Oil Spill Detection and Control by Utilitarian Solar Airplane and GNSS Satellites in Algeria

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***Abstract*— This paper presents the state of the art for oil pipeline surveillance in Algeria. We discuss different methods and oil spill detectability under varying conditions. In particular, we concentrate on the use of solar aircraft and GPS or GNSS satellites to control the oil pipeline network. The ability for an aircraft to fly during a much extended period of time has become a key issue and a target of research, both in the domain of civilian aviation and unmanned aerial vehicles. This latter domain takes an increasingly important place in our society, for civilian and military applications. However, other applications at high altitudes, such as communication platform for mobile devices, environmental monitoring, would require remaining airborne during days, weeks or even months. We conclude with a discussion of suggestions for further research with respect to oil spill detection systems.**

Keywords- Pipeline; Remote Sensing; Solar aircraft; Photovoltaic; electrical power; renewable energy.

I. INTRODUCTION

Due to environmental, economic and social cost of hy-drocarbon leaks [1], the oil and gas industry places great importance to the need to minimise problems of oil spill or destruction from occurring. The causes of pipeline damages could be categorised into four main classes: Opera-tional, structural, unintended or intended damages. Operational class includes all leaks from operation of oil and gas pipelines such as equipment failure (for instance flange sealing problems due to damaged seals or loose bolts/nuts), human error etc. Structural problems include the failure of pipeline in burst, collapse, fatigue, fracture, buckling, corrosion (wall thickness loss), and internal loadings etc. The intended damages come in the form of terrorist attack, sabotage/theft. The unintended damages are those that are often caused by construction workers working in the vicinity of the pipeline.

In Algeria, the control of pipeline oil and gas is currently insured by many helicopters of Tassily Air Company. This method is not efficient due to the expenses of fuel and crew in addition to the pollution provided by engines and the terroristic risk at very low altitude.

For the moment, it is only possible to reach such ambitious goals using electric solar powered platforms [2-3]. Photovoltaic modules [4] may be used to collect the energy of the sun during the day, one part being used directly to power the propulsion unit and onboard instruments [5], the other part being stored for the night time.

In order to reach the target endurance, the design of the airplane has to be thought carefully and globally, as a system composed of many subsystems that are continuously exchanging energy [6-7]. Due to these relationships, each part has to be sized accordingly to all the others. Simply because a crucial part lies in the combination of all the elements, and not only in their quality. This is true for multidisciplinary projects, the case of a solar airplane being an ideal example as it requires knowledge in the fields of actuators, sensors, electronics, energy storage, photovoltaic, etc.

This paper is organized as follows: Section II presents the data model and lists the assumptions and some preliminary notions. Section III presents the design of the solar airplane and Section IV is reserved to the conclusion.

II. DATA MODEL AND PRELIMINARY

In order to locate clearly where the contributions lie, we should first recall that the design process of a solar airplane is composed of three main phases [8]:

- Conceptual Design: it is in this phase that the basic questions of configurations arrangement, size, weight and performance are answered.
- Preliminary Design: in this phase, the specialists in areas such as structures, control systems, propulsion, and electronic devices will design and analyze their portion of the aircraft.
- Detail Design: the detail design phase begins in which the actual pieces to be fabricated are designed. The many little pieces not considered during the two first phases must be designed and it has to be decided how everything will be produced and assembled.

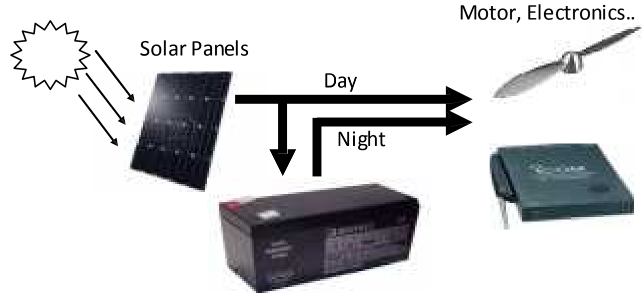

Figure.1 Solar airplane basic principle

The solar panels, composed by solar cells connected in a defined configuration, cover a given surface of the wing or potentially other parts of the airplane like the tail or the fuselage. During the day, depending on the sun irradiance and elevation in the sky, they convert light into electrical energy. A converter ensures that the solar panels are working at their maximum power point. That is the reason why this device is called a Maximum Power Point Tracker [9], that we will abbreviate MPPT. This power obtained is used firstly to supply the propulsion group and the onboard electronics (Figure 1), and secondly to charge the battery with the surplus of energy.

During the night, as no more power comes from the solar panels, the various elements consuming energy are supplied by the battery that has to last until the next morning where a new cycle starts.

We use two small wind power propeller generators to generate power from the wind so that they can create electricity and contribute to the recharging the batteries and at night or cloudy day.

A. Solar Cell

A solar cell or photovoltaic cell [3] is a device that converts solar energy into electricity by the photovoltaic effect. It is very widely used in space application [10] because it allows a clean and long-duration source of energy requiring almost no maintenance. Solar cells are composed of various semiconducting materials, constituting one or more layers. Silicon is very often used as it is the second most abundant element in Earth‘s crust and thus inexpensive. Solar cells mono crystalline silicon, 130 micron thickness.

B. Working Principles

A simple silicon solar cell is represented with two doped semiconductors layers, p-type and n-type. When the sunlight strikes the solar cell surface the cell creates charge carriers as electrons and holes. The internal field produced by junction separates some of the positive charges (holes) from the negative charges (electrons). The holes are swept into the positive or player and the electrons are swept into the negative or n-layer. When a circuit is made [11], the free electrons have to pass through the load to recombine with the positive holes; current can be produced from the cells under illumination.

The energy coming from the sun depends on the wavelength, leading to the solar spectrum represented in figure 2. The reference solar spectral irradiance AM0 (Air Mass 0) represents the irradiance at the top of the atmosphere with a total energy of 1353W/m2. At sea level, it is referred as AM1.5 and the total energy equals 1000W/m2.

C. Leak Detection Methods

Several method are used to control pipeline network like the acoustic impact detection system that often comprises of multiple acoustic sensors, power supply and remote transmitting devices which are placed along the pipeline at fixed intervals. The following table presents some other methods.

TABLE 1. DIFFERENT METHOD OF DETECTION LEAK

Leak detection methods	
Method	***Examples of tool/systems that use the method***
Laser Scanning	Laser scanning, Buckle detectors, etc.
Ultrasonic	Intelligent pigging, Automatic ultrasonic tester, TOFD, Ultrasonic probe testers etc
Acoustic	Acoustic Leak detector, hydrophones, Electromagnetic Acoustic Transducers(EMAT), piezoelectric meter etc.
Fibre Optics	Optical sensors (for leak, strain, fatigue and ground movement detection), etc
Visual Inspection	Use of human eye, Inspection light, Robotic crawlers etc.
Magnetic flux leakage method	Intelligent pigging, Eddy current, Magnetic particle inspection etc.

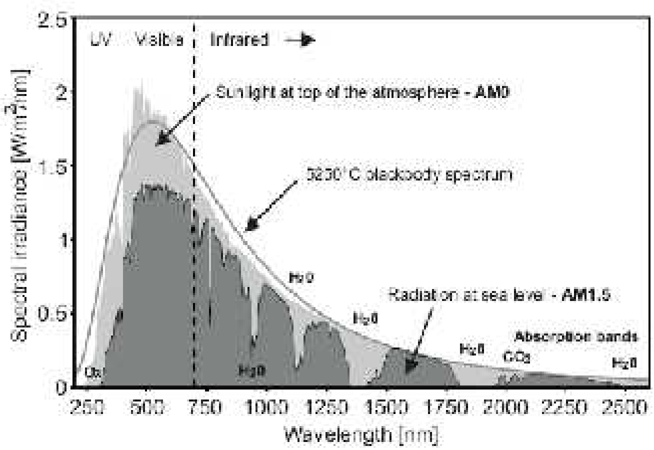

Figure 2. Solar radiation spectrum (Source: http://www.physforum.com)

III. SOLAR AIRPLANE DESIGN

The methodology is based on two simple balances, which are:

- Weight balance: the lift force has to be equal to the weight of all the elements constituting the airplane.
- Energy balance: the energy that is collected during a day from the solar panels has to be equal to or higher than the electrical energy needed by the airplane, we will first establish the expression of the power needed for an aircraft at flight level and then present the irradiance model that will lead to the daily solar energy available. After that, we will develop the weight prediction models for all the airplane elements, which will close the loop before presenting the analytical resolution and the solution of the problem.

A. Daily Electrical Energy Required

At steady level flight, the lift force generated by the wings exactly compensates for the weight and the propeller thrust compensates for the drag force. We have the following equations:

$$mg = C_L \frac{\rho}{2} S V^2 \tag{1}$$

$$T = C_D \frac{\rho}{2} S V^2 \tag{2}$$

$$P_{lev} = TV = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2(mg)^3}{\rho S}} \tag{3}$$

Using the definition of aspect ratio $AR = b^2/S$, where b is the wingspan and S the wing area, we can write the previous equation:

$$P_{lev} = \frac{C_D}{C_L^{3/2}} \sqrt{\frac{2ARg^3}{\rho}} \frac{m^{3/2}}{b} = a_0 \frac{m^{3/2}}{b} \tag{4}$$

To obtain the total electrical power consumption $P_{elec\ tot}$, efficiencies of the motor, its electronic controller, the gearbox and the propeller have to be taken into account, as well as the power consumption of the avionic system P_{av} and the payload instruments P_{pld} If the voltage of these two last elements has to be reduced, the efficiency of the step-down, also named in this case the BEC, has to be considered. This leads finally to a total electrical power consumption of:

$$P_{elec tot} = \frac{1}{\eta_{ctrl}\eta_{mot}\eta_{grb}\eta_{plr}} P_{lev} + \frac{P_{av}+P_{pld}}{\eta_{bec}} = a_1 P_{lev} + a_2 \tag{5}$$

The calculation of this daily energy consumption uses the total power consumption (Equation 5) and takes into account the charge and discharge efficiency of the battery [12] for the night period.

$$E_{elec tot} = P_{elec tot}\left(T_{day} + \frac{T_{night}}{\eta_{chrg}\eta_{dchrg}}\right) \tag{6}$$

It is clear that both sources, the solar generator and the battery are used and that the switch from one source to the other is progressive.

B. Daily Solar Energy Obtained

The irradiance depends on a lot of variables such as geographic location, time, plane orientation and weather conditions. A good model was developed based on [12].

For the present need, this model was simplified for flat surfaces and replaced with the positive part of a sinusoid, as shown in figure 3.

Here we will use a simple trigonometric model with only two parameters, the maximum irradiance I_{max} and the duration of the day T_{day}, that can be easily interpreted. The daily solar energy per square meter is the surface below the curve and can be easily calculated in equation (7). In order to take into account cloudy days, a constant η_{wther} is added with a value between 1 (clear sky) and 0 (dark). This constitutes a margin for the calculation.

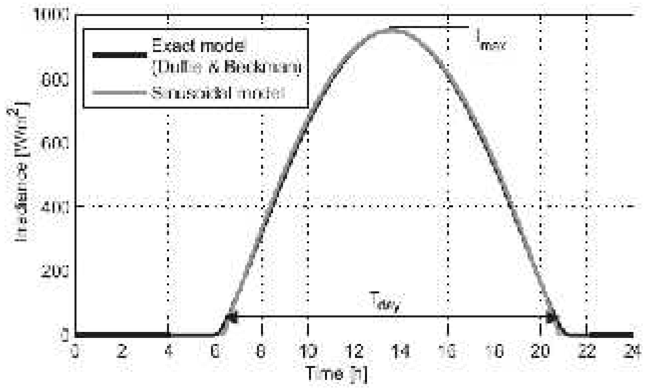

Figure 3. Approximation of irradiance as a sinusoid

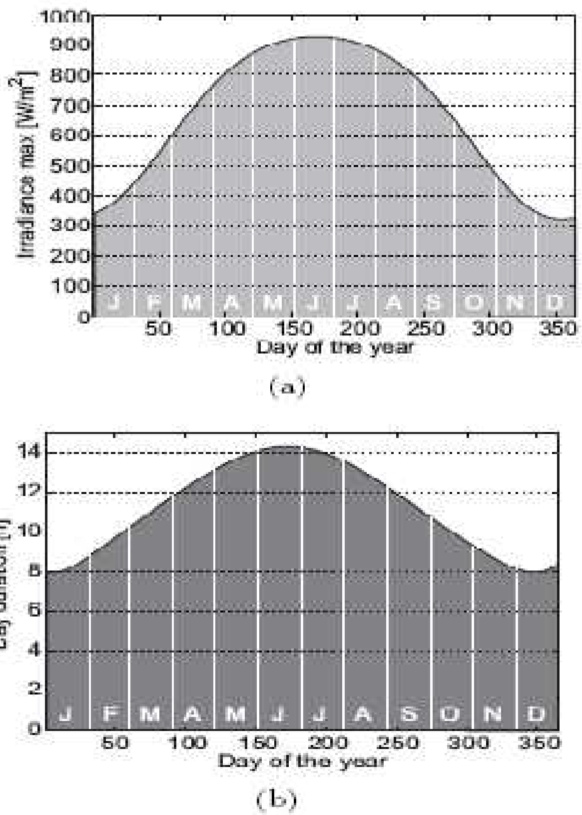

Figure 4. Maximum irradiance and day duration throughout a year in Algeria

$$E_{daydencity} = \frac{I_{max} T_{day}}{\pi/2} \eta_{wther} \tag{7}$$

The two parameters I_{max} and T_{day}, are depending on the location and the date. Figure 4 shows the evolution of these parameters throughout the year for given area.

The total electric energy is obtained by multiplying the result of equation (7) with the surface of solar cells, their efficiency and the efficiency of the MPPT. Additionally, we have to take into account the fact that the cells are not disposed on a horizontal surface but follow the cambered airfoil. In a series of interconnected cells, the one with the lowest irradiance limits the current for all the others. This problem occurs mainly at sunrise or sunset, when the sun elevation is low, and depends also on the airplane orientation. This situation is represented in figure 5 where the first cell, near the border of attack, has the smallest elevation angle θ_1 and will then penalize the other cells.

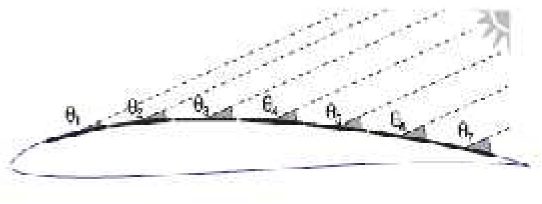

Figure 5. Variation of incidence angle on the solar cells for a cambered wing at sunrise or sunset

For this reason it is important to take care about the wiring configuration and preferably dispose the cells connected in series along the wings, so that they have the same orientation. Simulations have been realized in order to study this impact and the results show that compared to a flat disposition, thus, the daily electrical energy is:

$$E_{electot} = \frac{I_{max} T_{day}}{\pi / 2} A_{solar} \eta_{wther} \eta_{sell} \eta_{mppt} \quad (8)$$

The mass of the airplane structure is certainly the most difficult part.

This approach consists in calculating separately the mass of all the elements constituting the airframe, i.e. the spar, the leading and trailing edges, covering, ribs, control surfaces, fuselage and tail as functions of the total mass, aspect ratio and wing area with a weight between 1000 to 1600 kg with 32 m wingspan.

Concerning the battery [13], its mass is directly proportional to the energy it needs to store, which is the product between power consumption and night duration, and inversely proportional to its gravimetric energy density.

$$m_{bat} = P_{electot} \left(\frac{T_{night}}{\eta_{chrg} k_{bat}} \right) \quad (9)$$

Modeling the propulsion group is composed of four subparts (control electronics, motor, gearbox and propeller) that all have their own power densities and efficiencies. Additionally, we will always consider the maximum continuous power and not the short time peak power.

Looking at the past solar airplane designs [14-15], the main tendency is to assume a propulsion group mass that scales linearly with shaft power output. Also, many of them only take the motor into account, stating that it constitutes the major weight compared to the other parts.

Materials and structure are essentially constructed from carbon fiber and sandwhich structure is used with very thin materials with the lowest possible densities

For monitoring and control of this solar airplane, a ground station is needed and auto pilot must be installed to help pilot for long flights.

TABLE 2. TECHNICAL DATA SHEET OF SOLAR AIRCRAFT

Wingspan (two wings)	31 m
Length	11.85
Height	5.4 m
Weight	1460 kg
Motor power	3 x 10HP electric engines
Average flying speed	75 km/h
Motors number	3

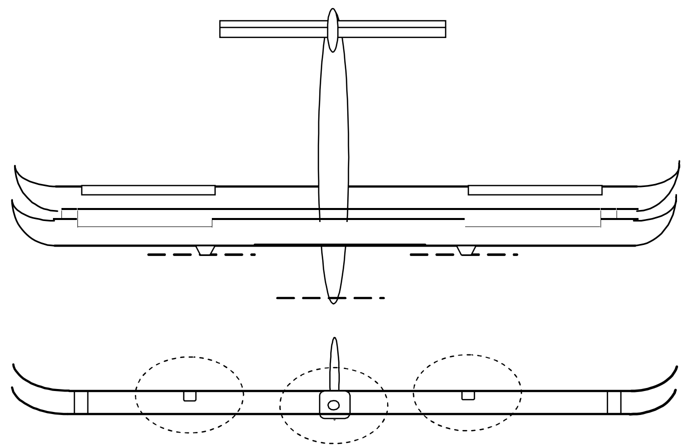

Figure 6. Drawings of the Solar Airplane prototype

C. Receiver Outputs/Data Exchange Formats

This section briefly describes the GNSS [16]receiver data output formats and various oil industry positioning data exchange formats that are used to record raw and processed GNSS and derived positioning data. In a surveying and positioning context the output from GNSS positioning systems may be regarded as the means to determining the positions both in real time and off line of survey sensors and points of interest. Figure 2 is a map of major oil and gas pipelines in the Algeria. The sum of oil and gas pipelines in the Southern and Northern regions is indeed a congested field.

The introduction of new and more sophisticated GNSS positioning techniques and of rigorous quality control based on statistical testing means that the traditional concept of a ‘receiver’ supplying a position (figure 7) is no longer appropriate. The GNSS receiver serves as the data source, and the position solution and associated quality measures are derived by separate software that for dynamic surveying and positioning typically run on computer hardware interfaced to the GNSS receiver or on land and other static surveys on a separate off line computer. Hardware configuration and software solution varies with e.g. type of solution, service provider etc. When discussing ‘receiver’ outputs, it may frequently be the case that the appropriate data will be made available by the software package rather than the GNSS receiver. The term data output is used in this section.

The objective of recording of GNSS data generally falls into two categories depending on the purpose of the surveying and positioning. On dynamic vessels and vehicles where real time positioning is necessary, raw GNSS data are typically recorded online as a back-up to ensure that re-processing of the data can take place if the real time positions are later found to be adversely affected by errors. On land and other static surveys GNSS data should be recorded to derive the positions of the surveyed points through post-processing techniques. Additionally raw GNSS data also needs to be recorded during equipment installation for testing and evaluation purposes.

In order to record, archive and exchange the calculated position data a number of position data exchange formats have been developed by the oil industry; these were primarily developed for exchange of seismic positioning data.

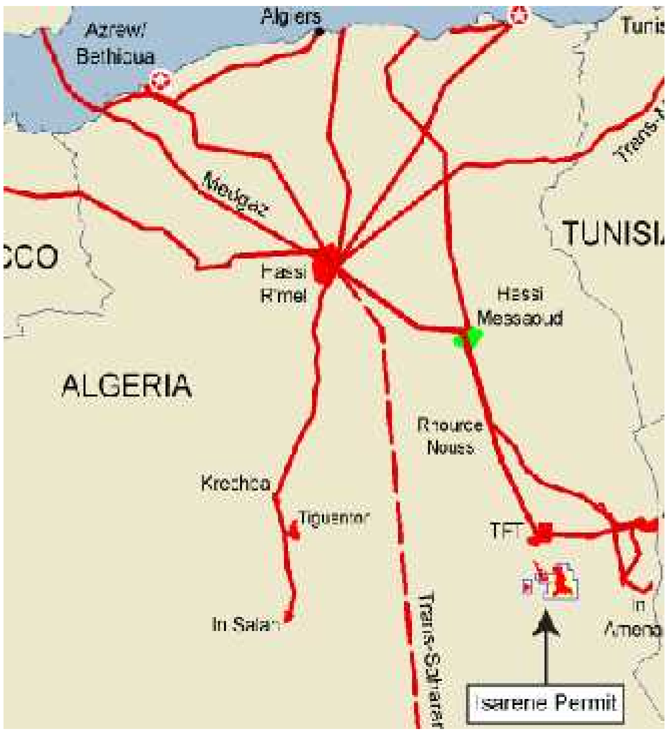

Figure 7. Oil and gas pipeline Algerian network (petroceltic.annualreport11.com)

Production of oil and gas has been increased significantly and pipeline network became so important (see Figure 8), therefore serious surveillance must be established. Microwaves are commonly used for transmiting control data pictures by remote sensing. They are often preferred to optical sensors due to the all-weather and all-day capabilities.

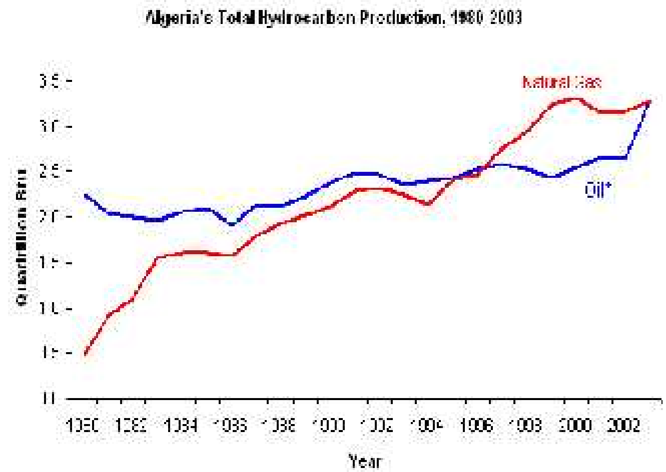

Figure 8. Algerian production of Oil and gas

CONCLUSION

As it has been shown in previous chapters, the control of oil pipeline by solar airplane and GNSS satellites used to ensure different missions, with small wingspan comparing to ancient model which allows a high degree of liberty in different operations. The control of pipeline ensure the security of national economy and minimize the consumption of fuel in order to save the environment at decreasing the rate of pollution of the air. As perspective we will try to develop the use of solar airplane in more fields.

ACKNOWLEDGMENT

The author wishes to thank the electrical department for the help provided.

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