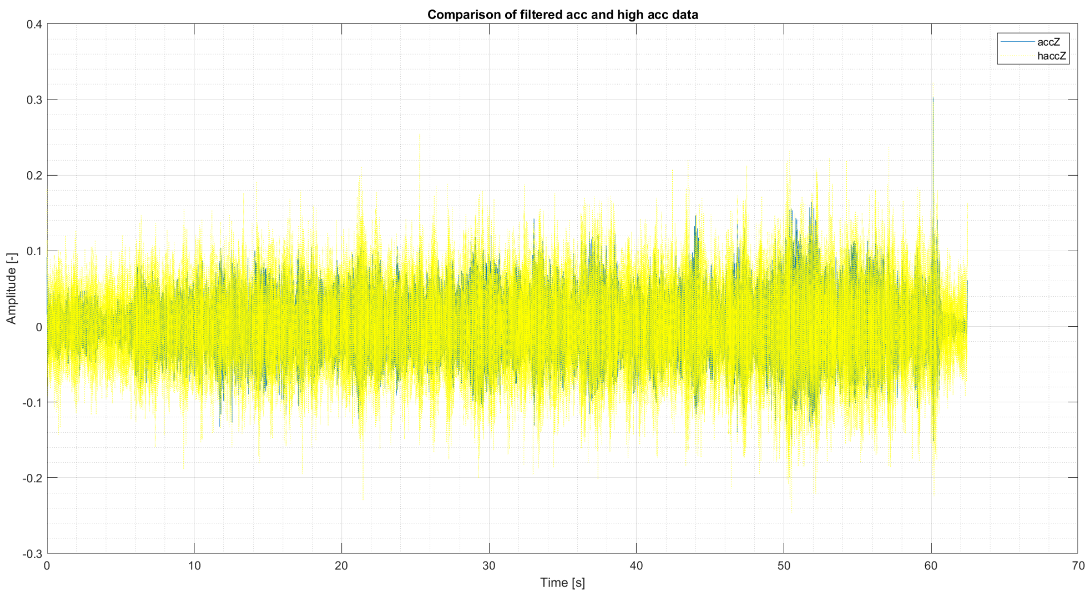

Figure 3.13: Results from a cage flight test transporting the mini IMU

Chapter 4

Biological payload container

Container clinical and normative requirements

When it comes to the transport of organs intended for transplant, the containers must meet stringent requirements both from a clinical and a regulatory point of view to ensure viability and compliance.

From a clinical standpoint, maintaining a constant, precise cold chain is essential to preserve organ functionality and prevent degradation. This involves advanced thermal regulation systems to maintain a constant cold temperature between 4°C and 8°C. Equally critical is ensuring a sterile, hermetically sealed environment to mitigate infection risks, alongside robust designs to protect against mechanical stresses such as vibrations, impacts, or abrupt movements during transit.

The team of Dr. Zailani, based in Cyberjaya in Malaysia, has already verified that this framework is perfectly attainable with a rigorous protocol (45).

On the regulatory front, it is important to guarantee safety, traceability and compliance with current laws and local authorities by adhering to the standard procedures for packaging and labeling donated organs. The container, in particular, must be compliant with the standards and certified to validate its suitability for biological material transport. During the journey, it must be accompanied by all the documentation necessary for the transplant to ensure legal accountability and operational transparency.

The case of ABzero's Smart Capsule

ABzero is a startup born as a spin-off of the *Scuola Superiore Sant'Anna in Pisa*, which deals with designing and creating an intelligent and sensor-equipped *Smart Capsule* container for the transport of biological material, such as blood samples and organs, compatible with different types of drones and with demonstrated thermal stability capacity, real-time quality monitoring of the temperature and mechanical vibrations (29) while also new environmental features are undergoing development (27).

The final product launched on the market aligns with the objectives of the INDOOR project, thus, ensuring the birth of a mutually beneficial partnership.

Figure 4.1: ABzero logo

Figure 4.2: ABzero Smart Capsule

Container design

In February 2023, a collaboration was established between ABzero and the PIC4SeR group. As part of this partnership, ABzero provided the research team with the CAD (Computer Aided Design) model of the ”Smart Capsule mini” container, a smaller version of the company’s existing commercial product.

The model of the received capsule had dimensions that were not adequate for the PRO S3 Venture multirotor drone initially evaluated for the demonstrative test. As a result, a 30% reduction in the overall dimensions of the capsule was preliminarily applied to realize a first 3D printed prototype. Furthermore, it was also observed that the interface between the capsule and the drone is not compatible; therefore, it was necessary to redesign entirely the connection to ensure a secure mechanical integration and to obtain a solution suitable for the needs of the project.

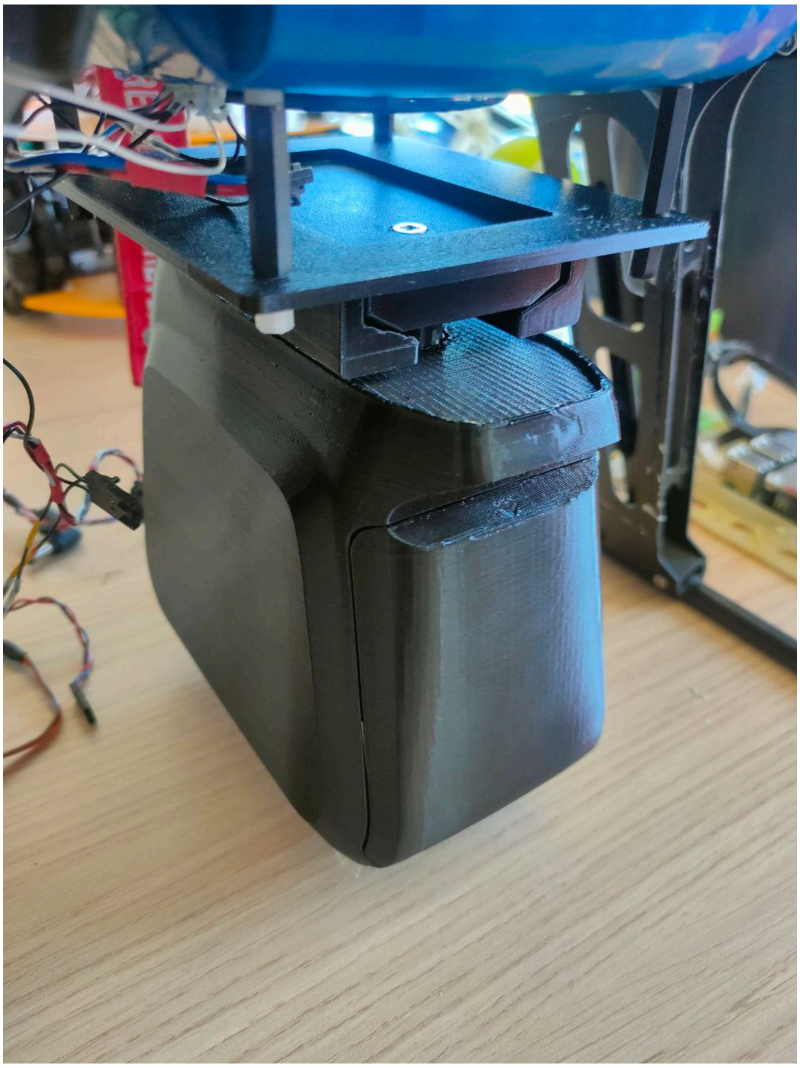

Figure 4.3: New design of the sliding interface between capsule and drone

As the dimensions of the container had been reduced due to the design requirements, only some test tubes with a maximum height of 82 mm (green, blue and purple caped tubes) could be introduced as payload in the internal compartment of the capsule, housed in a test tube holder specifically created from a suitable material that optimizes shock absorption.

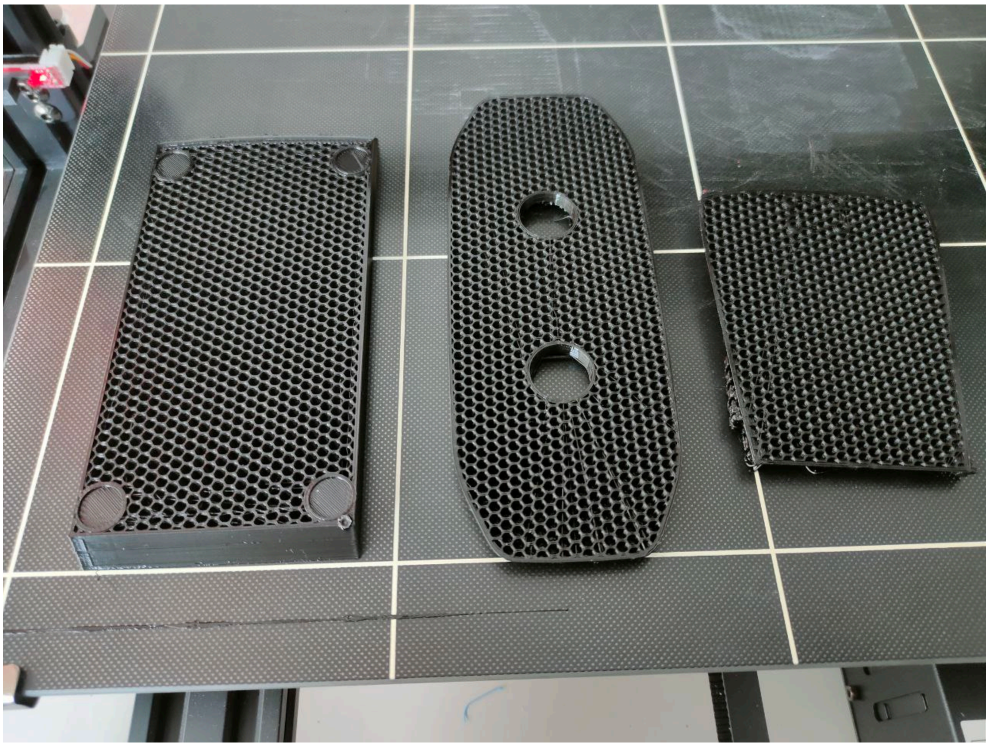

Figure 4.4: Internal view of the 3d printed hexagonal infill

The production of the elements to create the prototype model of the capsule was carried out with the 3D printing methodology, a cost-effective, precise manufacturing process that constructs solid objects layer by layer from a digital design, thanks to the printers and materials (PLA and TPU) present in the PIC4SeR laboratory. This production method is suitable for lightweight but durable product design as the inside structure is mostly hollow, and the infill occupies only between 15% and 30% of the inside volume and, thus, weight.

The custom design, moreover, allows us to directly test the necessary modifications that have to be made to the original design, as the production methods and materials expected for the final box are different.

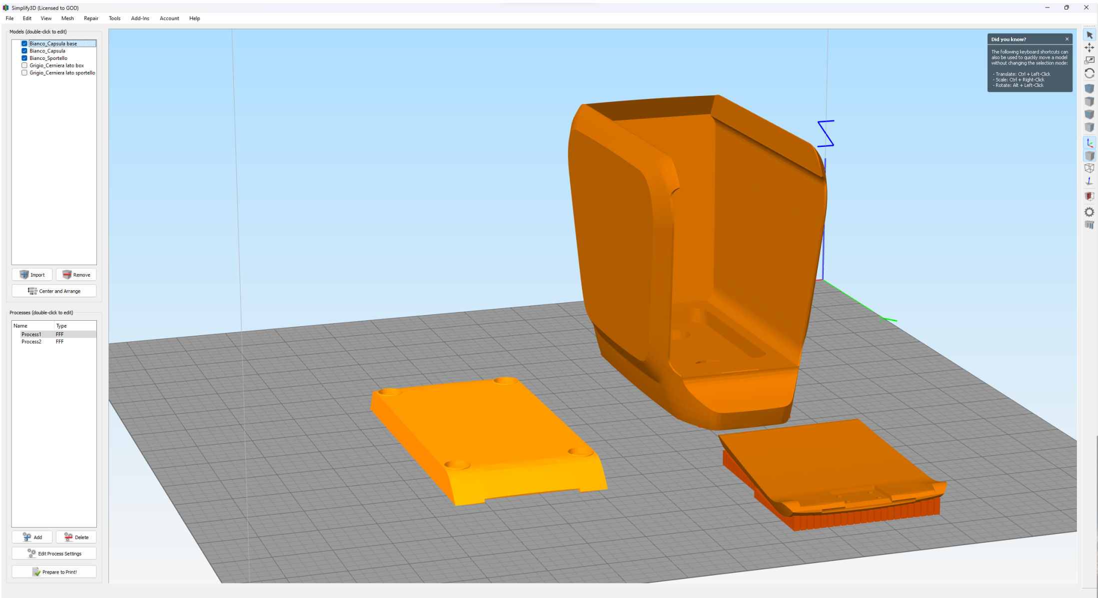

Figure 4.5: View of the slicer for the 3D printed mini capsule

The mounted capsule employed also bicomponent glue to help with the assembly of the finished product. Some additional embellishing elements were attached to the visible surfaces for more brand visibility.

Figure 4.6: 3D printed mini capsule assembled and mounted under the drone

LMA collaboration

Subsequently, in collaboration with the company LMA, the following aspects of the capsule were modified for a more precise integration with the drone:

- The external aesthetics of the capsule remain unchanged.
- The overall dimension is limited to the maximum size requirements of the transportable payload.
- Proceed with a single-piece printing of the main component, avoiding the fitting and assembly of multiple elements.
- Addition of a rectangular-shaped test tube holder drawer attached to the closing door, in order to ensure the stability of the internal load, as well as fulfilling the function of transporting the material itself.
- Creation of a slide on the inner base of the capsule for the guided housing of the drawer.
- Replacement of the hinge connecting the door and the main body of the capsule with the use of magnets placed in the end-of-travel lockers of the drawer and inside the capsule. The presence of the magnets prevents the possible opening of the door caused by vibrations and sudden movement. This ensures an additional level of stability of the internal component.
- Addition of two small compartments at the point of intersection of the diagonals of the door, to insert a fabric strap that allows for easy opening of the case.
- Modification of the capsule connection interface to adapt it to the drone specifications, keeping the pre-existing slide and updating the retention mechanism of the two coupled sliding components.

The capsule for the final demonstration flight has the following characteristics:

- Dimensions: approximately 85 x 160 x 145 mm (width x depth x height).
- Total weight of less than 500 g.
- Manufacturing: FDM (Dused Deposition Modeling) through 3D printing.

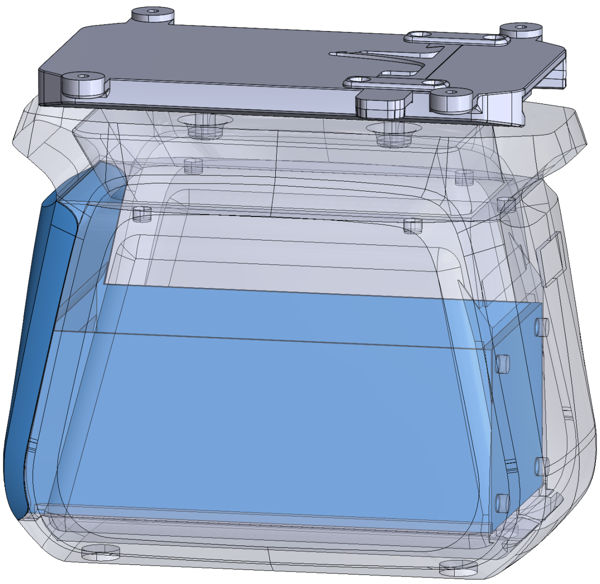

Figure 4.7: 3D printed assembly mini capsule

Figure 4.8: Capsule printed by LMA after slight adjustments

Test tube holder made of polyurethane foam

To house test tubes within the sliding drawer of the capsule, solutions were tested using polyurethane foam, that is a two component resin called ESPAK SOFT, from the chemical company Prochima (33). When mixed together, the resin undergoes an exothermic reaction and transforms into a material similar to foam rubber, used for the possible creation of a test tube holder that can dampen the vibrations transmitted by the motion of the drone's propellers. During this rapid expansion, the foaming material fills and conforms, when present, to the shape of the container in which it is poured. While the cured foam is safe to use for various applications, the mixing phase requires caution, as the reaction generates a significant amount of heat, posing a chemical burn risk if touched.

Figure 4.9: ESPAK SOFT two component resin

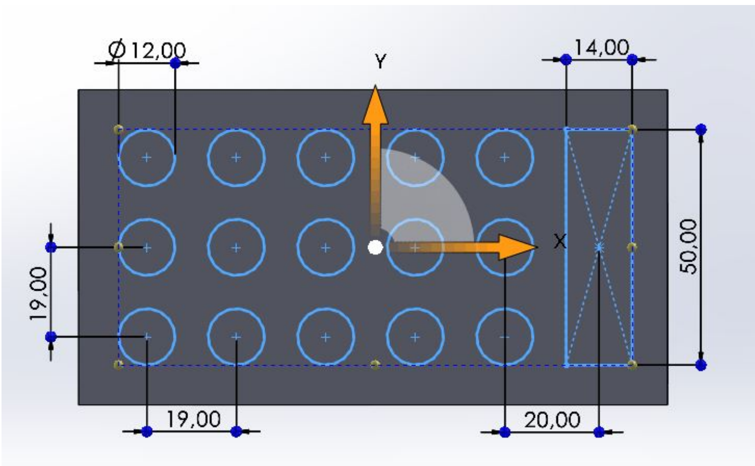

Figure 4.10: CAD design of the test tubes holder

Initially, a PLA mold was designed for the creation of the desired shape, but this approach proved immediately ineffective for the purpose, as the high adhesion between the components does not allow the clean detachment of the foam from the container as seen in figure 4.11.

Figure 4.11: Direct contact of the polyurethane foam with a PLA expansion chamber results disastrous

During various adjustments, the number of test tubes was varied to optimize the holder and different types of trials were carried out to search for an adequate non-stick material to cover the surfaces when the foam is expanding.

The size of the test tubes corresponds to the standard measurements of the BD Vacutainer brand, while there is also a parallelepiped-shaped hole for the secure placement of the ProMove sensor as shown in figure 4.10.

Tests have also been conducted on the use of 3D printed PVA as the principal component for the expansion container, as it dissolves in water and that would allow the desired shape to be obtained flawlessly. Even though the shape results would be excellent, the slow dissolution of the material and the long presence in the water may degrade the foam quality for the tube test holder.

Chapter 5

EVLOS flight in an urban environment

Description of the mission

In order to validate this feasibility study, a demonstration flight has been carried out between the hospitals CTO and *Molinette* of the *AOU Città della Salute e della Scienza di Torino*, specifically from the raised helipad platform to the *Ceppellini* building, crossing *Corso Unità d'Italia* and traveling along the Po river stretch adjacent to the road for around 500 m as shown in figure 5.1.

All UAV missions must be carried out in full compliance with civil aviation regulations in accordance with EASA *Implementing Regulation (EU) 2019/947* and *Delegated Regulation (EU) 2019/945*, to ensure operational safety and legal adherence (16). In Italy, ENAC serves as the national aviation authority responsible for enforcing European normative (11).

Concretely, it is necessary to request that ENAC issues a NOTAM (NOtice To AirMan) to indicate the presence of reserved airspace for a limited amount of time, as well as granting the authorization to fly in the *red* area "LI R34" of the City of Turin, in which it is prohibited for any type of extraordinary aeronautical activity to operate. Furthermore, the Prefecture in collaboration with the Drone Unit of the Municipal Police of the City of Turin will have to be involved to segregate the overflown area from the presence of uninvolved people, allowing a mitigation of the risk class on the ground.

In appendix B more detailed reference pictures are present for the planned mission flight path.

Figure 5.1: Mission path with emergency landing points and observation points

SORA Assessment

The SORA (Specific Operations Risk Assessment) is an EASA risk analysis methodology that generates a standardized document required for regulatory submission when requesting flight authorizations for specific missions, such as the transportation of biological material. Gound and air risk assessments establish the Specific Assurance Integrity Level (SAIL) that determines permissible drone operations that can be safely conducted, as well as the operational requirements needed to mitigate the risks involved (13).

Following an initial document drafting dated in September 2021, a revision to

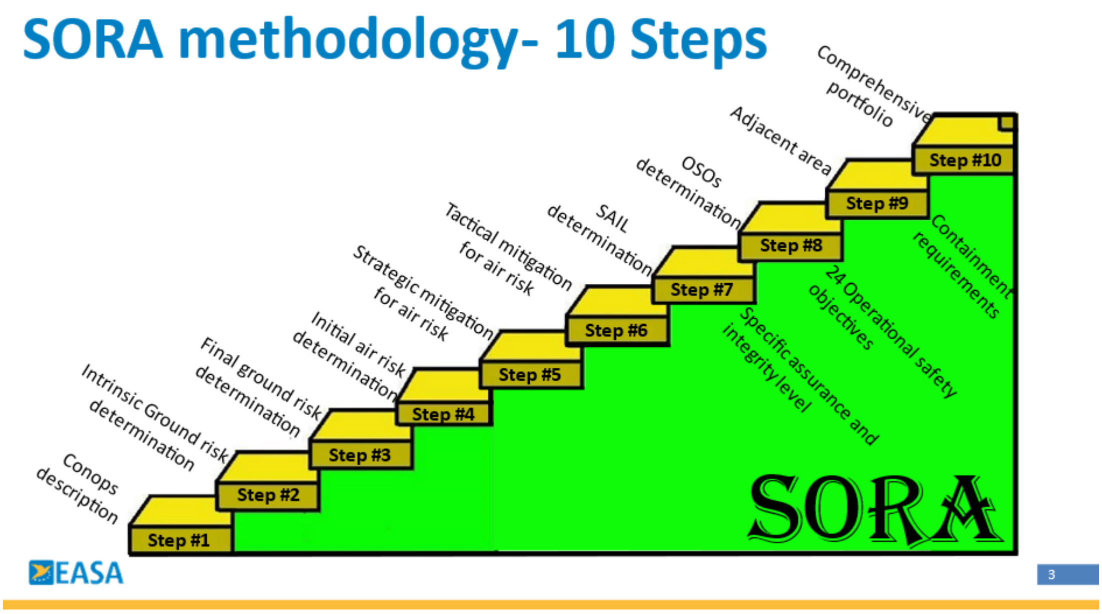

Figure 5.2: SORA 10 steps methodology

the SORA has been necessary. This update primarily involves the definition of contingency, buffer, and adjacency areas and their subsequent volume as shown in figure 5.3 along the mission' s predefined flight route (41). These are ground safety zones restricted to pedestrian and vehicular traffic with the coordination of local law enforcement, where a potential catastrophic UAV failure would result in an impact that does not affect the population. Additionally, the flight altitude for the automatic mission has been reduced further, with airspace segregation managed through a NOTAM to prevent conflict with other aircraft.

EASA MOC-Light UAS.2511

In May 2022, the MOC Light-UAS.2511, issued by EASA, came into effect across the European Union (14). It is part of the Special Conditions (SC Light-UAS) requirements for operating light drones within the European Union and it mandates "enhanced containment" for missions that are classified as "specific". This normative addresses point 9 of the SORA, concerning the scenario in which a loss of aircraft control occurs.

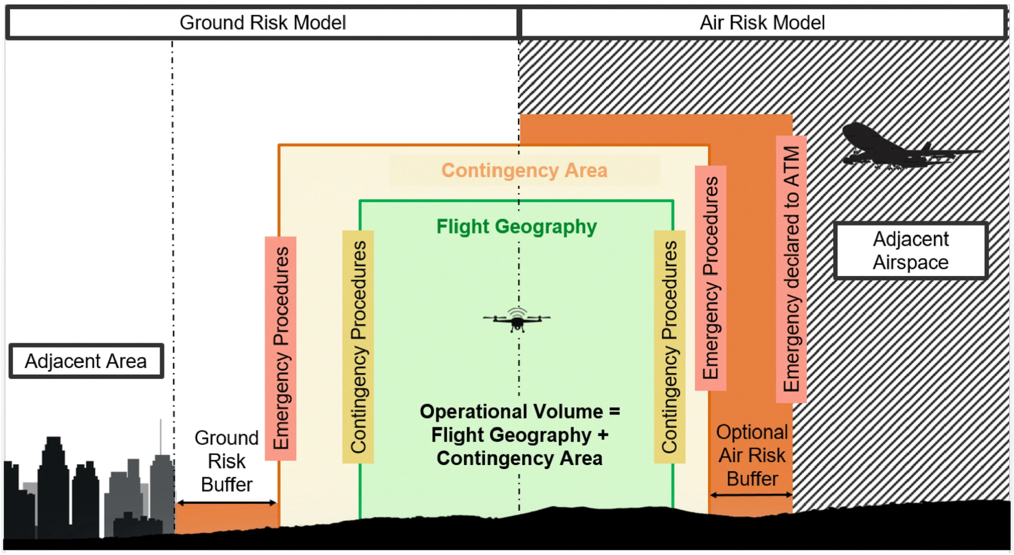

Figure 5.3: Graphical representation of operational volume and risk buffer interaction that need to be considered in a SORA

Under this regulation, operators can declare compliance with ENAC by submitting a document containing a standardized checklist and test results that certify the use of a Flight Termination System as a compliant emergency measure to mitigate crash risks. Eventually, a parachute system can also be added to safeguard the hardware. Notably, while operators must validate these systems through testing, the test documentation does not need to be formally reviewed by the authority.

Flight Termination System

As a result, there was a need to integrate a Flight Termination System (FTS) on the drone selected for the demonstrative flight. This system ensures that, in an emergency situation where the operational flight volume is exceeded, the mission will be halted, and the drone will impact the ground within the designated buffer zone. The command has to be activated manually if the pilot or a flight supervisor notices that the UAV is not following the set trajectory.

To meet the MOC requirements for ”enhanced containment”, several tests have to be conducted, including bench tests only with the terminator, ground tests, non-destructive flight tests, and end-of-life tests.

The terminator model can then be used for the actual trial flight mission.

The custom Flight Termination System was purchased from the sensor technology company SAL Engineering by Fondazione D.O.T. and has been managed by PIC4SeR.

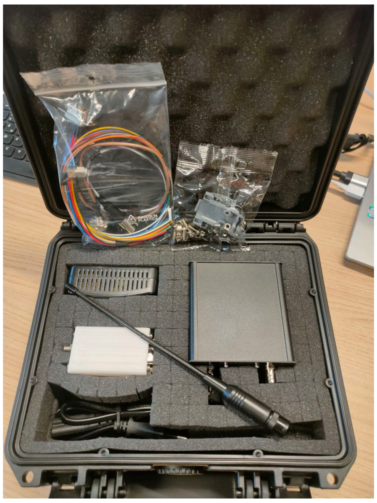

Figure 5.4: FTS T420 components in its case

This complete system, called *FTS T420*, is constituted of two units: an air unit to be installed on the drone and a ground unit to monitor the connection to the airborne segment and, if necessary, activate the terminator. It uses LoRa Long Range UHF technology at 433 MHz, a low power solution that allows the ground segment to remain connected to the airborne module for up to 20 km away in line-of-sight conditions; this range decreases to approximately 3-5 km in urban conditions, where buildings and infrastructure cause signal attenuation.

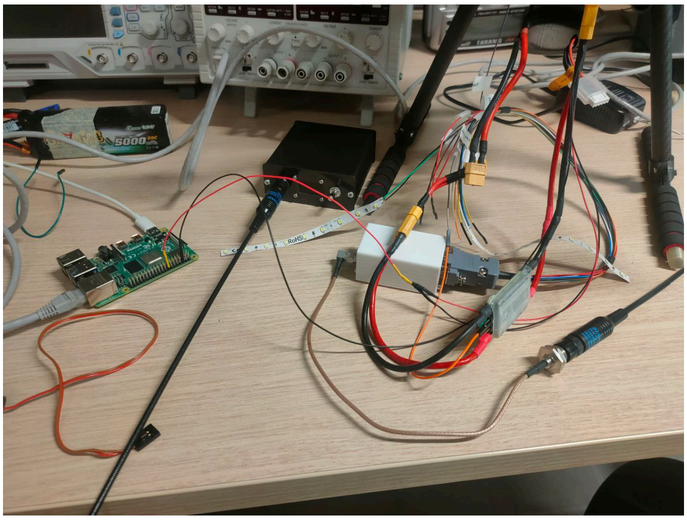

Figure 5.5: FTS installation, white air module, black ground module

The air module is composed of an electronic logic circuit (figure 5.6) powered by the drone’ s battery and connected to a long range RH701 antenna that transmits communication to the ground unit. The unit is also linked via a high-density 15-pin D-sub connector to the drone' s systems, including the autopilot and the GPS receiver, essential for flight control and navigation. This connection allows the operator to sever power when the FTS is activated, leading to the immediate shutdown of the vehicle if necessary. Additionally, some connectors activate concurrently with the terminator, providing audiovisual signals to confirm flight termination.

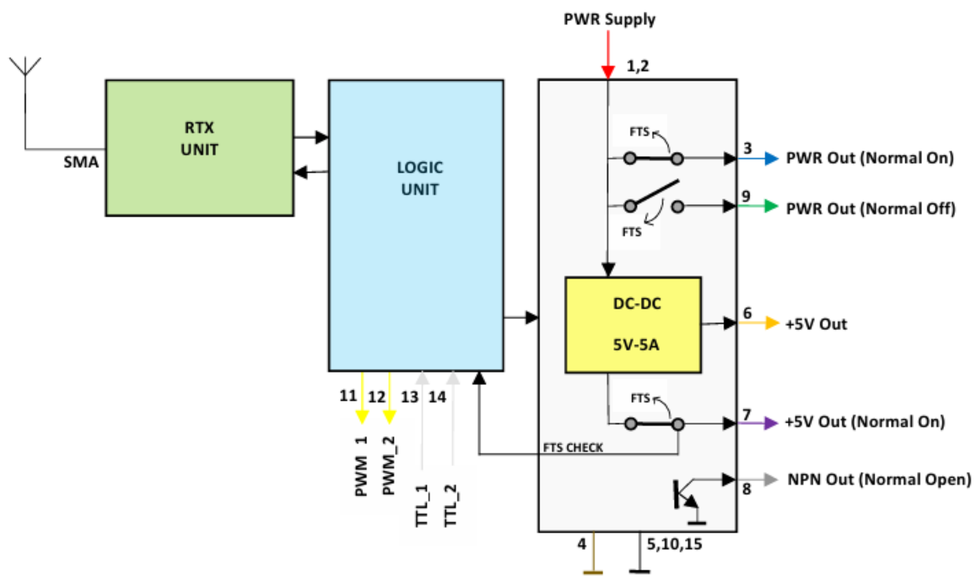

Figure 5.6: Representation of FTS air block diagram

The ground segment consists of a box with a connector for the UHF RH771 antenna, a safety-locked termination switch, and a display showing the connection status with the air module, as shown in figure 5.7.

An end-to-end setup for FTS testing was designed: a circuit was arranged where the terminator is mediated by an additional component in the power chain, the Safety Power Switch (5.8), an electronic power switch between the drone avionics and the battery, so that it does not directly control the autopilot shutdown. On the battery side of the circuit, the power for the terminator and the magnetic key for the drone' s power control (magnet disengaged for power on, magnet engaged for power off) are wired in parallel (18). The termination com-

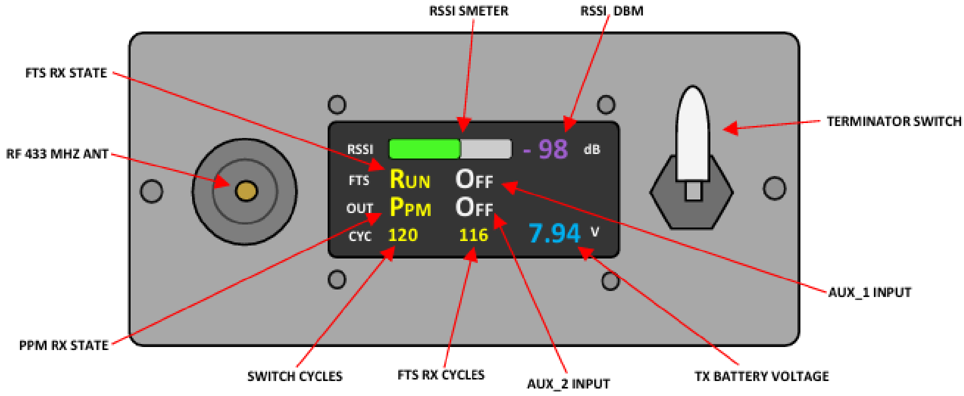

Figure 5.7: Representation of FTS ground module

mand is activated by connecting the NPN transistor output pin of the terminator to the second input pole of the switch, which transmits current flow information to sever drone power.

Figure 5.8: Safety Power Switch by Emcotec

The system was activated in succession: power on (key disengaged), termination via FTS and complete shutdown of the power chain, that is reinserting of the magnetic key in the slot and revert the termination switch to its initial position for each iteration. The procedure was repeated 500 times (all by hand!) to certify the final UAS-FTS system, and logs were recorded in the following format: [iteration number, year_month_day-hour_minute_second, drone status (1 for on, 0 for off)].

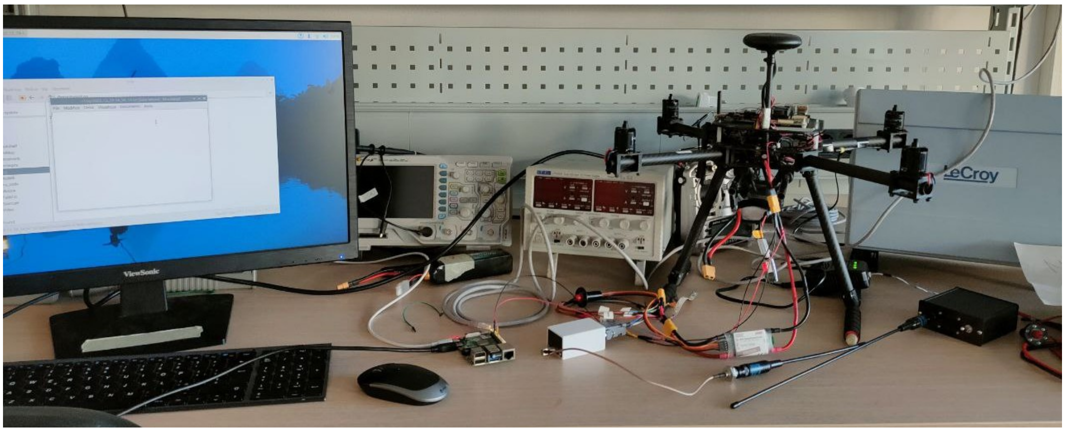

Figure 5.9: FTS end-to-end test setup in the PIC4SeR laboratory

Moreover, in July 2024, a parachute opening system associated with the FTS was also tested in collaboration with an intern from Limoges. By substituting the weight of the drone that it deploys from, it was possible to observe the opening velocity in the descent, from a height of 20-30 m.

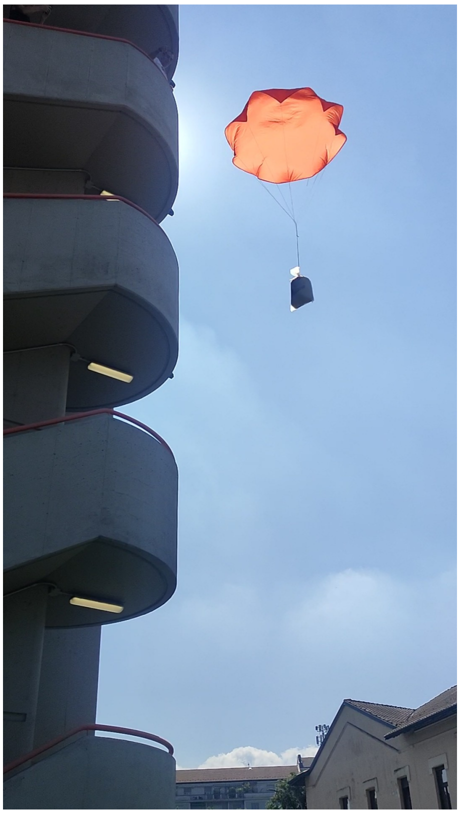

Figure 5.10: Parachute deployed by hand at the PIC4SeR offices

Figure 5.11: Parachute deployed by a drone at the test field

Preparatory tests for the mission

In April 2023, a system integration test was conducted between the Venture drone and the 3D printed capsule, followed by operational flight trials at a testing facility in Castellamonte, Turin. The integration proceeded without any issues, and the payload did not exhibit any significant anomaly during flight, particularly with regard to the retention mechanism of the sled to the interface, known as the "clack." Since this component is the most subjected to stress, modifications to the mechanism or the material may be considered in case it shows signs of failure after prolonged use.

The flight tests were conducted in two modes: remotely controlled via console and autonomously, to simulate the test flight at an altitude of 30 meters. The physical configuration of the drone has the following main characteristics:

- MTOW (Maximum Take-Off Weight) of 3.5 kg.
- T-Motor CF 18 x 6.1 carbon fiber double blade propellers.
- 11000 mAh battery.
- Ardupilot software to configure PID control parameters in order to improve flight performance.

Figure 5.12: Drone and capsule configuration in flight during the field test

Demonstrative mission

On October 1, 2024, at approximately 12:30 PM, the first demonstrative flight of a drone for the transport of biological material was carried out in collaboration with ABzero between two hospital facilities of the AOU Città della Salute e della Scienza di Torino. The flight departed from the area adjacent to the helipad of the CTO and arrived behind the Ceppellini Genetics Building at the Molinette hospital, crossing perpendicularly over Corso Unità d' Italia and following the adjacent river route along the Po river.

The experimental trial was conducted with the support of the Prefecture and the City of Turin, which provided non-financial assistance in managing and slowing down traffic through the involvement of local police, civil protection, and volunteers. A total of 42 people participated, including patrol units, motorcycles, and boats positioned along the route of the drone, including the river section, to ensure maximum flight safety for all people involved.

The required authorization was obtained through an assessment of local conditions using a general permit already held by ABzero for VLOSvlos missions, which included the presence of observers at strategic points along the route, hence an "Enhanced" Visual Line Of Sight operation. Meanwhile, the PIC (Pilot In Command) was stationed at an intermediate point between take-off and landing. The authorization issued by ENAC Rome constituted a clearance allowing the emission of a NOTAM by ENAV (12), which is shown in figure 5.13 and was published on the *Desk Aeronautico* during the predetermined period for the flight operation.

The drone, a hexacopter equipped with a specific attachment system for ABzero's Smart Capsule, features a parachute maneuvered by a FTS and their artificial intelligence technology. This allows it to autonomously take off, navigate via waypoints, and perform emergency automatic landings in case of necessity, making it a redundant and safer system compared to just manual piloting.

NOTAM W3675/24

Località: LIMM

Periodo (UTC): 01/10/24 08:00 - 03/10/24 13:00

Schedulato (UTC): 01 03 08:00-13:00

Limiti verticali: GND - 39M AGL

TEMPORARY RESTRICTED AREA IMPLEMENTED AS FOLLOW:
450222N0074030E-450217N0074056E-450152N0074045E-
450157N0074023E-450222N0074030E /TORINO TOWN /
ELEVATION 39M AGL DUE TO CIV UNMANNED AIRCRAFT ACTIVITY

Figure 5.13: NOTAM for the demonstrative mission

The transported material consisted of test tubes containing pre-tested blood to ensure that no issues arise in case of leakage, as the capsule holds a patent for biological material transport. The pilot is authorized for the transport of ”dangerous goods”, a classification used for potentially biological hazardous material such as blood. The container within the capsule complies with UN3373 regulations and is designed with 40 slots for test tubes.

At the takeoff site, stakeholders interested in the project were present, including institutional figures such as city and regional officials, as well as key figures in the healthcare sector. Various media outlets, including newspapers and television stations also attended the event. All guests were positioned at a safe distance of more than three meters from the launch platform, with clearly marked barriers.

The operation required coordination with the 118 emergency helipad, leading to a temporary suspension of flight activities to accommodate the arrival of a medical helicopter transporting a patient. This caused a slight delay in the operation, pushing the start time back by approximately 30 minutes from the initial estimate.

The entire flight consisted of a single round trip using the remotely piloted system, with each leg lasting approximately three minutes. The weather was cloudy but without excessive winds.

Figure 5.14: Drone for the demonstrative mission

This successful demonstration flight and its extensive media coverage validated the feasibility and potential of the INDOOR project in utilizing the river route to connect various hospital infrastructures in the City of Turin. The initiative aims to enhance healthcare services and optimize biomedical transport logistics, benefiting both citizens and the medical facilities involved, through the use of drones.

The costs for the ENAC procedures were financially covered by Fondazione D.O.T.

Chapter 6

Future development and dissemination

The INDOOR project initiative and its operational implementation represent a significant step forward in the use of drones for healthcare logistics. This advancement accelerates the transport of biological materials between hospital infrastructures and paves the way for high-tech developments in the transplant medicine transport field for the medium and long term.

In the immediate future, the efforts will be focused on the practical implementation of Beyond Visual Line Of Sight (BVLOS) flights, which would enable more efficient operations with reduced personnel requirements for mission monitoring. This modality would allow drones to be controlled even beyond the direct line of sight of the pilot. The initiative will be developed in collaboration with ABzero and with the support of key stakeholders, including end users such as the *Città della Salute e della Scienza di Torino*. One of the projects that is currently under planning involves establishing a new route along the Po river to connect *Molinette* Hospital or CTO with *Giovanni Bosco* Hospital, by crossing (under?) bridges and disused railway tracks to minimize risks for both the general population and the urban infrastructure.

Figure 6.1: Possible future drone pathway to connect hospitals in Turin

Additionally, the involvement of ENAC will be crucial for the design verification of the drone to be used in future missions, facilitating the issuance of continuous flight authorizations by considering successful past operations in both Turin and other Italian cities. The validation of the Flight Termination System, along with the installation of a parachute in compliance with EASA MOC Light-UAS.2511 and MOC Light-UAS.2512 regulations, will be a fundamental step toward ensuring the safety of urban drone operations.

Future trials will present various concrete challenges that will be adequately analyzed and addressed, aiming to learn key lessons from the mission procedures.

These insights will be essential for establishing a standardized protocol and an accessible service for the transport of biological materials via drones, creating a routine practice for hospitals that require it.

Dissemination

The media coverage of the demonstrative flight was fundamental in disseminating the progress of the project. Many newspapers and television networks gave significant visibility to the successful execution of the first urban flight demonstration implemented on the 1st of October 2024 between *Molinette* Hospital and *CTO*. Furthermore, the INDOOR project was also mentioned by Turin' s Councilor for Innovation, Chiara Foglietta, as one of the key initiatives that contributed to the city' s recognition as the *2024 European Capital of Innovation*.

Finally, a scientific paper will be drafted and published to share the results and insights gained with the scientific community interested in the topic. This contribution aims to promote further the dissemination of the developed innovations and serve as a reference for future research and applications in drone-based biological material transport. The publication will mark another step toward building a cutting-edge and sustainable technological ecosystem of the future.

Appendix A

Appendix to Chapter 3

Report di confronto esami ematochimici e sierologici PRE e POST prove di vibrazione su shaker

In data 16/01/2023 sono state eseguite le prove di vibrazione su shaker di campioni biologici (sangue) prelevati da donatori volontari.
Sono stati coinvolti 6 donatori, e per ognuno sono state prelevate le seguenti provette, destinate agli esami ematochimici e sierologici pre e post prova su shaker:

- 1 tappo lilla chiaro 3 ml (x2) per emocromo con formula leucocitaria
- 1 tappo azzurro 3 ml (x2) per coagulazione
- 1 tappo giallo 5 ml (x2) per biochimica
- 1 tappo trasparente per sierologia 7 ml (x2)
- 1 tappo beige 7 ml per Treponema Ab (x2)
- 1 tappo verde 4 ml per enzimi cardiaci (x2)
- 1 tappo rosso 6 ml (solo sui volontari maschi per dosaggio PSA) (x2)

Gli esami sono stati accettati sul programma DNLab utilizzando una anagrafica identificativa per campione PRE e POST prova.
Successivamente al prelievo, il set di campioni PRE è stato conservato a temperatura ambiente in attesa dell’ invio al Lab. Analisi, mentre il set di campioni POST è stato sottoposto alla prova su shaker, alloggiando simmetricamente le provette nel supporto di gommapiuma, nel seguente modo:

- 3 set di provette POST (tot 20) per la prima prova di accelerazione (Y);
- 3 set di provette POST (tot 20) per la prima prova di accelerazione (Z).

Al termine delle prove, tutti i campioni PRE e POST sono stati inviati al Lab. Analisi.
In base ai risultati ottenuti dalla analisi sui campioni pre e post sollecitazione si può evidenziare che:

- le indagini sierologiche (HbsAg, HBsAb, HbcAb, HCV Ab, HIV Ab/Ag p24, Treponema Ab, CMV IgG) risultano invariate (<0,01 per i titoli anticorpali);
- l’ esame emocromocitometrico con formula leucocitaria, riguardante le 3 linee cellulari ematopoietiche, presenta variazioni minime (media <0,05, mediana -0,01);
- le indagini coagulative e biochimiche, riguardanti i dosaggi enzimatici/proteici, presentano variazioni minime (media <0,05, mediana 0,00);
- il dosaggio degli elettroliti sierici risulta pressochè invariato (media<0,02, mediana <0,02).

Appendix B

Appendix to Chapter 5

Demonstrative mission additional images

Figure B.1: Mission flight path

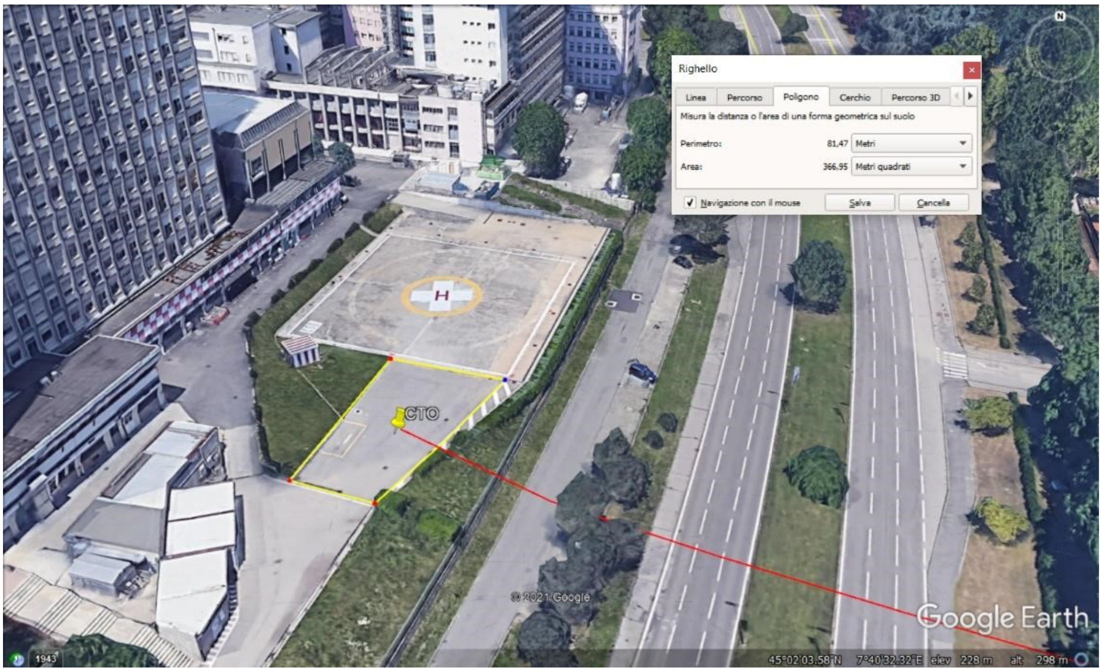

Figure B.2: Take-off point in CTO

Figure B.3: Landing point in Molinette

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