

The use of Unmanned Air Vehicles in Exploration and Production activities

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Abstract

The potential use of Unmanned Air Vehicles (UAVs) in Exploration and Production activities is investigated, leading to the conclusion that the UAV with a 9 Kg payload and a range of 1,800 Km has much to offer. UAVs are starting to be used in oil pipeline monitoring and in whale watching. However, before such UAVs will find widespread use in geophysical survey and pipeline monitoring activities, issues to do with reliability, flying in non-segregated air space, minimizing the consequences of a UAV crash and reputational damage, need to be addressed. The suggestion is made that the development of a reliable UAV, specifically for geophysical survey and pipeline monitoring applications and the development of a miniature gravity meter, will have a tremendous payback for the company, or, companies involved in this initiative.

Introduction

Unmanned Air Vehicles are re-usable robotic aircraft. There has been a huge upsurge in the development and deployment of these aircraft, primarily by the military services, in many countries. The US military, in particular, has allocated massive resources to UAV development and production. Many of the technological advances that have been created by the huge investment made by the military can be applied in the development of civilian UAVs.

Not surprisingly, UAVs in current production tend to be military in nature and range from the small, hand launched 2.7 Kg Dragon Eye by AeroVironment, with a maximum endurance of one hour and a price tag of less than \$100,000, to the massive 14,628 Kg Northrop Grumman Global Hawk RQ-4, with a maximum endurance of 36 hours and a price tag per UAV in excess of \$27 million.

Reported activities involving the use of UAVs

- UAV Systems: The Global Perspective 2005
“Aeronautics Defense Systems is using its short range Aerostar UAV to provide protection and patrol services for Chevron Texaco’s operations in Angola, under a two year contract awarded last year and reportedly worth US\$ 4 million. The Aerostar carries a payload of up to 50 Kg and has an endurance of 14 hours.” From “UAV Systems: The Global Perspective 2005” by Blyenburgh & Co.

- InSitu / Fugro Airborne GeoRanger

Fugro Airborne Surveys reported on the development and deployment of the Fugro GeoRanger. The 18 Kg GeoRanger, based on the InSitu Scan Eagle, is capable of fully autonomous flight. It has an endurance of up to 10 hours and a cruise speed of 75 Km/hr. The maximum fuel and payload weight is 5.4 Kg. This UAV is used in magnetic surveys. See www.insitu.com and www.fugroairborne.com web sites for more information.



The InSitu / Fugro GeoRanger UAV on a ship. The GeoRanger currently has a fuel and payload capacity of 5.4 Kg, a value that might change with ongoing developmental work. Image kindly supplied by www.insitu.com and www.fugroairborne.com.

- MagSurvey Prion

This 30 Kg UAV is targeted for use in magnetic field surveys, in which a very sensitive Cesium magnetometer is used. See www.magsurvey.co.uk.

- “Shell may enlist pilotless planes to aid in exploration”

According to a written statement by Terzah Poe of Shell Oil, “Drones are being investigated as an alternative to manned aerial flights for marine mammal monitoring in order to reduce the safety risk to humans associated with flights over remote stretches of Arctic Ocean. The unmanned aerial vehicle, or drone aircraft, would be

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used to monitor and track marine mammals in the areas where we are operating.” From www.alaskajournal.com

The advantages of using UAVs in E&P activities

- The UAV can stay in the air for up to 30 hours. This is far in excess of the duration of a manned aircraft, where the concentration span for a pilot is considered to be at most around five hours.
- The UAV can fly in hostile regions, where there is a real risk to the life of a pilot:
 - over the Arctic Region;
 - in the vicinity of extreme weather conditions
 - over regions experiencing low level civil strife
- The UAV is always “flying on instruments,” using advanced navigation systems, such as GPS and a scanning laser based altimeter, in combination with precise computer control and can:
 - perform a very precise raster scan of a region
 - fly at night, to take advantage of the lower interference from both sunspot activity and cultural noise (such as mobile phone signals, radio signals)
 - fly at night and at very low levels (such as 20 m above ground level) to increase data resolution
- The UAV is physically smaller than its manned counterpart and consequently there is less disturbance to the parameters being measured, such as the magnetic, or, gravitational field
- The UAV costs less to operate per line Km, since:
 - The UAV with a typical payload of 9 Kg is less expensive to purchase than a manned aircraft
 - The UAV has lower operating costs:
 - a UAV operator can manage several UAVs at the same time;
 - the UAV uses less than 20% of the fuel used by a manned aircraft (payload dependent)
 - a small UAV can often take off from a flat field, rather than from an airfield

Because of the lower operating cost of the UAV, relative to a manned aircraft, one can perform repeated surveys over the same area, to detect changes that occur over time, for example, the depletion of an oil reserve, or, leakage from a pipeline. One can use the data from extensive measurements of either the magnetic or the gravitational fields in a computer programme, to derive the three dimensional (3D) geology of the underlying ground. If the extensive measurements are made on a

regular basis, one can visualize the changes taking place to the 3D structure of the ground (such as depletion of oil from an oil reserve) over time. This representation of changes to the 3D geology over time T is often referred to as a “4D” (ie. 3D + Time) representation.

- The UAV is more environmentally friendly since it:
 - requires less materials to build;
 - uses less fuel per Km travelled;
 - creates less pollution per Km travelled;
 - makes less noise in flight
 - is easier to dispose of at the end of its life

Type 1 aircraft applications

Type 1 applications can be managed by a UAV with a 9 Kg payload capability.

- High resolution 2D and 3D visual imaging

For 3D imaging, one would use five high resolution cameras (one plan view, one each angled towards the north, the east, the south and the west), each weighing around 1.6 Kg = 8 Kg total. One has the imaging produced by the CropCam UAV as an example of the high resolution visual imaging that can be achieved through the use of a small UAV.



The 8 foot wingspan CropCam Unmanned Air Vehicle used to photograph agricultural and forest lands. Images kindly supplied by www.cropcam.com .

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An image of a region in British Columbia, Canada, created by stitching together 160 separate aerial photographs, taken at 2,100 feet altitude, by the CropCam, a small Unmanned Air Vehicle.

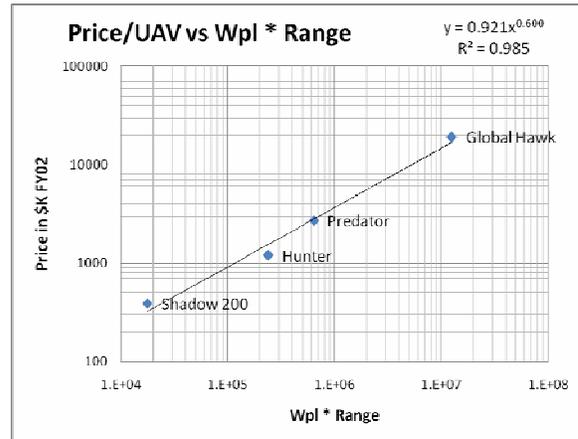
- Scanning LIDAR, used to create a Digital Elevation Map (DEM), where a typical scanning laser system weighs 9 Kg.
- Differential thermal imaging at dawn and at dusk, to detect leakage in underground pipelines using a 320 x 240 pixel thermal imaging microbolometer-based camera, sensitive to wavelengths from 7.5 to 13 um. A typical camera weighs 1.4 Kg.
- Hyperspectral imaging. This involves the breakup of an image into many (for example, 960) narrow band (for example, 2.5 nm) optically filtered images in a wavelength region, typically from 100 nm to 2.3 um. By mathematically combining different filtered images, one can gain information on the probable presence of oil, gas and mineral reserves under the ground. A hyperspectral imager can be constructed through the use of a CCD imager, a near infra-red imager and an infra-red imager. The weight of three such imagers is typically 6.3 Kg, to which one adds around 2.7 Kg for additional optics and electronics, to get an estimated total weight of 9 Kg.
- The Cesium magnetometer provides a very precise measurement of the magnetic field at the location of the magnetometer. A Cesium magnetometer, such as the Scintrex CS-3SI, weighs 0.82 Kg. The direction of the magnetic field can be derived through the use of three small magnetoresistance devices. In order to improve on the accuracy of the calculation of the three dimensional

structure of the materials in the earth, giving rise to the measured magnetic fields, one may need to measure the gradient in the magnetic fields. At least four magnetometers are needed to derive the three dimensional magnetic field gradients, with a total weight of 3.28 Kg.

- Gas sensing, using a quantum cascade laser, to detect minute amounts of ethane and other gases. Total weight estimated to be 9 Kg or less.

Type 2 aircraft applications

Type 2 applications would, at present, best be performed using a manned aircraft. The price of a UAV that would be needed to transport any of the following systems, would greatly exceed the cost of a light aircraft. The reason for this disparity in price results from the contrast between the sharing of the high development costs between a small number of UAVs and the situation in which the development costs for most light aircraft have long been written off and popular light aircraft have been and are produced in large numbers.



One can estimate the price of a UAV to be $0.921 * (\text{Payload_Weight} * \text{Range})^{0.6}$ in \$K FY02 from data for the prices of the existing UAVs shown above. It is clearly important to keep the payload and range to the essential minimum to contain the price of the UAV.

- Gamma ray mapping

Gamma ray mapping is used to monitor the gamma rays from the decay of minute amounts of uranium, thorium and potassium. Knowledge of the relative distributions of each of these three elements is used to understand hydrocarbon micro-seepage. The typical size of a

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sodium iodide crystal is 4"x4"x16" and weighs around 15.4 Kg. If one adds a nominal 2.6 Kg for the photomultiplier tube and the associated electronics and notes that a typical array consists of 14 such crystals, one ends up with a total weight of 252 Kg.

- Gravity field measurements

Gravity field measurements are used to infer the density of the materials under the earth's surface and changes in the materials under the earth's surface, such as the depletion of an oil reservoir. Gravity meters and gravity gradiometers are heavy, almost regardless of type. Typical weights are 450 Kg. Work needs to be done to reduce the weight of a gravity meter from the present typical weight of 450 Kg to 9 Kg or less, to enable the gravity meter to be flown on a small UAV. This miniaturization effort would require three years' work by a small technical team.

- Airborne ElectroMagnetic (AEM) probing

AEM probing is used to map the resistivity of the materials under the earth's surface and is used to locate mineral and oil deposits. An AEM probing system requires a power supply that can generate a 4 millisecond pulsed current of up to 1,000 amps, to drive a 24 m diameter coil. The estimated weight of the electrical pulse generator and the six turn coil, consisting of aluminium tubing, is 250 to 350 Kg.

The range required

A development survey typically covers an area of 400 square kilometers, whereas an exploration survey can cover up to 10,000 square Km. [1]. For a 400 square Km development survey of a region 200 Km from a suitable UAV take-off and landing strip, with a line scan spacing of 200 m. I calculate, from our GeoSurvey planning software, that 2 flights are needed, each flight covering **1,569 line Km** in just under 16.4 hours, for a UAV cruising at 100 Kph.

For an exploration survey covering a 10,000 square Km region 200 Km from a take-off and landing strip, with a line scan spacing of 400 m, I calculate a requirement for 24 flights, each flight covering **1,560 line Km** and lasting 15.7 hours, at a cruising speed of 100 Kph. This allows plenty of time to turn the UAV around for the next flight.

Regarding pipelines, one of the longest oil pipelines in the world is the **1,768 Km** long Baku-Tbilisi-Ceyhan (BTC). In this case, one could locate a UAV base midway along the pipeline and fly the UAVs from the base to each end of the pipeline and back again. The effects of any wind would be

cancelled, since the UAV would fly into the wind in one direction and with the wind in the other direction. Since cameras weigh less than 9 Kg, one could carry some additional fuel, in place of payload.

From the above considerations, I conclude that a UAV with a range of 1,800 Km would be suitable for both geophysical survey and pipeline monitoring work. The range could be extended to 2,100 Km by replacing 2 Kg of payload with a similar weight of extra fuel. From a logistics point of view, having a UAV flying at 100 Kph for 18 to 21 hours per flight, gives sufficient time for a regular aircraft servicing period and take off time each day.

Benefits of the UAV

One expects better quality data from a survey in which many UAVs are used, rather than one UAV, or, one manned aircraft, since:

- The precision flight capability of the UAVs, with their computerized flight control and navigation systems, enables several UAVs to operate in close proximity, if necessary. Because of the precision flight control, one can minimize the overlap of the scan lines, leading to a minimum number of scan lines for a given survey area.
- The use of several UAVs to cover the same area enables an improvement in the accuracy of the data, through the application of data averaging. Using several UAVs means that the results from several measurement systems can be correlated, so that errors and drift in any of the instruments can be identified. The measurement of the earth's magnetic field is best performed quickly, favouring the use of several UAVs, as the magnetic field strength changes from day to day, throughout the world. The gravitational field in a region can also change over time, if the density of the material under the earth changes, for example, as a result of extraction of oil from an oil reserve.
- As previously mentioned, the small UAV introduces less of a disturbance to the magnetic and gravitational fields than the larger manned aircraft, either of which can perform the survey.
- UAVs can fly in total darkness at night, or, at any other time when the sunspot activity and the cultural noise level is at its lowest, enabling measurements to be taken with minimal background noise.
- UAVs can fly very close to the ground ("tight drape"), through the use of precision navigation and computer controlled flight. This low level flying enables higher precision data to be gathered.

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- Since many UAVs can be used, each UAV can fly relatively slowly and the survey can still be completed in less time than it would take a single manned aircraft. The slow flying UAVs can also make use of time averaging of measured data, to improve on the accuracy of the data.
- The use of several UAVs introduces a fault tolerance to the survey. If one UAV experiences problems of any sort, that UAV can be returned to base, allowing the other UAVs to continue and complete the survey.



The AAI Shadow 200 UAV with a payload of 27 Kg, a take-off weight of 170 Kg and an estimated range of 600 Km. Image kindly supplied by www.aaicorp.com.

The outstanding challenges

- Reliability

Because many of the current UAVs are intended for use in military applications, where the need for the UAV has outweighed the lack of reliability, most of the UAVs require improvements to be made to their reliability. One obvious issue is the predominant use of a single engine. One would expect an improved reliability through the use of two low vibration engines, with the UAV being able to fly on one of the two engines.
- Flight in civilian airspace. For a UAV to fly in civilian air space, the UAV must:
 - satisfy national air worthiness criteria if the all-up-weight at takeoff is less than 150 Kg, or, international criteria, if it is larger;

- support a “sense and avoid” capability with respect to other aircraft, equivalent to that of a piloted plane. Sense and avoid systems are currently at an early stage of development;
 - be able to respond to ground-to-air and air-to-air voice communications. For long range UAVs, one needs reliable satellite communications.
- Loss of life, damage to property and reputational damage resulting from a UAV crash

One major concern is the possible loss of life, damage to property and damage to the reputation of an exploration organization caused by the crash of a UAV. This “reputational damage” can lead to the loss of the exploration licence by the exploration company associated with the use of the UAV.

In order to minimize the potential for loss of life associated with a UAV crash, one needs to include safety features in the UAV. One might equip the UAV with air bags that can inflate either on loss of power, or, under operator control. An auto-glide facility, running on a separate power unit, could and should be included to ensure a slow descent, if problems are encountered.

The damage caused by a flying vehicle is related to the kinetic energy of the vehicle: using light, slow flying, UAVs helps to minimize damage associated with a crash.

- Development of a miniature gravity meter weighing 9 Kg or less

Accurate gravity meters, accurate to 2 uGal (the “Gal”, named after Galileo, is a unit of acceleration and 1 Gal = 1 cm/sec²), with a typical precision of 15 uGal/sqrt(Hz), can be used to monitor the depletion of oil and gas reserves, due to the change in the local gravitational field, as the reserve is depleted. One should be able spatially to visualise an existing oil or gas reserve over time from gravity data and identify where the reserve is being depleted and where no depletion is occurring.

The optimal UAV for geophysical applications

The military requires UAVs:

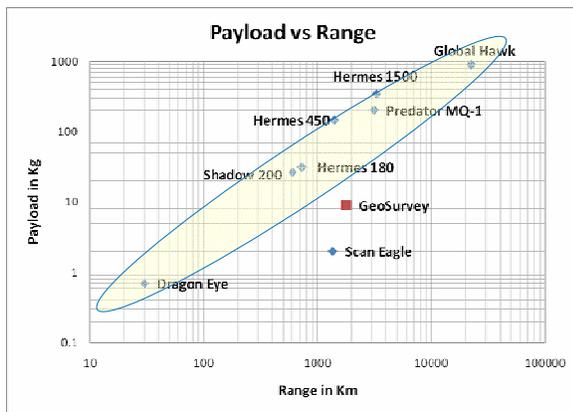
- with long endurance times, to enable them to loiter over an area of interest and watch what is going on below;
- that have stealth characteristics, so that they are not easily seen as they loiter over an area of interest;

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- that are agile, so they can escape any attack that might be mounted against them;
- now, with the hope and expectation that improved reliability will follow with time, usage and the number of vehicles produced.

However, for geophysical survey and pipeline monitoring work, one requires a UAV:

- with a long range, to enable the UAV to cover a large survey area, cost effectively, between refueling;
- with low vibration engines that also have a low magnetic “signature,” so as not to perturb the sensitive measurements being made and to increase the reliability of the UAV;
- that flies on a smooth and well controlled flight path, to minimize the overlap required between scan lines and maximise measurement accuracy;
- with a high reliability from the outset.



On the above chart we have plotted the data points for several military UAVs, all fitting within the oblique oval region. Notice that the Scan Eagle, which is used in magnetic mapping, and the UAV we propose for use in geophysical survey and pipeline monitoring work (referred to as “GeoSurvey”) both lie outside of the oval region.

Since the optimum UAV for use in geophysical survey and pipeline monitoring work has quite different specifications from the UAV developed for military applications and since the market for such a civilian UAV is at present relatively small, it is not surprising that this ideal UAV has yet to appear. These then are the suggested outline

specifications for an “optimal” small UAV, for use in geophysical survey and pipeline monitoring applications:

- Payload = 9 Kg
- Range = 1,800 Km
- The take-off weight should be less than 150 Kg, to minimize crash damage and to keep the aircraft within the national air worthiness certification category. If the take-off weight of the UAV is 150 Kg or more, it needs to satisfy more complex international air worthiness criteria. Using our UAV design software, we estimate the take-off weight for a UAV with a 9 Kg payload and a range of 1,800 Km, to be about 103 Kg.
- Speed from 50 to 150 Km/hour, cruising in the region of 80 to 120 Km/hour. The ability to fly slowly enables time averaging to be used to improve the quality of measurements that are made (for example, in magnetic field strength measurements). The UAV must also be fast enough to cope with strong winds.
- Two low vibration four stroke engines for low vibration levels and acceptable reliability. I estimate from our UAV design software that the capacity of each engine must be at least 80 cc, to enable the UAV to fly on one engine.
- Maximum vibration at the payload < 1 Gal (1 cm/sec²). Preferably, the vibration level should not exceed 10 mGal. The sensitivity of a precision gravity meter is around 2 uGal, hence the need for a very low vibration airborne platform for high accuracy gravity measurements.
- A perturbation of the Earth’s magnetic field in the region of the UAV payload, of less than 20 nT. The Earth’s magnetic field strength is around 48,500 nT and the noise level in a Cesium magnetometer is less than 15 pT/sqrt(Hz).
- Ability to operate in the Arctic region, where temperatures can drop to -40°C and the wings can ice up with serious consequences and in the Sahara, where temperatures can reach more than 50°C and the UAV can encounter abrasive dust storms.
- Ability to fly autonomously, including automatic take-off and landing, with location, system status and progress updates, via a satellite link, to a ground control station.

