PEGASUS : BUSINESS MODEL FOR A STRATOSPHERIC LONG ENDURANCE UAV SYSTEM FOR REMOTE SENSING

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ABSTRACT:

The PEGASUS (Policy support for European Governments by Acquisition of information from Satellite and UAV borne Sensors) project's aim is to provide an economic way to gather high resolution data (visual, IR and thermal imagery, laser altimetry, SAR, atmospheric measurements) from a high altitude platform. Because the platform will not be manned, it will be able to operate continuously for weeks or months.

The paper describes the business model for the data acquisition to information delivery flow. During the system's operation, it will acquire data for storage in a centralised database, where it's conformance to national and international standards is certified. The information derived from the data will be made available to the public *via* Internet. In case of emergency situations, the system will be able to provide data in near real-time, even in adverse weather.

Special attention is paid to evaluate the economic viability of the project and the remote sensing applications for which information can be provided.

RÉSUMÉ:

Le projet PEGASUS (Policy support for European Governments by Acquisition of information from Satellite and UAV borne Sensors) a pour but de fournir des images à très haute résolution spatiale au moyen de capteurs aéroportés (visible, infrarouge, thermique, LIDAR, SAR et mesures atmosphériques) placés sur une plateforme opérant à très haute altitude. De par le caractère inhabité de la plateforme, celle-ci pourra acquérir les données requises de façon continue durant des semaines, voir des mois.

Le présent article décrit le plan de gestion du projet (business model), et ce de l'instant ou acquisition des données à lieu jusqu'à la livraison de l'information utile aux utilisateurs. Durant son fonctionnement, le système acquerra les données qui seront par la suite archivées dans une banque de données centrale. Celle-ci sera conforme aux standard nationaux et internationaux en matière de certification. Les informations dérivées de ces données seront mises à la disposition du public *via* Internet. Dans le cas de situation d'urgence (catastrophe naturelles et autres) le système sera habilité à fournir des données quasiment en temps réel, et ce même lors de conditions météorologiques défavorables. Une attention spéciale est fournie quant à l'évaluation de la viabilité économique du projet ainsi qu'aux diverses applications de télédétection pour lesquelles le système présenté est utile.

1. INTRODUCTION

A thorough analysis of the present EO market and the foreseen user requirements points to the need for data with a high update rate, high accuracy and high ground resolution but at an affordable, i.e. low cost. This would require the merger of the advantages of both aerial and satellite data without their respective setbacks. It is believed that High Altitude Long Endurance Unmanned Aerial Vehicle (HALE UAV) can fulfill this promise and thereby grab the foreseen growth in the EO market.

2. REMOTE SENSING MARKET

2.1 Market evolution

The market outlook for commercial remote sensing (RS) data in Europe is that it will grow annually with a rate of nearly 9% (Frost, 2001). In 2001 the revenues from the total European commercial remote sensing data end-user market, both satellite and aerial recordings, was estimated at 1 170 M$ (1 298 M€). This amount is estimated to 1 790 M$ (1 987 M€) for 2006, with 1 152 M$ (1 279 M€) for Governmental institutions, 605 M$ (672 M€) for the Industry and about 33 M$ (37 M€) for other consumers (Frost, 2001).

2.2 Users

The users of these data are well known to the remote sensing community and consist primarily of the traditional mapping agencies. However recent initiatives jointly undertaken by the EU and ESA i.e. GMES (Global Monitoring of the Environment and Security) might add a new and potential important player to the market. These organisations will thereby also promote the use of RS data by the different users. Moreover, Homeland Security in its many forms will also contribute to the market growth in the USA.

2.3 Evolution of the requirements

To capture this growing market (in revenue and in users) there is a need for data with a higher update rate, a higher resolution and a higher accuracy. This is evident from the joint ASPRS-

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NASA-NOAA study (Mondello et al., 2004) which states : "There is a trend toward higher resolutions and accuracies as many users are presently faced with using data which do not comply with their requirements, either because these data are not present or too expensive". This report clearly indicates an inadequate evolution of the EO market: that there is a larger demand than what the EO market offers for data with sub-meter spatial resolution while a clear surplus is observed for data offering spatial resolution lower than 10 m (mostly satellite data). The same trend\ is reported with respect to both positional and elevation precision (insufficient data with precision higher than 1.5 meter and too much data with lower precision).

Typically the high accuracy, high resolution data can be found in aerial RS data, while the low accuracy, low resolution data originate from satellite observations. Since 2000 several high resolution satellite data are available (e.g. IKONOS) and reasonably priced but satellite data suffer from a lack of positional and vertical accuracy. They are also limited in their timely availability due to their orbital movement..

3. HIGH ALTITUDE LONG ENDURANCE UAV -

3.1 Carrier

A HALE UAV that is capable to act as a "very low-orbit" satellite by remaining in free airspace above 14 km (46 000 feet) for months should resolve the inherent drawbacks of both aerial and satellite platforms. Working with a constellation of HALE UAVs will combine only the advantages of both systems.

After a history of some 15 years, these UAVs are now becoming generally available, especially as energy-storage and solar cells technology have improved significantly during the last years. UAVs can either be aircraft or balloons (blimps). Balloons have a far higher payload capacity and a longer station-keeping ability but will not be commercially available within the next 5 to 7 years. Aircraft on the other hand are now already available and their capabilities will only improve in the close future.

Both NASA, through the Environmental Research Aircraft and Sensor Technology (ERAST) program, and recently ESA and the US MoD (Ministry of Defence) have issued studies or ordered solutions for unmanned aerial vehicle with a prolonged stay (months or even years) at stratospheric altitudes (between 12 and 25 km) (Erast, 2004; Heliplat, 2000; Küke, 2000).

As an example, in 2003 a 40 M$ contract was awarded by the Missile Defense Agency (USA) to Lockheed Martin to deliver a prototype of a High Altitude Airship by 2006 (Dell, 2003). This platform should be able to carry a payload of 1 800 kg at an altitude of 20 km and to deliver 10 kW electric power for the payload. The dimensions of the airship are estimated at 152 m length, 49 m diameter and a volume of 480 000 m^3.

Another example is the Helios-ERAST solar flying wing that set a world altitude record for non-rocket powered aircraft in 2001 by flying up to 96 863 ft (29 523 m). In the UK, QinetiQ worked out the Zephyr aircraft (figure 1, Bermyn et al., 2004). In this concept, the aircraft has been designed to provide immediate access to free airspace for prolonged time periods with a limited payload, at least in the first phase. The current design calls for a wingspan of approximately 15 m, a payload of 2 kg and 1 kW electrical power for the payload. In 2004 several test flights are planned while a 3 weeks continuous test period is foreseen in 2005. The roadmap of this aircraft allows for an upscaling of the wingspan up to 30 m with a 30 kg payload by 2005/6 and larger wingspan and payload in the following years.

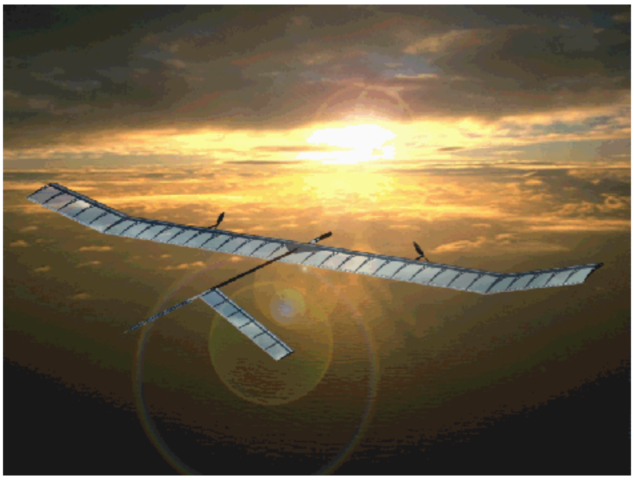

Figure 1. Artist impression of the Zephyr, a light weight HALE UAV

The Zephyr already complies with present UAV flight regulations and can thus be used immediately. Vito intends therefore to use this aircraft in the framework of the PEGASUS-project to deliver high accuracy and high resolution earth observation data with a high updated rate, and that not only for Flanders but by extension in the whole of Europe.

3.2 Instruments

Based on the requirements of the market and keeping in mind the present limitations on the weight and power consumption of the payload, the following instruments are being designed or are currently under construction :

- a multispectral camera by 2005,
- an aerial laserscanner by 2006,
- a thermal camera by 2006, and
- a mini-SAR by 2007.

It is the intention to provide imagery that is comparable in quality to present-day digital aerial cameras. The basic requirements are summarized in Table 2.

Flying altitude	12-20 km
Ground resolution	20 cm (at 20 km)
Spectral resolution	10 nm
# spectral channels	Initially 4, extensible to 10
# pixels per line	12000 – 30000
Image update	At least 100 Hz
Planimetric accuracy	Better than 15 cm
Data transfer rate	< 40 Mbit/s
Continuous use on daily basis	8 h at equinox
Weight	< 2 kg

Table 2. Basic requirements of the multispectral digital camera.
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Based on the standards for laser altimetry currently used in The Netherlands and Flanders, a similar set of requirements is obtained for the aerial laserscanner (Table 3).At a nominal flying altitude of 14 km, with a ceiling of 18 km albeit with perhaps restricted capabilities, a scanangle of 6° is foreseen so that the swath widths of multispectral camera and the laserscanner coincide. The complete payload description and the UAV issues are described elsewhere (Everaerts et al., 2004).

Pulse frequency	15 kHz
Laser beam divergence	<0.1 mrad
Scan frequency	At least 10 Hz
Scan mode	Nutating
Intensity	Yes
Multiple reflections	Yes
Data volume	26 Mbit/s
Estimated weight	< 5 kg
Continuous use on daily basis	at least 8 h during equinox

Table 3. Basic requirements for the laser altimeter

3.3 Ground segment

Based on previous experience at Vito with the Processing and Archiving Facility for several satellite sensors, a centralized ground processing center linked to multiple ground rececption stations will be installed (one reception station supports the HALE UAV in a radius of 200 km). One of the key features of the PEGASUS system is the centralized data processing from level 0 (raw data) to level 2 and level 3 data under standardized quality control procedures. This centralized and qualified ground segment guarantees users across Europe the same high-quality data as presently delivered by satellite data providers. This is not the case in the aerial survey business world where only the instruments are standardized, as there are just a few large manufacturers left (e.g. Leica Geosystems and Z/I Imaging for aerial cameras).

The multispectral data will not have stereo capability, due to the narrow view angle. The stereo aspect will be generated from the overlay of the multispectral data with the aerial laserscan data as elevation measurements derived from aerial laserscan data have a higher accuracy and consistency than those derived through photogrammetry at the same flying height. Therefore stereo multispectral data will be available but as a level 3 data, i.e. after merging the laserscan data with the multispectral data.

4. BUSINESS MODEL

The main features characterizing the business model of the PEGASUS project can be summarized as follow:

The PEGASUS project, by its targeted ground resolution, offers an alternative for aerial photography and aerial laserscanning data from a photo scale of 1:8 000 and smaller. These data will be comparable to and compatible with present-day modern digital airborne systems like Leica ADS 40, Leica ALS 40, etc…

Because several complete overpasses and observations per year will be performed and be made available to end-users across Europe, all required data will usually be available immediately. Even for disaster monitoring, nearly real-time data from the hovering UAV's will be available to the decision makers.

There will be one centralized and quality-assured system for the whole of Europe. This system will respond to the highest quality standards set for large scale digital mapping (the GRB-standard in Flanders and the elevation mapping standards in the Netherlands and Flanders). This will ensure mapping agencies and end-users of the desired quality without needing to wait for the appropriate flight season or the availability of sensors, or buying expensive equipment themselves. This centralized and quality-assured system will rely mostly on fully automated procedures for the production of data up to level 2, with substantial manual or semi-automated data quality checks and re-runs. The future is clearly for a centralized (state-wise or European wide) data and information provider with certified quality-approved production systems, standardized across Europe. All the data and subsequently derived information products will be available to both end-users and OEMs. This allows for a large dissemination and use of RS data in the society as a whole and not just among the current specialist users. OEMs will be able to define their own level 3 data.

The data will be delivered at a cost significantly lower than presently by wholly owned data acquisition. This is due to a better time-use and hence lower operating cost than present-day systems. Indeed, a specific UAV is targeted for a survey area varying between 100 000 km2 and 150 000 km2 at an system acquisition cost, inclusive of payload, of approximately 10 M€. This amount is significantly lower than the acquisition costs for the multitude of aircraft, digital and analog cameras and laserscanners presently needed to cover the same area..

Furthermore, both digital and analog cameras are only used under "blue sky" conditions (1/8 of cloud cover and preferably less). No data acquisition is undertaken when cloudy patterns are observed or forecast as the cost for mobilizing crew, aircraft, operating cost of the aircraft, etc., … are too high compared to the potential profit of data collection. In contrast the UAV will hover continuously over the area and collect data as soon as any area of 2 x 2 km² (on the ground) can be recorded cloud-free. This leads to vastly expanded operating hours as compared to today's airborne systems.

Moreover, the use of fully automated and/or semi-automated data QA/QC lowers the production cost of the data and information even further. More integrated automated solutions can be used because of :

1. the integrated design of the different sensors by the same manufacturer,
2. the completely digital set-up of all sensors and data-acquisition, and
3. the large development effort on the part of payload manufacturer i.e. Vito, as a research organization, to also spend considerable time improving the data processing algorithms.

Traditional hardware manufacturers only provide the hardware, but seldomly the automated tools to ensure quality-approved information collection.

Vito, as founding and chief scientific partner in the PEGASUS-project, has growing evidence of this theory in its own running data-information dissemination policy with regard to VEGETATION satellite data.

Figure 4 shows the dramatic increase of subscribed users to the centralized VEGETATION satellite-data and -products once the price and conditions of acquisition for the information where put at a par with those of the NOAA AVHRR data. This can easily be explained given the fact that due to the centralized data and quality-assured production process of VEGATION data these are vastly superior to those of NOAA AVHRR.

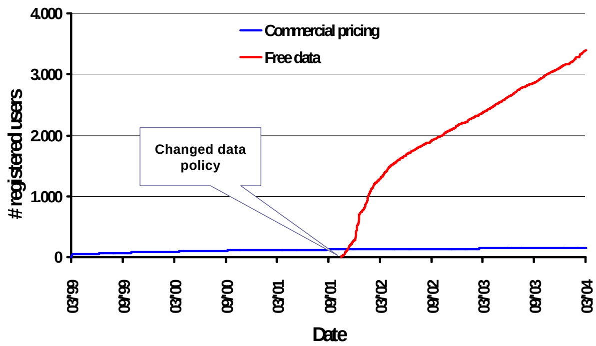

Figure 4. Evolution of registered users of VEGETATION data before and after changes in the pricing policy (from Van Speybroeck & Sayag, 2004).

All these features will lead to :

- a lower production cost for the UAV data and information as compared to present-day systems,
- a wide data dissemination of the data and hence an increased demand for such high-quality data, and
- a state-of-the-art data and information acquisition system wished by both national and supra-national organizations to standardize the data and information intake.

5. IMPLEMENTATION TIME SCHEDULE

	2004		2005				2006				2007	
	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Test- and clearance flights with UAV			■	■								
Development of multispectral camera (ongoing)	■	■	■	■	■							
Integration of multispectral camera in UAV					■							
Acceptance HALE UAV and ground segment					■							
Development of laser-altimeter			■	■	■	■	■	■				
Integration of laser-altimeter								■				
Development of thermal camera			■	■	■	■	■	■				
Integration of thermal camera								■				
Development of mini-SAR					■	■	■	■	■	■	■	■
Integration of mini-SAR												■

Figure.5. Description of the time-line for the first phase of the HALE UAV project

There are two main phases in the implementation of the present concept. On the one hand there is a specific Belgian R&D project which includes the development of both the first UAV and the full suite of payload instruments to be put in it in 2005 and later. As can be seen from Figure 5, this time line finalizes the development of the laserscanner by 2006 and the mini-SAR by 2007.

On the other hand there is the extension of the Belgian program into the EO community in Europe: the PEGASUS-project. The time schedule of this project can be given as follows :

Spring and Summer 2005

Demonstration flights with up to 3 weeks endurance over Flanders (Belgium) as part of the Belgian R&D program with the multispectral camera payload. This serves as a proof-of-concept for the complete effort.

Summer 2006

Demonstration flights over Belgium with an endurance of up to 6 months with multispectral camera and laser altimeter. Start of additional test flights over the complete Benelux (Belgium, The Netherlands and Luxemburg).

Summer 2007

7 months endurance with complete payload availability over Benelux, France, Germany and Denmark.

From 2008 onwards

Further expansion over Europe towards the east (Poland, Hungary, Czech Republic, Austria, etc., …) and the south (Spain, Italy, etc., …).

Free of charge test data will be available for interested parties from 2005 onwards to evaluate the data quality and to express further interest of the customers in the PEGASUS-project. These data will also spur additional research activities in the development of software automation tools to assist in the production processes from data toward information.

6. CONCLUSIONS

A thorough analysis of the present EO market and the foreseen user requirements point to the need for data with a high update rate, high accuracy and high ground resolution but at an affordable, i.e. low cost. This requires the merging of the advantages of both aerial and satellite data without their respective setbacks. It is believed that HALE UAV can fulfill this promise and thereby grab the foreseen growth in the EO market by showing specific features :

- data comparable and compatible with aerial photography from a photo scale of 1:8 000 or smaller, and aerial laserscanners whereby the data will be compatible with present day modern digital airborne systems,
- a centralized and quality-assured system available for the whole of Europe corresponding to the highest quality standards set for large scale digital mapping,
- all data will be immediately available through the internet. Even in disaster monitoring, real-time data from the hovering UAV's will be available on-line,
- all the data and subsequent derived information products will be available to both end-users and OEM's. This allows a large dissemination and use of RS data in the society as a whole, and.
- the data will be delivered at a cost significantly lower than presently by wholly owned data acquisition.

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