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Mobile Ground Station for the Unmanned Elettra-Twin-Flyer Airship

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ABSTRACT TITLE

In recent years the development of unmanned platforms has exasperated the concept of design and planning in aeronautics: for unmanned flight, in fact, the aerial segment is no longer the central issue and concepts like mission planning, mission and on board sensor management are becoming more and more critical. The majority of these functionalities have been separated from the aerial segment and transferred to the Ground Station (GS) which is one of the key elements of the Unmanned Aerial System (UAS) together with the Communication Link and the Launch and Recovery Element. Safety requirements are thus transferred to some of the GS components, especially to those which perform critical functions. This has contributed to increase the CS complexity. Regardless of the UAV architecture and overall dimension, in fact, the pilot must be able to operate under the same condition of situation awareness of a correspondent manned aircraft. In this context, advanced vision systems and innovative human-machine interfaces must be designed, to enable the pilot to process the flight data while accomplishing the mission task. This paper presents a technological solutions adopted for the Elettra-Twin-Flyer, a lighter-than-air unmanned platform, developed for civil applications.

1.0 INTRODUCTION

UAV systems have reached a level of complexity and completeness which makes them strongly competitive with regard to their corresponding piloted versions. However, in order for the UAVs to reach their full potentialities, significant technical issues must be overcome. Among the others, the most challenging aspect concerns command and control. In this context, the American DOD Roadmap[1] for UAVs has envisioned a ten-level scale of autonomy which sets the research trend for the next two decades. According to the American DOD, in fact, progress in technology should allow the UAV to pass from a dull remotely piloted version to a flying supercomputer, with human-like reconfigurable planning and strategic capabilities, which should synergically join other UAVs to form a completely autonomous, mission-oriented swarm. Transition from pilot-in-the-loop to autonomy is somehow a common trend, which is characterizing the UAV's evolution both in the military and civil applications, driven by different needs towards the same goal. The DOD, in fact, has the urgency of introducing persistent intelligence as well as very accurate and timely target-oriented instruments which are generally employed in the most aggressive battle scenarios. Performance and autonomy might seem less stringent requirements for civil applications, where UAVs are mainly employed in surveillance and reconnaissance missions. Nevertheless, even in the most standard non-critical operations a certain degree of autonomy is sought and pursued as a necessary measure to guarantee safety. The airworthiness authorities, in fact, have clearly stated that preliminary condition for UAV certification is the capability of accomplishing critical flight phases autonomously.
Transition from pilot-in-the-loop to autonomy[2] is hence a requisite and it is clear how it will affect the predominance on one technology over the other: the two different approaches to implementing unmanned flight, in fact, today rely predominantly on communication (data link) and microprocessor technology, respectively. If robust communication is a urgency today, the sense-and-avoid capability and the

reliability-enhancing health monitoring will be the prerequisites for tomorrow. Technology has to evolve along with the UAV concept and all the other elements of the system must be conceived and adapted to fill the gap towards the ultimate goal of safe and satisfactory autonomous operation. The key to development is to design all subsystems as auxiliary tools and foresee rapid and drastic change of use for each of these elements. The ground station is indubitable included in this category, as the pilot itself, along with the Human-Machine-Interface, which still represents an open issue also for piloted aircrafts. The ground station and all the related subsystems must be shaped around the aerial segment and must incorporate all the basic technologies, which are supposed to be transferred onboard in the next few years. Versatility is the key factor in a process where the ground station is initially designed to remotely pilot a single UAV, but can be transformed in a strategic operation center for autonomous UAVs and successively in a sorting and storing station of data collected from autonomous swarms of UAVs.
This paper describe the Mobile Ground Station (MGS) designed and assemble for the Elettra Twin Flyer[3], a unmanned airship capable of remotely-piloted and semi-autonomous flight.

2.0 GROUND STATION DESIGN

2.1 Requirements

It is commonly accepted that the ground station is one of three main segments of a UAS, being the other two the UAV itself and the communication link. Hence, despite the level of automation of the aerial segment, the ground station has to respect specific requirements. The control station, in fact, must be properly designed to ensure that the aircraft is safely piloted and that all the information concerning the air traffic is correctly handled, as to effectively operate also in emergency conditions. The ground station constitutes a novelty for safety and difficulties might arise from different sources:

- the ground station lacks physical references that allow the pilot to recognize certain failure scenarios and evaluate consequently the actions to be taken. Visual reference could be provided by low cost video cameras, but they might be misleading if not supported by the outputs of other sensors;
- experience in the operations of civilian UAVs is limited and access to the data base of military UAVs is highly restricted, if not impossible;
- the quantitative safety level should be defined not only on the basis of the hardware/software components and on the related architecture: great emphasis should be given on procedures.

The European authorities agrees that the airworthiness type-certification basis for civil UASs must include appropriate special requirements[3]. In this context the Control Station is not considered as a close and well defined device and no particular reference is made on the Control Station as a whole. On the contrary, the policy on UASs is openly concerned with functionalities, which can be allocated on the Control Station or directly on-board, depending on the level of automation of the aerial segment. Some of the functionalities related to piloting, are hence included in the airworthiness certification. In particular, there are issues related to Human Factors aspects of the Control Station, where considered relevant to the safe control of the UAV. In this category we shall include the Human-Machine-Interface, which brings about a great number of related topics, such as the number, type and location of displays, the choice of parameters which must be shown and which might be critical for safety, the warning indicators and the related emergency procedures.

Other issues, on the other hand, are considered strategic but will not be covered under the airworthiness definition and are expected to be subject to other forms of approval. Among the others, in this category we find also the control link, in terms of frequency allocation, minimum bandwidth, integrity and continuity of service.

2.2 Ground Station configurations

Although there is little literature on the subject, it is possible to catalogue the existing ground control stations in different groups. They differ mainly from the logistic point of view, depending on the mobility level (mobile/fixed), but also, in case of mobile ground station, depending on the autonomy level: some ground station, in fact, can be entirely transferred but are totally dependent on external vehicle. For example the components can be stored into standard containers, which are purposely modified to accommodate all the devices in the operative configuration, as well as the necessary personnel. In this case the container is dependent on special transportation vehicles but can be shipped (and used) on medium size vessels. Other configurations of ground stations are mounted directly on vehicles and can be moved without restrictions. Among the others, there is particular kind of ground station that is defined "man portable" GCS. Usually this solution is adopted for military small-to-micro short-range UAVs which must be operated efficiently and quickly. Portability makes the UAS versatile and usable in every conditions by walking soldiers in hostile war theatres.
At present, mobile ground stations are among the most widely used. This is mainly because of the radio-link range, which is usually limited to a few miles. More often the telecommunication technology would allow the aerial segment to accomplish very long range missions, but there are safety restrictions which prescribe the line-of-sight requirement.
The choice among the different configurations of GCS depends on various factors including:

- the autonomy level of the aerial segment;
- the number of aerial segments which must be piloted simultaneously;
- the onboard technology (radio-link, flight control systems…);
- the line-of-sight requirement.

The GCS is typically made up by a Piloting (or Mission Control) Station, the Mission Planning Station and the Data Analysis Station. The simultaneous presence of all the three capabilities is not strictly necessary. In case of small UAS such as the Pointer[4], for example, the data analysis functionality is reduced to receiving and displaying video and images, whereas data planning is considered a pre-mission procedure.
The fixed or semi-fixed configuration is more common in multipurpose ground stations, which are used to control multiple UAVs in different medium-to-long range missions, (Global Hawk[4]). Sometimes the different functionalities are split and distributed on different physical apparatus. In this case the Data Analysis Station is usually remotely located inside a convenient facility, where data can be safely received, post-processed and stored.
Mobile GCS (ETF or Predator[4]), at present, are certainly the most widespread. Regardless they are based on containers or on wheeled-vehicles, they are normally developed by adapting existing structures. The container solution is the most cost-effective as it only needs to be prepared to accommodate all the components with the right set of insertions and connection points. The wheeled vehicle solution is more expensive and the design phase is more complex as sometimes it is necessary to adapt the chassis to integrate all the systems. The advantages of adopting a wheeled vehicle, however, are evident, especially from the logistic point of view. It is obvious that the vehicle size will grow accordingly to the dimensions of the auxiliary systems and the number of ground crew members, who must operate simultaneously inside the ground station. For the Global Hawk, for instance, there are 6 operators working together in a 20 feet container.

Smaller system, such as the portable ones, have little logistic problems and can be transported and accommodate very easily by a single operator. Time to action is very short and flexibility is the predominant feature. In this case the ground station has the dimension of a laptop and can be stored in a small bag or a back-pack, sometimes together with the aerial segment, which might be easily and safely disassembled after each mission and assembled directly on the war field.

3.0 THE ETF GROUND STATION

The low-cost multi-purpose multi-mission platform Elettra-Twin-Flyers (ETF) is being developed by the synergy of Nautilus S.p.A and the Politecnico di Torino[5]. It is a very innovative remotely-controlled airship equipped with high precision sensors and telecommunication devices. For its peculiar features, it is particularly suitable for inland, border and maritime surveillance missions and for telecommunication coverage extensions, especially in those areas which are either inaccessible or without conventional airport facilities and where the environmental impact is an essential concern.

ETF is characterized by great manoeuvrability as well as low wind sensitivity[6]. Flight conditions range from forward, backward and sideward flight to hovering, both in normal and severe wind conditions. To achieve these capabilities the ETF has been conceived with a highly non conventional architecture based on a double hull with a central plane housing structure, propellers, on board energetic system and payload. The ETF command system mainly consists of two vertical rotational axis ducted propellers and four thrust-vectoring propellers mounted on rotating vertical arms. The ducted propellers provide the vertical thrust for steep rapid climb and descent and control the pitch attitude of the vehicle. In addition, their action is combined with the helium buoyancy to produce lift in hovering and forward flight, where the lift is also incremented by the aerodynamic component. The four thrust-vectoring propellers control the lateral-directional attitude of the airship through the variation of the rotational speed (RPM) together with the rotation of the supporting vertical arms.

A flight demonstrator[7], which is a reduced-scale reduced-complexity platform, has been already purposely assembled to test the most critical subsystems, such as the command system and the architectural solution.

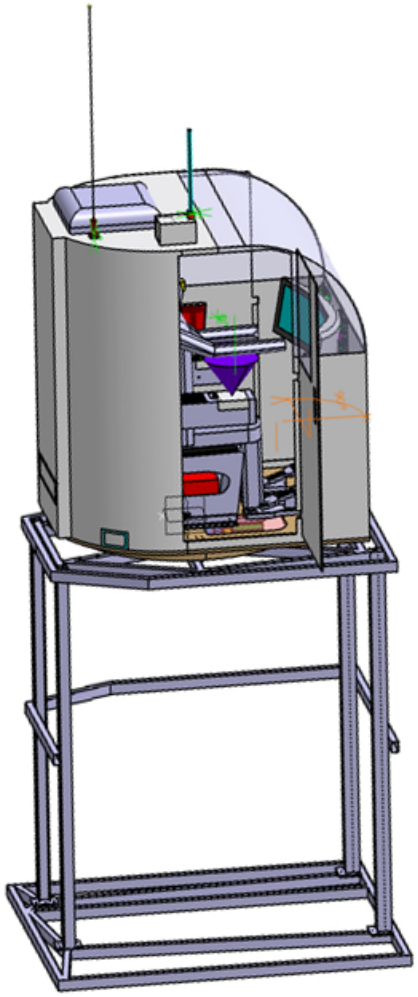


Figure 2: Pilot cabin

3.1 Layout

Physically, the ETF Ground Station is located in a commercial bi-axle camper, the ETF Mobile Ground Station (MGS), which has been purposely equipped and modified to accommodate a couple of twin stations, one for the pilot and one for the operator. The ETF MGS is almost completely self sufficient from the logistic point of view. It is not completely independent as it needs an external power source to operate, despite it is equipped with back-up batteries to compensate for temporary blackouts

The MGS is divided into three separate operating units:

- the driver cabin;
- the Technical Station, mainly dedicated to the payload management and/or to the flight data acquisition;
- the Pilot Station, completely dedicated to the UAV control.

The driver cabin was not altered as there was no need to integrate other capabilities. On the contrary, the rear part of the vehicle has been completely modified to accommodate the Pilot Station and the Technical Station. The Pilot Station (Figure 2) is contained in a sheltered cabin, made out of metal and fiberglass and

located behind the driver deck over a moving platform, which can be lifted over the camper roof and rotated, as sketched in Figure 3. The Pilot cabin is designed to comfortably contain the pilot, a personal computer for flight data analysis, a three-screen monitor to display all the flight and mission data parameters, an hotas device, a COM radio, a radio-link bridge and an air-conditioner.
The cabin is lifted over the roof level by the hydraulic system. Rotation is actuated through a brushless motor coupled to an endless screw which ensures irreversibility. This mechanism should provide the pilot with a 360° view on the airship and on the surrounding environment, to respect the line-of-sight requirement imposed at the present by the aeronautical civil authorities.



Figure 3: Pilot cabin movement system in the Mobile Ground Station

To allow the cabin to rotate continuously and indefinitely, power is supplied through a slip ring. Rotation can be commanded by the pilot, through a set of commercially available pedals, or controlled automatically through a dedicated software. Automatic tracking relieves the pilot from a consistent workload portion with little or negligible increasing of the cabin complexity. The tracking system of the directional antenna, in fact, is mounted on the cabin top and rigidly connected, in azimuth, with the cabin itself. The pilot cabin and the directional antenna are thus oriented at the same time through a GPS station and a digital compass, both located outside the pilot cabin. An omni-directional antenna is used as a back-up system and in the initial phase of the flight, when the directional antenna cannot be correctly pointed as the position data are still missing. As soon as the directional antenna establishes the contact with the airship, though, tracking can be accomplished automatically, through a very simple set of equations:

$$\Delta\lambda = \lambda_{ETF} - \lambda_{GS} \tag{1}$$

$$\Delta\varphi = \varphi_{ETF} - \varphi_{GS}$$

$$\varphi_m = \frac{\varphi_{ETF} + \varphi_{GS}}{2} \tag{2}$$

$$\Psi = \frac{\Delta\lambda \cdot \cos\varphi_m}{\Delta\varphi} \tag{3}$$

$$\Rightarrow az = \Psi - \Psi_{GS} \tag{4}$$

where λ_{GS} and φ_{GS} are the latitude and longitude of the MGS, while λ_{ETF} and φ_{ETF} are the coordinates of the airship, as sketched in Figure 4. As for the antenna, elevation angle is provided by a single axis motor, controlled by the same computer dedicated to the rotating platform:

$$S = \frac{R \cdot \Delta\varphi}{\cos\varphi_m} \qquad R = 6371Km \tag{5}$$

$$\Rightarrow el = \tan^{-1}\frac{h_{ETF} - h_{GS} + H_A}{S} \tag{6}$$

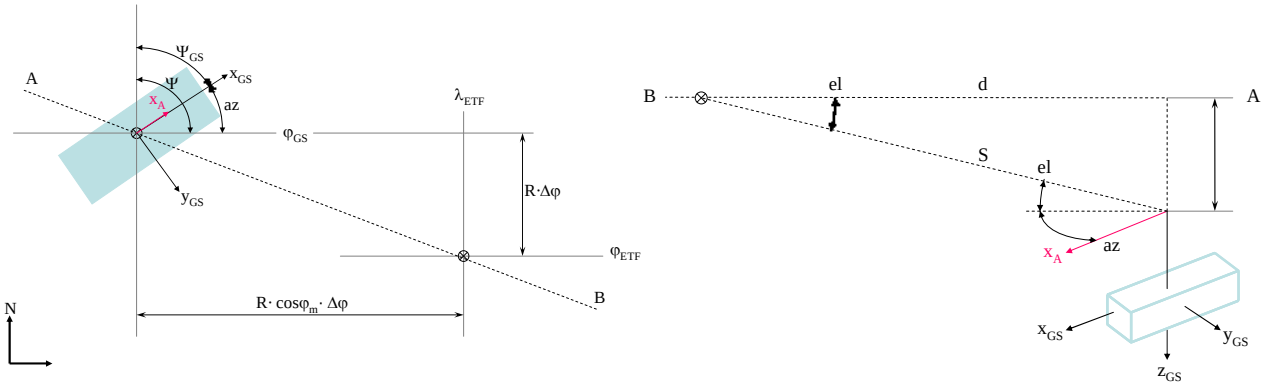


Figure 4: Orientation of the pilot cabin and of the directional antenna

The technical station consists of a personal computer and three monitors, on which data are displayed. At the moment data consists mainly of flight test telemetry as well as still images and videos collected from the on-board camera.
Power is supplied by an external generator. Every system is protected so that a problem on a computer or a short cut in the rotation system does not jeopardize the GS operativity.

Two main voltages are supplied: a three-phase 220V AC, which powers the computers and the rotation system, and a continuous 12V for the radio-link, radio COM, for the cabin lifting system and for the GS levelling system. The latter has been added to improve the camper stability during the piloting operation, to avoid that the vehicle dumping system is excessively stressed. This is particularly critical when the ground is not sufficiently even, to avoid that the centre of gravity falls in an unfavourable position once the pilot cabin is lifted in the operative configuration.

3.2 Certification and CE Approval

As the vehicle is equipped with an automated moving system (the pilot cabin), it must be certified according to Directive 98/37/EC. This Directive applies to machinery and lays down the essential health and safety requirements[8]. In general, it should guide the designer to obtain a safe product that meets all the

standards, whether they are related to the electric system or to other requirements. The Machinery Directive certification is based on a technical document, the Technical Construction File (TCF), which includes full detailed drawings, design calculations, functional test data, drawings of the electrical circuits, operating and maintenance manuals and in general whatever is necessary to demonstrate effective compliance with the directive. Once the TCF is completed, the machinery can be provided with the CE approval mark, as indicated in Annex III of the directive.
As for the ETF MGS the process of homologation according the 98/37/EC MD has implied several adjustments. The directive, in fact, clearly states that the machinery must operate safely, which means that its movement, or any related movement of part of the machinery, must be accomplished without jeopardizing the operator integrity or other people involved in the operation. To meet this basic requirement, the system has been equipped with sets of sensor/ actuator and physical barriers, which prevent access to critical areas or inhibit any machinery movement in case the same critical areas are unexpectedly occupied.
The cabin is equipped with two doors, one to provide access during normal operations and the other to provide the cabin with an emergency exit in case the other door is rotated towards the roof edge and is therefore impractical and unsafe as an escape route. A blinking led indicates the unlocked door, whereas a system of rotary encoders and relays enables the rotation during operation, or, conversely, the opening of the cabin door when the cabin is at rest.
Overcurrent protection devices are distributed where necessary to limit both threats to human life and damage to the structure.
The technical station has not showed any criticality during the design phase, as it is composed simply of a desk and enough room to accommodate comfortably two operators with two personal computers. Ergonomics and habitability have been a major concern. In this context, the vehicle has been equipped with two air conditioners, one for each specific area, which maintain the desired temperature in every season and ensure a good comfort level.
In the special case of a mobile ground station, based on a unconventional or modified wheeled vehicle, it is also necessary to show compliance with the Motor Vehicle Authority regulation, to prove that the vehicle can safely circulate on the European road network. Whenever a vehicle is somehow modified, in fact, it must undergo a new registration process, which basically consists in a measurement of the overall weight, to verify the compliance with the weight limitations for each category. There is also a formal mechanical assessment, to verify that the original parts of engine and transmission have not been modified. The mere alteration of the muffler layout, for example, would imply a new registration.

3.2 Mission Management

As part of a UAS, the Ground Station is called to participate to the pre-and post-flight procedures. The preliminary operations of preparation for flight take place on the ground station and are directed by the pilot. For this reason the positioning of the GS inside the operational area is a critical procedure, not only to provide the pilot cabin with stability, but also to ensure the pilot a correct view of the operative scenario. Once the GS is stabilized, and the pilot cabin in extracted, the pilot has to execute the pre-flight checks, which are supervised by the ground crew.
Before the aerial segment motors are powered, moreover, the pilot has to evacuate the flight area. He/she can communicate with the ground crew, but has the final responsibility to check visually that the flight area has been actually cleared. To this purpose, one of the main issues of the design phase, was to guarantee the widest field of view to enable the pilot to inspect the entire aircraft during the pre-flight ground tests.
The communication between the pilot and ground crew is another important issue and constitutes one of the potential weaknesses of the procedures. The pilot, in fact, should be able to communicate constantly both with the ground staff and with the control tower. For this reason the pilot is supplied with two main communication devices: an aeronautical radio (118-135MHz @ 5W) and a communication system for terrestrial civil applications (12.5 kHz @ 500mW).The communication protocol prescribes that during the airship preparation phase the ground staff can communicate on the 12.5 kHz frequency, just as long as the flight area is not clear. At this point the frequency is left free for communications between the pilot and

the GS technical station. The aeronautical frequency aircraft is always left free for the pilot exclusive use. During the flight, all the GS functionalities must be active, which means that the pilot must be able to communicate effectively with the ground crew and the control tower, rotate the cabin to meet the line-of-sight requirement, while visualizing the flight data on the three-screen monitor. To improve the reliability level, the system has been potentiated with back up modules and batteries, to give the pilot the possibility to land the airship safely in case of failure of the GS.
After the post-flight procedures have been concluded, the GS can be prepared for the re-entry operations: the pilot cabin is retracted and the levelling system is disabled, making the GS look like a normal camper. Considering the overall dimensions and the motor size, a standard driver licence of type B is considered the minimum requirement for the driver. The GS is perfectly independent during transfers. When operative, however, it relies on a second vehicle, which transports a 12kVA power generator and a three-phase 380/220V AC transformer.



Figure 5: Pilot Station

3.3 Human-Machine Interface

The Pilot and Technical stations are basically equipped with the same hardware and are specialized by proper software in the moment they became operative. Additional hardware might be necessary for the Technical Station, depending on the payload features. During flight tests on the demonstrator, however, the Technical Station is completely dedicated to the flight parameter analysis and is provided with all the information required to identify any possible source of failure[9]. Both the stations have monitors, where the real images broadcasted by the onboard video-cameras are integrated with synthetic scenarios. The Pilot Station, whose main concern is piloting, is provided with four views of the airship distributed on two monitors. The arrangement has been conceived in order to have the pilot focused on the rear observer point of view, such as the one shown in the central image of Figure 5. This view proved to be particularly useful in remotely piloting, when the pilot has no direct feelings of the aircraft attitude and movement[10-11].

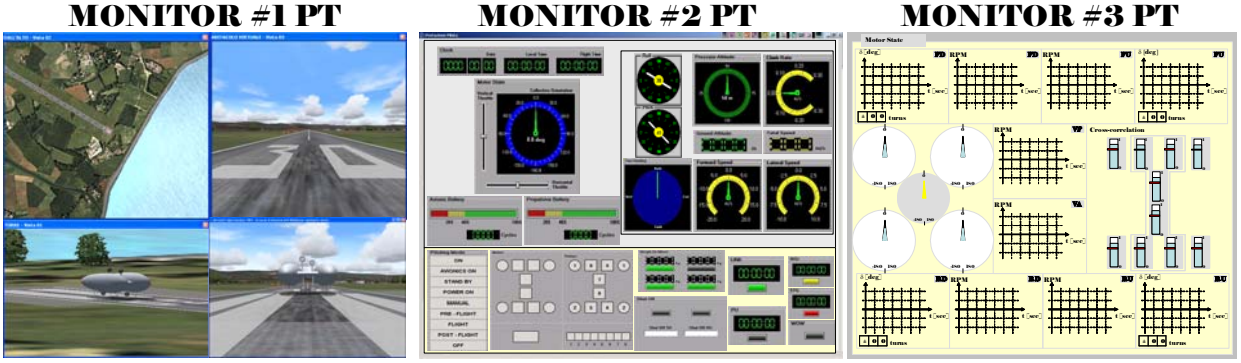


Figure 6: Technical Station

The third monitor is dedicated to the virtual cockpit, which has been designed with a minimal set of instruments and a bar for the diagnostic and the flight mode. The Technical Station, on the other side, is just partially concerned with the airship flight. During flight tests, however, it must have full visibility on all the parameters and for this reason the four-view system is compacted on one monitor, whereas the central one is dedicated to the instrumentation and the remaining one hosts a multiple-choice window system for the diagnostic of each airship subsystem (Figure 6).

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