First Flight of Scaled Electric Solar Powered UAV for Mediterranean Sea Border Surveillance Forest and Fire Monitoring *

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Abstract

A research is being carried out (within several EC funded projects) aiming at the design of Very-Long Endurance Solar Powered Autonomous Stratospheric UAV (VESPAS-UAV) and manufacturing of solar powered prototype. It could play the role of a pseudo satellite, with the advantage of allowing a more detailed land vision due to the relative closeness to the land and at cost much less than a real satellite. An area of 300km of diameter would be monitored by each one of this platforms. The full scale HELIPLAT® UAV and SHAMPO UAV have been designed by using the most advanced tools for obtaining an endurance of 4-6 months and being operable in almost all typical environment conditions (wind jet up to 50m/s) at stratospheric altitude (17 to 20 km) (wing span 73m). During the day it flies by 8 brushless electric motors in which power is generated by thin high efficiency solar cells that cover the aircraft's wing and horizontal tail. By night it is powered by fuel cell system fed by gaseous hydrogen and oxygen stored into pressurized tanks. A payload up to 150kg, with available power up to 1500W, could be installed on board for several global monitoring of environmental and security applications (GMES). A scaled size prototype (wing span 24 m , length 7 m) was built in order to show the technological feasibility. The flying model Small Electric Solar Unmanned Airplane (SESA), powered by solar energy, was built to carry out several experimental flight test with a small UAV and demonstrate some critical technologies and applications. The brushless electric motor was powered by high efficiency (21%) mono-crystalline silicon arrays and LiPo batteries. The structure is entirely realized using glass-fibre reinforced plastic, except for wing box, for which carbon-fibre composite materials are also used. A wing with span of up to 7m was manufactured and 2 m2 of solar cells have been bonded over the wing skin, obtaining in such a way a far higher endurance up to 8-10 hours during June and July in a level flight. With a total gross weight of 35 kg, payload capabilities are in the order of 5 kg. The experimental tests carried validated several critical technologies for high altitude very long endurance flight: high efficiency solar cells, electric brushless motor, controllers, video and thermo camera images transmission, telemetry system, autopilot.

1. Introduction

UAV technology has advanced sufficiently so that the aeronautical industry is ready to expand into a new 'added value' commercial industry: the young and growing Civilian Unmanned Air Vehicle (CUAV) industry. The total UAV market is growing at a rapid pace and it is imperative that the European community makes a serious effort to attain a significant segment of this market. The wide range of applications for civilian UAVs, will open up a variety of markets for potential sales and economic growth. Competitiveness in Aerospace is strategically important and the primary competition to the European community is from the United States. As the civilian market for UAVs increases, a great potential will be created to maintain and strengthen the competitiveness of the European aerospace industry in a new technology area, which will guarantee and create highly qualified jobs for the future. In a recent business market study carried out by Frost and Sullivan, the global market for UAVs in civil and commercial applications will be close to $2bn by 2014. The largest market shares are expected to pertain to Coastguard and Maritime Surveillance operations, Border Security and Forest Fire Management. The Scientific Community could benefit in many ways from employing UAVs in the civilian sphere. The utilisation of UAVs for border and costal patrol, homeland security, maritime surveillance, "Eye-in-the-sky" surveillance, will allow better law-enforcement in the protection of citizens and integrity of the borders. The utilisation of UAVs for forest fires mapping, real-time monitoring of seismic-risk areas, air turbulence, volcanoes eruption and other natural phenomena will assure that the public is aware of imminent disasters and can prepare for their advent. Under coordination of the first author, a research is being carried out (within several EC funded projects [1], [2], [3], [4]) aiming at the design of Very-Long Endurance Solar Powered Autonomous Stratospheric UAV (VESPAS-UAV) and manufactur-

*Based on paper presented at the XX Congresso Nazionale AIDAA, Giugno 2009 Milano, Italia ing of solar powered prototype. It could play the role of pseudo-satellite, with the advantage to allow a more detailed land vision, due to the relative closeness to the land, with continuous earth observation and at cost much less than real satellite. Typically, satellite sensors may bring a good accuracy - spatial area trade-off, especially when taking into account modern high resolution satellites - but such high accuracy data remain quite expansive today. Several satellites system used for earth observation are useless for a continuously real-time border surveillance due to their limited spatial resolution. From an high altitude (17-20 km), very-long endurance (several months) stratospheric UAV (payload up to 150 kg, power available for payload up to 1500 W), all the Mediterranean Sea border from Turkey to Spain and Canary Islands could be electronically controlled by 9-10 platforms. It is essential to manage who and what enters European homeland in order to prevent the admission of terrorists and the instruments of terror through borders, coastline and harbours. A continuous (24h by 24h) border monitoring shall be guaranteed, drastically reducing in such way the service cost and tedious work (Fig. 1). An area of 300km of diameter would be monitored by each one of this platforms. No special projects are at moment known on Border surveillance of Mediterranean Sea. Actually this service is made by several military ships or piloted airplanes with several personal on board increasing the cost tremendously. Furthermore, a spot control is actually made, since the large extension of the border. In Spain, the coast from Morocco (limited to 50-60 km) are controlled with a radar system (SIVE) at a cost of 145 MEuro. Similar very expensive system are being installed along all the Italian coast (more than 2000 km long). At which cost? Unit cost of a P-3 manned aircraft used by U.S. Immigration and Customs Enforcement is $36 million. Black-hawk, helicopters which are frequently used on the borders, cost $8.6 million per unit. However, the benefit of the Black-hawk's relative low unit cost is diminished by its lack of endurance (2 hours and 18 minutes). High costs are sustained by Italian Coast Guard for their ATR 42MP equipped for border surveillance. With 7 crew minimum, the cost of aircraft is around 7000-8000 Euro for hour of flight. The same platform would be conveniently used, with proper fire sensing tools, for forest fire monitoring (Fig. 1). It is greatly requested in all the Southern Europe (Spain, Italy, South France, Greece, etc.) for airborne imaging of wild land fires and other natural and man-induced disasters. Several payloads are available and mostly of them are used from satellite; indeed, existing and planned operational space-borne sensors, because of the very high altitude at which operate (500-600 km), show serious limitations if accurate parameters have to be obtained. As results, they allow only detection of very large fires, and not continuously.

Figure 1. Sea and terrestrial border monitoring and fire monitoring.

From electro-optic or infrared sensor airborne installation and flight altitude of 17-20 km, highest performances are available and it is possible to detect flame length lower than one meter. Just 4-5 VESPAS stratospheric platform should cover Italy from North to South. The electronic surveillance all over the South Europe could be clearly obtained by a good HeliPlat Network. Early forest fire mapping could be realised with infrared fire remote sensing tools. The maximum in the spectral radiance distribution of the vegetation fires occurs in the mid wave infrared (MWIR) region at 3-5 μm. Therefore, the mid wave infrared spectral range is commonly recognized as the optimal spectral range for fire detection. In order to reduce the high flight cost of piloted aircraft, it is indeed necessary to have unmanned vehicles with very long endurance (several weeks or months) to obtain an efficient service. UAVs are less expensive than other manned aircraft used for the borders surveillance. By UAV flying at 15-18 km altitude and with proper sensors, is possible to detect illegal boat or people along the border and with Total Life Cycle Cost of around 900-1000

Euro/hour fly. The main advantage of the VESPAS is that this system has less climbing and descending events, which is important when considering interference with aviation traffic. Other HALE-UAV configurations have a very limited endurance (24-36 hours), which would drastically increase any potential collision risk with civil aviation traffic. Double the number of UAVs would be necessary to continuously guarantee the surveillance service, thus the System Total Life Cycle Cost would be increased to a great extent. Other Medium Altitude Long Endurance (MALE) - UAVs have, as a further disadvantage, the fact that a much higher number of UAVs are necessary to continuously cover the entire Mediterranean Sea, since the covered area decreases with the square value of the flying altitude (Fig 1); the Total Life Cycle Cost system would increase remarkably with a MALE configuration. Very high endurance, indeed, calls for high mission reliability requirements of the air vehicle, its systems and payload. An integrated, multi-sensor, interoperable system based on the use of remote and local means of surveillance (e.g. UAV, satellite, etc..) and multiple sensor concepts (e.g. I/R and E/O sensors, SAR, hyper spectral, sensor fusion, processing, etc.) for border surveillance from stratospheric altitude shall be pursued to detect, also in adverse climatic weather, boats with illegal migrants or terrorists reaching the south European coasts from the North Africa or Middle East countries or boat of illegal fishery. The information obtained will be transmitted to the control station and from here to a network where data of Maritime Traffic Centre are exchanged through Internet. It also provides a powerful tool in characterizing the marine environment for habitat monitoring. All those features lead to:

- Reducing cost per Flight Hour by extensively increasing endurance flight hours.
- Potentially increased acquisition cost, while reducing maintenance and spares cost.
- Reduced cost - larger area coverage per aircraft, requiring fewer aircraft per area.
- Improved operational safety - due to flight above aviation traffic and above adverse weather condition, resulting in limited interference with aviation traffic.

NO ONE real very-long endurance stratospheric platform is actually available in Europe. Few ones are already available in USA. A solar-powered, unmanned aircraft is being developed by Boeing and QinetiQ for the US Government (US Defence Advanced Research Projects Agency) for use in military and civil tasks. Unmanned long endurance (months) air vehicles could be used to replace conventional satellites. POLITO (Scient. Resp. Prof. G. Romeo) is carrying on, since several years, one of the two existing world projects on solar powered aerodynamic stratospheric platforms. After a preliminary funding by the Italian Space Agency, a very great push to the project has indeed been obtained by the financial support received by the European Commission in the field of stratospheric platform (HeliNet, Capecon, Enfica-FC, Tango [1], [2], [3], [4]). The possibility of medium-long endurance (4-6 months) for a stratospheric platform can be realised with the application of an integrated Hydrogen-based energy system. It is a closed-loop system: during daytime, the power generated by thin high efficiency solar cells that cover the aircraft's wing and horizontal tail supply power to electric motors for flying and to an electrolyser which splits water into its two components, hydrogen and oxygen. The gases are stored into pressurized tanks and then, during night-time, used as inlet gases for fuel cells stack in order to produce electric DC power and water to be supplied to the electrolyser. Since fuel cells represent the promise of clean and efficient power generation, they are a suitable alternative to conventional energy sources. Within the EC funded project TANGO [4] (Scient. Resp. Polito: Prof. G. Romeo) the Heliplat/Shampo UAVs shall be analysed in cooperation with several satellite systems for few civil applications of the GMES (Global Monitoring Environmental and Security) action. Demonstrations will integrate satellite telecommunication solutions with on-going GMES developments in the framework of fisheries management. Inclusion of UAVs in the global relay infrastructure enables quasi real time and continuous access to dedicated zones for monitoring or surveillance. A flight test with a scaled solar powered UAV shall be prepared for final integration with on-going GMES developments in the framework of fisheries management.

2. HELIPLAT® VESPAS

The full scale HELIPLAT® (HELIos PLATform) UAV (Fig. 2) was designed by using the most advanced tools for obtaining an endurance of several months (4-6) and being operable in almost all typical environment conditions (wind jet up to 180km/h) at stratospheric altitude (17-20 km). ([5], [6], [7], [8], [9], [10]). The vehicle should climb to 17-20 km by taking advantage, mainly, of direct sun radiation and maintaining, thereafter, a level flight; electrical energy not required for propulsion and payload operation is pumped back into the fuel cells energy storage system and, during the night, the platform would maintain the altitude by the stored (solar) energy; the geostationary position would be maintained by a level turning flight. POLITO will capitalize on results and findings that are being obtained in the on-going EU funded project ENFICA-FC (ENvironmentally Friendly Inter

City Aircraft powered by Fuel Cells) co-ordinated by Prof. G. Romeo. A two-seat electric-motor-driven airplane powered by fuel cells is being developed and validate by flight-test, converting a high efficiency existing aircraft [3], [11]. A computer program has been developed for designing the platform capable of remaining aloft for very long period of time and then gain a thorough understanding about the feasibility of a near term aerodynamic high altitude concept, electric motor, solar and fuel cell technology, with special consideration to stratospheric platforms. The solar radiation change over one year, the altitude, wind profiles with altitude, masses and efficiencies of solar cells and fuel cells, aerodynamic performances, structural mass, etc are taken into account. A wide use of high modulus Carbon fibre has been made in designing the structure in order to minimize the airframe weight. The project of the platform has been completed up to a quasi-final detail design. A numerical aerodynamic analysis has been performed to obtain the highest efficiencies of the whole wing and airplane. Several experimental tests have been carried out on Low-Speed-Low-Turbulence Wind-tunnel, obtaining a very good correlation between analytical and experimental results. A first configuration of HELIPLAT® (Fig. 2) was worked out, as a result of the preliminary design study. The platform is a monoplane with 8 brushless motors, twin-boom tail type, horizontal stabilizer and two rudders. The design procedure followed in the analysis is based on the energy balance equilibrium between the available solar power and the required power for flying; the endurance parameter has in particular to be fulfilled to minimise the power required for a horizontal flight.

- Total weight: 8500N; Wing Area:176m2; Span:73m; Required Power:7500W; Aspect ratio=33; Cruise Speed = 71 km/h.

A payload up to 150kg, with available power up to 1500W, could be installed on board for several global monitoring of environmental and security applications (GMES). A numerical aerodynamic analysis has been performed to obtain the highest efficiencies of the whole wing and airplane including propellers (Fig. 2), by using the VSAERO software, at the flight Reynolds numbers. Advanced design tools (such as CATIA) (Fig. 2) and FEM structural analysis (MSC/ PATRAN/ NASTRAN) have been used to design the all advanced composite wing (about 75m long), payload housing, booms and tail structures, and obtaining the highest structural efficiencies. Wide use of high modulus graphite/epoxy material has been made to obtain a very light-high stiffened structure. A 1:3 scaled size prototype (wing span 24m, horizontal tail span 10m, length 7m) was built in advanced composite material (high modulus CFRP) in order to show the technological feasibility (Fig. 3). EADS - CASA Space manufactured the single CFRP elements: wing tubular spars and ribs, horizontal and vertical tail tubular spars and ribs, booms and the metal fittings . POLITECNICO-DIASP, and ARCHEMIDE Advanced Composite, has assembled the different parts of the aircraft (wing, horizontal and vertical tails, booms) and the whole aircraft. A payload up to 150kg, with available power up to 1500W, could be installed on board for several global monitoring of environmental and security applications (GMES). A numerical aerodynamic analysis has been performed to obtain the highest efficiencies of the whole wing and airplane including propellers (Fig. 2), by using the VSAERO software, at the flight Reynolds numbers.

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Strain gauges and transducers were mounted along the wing's main spar in order to estimate deformations and wing deflection. The strain results along the wing, for flight conditions corresponding to cruise flight of the n-V diagram (maximum limit load n = 3), as well as the wing deflection are reported in figure 4; maximum wing tip deflection of 500mm (left) and maximum wing strain of 650 microns were recorded.

A very good correlation has been obtained between analytical (in-house developed theory), numerical (Nastran) and experimental results. The maximum limit loads (n = 3) has been reached without any residual detrimental effect. Than, the prototype

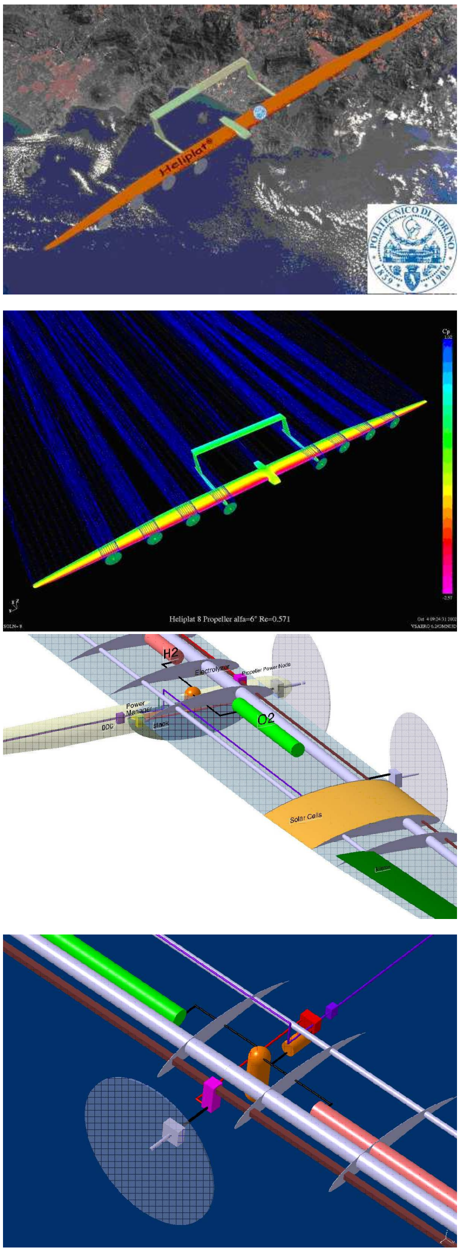

Figure 2. HeliPlat® Configuration, Aerodynamic Results and 3D details.

has been subjected to the ultimate load (n=4.5) to obtain the structural safety margin; in this case too, no any detrimental effects have been recorded. A static test up to failure load has been carried out up more than twice the limit load (N = 7.5) obtaining a very good correlation between analytical and experimental failure results. The results obtained in the CAPECON project [2], confirm the feasibility of a solar powered stratospheric UAV (SHAMPO satisfying the requirements of a long endurance stationary flight). A detailed aerodynamic and structural design, the flight

Figure 3. 1:3 Scaled-size HeliPlat® UAV.

mechanic and electric systems have been completed by Politecnico di Torino up to a quasi-final design. A greater aerodynamic and structural efficiency has been obtained allowing higher payload mass (150 kg) and power (1.5 kW). (Fig. 5)

3. Small Electric Solar Unmanned Airplane

The flying model Electric-Plane was built, within EC funded project CAPECON, to carry out several experimental flight test with a small UAV to demonstrate some critical technologies and applications. The starting model (1:2.8 scale replica of Super Dimona-wing span 5,8m, weight 20kg, efficiency 24, minimum cruise speed of 15m/s) was modified by replacing its combustion propulsion system with an electric one including a single brushless motor and a NiMh battery system. The structure is realized using glass-fibre reinforced plastic and carbon-fibre composite materials for wing box. Payload capabilities are in the order of 5-6 kg. Within the EC funded project TANGO, the NiMh batteries have been substituted by rechargeable LiPo batteries, mainly utilized during the take-off phase. A new wing with span of 7m was manufactured and 2 square meters of thin high efficiency (21%) mono-

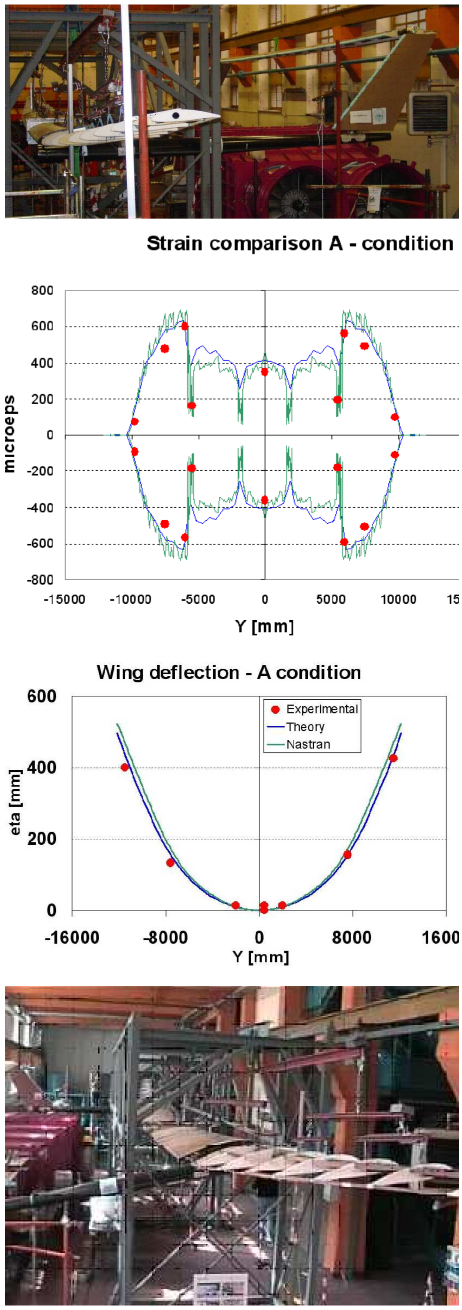

Figure 4. 1:3 Scaled-size HeliPlat® UAV and Shear/Bending and Torsion Tests and Results.

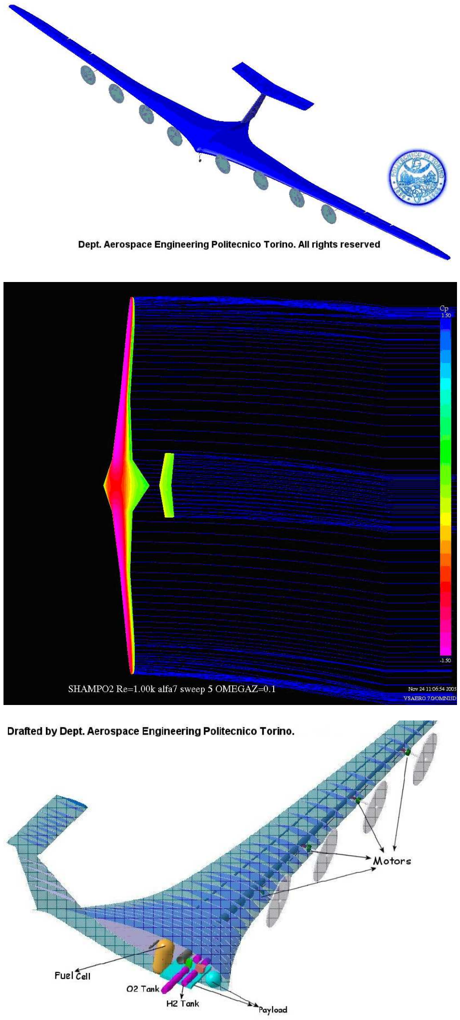

Figure 5. CAPECON SHAMPO Configuration, Aerodynamic Analysis and 3D details.

crystalline silicon arrays have been bonded over the wing skin (Fig. 6); during the level flight the needed power is being achieved from the solar cells system covering the wing, obtaining in such a way a far higher endurance up to 10 hours during June and July.

The power produced by SESA solar cell during the daily hour and for different months is reported in Fig. 7. The main characteristics of the Small Electric Solar Unmanned Airplane (SESA), are the following: Wing span: 7m; Wing area: 2 m2; Total gross weight: 35kg; Max Solar Power: 370-395 W (45°-36°N, June); Max power brushless Motor: 3000W; Horizontal Flight Power: 350 W; Minimum Speed: 36 km/h. SESA, powered by solar energy, has made its first flight, October 2007, near Torino (45° North latitude) at an altitude less that 500m [12]. The plane represents the first European Solar powered light UAV flying in Europe. In the '90, DLR (German Aerospace Centre) manufactured and flew the UAV scaled solar model "Solitair", but it is no more active. In September 2007, the UAV solar model "Zephir", by Qinetiq, flew in New Mexico. The experimental tests carried up to now validated few critical technologies for high altitude very long endurance flight: high efficiency solar cells, electric brushless motor, controllers, video and thermo camera images transmission, telemetry system,

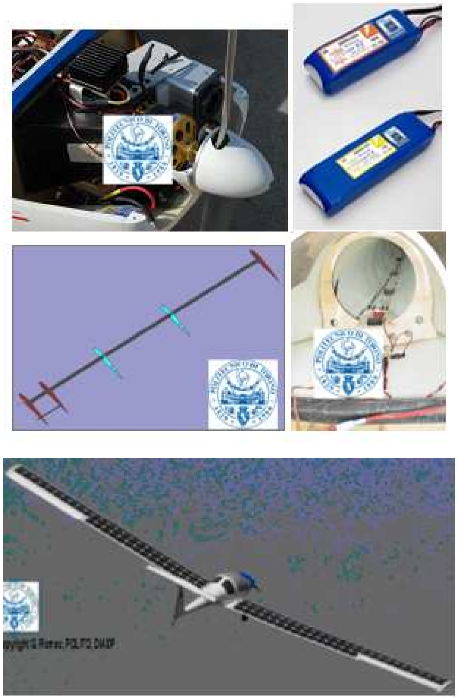

Figure 6. Small Electric Solar Unmanned Airplane SESA.

etc.

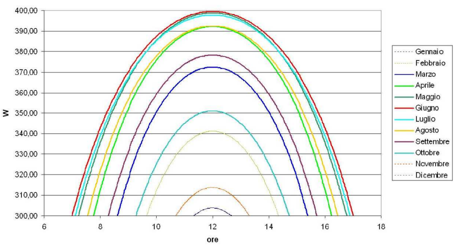

Figure 7. Daily SESA Power for several months.

3.1. Power electronic system

The flight management power electronic system is reported in Fig. 8.

The power produced by the solar cells is directly supplied to the brushless electric motor for the level flight. During take-off and climbing, or for some particular manoeuvre requesting more power, the power is also supplied by the LiPo batteries. The solar panel is composed by a series-parallel circuit of 130 solar cells each with efficiency of 21.5% (@1000 W/m2 and 25°C). The maximum solar panel voltage is of 43.5V. Of particular importance for the success of the flight mission has been the development of the MPPT electronic device (Maximum Point Power Tracking) in order to optimize the maximum power that would be obtained by the solar cells and improve endurance (Fig. 9).

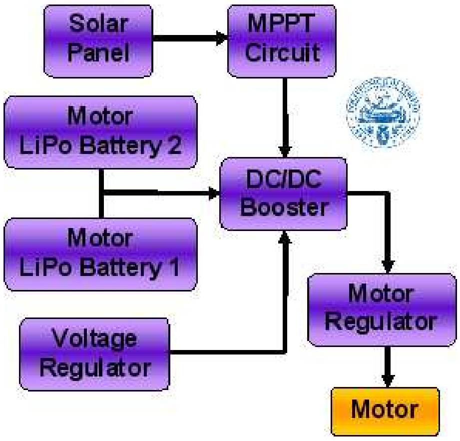

Figure 8. SESA Power electronic system.

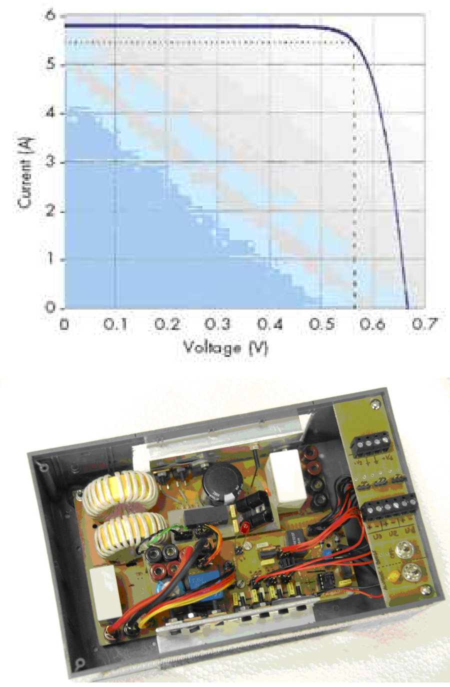

Figure 9. SESA solar cell curve and MPPT.

The inverter will finally supply a power (also greater than 3kw) to the brushless electric motor. Of particular importance the cooling of the inverter to avoid the shut-off of the system as a maximum allowable temperature is reached.

3.2. Payload system

In order to show the opportunity of introducing such platforms in surveillance or monitoring systems, the model is equipped with a wireless colours camera CCD(40x, resolution 720x576 pixel) and with an infra-red thermo-camera (160x120 pixel); video camera zoom can be remotely controlled by an RS-485. Both cameras can transmit (at 1.2GHz), in a range of about 1-1.5 km in open air and, through an appropriate capturing peripheral device, directly to a PC (Fig. 10); the PC could be used to analyze images in real-time, for example to automatically detect spot forest fires.

3.3. Remote control and telemetry system

Actually the UAV is remotely controlled by a radio modem. Up to 12 servo-actuators can be controlled for the UAV flight. Mainly the elements actually controlled are: Rudder and tail gear, 2 elevators, 2 ailerons, motor rpm. Also a telemetry system (Fig. 11) is installed on board to transmit in real time to the ground control station all the most critical data for the safety of the flight. The following data are being recorded and sent wireless to the Ground Control Station in order to continuously have the real flight conditions of the aircraft:

1. True Air Speed
2. Voltage and Current Brushless Motor
3. Voltage, Current and Consumption of main Motor Battery
4. Temperature Service of Motor and Inverter.

A data acquisition system (Enclosed Dash Logger-EDL2) measures and records the most important air vehicle parameters. The data are sent via a radio transmitter in the UAV to a radio receiver in the ground and, by an RS232, to the GCS. Here the data are elaborated and displayed (Fig. 12) allowing the engineers to monitor the main data while the air vehicle is still on flight. This increases the possibility to detect early signs of problems, warn the pilot on ground and helps to prepare for set up adjustments also during the flight.

3.4. Autopilot system and mission architecture

An autopilot has been acquired and is being installed on board for an autonomously flight up to 50km of distance by a highly integrated data acquisition, processing and control system which includes all necessary components for aircraft control. The Autopilot system (realized by Mavionics GmbH) consists of three main parts: 1) The TrIMU Sensor Block contains a complete 3-axis Inertia Measurement Unit (IMU) and two pressure sensors for barometric altitude and airspeed determination. It generates up to 12 independent servo control signals. 2) The Navigation Core hosts a sophisticated navigation filter for GPS/IMU data fusion enabling precise and long-term stable determination of position, velocity and the Eulerian angles, obtaining a reliable attitude determination. 3) a Satellite Navigation Receiver. 16channel GPS receiver with high sensitivity and integrated ceramic patch antenna. The connection between Core and Satellite Navigation Receiver is done by power and digital lines only, significantly reducing interferences. The on-board autopilot system communicates with Ground Control via a dedicated, direct bidirectional data link, using a radio modem which operates in the European 868 MHz band. The A/P periodically sends data (GPS time, position, Eulerian angles, flight speed, etc.) to GC at a rate of 4 Hz, and health monitoring data (battery voltage, electric motor current) with lower data rate. The direct control by radio modem does not give any latency problem; however, when we switch to the Iridium L-Band Transceiver the amount of data per Status Message (80bytes per data packet) from the aircraft seems not be a problem but the update frequency and latency could be critical. A latency of 5 up to 20 seconds should be possible by a Short Burst Data communication. Since the autopilot is operating even without connection to GC, latency is not directly a safety issue for the automatic flight itself; once sent to the autopilot, the A/P will follow the splines even without assistance from GC. So for the safety of the automatic flight itself, latency is not a severe issue, but for any kind of manual intervention, latency is important, and hence becomes also a safety issue. Furthermore, frequent losses of connection means loss of telemetry data and information about batteries consumption, loss of the Endurance control. Moreover, a delay in transmitting the picture of ship taken by the onboard camera would cause some problem in detecting the illegal boat. The small size of the demo scaled UAV preclude the use of high bandwidth geo satellite systems. The only systems capable of being installed are those which have small antennas, and thus it is the Low Earth Orbit (LEO) systems (Iridium/Globalstar). Satellite based Communication System shall be installed onboard for the Iridium©or similar network (Fig. 13). A completely separation between the autopilot system and Payload system has been adopted to obtain a Safe Flight configuration.

A direct radio connection will be used during the critical flight phases (take-off and landing) and for system integration and testing, and a Iridium satellite-based system for longer flights off-shore. The signal of the actual 2.4GHz on-board R/C receiver is connected to the autopilot and a special switching mechanism inside the autopilot will allow to override the autopilot by the remote control at any time, as long as the remote control transmitter is within range of the aircraft. Range of this system will be 1 to 2 km, suiting the visibility range of the manual pilot. Any possible malfunction of the autopilot or telemetry system is overcoming in such way, highly increasing the flight safety. For the ground segment, principally the same telemetry transceiver (radio modem) system is needed. In addition, a directional antenna can be used, greatly increasing range and reliability of the data connection. The ground control station is basically composed by a PC and a ground control software that is the user interface to SESA UAV system for mission planning and runtime control. All mission planning work is done intuitionally on top of an underlying map. This allows for a very flexible and safe flight path design. A check with respect to the aircraft performance is done automatically to ensure a realistic and safe flight of the UAV

4. UAV Flight Demonstration for Fishery

The SESA flight demo has the following characteristics: The UAV will take off from the Italian shores. (Fig. 13).

1. The UAV will be manually controlled for take off.
2. Once in the air, it will be switched to auto pilot mode to reach its destination.
3. The ship positions are sent to the local authorities which will program the UAV to reach the ship coordinates
4. The target boat will be beyond line of sight and reach of RF waves, ie 20nm
5. The flying altitude will be between 150m and 300 m high.
6. The flight will be entirely above water and as far as possible from the Italian coast but within the Italian EEZ
7. The images are transmitted continuously to the operation room (most likely a PC and antenna in a vehicle) at the place of take-off. The target coordinates for the auto pilot might be updated during the flight if the ship has moved.
8. When arriving at the ship location, the UAV will take some high resolution pictures.
9. Once the mission accomplished, the UAV is reprogrammed to automatically fly back to the place of take-off.
10. When plane reaches the remote control and within line of sight of the operator, the UAV is switched back to manual mode to be safely landed. When the UAV is at a distance less than 5km from the GCS a double redundancy of transmission is expected for safety reasons (both direct radio link and satellite transmission are possible for UAV control).
11. The total duration of the flight should be around 3h, depending on distance to shore. It is estimated 2h to take off, get to position and take picture, 1h to get back and landing.

Discussion with Italian CAA authorities to Fly the UAV is undergoing to get the Permit to Fly. Since the SESA weight is just 30kg and since it shall be used for research and scientific purposes, an EASA certificate is not requested. Nevertheless, the following items shall be pursed:

- See and Avoid system on board;
- Flight over a NOT populated area (although the Maximum kinetic energy of 95 KJ shall not be reached);
- a direct visual manual control is necessary to obtain a safe flight and for avoiding a double-triple redundancy. For the demo flight, SESA shall be followed by a boat with the pilot on board for any UAV emergency remote control. In any moment the R/C shall override the A/P control;
- No catastrophic failure condition shall result from the failure of a single component; allowable Quantitative Probabilities (per 1 flight hour) is less than 10^6.

5. Conclusions

The following conclusion should be issued as result of the many years of research in the field of solar powered UAV:

- Possible realisation of HAVE-UAV at least for low latitude sites in Europe and for 4-6 months continuous flight.
- Forest Fire Early detection, Border Patrol and Fishery monitoring would be possible at much cheaper cost and higher resolution than actual systems, and it would be obtained continuously.
- Showed feasibility of very light CFRP structural elements. Good correspondence between experimental analytical and FEM analysis was verified.
- Showed feasibility of brushless electric motors and fuel cell systems.
- Preliminary flight tests of few critical items were successively carried out.

6. Acknowledggements

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Figure 10. Video and Thermo camera wireless system and acquisition examples.

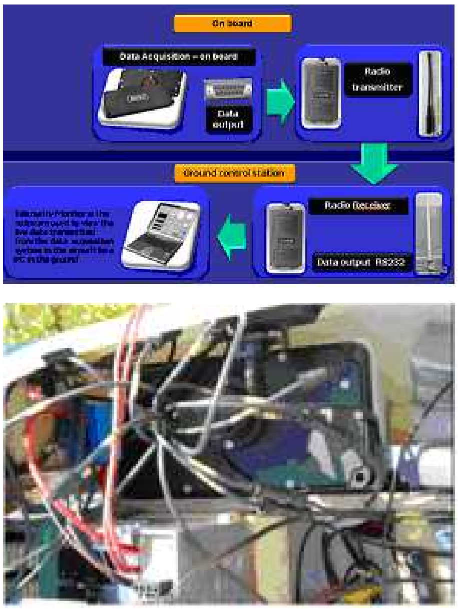

Figure 11. Telemetry wireless system and data logger.

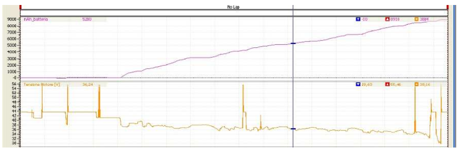

Figure 12. Telemetry wireless data display.

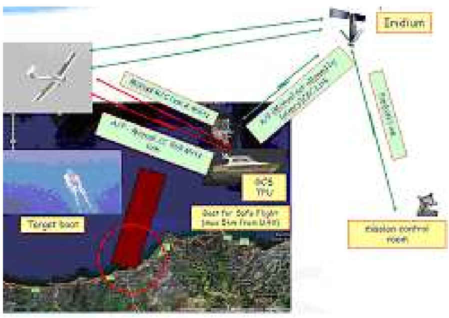

Figure 13. Possible Flight area and mission architecture.