Satellite Services for Unmanned Aircraft

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Unmanned Aircraft come in all sizes, although most are for military applications.

From the 12,110 kg Global Hawk on the right...

to the 2.7 kg Dragon Eye shown below.
The Unmanned Aircraft System

The UA flying beyond line-of-sight has an always-on satellite (Intelsat or Iridium) link to a ground station for telemetry and VHF radio relay.

The ground staff must reply to any Air Traffic Control voice communications with the UA so the UA appears to an Air Traffic Controller to be a conventional manned aircraft.
Unmanned Aircraft

Dyke Weatherington, author of the DoD “Unmanned Systems Roadmap 2007 – 2032” summed up the role of military Unmanned Systems as being missions that were “dull, dirty or dangerous”.

In oil, gas and mineral exploration and production activities, there are additional potential roles for UA:

- where they can generate better quality data than manned systems;

- where the operational cost (including insurance) is sufficiently low as to allow flights to gather data on a routine basis.
Unmanned Aircraft have already been used in Exploration & Production activities

Oil pipeline monitoring

Aeronautics Defence Systems provide pipeline monitoring services in Angola to ChevronTexaco under a $4 million contract.

More recently, Aeronautics Defence Systems have provided a similar service in Nigeria.

Problems with use of satellite imagery are:

- “It can take up to 14 days for the LEO satellite to be over the area of interest.”

- “Bandwidth is limited and expensive.”

from UAV Systems The Global Perspective 2005 by Blyenburgh & Co
Aerial photography: the most popular civilian application of Unmanned Aircraft

Aerial photography using CropCam

Image of 160 acres of land in British Columbia, derived from stitching together 12 separate images using the CropCam: from www.cropcam.com
Magnetic field surveys: the next most popular application of Unmanned Aircraft

A survey in which the Earth’s magnetic field is measured using high resolution, lightweight, Caesium beam magnetometers, as shown below.

MagSurvey Prion by Magsurvey Limited, from http://www.magsurvey.co.uk/
Universal Wing surveys completed in 2007 from Princeton, British Columbia

26 MAR 2007 – 10 APR 2007
1,600 line km (Alberta, Canada)

16 APR 2007 – 30 AUG 2007
>20,000 line km (Nunavut, Canada)

20 OCT 2007 – 23 NOV 2007
>6,500 line km (Northwest Territories, Canada)

Quality magnetic field data

Unmanned Aircraft can fly at lower elevations and at slower speeds than manned fixed wing aircraft and can deliver helicopter-like data quality at a fraction of the cost.

We have integrated a lightweight high performance Cesium magnetometer (model G-823A), combined with an ultra-small size CM-201 Larmor counter to provide high sensitivity (0.004nT/\%Hz RMS) and low heading error @ ±0.15nT over 360º equatorial and polar spins. This facilitates high quality data acquisition.

Superior resolution is provided by the Cesium Larmor signal with the Earth’s field tracking rates exceeding thousands of nT over 0.1 second periods.
Whale monitoring trials

ConocoPhillips tested the Scan Eagle Unmanned Aircraft to monitor marine mammals in Puget Sound in November 2006.

Photos on this slide and the next are courtesy Christer Broman at ConocoPhillips.
ConocoPhillips experience...

Arial Photography during Sea trials of Arctic Shuttle Tanker, Dec. 2007
Potential UAS Applications

1. Ice Reconnaissance, Ice Measurements
2. Ice navigation Assistance for Icebreaking Ships
3. Surveys of Icebergs and Floating Ice
4. Surveys of Marine Mammals and Wildlife
5. Security information and Guard Duty
6. Geophysical Surveys for Oil and Gas

From Christer Broman at ConocoPhillips
Potential UAS Applications

7. Inspection of Land based Oil and LNG tanks
8. Inspection of Flares and Flare Nozzles
9. Arial photography
10. Inspection of LNG carrier cargo tanks
11. Surveys and Inspection of Oil and Gas Lines
12. Metrological forecasting

From Christer Broman at ConocoPhillips
The Search part of “Search and rescue”

This is an embryonic activity.

An example is the Australian “Find Outback Joe Competition”

Queensland, Australia

28 September – 1 October 2009

The system must be capable of finding Joe in the Search Area, located near Kingaroy airport. The UAV must fly through a defined corridor of approximately 1 nautical mile (nmi) in length and 0.2nmi in width to the Search Area. The Mission Boundary, allocated for the competition, is approximately 2 x 3nmi. The rural search area for locating Outback Joe will be 0.5nmi within this boundary. If at any time the UAV flies outside the Mission Boundary for the competition, the UAV’s mission will be terminated by the Range Safety Officer (RSO).
Last year’s Team that came closest to winning the “Outback Joe” competition

Simeon O’Neill and Aaron Donaldson came closest to winning the main event, the Search and Rescue open category, taking home $5,000.

The Unmanned Airborne Vehicles Outback Challenge was held at the Kingaroy Airport in Queensland.
Characteristics of Unmanned Aircraft already used in commercial applications

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Max take-off weight</th>
<th>Max payload</th>
<th>Max range</th>
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</thead>
<tbody>
<tr>
<td>Aerostar</td>
<td>210 kg</td>
<td>50 kg</td>
<td>1,550 km</td>
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<tr>
<td>MagSurvey Prion</td>
<td>30 kg</td>
<td></td>
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</tr>
<tr>
<td>Scan Eagle</td>
<td>18 kg</td>
<td>3 kg</td>
<td>1,350 km</td>
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A common theme is the use of relatively lightweight Unmanned Aircraft in commercial applications.
What are the compelling capabilities of Unmanned Aircraft?

UAVs Today

UAV Performance Envelope

Service Ceiling vs. Maximum Endurance (hours)

UAVs can make observations beyond the reach of manned aircraft

Zephyr
Unmanned Aircraft can fly all night, night after night, at low levels (such as 50 feet AGL)...

From a presentation by James Macnae at SEG 2006
Unmanned Aircraft can fly where pilots prefer not to go

As exploration activities move to the more hostile regions of the Earth, such as the Arctic Ocean, and to more politically unstable areas, expect to see a growing use of Unmanned Aircraft operating in areas where it would be irresponsible to expect pilots to fly:

- low level, night flights over the Arctic Ocean;

- flights over regions in which there is low level strife, where the larger manned survey aircraft provide target practice and some excitement for the locals.
Unmanned Aircraft collect higher resolution data

Being smaller and always flying using precision navigation, the Unmanned Aircraft can fly closer to the ground ("tight drape") and collect higher resolution data.

Improved spatial resolution

200m LINE SPACING, 80m HEIGHT

30m LINE SPACING, 20m HEIGHT

Images courtesy Universal Tracking Systems Pty Ltd
The advantages of using Unmanned Aircraft in E & P activities

- Unmanned Aircraft create less of a disturbance to the parameters being measured such as the magnetic, or, gravitational field, since they are physically smaller than their manned counterparts. However, the instruments are closer to sources of electrical noise on the aircraft.

- Unmanned Aircraft can routinely fly missions covering the same area, day after day, night after night, to perform measurements for use in change detection and data averaging:
  - detecting a leak in an oil pipeline using differential thermal and / or interferometric SAR imaging.

- Unmanned Aircraft cost less to operate per line km, since:
  - an Unmanned Aircraft operator can manage several UA at the same time;
  - the Unmanned Aircraft uses less than 20% of the fuel used by a manned aircraft

- Small Unmanned Aircraft are more environmentally friendly since they:
  - require less materials to build and is easier to dispose of at the end of its life;
  - use less fuel and creates less pollution per km travelled;
  - make less noise in flight.
However, Unmanned Aircraft (“UA”) have not yet seen widespread deployment...

- Unmanned Aircraft are not permitted to fly in commercial (“un-segregated”) air space.
- Unmanned Aircraft do not have a protected aeronautical frequency band.
- UA are not sufficiently reliable. Almost all present day Unmanned Aircraft are single engine experimental aircraft which do not have air worthiness certificates.
- UA have not yet clocked up sufficient flight hours to provide data for a convincing safety case, without which the National Aviation Authorities, such as the FAA, the CAA, and the like will not issue of Certificate of Authorization (“COA”) to fly even in restricted air space.
- In the absence of sufficient flight hours, and a legally sound safety case, the insurance costs are astronomical, and blow any business case out of the water. Insurance costs are inversely related to flight hours: $10 million insurance cover cost = $k / n*100K_flight_hours.
- UA do not yet have a **sense and avoid system** to enable them to detect and avoid other airborne objects, such as the farmer flying a Cessna in the Canadian outback...
- Government security services need to be sure the Unmanned Aircraft cannot fall into the hands of, or be used by, or be taken over in flight by, criminals or terrorists.
It will take a few years before we see UA in widespread commercial applications...

- UA systems developers are getting their flight hours and experience in the military sector.
But, it will happen.

- Work on the development of sense and avoid systems is underway in the USA, Europe and in the Far East. The view is that once proven on Unmanned Aircraft, these systems will become mandatory on manned aircraft.

- The World Radio Conference will next meet in 2011, where it is hoped there will be progress on an assignment of a protected aeronautical frequency band for UA use.

- Many of the National Aviation Authorities have assigned staff to develop the regulations for Unmanned Aircraft flight in non-segregated air space:
  - US FAA and RTCA SC-203
  - EUROCONTROL and EuroCAE Working Group 73 on UAVs
  - Australian, Belgian, Canadian, Dutch, Austrian, South African, Swedish and U.K. CAA

- Both the FAA and EUROCONTROL are investigating solutions to the UA security aspects.

- The early uses of Unmanned Aircraft will be in hostile areas where it would be irresponsible to send pilots. Interestingly, this is one of the new frontiers for oil, gas and mineral exploration.

- If experiences in the military area are anything to go by, Unmanned Aircraft will provide copious amounts of high quality data. Developing software to interpret high resolution data will become a high priority and a new market area for scientific and AI software developers.
Suggested attributes of the ideal Unmanned Aircraft for geophysical applications...

It will take about three years to develop and test high performance, Unmanned Aircraft for geophysical applications. **That will take us to circa 2012.** More on this in a later presentation.
Exploration and Production activities take place throughout the world...

From a climate point of view, the Arctic region has some of the most severe weather conditions one could encounter:

- Total darkness (in winter time)
- Temperatures: drop to -40°C
- Spray icing
- Snow and ice

Part of the Trans Alaska Pipeline, from http://www.usgs.gov
In North Africa and in the Middle East, a survey plane could encounter:

- temperatures that reach +50°C during the day;
- abrasive sand storms.

*Satellite photograph of a dust storm showing fine sand from Morocco and Western Sahara (below Morocco) being blown over to Lanzarote and Fuertaventura.*
The instruments used in a geophysical survey can be divided into two groups:

- Those weighing less than 10 kg
- Those weighing more than 100 kg (best suited to manned aircraft at present)

Geometrics G822 airborne Cesium magnetometer

Gravity gradiometer: 350 kg+
Geophysical survey instruments weighing less than 10 kg

- High resolution (24.6 MPixel) digital camera
- 1.55 um InGaAs based near infrared and thermal imaging cameras
- Polarimetric (dual polarization) hyper-spectral imaging system
- Scanning LIDAR or mm RADAR unit for digital elevation mapping (DEM)
- Caesium or Potassium magnetometer for use in magnetic mapping
- Quantum cascade laser for ethane detection
- miniature SAR (such as the ImSAR NanoSAR)

**Ideal Payload = 9 Kg**

Above: the 1 kg NanoSAR from ImSAR, [http://www.imsar.net/](http://www.imsar.net/) has flown on a Scan Eagle
Synthetic Aperture RADAR (SAR) need not be hugely expensive...

BYU = Brigham Young University
ACR = Advanced Ceramics Research

**Figure 10.** Antenna, RF stack and data storage device produced by BYU, operated by CU, flown by ACR

**Figure 17.** The MicroSAR mounted onto the electric Silver Fox UAV prior to launch in Greenland.
Geophysical survey instruments weighing more than 100 kg

- Gravity meter (absolute or gradient): 450 kg + (could be made lighter)
- Gamma ray sensor: ~250 kg (very difficult to make lighter)
- Airborne ElectroMagnetic (AEM) probing: 1,000 amp pulses, 4 mSec long into a 24 m diameter, 6 turn, coil. Difficult to make smaller, or, lighter.

**Fugro Airborne Services AEM aircraft fitted out with a large electromagnetic coil.**
Geophysical survey instruments weighing more than 100 kg

- Gravity meter (absolute or gradient): 450 kg. Work is underway on a lighter, laser based, gravity meter.
- Gamma ray sensor: ~250 kg. This is very difficult (not saying impossible) to make lighter.
- What about Airborne ElectroMagnetic (AEM) probing with 1,000 amp, 4 mSec long pulses into a 24 m diameter, 6 turn, coil? Difficult to make smaller, or, lighter?

Fugro Airborne Services AEM aircraft fitted out with a large electromagnetic coil.
Low level flying enables the use of Unmanned Aircraft in Airborne EM surveys.

A **2 amp current** is passed through the coil wrapped around the relatively small Silver Fox Unmanned Aircraft shown above. The current in the coil is modulated at around **88 kHz**. A sensing coil is towed behind the Unmanned Aircraft and the signals detected by the towed sensor, shown below, enable the **Unmanned Aircraft to detect underground tunnels and buried wires.**
With reference to the above diagram, the magnetic field strength \( B \) at a distance \( Z \) from an \( n \) turn coil is given by the following expression:

\[
B = \frac{n\mu_0 I R^2}{2(R^2 + Z^2)^{1.5}}
\]

One observation is that the field strength decreases with the third power of distance between the coil on the aircraft and the region where the eddy current is induced.
The ideal range for an Unmanned Aircraft engaged in geophysical survey work

A development survey typically covers an area of 20 x 20 = 400 square kilometers:

2 flights x 1,569 line km each.

For a typical exploration survey covering a 100 x 100 = 10,000 square km region:

24 flights x 1,560 line km each

One of the longest oil pipelines in the world is the 1,768 Km long Baku-Tbilisi-Ceyhan (BTC) pipeline managed by a consortium headed by BP:

locate UA base midway along the pipeline: out 884 km and then return

A UA with a range of 1,800 km would be suitable for both geophysical survey and pipeline monitoring work. From a logistics point of view, having a UA flying at 100 kph for 18 hours per flight, gives sufficient time for a regular aircraft servicing period and take-off time each day.

Ideal Range = 1,800 km
Let’s have a look at the communications link situation...

The above arrangement, or more sophisticated and costly variations, can be used for line-of-sight telemetry and video data links.
BLOS in-flight communications requirements if things are going well...

Digitised FIS, Tower and ATC voice at 4,800 bps

STATUS MESSAGE
at 1 message per second = 4,800 bps

BLOCK 0 = 90 Bytes of PAYLOAD status information

BLOCK 1 = 255 Bytes of FEC coded Header + Power + GPS + Warnings + Comms status

BLOCK 2 = 255 Bytes of FEC coded IMU + FCU + Sense and Avoid status

Status Message copied to Black Box flight recorder on Unmanned Aircraft
If a problem (sensor or systems failure, collision detected) is encountered en route, we very quickly require **live video feed** from cameras on the Unmanned Aircraft with a sudden and urgent need for a low latency, high bandwidth, high reliability satellite communications link.
Always remember the legal and insurance issues

Someone is always responsible for the Unmanned Aircraft. (IAI / Belgian Hunter in the Congo).

One might think that the bandwidth requirements can be eased through the use of autonomy. However, if the “autonomous” Unmanned Aircraft crashes and injures or kills someone, or causes damage to property, somebody will be held responsible and could face criminal prosecution.

Typically, the person or organization assuming responsibility for the Unmanned Aircraft need to take out $10 million of liability insurance.

The need for a human-in-the-loop is something robotics technologists are trying to eliminate, but it will take a huge amount of hard evidence, experience and time to convince insurance companies and commercial users of Unmanned Aircraft to offer reasonable insurance fees.

Oil, gas and mineral exploration companies are concerned about the “Reputational Damage” that is likely to occur should an Unmanned Aircraft cause the death of innocent people. The consequences of Reputational Damage can be severe:

- loss of an exploration licence
- rejection of a bid to explore a region
- closure of an ongoing, profitable, activity
Some considerations of a satellite communications link

Legal:

☑ Who assumes responsibility to assure the UA user of the availability of the link?

☑ If a satellite communications link malfunction is established as the cause of an accident, who will assume legal responsibility for the consequences of the accident?

☑ How will usage of the available, protected, bandwidth be policed?

Technical:

☑ A low latency (< 1 second) is required for Air Traffic Control voice relay.

☑ Streaming video signals may be required, for example, in the monitoring of activities of pirates at sea. Each video channel could require a bandwidth of around 4 MHz.

☑ Global coverage is essential for developers to design in usage of a satellite system link.

Commercial:

☑ This solution will, in certain cases, compete with other solutions.
Estimated price for the ideal GeoSurvey UA System = $310,000 FY [02]

9 kg x 1,800 km range = 16,200 kg.km and price = 0.921 * 16,200^{0.6} = $ 310,000.
Caution over Unmanned Aircraft System prices... (UA Systems can be expensive)

The price of an Unmanned Aircraft System that would be needed to transport a payload in excess of 10 kg over a distance of 1,800 km would exceed the cost of a light aircraft.

Reason:
- UA have a high Non Recurring Engineering (“NRE”) expenses.
- The NRE costs of the Cessna are in the past.
- The Cessna is produced in larger quantities on equipment that has been written off.

Navigation instrument equipped Cessna Skylane 182-T

Max payload = 517 kg

Max range = 1,722 km

Price = $349,500

- from www.cessna.com
The military requires Unmanned Aircraft:

- 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;

- that are agile, so they can escape any attack that might be mounted against them;

- now, with the expectation that reliability will improve with time, usage and production.

Barnard Microsystems Unmanned Helicopter used to detect threats to military personnel.  
AAI Shadow 200 Unmanned Aircraft with US Forces in Iraq (photo supplied by AAI Corp).
For geophysical survey + pipeline monitoring, one requires an Unmanned Aircraft:

- with a long range, to enable the Unmanned Aircraft 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 Unmanned Aircraft;

- 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.

*InSitu Scan Eagle Unmanned Aircraft on launcher, from uav_roadmap2005.pdf.*
In conclusion

The Unmanned Aircraft has much to offer in the areas of oil, gas and mineral exploration and pipeline and facility monitoring. This is realized by staff in oil, gas and mineral exploration companies. However, the reliability of the Unmanned Aircraft simply has to be improved.

Unmanned Aircraft need to fly in un-segregated air space before large scale use can be made of this technology. Work is underway at EuroCAE WG-73, the US RTCA SC-203, ASTRAEA and the European Defence Agency and European Space Agency, to name a few organisations, to develop recommendations to enable Unmanned Aircraft to fly in un-segregated air space.

- Increasingly, oil, gas and mineral exploration companies are considering the potential roles of Unmanned Aircraft in Exploration and Production activities.
- A huge amount of experience is being gained in military operations.
- In my view, satellite communication is an essential component of Unmanned Aircraft operation Beyond-Line-of-Sight. In this respect, it is important at an early stage to consider:
  - the detailed legal and insurance aspects of this service
  - the technical aspects, including reliability, latency and bandwidth
  - commercial aspects, since some activities can be performed using manned aviation