Unmanned Air Vehicle
Features, Applications and Technologies

Version 25

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1st November 2006

Barnard Microsystems Limited

Figure 1 = Example of an Unmanned Air Vehicle in flight: the General Atomics Predator RQ-1. REF 1

The aim of this document is:

- to introduce the reader to the advantages of the UAV over manned light aircraft
- to explain the features of a UAV system, including ground control
- to identify technical developments that yet need to be made to enable UAVs to fulfil more of their tremendous potential
- to discuss the wide ranging potential applications for UAVs
- to examine the technologies and capabilities of some typical UAV payloads

Executive Summary

The Unmanned Air Vehicle (UAV) is a **robot plane** containing a flight control computer, precision navigation (GPS and an Inertial Measurement Unit) and flight control electronics, a low vibration engine (such as a Wankel engine), and a payload such as a high resolution camera. The UAV represents a new, cost effective and more environmentally responsible approach to aerial reconnaissance and geophysical survey work. This document discusses the wide-ranging applications of the UAV, **typical attributes** of which are:

	Typical Unmanned Air Vehicle	versus a Cessna Skylane
Payload	1 … 100 Kg	91 Kg
Speed min … max	30 … 150 Kph	91 … 276 Kph
Altitude min … max	20 m … 25 Km	100 m … 5.5 Km
Max flight duration	5 … 40 hours	11.8 hours
Max flight range	150 … 3,000 Km	1,793 Km
Purchase price	typically $ 35,000 for 10 Kg PL	$ 268,750
Operating cost	typically $ 26 / hr for 10 Kg PL	$ 300 / hr
Crash damage	74 Kg → 105 KJ KE for 10 Kg PL	1,243 Kg → 5,145 KJoule KE

Advantages of the UAV over a manned aircraft

- The UAV can fly day-after-day, **night-after-night**, in dangerous weather conditions for up to 30 hours at a time on an **accurate flight path under computer control.**
- Since UAVs can follow a precise flight path, they can fly close to each other to **complete a survey in far less time** than would be required for a manned aircraft.
- An advantage in using several UAVs is that a UAV that develops a fault in any of its systems can be replaced by a back-up UAV, ensuring the assigned task is always **completed on time**. Several UAVs can also measure data in the same locations in a survey to **provide quality data** by removing any instrument drift or errors.
- It can **fly safely at low altitudes**, enabling high resolution aeromagnetic mapping.
- **Network Centric approach** in which data from each UAV in flight updates a server computer in real time, allowing users to view the latest information via the Internet.
- It **costs less** to buy, to fly, to operate, to land, and to dispose of than a piloted plane
- The UAV is more **environmentally friendly**: it is small, uses less fuel, creates less CO_2 and is less noisy: 16 g/km fuel for a UAV vs 152 g/km for a Cessna Skylane.

Civilian UAV applications

Aerial reconnaissance	Security and control	Aerial Reconnaissance
		Aerial Policeman and crowd monitoring
		Aerial traffic and security watch
		Monitor civil engineering sites
		Monitor waterways and shipping
		Oil and gas pipeline watch
	Disaster effects management	Rescue and clear up effort supervision
		Disaster damage estimation
	Countryside and agriculture	Monitor the countryside
		Monitor litter on beaches and in parks
		Monitor agricultural activities
Survey work	Telecommunications	Telecom relay and signal coverage survey
	Oil and gas E+P	Geophysical surveys

Outstanding Technical Challenges in 2005

- demonstrating precision flying in terms of a defined flight path
- achieving high reliability, fail safe systems
- development of:
    - a low vibration engine and a gyro stabilised, modular, payload mounting
    - embedded, effective, “sense and avoid” intelligence
    - a high data rate duplex communication link between the ground and UAVs
    - a Network Centric infrastructure to manage data from UAVs
    - low cost, precision, magnetometer and gradiometer payloads
    - a small, sensitive, ethane monitoring payload
    - automated image data compression algorithms
    - automated data correction, fusion and interpretation software

Now is the time

- There is a global increase in mineral, oil and gas exploration activities, and an associated increase in environmentally unsustainable geophysical aerial surveys.
- There have been rapid advances in autonomous air and land vehicle technology, and high performance components are now readily available
- The introduction of more environmentally sustainable UAVs to replace manned aircraft in aerial reconnaissance and geophysical survey work will serve to reduce both the carbon dioxide emission levels, and the costs of these activities.

Figure 2 = A Shadow 200 Unmanned Air Vehicle, with "pusher" motor. REF 68

- Barnard, Joseph A.
- Introduction to Unmanned Air Vehicles and their applications.
- References (such as **REF 5**) to sources of photographs are located at the back.
- Metric units are used throughout, unless a copied block of text includes Imperial units.

Library Classification:
aerial photography, aviation, geophysical surveys, model planes, robots, robotics technology, sensor systems, Unmanned Air Vehicles (UAV)

First Edition 2005
Second Edition 2006

Acknowledgments

Thanks to the following growing number of people who have contributed suggestions, comments and document reviews:

Alex Bicknell and Dr Sue Wolfe at the Welsh Development Agency, Dr Ed Biegert, Saad Saleh, Tara Shiek, Dirk Smit and Kanglin Wang at Shell Exploration and Production, Malcolm Argyle at Sander Geophysical, Rolf Pedersen at Geotech Limited, Ken Keeler and Richard Partner at Fugro Airborne Survey, Tiaan Le Roux at Anglo American, Louis Palome at Spectrem Air, Dick West at BHP Billiton, Dennis Barnard, Steve Barnard, James Foster, David Hardcastle, David Lowe, Patrick Mosimann, Tony Richards, Dave Solman and Jean Wadsworth.

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Introduction

In its simplest form, the Unmanned Air Vehicle (UAV) is a pilotless plane. It is a small aircraft with an on-board computer or microprocessor together with control, sensor and communication electronics. Any aerial application in which the payload weighs less than an average adult male (say 85 Kgs, although the US military allows a “worst case” soldier weight of 136 Kgs: see REF 80) could be performed **less expensively** and in a **more environmentally friendly way** through the use of an Unmanned Air Vehicle.

UAVs have an historical military presence in the form of the German V1 flying bomb of Second World War vintage, followed by the modern turbine-powered cruise missile, such as the US Tomahawk cruise missile shown below, made by Raytheon. The early civilian UAV has taken the form, in recent years, of the smaller radio controlled aeroplane.

	V1 “Flying Bomb” 1944 – 45 REF 75	Raytheon Tomahawk 1983 - present REF 3	units
Max speed	656	880	Kph
Max payload	850	454	Kg
Max range	330	1,104	Km
Wingspan	5.3	2.67	m

The advantages and numerous potential applications for **multi-purpose UAVs** will lead to their widespread use after the concerns about their deployment have been effectively addressed. The manufacture and deployment of a cost effective family of multi-purpose UAVs, together with the management of the data generated by sensors on the UAV, will create a variety of global business opportunities, for both goods and services.

The inexpensive UAV can criss-cross a region, or repeatedly patrol an area, for up to 30 hours at a time under computer control, day and night, under almost any weather condition, in an environmentally sustainable manner. This makes it a **compelling solution** for all manner of aerial reconnaissance and geophysical survey work.

Figure 3 = Unmanned Air Vehicle used to verify navigation and flight automation algorithms. REF 5

An Unmanned Air Vehicle can range in size from a small plane as shown above, used for test purposes, to the larger NASA ALTUS II plane, shown below (REF 6).

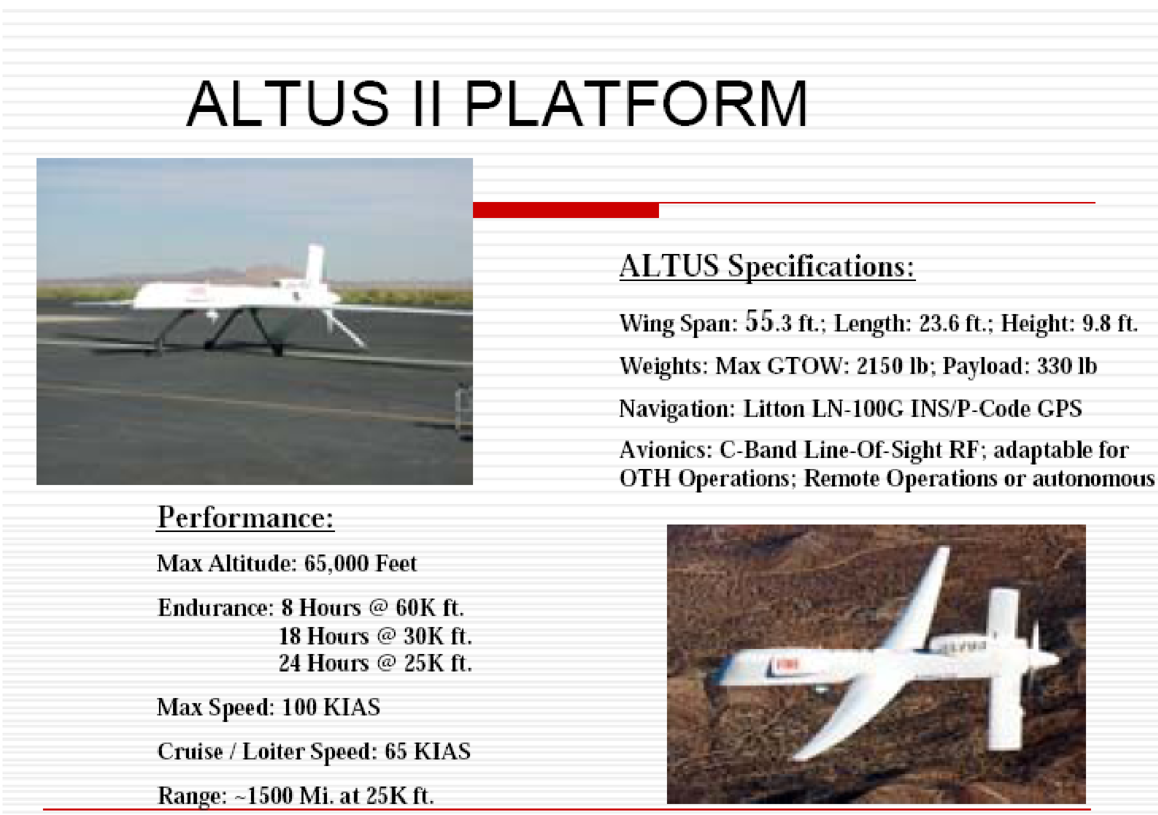


Figure 4 = Example of a modern Unmanned Air Vehicle (Imperial units used here). REF 6

Advantages of Unmanned Air Vehicles

The advantages of using an Unmanned Air Vehicle relative to use of a manned light plane, such as a Cessna Skylane, are that the UAV:

- **<u>does not contain, or need, a qualified pilot</u>**. Excellent! Saves cost and you are not affected by any pilot shortages…

- **<u>can stay in the air for up to 30 hours</u>**, performing a precise, repetitive raster scan of a region, that would drive a pilot to distraction, day-after-day, night-after-night in complete darkness, or, in fog, under computer control:
    - performing a geological survey
    - performing visual or thermal imaging of a region
    - measuring cell phone, radio or TV coverage over any terrain

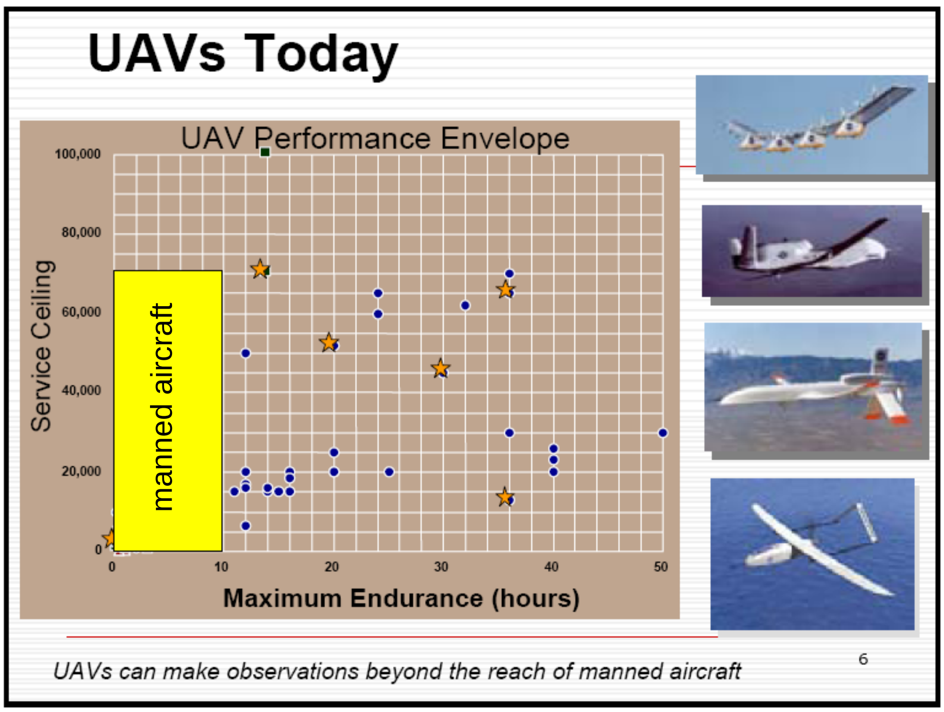


Figure 5 = Note the tremendous flight endurance for Unmanned Air Vehicles. REF 6

- **<u>supports a "fly and loiter" capability</u>** in which the UAV flies to a destination where it then flies slowly in small circles to conserve fuel. The UAV then uses its computer controlled imaging system to maintain a watch on a particular target.

- is **<u>more environmentally friendly</u>** since it:
    - requires less materials to build
    - uses less fuel per kilometre flown
    - creates less pollution (CO_2, for example) per kilometre flown
    - makes less noise in flight
    - is easier to dispose of at the end of its operational life

- **<u>can readily be stored</u>**, in large numbers if need be, and is easily transported

- **<u>can fly in dangerous situations:</u>**
  - over active volcanoes
  - in the vicinity of, or in the eye of, hurricanes and tornadoes
  - in adverse weather conditions, such as fog, heavy rain and thunderstorms
  - through poisonous gas clouds and over regions of high radioactivity
  - in challenging regions of the world: over the arctic, over the Sahara desert…

- **<u>has unique flight capabilities:</u>**
  - can take off, fly and land completely under computer control
  - can very precisely follow a flight path, enabling many UAVs to be used in close proximity without concern for any mid-air collisions
  - can safely fly "low and slow" following ground contours at a height of only 20 m above ground level for high resolution "drape" geomagnetic surveys

- can use **<u>high bandwidth Free Space Optics relay links</u>** between the UAV performing the reconnaissance or survey work and the Ground Control System to enable imagery and measurement data from several UAVs to be downloaded, as it is gathered, to a computer server in a **<u>Network Centric system</u>**. The Network Centric model allows multiple users connected to the Internet to access data from the UAVs as soon as it is automatically processed by fast computers.

Figure 6 = Aerosonde UAV. REF 14

Figure 7 = Cessna Skylane manned light plane. REF 13

$ 35,000 plane + 40 Kg fuel	$ 268,750 plane + 85 Kg pilot + 273 Kg fuel
small: length = 2.02 m, wingspan = 2.88 m	**large:** length = 8.84 m, wingspan = 10.97 m

- **<u>costs less</u>** since:
  - the UAV itself is less expensive to purchase
  - it has lower flight worthiness certificate and insurance costs
  - it is easier to transport from one place to another
  - it has lower operational costs, because:
    - it has lower landing and parking fees at an airport
    - less fuel is used per kilometre flown
    - no pilot's salary needs to be paid
    - it can fly day and night entirely under computer control
  - there is less damage and consequences from any crash (lower insurance):
    - lower property damage in UAV crash due to the lower Kinetic Energy
    - no pilot injury or pilot death in an accident
    - lower chances of civilian injury, or, death in a crash (again, lower K.E.)
  - a lower upkeep, smaller airport, with low quality runway, can be used

Consistent delivery of superior quality data

Civilian Unmanned Air Vehicles typically **deliver raw or processed data** from both Aerial Surveillance and Geophysical Survey work. Compared with manned aircraft, the **UAV is able to consistently deliver superior data quality** since **many UAVs** can be used at the same time, and can work together. UAVs can fly day and night, slowly and safely if need be, at low levels, closely hugging rugged terrain, precisely following a defined flight plan.

attribute	feature	comments
quality of raw data gathered by sensors on the UAV	high data accuracy	❑ **several UAVs** cover the same area to enable identification of instrument errors or drift, with post processing to reduce these inaccuracies ❑ precision flight path, closely following the terrain ❑ very low interference in the magnetic and gravity measurements from the small UAV ❑ low level **night flight** when the disturbances in the Earth's magnetic field are at a minimum
	high data resolution	❑ can use very high resolution ADCs since the small UAV introduces less field perturbations ❑ opto-isolation of sensitive circuits
	low data noise level	❑ use **many UAVs** to cover the same area N times to reduce the noise level by sqrt(N) ❑ fly slowly to increase sensor integration times ❑ use specially designed UAVs with very low payload vibration levels
	high spatial resolution	❑ very low flying (20 m above ground level) ❑ scan separation = flight height, as low as 20 m ❑ use **many UAVs** to create high resolution synthetic aperture receiver
survey time	on-time completion	❑ back-up UAVs used for mission completion, even if some UAVs suffer systems failures
	shorter survey duration	❑ **many UAVs**, flying slowly to get high quality data, complete the survey sooner than a manned aircraft generating lower quality data
aerial surveillance area coverage		❑ comprehensive, persistent, coverage resulting from the deployment of **many UAVs**
real time data		❑ adaptive data rate relay links, with bit rates up to 2.5 Gbps, support real time data downloads

UAV technology will contribute more accurate geophysical survey data

- the potential for low level (20 m above ground) night flying (when disturbances to the earth's magnetic field and cultural noises are typically at their lowest, and there are few civilian flights about) over what could be rugged terrain;

- the slow flying capabilities (down to 40 knots, or so) of the UAV, allowing for data integration and consequent noise reduction;

- the very small perturbation the small, mostly carbon fibre, UAV has on the surrounding magnetic and gravitational fields. The aircraft controls are in magnetically and electromagnetically shielded units, and the units are themselves linked using optical fibre technology;

- the ability to use several UAVs to cover the same survey area, so allowing for noise reduction through data averaging, and the detection of any instrument drift;

- precision, computer controlled navigation and flight control using precision GPS, several Inertial Measurement Units and a responsive flight control system.

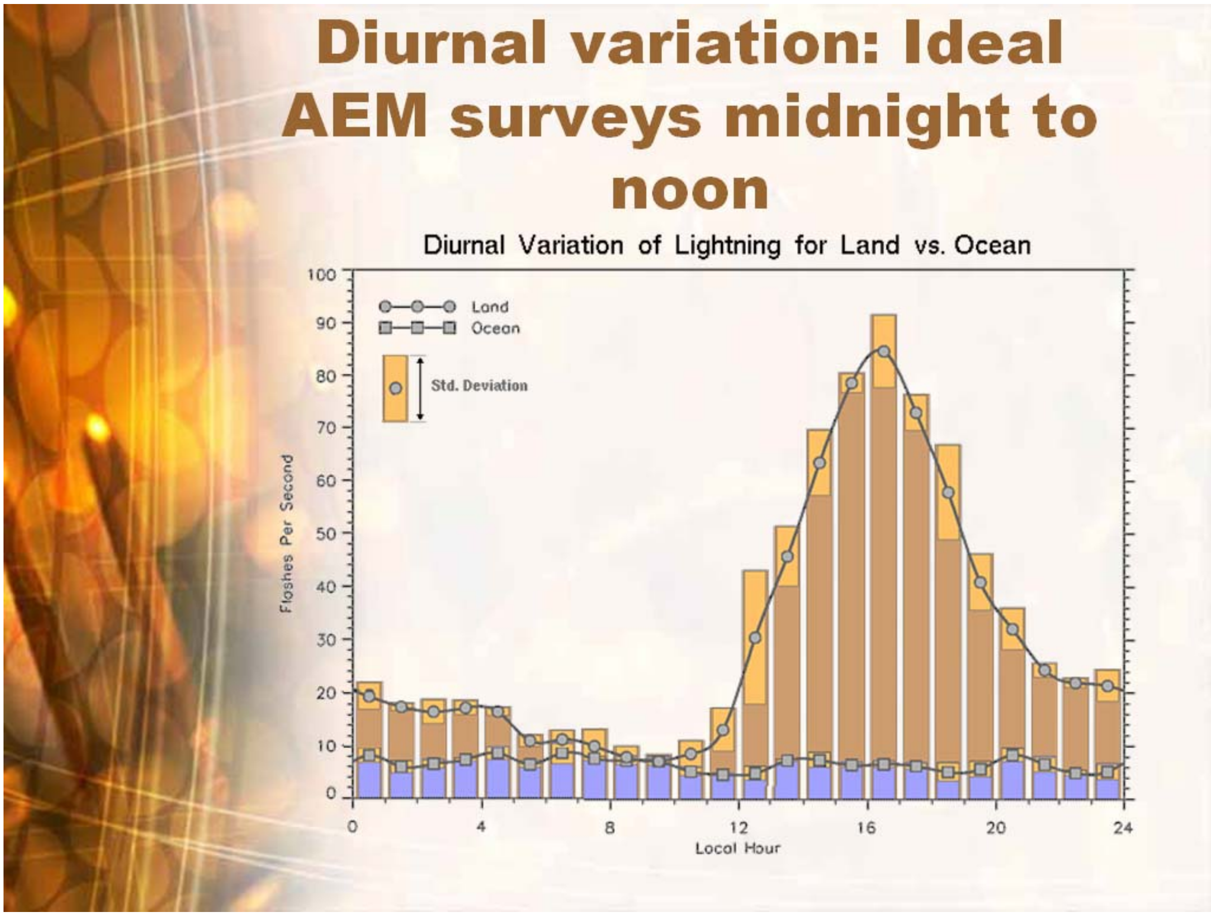


Figure 8 From James Macnae presentation at SEG 2006.

For Airborne ElectroMagnetic (AEM) surveys, the best time to perform the survey is from midnight to noon, ideal time for UAVs, especially at night, when there are few, if any, commercial flights around.

The Unmanned Air Vehicle concept

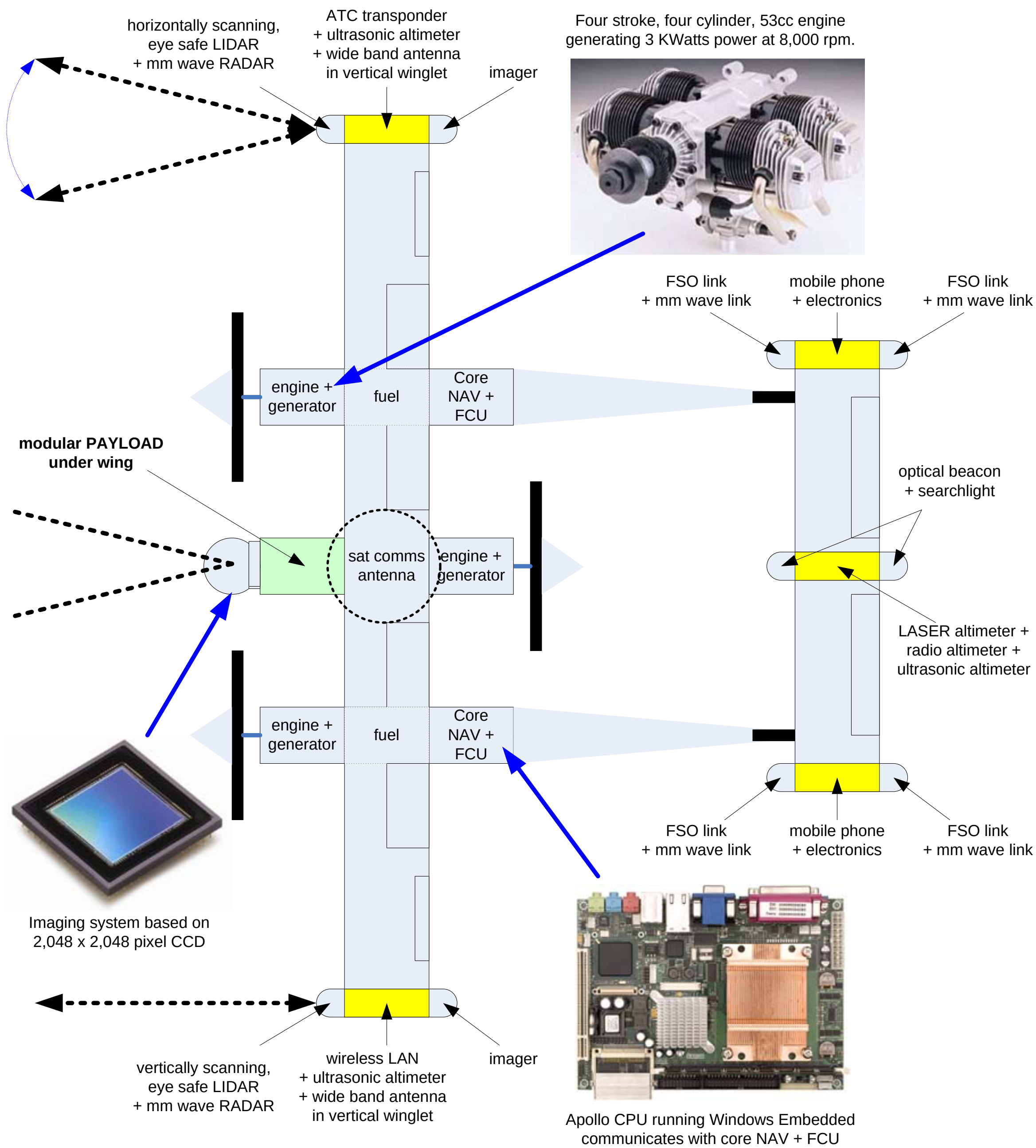


Figure 9 shows the modular payload carried by a three engined Unmanned Air Vehicle

The Unmanned Air Vehicle has a high electronic, communication, sensor and computation systems content, all of which need to operate reliably for up to 30 hours. The two engines with their associated electrical power generators provide some degree of back-up in the event of an engine failure. The successful Unmanned Air Vehicle needs to combine state-of-the-art, miniaturized, low power, navigation sensors, communications electronics and digital flight automation electronics with an efficient, reliable, low vibration engine on a high performance air frame.

Engine = REF7, CCD = REF9, electronics = REF79.

Examples of Unmanned Air Vehicles

AAI Corporation RQ-7 "Shadow 200"

Figure 10 The approximately $300,000 "Shadow 200" UAV from AAI Corporation http://www.globalsecurity.org/intell/systems/images/rq-7_shadow_01.jpg

wingspan	3.89 m		length	3.41 m
payload	27.2 kg		launch weight	149 kg
maximum speed	225 Kph		service ceiling	4,575 m
endurance	> 5 hours		http://www.vectorsite.net/twuav_08.html#m1	

launch scheme — Rocket Assisted Take-Off (RATO) booster or runway takeoff.
recovery scheme — net or runway landing with hook.
payload — day / night imager or other payload.
guidance system — programmable with radio control backup.

Figure 11 The ground control system http://www.shadowtuav.com/groundcontrol.html

Aerovironment Dragon Eye

features	Fully autonomous operation, in-flight reprogramming, small size, lightweight, bungee launched, waypoint navigation, laptop mapping, image capture			
payloads	Interchangeable nose assembly containing dual forward and side looking EO camera (standard and low light level versions) or side looking 640 x 480 pixel infra-red camera			
endurance	45 – 60 minutes on a single use battery			
operating altitude	30 – 300 m above ground level			
launch method	by hand or through the use of a Bungee cord			
recovery method	horizontal skid landing			
comms link	live video link to 10 Km		**range**	5 Km
speed	cruise 35, max 65 Kph		**wing span**	1.1 m
length	0.9 m		**weight**	2.7 Kg

Figure 12 This photo is of the Dragon Eye UAV system at work in Fallujah. Photo by LTC Norm Root

Figure 13 – from http://www.defense-update.com/products/d/dragoneyes.htm

Each $100,000 Dragon Eye unit has three aircraft, a ground control station (radio transmitter/receiver, laptop) and maintenance equipment. Operator's training requires less than a week for soldiers to be able to operate them. The new system currently under development will have a new Level-4 compliant communications control board with 16 software selectable channels for uplink and downlink, twice the current capacity.

Figure 14 - from http://www.strategypage.com/gallery/articles/military_photos_20052111.asp

L-3 Communications BAI Exdrone $ 45,000 to $ 90,000 depending on configuration

BAI Aerosystems has manufactured the Exdrone UAV continuously since the mid 1980's. Since then, technology advancements have enabled BAI to make many product improvements to the system, and the Exdrone's capabilities now rival those of much larger, more costly systems. Hundreds of Exdrones have been manufactured by BAI, making it one of the most produced UAV ever created.

The Exdrone UAV features a symmetrical delta-wing air vehicle moulded from fibreglass-epoxy composite material. This air vehicle design has been studied by NASA, and been proven through hundreds of flight hours, including operational deployment during Operation Desert Storm. Exdrone offers a cost-effective means to perform reconnaissance and surveillance, and has also been used to deploy small sensors and dispenser systems.

The Exdrone is launched from a trailer-mounted pneumatic launcher, and may be either skid-landed on an improved surface, or recovered using an optional parachute system. Total all-up weight is approximately 45.4 Kg, with a cruise speed of 145 Kph. Exdrone has a demonstrated effective range of 80.5 Km with over 2 hour flight endurance.

Exdrone's avionics include, as standard equipment, a ground or in-flight re-programmable GPS autopilot, forward looking navigation and a bell-mounted Pan-Tilt-Zoom color TV camera (equipped with or without Laser Rangefinder) and a 10 Watt Video / Telemetry Transmitter. Flight control functions include manual operation, autonomous flight with manual override, full autonomous flight. A programmable failsafe is also included.

Manufacturer	BAI Aerosystems, Inc	**Date in service**	late 1980’s
Number built	over 500 to date	**Engine**	5.96 KW 2 stroke MOGAS
Wingspan	3 m	**Length**	1.86 m
Wing area	2 m^2	**Weight empty**	20.4 Kg
Max payload	20.86 Kg	**Cruise speed**	145 Kph
Range	80.5 Km	**Endurance**	2 hour

- from http://oea.larc.nasa.gov/PAIS/Partners/BQM_147A.html

InSitu Group ScanEagle A-15

Figure 15 = Notice the absence of a tail fin in this UAV

Weights

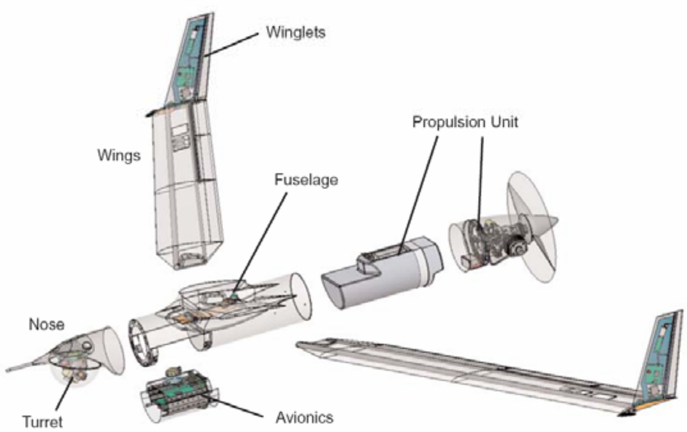
Empty Weight	26.5 lb	12 kg
Fuel and payload	13.2 lb	6 kg
Max Fuel	11.9 lb	5.4 kg
Max takeoff weight	39.7 lb	18 kg

Performance

Max Level Speed	70 knots	36 m/s
Cruise Speed	49 knots	25 m/s
Service Ceiling	16,400 ft	5000 m
Endurance	15 hours	15 hours

Dimensions

Wing Span	10.2 ft	3.1 m
Fuselage Diameter	7.0 in	0.2 m
Length	3.9 ft	1.2 m



Optional Features
(contact Insitu for availability)
· Carburetor Heat
· Ice-phobic Wing Covering

The InSitu Group ScanEagle A-15 – from www.insitugroup.com

Figure 16 ScanEagle: developed by InSitu and deployed by Boeing and InSitu

Network Centric Ground Control System

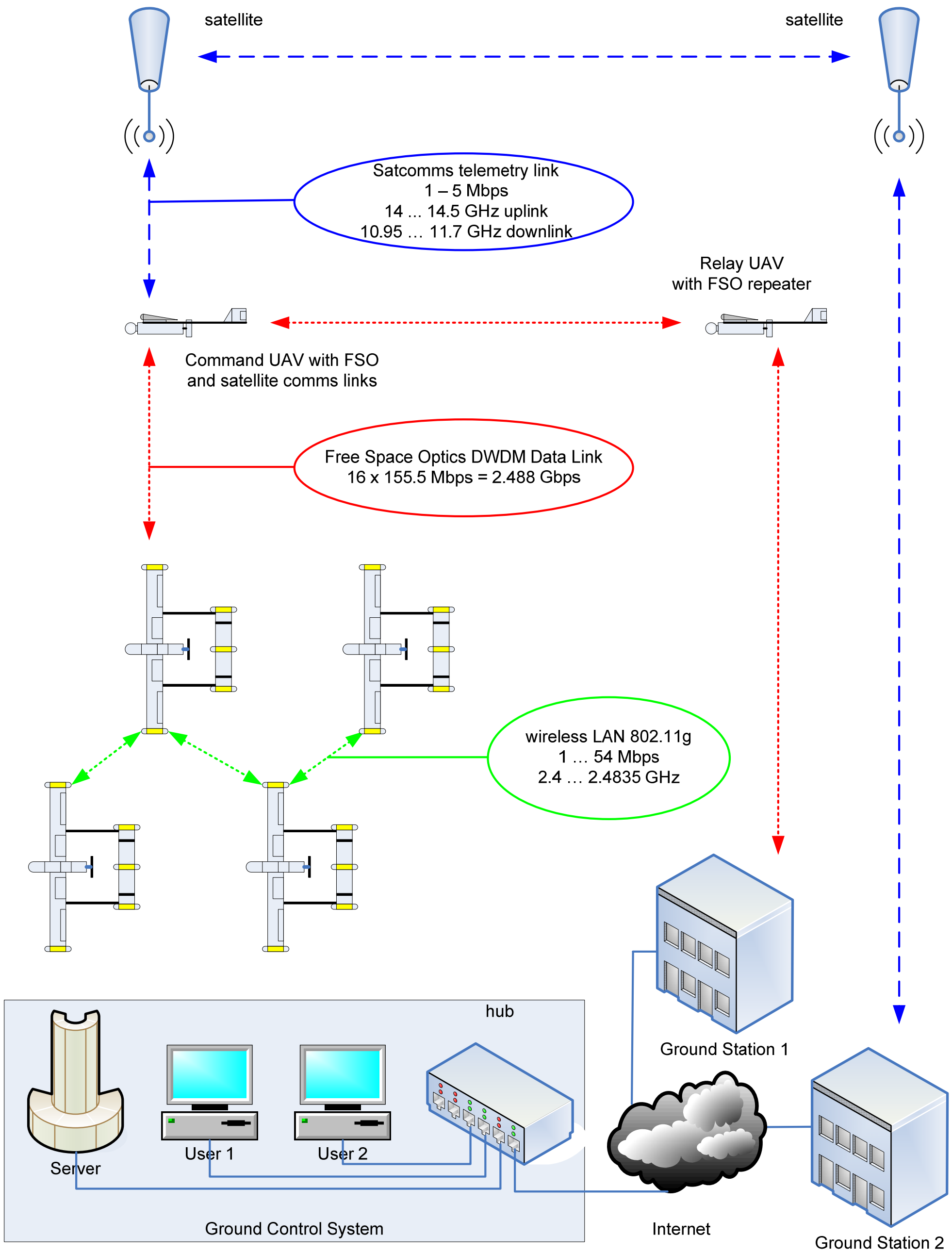


Figure 17 = The communications links between the Network Centric Ground Control and the UAVs

In the Network Centric approach, the swarm of UAVs form a mesh network of flying computers, interconnected through the use of a fast Wireless Local Area Network (WLAN). The high altitude Command UAV contains the WLAN hub, together with a high bandwidth, bi-directional Free Space Optics link and a bi-directional satellite communications link.

The Satellite Ground Station interfaces the signals with the Internet. This approach enables **many users to view the data as it is gathered by the UAVs**, and to direct the operation of the UAV in response to data as it is gathered in an interactive manner.

Figure 18 = Predator UAV Control Centre. REF 64

Above: an example of a military Ground Control System, in this case, for the US Predator military Unmanned Air Vehicle.
Below: staff from Israeli Aircraft Industries (IAI) Malat Division controlling the IAI Heron military Medium Altitude Long Endurance (MALE) Unmanned Air Vehicle.

Figure 19 = Staff at IAI Malat controlling the Heron UAV and viewing sensor information. REF 78

Emergence of autonomous vehicles

Figure 6 compares manned to unmanned funding from 2000 to 2010.[22] The chart reveals that UAVs will make up an increased portion of aircraft funding over the FYDP, growing from 4% in 2000 to 31% in 2010.

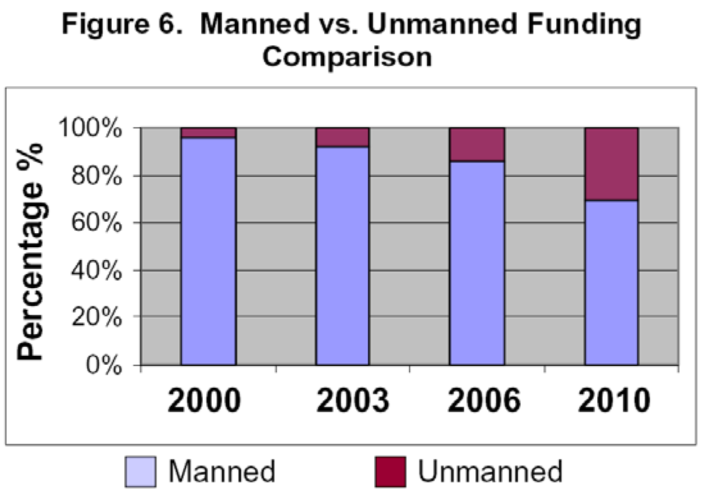


Figure 20 = Illustration of DoD view of the increasing usage of unmanned aircraft. REF 8

There is a widespread and growing effort throughout the world to develop and apply autonomous land and air vehicles, driven in part by the advantages that have been experienced with the use of early prototypes. The advantages have been so important as to cause an increasing amount of both corporate and Government funding to be focussed in this area on the development of vehicles for military and civilian applications.

In the plot below we see the steady increase in helicopters registered for agricultural use, with the majority of them being the Yamaha RMAX unmanned helicopter.

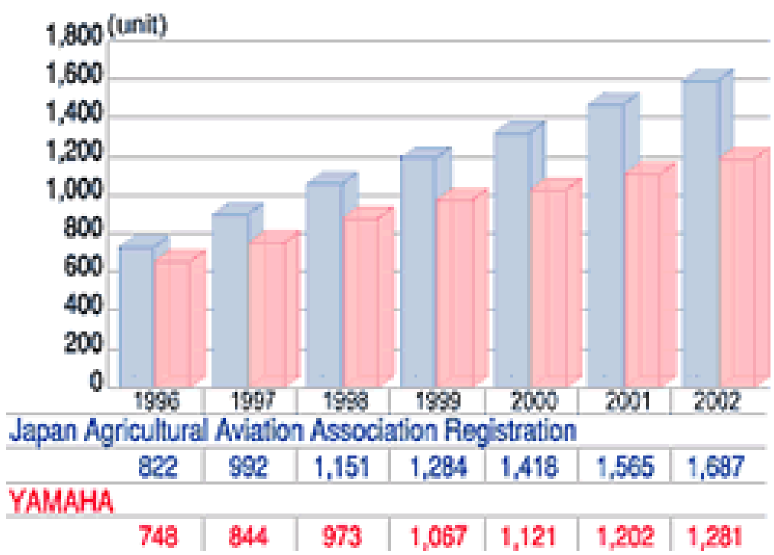


Figure 21 = With the health hazards associated with crop spraying, it is little wonder there is an increased use of unmanned helicopters from all manufacturers to perform this work. REF 32

Figure 22 = Carnegie Mellon University "Red Team" best performing, fully autonomous, vehicle in the DARPA Grand Challenge 2004. REF 69

"DARPA is the central research and development (R&D) agency in the DoD and has pioneered major technology breakthroughs such as the Internet, Stealth aircraft, smart bombs, and the pilotless Predator aircraft. DARPA is funding several robotics technology projects and is sponsoring the DARPA Grand Challenge 2005.

The DARPA Grand Challenge is a Congressionally mandated program that expressly authorizes DARPA to conduct contests and award prizes for advancements in vital technologies. In the 2001 Defense Authorization Act, Congress set a goal that **one-third of operational ground combat vehicles will be unmanned by 2015**."

Because no team won the $ 1 million prize for the DARPA Grand Challenge 2004, the prize for the DARPA Grand Challenge 2005 was increased to $ 2 million. The $ 2 million prize went to the Stanford Racing Team from Stanford University who used an unmanned Volkswagen Taureg Diesel and a collection of roof mounted Sick LIDAR sensing systems.

Figure 23 = $2m to the winner of the DARPA Grand Challenge 2005, 8th October 2005. REF 69

Figure 24 = Grand Challenge 2005 winning <u>unmanned</u> VW Taureg from Stanford Racing Team REF 33

Indications of expenditure on UAVs from REF 8

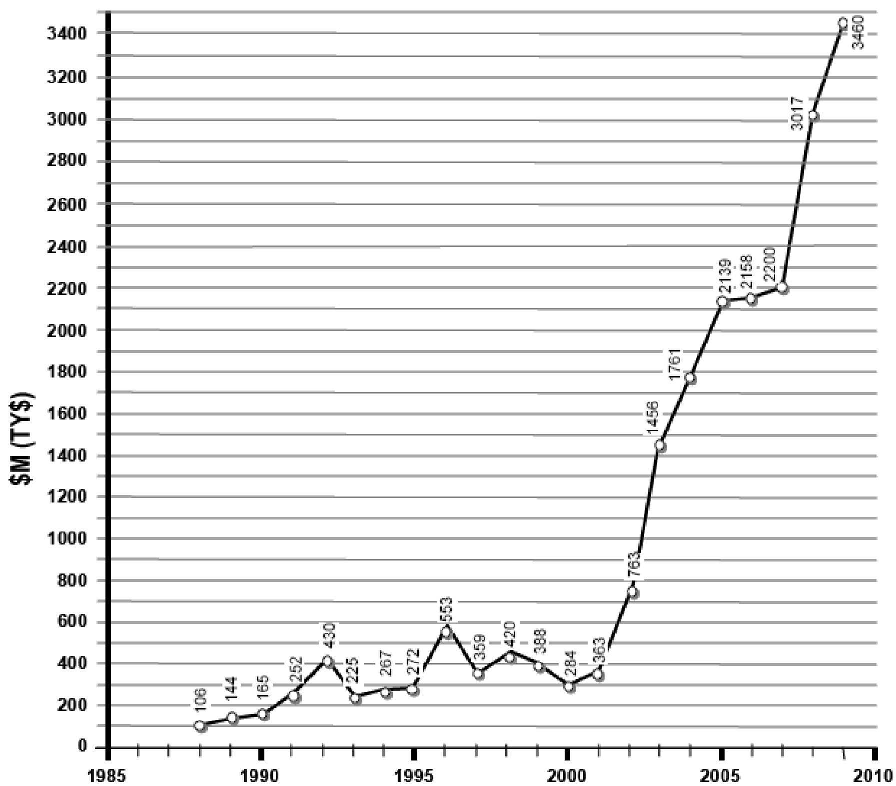


FIGURE 2.4-1: DOD ANNUAL FUNDING PROFILE FOR UAVS.

The above projection suggests a **28.4% year-on-year increase in US DoD spending** from the year 2000 to at least the year 2010. Given this tremendous, albeit planned, expenditure, it makes sense to keep track of developments in the military UAV area, to enable any relevant developments to be applied to UAVs for use in civilian applications.

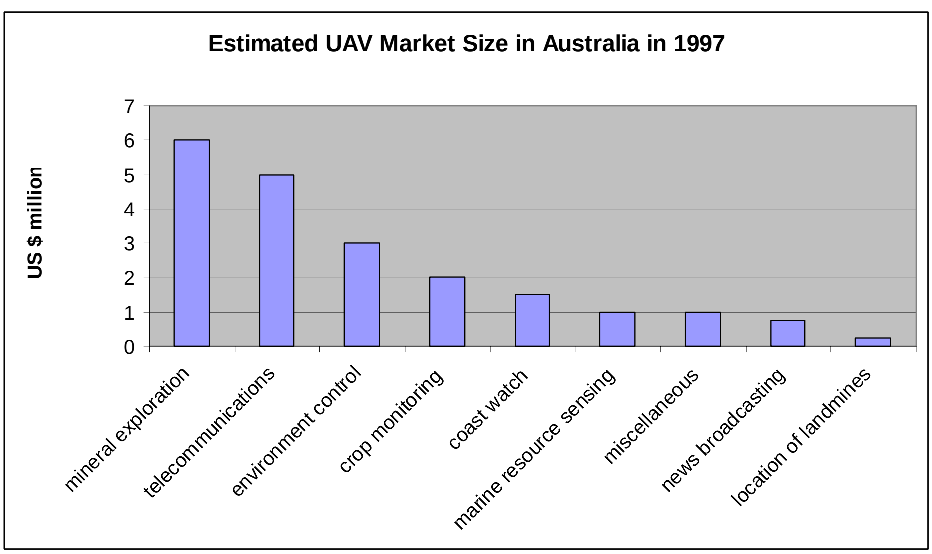
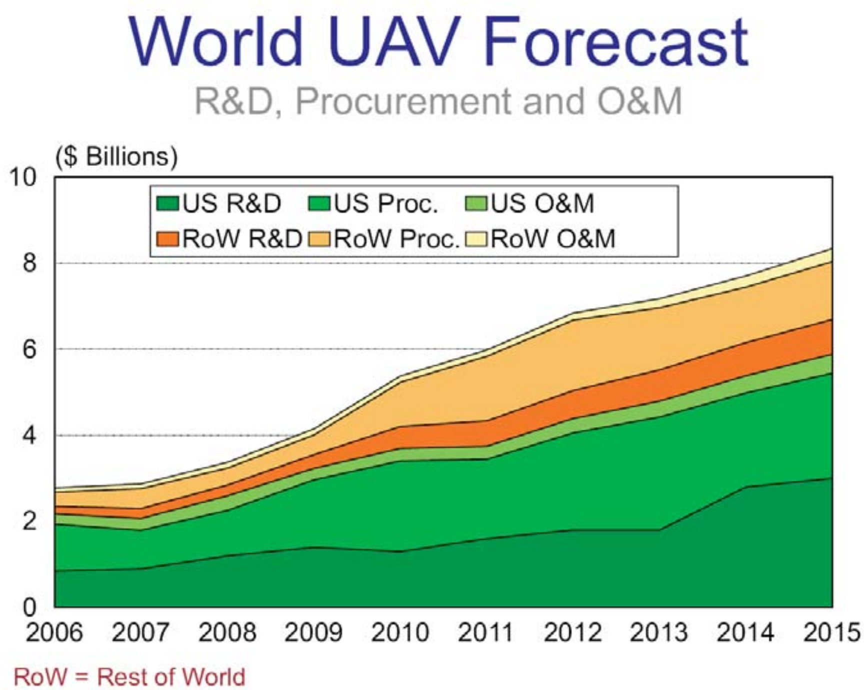


Figure 25 Indications of the Australian UAV market size from REF 8

The Outlook

UAVs are one of the most dynamic growth sectors of the aerospace industry. This Teal Group market study estimates that the market will more than triple over the next decade from current worldwide UAV expenditures of about $2.7 billion to $8.3 billion within a decade.



The most significant catalyst to this market has been the enormous growth of interest in UAVs by the US military, tied to the general trend towards information warfare and net-centric systems. UAVs are a key element in the intelligence, surveillance, and reconnaissance (ISR) portion of this revolution, and they are expanding into other missions as well with the advent of hunter-killer UAVs. This study suggests that the US will account for 77% of the RDT&E spending on UAV technology over the next decade, and about 64% of the procurement. These represent higher shares of the market than for defense spending in general, with the US accounting for about 67% of total worldwide defense RDT&E spending and 37% or procurement spending according to Teal Group International Defense Briefing forecasts. These discrepancies are due to the heavier US investment in cutting-edge technologies, and the marked lag-time in such research and procurement elsewhere, especially major aerospace centers such as Europe. This follows trends in other cutting-edge technologies observed over the past decade by Teal Group analysts in such areas as precision guided weapons, information and sensor technology, and military application of space systems.

Teal Group expects that the sales of UAVs will follow recent patterns of high-tech arms procurement worldwide, with Europe representing the second largest market and the second most significant center for high-tech research, about 20% of the worldwide total. The Asia-Pacific region is expected to be the principal market for UAVs outside the US and Europe, followed by the Mid-East. As in the case of many cutting edge aerospace products, Africa and Latin America are expected to be very modest markets for UAVs. A civil market for UAVs has yet to emerge in no small measure due to the lack of access to national airspace until suitable UAV standards and practices have been created. Teal Group expects that a civil UAV market will slowly emerge over the next decade, starting first with government organizations requiring surveillance systems similar to military UAVs such as coast guards, border patrol organizations and similar national security organizations. A commercial, non-governmental UAV market is unlikely to emerge except in some niche markets such as Japan until the airspace access issue is fully resolved.

Common concerns and technology challenges

The real concerns discussed next, many of which are in the process of being sorted out, have impeded the introduction and application of Unmanned Air Vehicles throughout the world. Fortunately, governments and regional bodies have become aware of the situation, and are establishing UAV Test Centres for use in the testing and certification of UAVs. In the next few pages, we cover the progress in resolving each of these items in more detail.

Item	Concerns
Safety: see page 28.	No pilot in the UAV: what happens if the UAV experiences technical problems, such as: ❑ loss of communications link ❑ loss of engine and / or electrical power How is the UAV certified as air worthy? How can a UAV avoid an impending mid-air collision?
Reliability: see page 32.	As a rule of thumb, reliability is related to the cost of the aircraft. The UAV is less expensive than a manned aircraft, so it may be less reliable. The consequences of an unreliable UAV are: ❑ potential for a crash, possibly injuring people, creating damage to property, or causing a road accident ❑ waste of time and money recovering the failed UAV ❑ the more unreliable the UAV, the greater the number of spare planes required, impacting the financial advantage
Environmental impact: see page 34.	How does the environmental impact of the UAV compare with that of the manned alternative in terms of fuel usage and noise levels? If the UAV is so inexpensive, there may be so many as to cause an environmental nuisance…
Potential use by terrorists or criminals: see page 38.	How can the use of UAVs by either terrorists or criminals be prevented? After all, on the 8th November 2004, Hezbollah flew a UAV from Lebanon over Israel…
Integration in Air Traffic Control Systems: see page 39.	How can UAVs be integrated in established commercial and military Air Traffic Control Systems? The Control Tower could not give flight instructions to the non-existent pilot in a UAV.
Flight automation: see page 40.	Can the operation of the UAV be de-skilled, since the pilot is no longer required? In fact, could the UAV take off, flight and landing be managed entirely by computer (ie. automated flight), leaving the only human intervention the servicing of the UAV?
Endurance: see page 42.	How long can a UAV remain airborne? Model planes only seem to manage ten to fifteen minutes…

Technical challenges

The following non-trivial technical challenges require the application of advanced, miniature, electronics technology, sophisticated software algorithms, and a huge amount of testing to verify the reliability of the solution. This work requires a close collaboration between the end users and a UAV company with the right expertise.

Aircraft

- Achieving a very high operational reliability, especially in the engine and airframe
- Development of fail-safe systems to guarantee high safety confidence levels, in the event of aircraft failure, or, the loss of all communications with the UAV.
- Demonstration of precision flying in terms of altitude and flight path over extended periods of time, in all weather conditions, both day and night.
- Development of low vibration engine and a gyro-stabilised platform technology for high resolution imaging and accurate measurements of gravitational field strength

Communications

- Development of a Network Centric infrastructure to enable any member of a team to control the UAV, and retrieve imagery and sensor information, in real time.
- Development of a lower data rate mm wave link to compliment the FSO, to be used in adverse weather conditions when it is not possible to support a FSO link. FSO and mm wave communication link re-establishment after link connection loss

Sensor modules

- In general, the cost of high performance sensor modules, such as Cesium beam based magnetometers, must come down for their use in a fleet of UAVs
- Development of a lighter, cost effective, reliable, compact absolute gravity measuring instrument (“gravimeter”) and / or relative gravitational field strength meter (“gradiometer”). Current gravity gradiometers weight typically 450+ Kg…
- Development of an air vehicle sense and avoid system to enable the UAV to become aware of its environment, enabling it to take evasive action if necessary.

Software

- Embedded “sense and avoid” intelligence, coupled with vectored engine thrust for enhanced manoeuvrability, small dry propellant rocket assisted emergency acceleration and fast acting air brakes to realise an effective ability to minimise the possibility of a mid-air collision with any other aircraft.
- Development of automated image data compression algorithms, stitching of aerial imagery, data fusion software to intelligently fuse many pieces of information from many sensors, and subsequent automated, computer based, interpretation of data.

UAV air worthiness certification: the first steps…

On a wing and a prayer: Rhodri Morgan hopes the Cardigan Bay testing centre for drones – like this Predator aircraft – will put Wales at the heart of the industry Getty

Unmanned-aircraft centre seeks happy landing

By James Boxell

The biggest public display in Britain of unmanned aircraft was held yesterday to help launch a plan to transform Cardigan Bay in Wales into a leading international centre for drone technology.

The display at Parc Aberporth included the first flight of a large military drone in the country.

The Parc Aberporth centre opened three weeks ago to provide testing facilities for unmanned aircraft as a site for research and development into the technology.

The Welsh assembly and the European Union have spent £8.6m on the centre, another £7.5m coming from the public and private sectors.

Rhodri Morgan, the Welsh first minister, said he hoped the site would put Wales at the "heart of the sector".

Unmanned drones have so far been developed primarily for military purposes, but the Welsh Development Agency wants Parc Aberporth to become a world leader in developing the technology for civilian use.

The agency signed a deal yesterday with Boeing of the US and Qinetiq, the UK defence group, to research the use of drones for monitoring the environment, farmland and fisheries.

The companies have joined forces with the Institute of Grassland and Environmental Research to test drones that could use sensors to help farmers manage crops or check for droughts.

Parc Aberporth aims to create 230 jobs in the next three years, though John Hayn, the international programme manager for Boeing's unmanned systems, said: "This is not really just about creating 100 or 200 jobs. It's to see if we can create an industry here."

Civilian use of drones is still extremely rare, although costs are coming down as newer systems become more autonomous and cut down on the need for human intervention.

Some drones are about to enter commercial use in North America in the fishing and mining industries, Mr Hayn said. They are being tested for meteorological surveys and fighting forest fires in the US and Canada.

Sue Wolfe, project manager for the Parc Aberporth drone team, said defence companies had been able to test drones before in the UK. "But at the moment there isn't anywhere that people looking to develop civil activities can do the same."

The Civil Aviation Authority has looked at test plans for unmanned aircraft on a case-by-case basis but Cardigan Bay provided an area of segregated airspace for continued testing. The WDA, Boeing and Qinetiq teams expect to spend about £1m a year on their five-year test and development plan.

Figure 26= The Financial Times, 8th September, 2005

Parc Aberporth UAV centre adjacent to West Wales airport, with Cardigan Bay in the background, from Parc Aberporth UAV Centre brochure.

Stimulating the UAV Systems Market

By André Clot, Director European UAV Systems Centre

André Clot

The UAV Systems Market is not a market that is capable of self generation but requires close co-operation between government and industry. ParcAberporth in West Wales has seen the emergence of significant practical developments based on the recognition that the United Kingdom has one of the most forward looking and innovative government and industry teams in Europe, if not the world. It also helps that there is an existing flight test range, an airport and a technology park located in an area that has had UAV operational experience spanning 40 years and hence a valuable local skills base.

However taking advantage of this still requires vision and boldness in today's uncertain world. The European UAV Systems Centre (EuroUSC) at ParcAberporth is one of those organisations

From the Parc Aberporth UAV Centre brochure.

UAV test range set up

Finnish company Robonic has unveiled plans for an unmanned air vehicle test range at Kemijarvi in the country's far north.

The range will initially be allocated 1,000-1,500km^2 (390-580 miles^2) of airspace, making it one of the largest facilities of its kind in Europe.

An existing airstrip at Kemijarvi with a 1,200m-long (3,900ft) runway will be used to provide the basic range infrastructure when it opens early next year. "We will be able to have the first test flights in the spring of 2006," says Robonic managing director Juha Moisio. Kemijarvi is inside the Arctic Circle, but remains open all year, he says.

The range will be offered for both civil and military UAV operations and may later include a UAV pilot training service.

Unveiling the range project at the Unmanned Systems International conference in London last week, Moisio said the private sector development reflects the rapid growth of the UAV sector internationally.

"UAVs are shifting into the mainstream as one of the powerhouse segments of the global aerospace and defence industries," he said. "This new range will provide a dedicated UAV test and training facility that can support year-round operations in an extremely wide range of climate conditions.

Figure 27 = Peter La Franch from Flight International, 13-19 September, 2005

Safety features

safety is the top priority

- The UAV must conform to national standards, such as CAA CAP 658 and CAP 722.

- **<u>Assume the UAV will at some time collide with a plane:</u>** the UAV must be made of readily destructible material, no harder than aluminium (in the engine) so that very little, if any, damage is done to the plane.

- The operating principle is “sense and avoid”:
  - use sensors to detect fixed and moving obstacles in front of the UAV:
    - 77 GHz automotive type collision avoidance mm wave RADAR
    - scanning laser based LIDAR
    - “distance aware” stereo imaging
  - the collision detection computer must fuse data from the above sensors and issue instructions to the flight control computer to avoid a collision.

- UAVs must be visible to both RADAR and the naked eye:
  - use corner cubes at wing tips and an aviation Mode A or C Transponder
  - use high power LEDs in the wing tips to increase visibility at night

- Accident prevention features:
  - emergency landing sites must be designated ab initio in the flight plan
  - UAVs to fly in pairs, so one UAV can “nurse” a faulty UAV back to base,
  - the UAV must support rain level detection, so it can return to base if need be
  - the UAV must be able to restart an engine in flight (eg. use compressed air)
  - make use of in-built airbags, “armed” once the UAV is in the air
  - aircraft operating parameters must always be monitored to enable the identification of any impending failure
  - a regular maintenance schedule must be strictly adhered to
  - use multiple electrical power supplies and multiple communications links

- On failure **<u>of all communications links</u>**, for example, due to sunspot activity, the plane flies to nearest known base using GPS + IMU, or just IMU, based navigation

Sunspots mayhem

A STORM on the surface of the Sun is threatening to disrupt communication networks. The storm could cause radio stations to go down and produce electricity blackouts. It is also expected to disrupt satellites, making it impossible for sailors and pilots to navigate. The storm is being caused by a giant sunspot (pictured) which throws out powerful flares that can damage satellites. 14SEP05

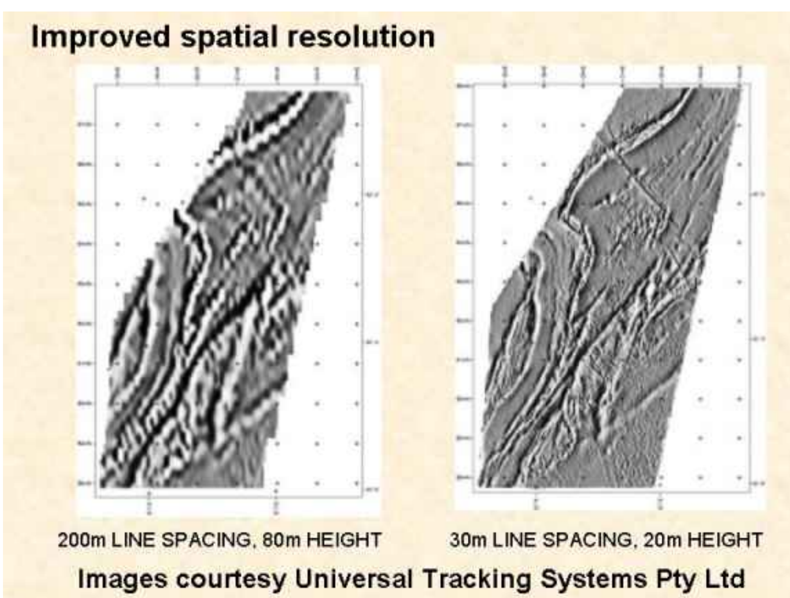
- If plane suffers from engine failure, or major power blackout, then:
  - dump fuel as necessary to reduce weight and the risk of fire on crashing
  - deploy air brakes to slow the descent of the UAV
  - parachute or airbag(s) deployed to bring plane slowly to soft landing
  - activate Emergency Locator Transmitter radio beacon to enable search planes with Radio Direction Finding equipment to locate the downed UAV
  - glide to a pre-defined emergency landing site

Fatal Survey Accidents Since 1977

Date	Aircraft	Location	Fatalities	Principal Findings
23-Oct-77	DC-3	Iran	3	CFIT while maneuvering at low altitude
21-Jul-85	Piper PA-31 Navajo	Canada	3	CFIT as a result of navigation error
02-Aug-88	CASA C212	Iceland	2	Lost control after right propeller failed
25-Jul-90	Aero Commander	Sweden	2	Wing Failure
21-Jun-91	Cessna 404	S. Africa	2	Unable to maintain altitude after engine failure
28-May-94	Cessna 320E	U.S	2	CIFT While maneuvering at low altitude
06-Jul-94	Cessna U206G	Australia	1	Engine failed and did not restart after changing
09-Nov-94	Aero Commander	Australia	2	Improper fuel management
19-Nov-94	Piper Navajo 1	Indonesia	2	Aircraft not found
18-Dec-94	Cessna 404	Namibia	2	Improper technique for terrain clearance
09-Mar-96	Twin Otter	Peru	3	Aircraft not found
10-May-96	Cessna 404	Peru	4	Aircraft not found
18-Oct-96	Cessna 404	Peru	3	CFIT for unknown reasons
17-Feb-97	AS-315B LAMA	Argentina	1	Operated without oxygen above 14,000 ft.
14-Apr-97	Cessna Caravan	Cambodia	2	CFIT gross navigational error
30-Sep-97	Cessna 210N	Australia	2	Loss control while attempting to avoid terrain
30-Sep-97	Kania Twin	Czech Rep	2	Flew into poor visibility
02-Feb-98	AS-315B LAMA	Indonesia	2	Hit power lines
06-Mar-98	Piper Navajo	Indonesia	3	Under investigation
12-Nov-99	SA315B Lama	Peru	2	Under Investigation
11-Jan-01	Islander	Brazil	3	Under Investigation
21	Crashes		48	Fatalities

Many accidents and fatalities occur during manned airborne geophysical surveys that are related to flying just above ground level. As can be seen from the images below, the resolution of an aeromagnetic survey improves with **decreasing** height, so it is very important for some geophysical survey work to fly just (such as 30 m) above ground level.

- both upper chart and lower images from www.geoexplo.com



Collision Sense and Avoid

Collision "Sense and Avoid" capabilities are an essential feature of an Unmanned Air Vehicle if it is to operate in commercial air space. Such a system must:

- be able to sense other flying objects, from hot air balloons to jet fighter planes, in 360 degrees, since a fast flying jet may collide with the slower flying UAV from any angle;

- consist of:
  - a primary, rotating RADAR antenna, typically operating at very high frequencies in the millimetre wave (30 to 100 GHz) band to enable a small antenna to be used (antenna size is proportional to operating wavelength: the higher the operating frequency, the smaller the wavelength);

  - a secondary, millimetre wave, RADAR system coupled with a high resolution CCD based imaging system to follow the closest target to calculate the target trajectory to enable the UAV to work out the best avoidance strategy…

- be capable of operating in diverse environments:
  - cloud
  - rain
  - day and night
  - desert sandstorms
  - over a temperature range from -40ºC (Arctic conditions) to 40ºC (Sahara)

Roke Manor Research Miniature RADAR Altimeter Mk 6			from www.roke.co.uk
parameter	microwave section	mm wave section	units
operating frequency	4.3	76 - 77	GHz
operating altitude	1.5 … 700	0.2 … 100	m
altitude accurate to	12.5	2	cm

Figure 28 Roke Manor Research MRA Mk6 Altimeter that can also be used to detect other aircraft.

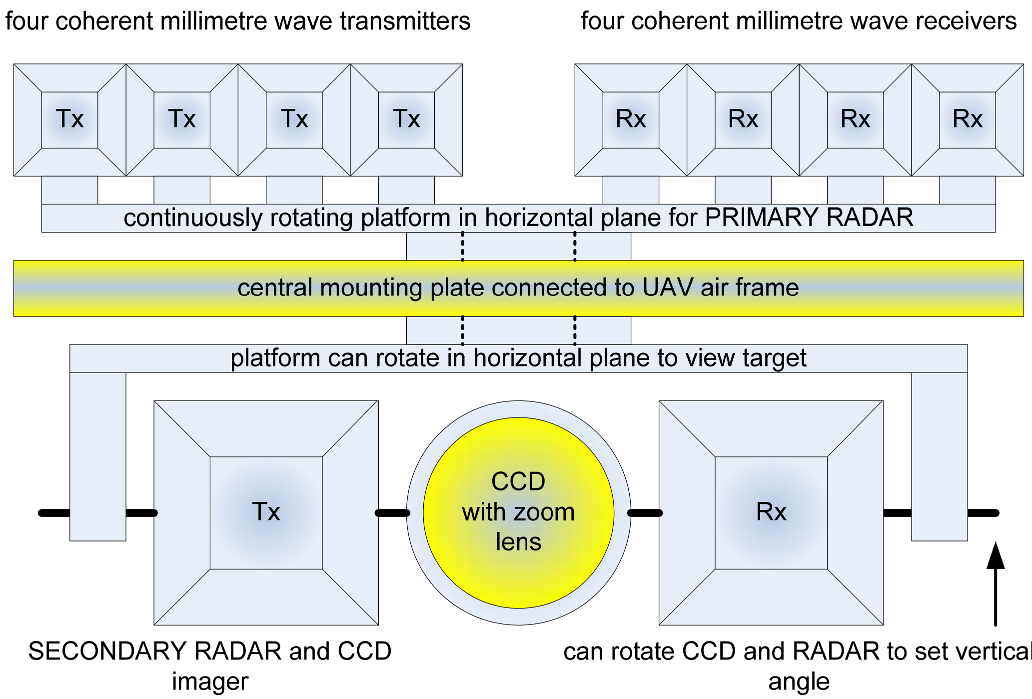


Figure 29 Example of a Sense and Avoid system

This is an example of a collision detection system based on the use of millimetre wave primary and secondary RADAR systems, coupled with a high resolution CCD imager with a zoom lens to accurately locate an oncoming air vehicle identified by the primary RADAR.

Below, one can see an example of a way in which a Collision Sense and Avoid radome mounted system can be implemented on a UAV, in this case, on a Northrop Grumman / IAI Hunter RQ-5A.

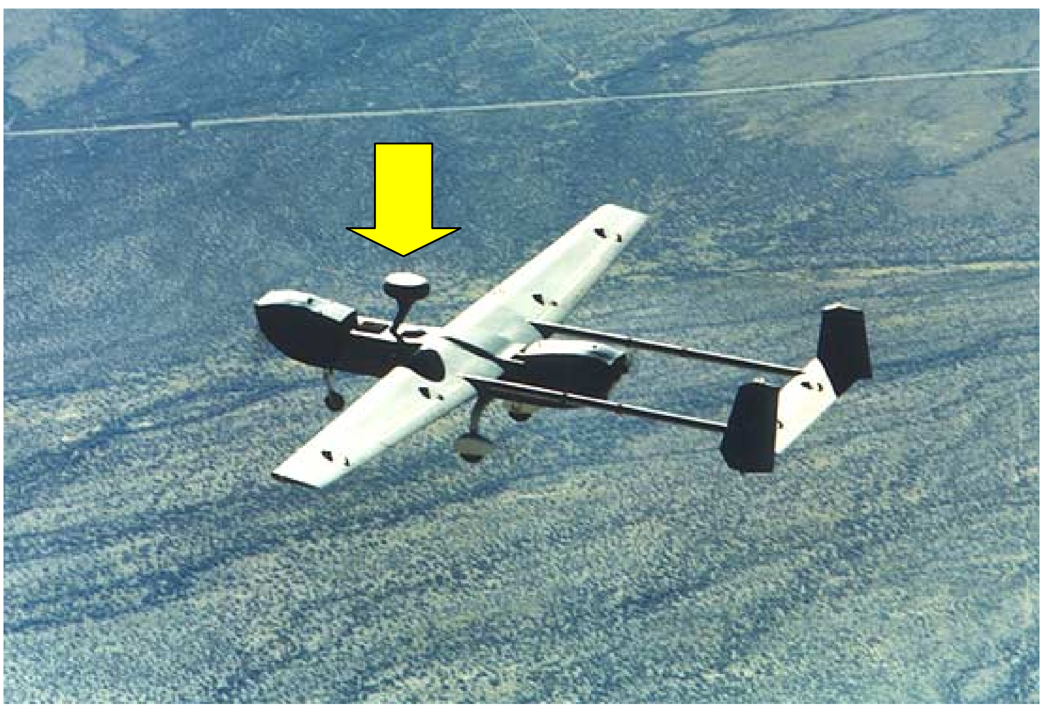


Figure 30 The Hunter RQ-5A Tactical Unmanned Air Vehicle in service with the US Army.
http://www.army-technology.com/projects/hunter/hunter1.html

Reliability

Approach

- Prototypes to be operated under Harsh Environment Test conditions, to encourage any design weaknesses to manifest themselves at an early stage.
- Detailed and ongoing in-flight tests need to be instituted, accumulating many hours of flight time, to identify failure modes and guide preventative maintenance.
- In a mission, several UAVs need to be used to ensure there is always a back up should any UAV experience any problems and need to return to base.

Design considerations

- Adopt a modular design approach in which aircraft modules (engine, fuel tank, wing, navigation and flight control modules) and payloads can be easily be changed.
- Design the engine unit to contribute minimal stresses to the airframe.
- The UAV should have multiple, optically isolated, engines, control surfaces and electronics to ensure backup should any system fail in flight.

One dead in DRC plane crash **REF 83**
05 OCT 2006 19:20 - (SA)

Figure 31 = REF 82: IAI / Belgian Hunter Consortium B-Hunter UAV

Kinshasa - A Belgian unmanned aircraft (UAV) crashed in Kinshasa when its forward and rear engines cut out for unknown reasons just after taking off, said an officer from the European Union force (Eufor) in the Democratic Republic of Congo (DRC) on Thursday.

One person was killed and three are suffering from burns after the UAV burst into flames when it hit the ground, according to the latest report by Eufor. The unmanned, remote-controlled aircraft equipped with cameras fell on Boulevard Triomphal, near Kinshasa's main stadium about one kilometre from the Ndolo air base where Eufor headquarters are.

"The aircraft had just taken off when its two engines cut out. Belgian Lieutenant-Colonel Yves Vermeer, the head of the Eufor UAV unit said: "It continued to rise, then glided before falling towards the boulevard." "It is too soon to give reasons as to why the engines cut out," he added, but said that it was "unlikely" to have been shot down.

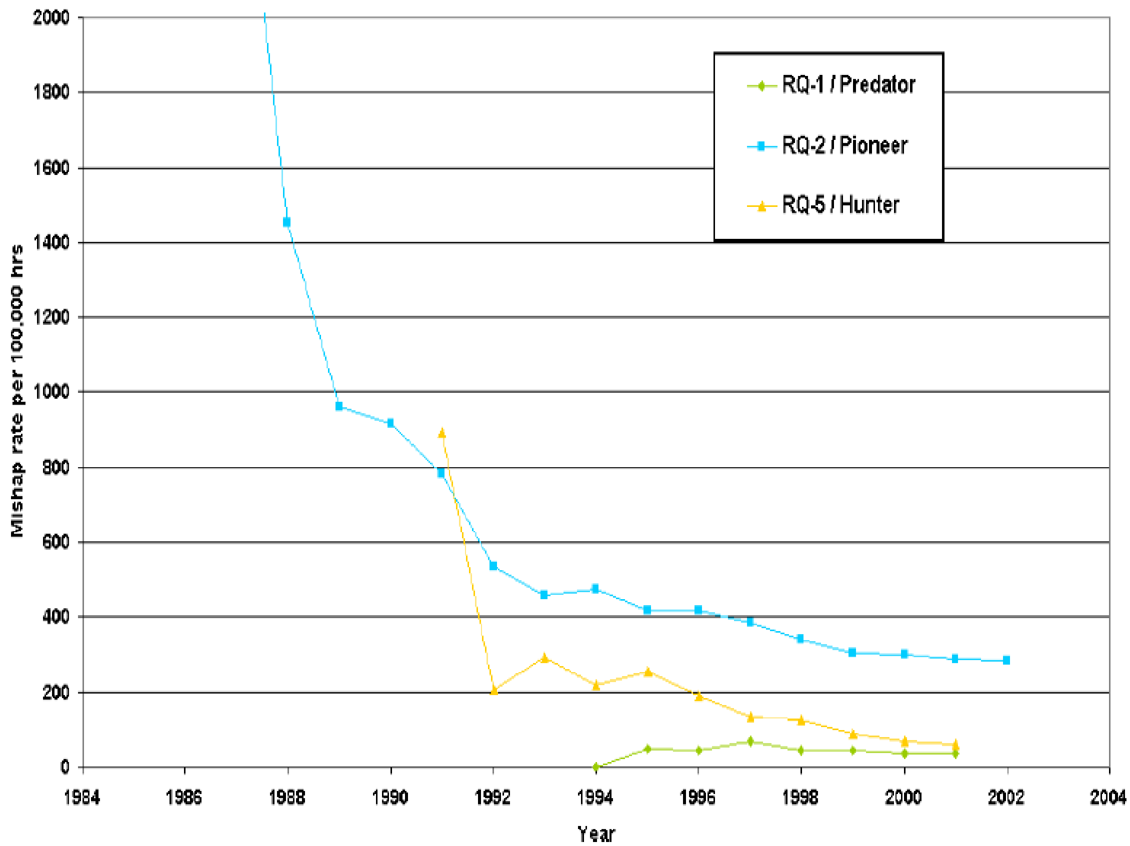


Figure 32 = REF 8 Figure 5.2-1: UAV Mishap Rates decreasing with time as a result of experience

Above, below: from the US DoD UAV Roadmap Document, Ref 8. The Predator, Pioneer and Hunter are all military Unmanned Air Vehicles in use by the US DoD. Note that 100,000 hours = 11.4 years.

1. Mishap Rate (MR) is the number of accidents occurring per 100,000 hours of fleet flight time, expressed as mishaps per 100,000 hours. Figure 5.2-2 depicts the historical MR trend for the Navy Pioneer, Army Hunter, and Air Force Predator. For comparison, in a recent year, Marine AV-8 Harriers had a Class A mishap rate of 10.5 per 100,000 hours and Air Force F-16s 3.5. Using the logic that aircraft mishap rates tend to be inversely proportional to their acquisition costs, current UAVs still have a reliability gap to close. **A Department-wide effort should be implemented to decrease the annual mishap rate of larger model UAVs to less than 25 per 100,000 flight hours by FY09 and less than 15 per 100,000 flight hours by FY15 while minimizing system cost growth.** For smaller UAVs, the interplay of the aerodynamics at low Reynolds Numbers (a non-scaling factor relating altitude, speed, and aircraft size) and flight controls is not well understood. In this case, flight control insufficiency, vice failure, may be a contributor to small UAV mishaps. **Low Reynolds Number aerodynamics, with a focus on improving digital flight control systems optimized for small (i.e., having Reynolds Numbers less than 1 million) UAVs, needs additional investment.**

Figure 33 = From the DoD UAV Roadmap. REF 8

Environmental impact

There is a rapidly growing awareness of the need for all of us to be more conscious of the environmental impact of our activities, and to reduce our use of fossil fuels.

DAVID J. O'REILLY
CHAIRMAN & CEO
CHEVRON CORPORATION

Chevron

Energy will be one of the defining issues of this century. One thing is clear: the era of easy oil is over. What we all do next will determine how well we meet the energy needs of the entire world in this century and beyond.

Demand is soaring like never before. As populations grow and economies take off, millions in the developing world are enjoying the benefits of a lifestyle that requires increasing amounts of energy. In fact, some say that in 20 years the world will consume 40% more oil than it does today. At the same time, many of the world's oil and gas fields are maturing. And new energy discoveries are mainly occurring in places where resources are difficult to extract, physically, economically and even politically. When growing demand meets tighter supplies, the result is more competition for the same resources.

We can wait until a crisis forces us to do something. Or we can commit to working together, and start by asking the tough questions: How do we meet the energy needs of the developing world and those of industrialized nations? What role will renewables and alternative energies play? What is the best way to protect our environment? How do we accelerate our conservation efforts? Whatever actions we take, we must look not just to next year, but to the next 50 years.

At Chevron, we believe that innovation, collaboration and conservation are the cornerstones on which to build this new world. We cannot do this alone. Corporations, governments and every citizen of this planet must be part of the solution as surely as they are part of the problem. We call upon scientists and educators, politicians and policy-makers, environmentalists, leaders of industry and each one of you to be part of reshaping the next era of energy.

Dave

Figure 34 = From The Financial Times, 12 July, 2005. REF 53

A responsible environmental approach is also a good business approach, echoing the maxim "waste not, want not" and supporting the GE drive to be more environmentally conscious.

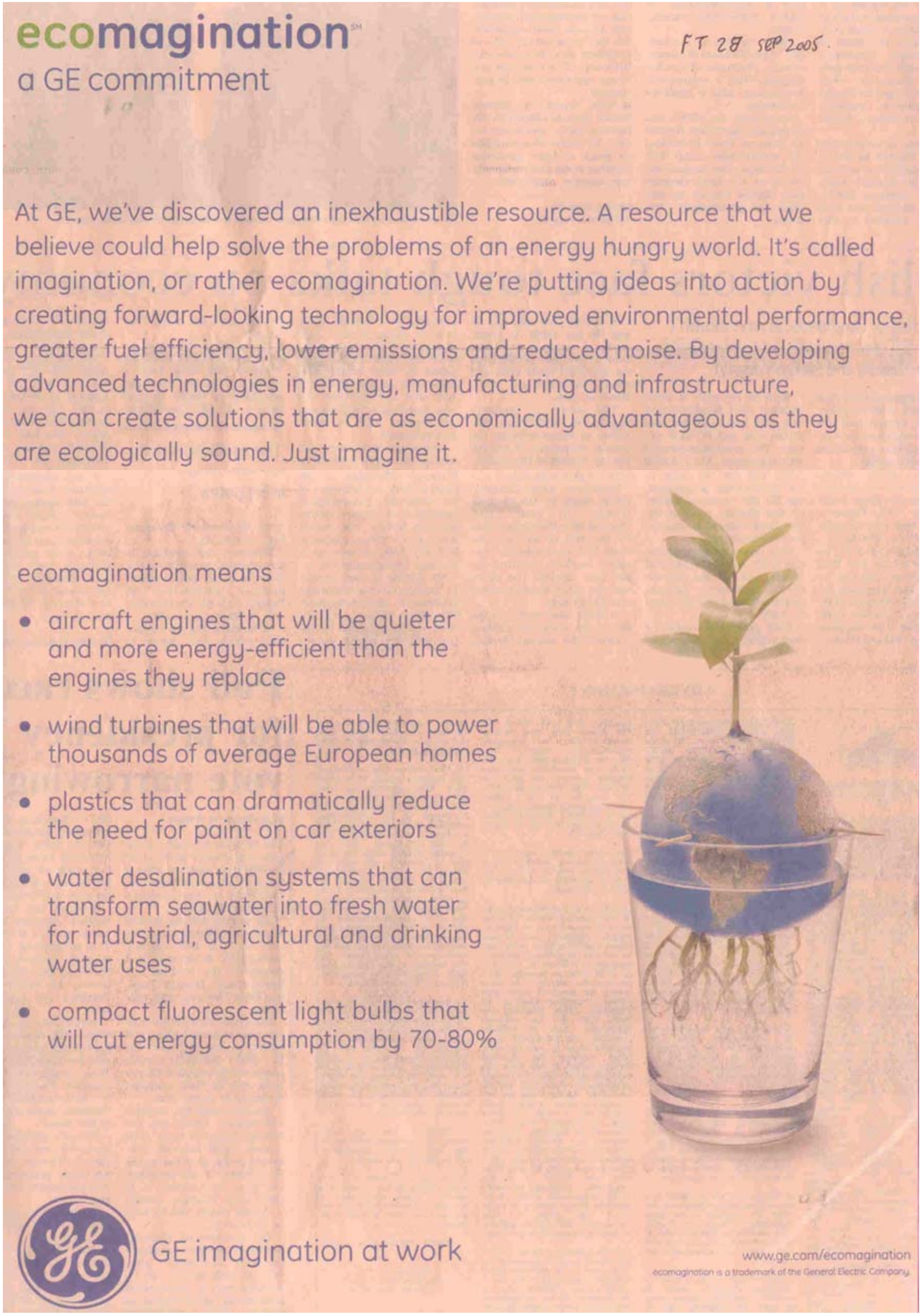


Figure 35 = From The Financial Times, 28 September, 2005. REF 54

Raw materials usage on building, and materials disposal on decommissioning:

- a manned Cessna Skylane **requires at least 860 Kg of raw materials to build**
- a UAV with a 10 Kg payload **only requires 34 kg of raw materials to build**

Warning over carbon dioxide levels

HOUSEHOLDERS, motorists and business need to stop producing carbon dioxide to balance out aircraft greenhouse gases, a study has revealed. Even if aviation's current growth is halved, the rest of the economy will require carbon dioxide cuts far beyond Government targets, the Tyndal Centre for Climate Change Research said. 'If ministers do not curb aviation growth, all other sectors of the economy will be forced to become carbon neutral,' said Dr Kevin Anderson, of Manchester University. Aviation is a major pollutant because planes burn vast amounts of kerosene fuel at high altitudes.

Figure 36 = from the "Metro", 21 September, 2005

For every kilogram of AVGAS aviation fuel used, an aircraft engine produces:

- 2.891 Kg of CO_2 +
- 1.124 Kg of H_2O +
- 0.019 Kg of NO_x

Fuel usage for every 100 Km flown:

- a manned Cessna Skylane **will use 15.20 Kg** of AVGAS.
- a UAV with a 10 Kg payload **will use 1.65 Kg** of AVGAS.

For a geophysical survey of a 100 Km by 100 Km region, at a line spacing of 100 m:

- a manned Cessna Skylane will **create 43,942 Kg of CO_2**
- a UAV with a 10 Kg payload will **create 4,770 Kg of CO_2**

NOISE LEVELS	manned Cessna 402 – REF 52	calculated for UAV-10K
cruising at 1,000 feet	72.2 dB	62.6 dB
climbing at 1,000 feet	76.5 dB	66.9 dB
Background noise level = 42 … 52 dB: primarily waves on the beach near the test area. Anything above 85 dB is considered harmful. Noise power is doubled for each extra 3 dB.		

Fuel usage comparison

Figure 37 = Maynard Hill's TAM5 UAV. REF 4

Figure 38 = Cessna Skylane manned light plane. REF 13

	parameter	**UAV-10K Target specifications $ 35,000**	**Manned aircraft Cessna Skylane $ 268,750**
weight	Dry (no PL, in Kg)	~34	860
	Max fuelled (Kg)	~81	1,406
	Max payload (Kg)	10	91=load + 182=pilot
operational	Fuel type	methanol / Avgas100	Avgas 100 or 100LL
	Fuel capacity Kg,L	40 Kg / 49 L	273 Kg / 333 L
	Max range (Km)	2,400	1,793
	Max flight time (Hr)	30 at 80 Kph	11.8 at 152 Kph
	Fuel used: g / Km	**16.5**	152
	CO_2 gen in L / Km	**35**	463
	Max speed Kph	145	276
	Stall speed Kph	50	91
	Impact of accident: $KE = 0.5mv^2$	**KE = 0.5x91x50x50 = 114 KJ**	KE= 0.5x1243x91x91 = 5,145 KJ

1. Note that the UAV could fly on either methanol of ethanol. Ethanol can be produced from sugar cane. However, the main problem with both methanol and ethanol is that the energy density of both is about 70% that of Avgas 100.
2. The density of Avgas 100 LL is taken to be that of petroleum = 0.82 Kg / litre.
3. In the event of an impending crash, planes dump fuel to try to avoid a fire after the crash: the **less fuel carried, the less the environmental impact of a fuel dump.**

Prevention of terrorism

Terrorists have already used Unmanned Air Vehicles. Since UAVs can fairly easily be adapted to carry a bomb or be used for surveillance purposes, robust measures need to be taken at the outset to prevent the unlawful use of UAVs by terrorists, or criminals.

- The software running on the main PC card, typically under Embedded Microsoft Windows, needs to be security protected from modification using a system such as the Aladdin Knowledge Systems HASP USB key.

- **No Fly Zone Data** must be stored in the firmware running on the core Navigation and Flight Control Microprocessor (FCM), which controls the UAV flight, even in the event of failure of the main computer card (see Appendix 4). Before any flight:

    - The flight plan from take off to landing is downloaded from the on-board PC card to the FCM, where the FCM checks the flight plan waypoints to ensure no trespassing of the UAV over any No Fly Zone as defined in the No Fly Zone Data, before validating the requested flight plan to be valid.

    - The UAV will only fly on a flight plan that has been validated by the FCM.

    - Any in-flight changes to the flight plan must be validated by the FCM before being accepted: otherwise the original flight plan remains in effect.

- All UAVs need to be supplied with a core GPS based No Fly Zone data set which cannot be read or altered by the user. This core data set is constructed from data for No Fly Zones throughout the world. The user can add additional No Fly Zone data, and can subsequently remove only user defined No Fly Zone data.

- GPS derived time will be taken as the universal time that cannot be altered by the user. This time could be used to require UAV users to update the microprocessor firmware each year, including any changes to the encrypted No Fly Zone Data.

Israel admits Hizb Allah drone flight

by Khalid Amayreh in the West Bank
Monday 08 November 2004 9:26 AM GMT

Israel has admitted that an unmanned spy plane launched by the Lebanese resistance group Hizb Allah flew over its northern territory on Sunday.

The drone flew over the Western Galilee area

The plane was in the air for more than 30 minutes before it returned to Lebanese territory.

The Israeli army initially denied reports from Lebanon that Hizb Allah had succeeded in flying a drone over Western Galilee.

Israeli media described the incident as "a bold and provocative step" by Hizb Allah.

Israeli Defence Minister Shaul Mofaz said he held the Lebanese government responsible for "all security incidents emanating from within its borders".

Hizb Allah said the UAV, dubbed Mirsad-1 (Arabic for ambush) had penetrated Israel up to the town of Nahariya at 10.30am (0830 GMT) on Sunday.

Figure 39 = The potential use of UAVs by terrorists / criminals has to be prevented by design REF 17

DATE: 6 SEP 2005
SOURCE: Flight International

Green light imminent for UAV airspace initiative

Initial funding for the UK's Autonomous Systems Technology Related Airborne Evaluation and Assessment (ASTRAEA) initiative is expected to be announced this week, starting a multi-year effort to normalise unmanned air vehicle operations in UK airspace.

The launch funding is expected to be provided by the UK Department of Trade and Industry (DTI) and regional government agencies, with announcements to be made at this week's unmanned air vehicle flying day at ParcAberporth, Wales.

The total cost of the project has previously been forecast as potentially up to £80 million ($140 million) to implement fully over a five-year period. ASTRAEA, set up by the DTI in July 2004, aims to carry out a major demonstration of routine UAV operations in non-segregated airspace by 2010.

The programme will include a review of existing UK air traffic policy, development of certification standards, and development of sense-and-avoid technologies. BAE Systems is the programme lead for industrial co-ordination, and the Welsh Development Agency is co-ordinating UK regional agency and local government involvement in the project.

The ParcAberporth UAV centre of excellence, being developed by the Welsh Development Agency with the support of European Commission funds, is being targeted as the main co-ordination centre for ASTRAEA. The facility is also the home of the recently launched Unmanned Aerial Vehicle Systems Association's (UAVS) Unmanned Systems Services company, the world's first UAV certification firm that is undertaking that task under devolved responsibility arrangements negotiated with the UK Civil Aviation Authority.

The ASTRAEA programme will build on an intensive five-year UAV airspace integration effort by the UK CAA. Current CAA policy – CAP 772 – provides much scope to open up airspace, but "is still evolving and will continue to be modified as progress is made", says Geoff Bowker, CAP 772 sponsor in the CAA's directorate of airspace policy. The CAA has an observer role on the ASTRAEA steering board and on the ParcAberporth pan-government stakeholder group.

Bowker says CAP 772 reflects close co-ordination by the CAA with the UK MoD, UAVS and participation in a variety of common European integration including those headed by EASA and Eurocontrol. He adds that the policy has generated "a lot of approaches from a number of European nations who have taken a great interest in the book, and are taking a number of principles from it for themselves".

But new challenges continue to emerge, he says. "The UK CAA has for many years recognised the need for UAV regulation for predominantly civil UAVs. We are at a unique point in aviation history, and it would be helpful if our civil UAV regulation was also in register with the military."

Flight automation

- from www.aerosonde.com

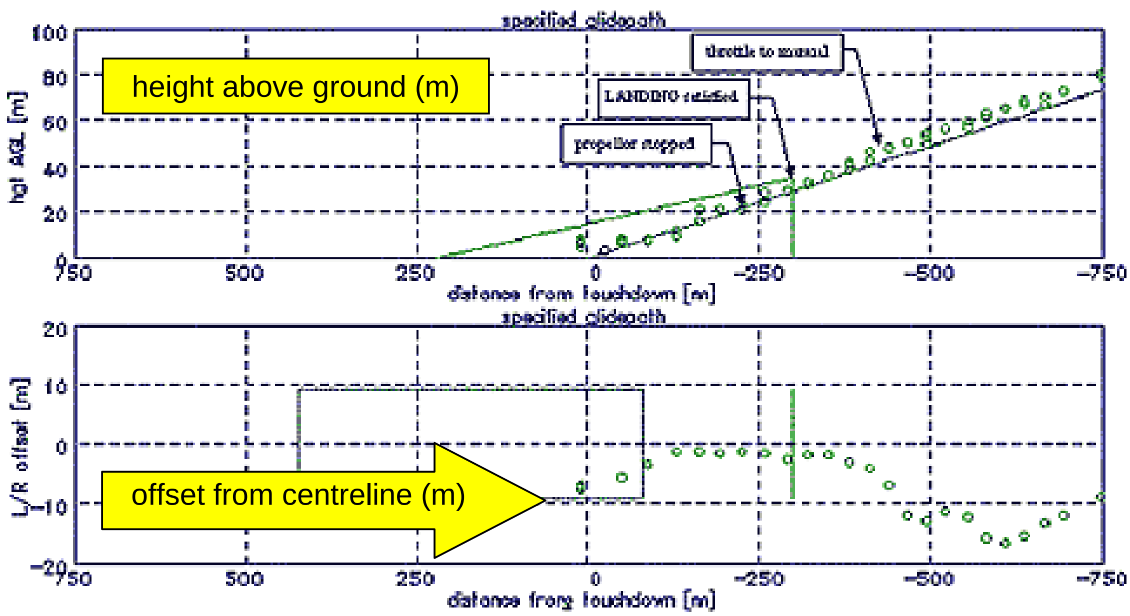
What follows is an account from the www.aerosonde.com site discussing the first fully automated take-off and flight of the Aerosonde "Millionaire" Unmanned Air Vehicle in 1997. Since that time, other UAVs have demonstrated fully automated take off, flight and landing.

Our First Fully Robotic Flight

On 22 September 1997 an important step was taken toward automatic rather than manual control of takeoff and landing. In a one-hour test at Trout Lake in Washington, Aerosonde "Millionaire" flew under autopilot continuously from launch to touchdown.

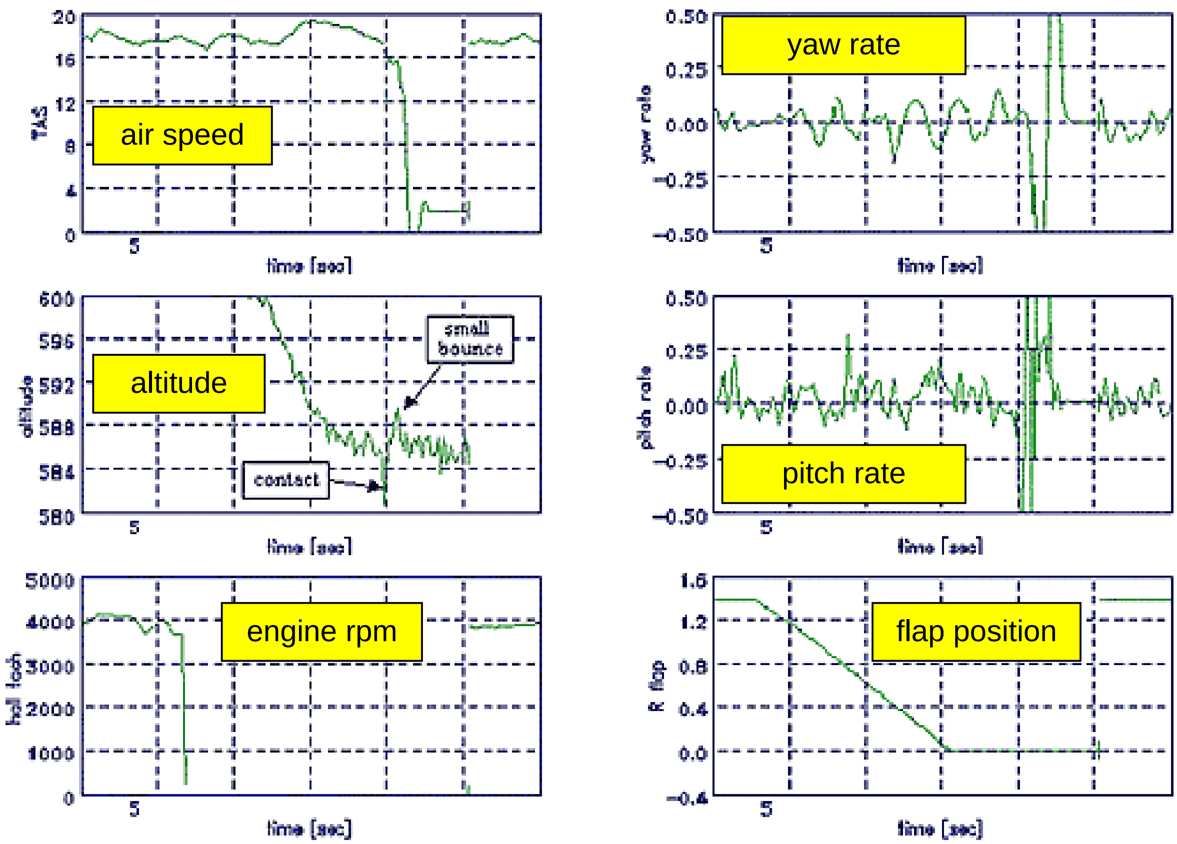
Figures show the landing as plotted on ground-station displays. The aircraft touched down smoothly on the Trout Lake runway, made one small bounce and a large-angle yaw, and then decelerated rapidly through some tall clover. Overall the performance was quite comparable to a good manual landing.

Although the landing was done under autopilot, it was not quite autonomous; guidance onto the runway centreline was done visually from the ground station rather than being left to the onboard tracker. However the test produced good results in position measurement by differential GPS.

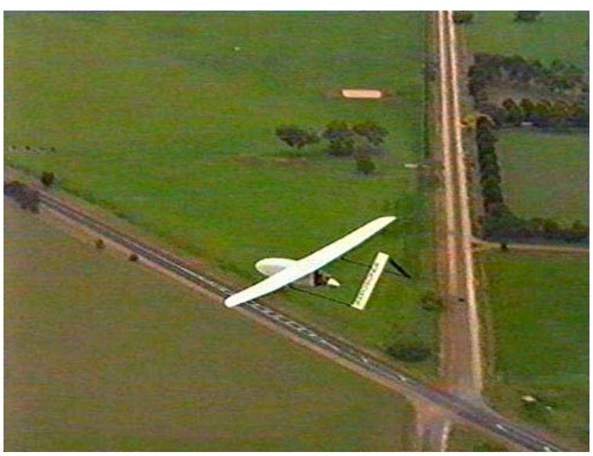


Height above ground level (top) and offset from the centreline (bottom) during the airborne computer controlled approach and landing of the Unmanned Air Vehicle.

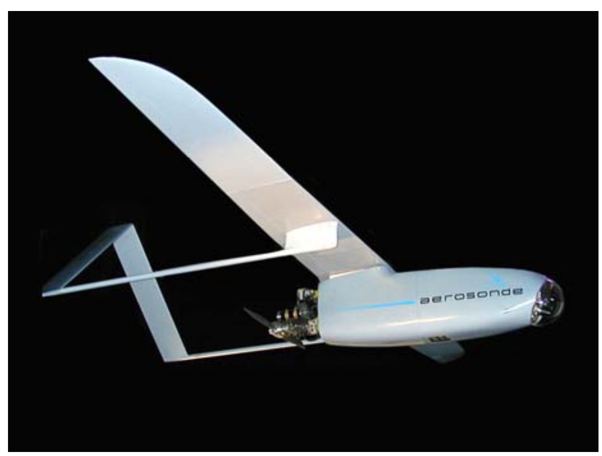
- from www.aerosonde.com



Above is shown the telemetry data for an Aerosonde Unmanned Air Vehicle as it lands entirely under the control of the onboard flight control computer, which uses information from onboard navigation sensors, including a GPS unit, to manage an accurate landing.



Aerosonde UAV in flight, monitoring the traffic on a country road.



Underside of an Aerosonde Unmanned Air Vehicle, showing the imager in the front, and the pusher engine on its swivel mount to enable the control of the thrust direction.

Endurance: the first FAI Class F / F3A Model Plane to fly 3,020 Km, in this case, from Canada to Ireland on 9th August, 2003

A small UAV, called TAM 5, flew 3,020 Km from Newfoundland in Canada to Stone Bog in Ireland using GPS guidance, while sending telemetry information back via satellite. The small plane used its GPS system to fly at an average altitude of 305 m (1,000 feet) above sea level to avoid ship masts and any other aircraft.

This feat has been mentioned in the BP Frontiers Magazine. Maynard Hill, a UAV pioneer, who used to work at the Johns Hopkins University in the USA continued, after retirement, in his quest for model aeronautic feats and together with a small team of like minded people, developed a small model plane called TAM (Trans-Atlantic Model) 5, which flew 3,020 Km from Newfoundland to Ireland in 38 hours and 23 minutes, using GPS guidance with telemetry communications via satellite and just under 2.2 Kg of fuel..

A group of model aeroplane enthusiasts with whom BP has been working to optimise a fuel formulation has recently set a world record.

Fuelling success – the record-breaking model plane

Mr Maynard Hill and his team were successful in flying a 2m-long balsa wood aeroplane, weighing 5kg, non-stop across the Atlantic Ocean from Newfoundland in Canada to Stone Bog in Ireland. The 3020km journey took 38 hours and 23 minutes, setting a record.

The special fuel used to power the plane contained BP's Indopol L-50 grade polybutene, a synthetic liquid polymer with applications including lubricants and greases, two-stroke motor oils, sealants, adhesives, tacky films, rubber modification, and many more. Indopol is manufactured at BP's refineries in Whiting, Indiana and Lavéra in France. Used in fuels, Indopol can reduce carbon deposits and engine wear, providing clean-burn and anti-fouling properties and improving overall engine lubrication.

Control of the plane was achieved through a receiver and three servos, a piezo gyro and a GPS receiver for navigation. A custom-designed autopilot used a microcomputer to process data from these devices and adjust the servos. Prior to launch, a memory chip was programmed with waypoints for steering, containing data on desired altitude and engine speed between these points. Two miniature telemetry transmitters kept track of the plane during the crossing, one providing short-range data to receivers at the launching and landing points to assess performance, while the other transmitted signals to satellites that relayed the data to ground stations. ■

Figure 40 = REF 11

From the BP “Frontiers_magazine_issue_09_patents_and_briefs.pdf” article REF 11.

Figure 41 = Aerosonde UAV flying over calm waters. REF 74

The first UAV to cross the Atlantic was the Aerosonde Mark I “Laima” flying from Bell Cross Airport in the USA to the DERA Benbecula Range in the Outer Hebrides, covering 3,270 Km in 26 hours 45 minutes at an altitude of 1,680 m, using only 5.6 Kg of fuel.

Figure 42 = Maynard Hill with TAM5. REF 12

Maynard Hill, who also designed the Exdrone UAV while at Johns Hopkins University in the USA, with the first FAI Class F / F3A model plane that crossed the Atlantic Ocean.

Key features and related applications

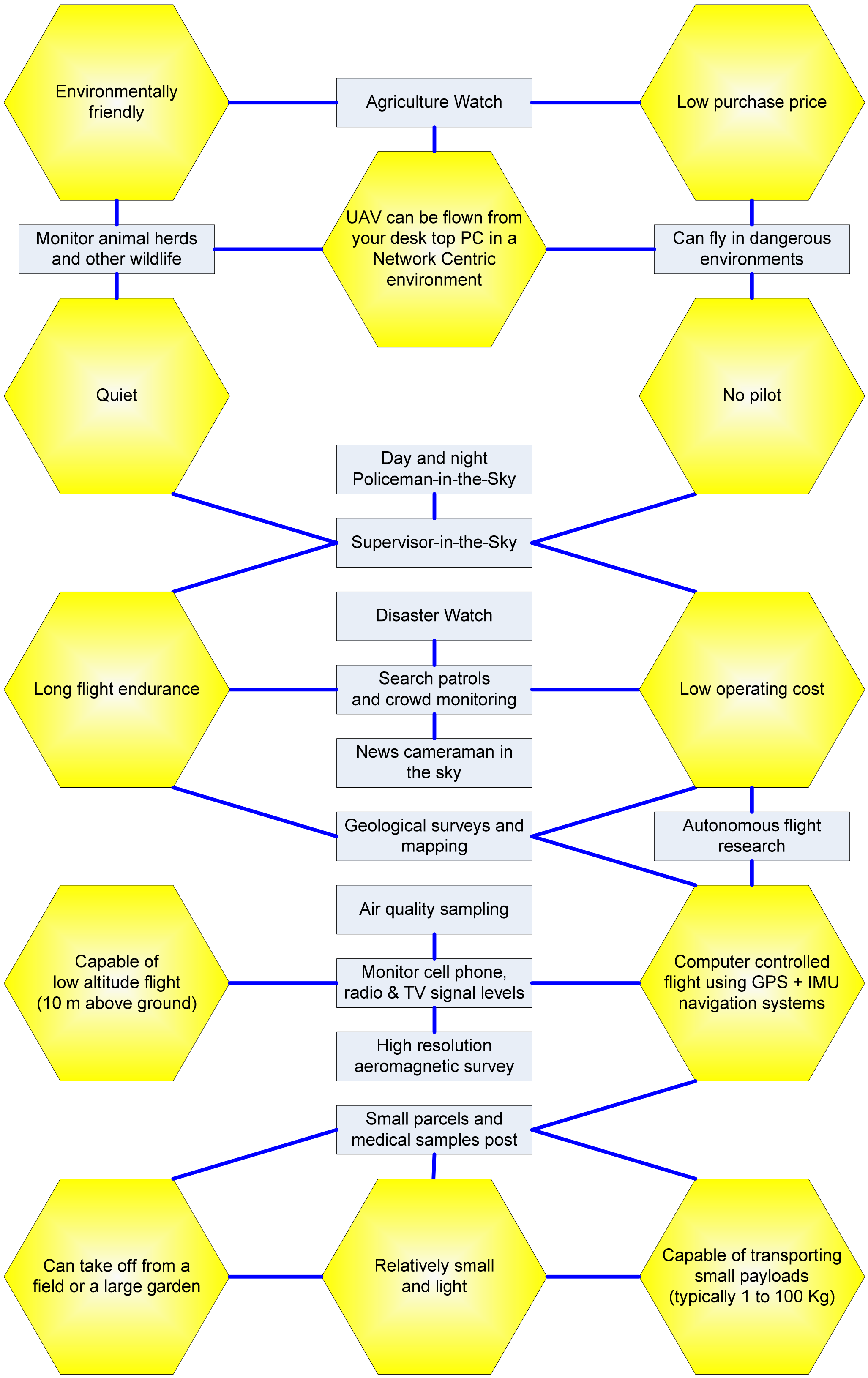


Figure 43 = The key features of a UAV and the related applications.

Applications

Aerial Photographer

- Monitor human rights abuses, such as the burning of houses, looting, intimidation of the local people by gangs of thugs or soldiers

Figure 44 = REF 23

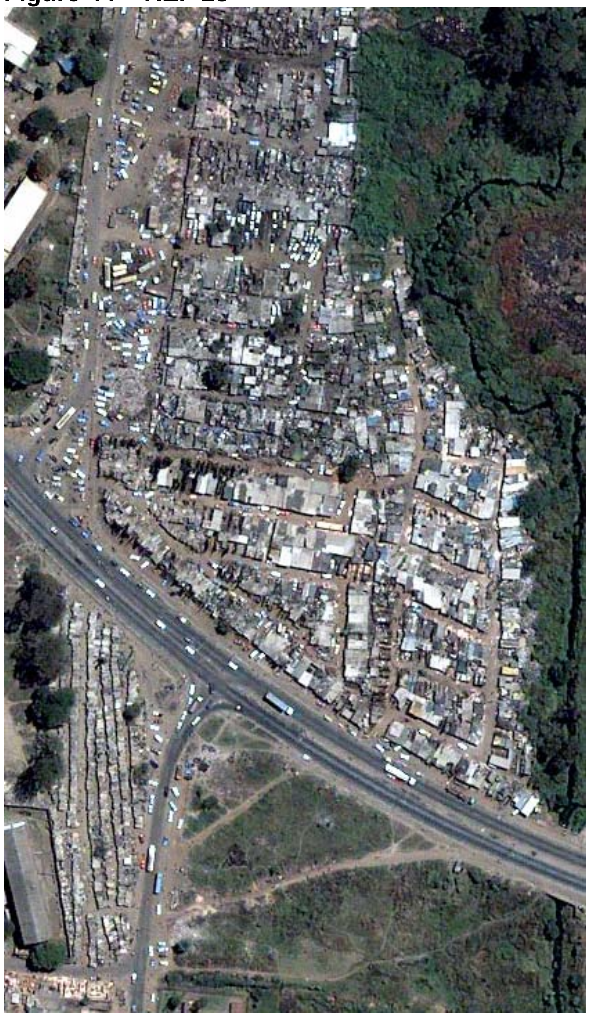


Figure 45 = Powerful support for the use of high resolution aerial photography. REF 24

Satellite images of an area of Harare before and after “Operation Murambatsvina”, in which a shanty town has clearly been destroyed, rendering many people homeless.

- For insurance purposes, in case of an accident, photograph critical events at:
    - a refinery, or chemical plant
    - a civil engineering activity
    - a building site
    - an airport
    - an oil platform at sea
    - a busy port
    - a city or region that has been flooded

- **<u>High resolution, vertical (plan view) and oblique stereo aerial imaging</u>** by day, with thermal imaging by night, for use in:
    - GPS navigation systems, including use of Digital Elevation Mapping LIDAR to generate 3D images of the land surface
    - imaging of buildings and land features
    - searching in the desert, hilly areas, in a jungle region, in difficult terrain, or at sea, where one or more UAV can spend up to 30 hours criss-crossing a region using visual and thermal imaging for people in need of rescue

- Monitor litter, and any illegal dumping of wastes:
    - on beaches
    - in cities
    - in parks
    - in residential and shopping areas
    - in industrial zones


ST 27 NOV '05

THE ALTERNATIVES

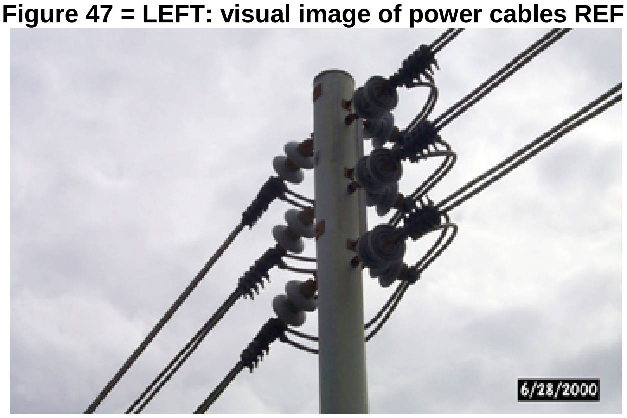
❑ **Cleaner coal** About 10 of Britain's coal-fired power stations must shut down or clean up under EU pollution rules. One option is to upgrade them to operate at higher temperatures and pressures and run on bio-fuels. This would raise efficiency and cut carbon emissions at a fraction of the cost of a new power station

❑ **Energy efficiency** Britain wastes more than half the power it produces through generation and transmission losses in the National Grid. Inefficient homes and businesses lose another 13%. Better transmission systems and insulated homes could reverse the growth in demand

Figure 46 = litter on the beach can be spotted from the air. REF 20

- Detection of hot spots in:
    - power distribution overhead power lines
    - electrical power transformers

Figure 47 = LEFT: visual image of power cables REF 21



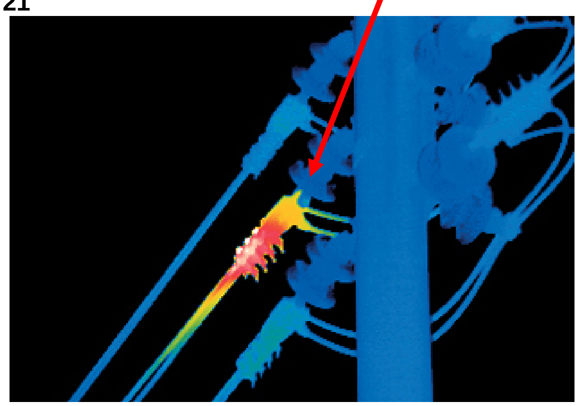


Figure 48 = RIGHT: showing a hot spot in a thermal image of a power cable connection. REF 21

UAV thermal infrared power line surveys

from REF 61

Power line generation companies have long used thermal infrared imaging to scan electrical components, ranging from service panels, to substations, to power lines. A typical power line survey requires a crew of at least two: a driver and a scanner, together with a field truck and an infrared camera.

The procedure is to drive the length of the power line, while the camera is pointed up at the connection points. Hot spots are then logged for follow up. This method is expensive in terms of labour and equipment, and is often not adequate to complete the task. Many power lines run over mountains and other impassable terrain.

The alternative method is to fly the power line in a manned helicopter, which increases costs and safety concerns. The UAV can fly in an autonomous mode, in which the aircraft is guided via GPS to preprogrammed waypoints.

Most power companies have already surveyed their poles and have a GPS map of their locations. By programming these co-ordinates into a UAV, equipped with the appropriate thermal camera, one operator can now perform an entire inspection from a safe ground point. The UAV will fly from point to point, imaging targets of interest and reporting back to the operator. The cost per hour of UAVs can be as little as $3.00. This makes the return on investment very favourable. Since there are no crew members on board, the vehicle safety concerns are alleviated and insurance costs are reduced, further improving the benefits of this approach.

TV news coverage

- images from www.sony.com

Today's news coverage is a highly competitive field. Getting the story first and providing uninterrupted coverage is of crucial concern. Most news agencies provide aerial footage of everything from traffic reports, to high speed police chases.

Most reporting is done from a helicopter. Between a staff pilot, aircraft purchase and maintenance, this is an expensive proposition, outside the budget of smaller regional and local outlets. Many of these smaller agencies share, or buy, footage from a central aircraft. This reduces flexibility and provides no market advantage.

The cost of running a TV news UAV using a high definition video camera (as shown below) is substantially less than the traditional approach. An agency can pay a UAV operator to provide the aerial news coverage, in a timely and cost effective manner.

Water Watch

Figure 49 = REF 25

Figure 50 = Solar powered UAVs promise very long endurance times, measured in days. REF 26

- Water and port watch, possibly using a solar powered UAV, as shown above…
  - unobtrusive life guard over beaches
  - watch for swimmers and sailors in trouble
  - identify the location of masses of phytoplankton, giving the likely location of tuna, which feed on this plankton
  - detection of oil spills at sea
  - monitor:
    - beaches for sharks, or people swimming in dangerous areas
    - beach erosion
    - smuggling activities
    - piracy at sea, particularly in South East Asia and the Horn of Africa
    - and manage shipping movements and shipping lanes
    - the thickness of ice and the height of waves at sea
    - ocean surface temperatures, and the effects of global warming

Figure 51 = Dead easy to monitor shipping from the air, especially if the coverage is regular. REF 27

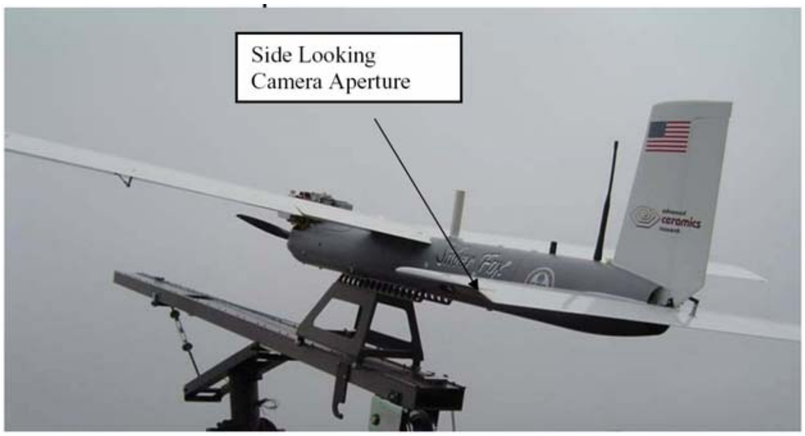


Figure 52 Silver Fox UAV from Advanced Ceramics Research Inc.
Above and below from http://uas.noaa.gov/silverfox/SilverFoxdemoSOWv8-1.pdf

The US National Maritime Sanctuary Program (NMSP) has identified requirements that could be met by Unmanned Air System (UAS) flights:

The NMSP also has scientific needs in a number of areas that can be addressed by UAS flights with camera payloads. Resource characterization needs include:

- identification and measurement of shallow water habitat types;
- documentation influences of watersheds and other inputs that affect water quality;
- temporal and spatial patterns of habitat use by living resources (e.g., haul out areas); and
- population assessments for large animals, such as birds and marine mammals.

Representative monitoring requirements for the NMSP include:

- periodic collection of data along predetermined flight paths to count birds and marine mammals;
- overflights of known haul out and bird nesting areas;
- documenting changes in kelp canopy cover;
- determining the location and extent of potentially productive convergence zones or upwelling areas;
- determining spatial and temporal affects of runoff; and
- counting vessels and assessing human use patterns.

Figure 53 from www.soc.soton.ac.uk/pdf_docs/EA/SOCAnnRep2004.pdf

Figure 54 = Useful to show the context of any planned real estate changes. REF 34

- Enhanced impression of the environment of a house you wish to sell or buy.
- Detect any illegal house building, extension work, or extensions.
- Superimpose development plans on an aerial map, for added clarity.

Figure 55 The markings superimposed on an aerial photograph help convey what is planned. REF 35

Building Watch

- Monitor progress of civil engineering projects
- Plan gas and water lines based on Digital Elevation Mapping
- Monitor the actual state of inventory at any building site
- Inspect a bridge or a building for corrosion, cracks and any other wear and tear
- Independently identify location of assets and personnel in real time

Figure 56 = Thames Tunnel (south bank) 16 OCT 2003 showing progress. REF 36

- Identify any illegal dumping of building waste, in the surrounding areas
- Use aerial photographs in any legal disputes with the building contractors, or, with the architects, or anyone else

- Detect illegal dumping of waste or toxic materials

- Monitor the drought regions in a continent and the expansion of the desert and other uninhabitable areas.

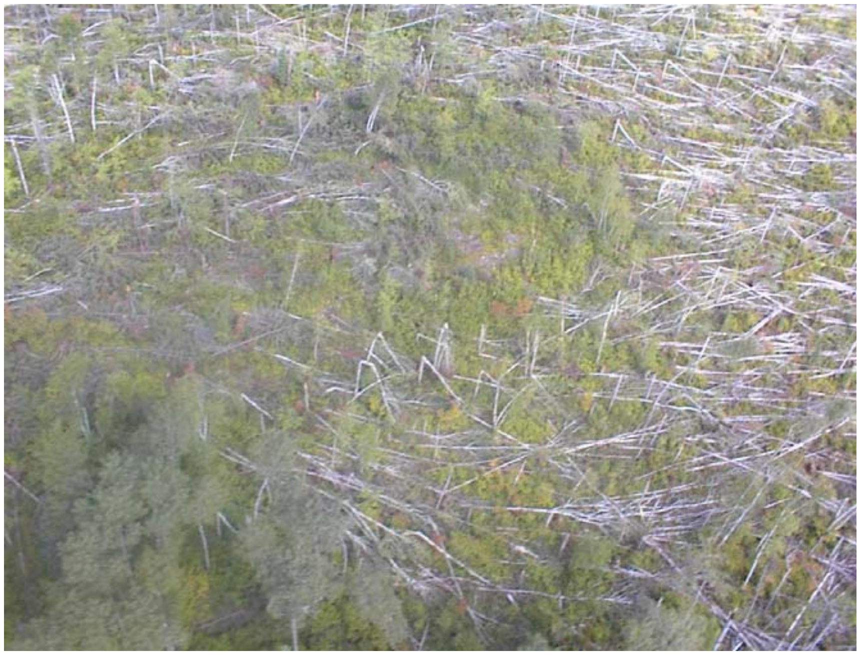


Figure 57 = clearly showing the extent of a tree "blow down" area. REF 28

- Monitor countryside attributes using visual and thermal imaging:
  - forest fires
  - wild animal poaching and illegal fishing
  - land temperatures
  - tree "blow-down" in a forest after a hurricane, or, following a heavy snowfall

Figure 58 = clearly showing the sources of fires in a forest. REF 29

Figure 59 = showing deforestation region in the Amazon rain forest. REF 30

Figure 60 = deforestation in the rain forests in Madagascar. REF 71

- Monitor agricultural attributes:
  - opium plantations
  - deforestation

- Keep track of animal herds without disturbing the animals

Figure 61 = showing an aerial view of wildlife in a game park. REF 31

- Spot illegal:
  - poaching in game reserves
  - coral removal from the sea bed
  - whaling

- Identify any destruction of the natural habitat for birds

- Using a larger UAV with a 50 Kg payload capability, perform, with greatly reduced danger of chemical contamination of personnel, for crop spraying and dusting.


SEPTEMBER 11, 2005 · THE SUNDAY TIMES

Crop spraying is health risk, say scientists

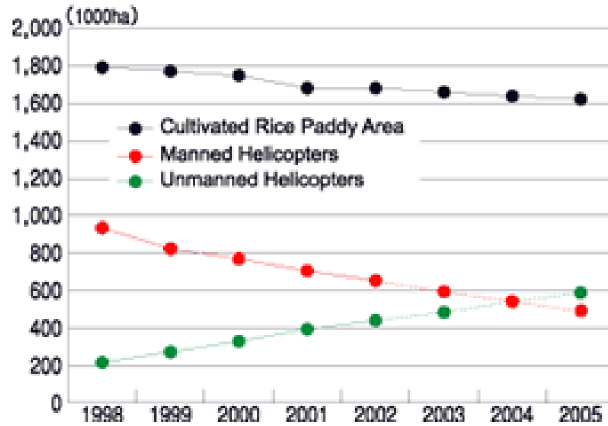


Figure 62 = With the health hazards associated with crop spraying, it is little wonder there is an increased use of unmanned helicopters in crop spraying work. REF 32

The hazards associated with manual crop spraying are being noted.	In the plot above we see (top) the slow decrease in hectares of cultivated rice paddies, with the (red dots: middle line) **decline in manned helicopters** used in crop spraying, and (green dots: lower line) the steady increase in areas sprayed using unmanned helicopters.

- Monitor farm and agriculture related features:
    - the spread of locusts
    - timber theft
    - moisture levels in crops and vineyards
    - how crops are growing throughout the country
    - state of plantation on the hillsides
    - coffee plantations
    - the spread of any crop destroying pests
    - location of farm equipment
    - progress and quality of work of autonomous combine harvesters

- Identify, using multi-spectral and thermal imaging, and LIDAR:
    - different crop regions
    - different varieties of the same crop
    - the condition of the crop: for example, healthy or diseased
    - live and dead vegetation in fields
    - where crops are being eaten by pests or rodents
    - theft of crops, or, farm animals
    - the height of trees in a forest or a plantation

- Plot outbreaks of animal diseases, such as “foot-and-mouth” and “mad cow”, on accurate, up-to-date maps, derived from aerial photography, to help identify the source of the disease and contribute to the containment of the outbreak.

Agriculture II

Rice Paddy

July to August

Area-wide communal control of insect pests Strategic application timing is highly effective for area-wide communal pest control. The Yamaha RMAX Aero Robot is being used in increasing numbers in the integrated rice paddy systems.

Wheat

April to May

The application of the Yamaha RMAX Aero Robot for insect pest control is expanding rapidly with the expansion of cultivated areas.

Soy Beans and Red Beans

August to September

The application of the Yamaha RMAX Aero Robot for insect pest control is expanding rapidly to save energy.

Pine Trees

The application of the RMAX for exterminating pine weevils is expanding.

Fruit Trees

The Yamaha RMAX Aero Robot has actualized energy-saving insect pest control for citrus fruit orchards, which are often located on slopes.

Vegetables

The Yamaha RMAX Aero Robot takes an active role in the maintenance of vegetable fields such as cabbage and onions.

Fertilizer

The Yamaha RMAX Aero Robot with its improved loading capacity exercises its power in fertilizer application.

Agricultural suggestions for an autonomous helicopter REF 32.

PESTICIDE USE

	No. times each crop sprayed per year	No. of chemicals in sprays
Cox apples	18	35
Potatoes	13	16
Onions and leeks	11	21
Strawberries	9	14
Wheat	6	12
Carrots, parsnips and celery	7	13

Figure 63 = Getting the unmanned Yamaha RMAX helicopter ready for a test flight. REF 32

Aerial Policeman

- The UAV aerial imagery must support the variable overlay of thermal imagery over higher resolution day time visual imagery to enhance the interpretation of a scene, and the identification of people and hazardous conditions. High power infra-red or flash illumination could be used at night in conjunction with image intensification to aid night viewing. Real time (ie. no delay) day and night surveillance of:
    - any private, industrial or state property
    - car parks
    - railway stations, rail traffic, freight yards and goods depots
    - railway tracks, for timely removal of children playing on the tracks, or, any other obstacles on the tracks, such as fallen trees, cattle,…
    - a city, to provide almost instant availability to monitor a crime scene, or monitor any looting in a city after an electrical power outage or a major flood

Figure 64 = Leftt: one could easily monitor comings and goings, and intruders, from the air. REF 18

Figure 65 = Right: monitoring New Orleans after Hurricane Katrina was augmented by UAVs. REF 55

- Computer controlled day and night loitering over large cities, key installations and shipping, keeping a lookout for any criminal activities or movement of pirates at sea.

- Permanent presence of UAVs in the sky will reduce the time taken to view any location from the sky, in a cost effective manner. The UAV detachment can form part of an <u>integrated crime prevention network,</u> in which people's homes are connected to a Response Centre. If burgled, a message is sent to the Response Centre, and an already airborne UAV is dispatched to investigate and track any fleeing burglars, if appropriate. The presence of the UAV, with a high power searchlight, will often cause the burglars to flee.

- Detect illegal day or night time mining activities using visual and thermal imaging

- Use sensitive, time synchronised acoustic sensors on several UAVs to pinpoint:
    - gunfire (for example, at a terrorist training centre in the countryside)
    - bomb explosions

- Visible (for example, red and / or green) laser illumination from UAV to:
    - deter criminals
    - identify a location for ground based personnel

Crowd Watch

- Detection of cross border raiding parties, smuggling of people and goods, illegal immigration at remote locations, such as desert areas, jungles, mountainous regions, …

- Monitor a protest march, demonstration, or, civil unrest / disturbance, for example, caused by widespread flooding, or an Avian (bird) flu pandemic.

Figure 66 = Crowd monitoring is straightforward using a quiet, unobtrusive UAV. REF 42

- Monitor crowds at, or, in the vicinity of:
  - football or other games arenas, such as the Olympic Games
  - airports
  - bus stations
  - open air market places
  - tourist areas
  - beaches
  - border areas, to monitor illegal border crossing and smuggling activities

Figure 67 = Example of the ability to monitor people near a car park. REF 43

Traffic Watch

- Perform traffic surveys in a cost effective manner, in real time if necessary, day after day, without adding appreciably to pollution levels or cost
- Use traffic flow information to best synchronise the timing of traffic signals.
- Spot traffic jams, to enable a web based route planner to take account of traffic conditions.

Figure 68 = Traffic near a busy interchange are easily visible. REF 37

- Identify stolen vehicles by detecting radio signals from a unit on the stolen car together with the use of radio direction finding equipment on the UAV.
- Follow vehicles of anyone thought to be about to engage in criminal activities, or, anyone thought to have taken part in criminal activities.
- Spot cars speeding along a motorway, or, any car or other vehicle which has broken down on a remote highway.
- Identify any accidents on remote roads, to enable an immediate response by emergency medical staff and police.
- Detect pot holes on roads, and general road surface quality
- Detect any obstacles such as animals, trees and rocks on roads, or, on railway tracks, so that the obstacles can be moved as quickly as possible, with drivers being warned, to prevent any possible accidents.
- Location in real time of trains and carriages on all railroads, so as to make best use of existing rail rolling stock and ensure unloading bays / docks are ready to deal with the anticipated arrival of freight trains.

Oil and Gas Pipe Watch

- Leak detection in buried oil and water pipelines (see Appendix 1):
  - using differential thermal imaging
  - using Ultra Wideband, or differential RF, sub-surface probing

- Ultra Wide Bandwidth (UWB) ground probing RADAR to:
  - spot oil leaks
  - detect buried metallic objects

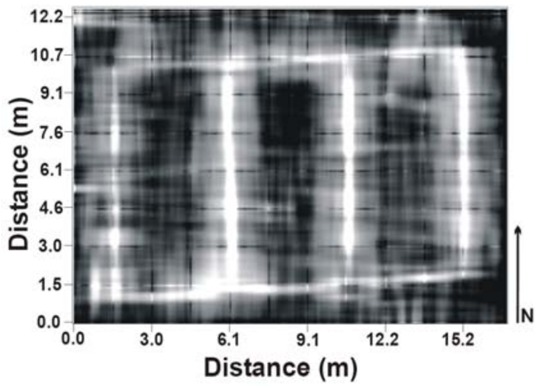


Figure 69 = Image from work at Ohio State University, using $20,000 … $25,000 Ground Penetrating RADAR to locate pipes from 0.7 ... 1.2 m below the ground surface with 81% effectiveness. REF 77

- Use thermal imaging and differential magnetometry to detect attempts to sabotage, or illegally to siphon oil from, an oil pipeline, or related oil installations;

As well as operating several Aerosky vehicles on behalf of the IDF, ADS is currently 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 50 kg and has an endurance of 14 hours. According to the manufacturer, it logged more than 10,000 flight hours after being selected in 2002 to carry out routine security missions for the Israel Defence Force.

Aerostar - Aeronautics Defence Systems, Israel

By Jimmy Burns and Thomas Catan in London

International terrorism, corruption and local activism are threatening oil operations in many countries, one of the sector's senior security advisers has warned.

Ian McCredie, head of Global Security Services at Shell International, said the growing risks had forced Royal Dutch Shell to make its own security arrangements in "hostile environments", covering many of the most important areas in which it operates. He pointed to 14 oil producing regions where local security forces were judged to be "largely ineffective".

Left, UAV Systems: The Global Perspective 2005. Right, Financial Times, 5th Oct 2005.

- Detect illegal entry to:
    - a power station, or sub-station
    - a telephone switching centre
    - a park or a car park
    - a water reservoir
    - any other restricted access facility, such as a nuclear installation

Figure 70 = The extent of fires is readily determined using both visual and thermal imaging. REF 19

- Real time day and night surveillance of:
    - security vehicles carrying:
        - bullion
        - criminals
        - senior Government and visiting officials
        - dangerous nuclear, biological or chemical materials
    - high value residential and industrial assets, such as:
        - oil refineries
        - airport perimeter areas
        - Government buildings, such as, Defence Ministries
        - Houses of senior Government officials

- Air sniffing: use a Photo-Ionization Detector and / or laser based LIDAR to monitor:
    - the air quality and pollution levels:
        - in and around a city
        - around an oil refinery, or, chemical plant
        - around an airport, or, a power station
    - poisonous gases in the air after a fire, or, an explosion at a chemical plant, or, at an oil refinery
    - leaking gas such as ethane from a gas field, or gas from a gas pipeline
    - gases that might indicate the presence of oil, or, gas in, or under, the ground

The fire at Buncefield: example of the contributions UAVs could have made…

At around 6:03 am on Sunday morning, the 11th of December 2005, a massive fuel:air explosion occurred in a huge liquid fuel products storage depot at Buncefield.

Flames and smoke rise from the Buncefield oil depot near Hemel Hempstead, England, on Monday. Firefighters attacked an inferno raging at the oil depot north of London, extinguishing half of the tank fires with sprays of chemical foam (photo: AP) Al-Ahram.	Aerial view of Buncefield Oil and Fuel Depot at Hemel Hempstead, with the explosion and main destruction area marked in red. Aerial photo data courtesy of www.getmapping.com COPYRIGHT © Getmapping plc

UAVs could be used to generate very useful composite images of the incident, using:

- high resolution visual imaging using a 10 MPixel digital camera with digital correction for lens distortion, showing the smoke and flames, as seen above;
- thermal imaging to **"see through" the smoke** and view the flames, and create a colour coded map showing all the temperatures in the image to within 1ºC;
- Interferometric Synthetic Aperture RADAR (ISAR, see Appendix 5 for technical details) to **"see through" both smoke and flames** and image the underlying terrain, including any bodies, vehicles, debris and the level of the flammable liquids in the open, damaged, storage silos.

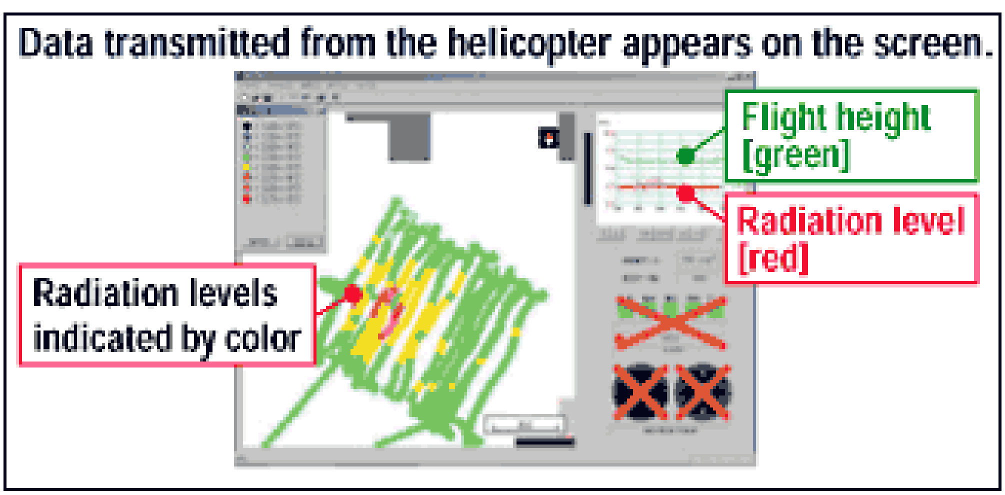
Additionally, UAVs could contribute by:

- continuously monitoring the fire;
- continuously monitor the effectiveness of the fire fighting activities;
- dropping canisters of very cold liquid nitrogen to both cool the fire and reduce its intensity by starving the fire of oxygen;
- flying through the smoke plume to gather samples for subsequent analysis;
- monitoring the extent of the spreading smoke plume;
- watching for any looting that might occur, or unauthorised entry to the danger zone;
- generating detailed 3D aerial imagery to gauge the extent of the damage.

With the potential commissioning of new nuclear reactors throughout the world to offset the increasing energy demands and need to manage pollution levels, the ability to monitor radiation levels in the vicinity of such reactors assumes a growing importance. This example from Yamaha Motor Corporation concerns the Japan Nuclear Cycle Development Institute Wakasa Wan Energy Research Center - from 2000.

> “Upon receiving a request from the Japan Nuclear Cycle Development Institute, we jointly developed a system that consists of a gamma-ray detector mounted on an unmanned helicopter, which transmits data wirelessly to a land station, and displays the radiation levels on a map on a real-time basis.
>
> Thus, it has become possible to fly an unmanned helicopter into an off-limits area to monitor the existing conditions in the area, in the event of an atomic energy accident.
>
> As this graph shows, this system can clearly capture the minute difference in the radiation absorption rates between land and sea, which also makes the system effective for monitoring the radiation in the environment.
>
> In 2003, we are engaged in the development of a dust sampler.” – *Yamaha, REF 60*

Helicopter mounted with a radiation detector	Radiation specimen (fertilizer containing potassium)



Extreme Weather Monitoring

Figure 71 = One would certainly not try to follow the tornado using a manned aircraft. REF 46

- Monitor the onset and progress of a dangerous climatic condition, such as a tornado or hurricane (“storm chasing”), possibly using Laser RADAR to detect turbulence in the atmosphere above both land and sea. No need to drop 20-25 expendable “drop sondes” from a manned aircraft flying in dangerous conditions, since the UAV can fly in, and return from, extreme climatic conditions.

Rescue Effort Supervisor

Figure 72 = Rescue efforts can better be managed through the additional use of real time (ie. immediate) aerial imagery. REF 44

- Provide assistance in the form of an aerial Command and Control Centre to the accident and emergency services at the site of:
  - a rail crash
  - an aircraft crash
  - a multiple car pile-up on a motorway
  - a sinking ship
  - a hostage crisis at a home, an embassy building, a school, …
  - an accident, or, explosion at a nuclear power plant (airborne radiation will only affect the electronics in the UAV after a period of many hours)
  - a fire at a factory, a warehouse, a hotel, or a chemical plant (the UAV can fly through poisonous gases and use thermal imaging to see through smoke)

Figure 73 = Left: remains of Air France flight 358 near Toronto Pearson Airport on 3 Aug 05. REF 45

Figure 74 = Right: view from the air of a road accident. Ref 56

Miscellaneous Applications

- **Small cargo carrier,** typically payload from 10 … 50 Kg:
    - human organs from hospital-to-hospital, for use in transplants;
    - medical supplies to remote and difficult-to-reach locations;
    - blood and urine samples from small remote field hospitals;
    - spare parts, tools and batteries for a remote installation;
    - samples from an exploration site being sent back to base for analysis;
    - letters and confidential documents to and from personnel in remote locations.

- **Aerial photography, including multi-spectral and thermal imaging, of archaeological sites**, to reveal the extent of ancient cities, agricultural activities and the locations of buried objects

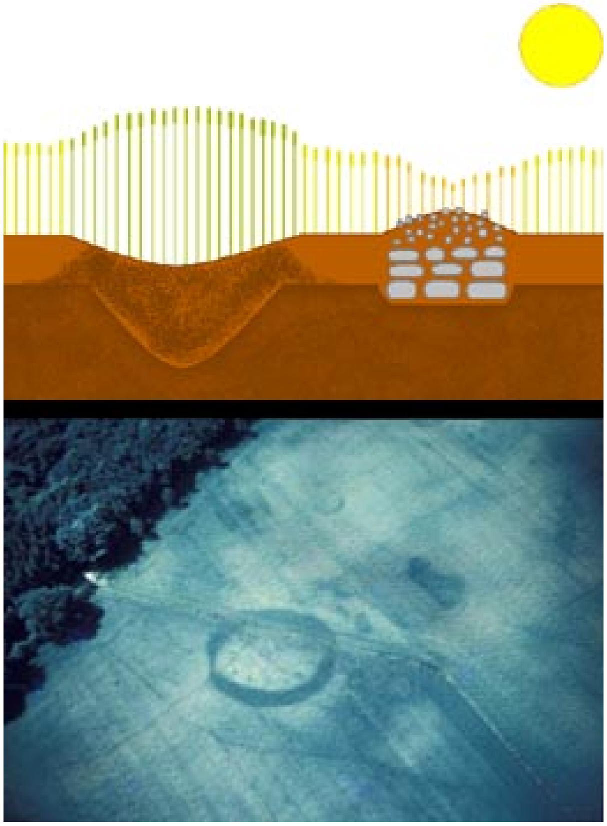


Figure 75 = Upper: soil covered recess, lower: aerial photograph of area. REF 50

Above: detect features buried under soil and vegetation.

- Use aerial photography in **movie making:**
    - Low level imaging of breathtaking scenes on land and sea
    - Reconstruction of past air battles, or, historical aviation achievements
    - Unusual material for innovative and eye catching advertisements

- Use Unmanned Air Vehicles in **pilot training**. After the candidate pilots have practiced using computer based flight simulators, they can graduate to remotely flying Unmanned Air Vehicles, which are far more realistic than any flight simulator. On proving UAV flight proficiency, they can then move on to fly real aircraft.

Damage Estimation I

Aerial photograph of the Northgate Information Solutions plc building damaged by the massive fuel:air explosion at Buncefield on the morning of the 11th December, 2005.

From: http://cryptome.org/hemel-eyeball.htm

- Perform continuous digital elevation mapping using LIDAR of regions that have just experienced an earthquake to monitor the changes in the earth's surface.

- Monitor relief efforts in a region that has suffered an environmental catastrophe, such as an earthquake, a tsunami, a hurricane, a tornado, flooding, or, a drought.

Figure 76 = Trail of destruction left by a tornado. REF 47

Damage Estimation II

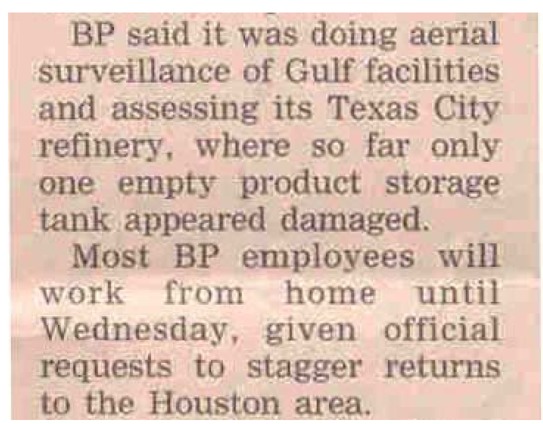
Figure 77 = REF 48

Figure 78 = UAVs were used to monitor the flood damage in the wake of Hurricane Katrina. REF 48

An oil platform ripped from its mooring in the Gulf of Mexico rests by the shore in Dauphin Island, Alabama on Tuesday August 30, 2005 after hurricane Katrina passed through the area. (AP Photo/Peter Cosgrove).	This photo shows flooded roadways as the Coast Guard conducted initial Hurricane Katrina damage assessment over-flights of New Orleans on Monday August 29, 2005. (AP Photo/U.S. Coast Guard, Petty Officer 2nd Class Kyle Niemi).

For insurance purposes and to help emergency relief and recovery services, photograph the consequences of accidents and natural catastrophes. Maintain continuous aerial monitoring of disaster and accident areas **using a fleet of UAVs in a Network Centric configuration** to enable a professional team to efficiently manage recovery efforts.

- flood and earthquake damage
- tornado and hurricane damage (such as after Hurricane Rita, see clipping)
- fire damage



BP said it was doing aerial surveillance of Gulf facilities and assessing its Texas City refinery, where so far only one empty product storage tank appeared damaged.

Most BP employees will work from home until Wednesday, given official requests to stagger returns to the Houston area.

Figure 79 = BP $1 billion Thunderhorse Platform listing at 20° in the Gulf of Mexico. REF 49

- Monitor radio emission spectral density throughout the country

- Measure mobile phone, radio and TV signal levels and quality throughout the country, to enable the cost effective and environmentally sensitive location of communications masts, to ensure adequate coverage throughout the country.

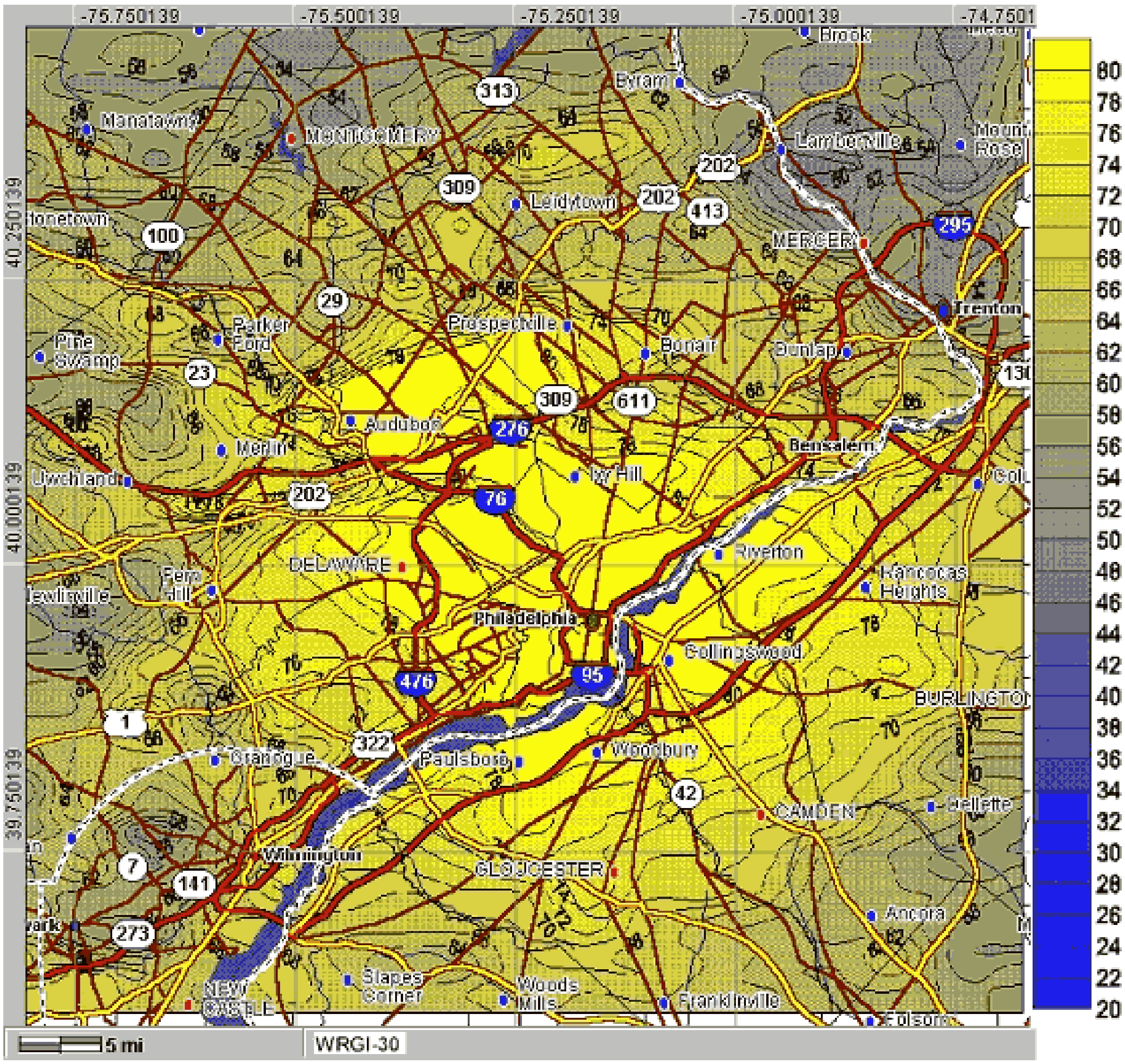


Figure 80 = Received Signal Strength in dBu for Station WRGI in the Philadelphia area. REF 2.

- Provide a temporary mobile phone and Internet LAN base-station-in-the-sky for a remote site or a devastated region, where there is no coverage:
    - where an aircraft, train or a bus has crashed, where people may have wandered from the wreckage.
    - ship-to-shore communications
    - for an oil and gas exploration unit
    - a recurring theme is the loss of mobile phone coverage in a region that has suffered a natural disaster, such as massive flooding or a devastating earthquake.

- Collect data from an array of Zigbee compliant sensors located in a remote region.

- Use Radio Direction Finding (RDF) technology to locate sources of :
    - illegal radio transmissions from the likes of pirate radio stations, commercial operators using unlicensed radio equipment, foreign agents and terrorists…
    - unintentional emissions, such as, electrically noisy motors, ignition systems
    - radio signals that might be interfering with cellular, radio, television or GPS navigation signals;
    - emergency radio beacon signals, as might be used by a “downed” aircraft pilot, a lost explorer, or, by sailors from a ship that has sunk;
    - use a pair of UAVs to track a vehicle fitted with a radio beacon using RDF.

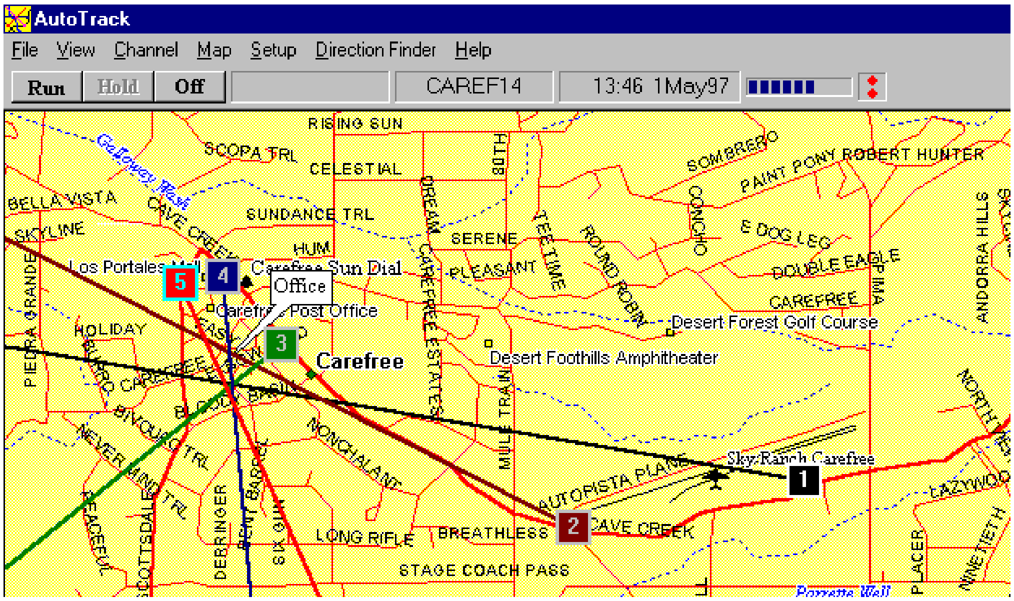


Figure 81 = Indication of the accuracy of RDF, using triangulation to locate the source. REF 39

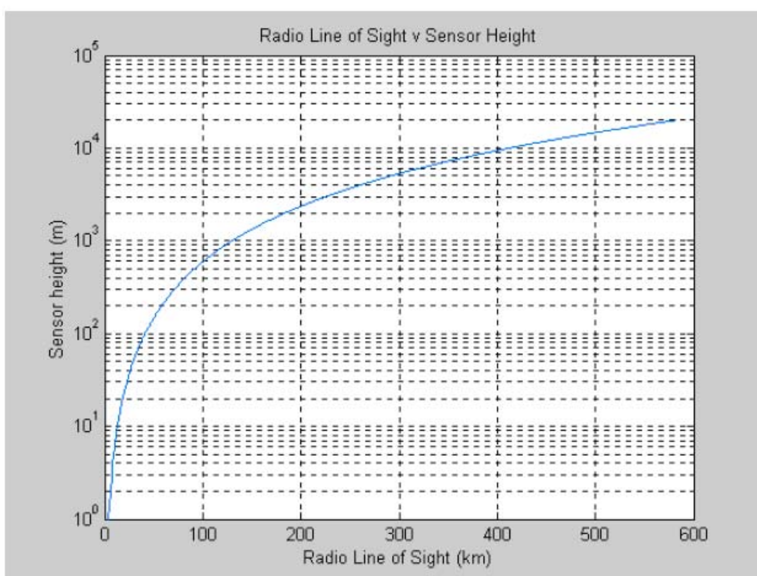


Figure 6: Radio line of sight vs. altitude.

Radio line-of-sight versus altitude, from REF 59.

Geological Surveying

- "In the case of petroleum exploration, wells are seldom targeted using only one exploration method. Seismic surveys are almost always included. As a consequence, there is hardly ever a direct link between a single exploration method and the discovery of hydrocarbons." - BHP Billiton in REF 66

- Geological surveys, for which a UAV is ideally suited to criss-cross a region under computer control for up to 30 hours at a time, using GPS signals and precision flight control, to follow an exact flight path. The UAV is its ability to operate in a "low, slow, fly mode", down to 20 m above ground level to get better resolution. The typical cost of a **manned aircraft survey is in the range from $15 to $20 per line mile**, whereas it drops to **$2 to $3 per line mile for a lower cost, pilotless UAV**.

- The **small physical size** of the UAV and its low metal content relative to that of a manned aircraft enables the UAV to make less of a perturbation to the magnetic and gravitational fields being measured, enabling more accurate measurements of:
  - field strength, and field gradient, measurements:
    - of magnetic field strength ("aeromagnetic")
    - of the vertical and horizontal magnetic field gradients
    - of the differential gravity field (gradiometry)
  - electromagnetic measurements:
    - of electromagnetic phase and magnitude reflection ratios over a wide frequency
    - time domain electromagnetic pulse reflection signal measurements
    - Ground Penetrating RADAR sensing of ground and rock dielectric constant
  - other measurements:
    - gamma ray spectrometer and neutron reflection level measurements
    - using a photo-ionization detector to measure ethane levels in the air
    - high resolution multi-spectral imaging, including thermal imaging

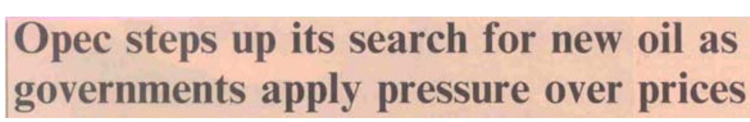
Shell lifts spending to $19bn in hunt for reserves

By Thomas Catan

Royal Dutch Shell yesterday raised its annual spending forecast by 27 per cent to $19bn (£10.8bn), citing increasing costs and the need to find new oil and gas reserves.

Europe's second largest oil company will next year invest at least $4bn more than previously envisaged and said it was likely to keep spending at that level for several years. Shell's increase in expenditure comes as the industry looks to plough more of its record profits into finding and producing oil and gas.

ConocoPhillips and Chevron of the US have both recently announced plans to raise their capital spending in 2006.



Opec steps up its search for new oil as governments apply pressure over prices

- from the Financial Times, 13 September 2005

Subsurface speaks to satellites

Once the expensive preserve of governments and the military, the results of decades of high-tech space and airborne research are now becoming commercially available, helping the oil industry use the skies to unlock the secrets of the subsurface.

AUTHORS
Shell International E&P Staff

Mention satellites and you invoke memories of the dawn of popular science, with Sputnik and Telstar, and the beginnings of the space race. Indeed, early satellites helped proliferate their own popularity, as their first commercial uses were in communications, linking one side of the globe to the other. And though, since the 1950s, myriad satellites have been launched, with most dedicated to recording the many facets of the Earth's surface, a more enduring image of them and their airborne relatives is of secret surveillance and spy planes.

GPS

Dirk Smit, Shell's Global Technology manager, exploration, is keeping a close eye on these emerging technologies. "Most people are familiar with the global positioning system, or GPS," he said. "Developed by the US military, only a low-resolution version was originally made available commercially. This could only be used effectively by professional surveyors — accurate readings took a long time.

"But since the 1990s, the upgraded signals have been made available, and now anyone can have a GPS in their car to show where they are to the nearest few meters. Satellite and airborne measurements of the Earth, such as of the gravitational and magnetic fields, have been possible for many years but have, until recently, given imprecise, ambiguous results. In a similar way to GPS, new hardware, much of it developed by the defense industry, is now becoming commercially available. Put together with processing power of today's computers, which make the Cray machines of the 1980s look like pocket calculators, we now have the ability to stretch the capabilities of remote sensing to the limits and use the techniques to help us look deep beneath the Earth's surface."

Most of these technologies are directly applicable in the remote land areas — deserts and mountains — which are now catching the attention of Shell's New Ventures exploration team. It means that other than the traditional marine exploration hunting grounds, Shell can look to new continental areas that are opening up to the international industry, such as Saudi Arabia and western Siberia.

One such technology is satellite radar. Radar has become increasingly sophisticated, with modern processing producing images with a few meters resolution. New satellites to be launched over the next few years will give further enhancements. The radar images can reveal valuable geological information that might not even be possible to see on the ground, such as faults and fractures and even, using dielectric properties, the rock composition. Vegetation maps can give indications of soil conditions and show naturally seeping hydrocarbons.

Seismic

"None of these methods will show where the hydrocarbons are directly," Smit added. "We must put all the information together to draw our conclusions. As we start to explore large remote land areas, it is important that we use all the relatively low-cost

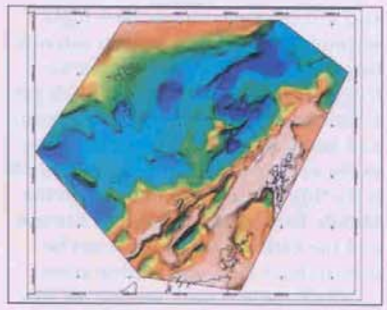


Figure 1. This image shows combined gravity and magnetic readings over the North Sea. (Image courtesy of Shell)

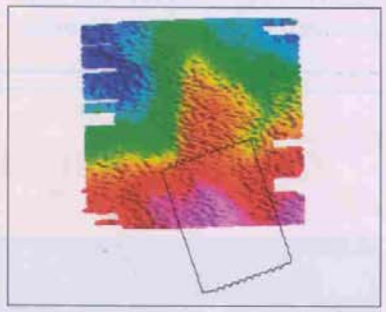


Figure 2. A standard gravity survey image in the Middle East. The black outline shows the area of a gravity gradiometry survey. (Image courtesy of Shell)

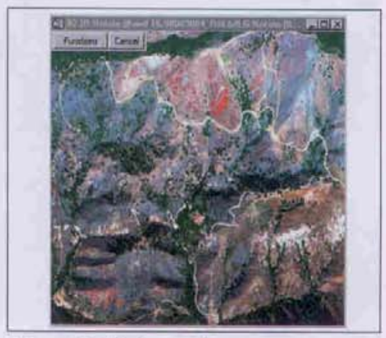


Figure 3. This image shows a hyperspectral survey. Red indicates where hydrocarbons in the subsurface have changed the soil conditions at the surface. (Image courtesy of Shell)

- from Hart's Exploration and Production, June 2005

Frontier Exploration

methods we can to zoom into prospective areas before embarking on expensive and difficult seismic."

Airborne techniques are also fast and still relatively cheap. New high-resolution aeromagnetic data can now be processed by looking at separate frequency bands to estimate the depth to features such as magnetic basement and basalt layers. Faults and fractures in the rocks can also be analyzed. Shell is starting to use this technique in the Middle East, offshore Western Europe and the Gulf of Mexico, as it can be used in both land and marine areas.

Gravity surveys were among the first subsurface oil exploration tools, pre-dating seismic and in use for nearly 100 years. Recent advances have meant that a more sophisticated and accurate version, gravity gradiometry, can now be used in airborne mode, enabling much bigger areas to be covered with greater accuracy than the tedious land-based surveys. The results of gravity gradiometry and high-resolution aeromagnetics can be merged to give us a fast and accurate picture of the geometry of a geological basin capable of generating hydrocarbons.

Airborne

A further future technology is hydrocarbon sniffing, known in Shell as "light touch." "We have proven a vehicle-based system and are now investigating an airborne version," Smit said. "It has to be done carefully to ensure there is no contamination. But ethane, which the technique measures, is only generated by hydrocarbon accumulations, in contrast to methane, which can come from decomposition of decaying matter such as swamp gas. It is possible to use this technique to prove the existence of hydrocarbons in an area even if we can't directly pinpoint the fields.

"All these techniques are part of the ongoing technology integration story," he added. "In the past we have been too fixed on seismic alone. We now consider all the other things available, most of them much less costly than our traditional techniques, to use in our efforts to reduce our exploration costs and risks in an ever more difficult field." E&P

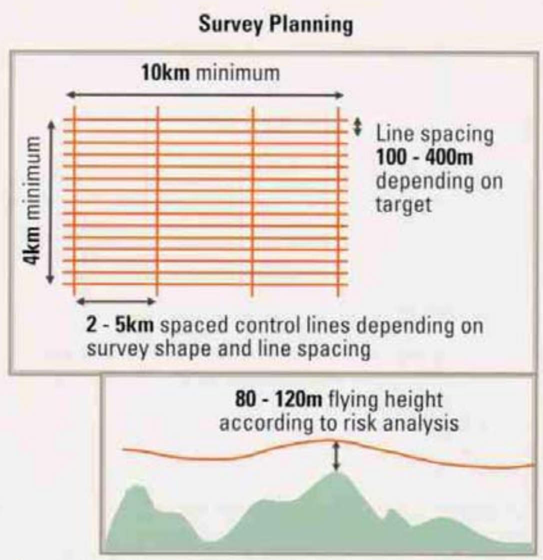
Editor's Note: *This article originally ran in "Changes," a Shell publication.*

In a gravity field survey, performed for example using the BHP Billiton gradiometer, the lower the flight altitude, and the better the plane hugs the ground (known as a "tight drape" in analogy to a curtain covering a non-flat surface) the higher the resolution of the gravity field plot. Low altitude flying is stressful to a pilot, particularly over long periods of time, and is positively dangerous if done at night. This is an ideal application for UAVs.

Logistical Performance

The FALCON™ system provides the means to rapidly and cost effectively map the gravity fields of large and inaccessible areas with the resolution necessary to detect many mineral deposits. Ground surveys that once took years to complete can now be completed in a matter of days. Average production for FALCON™ is 3,000 line km of data per week. Under optimal conditions, with two flights per day, FALCON™ has achieved production of more than 7,500 line km per week (or 1,800 km^2 at 250m line spacing).

There are currently three FALCON™ airborne gravity gradiometer systems in use by BHP Billiton, "Einstein" (commenced flying October 1999), "Newton" (April 2000) and "Galileo" (June 2002). All three systems are mounted in single turbine engine Cessna Grand Caravan aircraft. To provide global coverage and minimise trans-oceanic mobilisations, each of the systems is based in one of the zones, as illustrated on the back cover.



- Typical weekly production 3,000 line km
- Line km costs similar to airborne EM
- Restricted to approved countries (US State Department)

Figure 82 = The FALCON system is a differential gravity meter, or gradiometer. REF 72

The importance of performing aeromagnetic surveys at very low altitudes

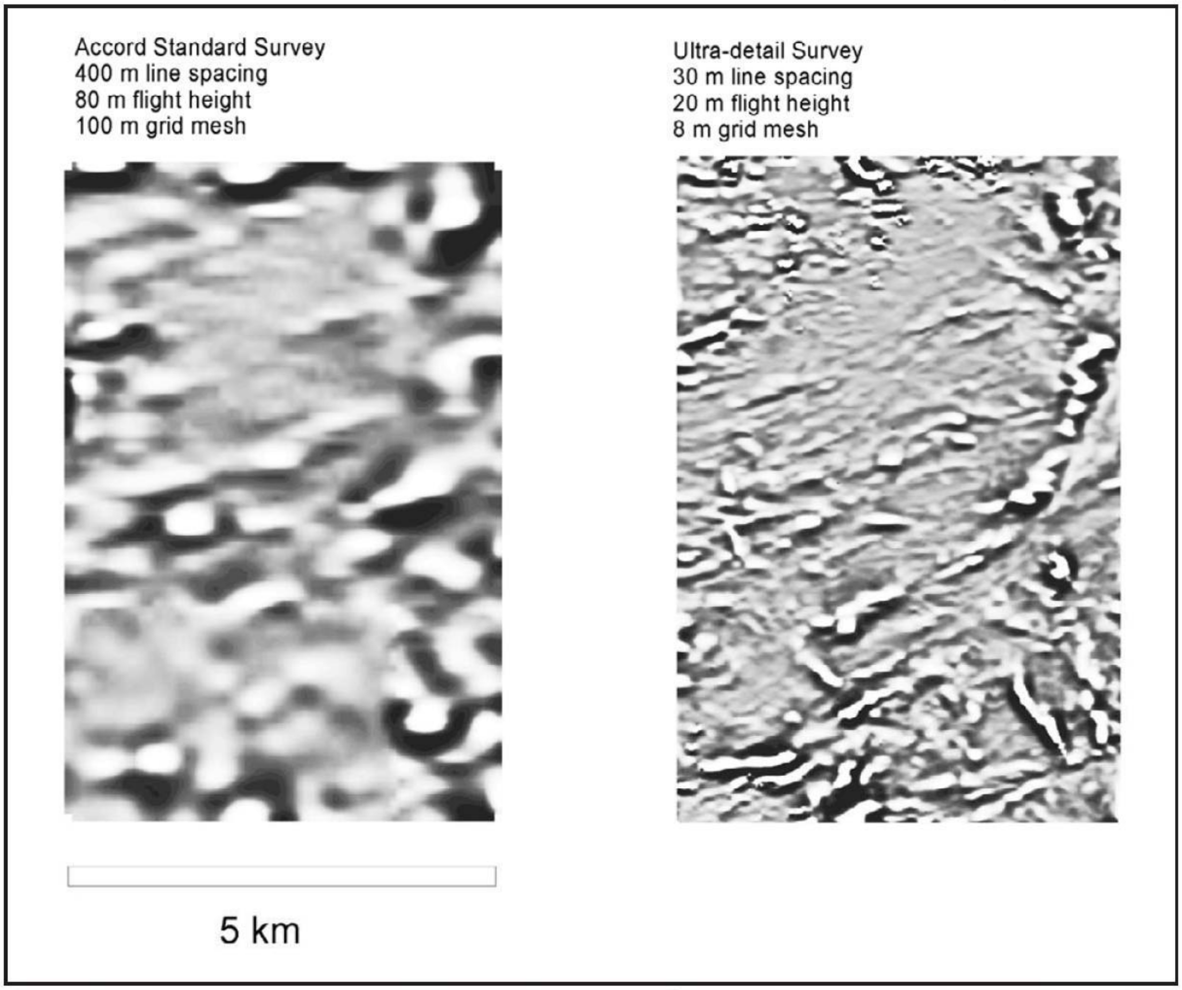


Figure 83 = clearly showing the improvements to be had from low altitude survey work. REF 70

<table>
<tr><td colspan="2">Comparison of regional and ultra-detail aeromagnetic data. High gain, AGC filtered, total magnetic intensity images with conventional grey scale, where white = high intensity.</td></tr>
<tr><td>On the left, flown with a 400m line spacing at a height of 80 m.</td><td>On the right is the same region in which a Cresco 750 crop duster was used to with a 30 m line spacing <u>at a height of 20 m.</u></td></tr>
<tr><td colspan="2">The improvement in anomaly resolution in the right most plot in which a low flying aircraft was used, is striking. <u>This is another area where the UAV excels: low level flight.</u></td></tr>
</table>

“The recent trend towards higher flight heights and loose-drape fixed-wing surveys using conventional aircraft results in unacceptable loss of resolution of small discrete magnetic anomalies, such as those produced by Kimberlites, even in moderately rugged terrain… Clearly for high resolution aeromagnetic surveys in Kimberlite exploration, tight-drape, low level surveys are essential. Aircraft designed to fly at low levels such as the Pacific Aerospace Cresco 750 … have the necessary performance within operational safety limits and provide a cost effective alternative to helicopter platforms, but with a better magnetometer noise envelope.” - REF 70

Use of a "swarm" of UAVs in geophysical survey work

The low purchase price and operating cost, coupled with automated flight capability, opens up the possibility of using several UAVs **at the same time, but sufficiently spaced to minimise the perturbation to the magnetic and / or gravitational fields** to perform a task, such as a geological survey. In order to minimise the extent of the necessary overlap regions in visual and thermal images, advantage is taken of the capability of the UAV to follow a precision flight path in both altitude and position.

To reduce the number of telemetry channels required when many UAVs are in the air, the UAV uses the on-board wireless LAN to communicate with nearby UAVs in a wireless mesh network, with only a minimum number of UAVs maintaining either costly satellite or mobile phone based communication links. The advantages of using a swarm of UAVs are:

- **that it will greatly reduce the time taken to perform a survey**, or task, with parallel operation of imaging and sensor systems with a combined data bandwidth of 4 GBytes / sec for ten UAVs all operating at maximum data transfer rates;
- increased fault tolerance, in that should a UAV or a sensor on a UAV develop a fault requiring it to return to base, then another UAV could continue with the work with minimal interruption to always ensure **the survey work is completed on time**;
- UAVs can repeatedly cover the same area, enabling the build up of an average time dependent representation for an image that might be slowly changing with time;
- the repeated scanning of the same region will allow the use of averaging techniques to achieve a **reduction in data noise levels.** Typically one realises a noise reduction equal to the square root of the number of samples taken.
- The ability to **identify and compensate for any drift or errors** in any of the magnetic or gravitational field sensor systems due to the use of more than one UAV to measure field strength in nominally the same location;
- one can synchronise time for each UAV from a combination of highly accurate, temperature controlled, 10 MHz quartz crystals and precision GPS time signals. The UAVs can then synchronously detect electromagnetic signals, effectively forming a large synthetic antenna, enabling very **high resolution imaging.**

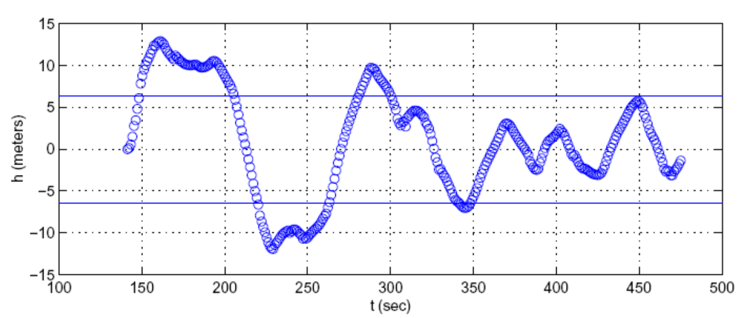


Figure 84 = showing the stabilisation of height control to within +/- 6m. REF 65

Stanford University DragonFly UAV height control at nominal height of 120 m. The excellent control of height allows many UAVs to be flown in one area, if need be.

Figure 85 = A swarm of UAVs ready for a mission. REF 57

A swarm of UAVs, including some back-up planes, could be used in one, or in a combination of any, of the following flight configurations due to their excellent speed and precision flight path control, to complete a high resolution aerial survey in record time:

- **all abreast in a large wing-like formation**, forming effectively a very wide wing (for example, 11 UAVs flying 400 m apart would form a 4 Km wide "wing" containing distributed sensors). Such a "wing" could cover a wide swathe of land to be surveyed at very high resolution with a massive combined data bandwidth.

- in a **planar matrix formation** (such as a 3x3 square or a 1+6+12 plane hexagon formation), forming in effect a large planar antenna, with the UAV at the centre of the formation emitting the electromagnetic stimulus signal, with all the UAVs sensing the reflected signals. The very large synthetic aperture of the UAV matrix will contribute to an increased resolution.

- in a **vertical stack formation**, enabling both near field and far field measurements of magnetic and gravitational fields, and field gradients. Excellent speed and height control means the UAVs can fly very close to each other, if necessary.

- in a **3D cube formation**, such as one formed by 27 UAVs flying in a 3 x 3 x 3 configuration with a 100 m … 400 m spacing. Such a formation can:
  - act as a large volume antenna
  - derive X, Y and Z magnetic and electromagnetic field gradient information
  - perform averaging of measured results to reduce measurement noise

Gravity measurements

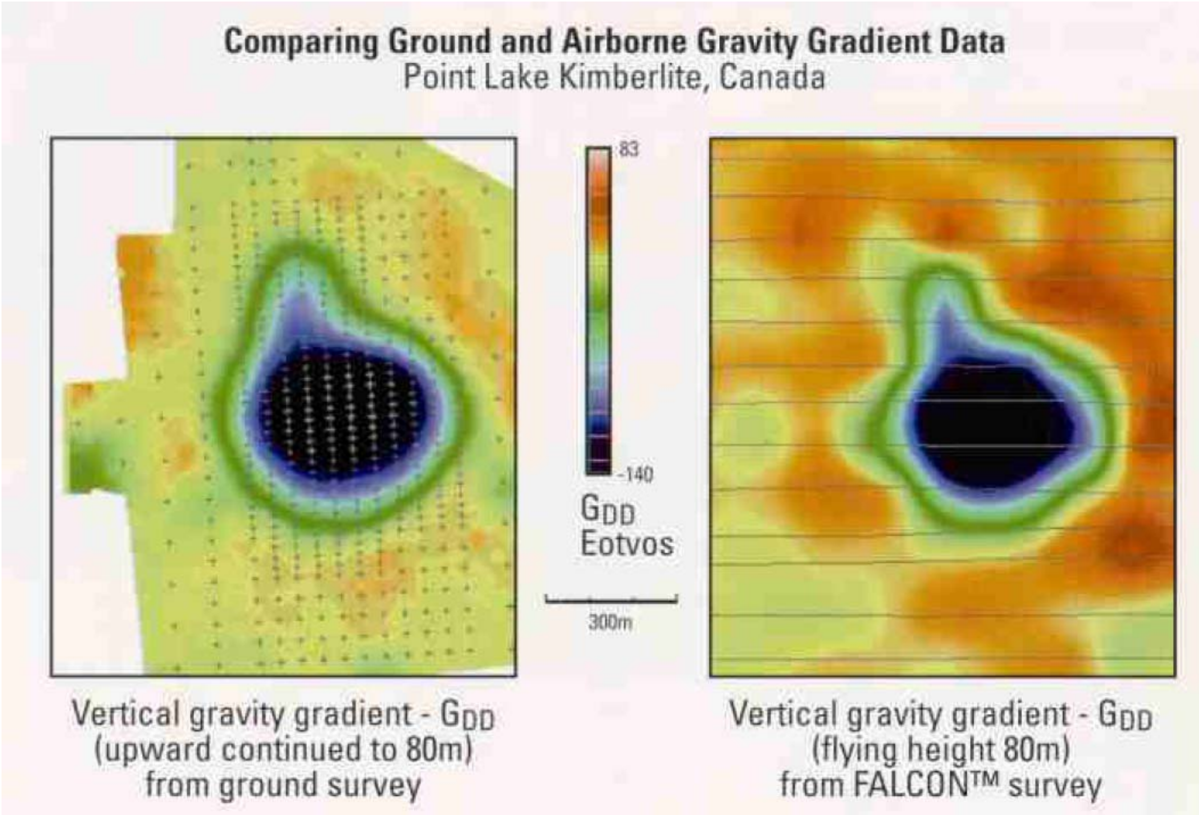


Figure 86 = REF 66

Above can be seen a very good correlation between gravity measurements taken on the ground and in an aeroplane.

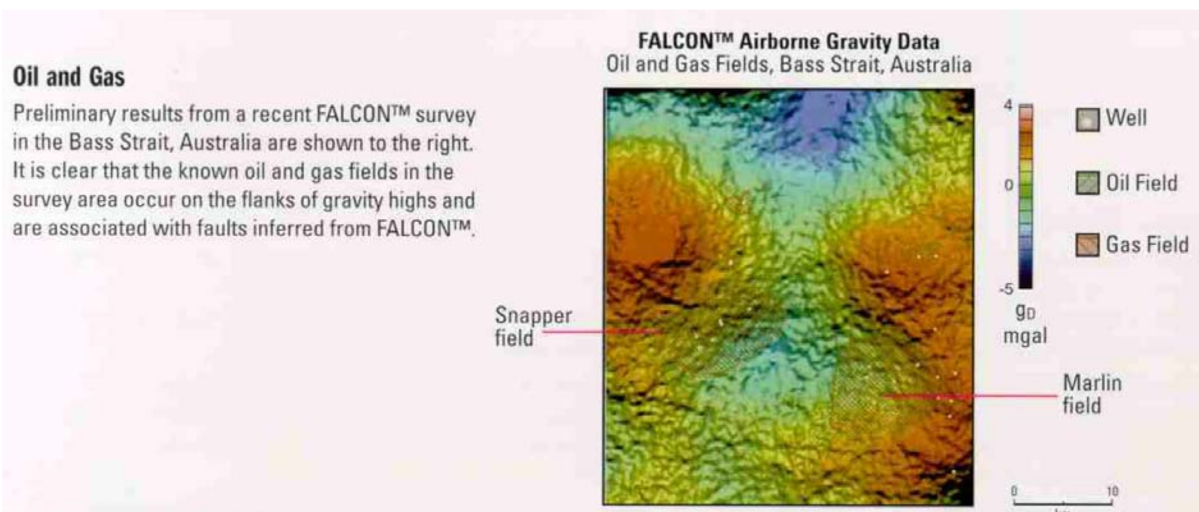


Figure 87 = REF 66

Gravimetric plots show a correlation between the oil and gas fields and the flanks of the high gravity areas. Note that the high resolution differential gravity measuring gradiometer instrument was developed by BHP Billiton of Australia and Lockheed. – REF 66

Differential measurements - suggestion by Tara Schiek at Shell International E & P

Differential tensor gravity, magnetic field, thermal imaging, hyperspectral imaging, precision LIDAR or Interferometric SAR information can be derived from measurements performed at regular time intervals (for example, each day) at the same time of day.

Leakage from a buried pipeline (see Appendix 1)	differential thermal imaging
Depletion of an oil reservoir	differential gravity
Ground deformation following gas extraction	differential Interferometric SAR
Depletion of a mineral deposit	differential magnetic
Leakage of gas from a pipeline	differential hyperspectral imaging

Large area coarse raster scanning and localised high resolution raster scanning

Raster scanning involves the coverage of a typically rectangular area of interest by flying in parallel lines up and down the area of interest. The separation between the parallel lines is typically the same as the altitude, or at most 1.5 times the altitude.

Following an analysis of the data, which can be performed as the UAV is collecting it if the UAV has a suitable communications link back to the Ground Control Centre, areas of particular interest could be raster scanned at an altitude of 20 m to get far higher resolution data of those selected areas. This combination of an initial coarse resolution raster scan followed by selective high resolution raster scans makes best use of time and resources.

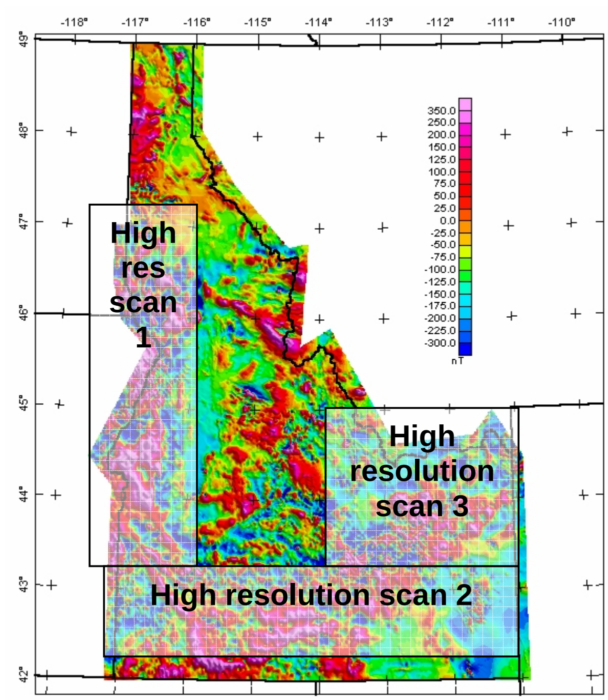


Figure 88 = The whole region receives a coarse scan, after which interesting areas are scanned at a higher resolution. Aeromagnetic map of Idaho, showing anomalies that might indicate the presence of valuable minerals REF 41

Monitoring oil and gas production induced surface subsidence over time

From “Monitoring and Modeling Production-Induced Surface Deformation” by Thomas Herring et al. at MIT http://geoweb.mit.edu/~tah. Presentation was given at SEG 2006.

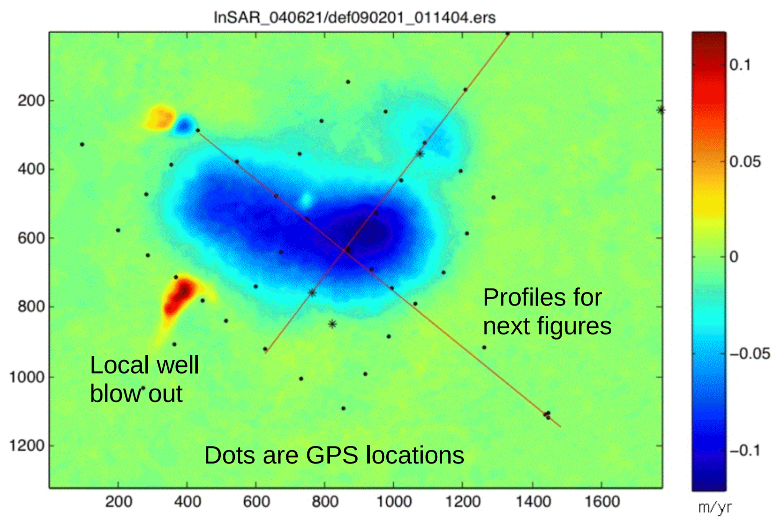
Reasons for subsidence at Yibal in the Oman:

- Major concern was whether gas (which lies above the oil) extraction was causing compaction well above the depth of the oil producing field.

Results from Interferometric Synthetic Aperture RADAR (InSAR) on ERS2 satellite:

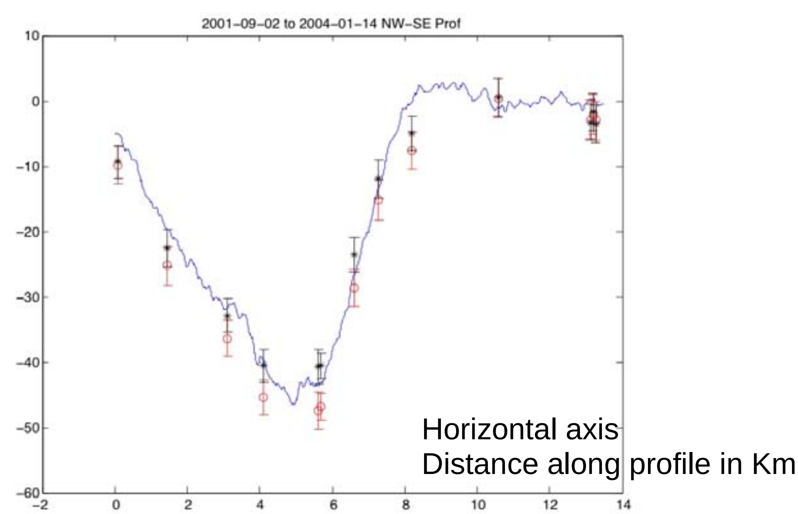
- These results give snap shots of the deformation between two times. The arid conditions in Oman allow long separations of the images.
- Measurements are line-of-sight changes, and are affected by orbit error, orientation and atmospheric delays. The data quality would be improved by mounting the InSAR on an Unmanned Air Vehicle.

InSAR derived indication of land deformation (09/2001-01/2004)



Good agreement in NW_SE profile below between subsidence rates derived from precision GPS (points + error bars), and those derived from InSAR (continuous line).

Vertical axis
Subsidence rate
(mm/yr)



Monitoring the presence of whales during ocean based seismic activities

"Offshore Seismic Activities in the Beaufort Sea

AGENCY: National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), Commerce.

ACTION: Notice of issuance of an incidental harassment authorization.

SUMMARY: In accordance with provisions of the **Marine Mammal Protection Act (MMPA)** as amended, notification is hereby given that an Incidental Harassment Authorization (IHA) to take small numbers of bowhead whales and other marine mammals by harassment incidental to conducting seismic surveys in the Western Beaufort Sea in state and Federal waters has been issued to Western Geophysical/Western Atlas International of Houston, Texas (Western Geophysical)."

- from http://www.epa.gov/fedrgstr/EPA-SPECIES/1999/July/Day-30/e19462.htm

Figure 89 Silver Fox UAV from Advanced Ceramics Research Inc.

From http://uas.noaa.gov/silverfox/SilverFoxdemoSOWv8-1.pdf by Steve Gittings et al. at NOAA. Interestingly, the NOAA has a very encouraging view of the potential applications of Unmanned Air Systems (UASs).

UASs are a relatively new asset available to NOAA research and operations. The importance of adding UAVs and newer technology to NOAA's mission is described in the 2007 Annual guidance Memorandum from the NOAA Administrator (VADM Lautenbacher):

> "*We must move new but proven observing systems into an operational environment and redirect associated resources and research toward exploring new technologies, such as unmanned aerial vehicles, to meet future requirements*."

The Silver Fox was originally developed to keep whales out of harm's way during naval exercises. The firm is working to give the UAV 24-hour endurance, a 1,500-mile range and a maximum altitude of 10,000-feet by 2004. The firm expects each UAV to cost $20,000 in series production.

From http://www.auvsi.org/iraq/index.cfm

Magsurvey Ltd is a UK company now offering an exciting new technology for explorers wishing to conduct high resolution magnetics surveys.

The Prion Unmanned Air Vehicle (UAV) collects magnetics data at a resolution only previously available from detailed ground or helicopter surveys, and without risk to life. It can be used at low altitude and in hostile environments that would be too dangerous for manned flying.

For mineral surveys over many small grids within a region, or where poor visibility due to dust, rain, cloud and so on restricts aircraft operation, Prion is ideally suited as it is not subject to the same flight time constraints.

With the advantage of total portability, a field system which typically consists of several aircraft can be mobilised anywhere in the world without the major costs associated with helicopter and fixed wing manned operations. Thus mine site geologists wishing to detail a small area, or grass roots explorers needing to assess the magnetic responses in a new region, now have an affordable choice.

The Prion is designed to operate in a wide range of terrains, and can be launched by catapult within confined spaces, or for marine surveys. Data is processed in-field, following strict quality control guidelines, with final processing undertaken in the UK.

Prion Unmanned Air Vehicle

The Prion (UAV) is the result of 7 years of research and development by MagSurvey Ltd, involving collaboration with leading aerospace and geophysical contractors. It is built largely of lightweight and strong composites, and is designed to be magnetically ‘clean’ to ensure minimal effect of manoeuvres on the magnetics data.

Recent advances in miniaturization allow the UAV to carry a wide range of payloads, without compromising safety. With its modular design the Prion can be configured to optimize the client needs, whether for ultra low level data, smaller spacing or for use at high altitudes.

Specifications:

Fuselage Length:	2 metres
Wing Span:	3 metres
Weight:	30 kg
Air Speed:	90 Kmph
Magnetometer Type:	Cesium Vapour
Magnetics Sample Interval:	0.1 seconds, 2.5 metres

Payload:

- Fluxgate Magnetometer
- Cesium Vapour Magnetometer
- Real Time Differential Global Positioning System
- Altimeter
- Video

- from http://www.magsurvey.co.uk/priondetails/priondetails.htm

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The GEORANGER Unmanned Air Vehicle from REF 67

Fugro Airborne Surveys performs high-resolution aeromagnetic surveys using state-of-the-art Unmanned Airborne Vehicles for the petroleum and mining industries. The GEORANGER UAV was developed in co-operation with the Insitu Group Inc., a pioneer developer of long-range, unmanned, autonomous aircraft.

❑ Capable of fully autonomous flight. ❑ Endurance of over 10 hours.	
❑ Cruises at 75 kilometres per hour. ❑ Can be operated from undeveloped sites in close proximity to survey areas, using the patent-pending point-location launch and recovery systems.	
❑ Full error-analysis capability, providing a return-to-base command in the event of difficulties while in flight.	
❑ VHF and / or Iridium satellite communications providing the operator with continuous system status, position and velocity updates.	

Speculative Applications

Pouring oil on troubled water really does work

"METRO" 26 JULY 2005

BY SARAH HILLS

SCIENTISTS have confirmed what sailors could have told them years ago – that pouring oil on troubled water helps calm a storm.

And a modern-day equivalent could be developed to help take the sting out of hurricanes.

For hundreds of years, barrels of oil were tipped into the sea during a squall to make the water less choppy.

Now scientists think the oil may also prevent winds from strengthening by stopping spray flying into the air.

A mathematical model has shown that tropical storms draw extra strength from water droplets thrown into the air by waves.

But the process can be disrupted by pouring oil on the surface, a group of US and Russian scientists have found.

Prof Alexandre Chorin, who led the team at the University of California at Berkeley, said: 'Since antiquity, seamen have had barrels of oil on the decks of their vessels ready to throw oil on the sea in critical moments of stormy weather.

'We now think the oil prevented water droplets from forming and helped reduce the intensity of the squall.'

He added: 'Perhaps hurricanes can be similarly prevented or damped by having aeroplanes deliver fast-decaying harmless chemicals to the right places on the sea surface.'

The findings were published in the Proceedings of the National Academy of Science journal.

Figure 90 = Pouring bio-degradable oil on the ocean may prevent the formation of a hurricane REF 51

- One could conceive of a swarm of heavy payload UAVs, each with a 50 Kg payload of bio-degradable oil, **spreading the oil on the sea in the vicinity of a hurricane** to either divert the hurricane to less densely populated areas, or, attenuate the hurricane altogether. One readily thinks of the damage caused by the hurricanes in the Caribbean, the Gulf of Mexico and the south eastern USA. Detecting the early build up of a hurricane would enable preventative measures to be initiated.

- Investigate **new geological mapping techniques**, such as use of:
  - Ultra Wideband (UWB) electromagnetic signal probing of the earth, where the UWB signal is transmitted from one UAV, with several UAVs monitoring the reflected signals as a function of time, so increasing spatial resolution;
  - Magnetic Resonance Imaging (MRI) to measure the resistivity of the earth as a function of depth to locate possible oil and mineral deposits;
  - neutron backscattering from hydrogen atoms to detect the presence of hydrocarbon deposits. Since no pilot is present in the UAV, no one will be exposed to the radiation for any length of time.

- Use LIDAR and millimetre wave RADAR to **detect other Unmanned Air Vehicles**, heading towards crowded venues. One could then destabilise or destroy a suspect UAV, using progressive GPS signal skewing, an intense electromagnetic pulse, or an explosive shock wave to shear the wings from the suspect UAV. Terrorist organisations have been known to use Unmanned Air Vehicles: "*Unmanned aerial vehicle (UAV) of Lebanese extremist organization Hezbollah intruded into Israeli airspace on November 7, 2004 approximately at 10:30 am local time." …* REF 15.

Appendix 1

Monitoring of oil leakage from pipelines

a. Introduction

The official opening (cutting from Financial Times) of the 1,768 Km Baku-Tbilisi-Ceyhan (BTC) pipeline in which BP is the leading shareholder with a 30.1% shareholding prompts the thought as to how a leak might be detected in the £ 1.8 billion pipeline. Here is a suggested way in which to detect leakage in a cost efficient manner.

BTC pipeline the 'new Silk Road'

By Vincent Boland in Baku

A pipeline that will carry oil for the first time from the Caspian sea to the Mediterranean was opened yesterday, marking the emergence of the Caspian region as a new force in the world's oil markets.

Hailing the biggest investment in the region since the collapse of communism, the leaders of Azerbaijan, Georgia and Turkey turned on the taps of the Baku-Tbilisi-Ceyhan (BTC) pipeline linking the three countries.

"This is the Silk Road of the 21st century," said Ahmet Necdet Sezer, Turkey's president, at the opening ceremony, held in sweltering heat at the Sangachal oil and gas terminal about 40km south of Baku.

The $3.2bn (€2.5bn, £1.7bn) pipeline will carry 1m barrels of oil a day when it is fully operational by the fourth quarter of this year, and more if, as expected, Kazakhstan joins the project in the near future.

Lord Browne, chief executive of oil major BP, the biggest shareholder and investor in the BTC pipeline with a 30.1 per cent stake, said in an interview that the project was "an important piece of the jigsaw of the world energy market".

As well as bringing together the presidents of Azerbaijan, Georgia, Turkey and Kazakhstan, the opening ceremony also attracted Samuel Bodman, US energy secretary, an early champion of the project for geopolitical reasons, including a desire to enhance the independence of former Soviet republics from Moscow.

The pipeline's circuitous 1,770km route through some of the most mountainous territory in the Caucasus bypasses Russia, which dominates routes to western markets for oil from the Caspian and central Asia.

Russia was a notable absentee. Lukoil, one of the country's big oil companies, was an investor in the project but sold its stake to Itochu of Japan two years ago.

Oil industry analysts said it was significant that Moscow did not try to block the pipeline, although it often voiced doubts that the project would be completed.

The pipeline also deepens the isolation of Armenia, which has fought a war with Azerbaijan and has no diplomatic relations with Turkey.

Ilham Aliyev, the Azeri president, said the pipeline would bring economic benefits to all participating countries.

He also vowed to restore Azeri sovereignty to the disputed enclave of Nagorno Karabakh, currently occupied by Armenia.

Some diplomats read this as a hint that some of Azerbaijan's new-found oil wealth might be spent on the country's military.

The opening came more than 10 years after the BTC project was announced. If it had not been built, Caspian oil would have had to be shipped through the crowded Bosphorus strait that runs through the centre of Istanbul.

Turkey is pressing for an end to tanker traffic on the strait, which is still used to ship large amounts of Russian oil.

The Caspian's oil reserves, though not as vast as initially hoped, are said to equal those of the North Sea.

World's reformers, Page 19

On a roll: celebrating at yesterday's opening of the BTC pipeline were (from left) Turkey's President Ahmet Necdet Sezer, President Mikheil Saakashvili of Georgia, US energy secretary Samuel Bodman, President Ilham Aliyev of Azerbaijan and BP's chief executive Lord Browne AP

Figure 91 = Lord Browne of BP (right) meeting with local politicians

b. The suggested solution

Use a small Unmanned Aerial Vehicle (UAV) on which is mounted a small thermal imaging camera to fly autonomously along the pipeline just after sunset to record the thermal images of the ground, from which one can deduce the thermal heat capacity of the ground around the pipeline.

Just after sunset there will be a drop in temperature, just as there will be an increase after sunrise, and one can interpret the thermal images to estimate the heat capacity of the ground. If these images are taken once a day, one should be able to detect leakage from any of the 60,000 pipeline joints (according to the Sunday Times article) as a change in heat capacity of the ground in the vicinity of the leaking joint.

In fact, one should have a time dependant view of the changes. This suggested approach rests on the heat capacity of the oil and the ground being different from that of the ground alone.

c. Pipeline overview

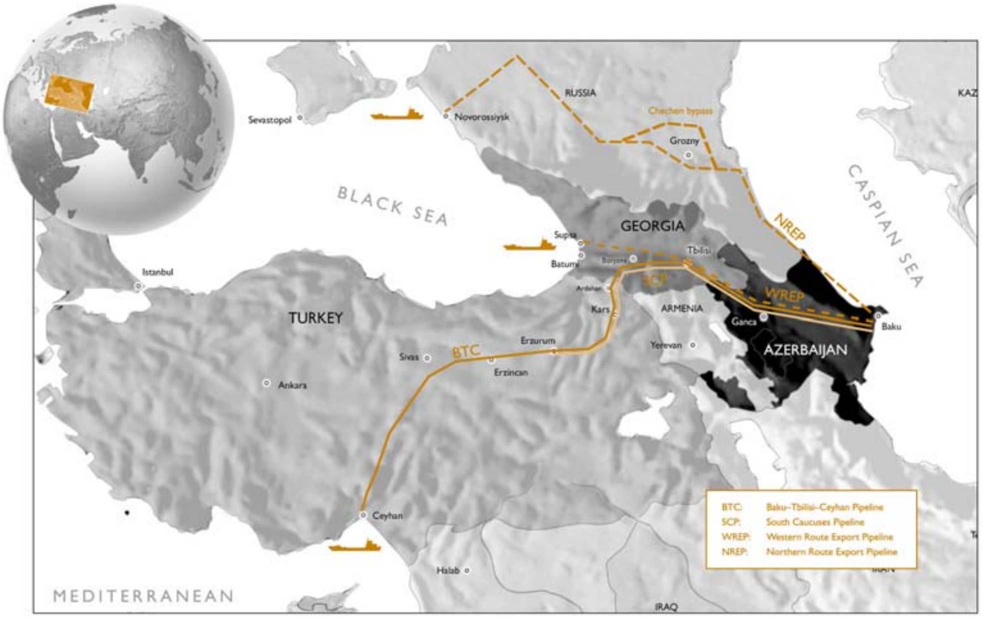
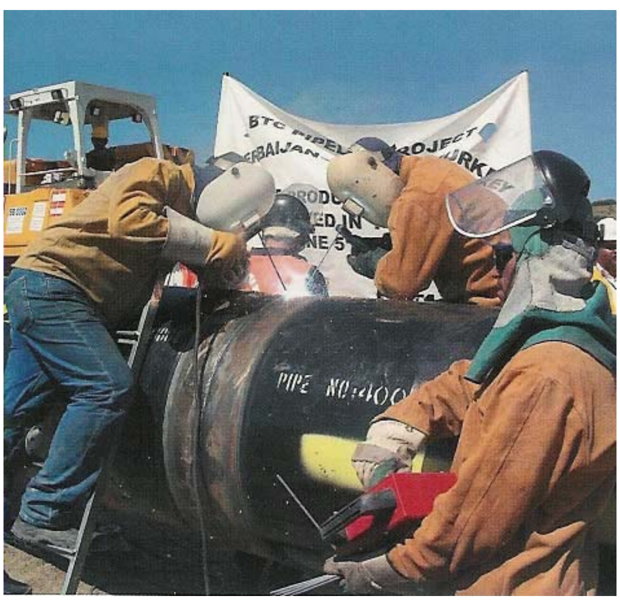


Figure 92 Route of the BTC pipeline

The BTC pipeline route through Azerbaijan, Georgia and Turkey

Features

- 1,768 Km long
- 655,000 tons of steel in over 150,000 steel pipes from Sumitomo
- 8 pumping stations
- Capacity of 1 million barrels per day
- Operational in May 2005



The first weld…

d. What would be involved

The average speed of first FAI Class F / F3A Model Plane to cross the Atlantic was 77.7 Kph as it flew from Canada to Ireland. TAM5 flew an incredible 3,020 Km relying on a GPS unit for guidance. In the TAM 5, a 10 cc four stroke model aircraft engine was used as the propulsion source for the 5 Kg fully fuelled weight of the plane.

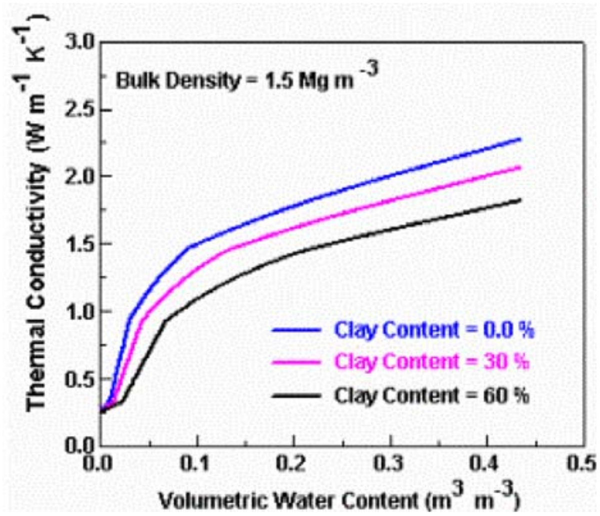
Since it would take a small plane flying 80 Kph roughly 22 hours to fly the length of the pipeline, it may be better to simply fly between pumping stations, including the end points of the pipeline. With 8 pumping stations, one would estimate an average distance between pumping stations of 221 Km. A small plane flying at 80 Kph would take 2 hours 45 minutes to cover the average distance between pumping stations. This is a more realistic proposition, but would require at least 8 small planes to scan the entire pipeline in under 3 hours. Issues one would need to address are as follows:

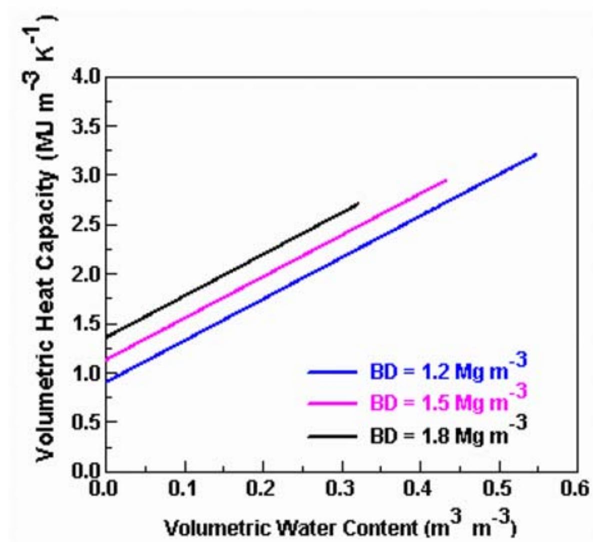
- Use both thermal and visual imaging systems on each UAV.
- Use GPS navigation, with an inertial guidance system as a back up.
- Use satellite telemetry, with GSM mobile phone as a telemetry back up.
- Use automated take-off and landing so skilled air staff will not be required to operate the regular flights: all someone will need to do is to add fuel and start.
- Make sure the plane is designed not to cause damage or injury should it crash (for example, run out of fuel, or electric power, or whatever).
- Make sure international boundaries and regulations (including use of air space, and permitted noise levels) are adhered to.
- Might need to use a low vibration Wankel engine to propel the UAV rather than a four stroke engine for improved imaging quality.
- Use computer based image analysis to help in the spotting of a spreading sub-surface oil leak from any part of the pipeline.

In the first instance, one would construct a 3D computer based thermal model of the buried pipeline and surrounding soil complete with heat capacity and thermal conductivity data for the materials in the vicinity and along the pipeline. One would also need to monitor the temperatures at various depths along the pipeline to determine the heating effect of the sun's rays during day time, and the rate of cooling as a function of depth and location along the pipeline during the night time.

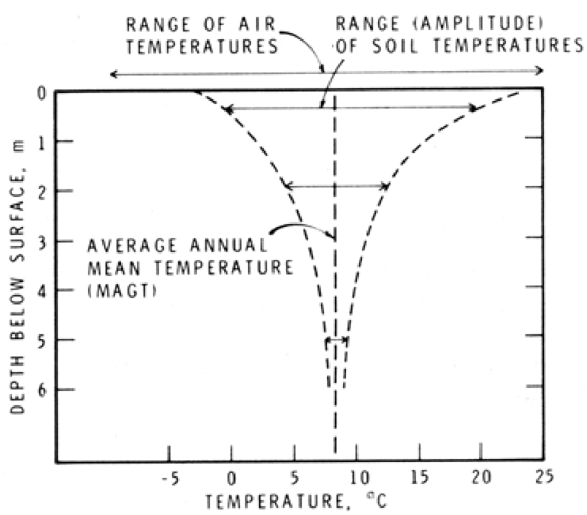
With a combination of the computer model and measurement information, one would relate the minimum sensitivity of a thermal imaging system to the size of the leak that could be detected. The measurement information would also be used to determine the best time to perform the thermal imaging, intuitively, just after sunset.

Above is shown a small, uncooled, thermal imaging camera from FLIR Systems which has a thermal noise level of less than 85 mK and weighs < 120 grams.



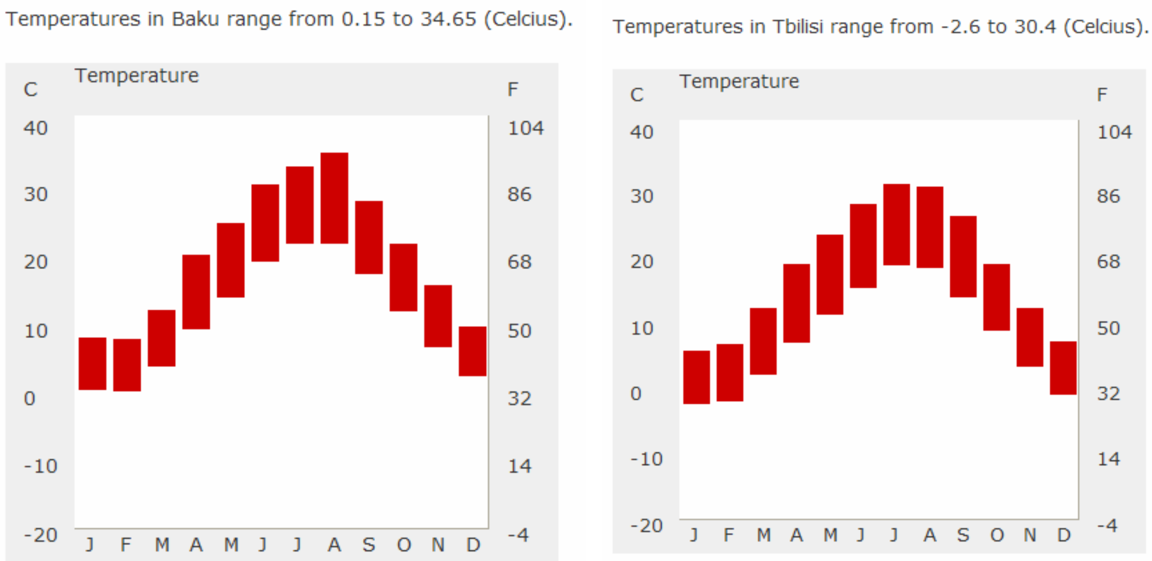


Above: change in thermal conductivity as water is added to soil	Above: change in volumetric heat capacity as water is added to soil.
From "Soil Temperature Changes with Time and Depth: Theory" by D. L. Nofziger. One might expect a similar effect as oil (from a leaking pipe) is added to soil.	

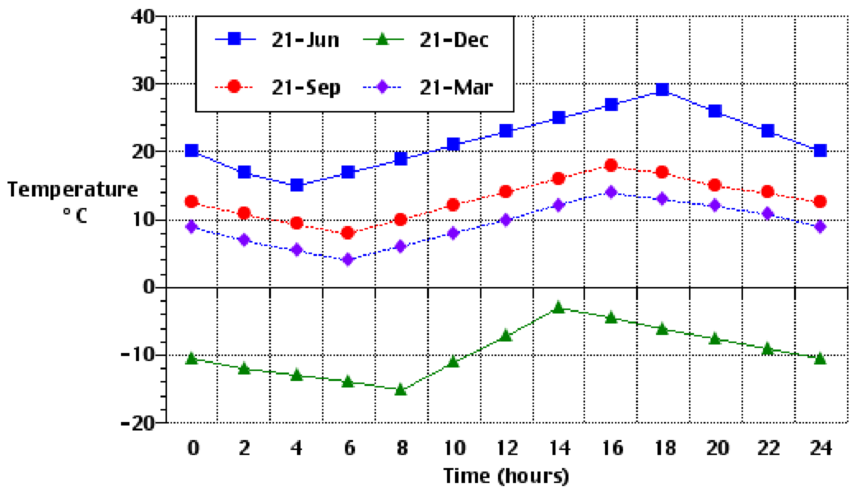


Above: depth dependence of the annual range of ground temperatures Ottawa	Above: the BTC pipeline seems to be buried no more than 3 m down…

"The amplitude of a temperature variation at the surface is normally about equal to that of the corresponding one for air. It decreases exponentially with distance from the surface at a rate dictated by the time necessary for one complete cycle. This behaviour is shown above for the annual temperature variation. For depths below 5 to 6 m, ground temperatures are essentially constant throughout the year." – Canadian Building Digest, "CBD-180. Ground Temperatures" by G.P. Williams and L.W. Gold.



Annual temperature range in Baku and Tbilisi - from www.world66.com



Hourly variations in surface temperature for a location at 45° North latitude over a 24 hour period. – from www.physicalgeography.net

From the above information, it seems that we would need to:

- have a thermal imaging resolution of less than 1 K (see NEdT data below)
- make use of differential thermal imaging
- use a computer to compare images taken of the same region on different days
- use advanced data fusion techniques such as Kalman filtering.

Camera Name	λ um	NEdT	Pixel H x V	ADC enob	FPS
FLIR Phoenix MID	1 – 5.4	< 25 mK	640 x 512	14 bits	25
FLIR Micron	7.5 – 13.5	< 85 mK	160 x 128	14 bits	100

NEdT = Noise Equivalent differential Temperature
ADC enob = effective number of bits in the Analog-to-Digital converter (ADC)

f. Examples of existing approaches

The approach involving the use of thermal imaging has been used in Russia according to the information quoted next from agp@aerogeophysica.com:

Mapping and condition diagnostics of product pipes, including leakage point detection. First of all, oil and gas pipelines are sometimes as long as thousands of kilometers. Due to their increased temperature compared with the environment, they form detectable thermal contrasts, even under ground. Our experience proves that survey can be carried out at a low flight altitude (up to 100 m) and with an actual resolution of 0.1 - 0.2 m. Images of such quality clearly show pipeline thermal traces, watered sites (high corrosion danger), hydrant stoppers. Leakage points look different. They have a high contrast, and are very cool due to adiabatic gas extension in gas lines: they are warmer than the environment in oil pipelines. Sites of oil spills are easily mappable.

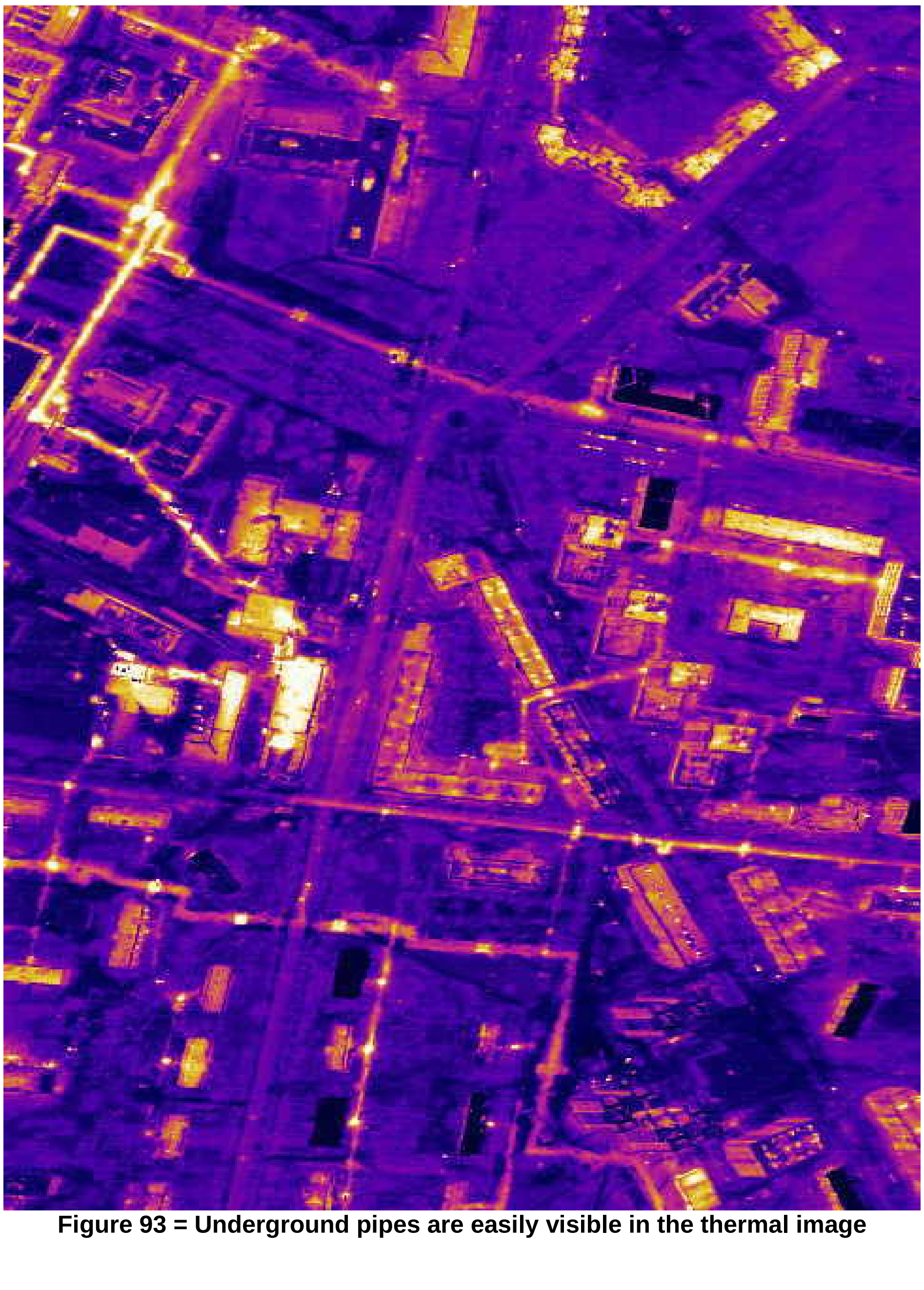


Figure 93 = Underground pipes are easily visible in the thermal image

APPLICATION OF GIS AND AERIAL THERMAL IMAGE PROCESSING METHODS TO SOLVE ENVIRONMENTAL PROBLEMS OF THE OIL INDUSTRY

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During 30 flights some leakages were discovered, and not only the position of the leakages could be determinated by the utilization of GIS environment, but the size and the type of the leakages were also measured and described (Fig.5.)

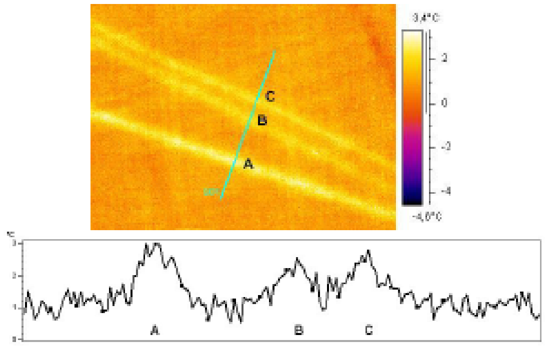


Fig 5 Thermal image of parts of pipelines and a typical thermal section of them

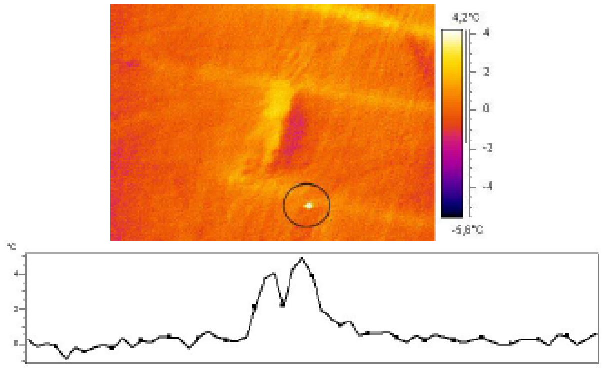


Fig 6. Localization of a "hot" leakage on a thermal image and its thermal section

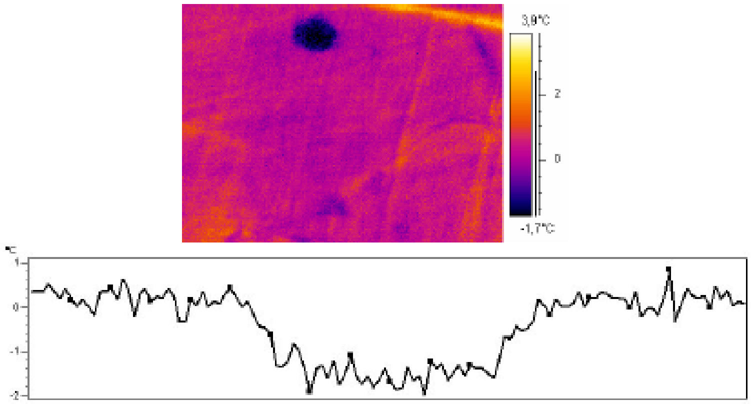


Fig 7. Localization of a "cold" leakage on a thermal image and its thermal section

Leakage from pipelines as detected by thermal imaging.

g. Limitations and extensions to this suggestion

Time varying thermal properties of the soil around the pipeline would make it far more difficult to make any meaningful interpretation. Such variations are:

- Rainfall increasing the thermal conductivity and heat capacity of the soil.
- Growth / death of vegetation changing the emissivity of the land surface.
- Leaking oil might preferentially leak along and under a stretch of pipe, before diffusing laterally away from the pipeline, making early detection of a leak difficult, although the leak could be detected once lateral spreading occurred.

The effect of rain might be interesting. Should a leak occur, some leaking oil might seep to the surface should rain have dampened the ground to the point at which the moisture contacts the leaking oil. The small amount of oil that might reach the surface could change the emissivity of the surface, and potentially could be detected.

If we were to regularly scan the entire length of the pipeline from a low flying UAV, we could use additional sensing schemes to detect leakage from a buried pipeline:

- UWB (Ultra Wide Bandwidth: from 3.1 GHz to 10.6 GHz, -41.3 dBm/MHz) surface penetrating impulsive probing of the soil along the length of the pipeline to detect changes in reflected waveform caused by leaking oil
- Reflection complex impedance measurements of the ground along the pipeline, looking for change in complex impedance of the soil caused by leaking oil
- High resolution (low ppb to hundreds of ppm) photo-ionization (Krypton 10.6 eV lamp) based gas chromatography to detect benzene, toluene, ethylbenzene, m-xylene and other volatile organic compounds leaking from the pipeline

h. Discussion and conclusion

The suggestion is that a leak from a pipeline could be detected as a consequence of the increase in heat capacity of the **soil + oil** relative to that of the **soil** alone, suggesting that regular thermal imaging of the land in the vicinity of the pipeline just after sunset should reveal the different thermal properties attributable to the leakage.

Computer software would need to be used to automate the interpretation of the data, and the availability of regular imaging data will increase the sensitivity of the data through the use of averaging techniques to enable small differences in heat capacity of the soil to be detected on a day-by-day basis.

The use of autonomously guided, UAVs with an on-board thermal imaging camera to map the ground temperature would be a particularly energy and cost effective way in which this task could be routinely performed with minimal atmospheric pollution:

- the TAM 5 would have used only 1.33 Kg of fuel to fly the BTC pipeline
- no pilots are needed, and the takeoff and landing can be automated
- 16 planes would be needed to have a spare at each pumping station
- automated data analysis could take place anywhere in the world

Appendix 2
Unmanned Air Vehicle milestones

a. Drones may aid Arctic oil exploration — REF 73

by ALAN BAILEY, published in Petroleum News November 8, 2006

With heightened interest in offshore oil and gas exploration coinciding with elevated awareness of the need to protect marine wildlife, oil companies are scrambling to find ways to meet government requirements for wildlife protection. And, in the Alaska Arctic, the protection of Native subsistence hunting of marine mammals such as the bowhead whale is a major issue.

For this year, the National Marine Fisheries Service issued "incidental harassment authorizations" that included requirements for aerial surveys or acoustic monitoring of underwater sounds, to detect the presence of marine mammals and avoid harassment of those mammals. The IHA stipulations include, under some circumstances, a new requirement to monitor a zone within which the sound from the seismic air gun shots would exceed 120 decibels. In earlier years, monitoring was only required in a zone with sound levels exceeding 180 decibels; the new 120-decibel requirements greatly increase the area to be monitored to huge expanses of ocean.

"Conoco Phillips was definitely unwilling to fly manned aircraft in the Chukchi Sea," Michael Faust of Shell told the NMFS at a recent meeting on Arctic open-water seismic activities. "We just basically made the decision that ... we don't think we can rescue someone if they go down."

Conoco plans to start testing the drone technology in the Chukchi or another suitable location off the shores of Alaska this year. And Shell plans to use military airspace in Washington's Puget Sound this winter to test drone wildlife surveillance. "We believe we're really on the cusp right here of ushering in a new era in research and mammal monitoring," Faust said. "We believe that this technology is going to move forward very rapidly and be extremely important for monitoring in remote areas."

b. FAA certifies Raytheon Cobra test UAV — REF 40

TUCSON, 3 November 2006 (UPI) -- The U.S. Federal Aviation Administration has certified the airworthiness of Cobra, an experimental UAV being developed by Raytheon.

The FAA ticket allows the new UAV to begin test flights in airspace over southeastern Arizona. Thursday's announcement cast some new light on the Cobra project, which is being undertaken by Raytheon units in Arizona, Texas and California. Cobra is being created as a test bed for the development of new sensors, communications networking and airframe designs for integration into other UAVs. It allows new technology to be checked out without removing operational UAVs from the field.

"The Cobra will significantly decrease costs and compress schedules for bringing new technologies to market," said Raytheon Vice President Ken Pederson. The 9-foot-long aircraft has a wingspan of 10 feet and is the first UAV of such a relatively small size to receive an Experimental Airworthiness Certificate from the FAA.

Figure 94 http://www.engadget.com/2006/11/02/raytheon-announces-new-uav-cockpit-setup/

FALLS CHURCH, Virginia, 1 November 2006 (UPI) -- A new remote "cockpit" has been developed to give operators of unmanned aerial vehicles (UAVs) a better view of what is going on around the aircraft.

Raytheon Tuesday unveiled the Universal Control System (UCS), which was built with heavy input from UAV operators and borrowed advanced intuitive interface technology from the high-tech video game industry.

"We took the best-of-breed technologies from the gaming industry and coupled them with our 35 years of command-and-control expertise and developed a state-of-the-art universal cockpit built around the operator," Raytheon's Mark Bigham said at an industry conference outside Washington. "We broke down the operator's tasks and objectives and constructed a system built entirely around them," he added.

The UCS is arranged in a "wrap-around" fashion that places the operator in a virtual cockpit that allows for multiple views of what is going on around the UAV, and can control multiple aircraft simultaneously.

The goal of the new control system is to reduce the number of accidents involving UAVs. Raytheon said a 2004 study by the Federal Aviation Administration found that operators were a factor in 21 percent of the accidents involving the Shadow UAV and 67 percent of Predator mishaps.

The use of intuitive user technology in the UCS should help operators learn the finer points of flying UAVs and managing the large amounts of flight and intelligence data produced by the aircraft more quickly and with less formal training.

d. AAI-Built Shadow® UAV Surpasses 100,000-hour Milestone REF 84

HUNT VALLEY, Maryland, 20 June 2006 —Shadow Tactical Unmanned Aircraft Systems (TUAS), designed and built by AAI Corporation, surpassed 100,000 flight hours during a June 2006 combat mission in support of U.S. forces in Operation Iraqi Freedom (OIF), less than a year after reaching 50,000 hours in total flight operations.

The hours-of-operation milestone was recorded in the week of June 12 during a sortie flown by a U.S. Army unit supporting ground operations against terrorism in Iraq. The 50,000-hour mark was reached on 9 August 2005.

"Shadow systems have proven to be key surveillance and intelligence-gathering assets in support of U.S. Army and National Guard units in Iraq," said Steve Reid, AAI's vice president of unmanned aircraft systems. "For instance, achieving 50,000 flight hours over the last 10 months means that between seven and eight Shadow aircraft were in the air simultaneously, on average, during every hour, day and night of that entire stretch."

Since being deployed to Iraq at the outset of military operations there in early 2003, Shadow systems have flown more than 19,000 sorties and more than 84,000 flight hours in support of U.S. and allied operations. Total hours include sorties in training and other deployments.

e. First flights of UAVs powered by electric fuel cells

In November 2005, the Naval Research Laboratory (NRL) flew a 5.6-pound 'Spider-Lion' micro UAV for three hours, 19 minutes with a Protonex fuel cell power system fuelled by compressed hydrogen as the sole source of power for the duration of the flight. The UAV and fuel cell were developed by Protonex Technology Corporation, a leading manufacturer of high-performance fuel cell power systems for portable and remote applications.

This flight demonstrated the potential of fuel cells to offer a significant improvement over batteries for long- endurance UAVs, which are used by the military for surveillance, search and rescue, chemical-biological monitoring and missions that require extended flight times.

http://www.evworld.com/view.cfm?section=communique&newsid=10705

Figure 95 The "Spider-Lion" micro UAV powered by a hydrogen fuel cell

On the 28th August, 2006, researchers at the Georgia Institute of Technology announced that they had conducted successful test flights on the 14th June 2006 of a hydrogen-powered unmanned aircraft believed to be the largest to fly on a proton exchange membrane (PEM) fuel cell using compressed hydrogen.

The fuel-cell system that powers the 22-foot wingspan aircraft generates only 500 watts. "That raises a lot of eyebrows," said Adam Broughton, a research engineer who is working on the project in Georgia Tech's Aerospace Systems Design Laboratory (ASDL).

Figure 96 The hydrogen fuel cell powered UAV developed at the Georgia Institute of Technology

- from http://gtresearchnews.gatech.edu/newsrelease/fuel-cell-aircraft.htm

f. Landmark event for Aerosonde as UAV flies 10 hour mission into tropical storm Ophelia - from Shephard www.uvonline.com

16 Sept. 2005 — Hurricane researchers at the NOAA Atlantic Oceanographic and Meteorological Laboratory in Miami, Fla., marked a new milestone in hurricane observation as the first UAV touched down after a 10-hour mission into Tropical Storm Ophelia, which lost its hurricane strength Thursday night. The Aerosonde UAV provided the first-ever detailed observations of the near-surface, high wind hurricane environment, an area often too dangerous for NOAA and U.S. Air Force Reserve manned aircraft to observe directly.

"It's been a long road to get to this point, but it was well worth the wait," said Joe Cione, NOAA hurricane researcher at AOML and the lead scientist on this project. "If we want to improve future forecasts of hurricane intensity change we will need to get continuous low-level observations near the air-sea interface on a regular basis, but manned flights near the surface of the ocean are risky. Remote unmanned aircraft such as the Aerosonde are the only way.

NOAA's partners in this effort include the Aerosonde company, which designed and operates the aircraft, and NASA Goddard's Wallops Flight Facility, located on Virginia's Eastern Shore, which houses the U.S. base for Aerosonde North America and served as the departure and landing location for this historic flight. The Aerosonde hurricane project is funded by NASA and NOAA Research to test this promising new observational tool.

"The concept of the Aerosonde as a small, robust unmanned autonomous vehicle, or AUV, arose directly from our need for observations in dangerous areas such as the hurricane surface layer," said Greg Holland, president of Aerosonde North America and one of the Aerosonde originators. "I am particularly grateful to the hard work by Aerosonde staff and the support of NOAA and NASA that has now made this possible." The Aerosonde was launched at about 7:30 a.m. EDT on Friday and returned at about 5:30 p.m.

While the successful use of NOAA's WP-3D Orion, its Gulfstream-IV aircraft and the U.S. Air Force Reserve's WC-130H aircraft have been important tools in the arsenal to understand tropical cyclones, detailed observations of the near-surface hurricane environment have been elusive because of the severe safety risks associated with low level manned flight missions.

The main objective of the Aerosonde project addresses this significant observational shortcoming by using the unique long endurance and low-flying attributes of the unmanned Aerosonde observing platform, flying at altitudes as low as 500 feet. Tropical Storm Ophelia provided the perfect test case for using Aerosondes as it was a minimal hurricane within flight range of the Wallops Flight Facility.

The Aerosonde platform that flew into Ophelia was specially outfitted with sophisticated instruments used in traditional hurricane observation, including instruments such as mounted Global Position System (GPS) drop wind sondes and a satellite communications system that relayed information on temperature, pressure, humidity and wind speed every half second in real-time. The Aerosonde also carried a downward positioned infrared sensor that was used to estimate the underlying sea surface temperature. All available data were transmitted in near-real time to the NOAA National Hurricane Center and AOML, where the NOAA Hurricane Research Division is located.

The environment where the atmosphere meets the sea is critically important in hurricanes as it is where the ocean's warm water energy is directly transferred to the atmosphere just above it. The hurricane/ocean interface also is important because it is where the strongest winds in a hurricane are found and is the level at which most citizens live. Observing and ultimately better understanding this region of the storm is crucial to improve forecasts of hurricane intensity and structure. Enhancing this predictive capability would not only save the U.S. economy billions of dollars, but more important, it could save many lives.

g. The MP2028g successfully flies UAV over Amsterdam - www.micropilot.com

5 July 2004 -- In a historic flight, being touted as the first UAV to fly in the crowded airspace of a major western European city, the 1.5 m long Birdeye 500, with a 2 m wingspan, demonstrated its low level surveillance capability over Amsterdam, Netherlands.

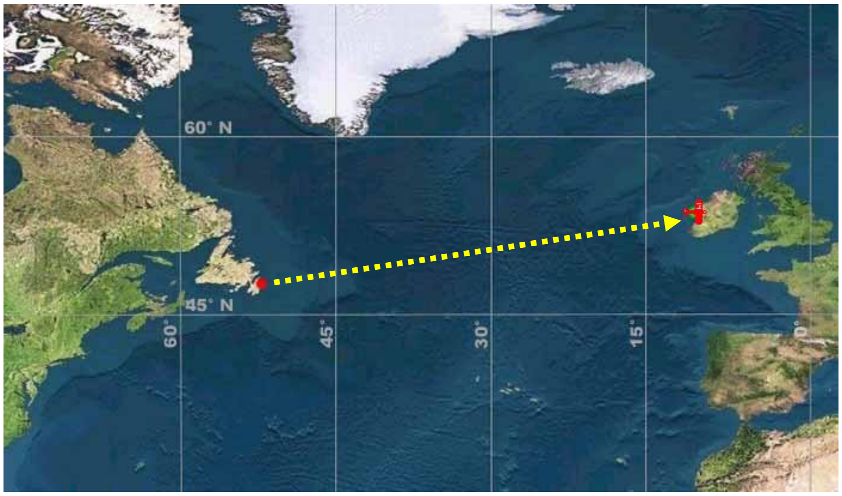
Figure 97 Birdeye 500 UAV from http://www.defense-update.com/products/s/spythere.htm

The 5 kilogram electric Birdeye developed by Israel Aircraft Industries-Malat uses a MicroPilot MP2028g autopilot for navigation. The Birdeye with an endurance of one hour is equipped with a zoom-capable, 850 gram, daylight colour video camera that is interchangeable with an infrared sensor for night surveillance.

The demonstration was organized by the Dutch distributor (Condor UAV) for the Amsterdam metropolitan police. The flight was performed at an altitude at 500 feet and a speed of 40 knots. The aircraft inspected railways tracks, passenger terminals for the ocean liners and had to manoeuvre between lamp posts before landing safely. Howard Loewen, President of MicroPilot, stated "This test flight makes a point to the world that mini-UAVs are safe, from police to farmers and countless other applications."

h. Long distance record for FAI Class F / F3A model plane

9 August 2003 - First FAI Class F / F3A Model Plane to cross the Atlantic, flying 3,020 Km from Cape Spear in Newfoundland (Canada) to Stone Bog (Mannin Beach) in Ireland in 38 hours and 23 minutes, FAI distance record number 142.



THE PLANE HAS LANDED!

Last reported position of TAM5 is indicated on map by the small red plane.
Latest telemetry data received from TAM 5 at 1212 GMT August 11th

Last Telemetry Data			
Latitude N:	53d 27.67m	**Engine RPM:**	3700
Longitude W:	10d 4.20m	**# Satellites:**	8
Speed (Km/hr):	68	**Temperature (°C):**	14.6
Altitude (m):	289	**Heading (°):**	95
ETA (GMT):	1245 UTC Monday 11 August 2003		

Dry weight	2.721 Kg
Fuel weight	2.261 kg
Fuelled weight	4.982 Kg
Fuel used	2.261 (at start) – 0.043 (at end) = 2.218 Kg
Fuel	Coleman Stove Fuel + 2.2 Kg Indopol L-50 lubricant
Engine	O.S. Engines OS 0.61 FS Four Stroke
Propeller	355mm x 305mm (14” x 12”)
Engine RPM	3,100 … 4,100, although the plane should have stayed at 3,900 rpm
Navigation System	GPS + autopilot + harness + piezoelectric gyro + pressure sensor
Weight of NavSys	0.227 Kg
Altitude	280 … 320 m, although was meant to stay at 305 m (1,000 ft)
Ignition system	C & H Electronics CDI spark ignition system
Electrical generator	Aveox brushless motor core

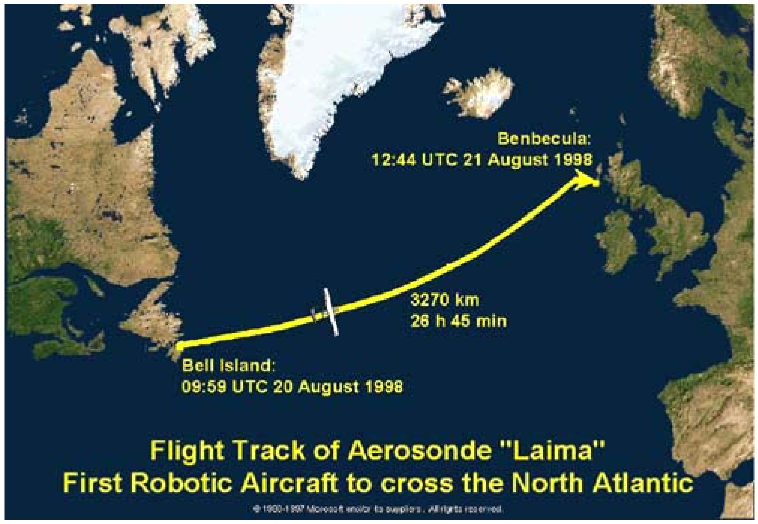


Figure 98 Illustration Copyright Aerosonde Pty Ltd

August 1998 - "In August 1998, Aerosonde "Laima" flew into the record books by making the first crossing of the North Atlantic by a robotic aircraft and becoming the smallest aircraft to make the crossing."

"Laima", named after the Latvian Goddess of good fortune, was one of three Mk I Aerosondes built in Melbourne, Australia by Environmental Systems and Services (ES&S) for the University of Washington under a contract from the US Office of Naval Research. The Mk I Aerosonde, first defined by Holland, McGeer and Youngren (1992), was developed to operational status by a consortium consisting of ES&S, The Insitu Group from Washington State, and The Australian Bureau of Meteorology."

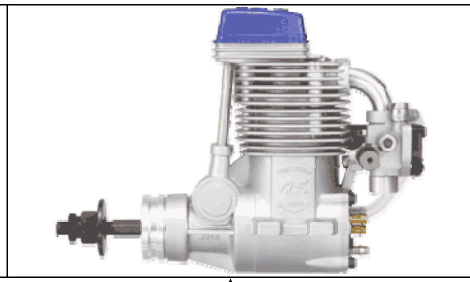
- Dr Greg Holland, CEO, Aerosonde Pty Ltd.

Launch	
Place	Bell Island Airport, Newfoundland: 47º38' N, 52º59' W
Time	09:59 UTC August 20 1998
Launch Weight / Fuel	13.1 kg / 4.9 kg = 7 litres
Landing	
Place	DERA Benbecula Range, Outer Hebrides: 57º21' N, 7º23' W
Time	12:44 UTC August 21 1998
Landing Weight*	~9.1 kg
Flight Statistics	
Elapsed Time / distance	26 h 45 m / 3270 km
Mean Speed / altitude	120 km per hour / 1680 m
Fuel Used* / Economy*	~3.9 kg = 5.6 litres / ~580 km / litre

*Approximate only: Potential variation 3.7 to 4.3 kg fuel used, 540 to 610 km / litre

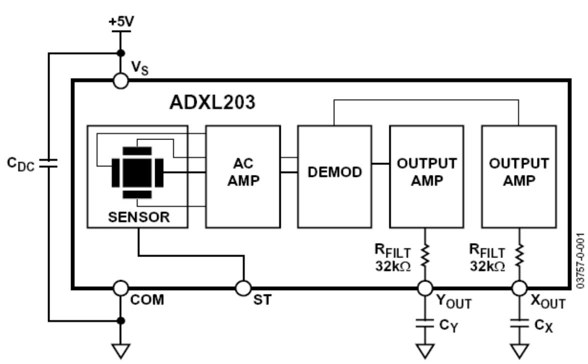
Appendix 3
Engine induced vibration

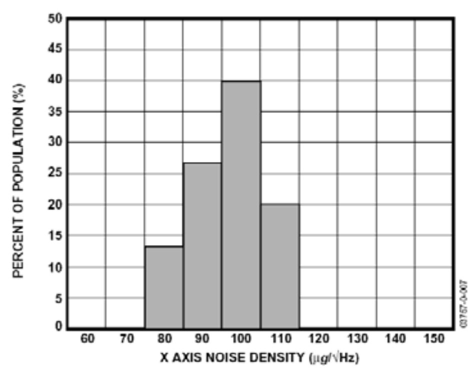
engines from www.towerhobbies.com



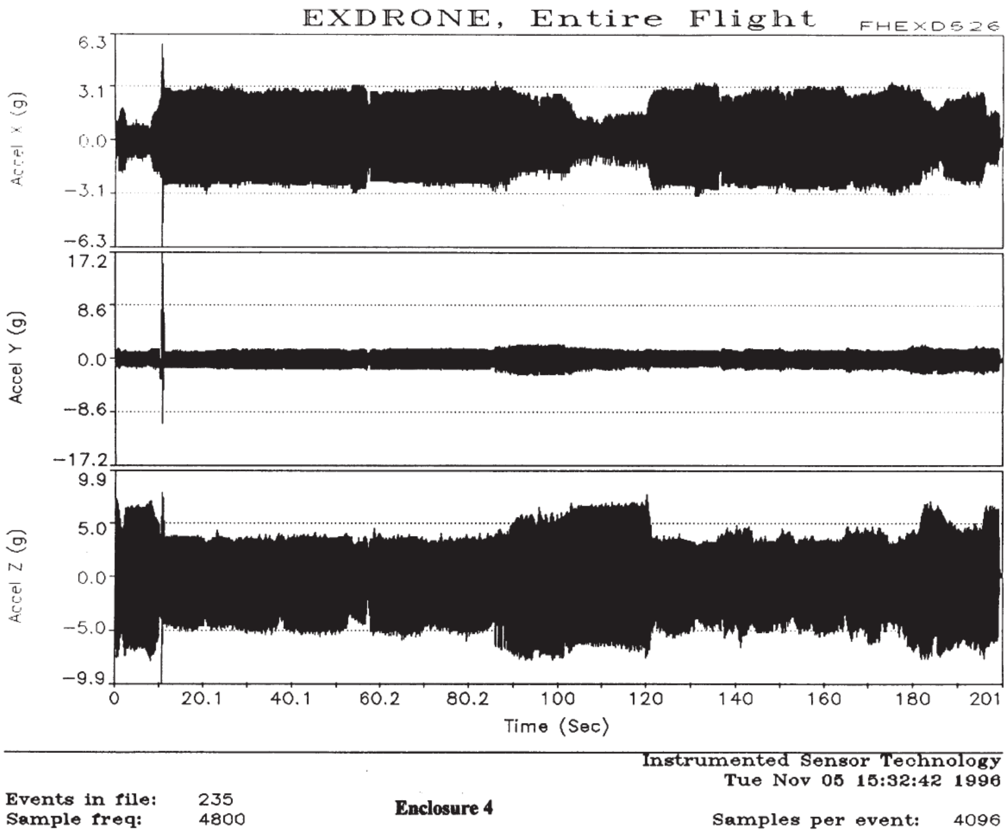
Parameter	2 stroke	4 stroke	Wankel	units
Capacity	23	11.45	4.97	cc
RPM range	1.8 … 10	2 … 13	2.5 … 18	K rpm
Power	2,610 @ 9K rpm	895 @ 11K rpm	947 @ 17K rpm	Watts
Engine weight	0.807	0.502	0.335	Kg
Power / weight	**3.234**	1.783	2.827	KW / Kg
Fuel efficiency	483	**426**	541	g / KW / hr
Vibration level	high	intermediate	**very low**	

In a microgravity survey, the range of gravity values is typically of the order of 150 uGal. An in-flight two-stroke engine induced vibration level of 2.7 g rms = 2,647,795,500 uGal would completely swamp any sensitive microgravity measurements. The maximum allowable vibration level = 1,000 times the maximum gravity measurement value, in other words, 150,000 uGal, suggesting the need to use a very low vibration Wankel engine.





The minimum, noise limited, measurable acceleration using 16 inexpensive MEMS-based Analog Devices ADXL203 accelerometer ICs operating in parallel is 27,000 uGal / sqrt(Hz), based on data from www.analog.com. This measurement limit is suitable to detect unacceptable vibration levels in a UAV in excess of 150,000 uGal, for example.



Above one can see the vibration levels for X, Y and Z directions measured in an Exdrone UAV containing a 2 stroke engine, during flight, from uav.wff.nasa.gov/exdrone.pdf. Below you see the spectral representation of the above data for the Z direction in which the vibration is largest. The **2.7 g root mean square vibration level** in the Z axis for the Exdrone UAV is way above the acceleration level we might wish to measure using a sensitive gravity meter, and would completely swamp any microgravity measurements made, which would **typically only change by up to 0.153×10^{-6} g**.

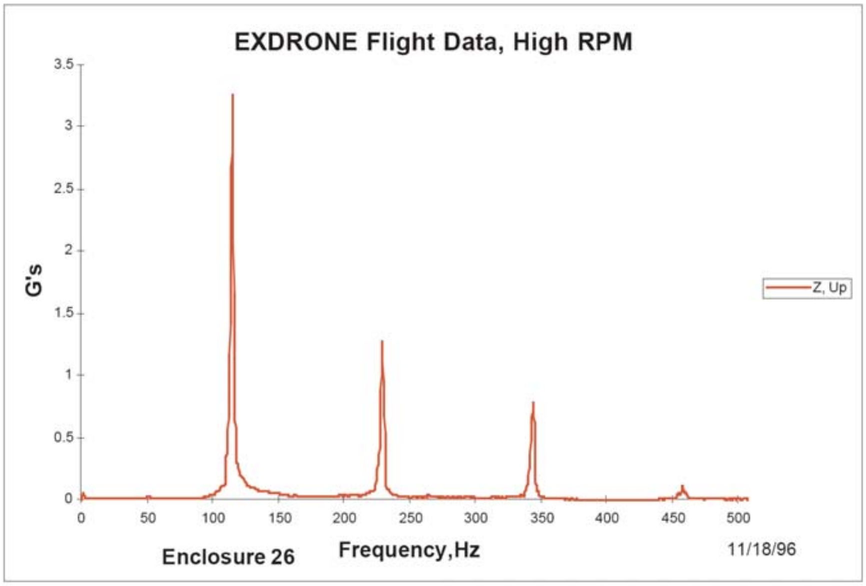


Figure 99 = Vibration spectrum with a 3.3 g peak around 115 Hz (6,900 rpm) with higher harmonics

Popular UAV engines: the UAV Engines Limited AR741 Wankel engine

The AR741 has an outstanding power-to-weight ratio combined with much longer life and better SFC than any alternative engine. It has been developed from the mature AR731 target drone engine to meet the needs of small surveillance-type UAVs. The engine has successfully completed a 150 hour FAR-33 type endurance test.

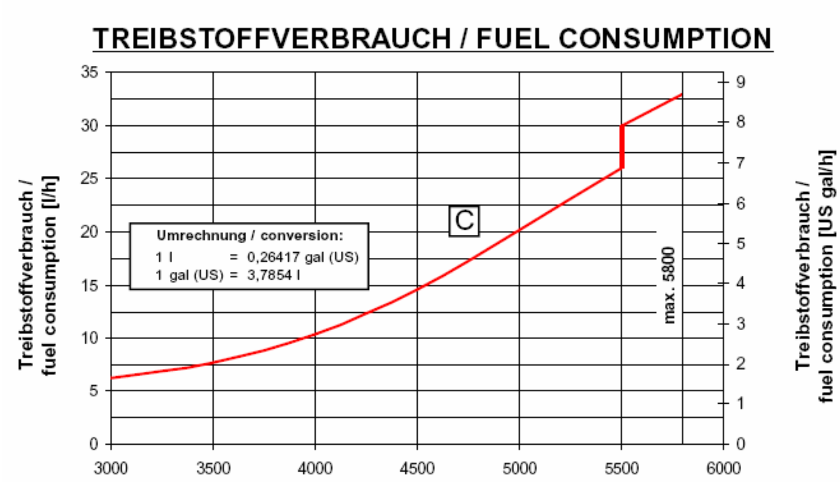
Design Features

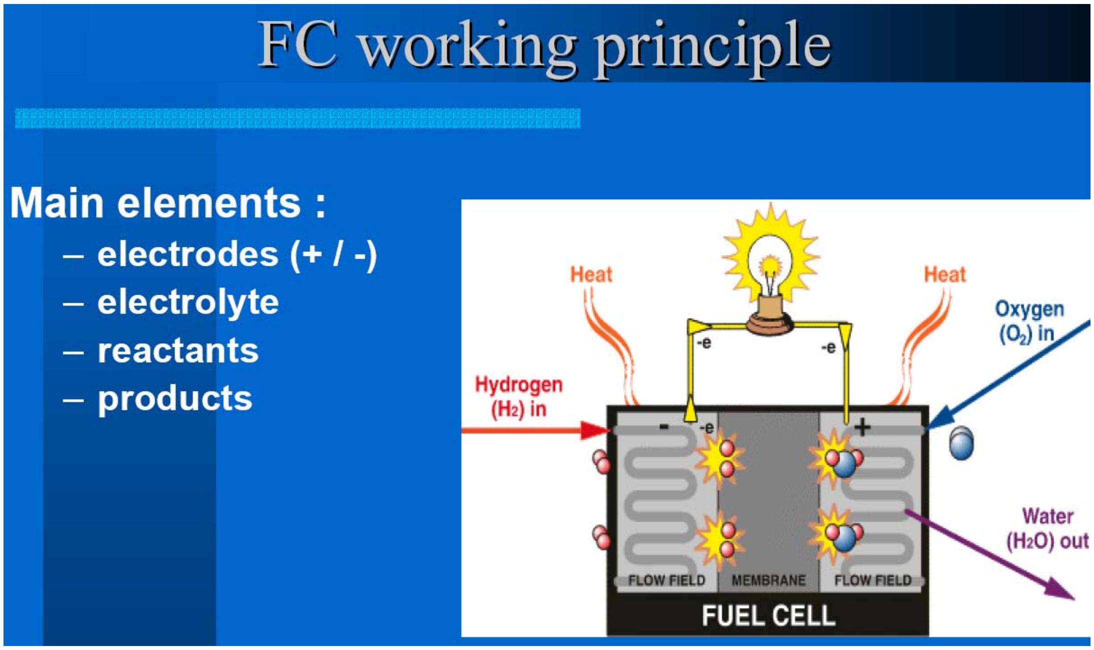
- Exceptionally high power-to- weight ratio.
- Economical fuel consumption.
- Low cross sectional area.
- Low levels of vibration.
- Long life

Technical Specification

Engine Type	Single rotor Wankel-type spark ignition engine.
Capacity	208 cc chamber size.
Power Output	28.3 KWatt maximum at 7800 rpm.
Weight	10.7 Kg without generator.
Fuel Consumption	9.84 Kg/hr at maximum power, 9.0 Kg/hr at cruise 348 g/Watt/hr at maximum power
Vibration Level	Nominally zero radial vibration. Peak instantaneous torque is 4 times mean.
Ignition System	Electronic contact-less magneto. RFI suppressed HT system
Generator	Provision for mounting GEC/Plessey 28 V, or 900 or 1500 watt

Performance of the four stroke, four cylinder, Rotax 914 F D.C.D.I UAV Engine		
power	84.5 KW	@ 5,500 rpm
maximum RPM	5800	rpm
displacement	1211.2	cc
generator performance	250 Watt DC	@ 5,500 rpm
voltage	13.5	V
fuel usage at 5,400 RPM	20 Kg/hr (25 L/hr) 237 g/KWatt/hour	AVGAS 100 LL
engine weight	70	Kg
weight of optional extras	6.7	Kg

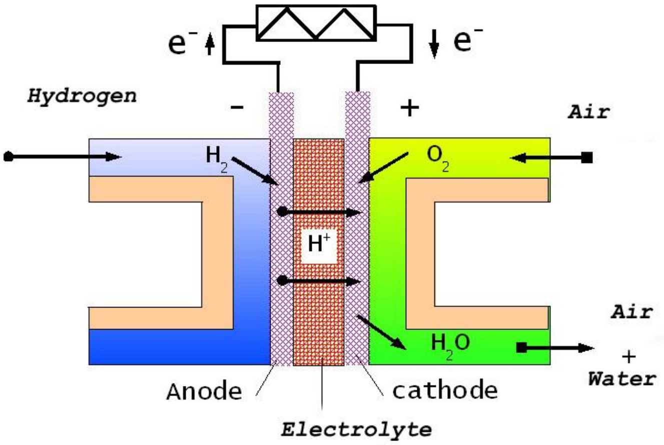




These slides from a428755.pdf, a presentation by A. Hendrick et al. of the Royal Military Academy of Belgium, presented at ISABE 2003 1185 in Cleveland in 2003. The next explanation as to how fuel cells works comes from http://en.wikipedia.org/wiki/Fuel_cell.

In the archetypal example of a hydrogen/oxygen proton exchange membrane fuel cell (PEMFC), a proton-conducting polymer membrane, (the electrolyte), separates the anode and cathode sides.

On the anode side, hydrogen diffuses to the anode catalyst where it dissociates into protons and electrons. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have travelled through the external circuit) and protons to form water. In this example, the only waste product is water vapor and/or liquid water.



$H_2 \rightarrow 2H^+ + 2e^-$

$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

“Medis Technologies Limited announced an agreement with Israel Aircraft Industries (IAI) to develop an 800 watt fuel cell to electrically power Unmanned Air Vehicles. The contract provides for two phases of activity. The first six month phase involves the Israeli company developing a demonstration system which would pass functionality tests and which can be demonstrated to be re-designable to achieve the weight (6 kilograms) goals of the final system. The first phase is funded by IAI, who will pay the company $400,000. Upon the successful completion of the first phase, the second 18 month phase would require IAI to pay the company approx $1,500,000 to complete the development. During the first phase of the contract and dependent on minimum purchase requirements thereafter, IAI will be granted exclusivity with respect to large fuel cells for unmanned vehicles.”

http://news.moneycentral.msn.com/provider/providerarticle.asp?Feed=BCOM&Date=20061024&ID=6131225

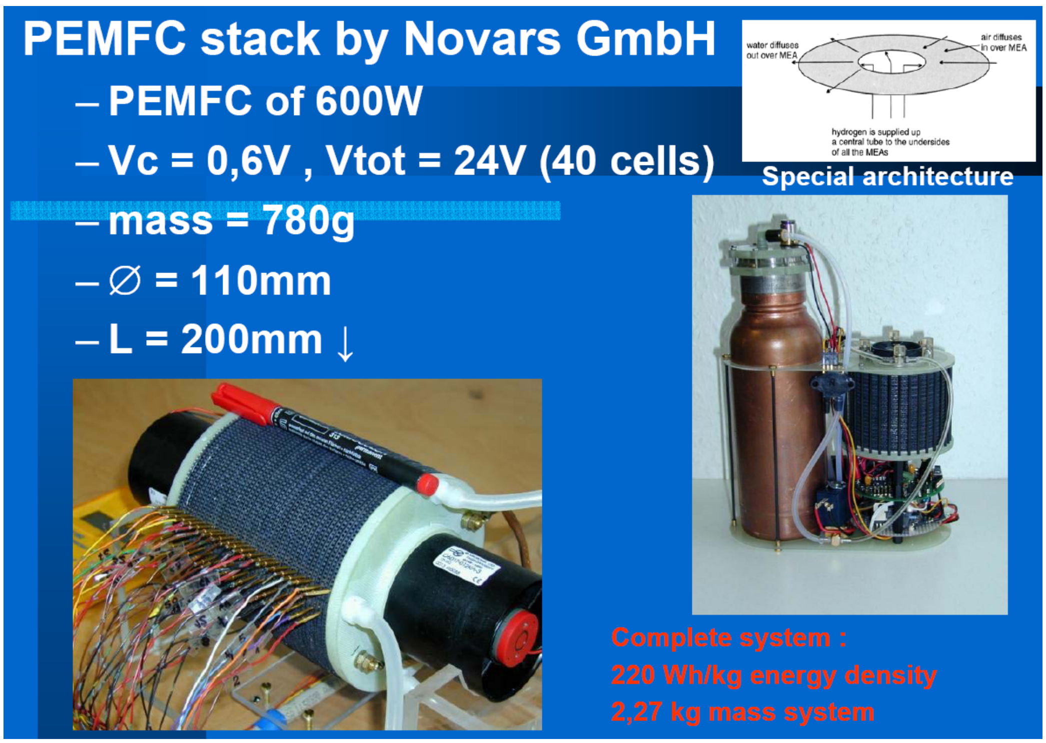


Figure 100 Aveox/Zagi brushless d.c. motor with electronic motor controller
http://www.zagi.com/index.php?main_page=aveox_mod

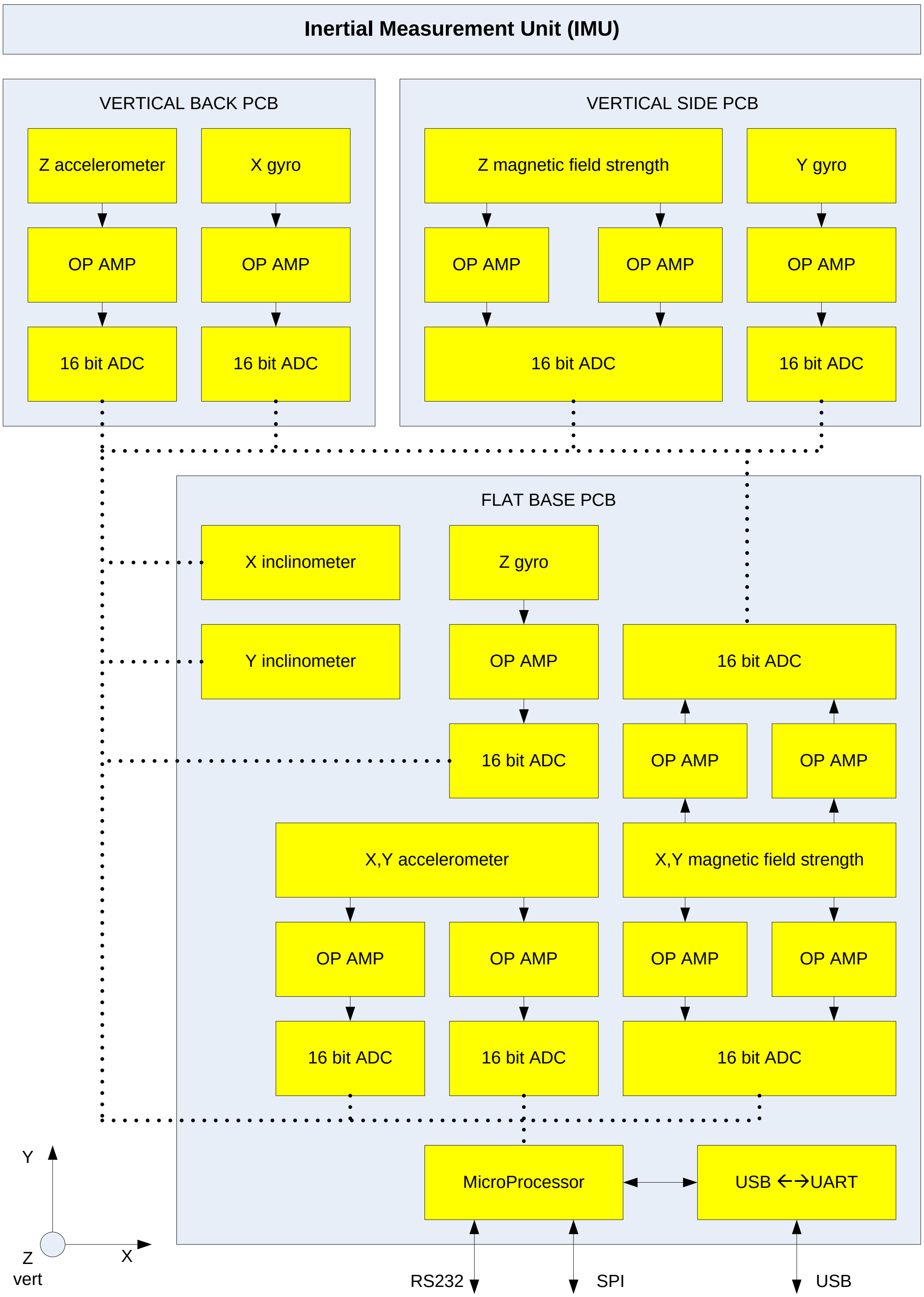


Figure 101 Example of the circuitry in an Inertial Measurement Unit.

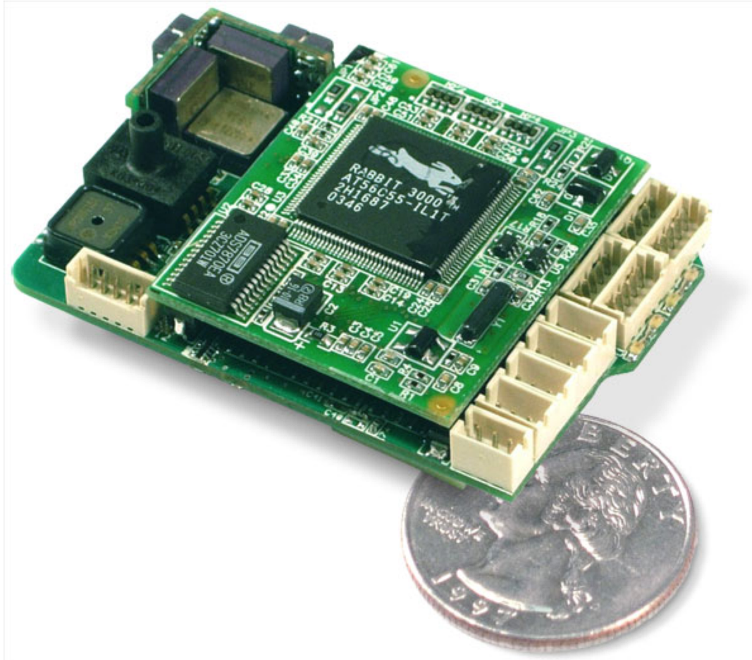


Figure 102 Procerus Kestrel 2.2 IMU circuit from www.procerusuav.com

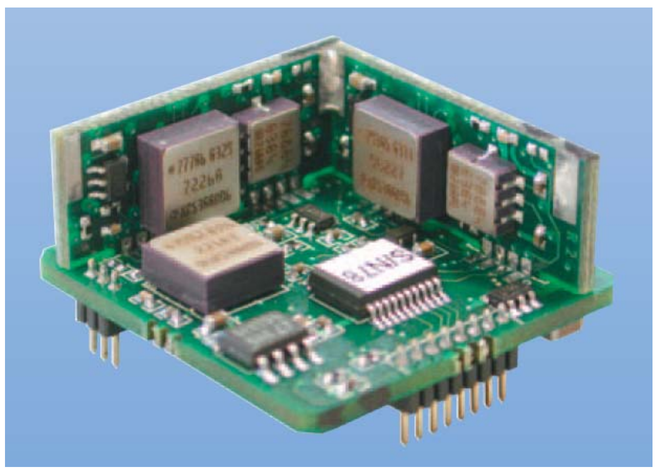


Figure 103 Crista IMU from www.CloudCapTech.com

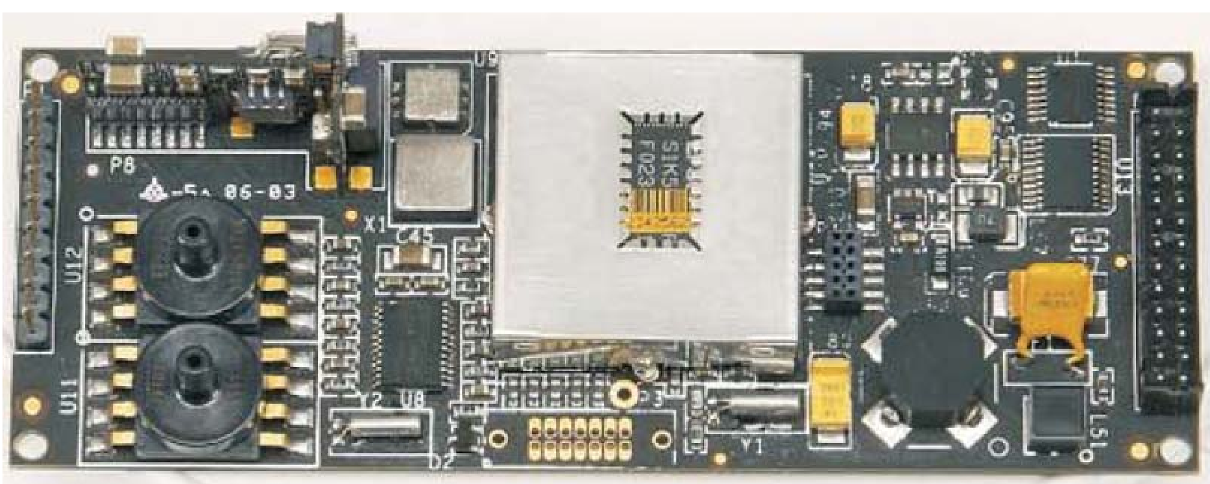


Figure 104 Micropilot 2128 IMU and UAV guidance and control electronics for around $4,000 from www.micropilot.com

Example of the core, microprocessor controlled, flight management system

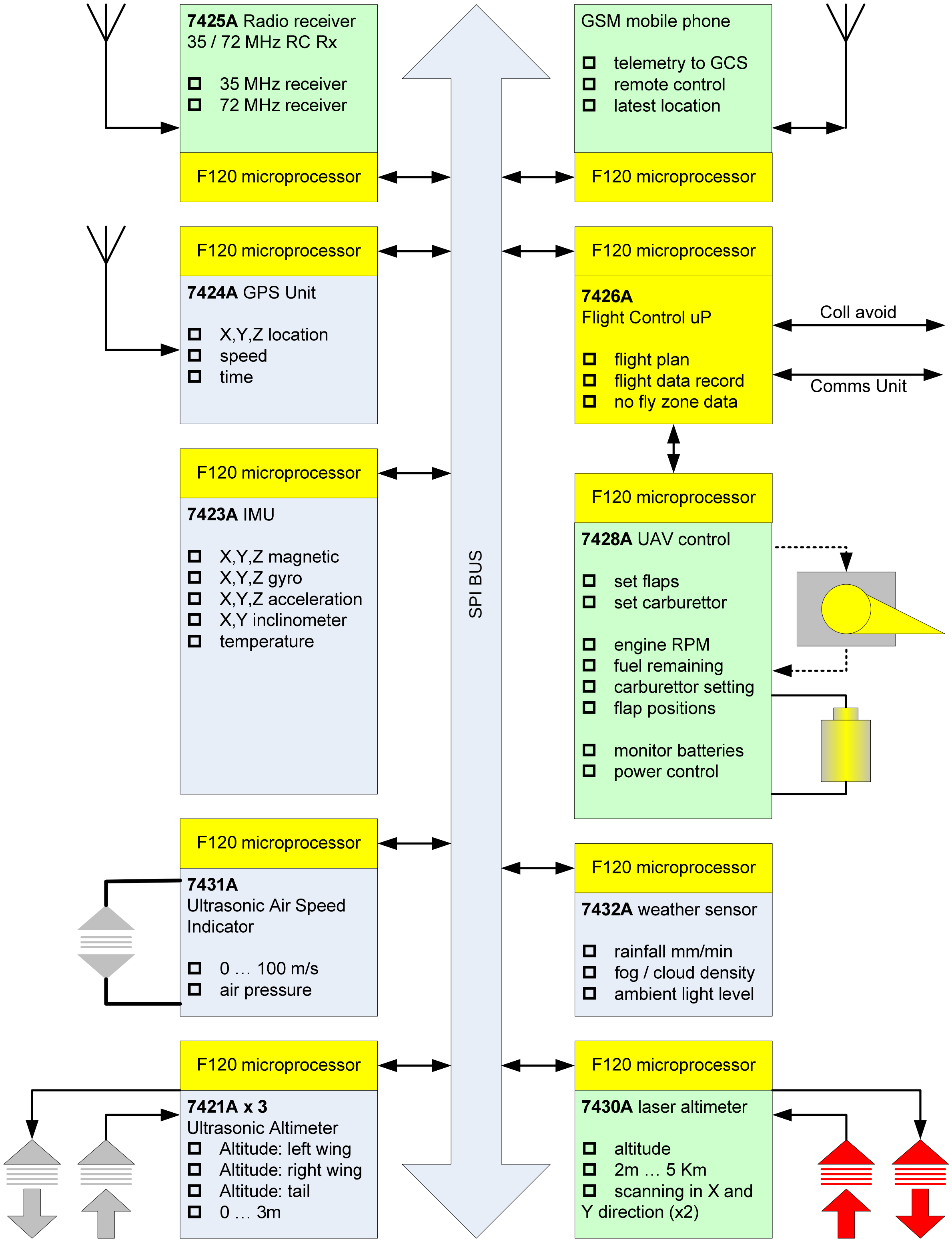


Figure 105 shows the make-up of the core Navigation and Flight Control Unit

Example of navigation, flight control and communications systems for a small UAV

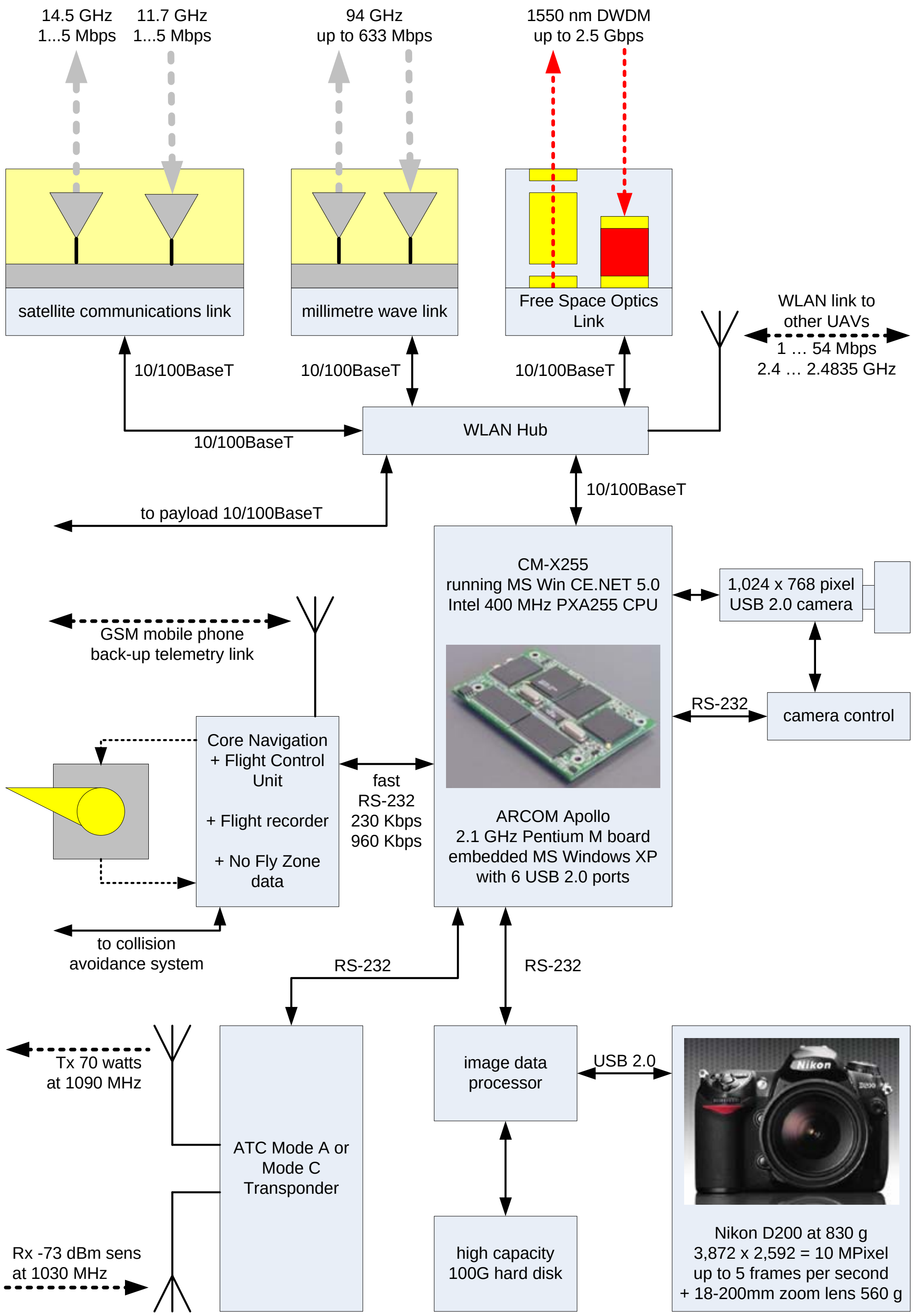


Figure 106 = diagrammatic view of navigation, control and communications systems

At the centre of the small Unmanned Air Vehicle is the 0.2 to 2 watt power consumption Microsoft Windows CE.NET module running at speeds from 100 MHz to 400 MHz depending on the data to be processed and the power available. The sensor payload will have additional processing capability, typically a Pentium M based PC card. Note that the core navigation and Flight Control Unit with its GSM mobile phone back up telemetry link can continue to function in the event of problems in the modules running MS Windows.

Appendix 5
UAV payload technologies and applications

PAYLOAD 1: High resolution visual imaging system - from www.nikonusa.com

Figure 107 Nikon D200 camera

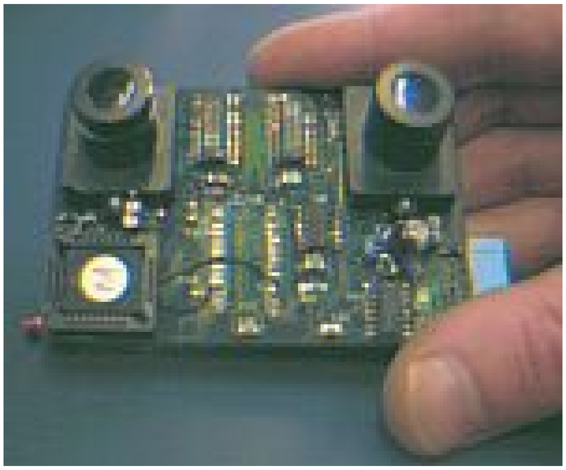
Figure 108 = Nikkor 135 mm f/2D AF lens

Nikon D200 camera body with Nikkor AF lens		
resolution	3,872 x 2,592 = 10.2 M	pixel
wavelength	100 - 800	nm
frame rate	5	fps
data size for one image	20.7	MBytes
weight (body only)	830	grams

Nikon AF Nikkor series lens viewing angles and weights						
35mm f/2D	62° x 43.4°	204 g		50 mm f/1.4D	46° x 32.2°	256 g
85 mm f/1.4D	28.5° x 20°	562 g		105 mm f/2D	23.5° x 16.5°	622 g
135 mm f/2D	18° x12.6°	812 g		180 mm f/2.8D	13.7° x 9.6°	720 g

Applications:

- high resolution aerial photography
- can generate stereo imagery using adjacent aerial photographs
- can generate additional information by using orthogonal polarisations
- can use a computer to subtract images taken at different times to spot differences
- can detect the presence of something that should not be there
- can estimate the number of people in a crowd, or the number of items in a collection



Stereo imaging can be accomplished through the use of two imaging CCD cameras, and suitable software, such as the Stanford Research Institute (SRI) Small Vision System software developed by Kurt Konolige at SRI. A complex, optimised, mathematical procedure is applied in real time to the information from both cameras to generate the 3D imagery for automated scenery interpretation in which the depth-to-any-feature is known.

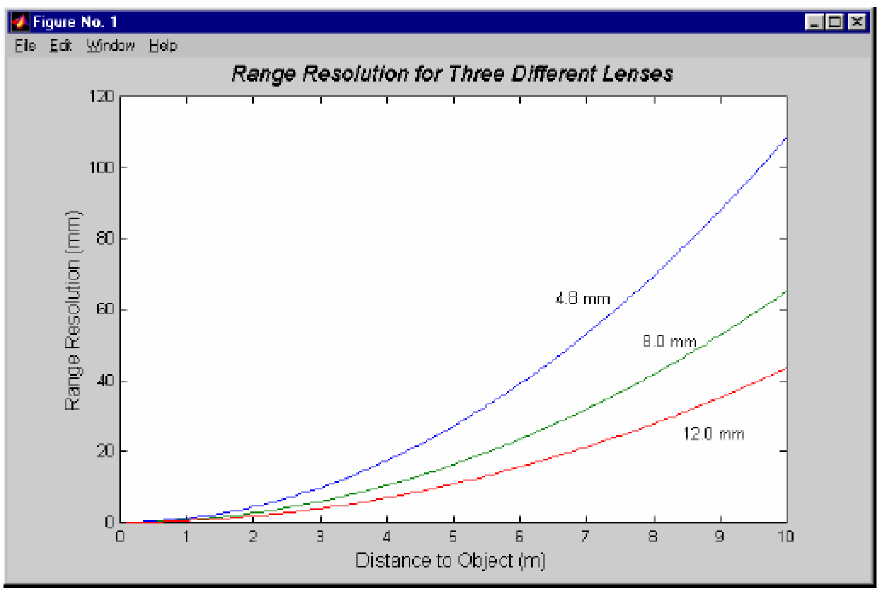


Figure 6-1 Range resolution in mm as a function of distance, for several different lens focal lengths.

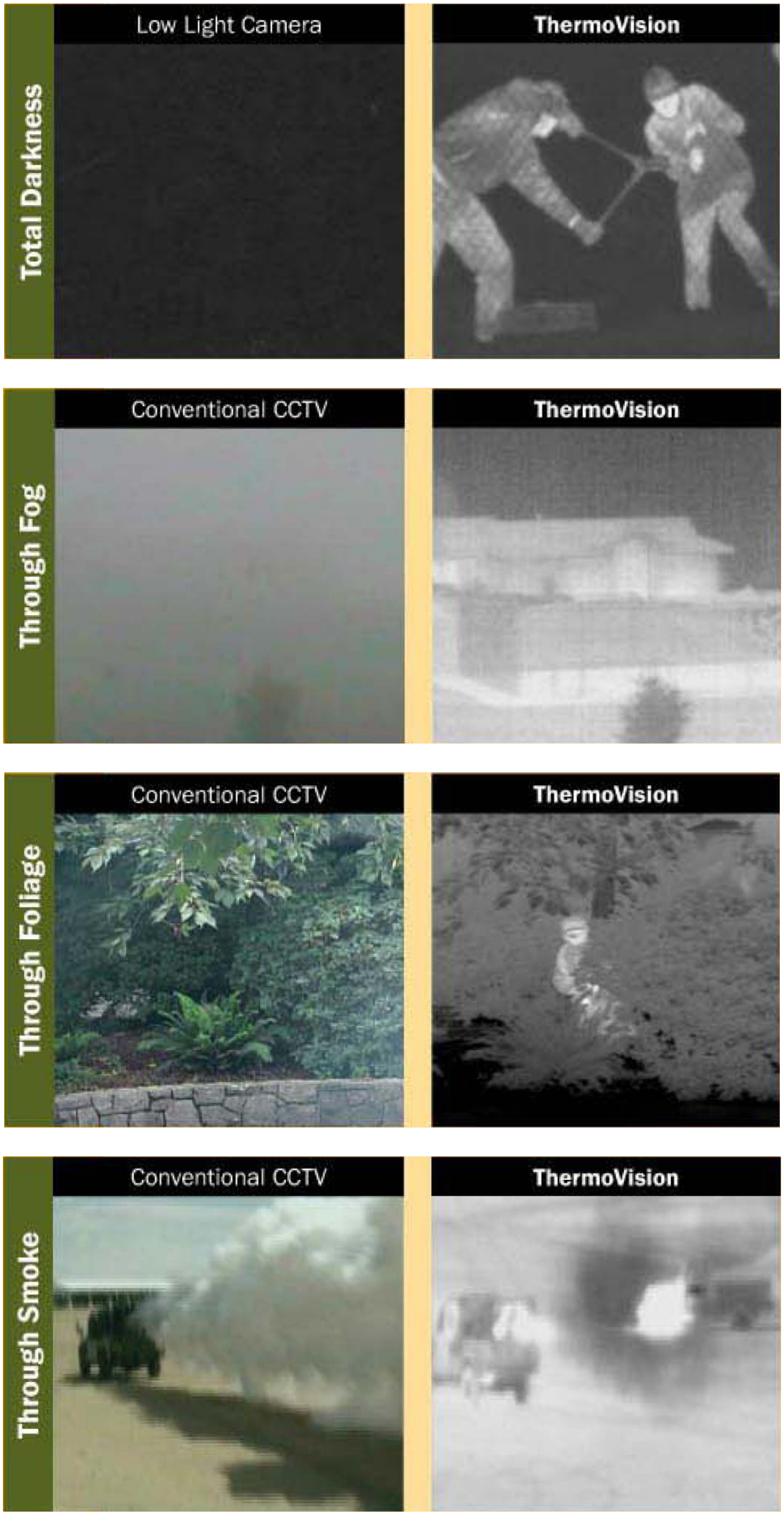
Stereo imagery can be used to:

- work out the distances to any obstacles, such as any planes, buildings or mountains ahead
- detect the nearest object in the field of view, to enable a warning to be issued if the UAV is about to collide with the obstacle
- enable the UAV to use the distance-to-obstacle feature to calculate a flight path to avoid the obstacle


	Alpha NIR	Merlin Thermal	Thermovision A40M	
DETECTOR wavelength (H) x (V)	InGaAs 0.9 – 1.7 320 (H) x 256 (V)	InSb 1.5 – 5.0 320 (H) x 256 (V)	Microbolometer 7.5 – 13 320 (H) x 240 (V)	 um pixels x pixels
pixel size	30 x 30	30 x 30		um x um
sensitivity	< 1E10 ph/cm^2/s	25 mK (typ 18 mK)	80 mK	
frame rate	30	50	50 or 60	Hz
power	4.5 (max)		6	watts
weight	0.350	4.3	1.4	Kg
Lenses		13 mm 41° x 31°	18 mm 45° x 34°	
	25 mm 22° x 16°	25 mm 22° x 16°		
	50 mm 11° x 8°	50 mm 11° x 8°	71 mm 12° x 9°	
		100mm 5.5° x 4.1°	122 mm 7° x 5.3°	
		180mm 3.1° x 2.4°		

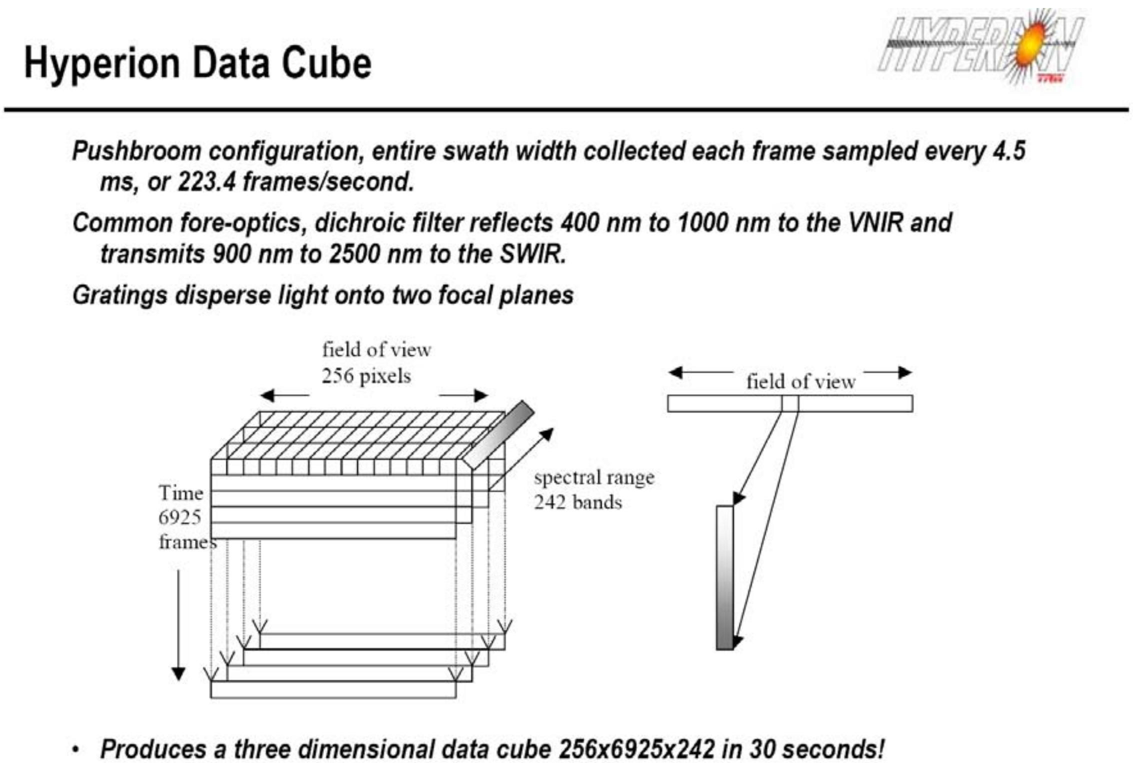
Multi-spectral, thermal and infra-red, polarisation sensitive, imaging is used to see:

- hot spots, as might be found along power lines, at power sub-stations
- human beings on the ground at night, as part of a search and rescue operation
- in total darkness
- through fog and smoke
- through foliage
- temperatures of **distant objects** to within 0.1°C (100 mK)
- regions of diseased crops in otherwise healthy crops


Total Darkness
Low Light Camera
ThermoVision
Through Fog
Conventional CCTV
ThermoVision
Through Foliage
Conventional CCTV
ThermoVision
Through Smoke
Conventional CCTV
ThermoVision

Hyperspectral imaging is a very high spectral resolution form of multi-spectral imaging. In hyperspectral imaging one derives multiple images of the same area through the effective use of multiple, contiguous, narrow band (for example, 10 nm Full Width Half Maximum = FWHM) optical filters. A practical implementation of hyperspectral imaging is to be found in the Hyperion system developed by TRW. In this system, a satellite orbits the earth, and:

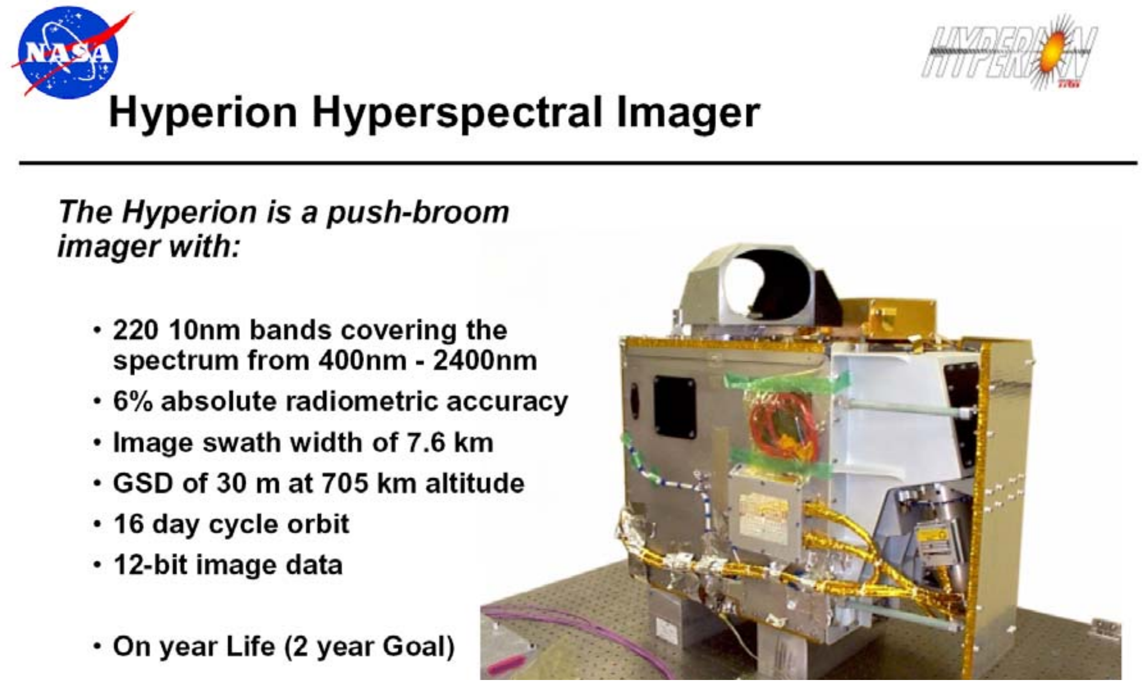
1. samples a 256 pixel line scan image every 4.5 mS
2. uses an optical diffracting element such as a diffraction grating to derive a 242 bin optical spectral distribution from each pixel in the line scan, covering an optical spectral range from 400 nm to 2400 nm. Each bin = 10 nm FWHM spectral width.
3. uses 256 x 242 pixel CCD arrays followed by a 12 bit analog-to-digital converter to digitise the optically diffracted hyperspectral image information for each line scan.

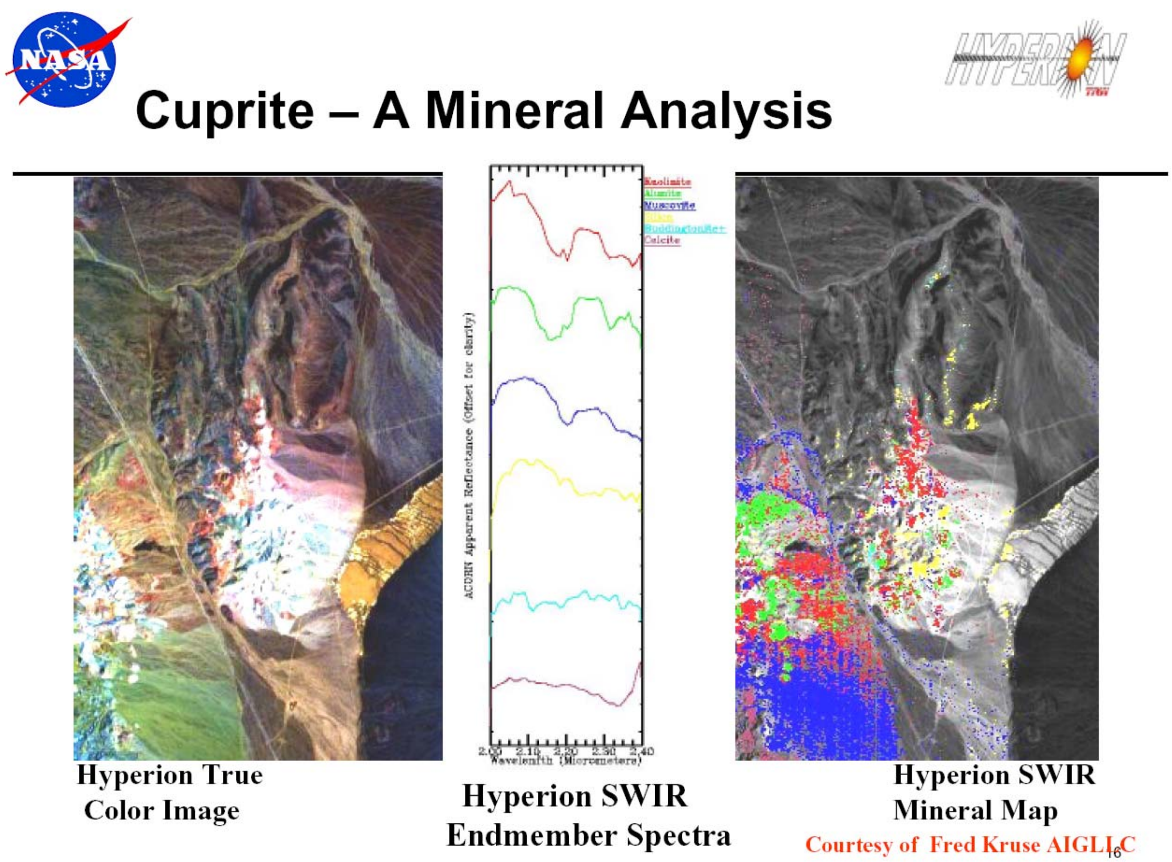


Implementation using commercially available imaging systems

	CCD visual	Alpha NIR	Merlin Thermal	
wavelength	0.1 – 0.8	0.9 – 1.7	1.5 – 5.0	um
(H) x (V)	2,048 x 2,048	320 (H) x 256 (V)	320 (H) x 256 (V)	pixels x pixels

The light for each of the three imaging systems is filtered using dichroic filters. Each pixel in the linescan is then split by wavelength, using a diffraction grating, into one of 256 bins. In order to increase the light level on each pixel, the dispersed images of successive line scans can be superimposed on the imaging CCD, with software then being used to extract the hyperspectral information from the superimposed data.





The enhancement of the mineral rich regions can be clearly seen in the hyperspectral composite image, above right, relative to the true colour image, above left.

All information derived from REF 81.

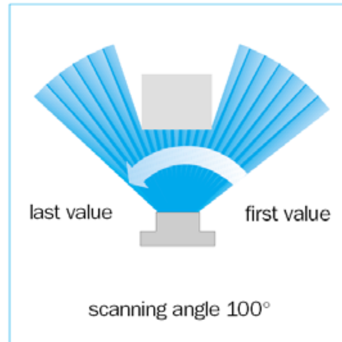
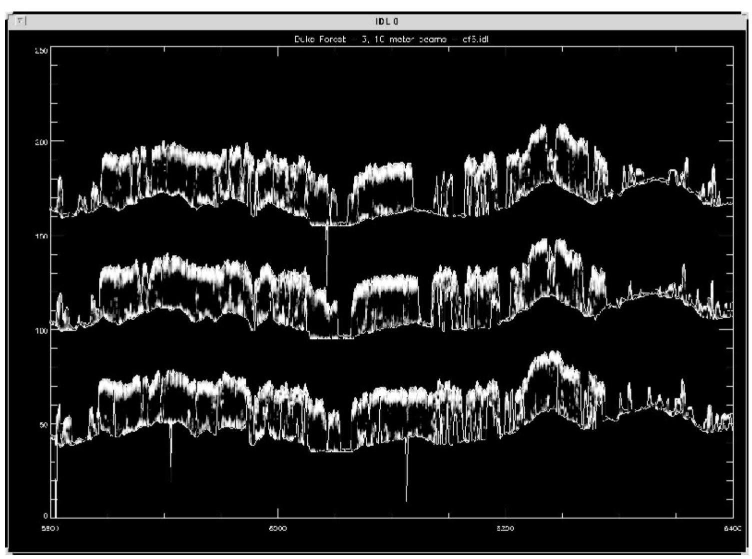


Fig. 5-1: Direction of transmission for LMS 211 scanners

Sick LMS 211-30206	**value**	**units**
scanning angle	100	degrees
resolution / accuracy (+/-) / range with 10% reflectivity	10 / 35 / 30	mm / mm / m
angular resolution (selectable)	0.25 / 0.5 / 1	degrees
response time	53 / 26 / 13	mS
weight	9	Kg



Three LIDAR scans, showing trees and the ground level, from
http://denali.gsfc.nasa.gov/research/laser/slicer/slicer.html

Scanning LIDAR is used to:

- detect the distance to obstacles in front of the UAV to help with collision avoidance
- generate data for a Digital Elevation Map of the area under the UAV
- detect the presence and height of trees, as shown in the plot above

Fig. 6—Appearance of the Developed Millimeter-Wave Radar. The radar unit is more compact than the conventional product and is easily mounted on an automobile.

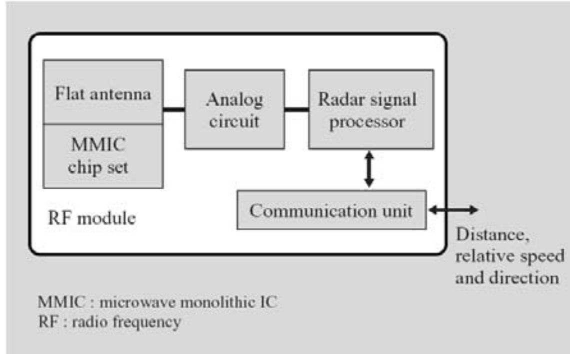


Fig. 7—Circuit Block Diagram of the Millimeter-wave Radar. Using MMICs and flat antenna makes a compact unit possible and a single-body millimeter-wave radar was realized.

For the very high frequency millimetre wave RADAR system, we apply the most recent developments in automotive driver safety support, such as this 77 GHz RADAR system from Hitachi. The demanding cost requirements and relatively high volume production generally associated with the automotive industry suggest a very cost competitive part.

TABLE 1. Main Specifications of the Millimeter-wave Radar
Specifications suited for the driving safety support system.

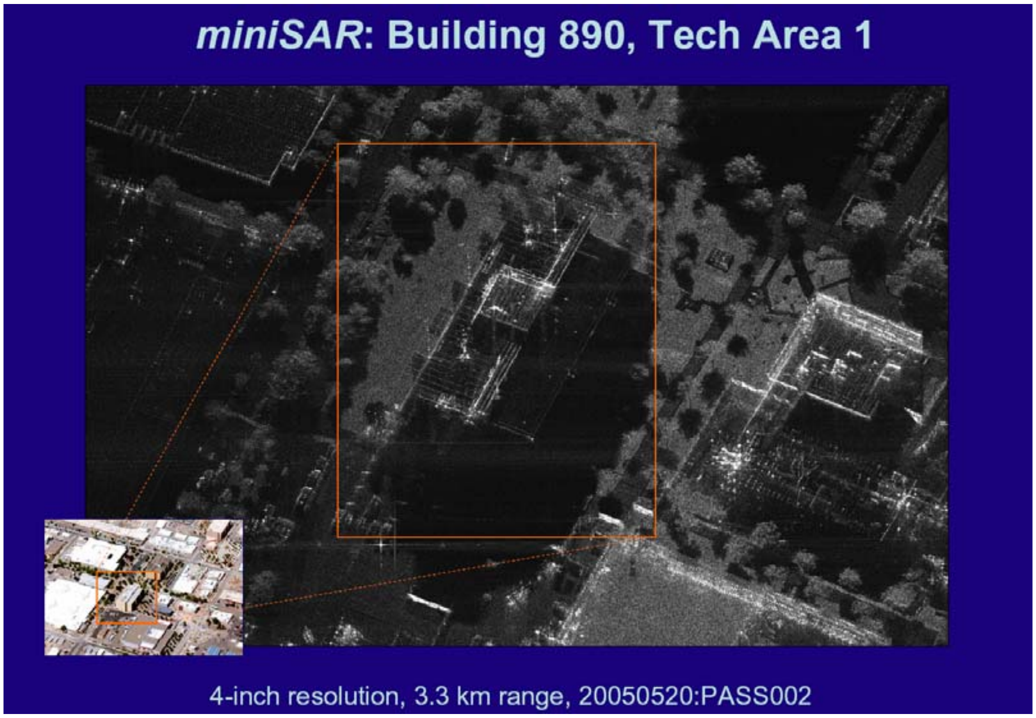
Item	Specification
Frequency	76.5 GHz
Modulation	Two-frequency CW (FSK)
Azimuth angle detection	Monopulse
Field of view	16°
Relative speed detection range	± 160 km/h
Relative speed detection resolution	0.1 km/h
Maximum detection distance	120 m
Minimum detection distance	Less than 1 m
Power consumption	Less than 6 W
Unit size	75 × 103 × 59 (mm)
Weight	0.5 kg

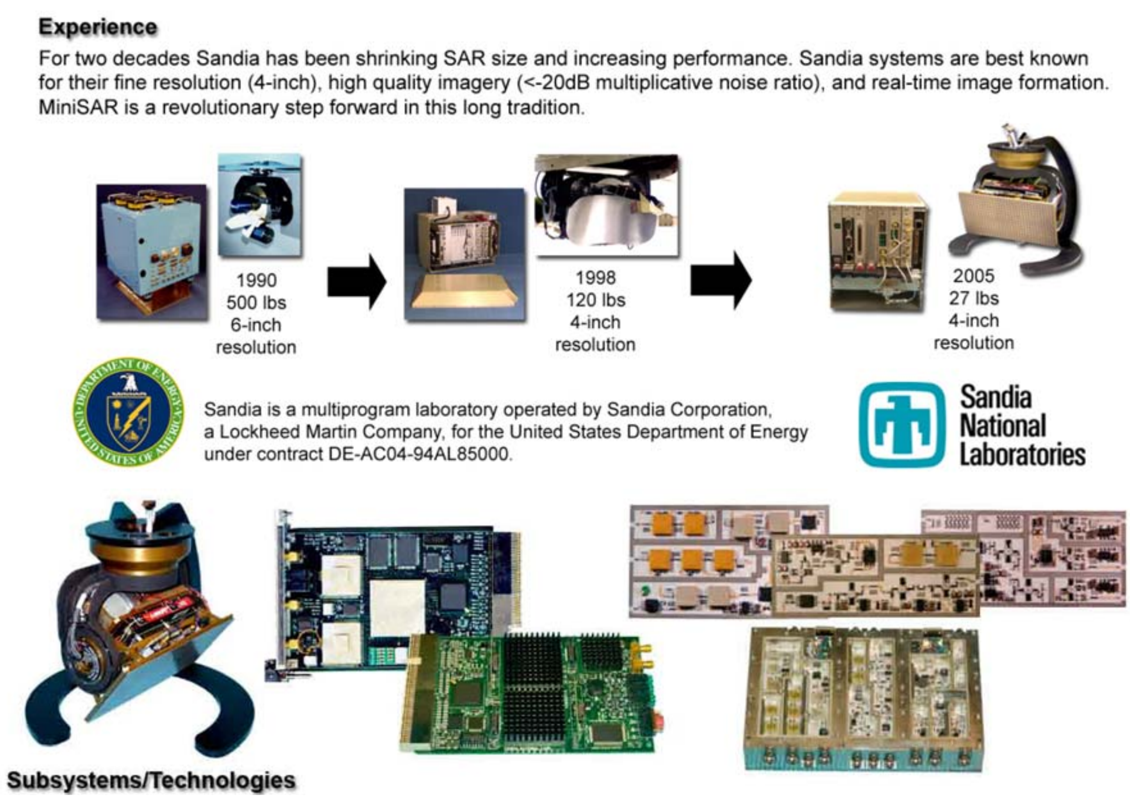
CW : continuous wave
FSK : frequency shift keying

This mm wave anti-collision RADAR system uses a very narrow pencil beam to:

- detect the presence and speed of obstacles in front of the UAV
- detect fine horizontal wires if a horizontally polarized mm wave beam is used
- detect the altitude (radio altimeter function) and confirm the attitude of the UAV
- determine the ground speed of the UAV itself
- can “see” through fog, cloud and rain

Synthetic Aperture RADAR ("SAR") uses mathematical techniques to combine reflected signal phase and amplitude information as a function of time from several adjacent-in-time RADAR pulses to build up ("synthesise") a high resolution image, matching the quality achievable from a much larger antenna without any additional mathematical manipulation.





Performance/Specifications

Specification	*Value*	*Notes/Comments*
Weight	Radar electronics assembly (REA): 9 lbs Antenna/gimbal assembly (AGA): 17 lbs System total: 27 lbs with cables	Follow-on version will be 18 lbs
Size	REA: ≈ 7-inch cube AGA: ≈ 10-inch cube	
Frequency	16.8 GHz	Readily extensible to X/Ka-bands
Resolution	4-inch minimum	Spotlight mode, real-time
Range	10 km @ 4-inch resolution 15 km @ 1-foot resolution 23 km @ 12-inch resolution	Other range/weight tradeoffs 35 km with 31.5 lb AGA 5 km with 7 lb AGA
Tx power	60 W	
Modes	Spotlight	Stripmap, GMTI, CCD (follow-on)

Sandia SAR Website: **www.sandia.gov/RADAR/sar.html**

Contact: Kurt Sorensen
(505)845-9583
E-mail: kwsoren@sandia.gov

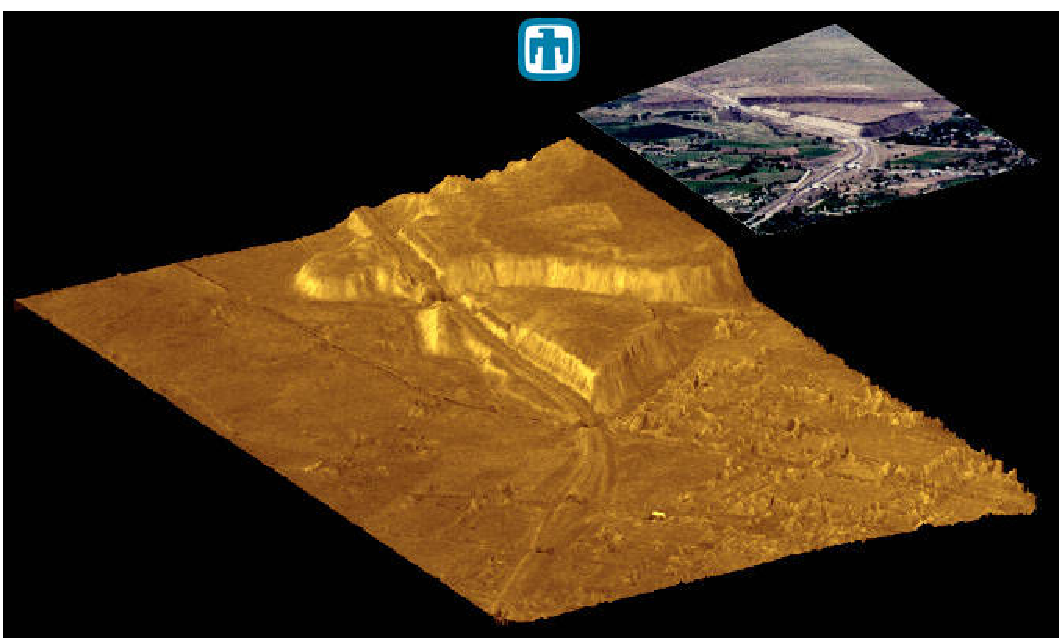
While SAR is often used because of its all-weather, day-or-night capability, it also finds application because it renders a different view of a "target," with synthetic aperture radar being at a much lower electromagnetic frequency than optical sensors.

Reconnaissance, Surveillance, and Targeting.

Many applications for synthetic aperture radar are for reconnaissance, surveillance, and targeting. These applications are driven by the military's need for all-weather, day-and-night imaging sensors. SAR can provide sufficiently high resolution to distinguish terrain features and to recognize and identify selected man made targets.

Interferometry (3-D SAR, IFSAR).

Interferometric SAR data can be acquired using two antennas on one aircraft or by flying two slightly offset passes of an aircraft with a single antenna. Interferometric SAR can be used to generate very accurate surface profile maps of the terrain, as shown below.



Sandia has developed new mathematical techniques for relating the radar reflection from the terrain surface to the time delay between radar signals received at the two antenna locations. The techniques are directed at removing ambiguities in estimates of surface heights and are referred to as 2-D least squares phase unwrapping.

Navigation and Guidance.

Synthetic aperture radar provides the capability for all-weather, autonomous navigation and guidance. By forming SAR reflectivity images of the terrain and then "correlating" the SAR image with a stored reference (obtained from optical photography or a previous SAR image), a navigation update can be obtained. Position accuracies of less than a SAR resolution cell can be obtained. SAR may also be used in guidance applications by pointing or "squinting" the antenna beam in the direction of motion of the airborne platform.

Foliage, Ground and Flame Penetration.

Synthetic aperture radars offer the capability for penetrating materials which are optically opaque, and thus not visible by optical or IR techniques. Low-frequency SARs may be used under certain conditions to penetrate foliage and even soil. This provides the capability for imaging targets normally hidden by trees, brush, and other ground cover. To obtain adequate foliage and soil penetration, SARs must operate at tens of MHz to 1 GHz.

Recent studies have shown that SAR may provide a limited capability for imaging selected underground targets, such as utility lines, bunkers, mines, etc. Depth of penetration varies with soil conditions (moisture content, conductivity, etc.) and target size, but individual measurements have shown the capability for detecting 55-gallon drums and power lines at depths of several meters. In dry sand, penetration depths of tens of meters are possible.

Change Detection.

A technique known as coherent change detection offers the capability for detecting changes between imaging passes. To detect whether or not a change has occurred, two images are taken of the same scene, but at different times. These images are then geometrically registered so that the same target pixels in each image align. After the images are registered, they are cross correlated pixel by pixel. Where a change has not occurred between the imaging passes, the pixels remain correlated, whereas if a change has occurred, the pixels are uncorrelated. Of course, targets that are not fixed or rigid, such as trees blowing in the wind, will naturally de-correlate and show as having "changed." This technique does not measure direction or the magnitude of change.

Environmental Monitoring.

SAR is used for a wide variety of environmental applications, such as monitoring crop characteristics, deforestation, ice flows, and oil spills. Oil spills can be detected in SAR imagery because the oil changes the backscatter characteristics of the ocean. Radar backscatter from the ocean results primarily from capillary waves through Bragg scattering (constructive interference from the capillary waves being close to the same wavelength as the SAR). The presence of oil dampens the capillary waves, decreasing the radar backscatter. Thus, oil slicks appear dark in SAR images relative to oil-free areas.

- from www.SANDIA.gov/RADAR

PAYLOAD 7: Radio Direction Finding

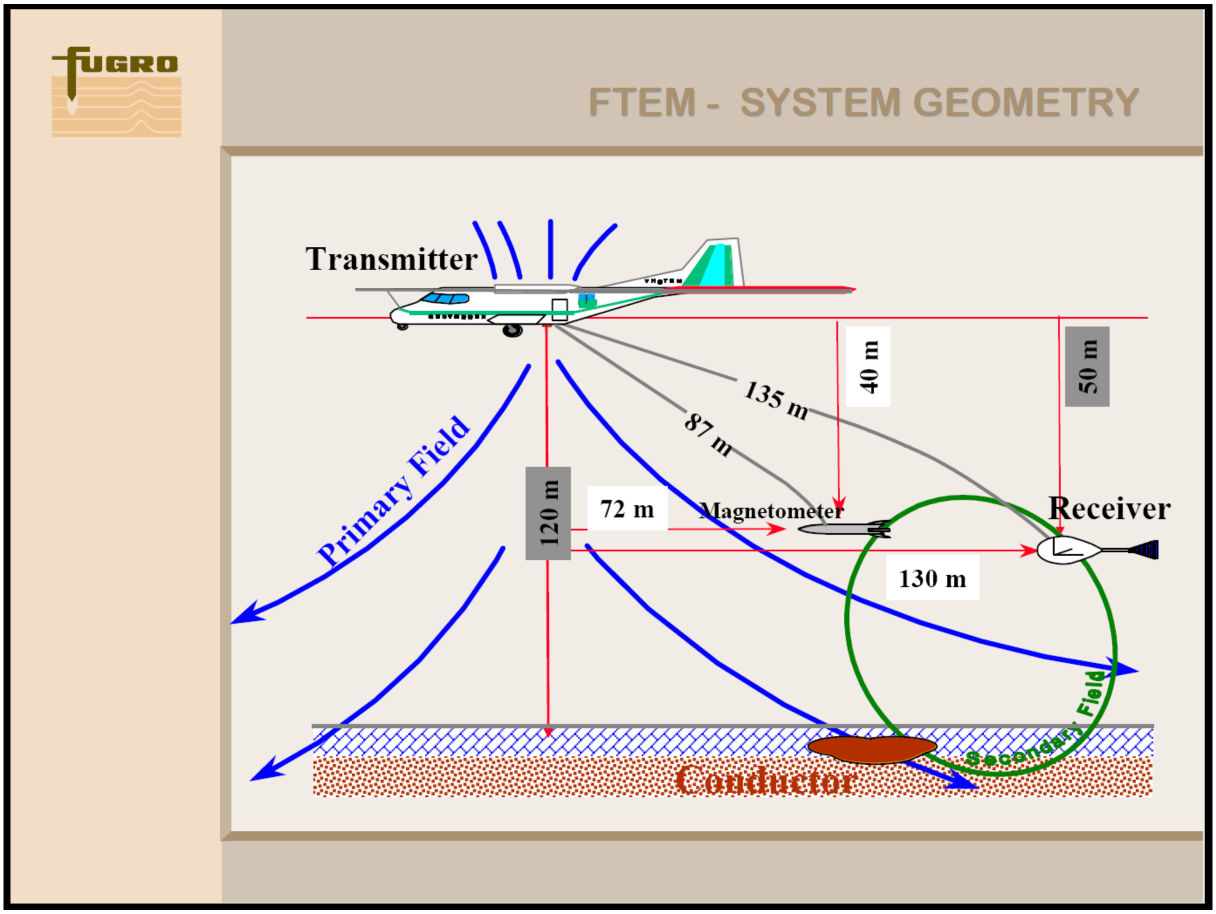
A Radio Direction Finding (RDF) system consists of several antennae connected to a signal processing unit, and is used to find the bearing (angle) to a radio transmitter.

Figure 109 = Example of a Radio Direction Finding device with multiple antennas. REF 38

Bearing Errors – Standard Reflection Field			**from www.servo.com/radio.htm**
Antenna type	Operation details	Peak error	RMS error
Two-spaced	Adcock / Time Of Arrival	11.4°	8.0°
One-quarter size Doppler	4 arms	8.0°	5.4°
One-half size Doppler	8 arms	5.2°	2.8°
Full size Doppler	16 arms	3.4°	1.5°

Radio Direction Finding is used:

- to locate a radio transmitter, using “triangulation”, from REFs 38 and 39.
- to locate the source of interference signals, for example, from a motor
- as a navigation aid using the known location of radio and/or cell phone antennas.



- from Fugro document called AEMdev.pdf

MEGATEM, Dash 7

Up to six windings in the large coil running along the outside of a Fugro Airborne Survey aircraft, from Fugro documentation, FTEM2.pdf.

Transmitter Dipole Moment

GEOTEM					
90 Hz	2ms	540A	231m²	5T	0.62M Am²
30 Hz	4ms	500A	231m²	6T	0.69M Am²
30 Hz	6ms	500A	231m²	6T	0.69M Am²
MEGATEM					
90 Hz	2ms	595A	406m²	4T	0.97M Am²
30Hz	4ms	665A	406m²	4T	1.08M Am²
15Hz	4ms	665A	406m²	4T	1.08M Am²

The latest Fugro MegaTEM II achieved a dipole moment of 2.2 M Am^2. Both items from Fugro documentation. The optimal shape for an Unmanned Air Vehicle would be a large diameter (say 24 m → 452 m^2 area) flying saucer, with the coil cables running around the perimeter of the craft. With a six turn (6T) coil, one would need a peak current of 811 A to generate a dipole moment (= NumTurns x PeakCurrent x Area) of 2.2 M Am^2.

Effective Exploration Coverage

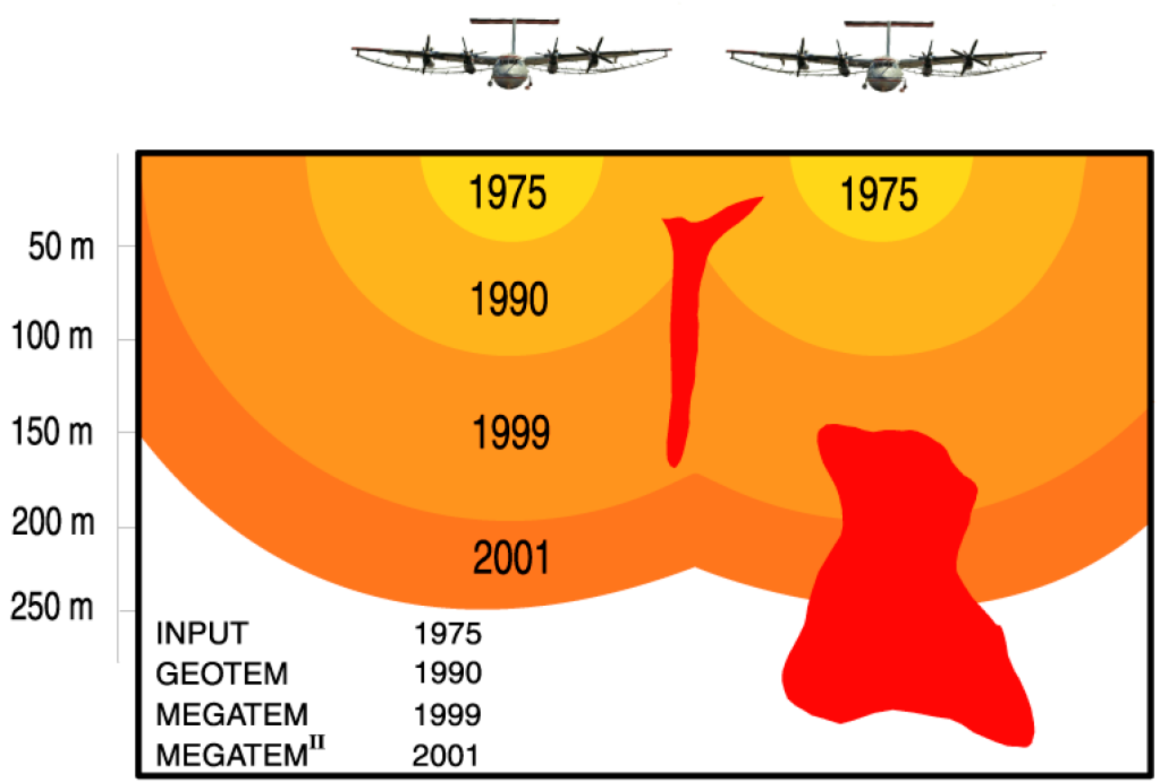
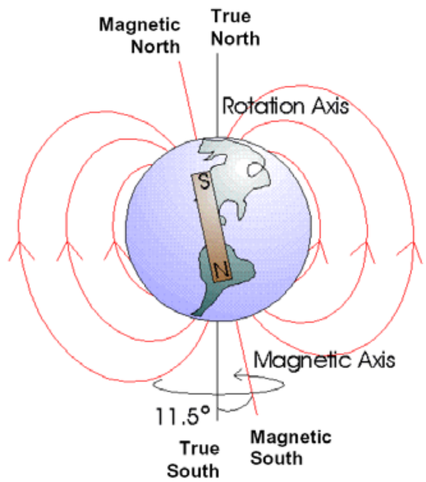


Illustration based on 200 m Line Spacing

PAYLOAD 9: Precision magnetometer

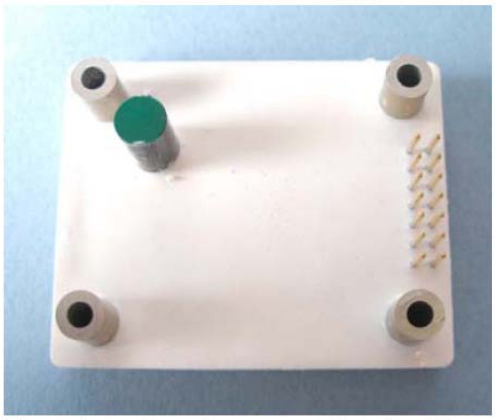
A magnetometer is used to measure the strength of the Earth's magnetic field. To get a feel for the sensitivity of these magnetometers, the earth's magnetic field strength in London on 24 SEP 2005 was 48,489 nT, increasing by 31.43 nT per annum. The 0.100 nT accuracy of the potassium magnetometer is very close to the 0.086 nT daily increase in the earth's magnetic field strength in London. Diagram of the Earth's magnetic field, shown below, from www.philips.com .



The Geometrics G-822A Cesium beam magnetometer – from www.alphafisica.com.br - magnetometer sensor (339 g) + electronics (750 g)

- *Airborne and Vehicle Applications with Multi-Sensor Array Capability*
- *Automatic Hemisphere Switching*
- *Highest Sensitivity ___ 0.0005 nT/√Hz RMS with the G-822A Super-Counter*
- *Highest Versatility ___ Full Aircraft Compensation with RMS AADCII or Button-on Towed Bird system with CM-201 Internal Mini-Counter, with 6 Channel 12 bit A to D converters*
- *Superior resolution of the Cesium Larmor signal, tracking earth's field variation rates exceeding thousands of nT (ã) over 0.01second periods when using the G-822A Super-Counter*
- *Gradiometer arrays offering simultaneous operation of up to four separate sensors with the RMS Instruments AADCII , Geometrics' G-822A Super-Counter or CM-201 Internal Mini-counter (See 823A Data Sheet)*
- *Geometrics offers complete turnkey systems including Birds, Stingers, Wingtip installation accessories as well as Digital Data Acquisition Systems, Flight Path Recovery, GPS Navigation, Gamma Ray Spectrometers, VLF EM , Post Acquisition Data Processing Software and Training*

Low power three-axis magnetometer



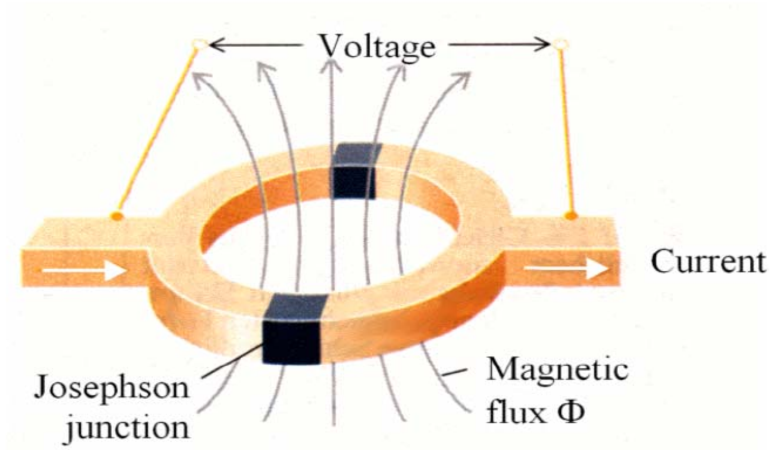
Top view showing connector & pillars

Underside view showing label

Earth's magnetic field strength: London, 24th September 2005		48,489,000 pT
solid state magnetoresistance device Honeywell HMC1001 / HMC1002: 3D	accuracy	700,000 pT
	noise level	270 pT/sqrt(Hz)
Fluxgate magnetometer 3D tensor measurement	accuracy	3,000 pT
	noise level	25 pT/sqrt(Hz)
Cesium beam magnetometer scalar magnitude only	accuracy	100 pT
	noise level	0.5 pT/sqrt(Hz)

Applications of high sensitivity magnetometers:

- geophysical surveys measuring the minute variations in the Earth's magnetic field strength to identify the location of mineral Kimberlite pipes and provide hints as to the location of hydrocarbon deposits
- compliment seismic surveys in oil and gas exploration work
- detect underground metallic structures, such as pipes, tunnels, barrels, items of archaeological importance
- detect the presence of metallic structures in dense foliage, such as trucks, pipes, crashed aircraft, artefacts from lost civilisations using differential magnetometry
- detect metallic structures under rivers and oceans, such as pipes, ship wrecks
- detect the presence of intruders in dense undergrowth, such as armed militia with metal guns possibly travelling on metal bicycles, motorbikes or in metal trucks…



Materials:

- “Low temperature” :Classical: Niobium, working at 4.2 K
- “High Temperature”: YBCO, working at 77 K
- Diameter mm to cm, application dependent

supracon
SQUID and Microfabrication Technologies

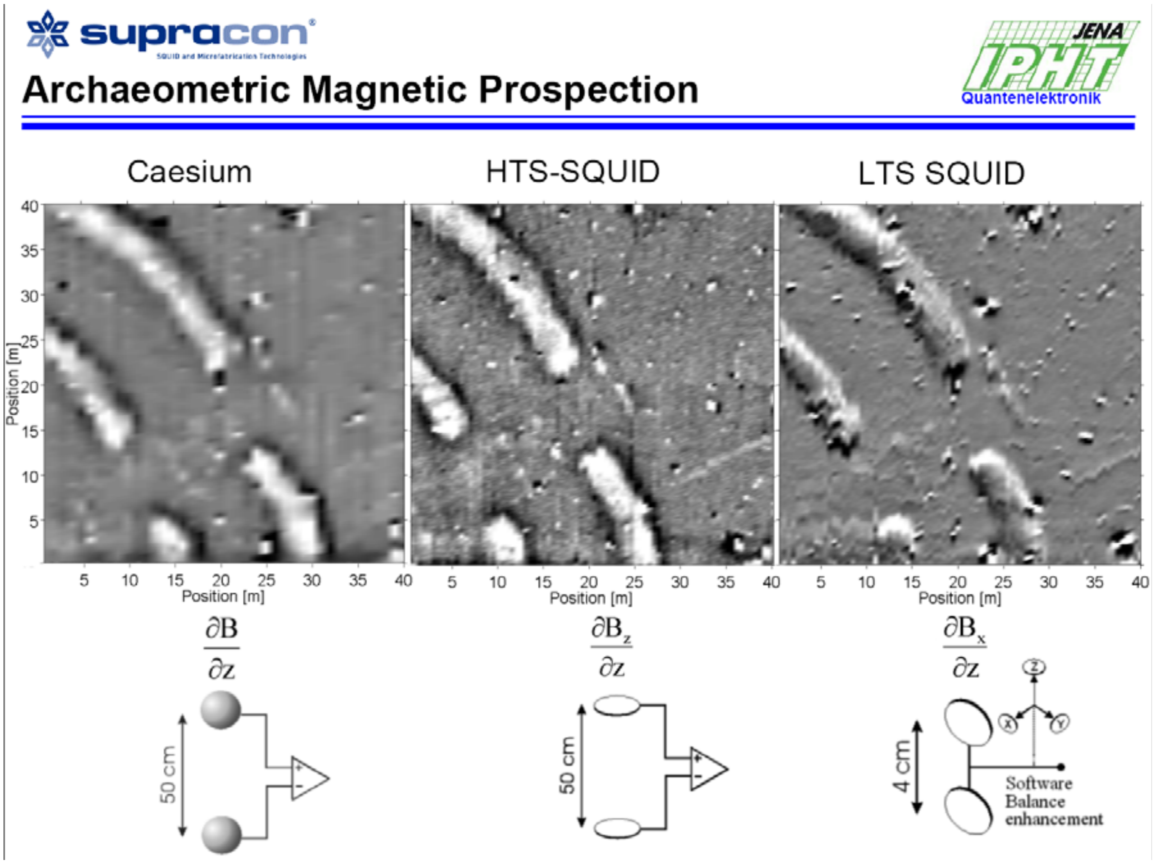
Archaeometric: Why SQUIDs for Magnetic Mapping

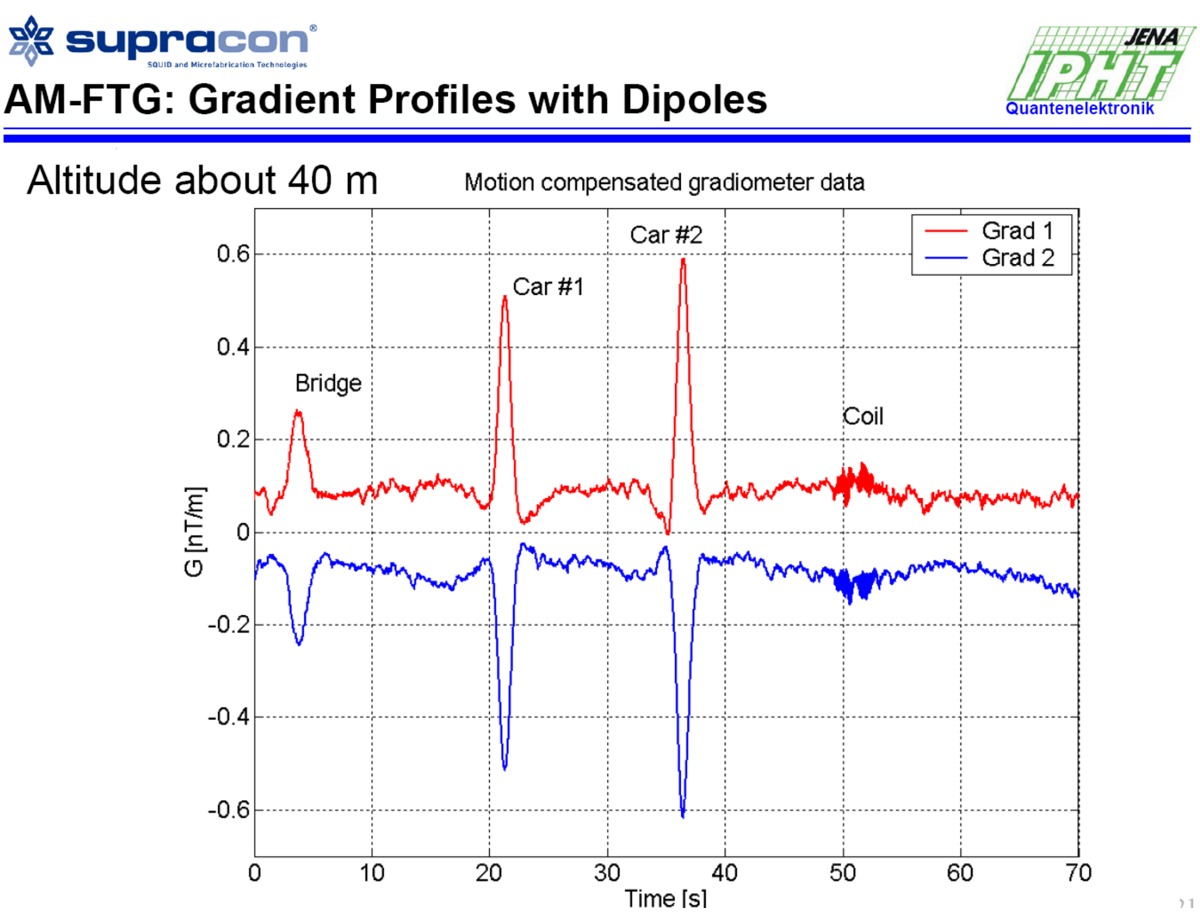
JENA IPHT Quantenelektronik

	Caesium	Fluxgate	SQUID
Measures	Total field	Vector	Vector
Bandwidth	10Hz	>1kHz	>1kHz
Noise 0.1-10Hz	>5pT/m	80pT/m	<0.5pT/m

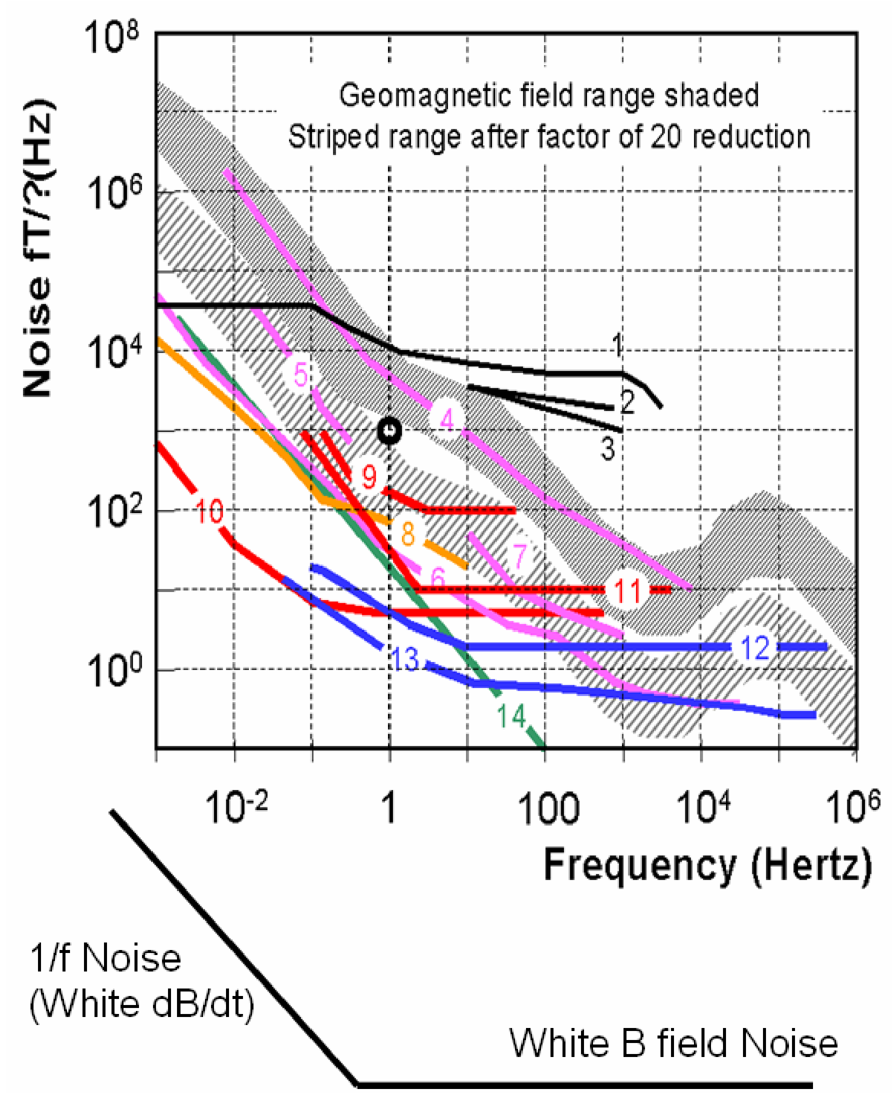
SQUIDs:

- low noise floor: suitable for archaeometric purposes
- high bandwidth
  - ➔ increased scanning speed
    - ➔prospection of large areas


supracon
SQUID and Microfabrication Technologies
Archaeometric Magnetic Prospection
JENA
IPHT
Quantenelektronik
Caesium
HTS-SQUID
LTS SQUID
Position [m]
Position [m]
Position [m]
Position [m]
∂B / ∂z
∂B_z / ∂z
∂B_x / ∂z
50 cm
50 cm
4 cm
Software
Balance
enhancement


supracon
SQUID and Microfabrication Technologies
AM-FTG: Gradient Profiles with Dipoles
JENA
IPHT
Quantenelektronik
Altitude about 40 m
Motion compensated gradiometer data
Grad 1
Grad 2
Car #2
Car #1
Bridge
Coil
G [nT/m]
Time [s]

Sensor noise as a function of frequency from James Macnae presentation at SEG 2006



Legend: Noise specification derived from various sources of varied reliability and experimental procedure

1. Bartington commercial fluxgate
2. Narod fluxgate
3. NPO Geophysica fluxgate
4. UTEM Borehole coil
5. Newcastle University coil
6. Metronix coil
7. CSIRO Drover coil
8. GEM systems K vapour
9. HT-RF Squid, Julich
10. HT-DC Squid, Berlin & UC Berkeley, shielded environment
11. HT Squid CSIRO
12. LT-DC Squid, Berlin
13. LT Squid, IPHT, Jena
14. 100 m square wire loop

O Reference point for cost/power comparison (1 Hz, 1 pT/√Hz)

Typical Detection Range For Common Objects		
Ship 1000 tons	0.5 to 1 nT	at 244 m
Light Aircraft	0.5 to 2 nT	at 12 m
Pipeline (12 inch)	1 to 2 nT	at 60 m
Pipeline (6 inch)	1 to 2 nT	at 30 m
Automobile	1 to 2 nT	at 30 m
100 Kg of iron	1 to 2 nT	at 15 m
45 Kg of iron	0.5 to 1 nT	at 9 m
4.5 Kg of iron	0.5 to 1 nT	at 6 m
0.45 Kg of iron	0.5 to 1 nT	at 3 m
Screwdriver 125 mm	0.5 to 2 nT	at 4 m

- from http://www.heritagegeophysics.com/Magnetometers/Magnetometers.htm

Sensor noise during winter atmospheric ("sferic") disturbance: minimum response

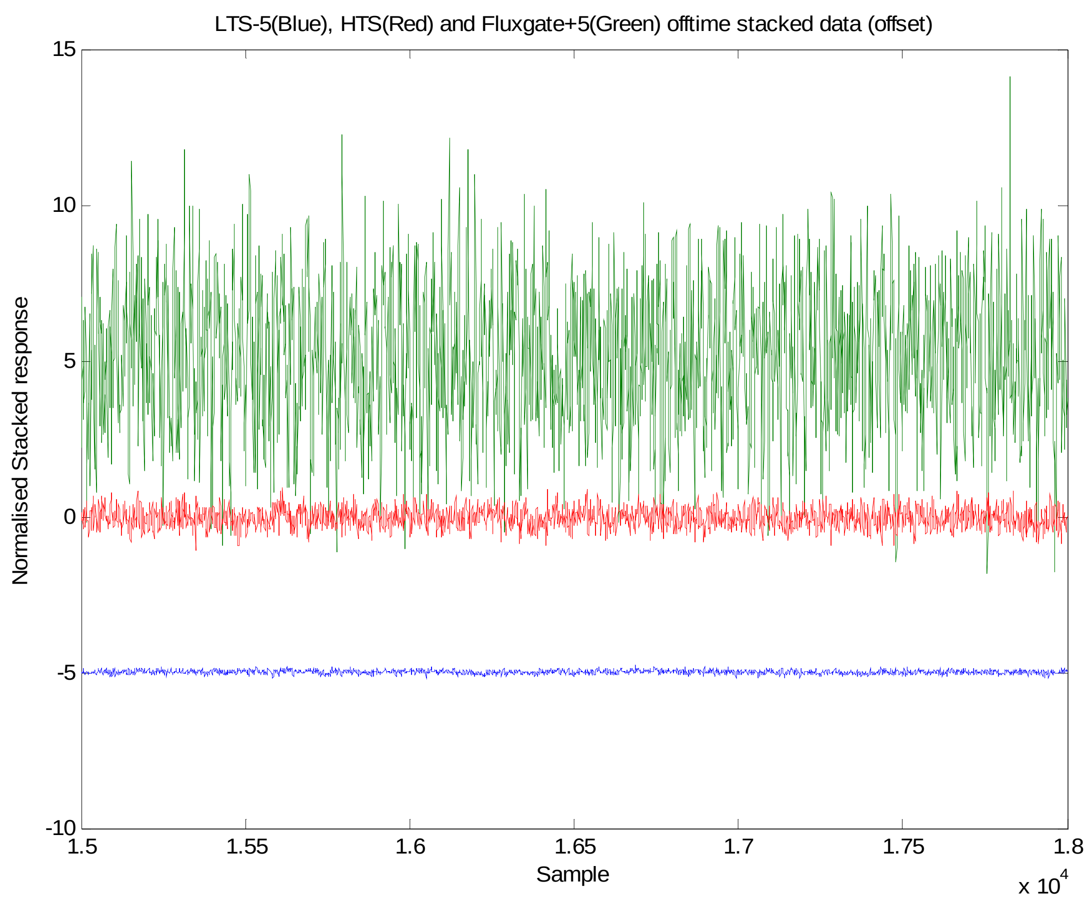
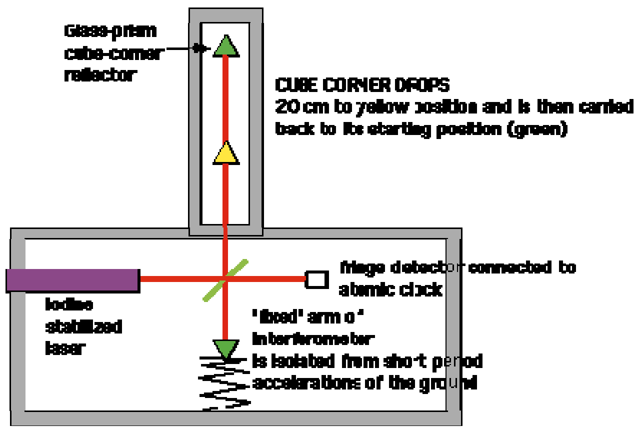


Figure 110 From James Macnae presentation at SEG 2006

PAYLOAD 10a: Gravity Meter (often called a “gravimeter”)

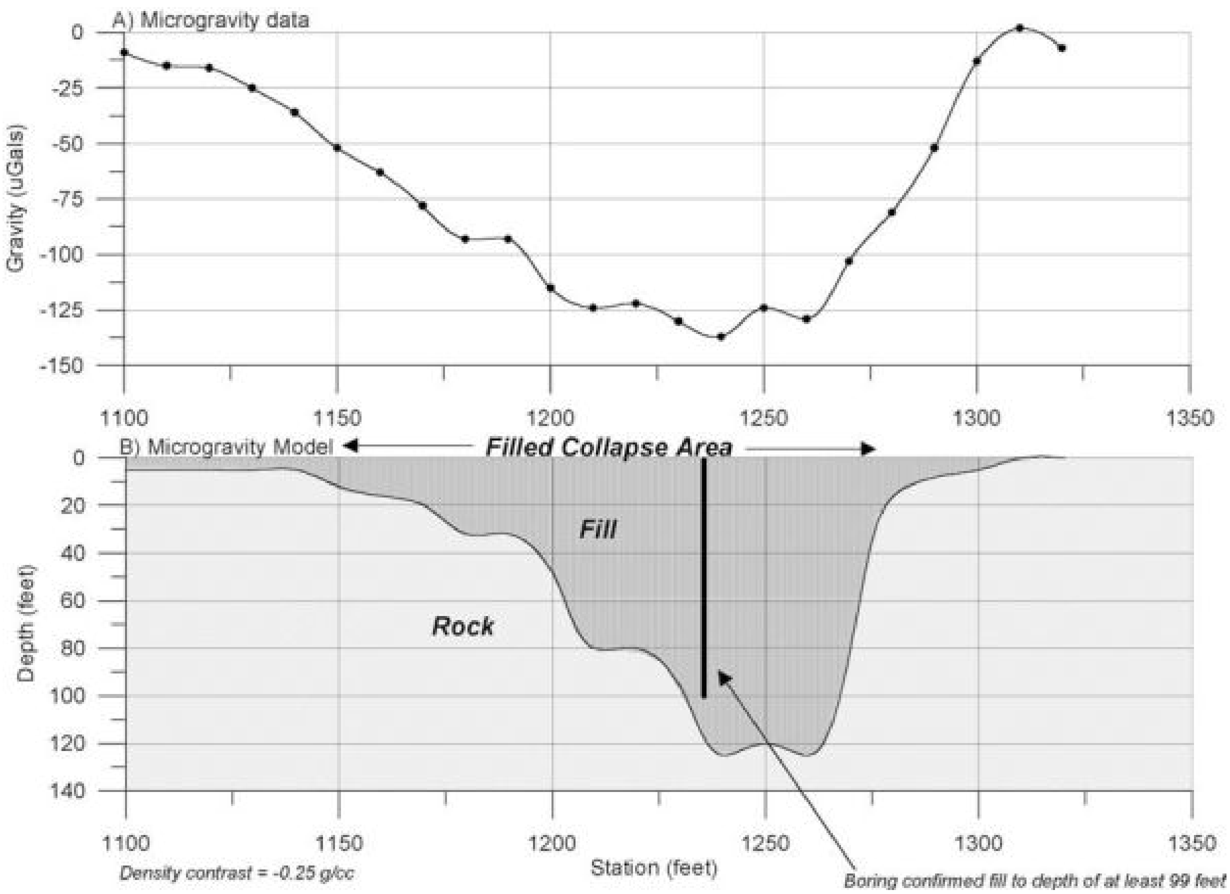
The FG5 absolute gravimeter and the CG-5 AutoGRAV gravimeter

The heart of the gravimeter mechanical unit operates within a hard vacuum. A cube-corner reflector drops in free-fall a distance of 20 cm, its position detected both by an iodine stabilized interferometer, and by a photocell that accelerates an elevator ahead of its downward path, removing stray remaining molecules from interfering with its descent. After its fraction-of-a second journey the elevator catches the reflector and transports it back to its starting point from where it is ready for another drop. The cycle has a duration of roughly 1 second. Electronic circuitry sequences the move, timing the zero-crossings of the interference fringes to sub-nanosecond accuracy. The absolute value of gravity is then calculated from the precisely measured time to travel a really well known distance.



The **Scintrex CG-5** from www.scintrexltd.com has a resolution of 1 uGal, and a standard deviation of less than 5 uGal. The “Gal” unit is named after “Galileo”, and equals 1 cm/s^2. The gravitational constant = g = 980.665 Gal.

The accuracy of the FG-5 shown on the top of the opposite page is 2.1 uGal, equivalent to 6 mm change in altitude. Sander Geophysics Limited report a resolution for their airborne AIRGrav system from 150 … 300 uGal. To put these figures in context, the earth's gravitational field strength is 980,600,000 uGal. The **major challenge** is to have an extremely low vibration level in the aircraft to enable accurate microgravity measurements. An alternative approach is to measure the gradient in the Earth's gravitational field using a completely different, and expensive, instrument called a "gradiometer".



Above: Microgravity data (A) and model (B) showing anomalous area. Areas of low gravity anomalies (100 to 175 µGals) were identified in five of the survey lines. The anomalous areas are centred within the collapse area and are aligned with the strike of the mine. An example of the data along one of the profile lines is shown above.

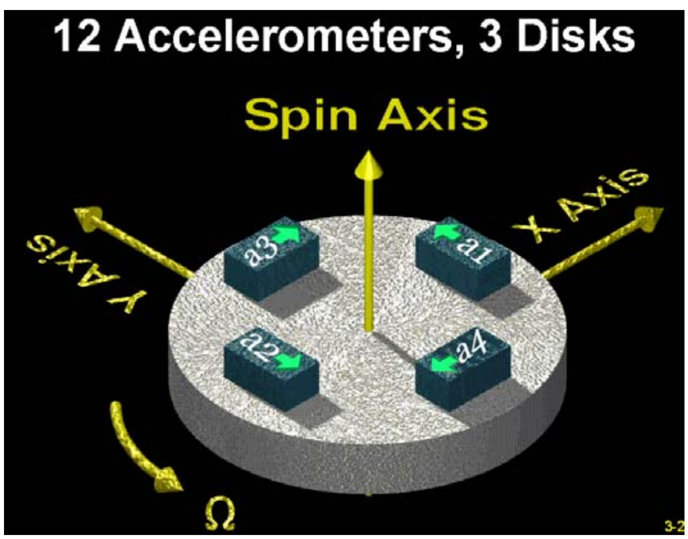
- from www.fhwa.dot.gov/mine/ky0316.htm

Measurements of minute (1:200,000,000) changes in the gravitational field over a region can indicate the location of:

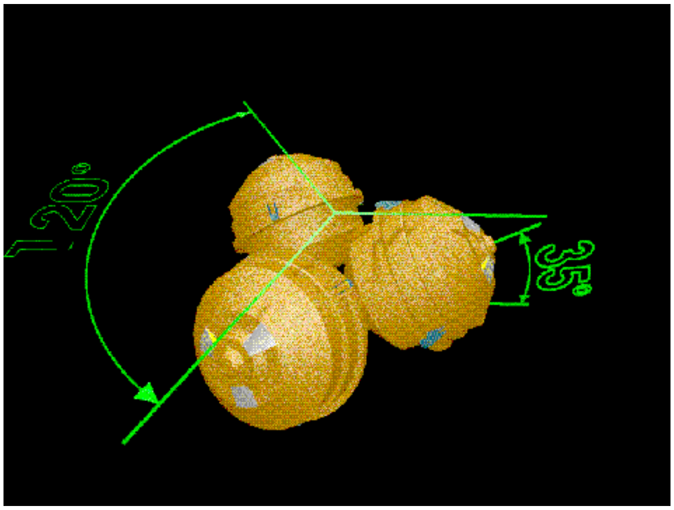
- hydrocarbon deposits, such as oil and gas
- minerals
- underground tunnels
- new tunnels through the use of differential gravity measurements
- collapsed mines and tunnels, refilled by earth (as shown above)

The 3D Full Tensor Gradiometer (FTG) System was developed and manufactured by Lockheed Martin Federal Systems. Bell Geospace purchased two systems for use in marine applications. Both units have been upgraded for airborne surveys but still maintain the capability to acquire high quality Marine-FTG® data.

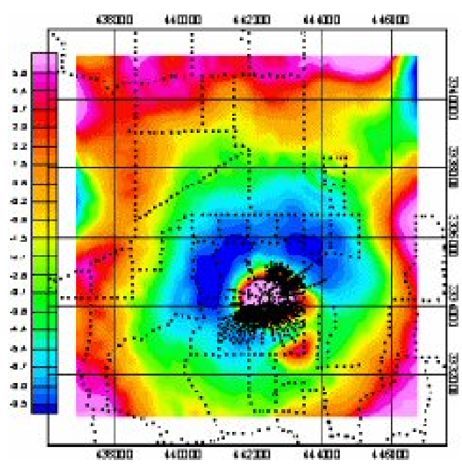
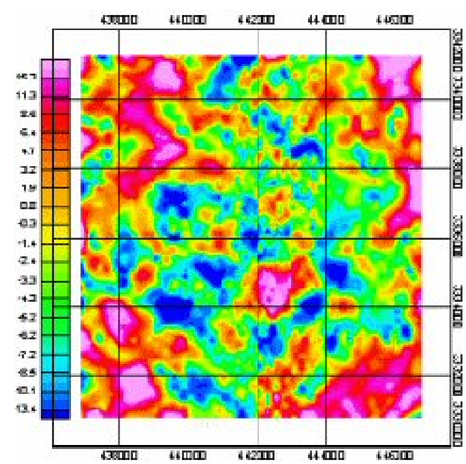
- above and below from http://www.bellgeo.com/tech/measurements.html



The 3D FTG system consists of 3 Gravity Gradiometer Instruments (GGI's). Internal to each GGI is a rotating disk with 4 accelerometers. The opposing pairs of matched accelerometers are mounted 10 cm apart. The disk rotates at a commanded rate, usually 0.5 Hz. Gradients are measured by the difference in readings between opposing pairs of accelerometers. The output of all 4 accelerometers are summed together to measure the gradient accelerations with linear accelerations removed. Data is sampled at 128 Hz.



The GGI's are mounted on a 3 gimbaled stabilized platform, oriented at 120 degrees from each other and 54.74 degrees from vertical. The azimuth gimbal is set to carousel at a commanded rate, usually 300 degrees /hour. Rotation of the GGI's through all the planes allows for improved noise reduction.

	
The above figure represents the first vertical derivative of a ground gravity survey run over a salt dome in Vinton, LA. The data has been upward continued and had a linear trend removed to allow comparison to Air-FTG® data. Note particularly the data missed from the ground gravity where coverage was sparse (stations are shown as small black dots)	The above figure represents the vertical gravity gradient Tzz as measured by Air-FTG® on a survey run over the same salt dome in Vinton, La. The data has a linear trend removed to allow comparison to ground gravity. Note the similarity in overall shape with the extra resolution afforded by Air-FTG®.

Historical note. In 1982 the USAF Geophysical Laboratory started a program to develop a Gravity Gradiometer Survey System (GGSS). With funding from the Defense Threat Reduction Agency, Lockheed Martin further improved the gradiometer, creating the basis for both the Bell Geospace Air-FTG system and the BHP Billiton Falcon Gradiometer.

PAYLOAD 11: Gamma Ray Spectrometer

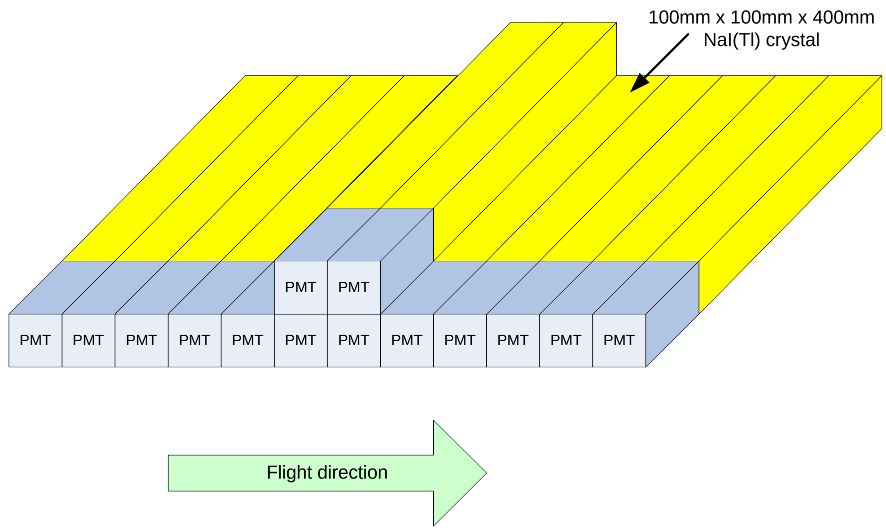
The purpose of gamma-ray spectrometry is to provide information about the distribution of the three radioactive elements, uranium, thorium, and potassium. The distribution of these elements with regard to hydrocarbon exploration is significant since they are affected by the alteration effects of hydrocarbon micro-seepage.

Radiometrics is a term applied to the measurement of the gamma ray spectrum at three specific windows where emissions for uranium, thorium, and potassium are located. Bismuth 214 represents the Uranium window at 1760 KeV, Thallium 208 represents the Thorium window at 2620 KeV, and Potassium has a single emission energy at 1460 KeV.

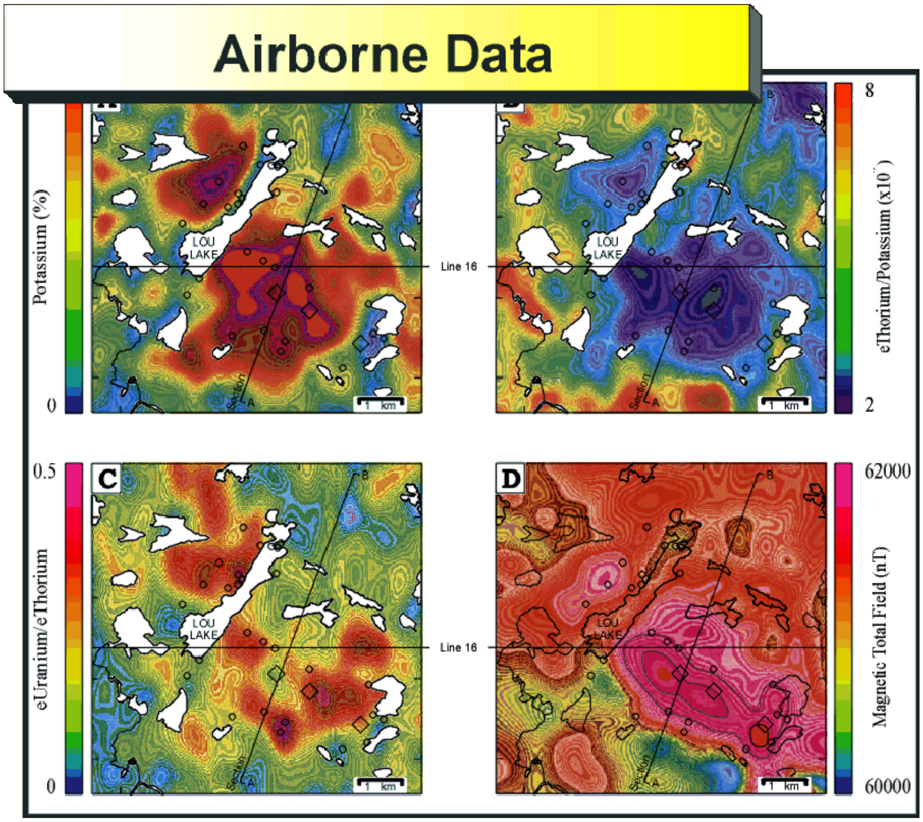
A standard interpretation for hydrocarbon exploration consists of looking for decreases in gamma emissions from all of these windows or a decrease in the total count. Seepage anomalies from those are related to the lithology. Changes in radiometric response can also be attributed to road surface changes, outcrops, drainages, road cuts, and road fill. Keen observation is the key to culling the false anomalies from the seepage anomalies. Radiometrics is a first wave culling tool for other types of geochemical survey.

A gamma ray spectrometer consists of a detector crystal and an optical sensor. The detector, typically a sodium iodide crystal, absorbs the gamma radiation and converts it to a light flash or scintillation. The NaI is doped with Thallium which acts as an 'activator'. The Thallium doped NaI is described as NaI(Tl). The light sensor is a sensitive photomultiplier tube which converts the light flash to a voltage proportional to the intensity of the light flash. The magnitude of the peak voltage is indicative of the energy of the gamma ray. The larger the crystal volume (112 cubic inches or more) and the slower the aircraft (40 knots for UAV; 130 for manned), the higher the number of gamma counts that can be collected.

The above from http://www.grdc.com/radiometrics.html



Each gamma ray detector typically consists of a 4” x 4” x 16” NaI(Tl) crystal integrally mounted with a high sensitivity photomultiplier tube (PMT). Each of these crystals weighs 15.4 Kg, and the integral unit, as supplied by Saint Gobain, costs around $15,000. A typical airborne configuration is as shown above, consisting of 12 units to detect ground gamma rays, and two upper units to detect the level of cosmic gamma rays.



From http://gsc.nrcan.gc.ca/gamma/survey_e.php

Integrally Mounted Scintillator/Light-sensing Device Assembly –

In this integral design, the light-sensing device (usually a PMT) is optically coupled directly to the scintillator. The scintillator is mounted in a container (usually aluminum) and a mu-metal shield is fitted over the PMT. The detector package is hermetically sealed when a hygroscopic scintillator, such as NaI(Tl) is used. The scintillator container and mu-metal shield are sealed together to form a low-mass and light-tight housing for the detector.

This design usually yields better and more consistent energy resolution. Therefore, these are the detectors of choice for spectroscopy and radioisotope assay.

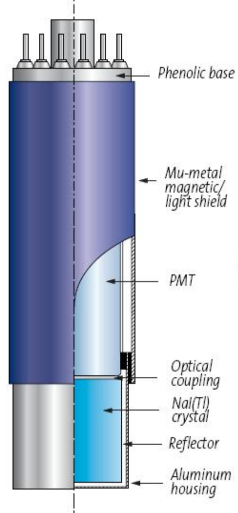


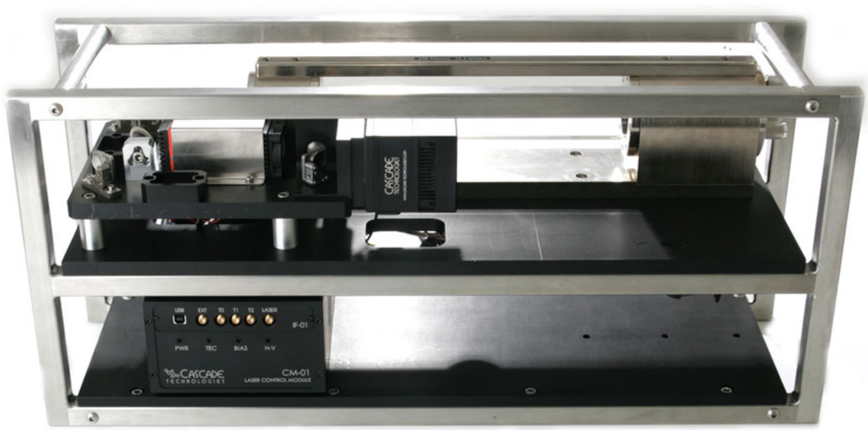
Illustration of Integrally Mounted Scintillator/PMT Assembly

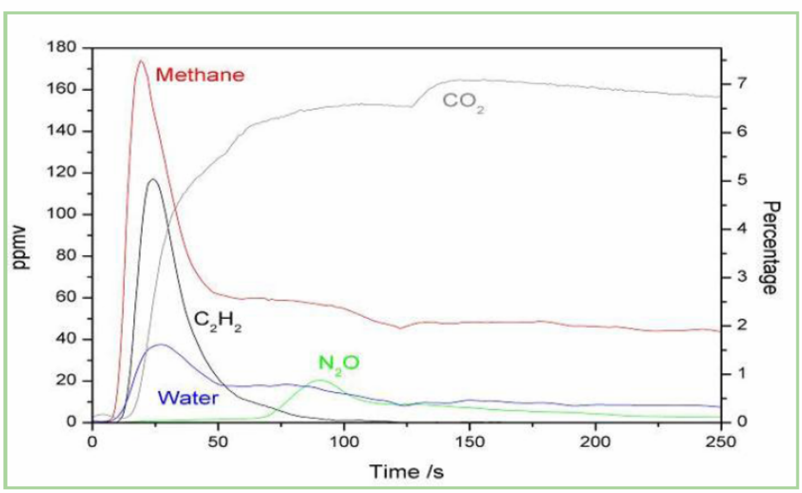
from "SGC Scintillation Materials and Assemblies Brochure 1024.pdf" at www.detectors.saint-gobain.com

PAYLOAD 12: The tuneable laser based precision gas sensor

In order to detect hydrocarbons such as methane or ethane from natural gas leaks, the laser must be set to a wavelength at which these gases have appropriate absorption lines. For a low measurement threshold, the absorption value of the gas should be as high as possible. Potential absorption curves for the detection of methane (CH_4) are located in the spectral range from 1.6µm to 4.0µm, with three significant bands at about 1.6µm, 2.3µm, and 3.3µm. The strongest absorption lines are located at about 3.3µm. Ethane (C_2H_6) also has absorption lines in this range. However, overlapping with the absorption lines of water vapor must also be taken into consideration. The design calculations made in the course of work on this feasibility study indicate that appropriately selected LIDAR systems would be in a position to detect the required very small leaks of below 0.1 cubic meters per hour from altitudes of up to 300 meters. This method therefore appears to be suitable for gas-leak detection during regular aerial patrols with small helicopters.

High-Resolution Remote Sensing Used to Monitor Natural Gas Pipelines
by W. Zirnig, D. Hausamann and G. Schreier
http://www.eomonline.com/Common/currentissues/zirnig.htm





Environmental Monitoring
Multiple Constituents of air can be monitored with a single laser.

from www.cascade-technologies.com

Shell turns to cascade lasers for oil exploration

A cross-disciplinary UK consortium wins funding to develop a laser detection system that could be used to discover hidden fields of oil and natural gas. A UK team is working on a £2.4 million ($4.5 million) project to develop an optical system based on quantum cascade lasers for oil and gas prospecting.

Comprising the III-V foundry Compound Semiconductor Technologies (CST), the Universities of Sheffield and Glasgow, Shell Global Solutions and laser system specialist Cascade Technologies, the consortium has received just over £1 million from the UK government's Department of Trade and Industry (DTI). The industrial partners are providing the remaining £1.4 million. Energy giant Shell will fund field testing of the instrument once the development is completed.

The detection system will be based on photoacoustic spectroscopy, a technique that can be used to measure gas concentrations with remarkable sensitivity. CST commercial director Wyn Meredith explained that ethane (C_2H_6) is the crucial hydrocarbon that gives a strong clue as to the likely location of an undiscovered field of oil or gas.

Ethane and methane (CH_4) gas are produced when larger hydrocarbons - typically found in oil and gas reserves - "crack" into smaller molecules. Unlike methane, however, ethane is not produced by biological decay, and so it is a far more reliable indicator. QCLs allow instrument size reduction

Shell already uses a system based on a mid-infrared lead-salt laser to probe for ethane in its so-called "LightTouch" prospecting equipment. However, these relatively bulky lasers require cryogenic cooling, and the mobility of the system can be an issue. By incorporating III-V-based quantum cascade lasers (QCLs) instead, the size of these systems could be greatly reduced. "Using the photoacoustic spectroscopy approach, we hope to produce an instrument that has an ethane sensitivity of around 100 parts per trillion," said Meredith.

Researchers at the University of Sheffield will be growing QCL structures using novel antimonide-based epitaxy to reach the crucial 3.35 μm absorption band of ethane. The material development is needed because commercial QCLs that are currently available operate at longer wavelengths.

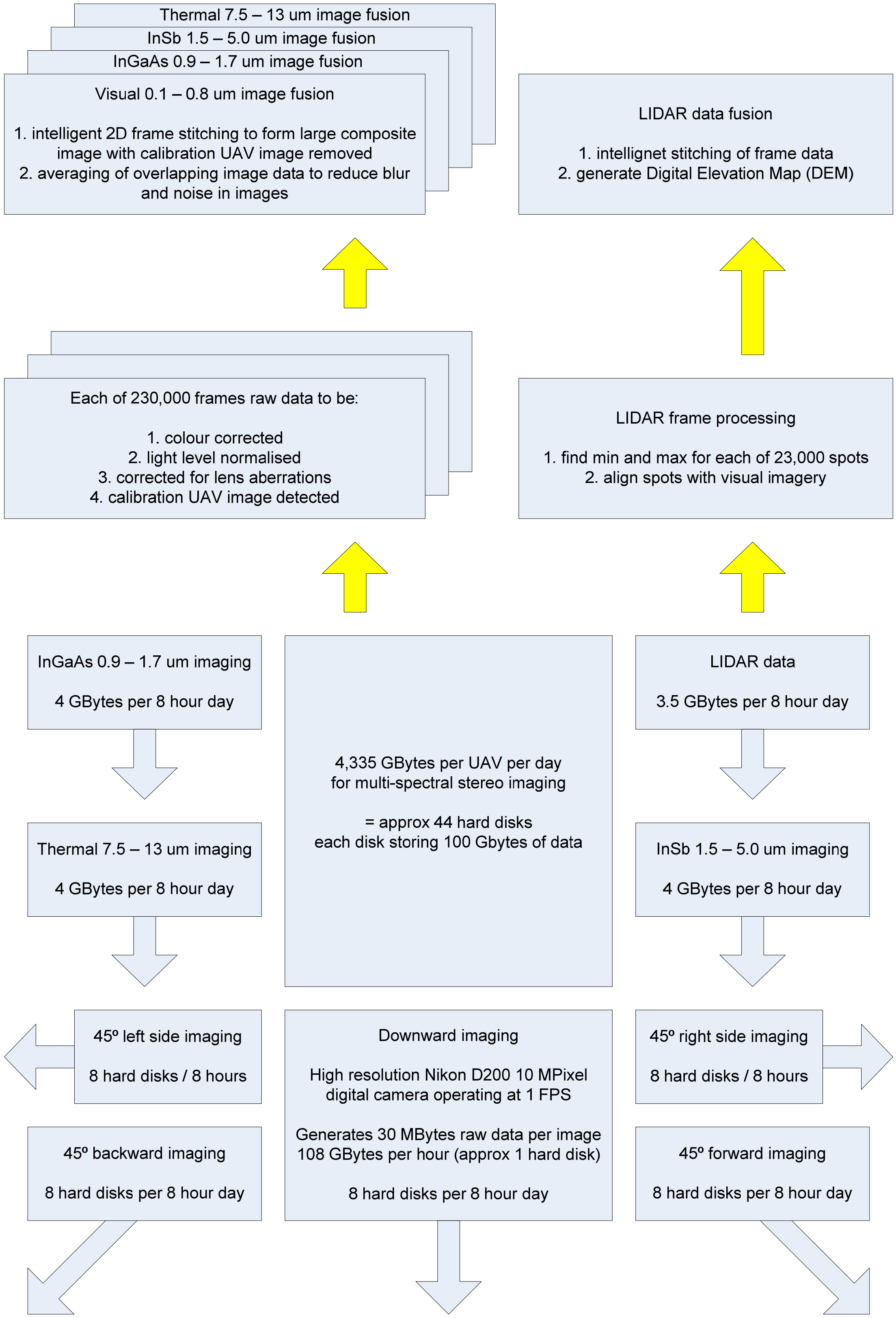
Using designs developed with the electronics and electrical engineering department at Glasgow, CST will fabricate laser devices from the material produced at Sheffield, while Cascade will provide module-level packaging and control electronics.

Glasgow's physics department will then develop the photoacoustic instrument in conjunction with Shell until it is ready for field trials. "The long-term aim is to set up a UK supply chain - from design to packaged device to system implementation," explained Meredith. "This is strengthened by Cascade securing the rights to source QCLs from foundry manufacturers." Cascade and Lucent Technologies recently signed a deal over the intellectual property relating to QCL devices.

About the author
Michael Hatcher is editor of Compound Semiconductor

- from http://optics.org/optics/Articles/ViewArticle.do?channel=business&articleId=26114

Appendix 6
Data processing, fusion, noise reduction and interpretation



Software plays a crucial role in transforming the myriad of raw data blocks into an accurate, coherent, large scale image or map of the survey region. The quantity of data can be enormous, for example, in excess of 43,000 GBytes of data per day from 10 UAVs performing stereo, multi-spectral, imaging, necessitating the use of a High Performance Computing system, typically comprising from 64 to 1,024 high end 64 bit PCs, all running LINUX because of its good scalability in a multi-processor system, and its reliability, to parallel process the survey data in a reasonable time.

Figure 111 Hewlett Packard computer cluster, shown at the SEG Conference, 2006

The end product of the UAV survey work has to be an accurate, high resolution, multi-layer image / map from which the user or a computer system can infer sub-surface geological features from the selective superposition of the available images and maps.

In the aerial reconnaissance context, software could be used to subtract images and maps taken at different times, such as different days, to indicate the appearance or disappearance of objects and personnel. In fact, with sufficiently smart software, and regular imaging of the terrain, the software should be able to indicate the movements of objects and personnel, even objects and personnel that are heavily camouflaged.

In an ongoing aerial surveillance situation, various portions of the large data sets will be updated in real time following the receipt of the data via a fast Free Space Optics data link, and in a Network Centric infrastructure, will then automatically be accessible by users connected to the Internet.

Indeed, once the UAV platform and sensor systems are stabilised, manufactured and used in increasing volumes, the principle development work will be in the areas of:

- High Performance Computing, with low latency data transfer between computers
- the application of High Performance Computing to correct lens and other aberrations in the data, and to generally enhance the quality of the raw data
- the fusion of the many data frames into a few large, coherent data sets for viewing across a Network
- the automated interpretation of the large, processed, data sets
- the integration of updated data in a Network Centric infrastructure

The final and most impressive software element is the data interpretation software which is able to automatically analyse all the available data and determine the location and attributes of geologically interesting features such as mineral, oil and gas deposits.

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Useful web sites

Name	Web Site
Aerosonde corporate site	www.aerosonde.com
Crossbow Technologies	www.xbow.com
Earth mapping by Google	www.earth.google.com
Federation of American Scientists	www.fas.org/irp/program/collect/uav.htm
Flight International magazine	www.flightinternational.com
German site covering TAM 5	www.kh-gps.de/flug.htm
Israeli Aircraft Industries	www.iai.co.il
Model aeronautics site	www.modelaircraft.org
Model planes and UAVs	www.miniplanes.net
Model shop	www.towerhobbies.com
National Geophysical Data Center	www.ngdc.noaa.gov
Nellis Air Force Base, USA	www.nellis.af.mil
Pulse jets	www.airtoi.com
Sander Geophysical Limited	www.sgl.com
Small gas turbines	www.amtjets.com
Small rockets	www.aerotech-rocketry.com
Small rockets	www.missileworks.com
TAM 5 and Maynard Hill	www.tam.plannet21.com
UAV applications	www.uav-applications.org
UAV components	www.cloudcaptech.com
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UAV general forum	www.uavforum.com
Wankel engines for UAV use	www.uavenginesltd.co.uk/
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Acronyms used

ADSL	Asymmetric Digital Subscriber Line, as used in broadband Internet access
ADC	Analog-to-Digital Converter, typically in integrated circuit form
ATC	Air Traffic Control
BW	Bandwidth in Hertz (Hz)
CCD	Charge Coupled Device, used as the imaging element in a digital camera
CCTV	Closed Circuit TeleVision, as used to monitor security in buildings
DEM	Digital Elevation Mapping
DoD	US Department of Defense in Washington, D.C.
DWDM	Dense Wavelength Division Multiplexing (of optical wavelengths)
FAI	Fédération Aéronautique Internationale is the world's air sports federation
FSO	Free Space Optics in which light beams are used to transmit signals
GCS	Ground Control System
GPS	Global Positioning System, using satellites to determine an exact location
GSM	Global System for Mobile communications, as used by mobile phones
IMU	Inertial Measurement Unit containing gyros, accelerometers & inclinometers
ISM	Instrument, Scientific and Medical (band)
KE	Kinetic Energy, the energy of motion = $0.5mv^2$
LAN	Local Area Network, as used in a computer network
LED	Light Emitting Diode, basically, a small semiconductor lamp
LIDAR	LIght Direction finding And Ranging = laser based RADAR
mm wave	millimetre wavelength, typically for microwave frequencies above 30 GHz
MTBF	Mean Time Between Failures, as a measure of reliability, usually in hours
NASA	National Aerospace and Space Administration
nT	nanoTesla, a measure of magnetic field strength
PC	Personal Computer
PCM	Pulse Code Modulation, widely used in telemetry and model radio control
PE	Potential Energy = mgh
R+D	Research and Development
RADAR	RAdio Direction finding And Ranging
rms	Root Mean Square, an accurate measure of the average power of a signal
RoHS	Restriction of the use of certain Hazardous Substances in EE equipment
TV	Television
UAV	Unmanned Air Vehicle, the topic of this document
UWB	Ultra Wide Bandwidth, typically from 3.1 … 10.6 GHz
VSAT	Very Small Aperture Terminal, as used to receive signals from a satellite

Conversion Table

1 BHP	=	745.7 watts		1 KWatt	=	1.341 BHP
1 ft	=	0.3048 m		1 m	=	3.281 ft
1 pound	=	0.4536 Kg		1 Kg	=	2.2046 pounds
1 US gallon	=	3.785 litre		1 litre	=	0.2642 US gallon
1 Imperial gallon	=	4.546 litre		1 litre	=	0.22 Imperial gallon

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Figure 112 = The early version Predator UAV landing. REF 58