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Sense and avoid

Analysing a key technology

Falco UAV dossier

Investigating a hawk-eyed Italian

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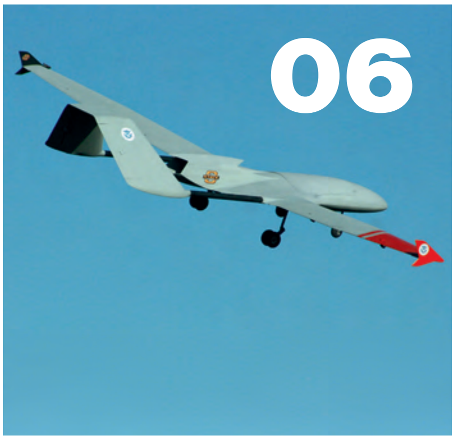
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Don’t miss the boat (or car…)

Throughout the world of unmanned systems, creative engineers, sensing the opportunities as the market expands, are coming up with fresh technological solutions. This may well be looked back on as the golden age of innovation. We are certainly proud to be playing our part in documenting it – but will it, rather, be the age of lost opportunity?

Those in a position to exploit the available technology tend to be extremely conservative. That is particularly true in the aviation sphere. There, encouraged by those in authority who certify craft, the philosophy has long been ‘if it ain’t broke, don’t fix it’ and unmanned examples already seem to be following that ingrained mindset.

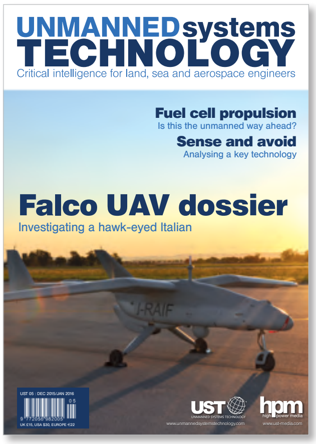
It is refreshing then to learn that driverless cars are to get their own race series, accompanying the high-profile international Formula E competition. Depending on how well the regulations are written, that arena should highlight alternative technological solutions and, in pitting one against another, spotlight their strengths and weaknesses.

Similar competitions for air, sea and even underwater craft – with elements beyond simply the goal of getting from A to B quicker than the competition – could play a valuable role in giving alternative technologies a much-needed showcase. Let’s not leave them at the mercy of inherently conservative market forces.

Ian Bamsey | Editorial Director

Editorial opportunity

This publication has had such an enthusiastic reception that we are expanding fast. That has opened the door for more experts to contribute to our pages. If you have a strong technical knowledge of any aspect of the field and would like to explore the possibility of writing for us, do let me know: **ian@ust-media.com**



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The Talos fixed-wing UAV is designed to be deployed quickly and fly at the edges of storms

Storm-chasers unveiled

Weather monitoring

Researchers at the Oklahoma State University (OSU) in the US are designing a series of unmanned aircraft to monitor bad weather and improve the accuracy of data for forecasting.

The $6m, four-year project will develop craft that can climb vertically and autonomously to 1000 m carrying sensors to measure temperature, humidity and pressure. It will also develop fixed-wing systems with an endurance of up to eight hours that can be deployed quickly to fly at the edges of storms to monitor conditions.

Although researchers have in the past used large UAVs like the Predator to study hurricanes, the cost is prohibitive for more widespread study of atmospheric conditions.

"We've been working on this for a couple of years now, and the goal is to keep this in the small UAV realm as we want these to be easily deployable by the scientists in the field," said Dr Jamey Jacob, Professor of Aerospace Engineering in OSU's College of Engineering, Architecture and Technology (CEAT), the project's principal investigator. "We are letting the requirements drive the design but we are working on both fixed-wing and rotary craft, and hope to integrate these systems into the daily meteorological information-gathering that goes into the weather models.

"We get a lot of severe weather in Oklahoma but we have only two locations with balloons that watch the weather," he said. "But we do have an extensive network of towers that monitor the weather, and we want to extend those to 500 or 1000 m virtually with an aircraft, collect the data and come down, and that could be hourly on demand. These platforms will be some kind of rotor craft, both in-house and commercial.

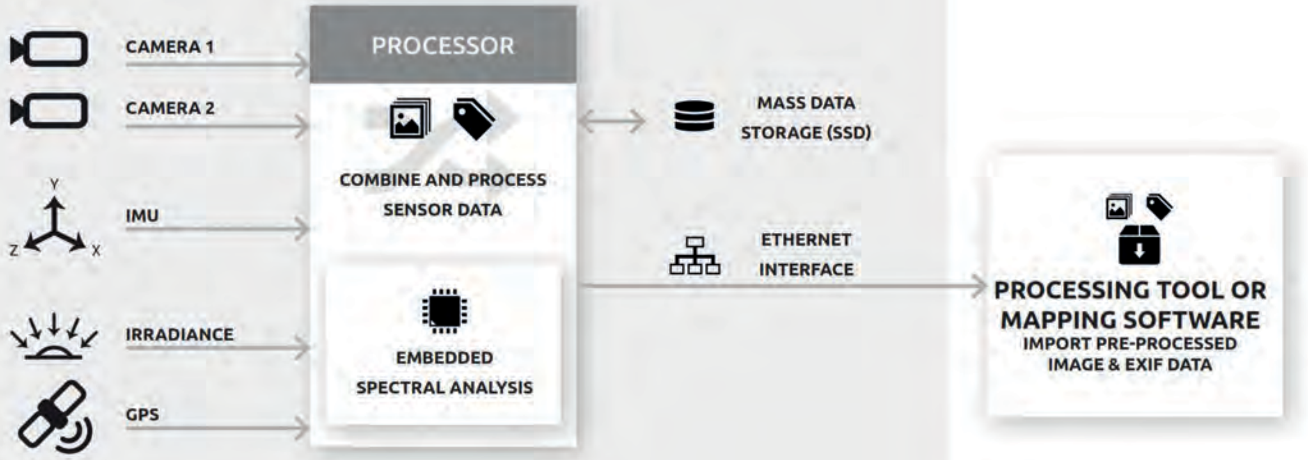
"The issue is not developing new systems but modifying off-the-shelf platforms," he said. "One thing we are developing right now is to use the onboard inertial measurement unit as an accurate wind sensor based on the effort required to maintain the craft's position.

"For the severe weather applications, the real interest is what happens before that weather arrives. Most storms form by a process called convection initiation that pushes a plume of warm air into the atmosphere, so we need an endurance of six to eight hours to be able to get this basic thermodynamic data. We use in-house UAVs with sensors and dropsondes that can be dropped on demand by parachute to provide profile data from altitudes up to 2000 m."

The platforms are all composite construction using carbon composites, a Kevlar skin and fibre glass body, and the team is designing for 10 *g* vertical and lateral stresses and 120 mph side loading, which will handle up to 99% of expected environmental conditions.

"The goal is not to fly into a tornado, where you see speeds of 300 mph, but around it," said Jacob. "One of our plans is to have a multi-week campaign to test these technologies in the field. We have severe weather from early March to June, and we will be able to bring the various team members together to test the technology. Simply having the ability to fly multiple vehicles at the same time in the same environment hasn't really been done."

Schematic of the 3D-One camera and image processing system



Camera has crops in its sight

Image processing

Dutch sensor and camera developer 3D-One has launched an OEM camera system that is optimised for unmanned aircraft in agricultural applications.

The system uses two hyperspectral sensors from research laboratory IMEC in Belgium that cover visible and near-infrared light, with embedded processing. A field-programmable gate array (FPGA) processes the images in real time to build a hypercube of data that is then managed by an embedded computer running the Linux operating system.

"Rather than line scanning, the IMEC sensors in the 3D-One system use a snapshot which is required on a UAV because the UAV is not stable enough for line scanning," said Marco van Hout, business development manager at 3D-One. "That makes it a lot easier to get good data – typically you make 30 frames per second, and in each image acquisition you capture all 40 spectral bands."

The sensors use a CMV2000 2K x 1K CMOS array from CMOSIS that is usually used for HDTV cameras. IMEC adds a hyperspectral sensing layer over the top, creating macropixels onto a matrix of 5 x 5 pixels. This allows each macropixel to sense up to 25 bands.

"That's delivering a stunning amount of data, so we developed an acquisition and processing engine that pre-processes the data coming from the sensor and presents it to an embedded computer," said van Hout.

"It's a two-stage processing engine where the first stage is an FPGA for real-time processing that reconstructs all the information into one hypercube. We do all sorts of corrections as recommended by IMEC so that the data is ready for analysis, and we add information from the GPS navigation system with a timestamp on each image and data from the inertial measurement unit.

"We can also do a reflectance calculation from a spectral meter," van Hout said. 'This takes the reflectance of the incoming light, for example when flying a UAV over a field of crops; at certain points the sun is shining directly on the field, then you fly into a shadow and you don't want this to influence the measurement. All these go into the FPGA to prepare the data for spectral analysis on the UAV." The processing algorithms have agricultural applications in mind.

The total system of the two cameras, acquisition and processing engine weighs less than 400 g, including the computer, which has an Intel quad-core processor using the PC-104 board format and the Qseven embedded module standard. "We have used an Altera Cyclone 5 FPGA on the acquisition board and a mass storage SSD up to 1 Tbyte with a SATA interface," van Hout said. "That is more than enough to store the images produced during the flight.

"Another thing we have to consider is power consumption, since every Watt you use is taken from the same battery that is used for flying," he said. The system uses between 12 and 15 W depending on the processing requirements.

UMEX and Simulation and Training 2016

Industry

From 6-8 March 2016, Abu Dhabi National Exhibitions Centre will host the second edition of Abu Dhabi Unmanned System Exhibition (UMEX), which was previously held alongside the International Defence Exhibition & Conference (IDEX). It is organised by Abu Dhabi National Exhibitions Company in collaboration with the UAE Armed Forces.

A gateway for manufacturers and suppliers to build relationships with influential decision-makers within the industry, UMEX showcases unmanned systems and technologies used in air, land and marine operations.

The event gives visitors the opportunity to view equipment showcased on static display stands and examine unmanned systems capabilities at live demonstrations.

As part of its agenda, UMEX will stage the first Simulation and Training Exhibition and Conference. The segment is set to showcase the latest technologies in simulation systems used both in defence and civilian applications. The event will also include a dedicated corner for companies specialising in defence training and development.

UST diary

Bahrain Airshow
Thursday 21 January – Saturday 23 January 2016
Sakhir Airbase, Kingdom of Bahrain
www.bahraininternationalairshow.com

SkyTech
Wednesday 27 January – Thursday 28 January
London, UK
www.skytechevent.com

TUSExpo
Tuesday 2 February – Thursday 4 February
The Hague, Netherlands
www.tusexpo.com

UMEX
Sunday 6 March – Tuesday 8 March
Abu Dhabi, UAE
www.umexabudhabi.ae

XPONENTIAL – AUVSI USA
Monday 2 May – Thursday 5 May
New Orleans, LA, USA
www.auvsi.org/events/upcomingevents

ICUAS16 – The 2016 International Conference on Unmanned Aircraft Systems
Tuesday 7 June – Friday 10 June
Arlington, VA, USA
www.uasconferences.com

Unmanned Global Systems (UGS) & Eurosatory
Monday 13 June – Friday 17 June
Paris, France
www.ugsevent.com/2016/ & www.eurosatory.com

Farnborough International Airshow
Monday 11 July – Sunday 17 July
Farnborough Airport, UK
www.farnborough.com

World Congress on Unmanned Systems Engineering
Thursday 28 July – Friday 29 July
Cebu, Philippines
www.wueng-congress.com

InterDrone
Wednesday 7 September – Friday 9 September
Las Vegas, USA
www.interdrone.com

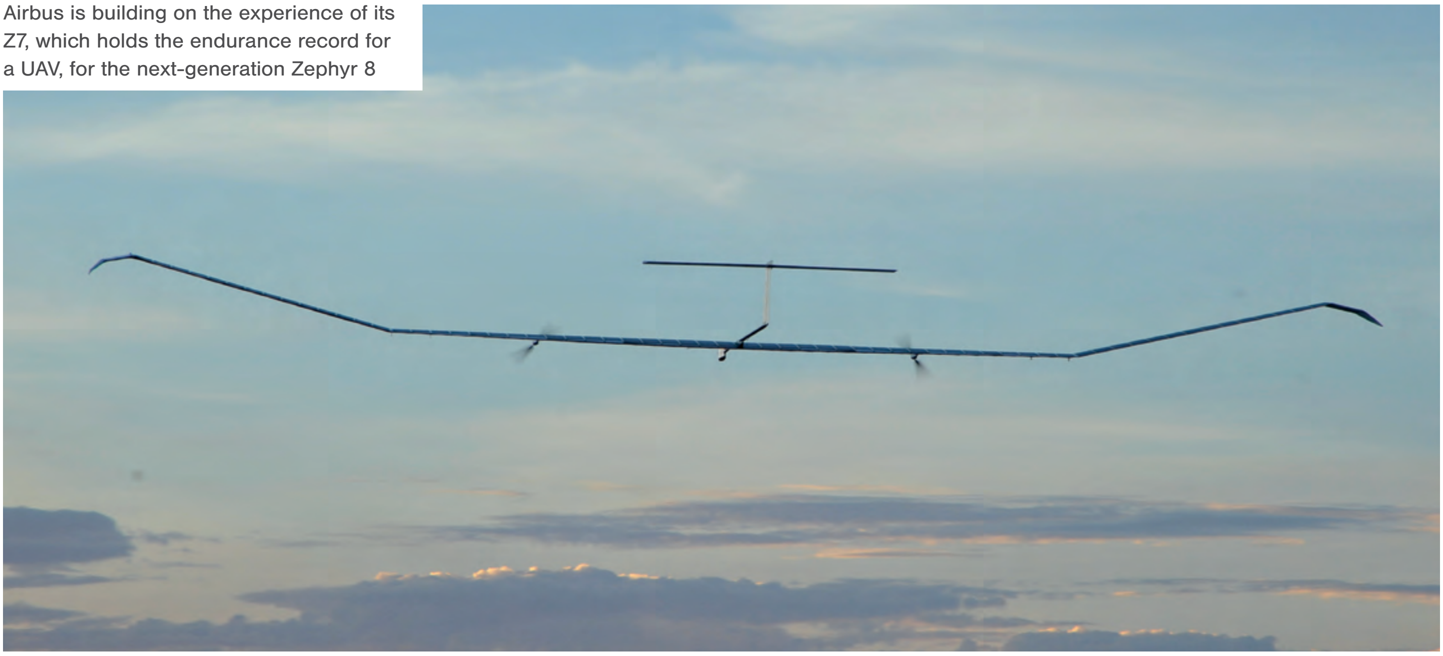
Commercial UAV Show Asia
Tuesday 20 September – Wednesday 21 September
Singapore
www.terrapinn.com/exhibition/commercial-uav-asia

Commercial UAV Show
Wednesday 19 October – Thursday 20 October
London, UK
www.terrapinn.com/exhibition/the-commercial-uav-show

Commercial UAV Expo
Monday 31 October – Wednesday 2 November
Las Vegas, NV, USA
www.expouav.com

Unmanned Systems Canada
Tuesday 1 November – Thursday 3 November
Edmonton, Canada
www.unmannedsystems.ca

Airbus is building on the experience of its Z7, which holds the endurance record for a UAV, for the next-generation Zephyr 8



Zephyr becomes even lighter

UAVs

At the DSEI 2015 show in London last September, Airbus provided *UST* with some insights into the next generation of its solar-powered long-endurance Zephyr UAV, which is capable of reaching up to 70,000 ft.

Steve Whitby, head of business development and sales for the High Altitude Pseudo Satellites (HAPS) programme, said the Z9, or Generation One – the name is not settled yet – builds on the technology baseline established by the Z8.

With an initial operational capability scheduled for 2016, the Z8 embodies experience from previous generations including the endurance record-holding Z7, which flew for 14 days and 14 nights in 2010. At 25 m, the Z8's wingspan is slightly larger but 40% lighter than the Z7's, a feat achieved by accurate modelling to optimise the structure without changing materials. The solar array is load-bearing, 30% more powerful than the Z7's, and very light. "We're talking something that you can wrap around your finger," said Whitby. The structure is hollow and serves as a high-gain antenna.

The Z9 adds 10 m to the wingspan, meaning a larger solar array, more battery capacity and a larger payload. "We've finished the design and done the wind tunnel tests," Whitby said. "The only change in technology is the batteries."

Ground-level avoidance code

Sense and avoid

A research student at the Computer Science and Artificial Intelligence Lab (CSAIL) at the Massachusetts Institute of Technology has developed open source software that provides sense and avoid capabilities for a small unmanned aircraft moving at 30 mph at ground level.

The Pushbroom Stereo was developed by Andrew Barry and his supervisor Russ Tedrake of the Robot Locomotion Group at CSAIL, and uses two cameras running at 120 frames per second on a fixed-wing design with a wingspan of 70 cm (34 in). The separation of the stereo cameras provides detection 10 m ahead of the craft to avoid individual objects. With a processing time of 8.3 ms per frame to detect an object in its path, this allows the 30 mph speed. The system is used to avoid objects and also to build a map using a commercial Qualcomm processor.

"Our current approach results in occasional incorrect estimates known as drift," said Barry. "As hardware advances allow for more complex computation, however, we will be able to search at multiple depths and therefore check and correct our estimates. This lets us make our algorithms more aggressive, even in environments with larger numbers of obstacles."

• *Focus on sense and avoid technology, page 34*

Price of Lidar set to drop

Sensing

Velodyne is aiming to reduce the cost of its multi-channel Lidar laser rangefinders to below $500 for volume production. It also plans to have multiple channels, from 16 to 32, for the systems to maintain their detection accuracy, said Dr Wolfgang Juchmann, director of sales and marketing for the Lidar division of Velodyne.

Driverless car systems are already using 16-channel Lidar sensors that weigh 800 g and generate up to 300,000 data points per second, but these can cost up to $10,000. Velodyne aims to reduce the cost of these systems through volume manufacturing for the automotive market, rather than reduce the number of channels.

"The goal is to produce 10,000 units a year; that will help bring the price down," said Dr Juchmann. "Car makers tell us four channels gives too narrow a view so we are looking at 16, maybe more."

The company is due to deliver the new sensor to car makers in the first quarter of 2016.

In the recent Intelligent Vehicle Future Challenge (IVFC) at Changshu city, China, 17 of the vehicles were using Velodyne's 64-channel Lidar sensor. The IVFC was inspired by a similar challenge in the US organised by DARPA, and involves competition along a varied 13 km course with teams drawn from universities and research labs.

The course included urban, off-road and highway settings, with teams offered the option of skipping the off-road setting, and vehicles were judged on safety, speed, 'smartness' and smoothness. The 2015 contest added a new challenge for passing other vehicles and was won by China's Military Transportation University for the second year running using Velodyne's HDL-64 as its core sensing technology.

China's Military Transportation University's IVFC-winning entry, which used Velodyne Lidar technology

Amazon's latest proposed delivery UAV has a range of 10 miles with a payload of 2 kg

Options grow for deliveries

UAVs

Amazon has demonstrated its latest candidate for an unmanned aircraft for delivering packages.

The hybrid platform uses four rotors for vertical lift and a rear rotor for propulsion. Amazon aims to operate the system between 200 and 400 ft, carrying a payload of 2 kg (5 lb) a distance of up to 10 miles at speeds of up to 60 mph.

Key to this capability is sense and avoid technology using passive sensors and active communications that can operate day and night and in poor weather. Amazon is proposing to use an ADSB transceiver to keep track of the UAV, with automatic collision avoidance algorithms that do not rely on an operator. It will include geospatial data mapping of all hazards to navigation over 200 ft, as well as long-range detection, based around camera sensors.

"We are testing many different vehicle designs and delivery mechanisms to discover how best to deliver packages in various environments," said the company. "We have more than a dozen prototypes that we've developed in our r&d labs, and the look and characteristics of the vehicles will evolve over time."

Systems will be tested in the US, in the UK at its Cambridge laboratory and in Israel, with the aim of launching a commercial service in 2017.

DJI makes crossing from the retail to the rural

Consumer UAV maker DJI has entered the industrial market for the first time with a dedicated crop-spraying octocopter. The eight-rotor Agras MG-1 is dustproof and water-resistant, and can carry 10 kg of spray liquid to cover from seven to 10 acres per hour at 8 m/s.

Its motors are cooled by incoming air that is triple filtered to avoid problems with dust and spray, and this can extend the life of the motors by a factor of three, the company says. Four ceramic nozzles are powered by four additional motors for spraying, and a memory function allows the craft to return to base for recharging and then continue from the point at which it left off.

The $15,000 (£10,000) craft also includes a microwave radar to scan the terrain to maintain a constant height, as well as DJI's 2.4 GHz Lightbridge 2 HD video transmission and control system that has a range of up to 1.7 km.

UAV boards in launch double

Onboard processing

Chip makers Qualcomm and Nvidia are going head to head with the latest silicon technology for UAV systems.

Chinese UAV maker DJI has developed an embedded processor board for adding machine learning to small UAV systems using Nvidia's K1 processor. The Manifold board uses Nvidia's Tegra K1 quad-core ARM Cortex-A15 processor and 192 graphics processing unit (GPU) cores with clock speeds of up to 2.2 GHz.

This will open up machine learning and artificial intelligence in aerial platforms by using Nvidia's software development tools and libraries that already include these technologies, according to DJI. It weighs less than 200 g and consumes a maximum of 15 W.

Meanwhile Qualcomm Research has launched what it calls a 'drone development platform'.

Snapdragon Flight is the first UAV-specific development board and is based on a Qualcomm Snapdragon 801 series processor. This includes four of Qualcomm's Krait 400 processor cores, based on the ARM 32-bit architecture running up to 2.5 GHz, and the Adreno 330 graphics processing unit.

Real-time flight control algorithms can be run on the Hexagon DSP processor in the chip, and wi-fi, Bluetooth connectivity, and automotive-grade GPS are included on a board that measures 58 x 40 mm. It also includes support for a 21 megapixel camera sensor and fast charging of the battery system with QuickCharge 2.0 technology.

Although this is two generations behind the 820 processor used in the latest Android phones, the software development tools are the same, allowing rapid software development and testing. General access to a development board will be available in early 2016.

DJI's Manifold board will allow UAVs to incorporate machine learning and AI

The GATEway trial, which TRL is part of, will investigate the implications of introducing automated vehicles into the urban environment

The UK's Transport Research Laboratory's Academy Director tells **Nick Flaherty** about the range of studies it's conducting into autonomous vehicles

Driverless ambitions

Many current driverless vehicle projects are focused on driverless 'pods', says Professor Nick Reed, Academy Director at the Transport Research Laboratory (TRL) in the UK, as opposed to adding autonomous operation to the advanced driver assist systems that are already in modern cars. There's a separate development process for the pods, and the parameters of many recent projects has been influenced by the thought processes Google has been through with its driverless car project, he says.

"Google's experience was that people aren't well equipped to perform the monitoring and fallback option," he says. This was highlighted recently where drivers using Tesla's Autopilot system have struggled to take back manual control of the vehicle after it has been in a self-driving mode.

"So Google switched to developing vehicles that have no controls in them, and that operate in restricted areas. This means the incremental steps in the development are in the environment in which the vehicle can operate, rather than in the functions of the vehicle."

The autonomous functions are defined in levels by the Society of Automotive Engineers (SAE), where levels 1 and 2 refer to driver assistance systems, and the driver must remain alert and attentive, while levels 3 to 5 describe increasing levels of automation in which the driver can attend to other activities while the vehicle is in control.

"Companies such as Google are not going up through the SAE levels of automation; they are starting at the high level," says Prof Reed. "I think we'll see development of vehicles up through the SAE levels but we'll also see the introduction of a spectrum of different vehicles across those levels. This is familiar territory, as we already have driverless pods at Heathrow that operate autonomously; developments now will see automated transport systems gradually operating in more complex and less segregated environments."

This has led to several trials of autonomous vehicles in the UK which were announced in 2015, including the GATEway trial at Greenwich in London that TRL is leading. This will operate autonomous shuttle vehicles in areas crowded with pedestrians.

One control mechanism for driverless shuttles being tested in the GATEway project in Greenwich is passenger interaction via a touchscreen

"Looking at the trials now, they do look a little conservative, but they were put together 18 months ago and seemed a lot more exploratory at the time, but it is amazing how fast the technology is moving," says Prof Reed. "We will be operating driverless shuttle vehicles, and we saw those on public roads at the ITS World Congress in Bordeaux earlier this year. They started out on a private road and then ventured out into traffic.

"That's quite impressive, and it's very interesting to see how the public responds to the vehicles – some are frustrated by the slow speed, and there's a lot of curiosity, and we are expecting to encounter the same things with the shuttles in Greenwich."

> It's very interesting to see how the public responds to the vehicles – there's a lot of curiosity, and we are expecting the same thing at Greenwich

Bids to supply equipment for the trials have gone out, and decisions are due before the end of 2015. The bids cover the three trials backed by the government's Innovate UK agency – GATEway, the Venturer project in Bristol, and UK Autodrive in Coventry and Milton Keynes.

"We are going through the procurement process and talking to manufacturers," says Prof Reed. "Suppliers were able to bid for the trials individually or for all three trials as a package. That fits with our model for the project, with Greenwich as a test bed where organisations can bring their technology for development and evaluation with test routes and risk analyses all in place.

"As a technology-agnostic project we are welcoming vehicle manufacturers and technology developers during and after the end of the two-year project."

Companies developing driverless shuttles include Phoenix Wings, which has a 35% holding in a French start-up called Induct that developed the Navia driverless shuttle being used in Tampa, Florida and Singapore, as well as Starship, established by the founders of videoconferencing company Skype, and Sidewalk, which is working with delivery company DHL on systems that could handle deliveries in cities, for example from a distribution centre to retail stores.

Data collection

"The competition launched by Innovate UK is about urban mobility, so the focus has been more on the shuttle and the pod," Prof Reed says. "Beyond that we are really interested in the data that is collected by automated vehicles and how that can be used in a number of contexts – to understand how to optimise the transport network, to look at incidents that occur, even for asset management.

"TRL has devices for assessing road conditions for Highways England, and these are similar to the technologies in the trial. Is there value in having a different approach when, instead of having one super-high quality instrument that's hugely expensive and used rarely, we can get data from autonomous vehicles as they move about?"

TRL is also part of an £11m project to develop fully autonomous cars. This is jointly funded by the UK's Engineering and Physical Sciences Research Council and Jaguar Land Rover, and will look at some key technologies and questions that need to be addressed before driverless cars can be allowed on the roads, says Prof Reed.

In addition, TRL is working with the University of Surrey, Warwick University and Imperial College London to understand how distributed control systems and cloud computing can be integrated with vehicles. This project aims to design and validate a new software framework called Secure Cloud-based Distributed Control (SCDC) for connected and autonomous cars.

"SCDC will look at the use of the cloud for autonomous control, including how we provide secure reliable connections with the cloud," Prof Reed explains. "Vehicle-to-vehicle [V2V] and vehicle-to-infrastructure [V2I] technologies are part of that, but there's also low-latency high-speed 5G cellular phone technology coming along by 2020. One question we will be looking at is whether V2V and V2I technologies are an interim step or is waiting for 5G a better solution?"

Mapping is another key area. "Digital mapping is important because of the need for up-to-date maps," he says. "That's one of the considerations for the data collection from vehicles for updating the digital maps in the cloud."

Getting connected

The project will also explore how increasingly automated and connected vehicles can operate safely and securely when connected to each other and, via the road infrastructure, to cloud-based resources. Ultimately the aim is to develop a secure framework that will enable the implementation of safe and robust semi-autonomous functions on future cars in the short term, and fully autonomous cars in the long term.

This is part of a wider programme called "Towards Autonomy – Smart and Connected Control". Other projects include the development by the universities of Birmingham and Edinburgh of new radar sensors and video analysis techniques that would allow the cars to better identify obstacles and hazards on the road, while researchers from the University of Warwick will focus on developing a self-learning car that will minimise distractions and enhance safety.

TRL is also involved in the Sentience programme for testing partial automation on UK roads; Adaptation, which uses TRL's DigiCar driving simulator for research into the behaviour of drivers when driving in mixed and automated traffic; and a heavy vehicle platooning study for the UK's Department of Transport to understand the practicalities of electronically linking large trucks to improve fuel efficiency.

Going forward, safety concerns are high on the agenda as the different technologies start to roll out. "In the coming year, are people going to start pushing the limits, so are we likely to see the first autonomous vehicle collision?" Prof Reed muses.

"That may have a range of consequences for the technology's adoption in terms of public acceptance of automation, and the technical regulations that may be imposed as a result. We therefore need to be confident about the true benefits of autonomous vehicles if there is a collision."

Prof Nick Reed, TRL Academy director

Prof Reed joined the Human Factors and Simulation group at TRL in January 2004 after post-doctoral work in visual perception at the University of Oxford. He has led a variety of studies using full-mission, high-fidelity car and truck simulators and has championed work in the area of vehicle automation at TRL, culminating in his technical leadership of the GATEway (Greenwich Automated Transport Environment) trial – a flagship UK government project to investigate the implications of introducing automated vehicles into the urban environment.

In addition to GATEway, his role as TRL Academy director is to ensure the technical quality of TRL's research outputs, for supporting the academic development of TRL staff and for managing TRL's engagement with stakeholders in industry and academia on programmes of collaborative research.

The Academy aims to reinforce TRL's scientific and engineering expertise and reputation as a leading international transport research institute and centre of excellence through long-term research programmes and projects that develop major intellectual property.

> Will we see the first autonomous vehicle collision in the coming year? If so, we need to be confident about the true benefits of these vehicles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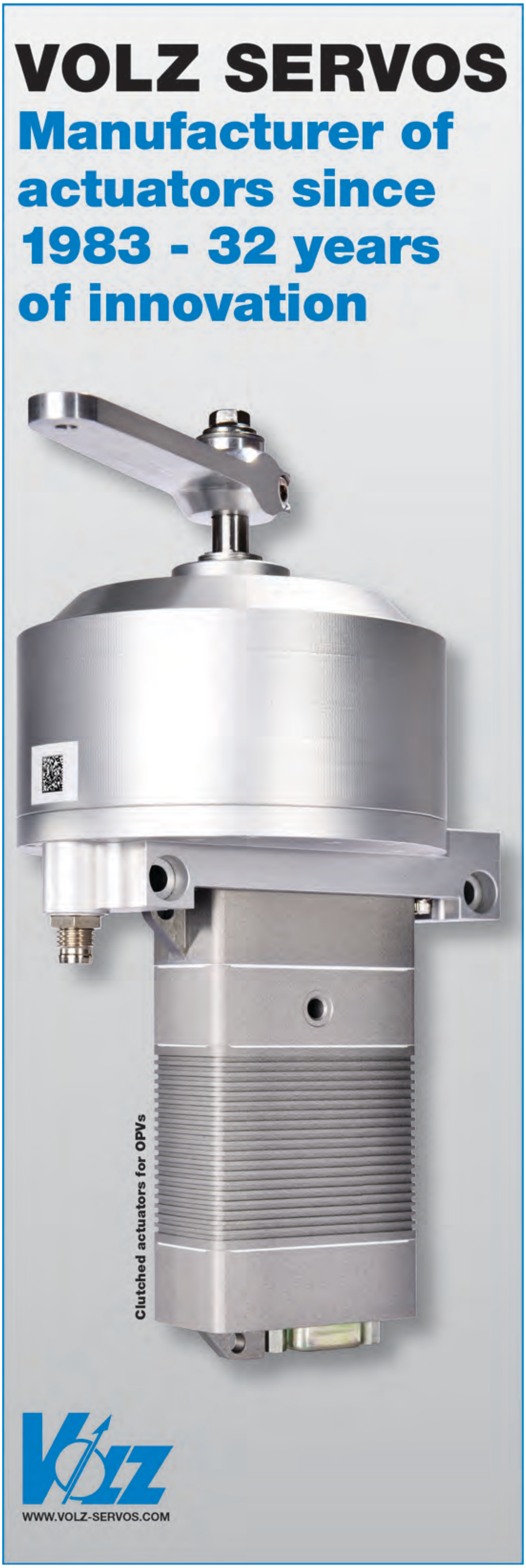
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Watching like a hawk

Ian Bamsey investigates the technology of this surveillance UAV

Falco is the Italian word for hawk, and that neatly sums up one aspect of the UAV designed and produced by Selex ES in Italy. A hawk is a bird of prey of course, but whereas the Falco wasn't designed to kill it does share its namesake's exceptional vision capability.

It was designed as a medium-altitude, unarmed, surveillance-oriented platform capable of carrying a wide range of payloads including several types of high-resolution sensor. Powered by a small internal combustion engine, it has a 7.2 m wingspan, can reach a flight speed in excess of 100 knots and has an endurance of more than 12 hours.

Aside from its Wankel-type rotary engine, the Falco – including the control system and many payload options – is produced by Selex ES at its Ronchi dei Legionari plant near Venice. Its design is intended to meet European Aviation Safety Agency (EASA) guidelines for airworthiness, it has automatic take-off and landing, and can be operated at night.

Now well proven, the Falco made its maiden flight at the end of 2003 and has been operated by customers since 2007. In addition, for almost two years the United Nations has used Falcos in a peacekeeping role in the Democratic Republic of Congo. It was selected because of its proven track record in long-endurance surveillance missions, together with its ease of deployment.

Background

Finmeccanica is noted for allocating a high proportion of its total expenditure to r&d. Within the Finmeccanica group, Selex ES, Alenia Aermacchi and AugustaWestland are all currently involved in the development of UAVs, the latter having recently developed through its Polish subsidiary an optionally piloted version of an existing helicopter, the SW-4 Solo. It has also co-developed with Italian helicopter technology specialist IDS the smaller, unmanned SD-150 Hero rotor craft.

At Selex ES, unmanned flight began in the mid-1950s, through the Meteor CAE Spa company that it now embraces. At that stage the owner of Meteor, Furio Lauri, famed for his exploits as a fighter pilot during World War II, had been asked by his wife to give up flying after surviving a crash in a prototype light aircraft.

That prompted an interest in remote piloting, which in turn led to the development of reciprocating-engined unmanned aerial targets, which were used at the Italian air force's Salto di

Quirra weapons testing range in Sardinia.

The next key step was the development of a turbojet-powered target, which led to the Mirach family of high-performance targets that are still in production, having been used by many forces worldwide, including NATO. The current turbojet-propelled, 4.07 m long Mirach 100 reusable target, can fly in one guise at Mach 0.95 and can operate at altitudes from 3 m to 12,500 m. In turn it can air-launch a smaller target jet that can reach Mach 0.7.

In the past, UAVs from the Mirach family have been modified for deployment in military surveillance roles, using sometimes reciprocating, other times jet engines. That was back in the days of the Cold War; since then the emphasis has been on developing UAVs for peacekeeping and civilian roles, giving rise to the Falco.

It is clear that UAVs are not easy work; it has taken Selex ES decades of trial and error, of lessons learnt, to get where it is today.

> The Falco is designed to be capable of being integrated into different networks and to have a high degree of autonomy

Design considerations

The design of the Falco system was presented to *UST* by team members based at Ronchi dei Legionari, from the aeronautical systems and the systems project engineering departments within the airborne and space systems division of Selex ES.

Conceptually, the Falco is seen as a data node within a customer's overall information-gathering network. As such, it is designed to be capable of being closely integrated into different networks and to have a high degree of autonomy.

Designed from a clean sheet of paper, the Falco is a system, the craft operating in conjunction with a specific ground control station (GCS) and ground data terminal (GDT). It flies with a man 'in the loop' based in the GCS but from early on in its development 'hands off' take-off and landing has been possible within fully autonomous operation.

The Falco can be taken from its hangar, its engine started and thereafter its operation can be autonomous. Moreover, if it is operating alongside manned aircraft, air traffic control (ATC) doesn't need to differentiate between it and other aircraft (assuming

Selex ES operates a fleet of Falcos for the UN

prevailing regulations allow that scenario).

The Falco was designed to fill the gap between 'Tactical' and 'MALE' (Medium Altitude Long Endurance) UAVs. This led to compromises between the features of both types. Most fixed-wing Tactical UAVs were characterised by low weight (generally 200 to 300 kg), had a small wingspan, were launched typically by catapult and often made a parachute landing. Larger wingspan MALE UAVs had higher weight (around one tonne) and were generally able to take off and land using their own landing gear.

The flight duration of Tactical UAVs was invariably less than impressive. The Falco was intended as a larger craft with much longer flight duration, which could take off and land in the manner of a conventional aircraft, ready upon touchdown for refuelling and another mission.

The Falco's 7.2 m wingspan was driven by operational considerations. In essence, the longer the wingspan, the better in terms of payload capability and flight endurance. At the same time, it was considered important that the craft could be stored in a conventional container and handled by no more than two people.

Ultimately though there was clearly a trade-off to be made. To that end, it is significant that Selex ES recently developed the longer-wingspan Falco EVO to suit customers who put payload weight and endurance ahead of the aforementioned operational considerations (see sidebar: Falco EVO).

The Falco was designed to take off and land in the manner of a conventional aircraft, ready upon touchdown for refuelling and another mission

UAVs smaller than the Falco have often been likened to sophisticated model aircraft. By contrast, in all respects of its design and development – including the use of finite element analysis, computational fluid dynamics (CFD) study, static and dynamic tests and so on – the Falco was treated as a real aircraft, albeit one that happens to be unmanned.

The upshot was that, owing to its size and sophistication, including a full taxiing capability, the Falco would be much heavier than a typical 'model aircraft style' UAV, actually weighing in at 530 kg. That in turn meant careful attention had to be paid to its 'crashworthiness' in view of the desire to have it CAA-certified. It was necessary to study the implication of loss of control in terms of energy dissipation upon impact, following recommendations set out by the joint JAA-Eurocontrol Task Force Final Report in 2004.

In this respect the Falco was a pioneer, as it was designed just before the preparation of the JAA-Eurocontrol recommendations. In the Falco's case there was no pilot to protect within the craft; however, there is sophisticated equipment on board, and as usual the potential impact of any crash on the environment has had to be taken into account.

It follows that the Falco carries a parachute for emergency use, and that in turn has driven a number of considerations in its configuration, for example the need for reinforcement of the airframe in certain areas. There was also a careful design study to maximise the probability that the parachute deploys safely and effectively, following a major failure onboard or on the pilot's command, in all foreseeable flight conditions.

Certification took into account the fact that although there would be no person on board, there would be a pilot in the loop via the GCS: even in fully autonomous mode, the pilot would continue to monitor the craft. However, in terms of the need for certification, that scenario was more tricky than the normal case of having a person always in the

> The Falco's flight laws are scheduled and controlled by its flight management system according to the current flight phase and the pilot's inputs

loop on board the craft. For example, a manned aircraft, certified according to CS-23 or FAR-23, can be designed such that if a key control electronic servo fails then the pilot can take over operation through manual action. There is no such straightforward 'redundancy' option for an unmanned craft.

Considerable effort thus went into the development and optimisation of the automatic flight control system, which was built incrementally from the lower CSAS (Control Stability and Augmentation System) to the upper fully autonomous autopilot, using state-of-the-art control design tools and flight simulation techniques. There were also actual flight trials expressly designed to test the aircraft's handling qualities.

The Falco's control laws are scheduled and controlled by its flight management system according to the current flight phase and the pilot's inputs. There is a high level of autonomous failure management in both manual control modes and fully automatic flight.

Concept

The initial design of the Falco involved studying a wide range of aerodynamic architectures, some conventional, others unconventional. This phase embraced evaluation of a 'box wing' concept and an all-wing configuration.

It was discovered that there wasn't a great difference in key flight

Anatomy of the Selex ES Falco

Specifications

Wingspan: 7.2 m
Length: 5.25 m
Height: 1.8 m
Maximum take-off weight: 530 kg
Maximum payload weight: approx 70 kg
Endurance: 8-14 hours
Service ceiling: 6000 m
Maximum level airspeed: >60 m/s

The Falco in service for the UN

The Falco is manufactured in-house, although some aspects of fabrication are subcontracted following make-or-buy assessment. For example, at the company's Ronchi dei Legionari plant there isn't an autoclave large enough for curing the main wing or fuselage sections, so that work is outsourced and the various components brought together in-house.

In terms of general layout, the Falco's fuselage isn't full length but carries at its rear the propulsion system, with the propeller then operating between twin booms that extend back from the wing to carry the tail assembly.

Within the fuselage, behind the nose (reconfigurable as a payload bay) is the avionics bay, then behind that again the main payload compartment. In turn, behind that is the fuel tank, above which is the wing. The tank contains fuel in a bladder, and if necessary additional fuel bladders can be carried within the centre section of the wing.

Between the fuel tank and the firewall at the front of the engine bay (which forms the rear of the fuselage) is a bay housing the landing gear shock absorbers, braking system components and the main parachute.

The fuselage is made primarily from carbon fibre skins over a foam core. It does contain four aluminium bulkheads though, and there are also fittings in aluminium to act as attachment points for various items. The airframe is left open above and below the payload and main avionics bay, so that quick-release fairings can provide easy access to these key items.

The wing is made in three sections, the centre section spanning the boom attachments. Just beyond those attachments are the connections to the two outer sections, which can be quickly unlatched. At each end the central wing section is closed by a rib, and just inside that is the machined aluminium fitting into which the respective boom slots. A pair of connectors secures each boom. The door for the main parachute release closes the middle of the wing centre section.

The wing is formed around aluminium (transverse) ribs and carbon fibre (longitudinal) spars. Each outer section has three such ribs, plus a pair of latches that slot into the centre section's spars.

In turn, the centre section has a lug on each side to slot into the respective outer section, where it is secured by a pair of locks.

Pitch and roll are controlled by three control surfaces on each side of the wing and a pair of elevators at the tail, where there is also a pair of rudders to control yaw. Each control surface is operated by an individual servomotor. All wing sections have doors for easy access to the control flap servomotors.

Each control flap is carbon fibre and pivots on an aluminium bracket. It is driven by its respective servomotor via a short aluminium arm.

The hollow tubular booms are made from carbon fibre, using a filament winding process. The tubular boom is circular in cross-section towards the rear but is rectangular with rounded corners at the front to better support the bending load where it attaches to the wing. At the rear, each boom attaches to a rib inside the respective tail fin. The construction of the tail assembly mirrors that of the wing.

Supplied by UAV Engines in the UK, the engine is of the Wankel type, a two-rotor design having 294 cc per rotor with water cooling for its case plus through-rotor air cooling. It has carburettor induction. Avgas is the normal fuel, although unleaded petrol can be used if the customer desires.

Maximum power is 90 bhp at 7000 rpm, and fuel consumption is quoted by the manufacturer as 0.55 lb/bhp/h at 70% cruise.

Engine weight is 56.5 kg including the cooling system and a generator. The rotary-type engine is notable for a lack of external vibration but inevitably there is some associated with its operation, in view of which it and its accessories mount to the airframe via anti-vibration mounts.

At the front of the engine bay is a structural aluminium bulkhead that carries a sheet steel panel to act as a firewall. Two electric pumps draw fuel from the tank to the engine (two are used for redundancy) and these are mounted on the engine bay side of that firewall. Where the fuel lines pass through the firewall there are non-return and shut-off valves. These valves isolate the engine bay from the fuel tank in the event of fire.

The main fuel tank bladder sits inside a carbon fibre box, which in turn is bonded to the fuselage.

Engine lubrication is provided by passing oil through it to be burned off in the exhaust on a total loss basis. In view of this a metal tank in the engine bay holds a supply of lubricant, which is fed to the engine by a mechanical pump driven off the rotor shaft. As temperature drops with altitude, so does the viscosity of the oil, and for this reason the tank is heated using hot engine coolant.

The radiator for engine cooling is located in a through-duct underneath the engine. This duct extends below the depth of the main fuselage to present an opening to the oncoming air. Having passed through the radiator, the exit is in the direction of the propeller, with the action of its blades helping draw the flow through it.

The propeller is driven via a toothed rubber belt, and consequently it is always turning with the rotor shaft. The two drive pulleys are sized to provide a speed reduction, normally arranged to be of the order of 2:1. Typically therefore the crankshaft will run at 6000 rpm with the propeller turning at about 3000 rpm.

The propeller is three-blade, with pitch adjustment only possible manually (while stationary). The propeller is a wooden construction with a fibreglass covering and metal reinforcement for the leading edges.

The engine management system is part of the electronic control system developed in-house for the entire craft. It is a redundant system, having all sensors and each processor duplicated. The flight management system was specifically designed for the Falco and is produced by Selex ES.

The key servo controllers are those operating the ten ailerons/rudders, the engine throttle, the two individual wheel brakes and steering for the centrally located front wheel.

For taxiing, the single central nose wheel is steered while the side wheel under each wing can be individually braked as appropriate. The steering and the individual wheel brakes are all controlled by individual servos. The wheel brakes are hydraulic disc brakes, each disc restrained by pads in a single-piston caliper.

Thus the landing gear consists of three aluminium legs, each of which is shrouded by a carbon fibre fairing, carrying steel hubs that in turn are fitted with pneumatic tyre-shod aluminium wheels. All three wheels are connected to an individual oleo-pneumatic shock absorber. The wheels under the wings have angled legs that cross each other (forming an 'X' when seen in front elevation) within the fuselage. The respective shock absorbers are mounted in the top of each leg beyond the crossover point.

The nose wheel is equipped with a mudguard to protect the payload behind from dirt and debris thrown up when taxiing on a semi-prepared airstrip. In addition to the main parachute there is a rear parachute mounted centrally on the tail section.

In terms of environmental protection, the fuselage is designed to expel any water ingress. All air cooling ducts are designed such that water will separate from the airflow, falling downwards through drainage channels.

The key to the successful operation of the onboard electronics is to keep system temperature under control. This is achieved by forced air cooling of the avionics and payload bays. The Falco is fully equipped with aviation lights, as per a conventional aircraft, including taxiing lights.

Some component suppliers to the Falco

Engine: UAV Engines
Composite components: Compositex
Composite components: Riba Composites
Recovery system: DBS Avio Para Service
Wideband data link: Italiana Ponti Radio
Propeller: Hoffmann Propeller
Quality control equipment: MDL Renishaw
Fuel tank bladder: ATL

The Falco's landing gear allows it to taxi as per a regular aircraft

performance factors between the various options, once each had been optimised at the design stage. Overall, a traditional approach with high aspect-ratio wing and twin booms carrying the tail was considered preferable to anything less conventional.

One consideration in favour of a conventional architecture was stability of the centre of gravity in the face of differing payloads and the intrinsic flexibility of the twin-boom architecture in providing suitable structural 'break' points for disassembling and storing the aircraft. Moreover, the twin-boom architecture almost decouples the aerodynamic design from other aspects (weight and balance, propulsion), providing some degrees of flexibility and growth capability during the whole lifecycle of the product, as in the development of the Falco EVO from the original Falco XN.

The Falco's engine directly drives a pusher propeller, which means it can be mounted at the rear of the fuselage, with the propeller located between the twin booms that run back from the wing to carry the tail assembly. This drive arrangement is structurally sound, and clearly it provides more nose payload options than the alternative of having the engine and propeller up front.

This drive arrangement is also seen as beneficial in terms of overall aerodynamics and of putting the engine close to the craft's centre of gravity, facilitating the installation of alternative engine solutions. One drawback though was the proximity of the propeller to Falco's centrally located emergency landing parachute.

The parachute is released through a door in the top of its compartment, which is situated just ahead of the engine compartment; it will tend to be pulled rearwards when released. In fact, its door is hinged at the rear, and its design has been optimised to protect the

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The Falco ground control station

The payload and main avionics package are located in the belly, and are protected on landing by substantial landing gear

propeller from the parachute as it opens. This was validated through full-scale parachute deployment tests carried out in a large wind tunnel in Milan.

Setting a target endurance of about 14 hours for the Falco – a very long flight time for an aircraft of this size – called for exceptional aerodynamic performance. A major factor in obtaining that was opting for a wing consisting of main element plus slotted flap that provides high lift for a given level of drag.

This was a concept presented a few years earlier at the 1996 International Council of Aeronautical Sciences (ICAS) conference held in Sorrento, Italy. The presentation of the concept by senior UAV aerodynamicists demonstrated that a narrow chord makes for a high aspect-ratio wing that has a high lift-to-drag ratio at the low Reynolds numbers associated with a craft of this size and operating speed.

The Falco's wing section was optimised in conjunction with CIRA, the Italian Aerospace Research Centre, based near Naples, using state-of-the-art CFD for aerofoil aerodynamic analysis and optimisation tools based on genetic algorithms. A wind tunnel test programme, using a 22% scale model of the entire craft and running at very low Reynolds numbers in natural transition, validated the Falco's aerodynamics and confirmed the optimisation carried out specifically for the low-speed regimes typical of this kind of vehicle.

A particular challenge at the early design stage was the paucity of options for a suitable engine. A particular Wankel-type rotary was identified as the best available, and this proven 85 bhp unit from UK-based manufacturer UAV Engines continues to power Falco to this day.

The Falco's payload and the main avionics package are located in the belly, and are protected on landing by substantial landing gear. The size and weight of that gear, which includes shock absorbers for each of the two under-wing legs and the single front leg wheels, is considered a small price to pay for protecting the highest value items on board.

Even a semi-prepared airstrip is useable for take-off and landing given the sophistication of Falco's landing gear, which also incorporates pneumatic tyres. The central location of the parachute bay means that when it is controlling a landing (normally only in the case of an emergency) the underwing wheels will tend to contact the ground ahead of the nose wheel for a stable touchdown.

Design process

Design of the Falco began in 2000. Selex ES used wind tunnels in Milan and Turin to assist initial design studies, correlating with its in-house CFD work. That CFD work was cross-checked with the wind tunnel and vice versa.

The CFD work started with relatively simple software (in-house developed programs using formulations such as vortex lattice and panel solvers coupled to viscous 2D boundary layer algorithms). It then progressed through increasingly powerful tools (3D Panels, Euler and full Navier-Stokes solvers), demonstrating good correlation with wind tunnel tests and providing a deep insight into the phenomena observed during experiments and, later, full-scale flight trials.

There was an initial wind tunnel study into the wing section geometry, then a study of the wing body as a complete item and finally a study of the entire craft with payloads and all other items that cause parasitic drag. Tests included the use of flow visualisation through the use of coloured surface oils, tufts and smoke injected into the airstream. All in all, the study was very time-consuming; the pay-off was excellent aerodynamics.

Payload

A typical Falco payload consists of imaging sensors plus radar. Its standard imaging system uses an electro-optical/

The Falco under construction at Selex ES

infrared sensor and offers the possibility of zooming the lens. As standard, the Falco also uses Selex ES' PicoSAR radar. All-weather surveillance is possible using radar as opposed to camera imagery.

PicoSAR is a compact, lightweight airborne ground surveillance radar system. It is an active electronically scanned array (AESA) rather than a traditional fixed-plate system. Selex ES says the key to PicoSAR is the use of AESA technology in a small, compact configuration, adding that "using many low-power, solid-state transmit/receive modules within its array, the PicoSAR radar is more reliable than conventional radar systems".

PicoSAR can be mounted directly onto the Falco platform and the beam steered electronically, or it can be mounted on a gimbal for an even greater field of view. It delivers high-resolution synthetic aperture radar imaging with a ground moving target indication capability. It is that which gives the Falco its all-weather ground mapping and surveillance capability.

PicoSAR's frequency is X-band. Its scan coverage is about 45º, and its maximum range is about 20 km. Often the Falco's payload will give it a multimode radar capability, such as Selex ES' Gabbiano. This means not only long-range air to ground (PicoSAR) but also air to air and air to sea, both with the capability to classify other craft from their signatures, plus a navigation mode, including a weather avoidance capability.

The Gabbiano radar family provides an efficient, mechanically scanned, X-band solution for surveillance over land, along coasts and on sea in all weather conditions. In addition to standard air-to-surface search modes, it offers high resolution ISAR (Inverse Synthetic Aperture Radar) modes. These provide automatic target feature extraction, allowing the early classification of intercepted targets during missions at sea.

The Synthetic Aperture Radar (SAR) mode provides a high-resolution imaging and mapping capability over wide areas. Other modes include Sea Moving Target Indicator (SMTI) and Ground Moving Target Indicator (GMTI), which support the detection of moving targets at sea and on the ground respectively.

Ground mapping, weather modes (compliant with civil regulation requirements), all standard beacon modes and terrain avoidance modes provide effective navigation aids and advanced search and rescue capabilities, which include recognition of survivor beacons. There is also the option of avoiding the use of radar operation in certain directions, for reason of stealth.

Normally the Falco is flown line of sight. Between the Falco and its GCS are two types of data link: narrowband for command and control, and wideband to serve the payload. The latter can support full HD-quality video.

In line-of-sight operation both types of link can reach up to 250 km, depending on the local terrain and transmission conditions. Onboard data storage is solid state and is sufficient to record more than 20 hours of HD video plus associated data.

Ground control

There is a fibre-optic link between the GCS and the GDT, which in turn supports the three primary antennas transmitting to and from the craft. The GDT is normally housed in the GCS module, with the antennas located outside.

At any time the autopilot can be overridden to allow the pilot to directly operate all the control surfaces, although that option is rarely used

The GCS houses the human operators and the equipment needed to control and support the Falco. Designed to be mobile, it uses a standard 20 ft (6.1 m) steel shelter, with enough headroom for a person to stand inside. It is powered by a buffer battery, which in turn can be fed from the mains or from a combustion-engined generator hooked up to it.

The GCS is configured to control one aircraft at a time. Normally it houses three operators: the pilot, a co-pilot and the GDT operator. Both the pilot and the co-pilot have identical consoles (interchangeable in case of emergency) and sit on each side of the data display board, with the GDT operator located between them. Normally the co-pilot will have the job of operating the payload sensors while the pilot concentrates on monitoring the flight.

The Falco carries a nose camera from which the view ahead is constantly fed back to the GCS. The pilot has conventional aircraft controls at his disposal and can fly the Falco manually by remote control if desired. In addition to the view from the nose camera, normally the Falco's air-to-ground radar provides a 'map' of the terrain over which it is

The Falco takes off and lands as per a regular manned aircraft

flying on a second monitor in the pilot's view, which can be overlaid on the stored geographical area map.

At any time the autopilot can be overridden to allow the pilot to directly operate all the control servos on the aircraft, although that option is rarely used. It is useful for test flights though, and otherwise is primarily for emergency situations. For pilot training, the trainee will normally fly a simulated craft in a synthetic environment; from within the confines of the GCS the difference will not be detectable.

As per normal UAV practice, in autonomous mode the Falco flies between pre-assigned waypoints. In semi-autonomous mode the pilot might opt simply to steer the craft, leaving altitude and speed control to the autopilot, or assume those control functions as well.

Communications antennas provide a radio link between the crew in the GCS and any air traffic controller into whose remit the craft might come. The crew will talk to ATC even if the craft is in fully autonomous mode, as it is still constantly monitored by them and they will be acting as the 'eyes' for ATC.

Collision avoidance comes from a combination of an onboard transponder, or IFF, the comms radio link and the constant monitoring of the flight by the crew using the nose camera, the E/O-IR payload and radar. Since it has a transponder fitted and the GCS is in two-way radio communication with ATC the Falco can be treated as just another aircraft by ATC.

In 2011 the Falco obtained a Permit to Fly from ENAC (the Italian CAA) to participate in the Sistema Monitoraggio Avanzato del Territorio – Fase 1 (SMAT F1) research programme. Through this, operating from the Cuneo-Levaldigi airfield in northern Italy and overflying populated territory, it demonstrated the capability to provide a suitable airborne monitoring system for civilian applications.

If data transmission between it and the GCS is broken, the Falco will go into autonomous failure management mode, which ultimately will deploy the parachutes for an emergency landing.

There are two parachutes on the Falco. In addition to the main centrally located one there is a small drogue parachute mounted on the tail, which is designed purely to decelerate the craft. It is deployed first in cases where the dynamic pressure would rip the wing off the aircraft following a main parachute deployment. Then, as airspeed falls, the main recovery parachute is brought into play.

The design of this unique feature, which enhances the overall safety of the system, was driven by the experience held by Selex ES in the design of fast subsonic aerial targets, which normally deploy their parachute at speeds well in excess of 200 m/s.

The Falco is now in service with five customers around the world, and has proven itself across a wide range of demanding environments

Falco EVO


The EVO is the latest long-wingspan derivative of the Falco

The ease with which the EVO variant was recently produced illustrates the flexibility of the Falco's architecture. With no fundamental changes to it, merely an extended wingspan and corresponding increase in tail boom length, it was possible to increase payload capacity by more than 25% and to increase flight endurance by more than 50%.

The EVO has a 12.5 m wingspan, up from 7.2 m, together with 1 m longer booms. Aside from the consequent repositioning, there was no other change to its tail assembly. The strength and rigidity of the Falco's airframe is such that no significant reinforcement of it was needed for the EVO version, despite its 70% longer wingspan.

The EVO's increased wingspan increases maximum take-off weight from 530 to 650 kg, and in terms of payload an increase from 70 kg to more than 100 kg. It also benefits from an increase in operational ceiling from 6000 to 7000 m, and longer endurance, up to more than 20 hours.

Falco in service

The Falco's payload capacity is nominally 70 kg, although it has been successfully tested at 80 kg. It has an operational speed of 50-100 knots but normally flies at 60-80 knots. In standard air (as opposed to hot or humid conditions) at maximum take-off weight it can fly to 6000 m. Maximum altitude is normally obtained later in the mission, when the fuel load has decreased.

The range in fully autonomous mode is dictated only by the flight duration imposed by the fuel load, which can be up to 14 hours. In line-of-sight operation 250 km is a normal maximum distance from the GCS but this depends on the terrain.

The Falco was the first unmanned aircraft in Europe to obtain CAA registration marks. They were awarded by the Italian authority and permit it to fly in certain designated areas. This followed an extensive survey of its flight dynamic characteristics (including evaluation of stability and control, level and accelerated stalls, and so on). That survey, in July 2005, followed cooperation between Selex ES and the authority to define the certification basis for it, mostly revolving around safety concerns.

The UK's CAA has since endorsed its Italian counterpart's recognition of the Falco's status for flight in given areas.

The prototype Falco first flew in November 2003 from the Salto di Quirra test range, and the first customer delivery was made in 2007. In the intervening time there have been many test flights to prove the craft's durability. In all, three prototypes were flown, and trials of the prototype included flights on different continents to evaluate the Falco in a diverse range of conditions, many of them demanding.

To date, more than 60 examples of the Falco have been built. Since the prototype first flew, there have been no major alterations to the hardware, although clearly small modifications have been made in the light of flying experience. Software development has been ongoing: functionality has been increased and there has been further development of the data link. New payloads have also been integrated to meet new customer requirements.

In August 2009 a catapult launch option, the Robonic MC2555LLR pneumatic launcher, was added. This creates an acceleration of 10 *g*, and is thought to be the first time a UAV of this weight has been successfully launched in this way.

Having built a strong relationship with the Italian armed forces, there was disappointment at Selex ES that the nation's military overlooked the Falco in favour of a smaller UAV system. However, it initially went into service in an Asian country, where it proved rugged and reliable. Other customers followed, making the project a commercial success.

These days the Falco is in service with five customers across the Middle East, central East Asia and Africa, and has proven itself across a wide range of demanding environments, from monsoon to desert. Exact flying hours are undisclosed because of customer confidentiality; it is understood though that it has clocked up more than 10,000.

Simulating the Falco in flight

Selex ES also offers a service whereby it will operate the Falco on behalf of a client on a pay-per-byte-captured basis. This resulted in a three-year contract for the Falco to provide information gathering and surveillance capabilities on behalf of the UN's MONUSCO peacekeeping operations in the Democratic Republic of Congo (DRC).

The Falco runs on gasoline and heavy fuel

This role began in December 2013. The DRC is a particularly demanding environment thanks to high temperatures and humidity, and frequent heavy rain. It is also necessary to fly close to towns. For this programme, Selex ES developed functionality to extend the line-of-sight operational range by using one Falco as a relay to transfer the data link to another, operating further away or in mountainous terrain.

In May 2014 a Falco on this mission picked up images of people in danger after a boat capsized in Lake Kivu near the city of Goma. Thanks to the alert, UN peacekeepers were able to intervene and 14 people were rescued.

The deployment of the Falco was the first time the UN had contracted with a civilian operator to provide UAV technology to aid in its humanitarian mandate; it is now seen as essential by the UN to have a UAV capability. The UN tender that Selex ES won started with no fewer than nine rival UAVs. The success of the Falco in that environment proves it is very exploitable and very robust. ☐

Top tech

A round-up of what's new and most popular on *UnmannedSystemsTechnology.com*

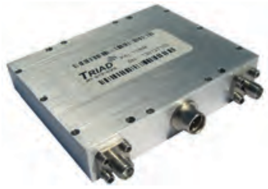
New technology

16 Megapixel high-performance USB 3.0 camera
Lumenera Corporation has released the Lt16059H, a high performance USB 3.0 camera built with leading edge ON Semiconductor KAI-16070 sensor technology. It delivers a powerful combination of high resolution, high sensitivity, high dynamic range and low-noise results.

New 8 hp two-stroke UAV engine
Hirth Motors has launched a new air-cooled, rotary valve controlled two-stroke boxer engine with electronic fuel injection. The 4103 engine features advanced closed-loop fuel control, CAN bus or RS485 interface for easy communication with the UAV flight computer, shielded ECU/harness and optional lightweight 500 W starter/generator to provide remote start and air vehicle electrical power.

World's smallest high-definition ISR encoder
VITEC has launched MGW Pico TOUGH, the world's smallest dual-channel H.264 HD/SD encoding solution. The unit weighs less than 400 g, setting a new standard of performance for manned and unmanned airborne platforms, military vehicles, and grounds units. The MGW Pico TOUGH consumes less than 7 W of power for 1080p encoding with KLV/STANAG metadata.

New and updated supplier profiles



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Steering clear of trouble

UAVs must be able to sense and avoid other craft if they are to operate in much of the world's airspace. **Nick Flaherty** reports on efforts to overcome this challenge

While current air traffic control (ATC) proposals are to create corridors for operating UAVs safely, the challenge with allowing operations on a wider scale requires a sense and avoid capability. Part of this challenge is the wide range of UAV platforms, from small quadcopters to larger, 60 kg systems and multi-tonne platforms.

UAVs larger than 60 kg have to carry a transponder, which these days fit into the existing ATC procedures by identifying the UAV, but this approach requires the air traffic controller to inform a remote pilot to take evasive action if needed. Allowing ATC to take control of an autonomous UAV to take evasive action is a much bigger step that would require significant integration with systems on board a UAV, but this option is being explored.

So there is a significant effort to provide a localised sense and avoid capability in a UAV so that it can detect other aircraft and take evasive action if necessary. Developers are also looking at how these technology implementations can be extended for longer range detection of other aircraft as well as for detecting obstacles, particularly power lines.

There is a range of technologies and approaches being adopted for this task, bearing in mind the challenge of size, weight and power (SWaP) for such a system. Radar systems at 10 kg with 1 kW power have been regarded as too large and power-hungry to operate on smaller UAV platforms, but advances in technology are making this a more viable proposition.

Consequently there is a focus on using cameras to look around the sky to sense other aircraft. There are different approaches to using vision sensors,

The Ikhana Predator B UAV is being used for sense and avoid trials linking onboard sensors to air traffic control and then notifying remote operators (Courtesy of NASA)

Pods with small radar systems are being installed on test systems for sense and avoid applications (Courtesy of IMSAR)

and different processing algorithms, as well as how to combine the data from the various sensors around the craft. A newer technique is to use the power of processing in the cloud to collate position data transmitted from UAVs, and combine this with other data to create an automated sense and avoid ATC system.

So there are various options, which vary with the type of platform. They also vary with the operating conditions, notably under Visual Flight Rules (VFR) or Instrument Flight Rules (IFR). While IFR is easier to address with technical solutions such as radar and transponders, VFR presents the greater challenge of replicating the pilot's view and improving on the time available to provide a change of course to avoid any risk of a collision.

For larger UAV platforms that are often piloted remotely, the challenge over the past few years has been airspace integration – allowing these craft to be used in controlled airspace.

Rules of engagement

One of the main challenges to overcome is not to replace the human in the cockpit but to give remote pilots the same capabilities an onboard pilot would have. That means having to detect and track aircraft further out to give the pilot more time to talk with ATC, which may mean sensors with higher performance.

The problem and the solution are very different depending on the type of operation for the unmanned aircraft. For example, in the US the requirements for a small craft under 25 kg (55 lb) and flying anywhere under 500 ft are very different from one flying at 3000 ft in controlled airspace. Larger manufacturers are focused primarily on the IFR environment, which allows operation in all controlled airspace, particularly at altitudes above 1000 ft. These manufacturers are looking at mature solutions, integrating established technology into the aircraft to solve the problems in the near term.

> One challenge to overcome is not to replace the human in the cockpit but to give remote pilots the same capabilities an onboard pilot would have

One of the key projects uses Ikhana, a variant of the Predator B UAV, for flight tests as part of the UAS Integration project in the US. It is being used to deliberately trigger on-board collision avoidance (CA) systems and to allow the remote pilot to perform self-separation via specially designed traffic displays.

Here the idea is a combination of CA and self-separation or traffic avoidance, so that a craft can remain 'well clear' of others and be a good user of the airspace. The aim is ideally never to trigger a CA situation, and one approach is to define what that means for an electronic system.

One concept is to keep the remote pilot in the loop as much as possible – there's not necessarily an algorithm telling the pilot how to manoeuvre, giving them all the information from the UAV on a display on the ground. This is exploring different ways to help the remote pilot understand where the potential collision risks are and to allow them to determine the best solution based on right-of-way rules and the objectives of the mission.

To develop statistical data on how these encounters can happen, computer simulations using ATC in 'human in the loop' (HIL) systems help developers understand how pilots and controllers interact by testing out different display and ground station concepts. More than 1000 scenarios with various collision courses give the remote pilot the ability to determine how to manoeuvre in response to a potential collision.

There are three sensor systems currently being used for prototype sense and avoid on platforms above 60 kg. The TCAS (Traffic Collision Avoidance System) interrogates other aircraft transponders, and over time builds up a picture of where all the other aircraft are, and this works at up to 14-20 miles. ADSB – automatic dependent surveillance broadcast – then provides GPS information about other ADSB-enabled aircraft in an area of 60 miles.


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Radar

The third is radar. 'Due Regard' air-to-air radar technology has been adapted from fighter aircraft, and uses an active electronically steerable array (AESA) to track multiple aircraft simultaneously while continuing to look for other aircraft. The AESA is a set of antennas that can 'look' in different directions by changing the phase of the outgoing signals, which can also reduce the power consumption. These systems can currently track objects beyond eight miles and will pick up an aircraft such as a King Air at a distance of 12 miles.

There is a growing focus on reducing the size and weight of radar systems for CA. Synthetic aperture (STAR), a single antenna with separate transmit and receive channels, can be optimised for lower weight and power by using a duty cycle that is much longer than the current 10% active time, which provides better gain and signal-to-noise ratio. Prototype systems that weigh less than 454 g (1 lb) and use less than 30 W rather than kilowatts of power are already being tested on sub-30 kg UAVs.

Radar systems will be packed in handheld units for UAV systems in 2016 (Courtesy of IMSAR)

> Passive sense and avoid using image sensors and machine vision algorithms is seen as the next step, but the challenge is the processing power

They are suitable for small UAVs that don't have the power to handle complex algorithms. Also, they have a modular design, which allows them to be tailored to a given platform. For example, some platform makers want a 210° viewing angle in front of the craft, while others want the full 360°, and the needs of a fixed-wing craft are different from those of rotor craft.

This can be for a number of reasons. Fixed-wing craft are generally moving faster and need more time to change direction than a rotary craft, and the shape of the craft can require the antennae to be placed in different locations. Typically with a fixed-wing design the antenna is a vee shape on the front that can see in front, and one mounted on the back of the craft to cover the rear. In contrast, a rotor craft may have antennas around the body of the aircraft as there is no front as such. Other craft might have only one revolving antenna, mounted above or below the airframe, to provide the radar data.

These small radar systems are intended to meet the regulatory requirements for a 'sufficient' distance to see and avoid other craft. They need to provide a detection distance of at least a mile, but that can depend on the airspace and the speed of the aircraft – for faster, fixed-wing craft a longer range may be necessary, for example.

Implementing such systems requires a combination of technologies. Off-the-shelf antennas with a combination of signal generation, data acquisition on the receive path and processing are all tightly coupled to reduce the size and weight but still provide the ability to sense other aircraft and predict any potential collision. These systems are now being tested and are expected to be on the market towards the end of 2016.

Standardisation

To standardise systems that rely on radar, the UAV community is working closely with the RTCA, which develops the technical standards for aviation systems, and within the RTCA the SC-228 committee is developing the minimum operational performance standards for unmanned aircraft systems. This has two working groups, for detect and avoid (DA) and command and control (CNC). The radar subgroup within the DA group is defining the minimum requirements for the radar systems, which translates to the smallest target of roughly one square metre.

This is an IFR-based approach that uses a standard called TCAS II for collision avoidance for larger unmanned aircraft. TCAS itself was designed for transport-type aircraft rather than UAVs, and uses simplified radar to monitor the airspace around an aircraft for other aircraft equipped with a corresponding active transponder that is independent of ATC. It has to be fitted to all aircraft with a maximum take-off mass of more than 5700 kg (12,600 lb) or carrying more than 19 passengers, but the SC-228 group believes it will be suitable for larger UAVs.

One challenge here is that these platforms are not designed for high-performance manoeuvres, so regulators have been working with the UAS community to determine the minimum level of aircraft performance for TCAS II. This is important for other airspace users as there are helicopters and other aircraft that are being equipped with TCAS II.

Recent flight tests have been run to create encounters that trigger CA manoeuvres automatically to order, to measure the response of the Ikhana platform and set the expectations for how a UAV should respond. This response is expected to require the ability to change altitude at rates of about 500 ft/minute as the lower limit. This is viable for larger platforms such as Ikhana but will certainly be a challenge for smaller aircraft and other UAV systems. The speed at which a UAV can respond is a key consideration.

The replacement for TCAS is called ACAS -X, with the ACAS-Xa version intended as a drop-in replacement for TCAS II. Another version, ACAS-Xu, is being defined specifically for unmanned aircraft by supporting multiple sensor inputs, and in the longer term it is expected to take into account aircraft with lower performance and all airspace users, whether or not they have a transponder.

ACAS-Xu may also incorporate support for non-cooperative air-to-air radar and then infrared electro-optic sensors. The ACAS-X standards are planned to start coming into use from 2020. One of the challenges with passive non-cooperative sensors such as camera systems is that they don't give a direct measure of range, and that is one of the primary pieces of information used in TCAS and ACAS-X.

The SC-228 DA working group is also developing a standard for the transition to controlled airspace up to class A at 18,000 ft. This is looking at the larger platforms that can get up to class A airspace, and is due at the end of 2016. The next step is to include lower-altitude operation, probably by 2020, and to fit in with the Xu standard.

The ScanEagle UAV is being used to test small radar systems (shown in red) for sense and avoid applications (Courtesy of Insitu)

Passive visual sensors

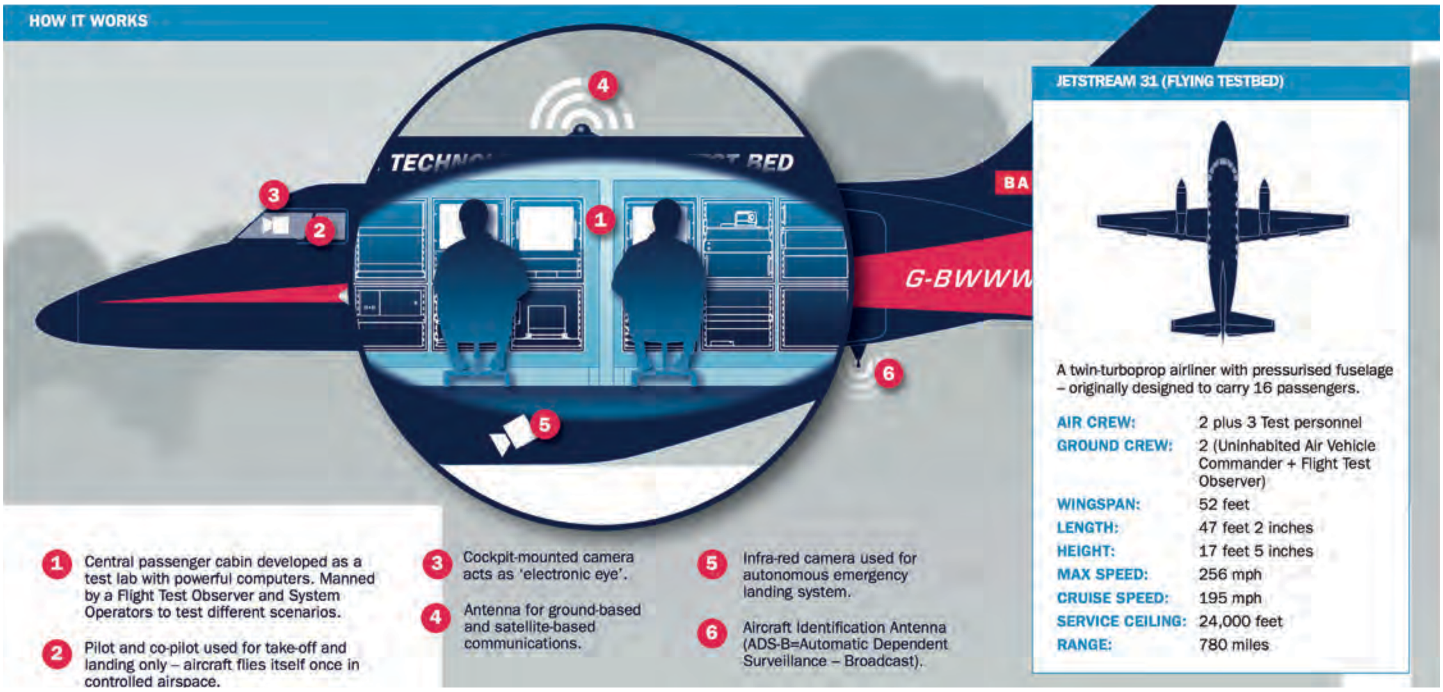
Passive sense and avoid using image sensors and machine vision algorithms is seen as the next step, but the challenge is the processing power. Graphics processing units (GPUs) are increasingly common in mainstream processors and can be used to implement elegant, efficient machine vision algorithms, while more processing power can be traded for lower power consumption and smaller size, but GPU-based systems and the software implementations of the algorithms do not currently have the standards approvals such as DO-178C that are needed for avionics equipment.

Part of the challenge with testing these systems is pitting the performance of the machine vision system against that of a pilot's eyesight, determining the point at which a pilot picks up a potential collision. Vision systems are consistently beating pilots by two to three miles, with the machine vision not knowing which direction another craft will come from and still picking up potential collision risks. With test craft cruising at around 120 knots, that is enough for a few minutes to instigate collision avoidance.

For vision systems there are also some physical challenges. First, there is the positioning of the camera sensors, whether a field of view is required all around the aircraft, above and below. A view below the aircraft is often used for landing, but suffers from 'below the horizon' challenges of separating out the background images, and fusing the data from multiple cameras around the aircraft contributes to the complexity of the CA decision-making.

The current regulations that expect to replicate the view a pilot would have would require one vision system at the front with a 180° field of view. There is also the challenge of where to place cameras on the airframe – in some trials a single array has been seen as more efficient and carrying a weight penalty but preferable to the need to have mounting holes for separate cameras around the airframe. Other solutions are using a turret with a camera that can scan a field of view, using a technique called 'step stare' image gathering rather than a fixed lens.

In other work, a European research project is using a standard 5 megapixel CMOS camera with a high-quality lens and a standard dual-core processor to track moving objects in the sky. Those determined to be aircraft are tracked, but the system can also be used to track birds that may be on a collision course. The system will detect objects up to two miles away, giving up to 50 s for



BAE Systems in the UK used a manned aircraft to test out a camera tracking system for sense and avoid applications under the European Astraea programme that finished in September 2015

evasive manoeuvres, and the hardware requirements are such that it will fit with current avionics standards approvals when it's available for UAVs, which will be in the next five years.

This visual system has the added advantage of helping with the wider sense and avoid challenge of weather conditions. The second processor core is being used to identify weather fronts and other related risks to the aircraft, and feed this data into the autopilot to provide an alternative direction of flight.

This is also being linked to a mapping database on the aircraft that highlights areas where the craft cannot land in an emergency, such as built-up areas or power pylons, and identifies a safe area within the glide path of the aircraft for landing. They can then be used to identify any moving objects within the potential landing area to highlight obstructions.

The project highlights another SWaP challenge for sense and avoid systems. Installing camera sensors in an airframe can increase its weight, as the holes for the sensors have to be reinforced. This may mean that having an array of sensors in one location replacing the view that a pilot would have is a lighter solution than separate sensors spread out across the airframe. This trade-off between sensor arrays and visibility will be key in future designs, although the single array meets current regulatory requirements.

Another approach being developed is to use sensors that remove the static background from the CMOS array, highlighting any movement. This could be used to identify the movement of aircraft underneath a UAV against the ground, which is a key challenge for sense and avoid systems that tend to assume a background of the sky.

Cloud computing

A very different approach to the sense and avoid challenge is being taken by systems that use cloud computing resources linked to apps on a smartphone used to control smaller craft. A leading quadcopter developer has updated its app to check the location of the smartphone via the phone's GPS sensor. The location is sent back to a database in the cloud, and if the phone is in or close to a no-fly zone the quadcopter will be grounded and the operator notified.

This can work with fixed no-fly zones, such as those around airports, and temporary zones such as wildfires. Quadcopters taking video have previously interrupted fire-fighting aircraft, which cannot operate without risking a collision with these craft.

The benefit here is that the no-fly zones can be constantly monitored and updated via the cloud. However, this approach can struggle if the smartphone is not the controller, if it is a significant distance away, if the link to the cloud fails or if the GPS location monitoring is switched off or deliberately changed ('spoofed').

Other cloud-based approaches are even more ambitious. One aims to give every UAS a unique identifier, and linking the craft to the internet using mobile phone technology allows the cloud to automatically monitor every craft in the air and issue avoidance instructions to any of those craft when required.

Every craft in the network has its own globally unique identifier that is linked with position data from the craft's GPS navigation sensor. This combination of identifier and position data is

Some examples of sense and avoid technology suppliers

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fed into the cloud alongside telemetry data, aviation data from radar and weather data, and this is all combined with a database on the local laws and hazards. The system then sends targeted avoidance instructions directly to the UAS as waypoints or turn rates.

To do this, the application programming interface (API) for the network is made available to UAS platform manufacturers to integrate into their designs. The link to the internet can be either directly through a mobile phone modem module on the craft or through the downlink and then to a mobile phone held by the operator. If the operator ignores an alert though, it would still be possible for the network to implement changes directly to avoid collisions.

The aim is to support any aircraft, any vendor and any hardware. The network draws on the experience of building cloud-based systems with millions of items for the Internet of Things to provide a system that scales with millions of pieces of real-time data and responds with a latency of only a few milliseconds. This is necessary with relatively fast-moving craft to give time to notify the operator, make a course adjustment, take evasive action or take over the craft.

The API allows developers to build robust, internet-scale applications that can provide command and control capabilities to one or more UAS systems, using a common interface. However, it is up to platform developers to integrate this technology into their aircraft, although it is a software upgrade that does not require extra hardware.

Conclusion

It may seem strange, but the definition of autonomous operation is unclear from a regulatory standpoint. Although many systems, large and small, are heading for autonomous operation, the regulatory environment is confused.

Most of the technology is available now, and the last remaining elements for sense and avoid, such as lighter radar systems, will emerge as commercial systems in 2016. The challenge is the confidence of regulators to trust the technology and how the UAS industry works with the regulators to make it a reality sooner rather than later.

Acknowledgements

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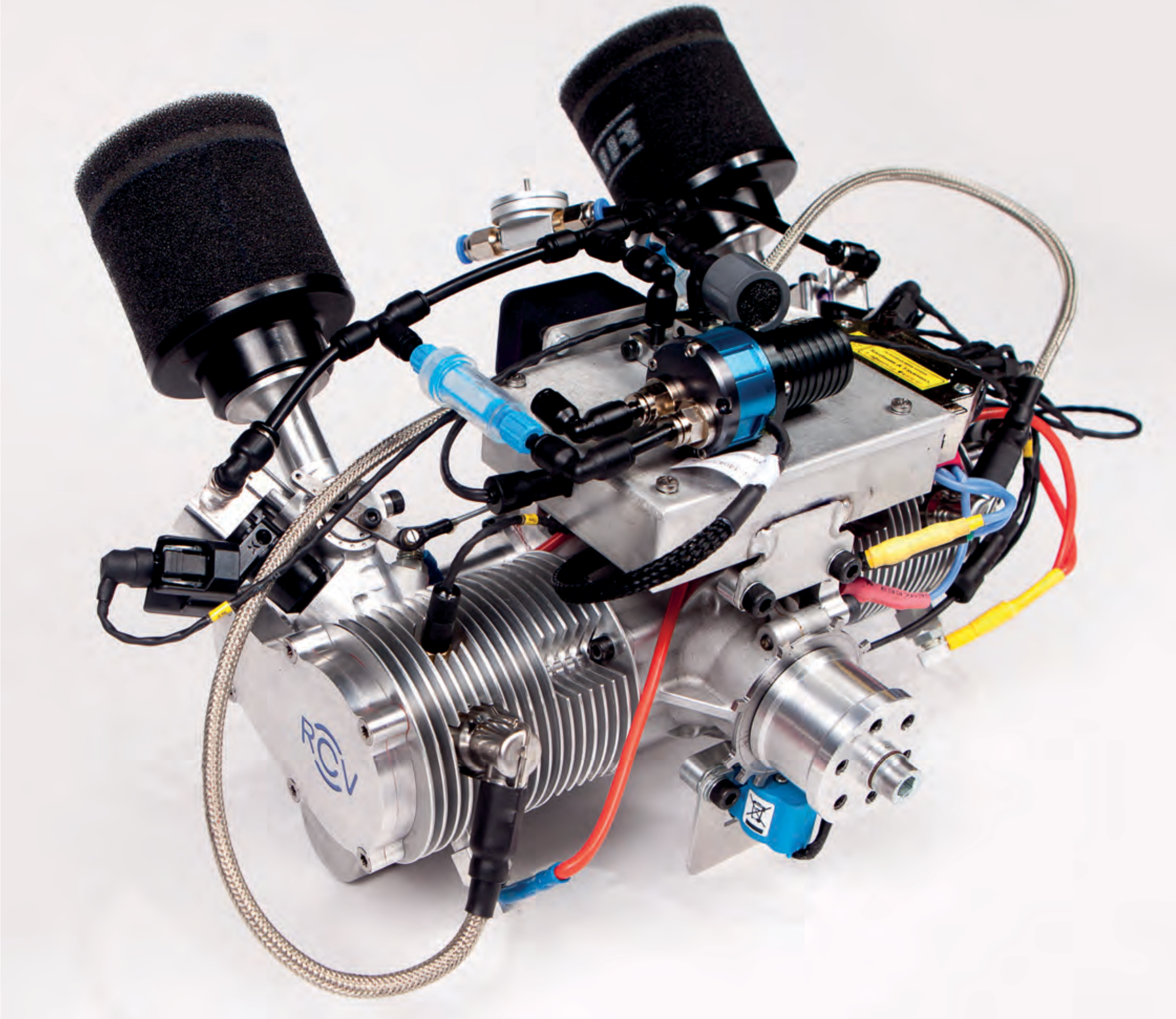
RCV Engines' DF70 rotary valve boxer



Rotary club

Ian Bamsey dissects this rotary valve four-stroke that brings fresh thinking to the UAV market

As a specialist manufacturer of highly efficient ultra-light engines, it is no surprise that RCV Engines (RCV) should have established itself as a key player in the market for UAV internal combustion power plants. The company has a unique technology, at the heart of which is its own development of the rotary valve concept.

Rotary valve (as opposed to Wankel-type rotary) four-stroke engines are rare but not unknown. Mercedes, for example, tested a rotary valve Formula One engine, only for the rule makers to ban it before it could be raced. In a world of small-displacement engines where the norm is either a two-stroke or a Wankel-type rotary, RCV's DF70 UAV boxer twin, with heavy-fuel capability, makes a refreshing alternative.

Background

The origin of the DF70 was a tiny, single-cylinder four-stroke internal combustion engine devised for model aircraft, and it had a unique feature – its cylinder liner/

sleeve had its top closed and it had an opening in the bore wall between the top dead centre position of the piston and the roof. This liner/sleeve was arranged to rotate about the cylinder's main axis at half crankshaft speed. As it rotated, its aperture uncovered an intake port, then a spark plug, then an exhaust port.

Thus was charge admitted to the combustion chamber, ignited and exhaust gas expelled, with the cylinder acting as its own valving through the rotation of its liner/sleeve; that rotation was obtained by gearing from the crankshaft. To keep things simple, the rotating cylinder of this 10 cc engine directly drove the propeller via a shaft extending from its roof, with the unit then horizontally mounted.

Being primarily cylindrical in external form, this compact engine neatly fitted the cowling of a model aircraft using a puller propeller. It was very effective for its size, and model aircraft enthusiasts liked the noise it made. Inventor Keith Lawes called it the Rotating Cylinder Valve, giving rise to the name of the company created to commercialise the concept, RCV Engines.

RCV quickly gained a firm foothold in the market, and there was soon an alternative engine that had a drive for the propeller directly from the crankshaft to suit certain applications. The cylinder drive variant was offered in 10, 15 and 20 cc versions, and the crankshaft drive version in 10, 15 and 22 cc versions.

About 15,000 examples of these model aircraft engines have been sold over the past ten years. Six years ago the licence to produce them was sold to another company, Weston UK, and since then RCV has concentrated on developing the concept for other applications that need small-displacement four-strokes: it has explored markets for the likes of handheld power tools, scooters and UAVs.

Model aircraft run on methanol, which is easier to burn than gasoline or heavy fuel. Nevertheless, RCV's rotary valve concept is inherently free from detonation, and the company has successfully developed power units for gasoline and heavy fuel-burning UAVs. This work came about through a contract awarded in 2000 by DARPA, the US Department of Defense agency responsible for developing emerging technologies.

DARPA engaged RCV to develop a heavy fuel-burning 44 cc boxer twin using its rotary valve concept. In view of the horizontally opposed rotating cylinders, the crankshaft was replaced by a 'cam track'. "That cam track system wasn't particularly reliable but the combustion system worked well," says RCV's commercial director Brian Mason.

In 2004, a continuation of the DARPA commission saw RCV develop a 35 cc heavy-fuel version of its single-cylinder suitable for the Honeywell RQ-16A T-Hawk, a ducted-fan VTOL micro UAV suitable for backpack deployment. Given the absence of the cooling benefit of methanol fuel and the larger displacement, that version had the cylinder oil-cooled. The downside of that though was the added weight and complexity of the cooling system.

To optimise power to weight, RCV developed a 60 cc boxer twin using the concept of a belt drive to the top of the cylinder rather than a bevel gear drive to the base of the cylinder. A customer requirement for more power led to a 70 cc rotary cylinder engine being built, but this proved to be problematic as the rotating cylinder concept had reached its thermal limits.

RCV switched to an arrangement whereby the cylinder bore remains stationary throughout the length of the stroke, and just a top combustion chamber 'hat' rotates – the vertical rotary valve (VRV).

This new development called for

The DF70's cylinder and vertical rotary valve

The origin of the DF70 was a tiny internal combustion engine devised for model aircraft whose cylinder liner/sleeve had its top closed

DF70 crankshaft

a belt or gear-plus-shaft drive from the crankshaft to the VRV atop each cylinder. A belt drive does not tolerate the dust or sand associated with desert operation, leading RCV to concentrate on the purely mechanical gear drive system for its UAV engines.

DF70 design work embraced advanced finite element analysis, which was sub-contracted to specialist engineering consultancy AAL. This embraced the likes of crankshaft behaviour and the optimisation of the VRV and its bore under cold conditions and at running temperature.

Ricardo Wave engine simulation software was used to help optimise engine performance, including consideration of noise. Mason notes that the software had to be 'tricked' into assuming that the engine under evaluation used poppet valves.

The DF70 first ran on the dyno in 2008. Development work since then has focused on durability and optimising fuel consumption. When it comes to noise, a more effective silencer has been developed that costs what Mason terms "a small performance loss" for those customers that want to prioritise stealth.

In addition to the DF70, RCV currently offers a 35 cc single and a (downsized) 50 cc twin for the UAV market.

> The DF70 is almost square and is a pure boxer: in effect the two pistons 'box' towards and away from each other

The first application of the DF70 came in 2010, in a fixed-wing UAV called the Spear from Brock Technologies, which had originally been electrically powered. The manufacturer reported that the switch to a heavy fuel-drinking DF70 "significantly increased" payload capacity, top speed and endurance.

Brock was supplied by Ultra Electronics, which had been licensed the right to market the DF70 from RCV. That same year, Ultra Electronics also supplied the engine for a small unmanned helicopter developed by Flint Hill Solutions. Since 2013, RCV has provided DF70 and DF35 engines for a further nine applications, mostly undisclosed.

The DF70

The DF70 is almost square, with a 36 mm bore and 35 mm stroke for 71.25 cc. It is a pure boxer, with each con rod having its own crankpin, arranged so that in effect the two pistons 'box' towards and away from each other. The offset of the two crankpins is kept to a minimum to minimise the couple associated with it – it is just 18 mm.

None of the webs are counterbalanced. "Since this is a small-displacement boxer, we don't need counterbalancing," notes Mason, "and we don't require any vibration dampening either."

The engine has a built-up steel crankshaft that allows for the use of ball bearings as the main bearings, and needle rollers for the big ends. The small end also uses a needle roller bearing, which is prudent given that the engine's lubricant is mixed with its fuel, in two-stroke fashion. It is also in the interest of low friction.

Steel I-section rods are driven by light alloy slipper-type single-ring pistons. The DF70 has an aluminium structure, with the cylinders formed separately from the crankcase. The piston bore and the VRV bore are both formed linerless within the respective aluminium alloy cylinder, and both bores are coated with nickel silicon carbide.

The VRV is shaft-driven from the crankshaft, and the use of two bearings at the bottom end of the shaft has been found to enhance the life of the timing drive. The hardened steel VRV is DLC coated inside and out so that its portion of the combustion chamber is thus treated.

Atop the cylinder is a timing drive gearbox sandwiching the gears that drive the VRV and having upper and lower elements, the former simply sealing the assembly.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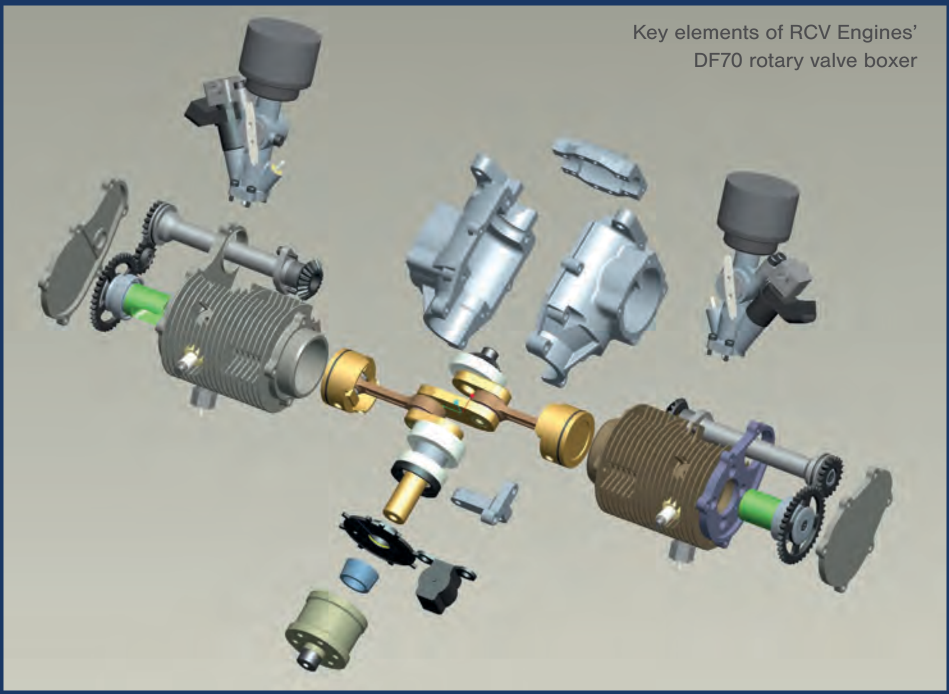
Anatomy of the DF70


Key elements of RCV Engines' DF70 rotary valve boxer

Horizontally opposed twin
36.0 mm bore x 35.0 mm stroke
= 71.25 cc
Naturally aspirated
Heavy fuel
Aluminium crankcase and cylinders
Linerless; nickel silicon carbide bore coating
Three main bearings, ball
Steel crankshaft, two pins
Steel con rods
Light alloy pistons, one ring
Gear- and shaft-driven vertical rotary valves
One rotary valve per cylinder, one plug
Electronic ignition
Sequential port injection
Engine management system
8.5:1 compression ratio
Maximum rpm, 14,000
(8500 rpm normal operating limit)

The DF70's crankshaft runs in three main bearings, two of which sandwich the pair of crankpins and the three webs that connect them, with the third outrigged to the front to support the output drive to the propeller. The propeller is intended to attach directly to the front of the crankshaft; as standard, there is no form of clutch.

The crankshaft is built from five elements. The first is the front section of shaft (running through the front two main bearings) and the associated front web. The second is the front crankpin, the third the web connecting that to the rear crankpin, which is the fourth section of shaft. The fifth section forms the rear web and the rear section of shaft (running in the rear main bearing).

The crankcase directly carries the three main bearings, which are steel deep-groove ball bearings running on journals 15 mm in diameter.

The two crankpins are a push fit into the respective webs, using an interference fit. Both pins carry a needle roller bearing. Steel rather than ceramic bearings are used throughout the engine.

The steel con rods are I-section, 55 mm from eye to eye and, thanks to the built-up crankshaft, are made in one piece, with needle roller bearings at both big and small ends.

The piston pin is 8 mm in diameter. It runs in a simple, single-ring slipper-type aluminium piston, with one end blind and the other carrying a PTFE button to retain it. Neither the aluminium piston nor the steel pin is coated but the steel ring, which runs against a nickel silicon carbide bore, has a chrome plating.

The crankcase splits into two halves, vertically along its main axis such that each half carries one of the two cylinders. Six bolts tie those two halves together. The assembly is completed by a back plate, likewise aluminium, which, attached by eight bolts, adds to the integrity of the overall structure. Four bolts attach the base of each cylinder assembly to the respective crankcase side. Liquid gasket is used for the sealing faces.

The cylinders are machined from billet aluminium, with the cylinder bore and the bore within which the VRV rotates given a nickel silicon carbide coating. Atop each cylinder is a timing drive gearbox, which encloses the gears driving the VRV. Six bolts attach this to its cylinder.

Concealed by the crankcase back plate is a bevel timing drive gear, keyed to the crankshaft behind the rear main bearing. Each VRV timing drive shaft has on its lower end a mating bevel, which is keyed to it. At the top of the shaft, within the timing drive gearbox, is a spur gear, again keyed to it.

The spur gear on one side mates with the gear mounted atop the VRV. On the other side there is an intermediate idler gear to reverse the

Components of RCV Engines' DF70 rotary valve boxer in the metal

rotation, so that both VRVs run in the same direction. This allows the inlets and exhausts to be on the same side of the engine respectively. The shafts and gears are all steel.

There is an aluminium housing for each shaft, which provides support for the shaft's deep-groove roller bearings. This housing bolts to the crankcase and to the timing drive gearbox, with O-ring sealing.

Removing the timing drive gearbox top cover allows access to the VRV and its overhead gear for ease of servicing. The VRV and its drive gear can quickly be re-assembled and timed.

The VRV is hardened steel with an all-over DLC coating. It is plasma nitrided prior to the application of DLC. It runs in a ball race and is driven by a gear mounted atop it with a locating pin to determine the valve timing.

In most applications each throttle body is fed through a tuned-length pipe with an independent air filter. The throttles are mechanically linked so as to be operated by a single servo. Four bolts attach the aluminium throttle body directly to the cylinder. The throttle body mounts the single injector downstream of the barrel (and pointing forwards down into the airflow). Opposite the injector is the throttle body cartridge heater.

Each exhaust primary is attached to the cylinder by four bolts. The two steel primaries (one emerging from each cylinder) feed into an aluminium cross-pipe/muffler body. In turn there is a single central rearwards exhaust exit from that.

The DF70 is run by an ECU that is custom made for RCV, while the software is based on a universal field-proven code.

The engine is port fuel injected using a single injector per cylinder. The fuel injectors are conventional off-the-shelf components from a 49 cc four-stroke scooter engine. The ignition is distributorless using a double-ended ignition coil with a wasted spark system to fire both plugs at the same time. The ignition system is inductive, providing a higher spark energy and duration than a more conventional CDI system.

The miniature fuel pump is electric. It pushes pressurised fuel through a pressure regulator and back to the fuel tank, and supplies both injectors at a pressure nominally set to between 2.5 and 3 bar (and there is no link between the two cylinder supplies).

The engine management system controls only the ignition coils and the injectors – the throttle is operated by the wider craft control system, together with the louvres controlling the cooling airflow. Meanwhile, the electrically driven gear-type fuel pump operates at a constant speed, so only needs to be switched on and off.

The engine management system, aside from speed and load sensors, monitors cylinder head temperature, manifold pressure and fuel pressure. To measure engine load, the system uses inlet manifold pressure, which is sampled over a specific period in the four-stroke cycle to give a more linear representation of the amount of air flowing into the cylinder.

Fuelling is primarily governed by the main fuelling map. This is two-dimensional and adjusts the amount of fuel according to rpm and engine load. Fuelling is then further adjusted according to cylinder head temperature, inlet air temperature and barometric pressure. There is a facility to monitor fuel consumption when the engine is in use.

Lubrication is by means of adding a tiny proportion of oil to the fuel, in typical two-stroke fashion; the lubricant is fully synthetic two-stroke oil. The engine is air-cooled and has glow plugs for cold start on heavy fuel.

The DF70 can have a starter linked to the rear of the crankshaft or, for packaging reasons, either of the two VRV driveshafts. Some customers put an electrical generator between the propeller and the crankcase, and this can be operated in reverse as a starter motor.

The propeller bolts to the front of the crankshaft with half-a-dozen bolts.

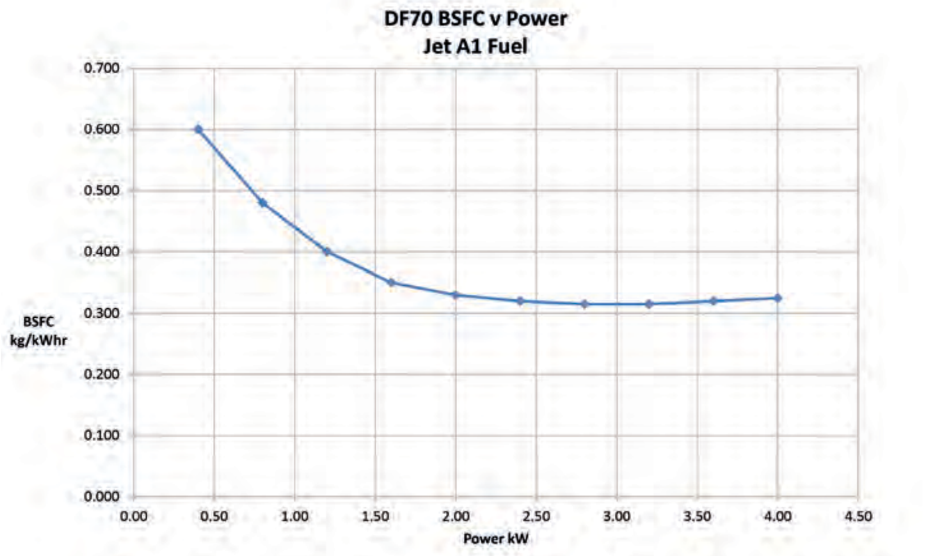
Anatomy continued…

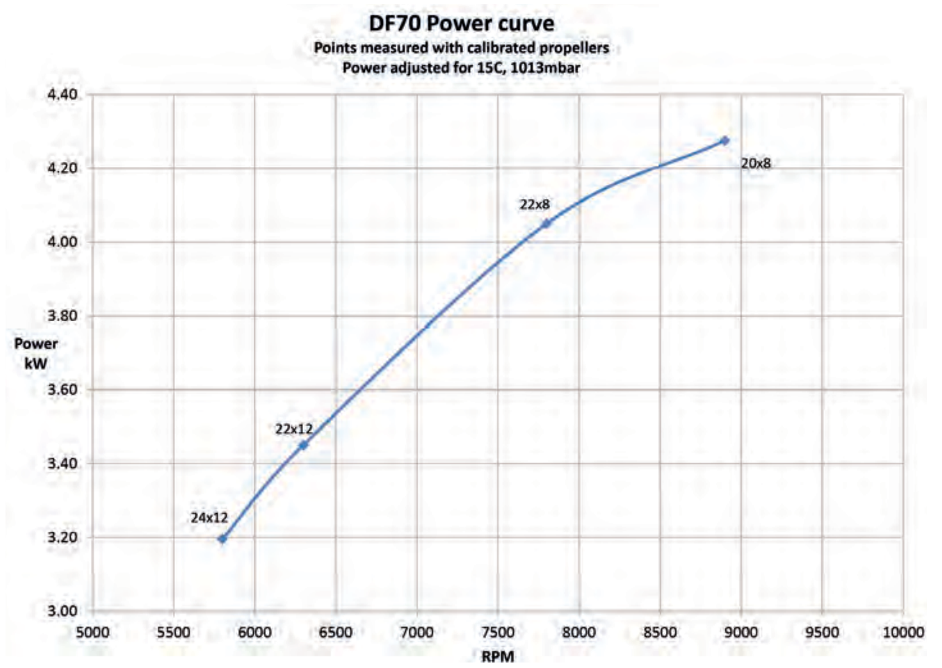
Since this boxer engine causes little external vibration it can be rigidly mounted in the airframe. There are four bolts on the rear of the crankcase for attachment.

It takes no more than 10 man-hours for a major overhaul including rebuilding with a calibration check and pass-off test.

Key suppliers to the DF70

Engine structure: in-house
Bore coating: Poeton Industries
Crankshaft sourcing: HC Concepts Engineering
Con rod sourcing: HC Concepts Engineering
Timing gears: Biddle & Mumford Gears
Pistons: in-house
Rings: Stihl
Piston pin sourcing: HC Concepts Engineering
Big-end and main bearings: SKF
Valves: in-house
Ignition coils: Gill Sensors & Controls
Spark plugs: NGK
Fuel injectors: Honda
Engine management system: GEMS
Sensors: GEMS
Data acquisition: GEMS
Generator: Sullivan Products
Exhaust: in-house
Air filters: Ramair
Wiring loom: Racelooms
Fuel pump: TCS Micropumps
Plasma nitriding: JJ Castings
Metals: Wessex Metals
Machining and fabrication: Manutech Manufacturing
Machining: Bridge Precision Engineering
FEA work: Advanced Analysis (AAL)
Engine simulation software: Ricardo





Fuel consumption and power readings for the DF70

The VRV is bolted to its drive gear by a single countersunk screw and is timed by a 2 mm dowel pin. In between the valve and its drive gear is sandwiched a conventional ball race, the outer ring of which is clamped into position in a counterbore formed in the top of the cylinder by the lower element of the timing drive gearbox.

The ball race controls the vertical position of the VRV and allows it to rotate. It takes the radial gear separation forces and the axial load applied by cylinder pressure to the VRV. There are no sealing elements above the VRV aside from the gearbox top cover.

There is also no sealing element between the exterior of the VRV and the bore within which it rotates; clearly that clearance alters with thermal expansion. Excessive clearance will result in loss of performance through gas leakage, while insufficient clearance will result in loss of performance as a consequence of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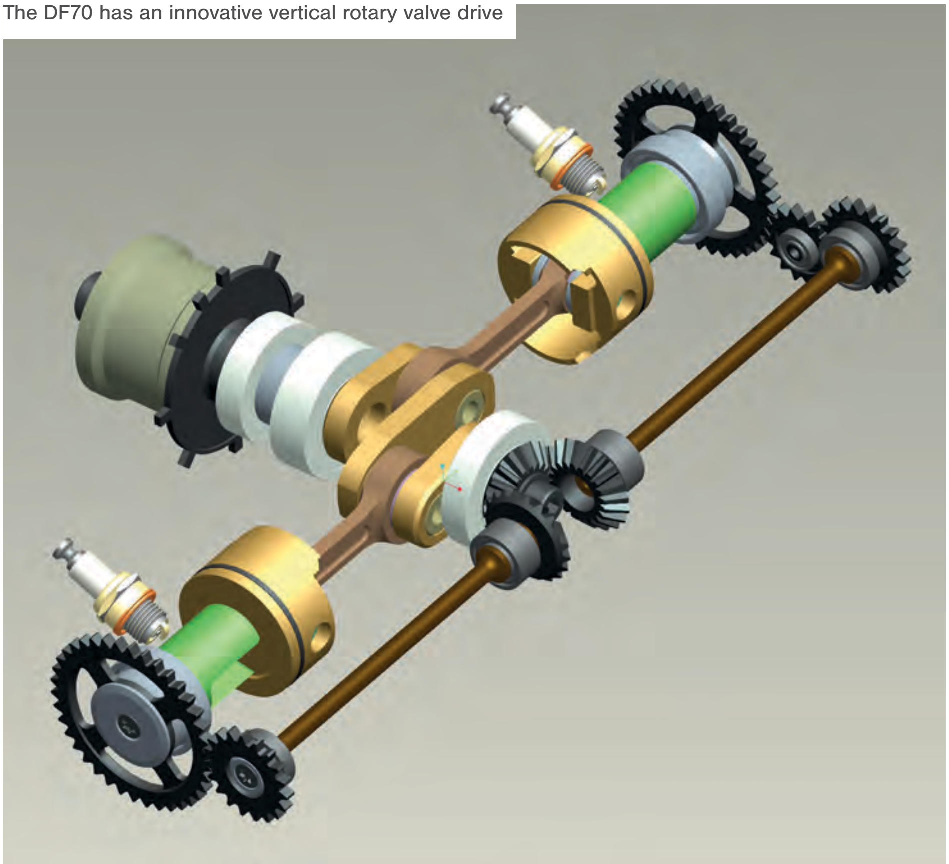
START

The DF70 has an innovative vertical rotary valve drive



rubbing friction or even partial seizure.

Mason refers to this as "valve grip", which the use of a DLC-coated VRV running within a nickel silicon carbide coated bore helps to counter. However, there remains a thin line between excessive clearance and insufficient clearance. Mason explains that the necessary sealing is accomplished by careful tolerancing between the VCV and its bore, with materials carefully selected considering thermal expansion and distortion.

Moreover, the VRV is allowed to float radially so that cylinder pressure pushes it against the intake and exhaust ports, minimising the leakage path. The width of the VRV aperture and the intake and exhaust port geometry together determine the valve timing. The intake valve opens at 24º BTDC and closes at 60º ABDC; the exhaust valve opens at 60º BBDC and closes at 24º ATDC.

Each cylinder has its own charge air intake with a throttle body that contains a barrel throttle. When the barrel is wide open, the charge has a straight tube to run through to the intake port exit controlled by the VRV. The intake and the exhaust geometry is tuned for performance in the normal manner of a four-stroke engine, exploiting pressure wave reflection to enhance volumetric efficiency.

> The use of a 50:1 fuel-oil mixture saves the weight and complication of a dedicated lubrication system, as on a four-stroke engine

In general, lengthening the exhaust primary pipes enhances performance, but the gain is marginal when the implicit increase in weight is taken into account.

The DF70 is run by an electronic management system. It uses distributorless ignition, and there is the option of dual ignition for redundancy – if one spark plug fails then the other will get the craft home (and in the case of this boxer, one of the two cylinders is enough to limp home).

Interestingly, the dual ignition has been found to enhance combustion, as seen in improved fuel consumption figures. Mason notes that the 9 mm plugs stay very clean, regardless of the fuel used, which is a function of using the VRV.

Fuel is injected into the inlet manifold just upstream of the VRV using a single injector per cylinder. This, notes Mason, avoids the carbonisation and other problems that can occur with a direct injection system running heavy fuel. The fuelling also includes altitude compensation.

A fuel return system allows the electric fuel pump supplying both cylinders to run at a constant speed. Fuel pressure (nominally 2.5-3.0 bar) is measured by a sensor in the ECU, and fuel injection times are then adjusted to allow for changes in this pressure, making the system robust to changes in pressure that occur during normal use.

The use of a 50:1 fuel-oil mixture saves the weight and complication associated with a dedicated lubrication system, as normally found on a four-stroke engine. Lubrication of the VRV gear drive is provided by the fuel-oil mixture blowing past the VRV; likewise, lubrication of the bottom end is provided by the fuel-oil mixture blowing by the single piston ring gap.

The 'boxing' motion of the pistons creates alternating compression and expansion of the internal air-oil mist within the crankcase. While this

Selection of DF70 crankshafts

represents a power-sapping pumping loss, in this instance it is seen as beneficial as a means of creating motion of the air-oil mist in the interest of lubricating the internal components.

Lawes explains that, although only a small amount of lubricant is introduced per engine stroke, oil will build up in the crankcase until the amount entering the crankcase each stroke reaches equilibrium with the amount leaving each stroke via the crankcase breather. That breather is positioned on the centreline of the crankshaft at the rear of the engine in a position where the oil is centrifuged away from the exit point.

This minimises the rate at which oil leaves via the breather, and the oil level builds to a fairly high level in the crankcase before the equilibrium point between oil in and oil out is reached.

"This is a conventional method of lubricating the crankcase on nearly all four-stroke model aero engines," Lawes says. "No problems with bottom end or valvetrain durability have been experienced during extensive testing."

An issue associated with the use of heavy fuel is carbonisation – parts of the engine that get hot when running are prone to carbon build-up. The original rotating cylinder concept made piston cooling a challenge, so it was not well suited to the use of heavy fuel. In contrast, the current stationary-cylinder-plus-VRV solution lends itself to a simple and hence light air-cooling system, even when using heavy fuel.

A heavy-fuel engine needs to be kept within a 40 C window: if it runs too hot then there will be carbon build-up, if it runs too cold it will misfire

Lawes notes that a heavy-fuel engine needs to be kept within a 40 C temperature window: if it runs too hot then there will be carbon build-up, whereas if it runs too cold it will misfire. Air cooling can obtain the correct running temperature, avoiding the additional weight and complexity of an oil or water cooling system.

The secret is in the design of the engine cooling fins and in working with the developer of the craft it will power to obtain sufficient flow from the engine cowling. Normally, adjustable louvres can provide the optimum level of cooling for any given operational situation. However, in the case of a rotor craft, the lack of the wash that would be created by the propeller of a fixed-wing craft means that a cooling fan needs to be used.

The turbulence in the combustion chamber generated by the rotation of the VRV assists starting; however, when using heavy fuel a major issue is always starting from cold.

In view of this there is a small electrical heater in each intake port and one next to each VRV. The fuel itself is not heated but these four cartridge heaters are switched on for a short period to obtain the induction and combustion chamber temperatures necessary for the ignition of heavy fuel.

Lawes says, "Starting from cold on heavy fuel requires more complex cold-start algorithms than with gasoline. These, along with the rest of the calibration factors, are set at the factory and require no operator intervention. The one extra operation required for cold start on heavy fuel is pre-heating the engine via the conventional diesel glow plugs, and typically takes one or two minutes."

Engine operation

To keep the compression ratio down to 8.5:1 the piston crown is slightly dished. A higher compression ratio is avoided since it promotes excessive blow-by through the VRV; this compression ratio compromise is the key drawback with using the VRV.

While the bore is 36 mm, the external diameter of the VRV is 20 mm, and its wall thickness is 4 mm. It follows that the base of the VRV contributes 4 mm to a total effective squish band width of no less than 12 mm.

Mason notes that the rotation of the VRV "creates a paddle-wheel effect that enhances mixture preparation." He adds, "The side of the valve aperture hits the charge, causing it to change direction, so the 3D geometry of that aspect of the valve is very important for performance."

Mason further explains, "The in-cylinder air motion is quite different from a poppet valve engine, as the inlet flow is close to the centre of the cylinder rather than to the side. If the port is fully open then the air motion will be tumble as the scallop in the valve directs the air into the cylinder.

"The rotary valve creates a high level of in-cylinder air motion. Approaching TDC, this bulk air motion will break down and, combined with the large squish area, this results in a high level of turbulence in the compact chamber.

"While the spark plug is offset on one side of the combustion chamber formed by the valve, as the valve exposes it the homogeneous mixture generated by the turbulence achieves consistent combustion," continues Mason. "As the cavity formed by the valve is the combustion chamber in the axis of the cylinder, flame propagation is similar to having a central spark plug.

"As the valve sees both inlet and exhaust flow, its temperature distribution is similar to that of a piston. The combination of a high level of turbulence and absence of a hot exhaust valve means the engine is insensitive to detonation and can operate over a wide range of air-to-fuel ratios."

Customers run the DF70 successfully on a broad range of fuels, including gasoline and a range of kerosene-based heavy fuels – even paraffin. Heavy fuel (Jet A-1, JP5 and JP8) is inconsistent in terms of octane rating, and is in any case very low at about 15-25 RON. Nevertheless, the VRV combustion system can cope.

In his work, *Internal Combustion Engine in Theory and Practice*, the late Charles Fayette Taylor, Professor Emeritus of Automotive Engineering at MIT, who directed the Sloan Automotive Laboratories at MIT from 1926 to 1960, identified five ways to avoid detonation – a small bore, a high velocity through the intake porting, a short ratio of flame path to bore, the absence of hot surfaces in the end gas region and the use of squish area, in particular in the end-gas region. "Our technology ticks all those boxes," notes Mason.

Key people at RCV Engines (from left): Keith Lawes, Eric Hill and Brian Mason

He reports that detonation is not in RCV's vocabulary. "We once ran an engine on n-heptane, the fuel that is used to provide a zero rating on the RON and MON octane scales. Even then we could only find detonation on extreme occasions."

Mason adds that the DF70's combustion system is particularly robust. It can operate successfully across a broad air-to-fuel ratio band as well as over a wide range of engine load and speed combinations, from part- to wide-open throttle.

VRV versus the poppet valve

Compared with an equivalent poppet valve engine, the main drawback of the VRV is the way in which it compromises compression ratio. Moreover, increased valve area relative to a poppet valve engine is no real advantage when valve opening rate is taken into account. A poppet valve can be made to open quicker than a VRV.

On the other hand, the VRV presents no restriction to flow once aligned with the port, which enables high volumetric efficiency to be obtained at high rpm. In addition, the VRV lowers the component count, and there are no valve springs or associated dynamic issues. There is also no valve-to-piston clearance issue to limit crankshaft speed potential, plus there is no hot exhaust valve or hot residuals to promote detonation.

Mason notes that, compared with an equivalent poppet valve engine, there is less friction attributable to the valvetrain. This is particularly significant in the context of a small-displacement engine, since the smaller the displacement, the proportionally higher the valvetrain friction. More important than that though, he stresses, is inherently superior volumetric efficiency.

He says, "Compared with

traditional small-displacement four-strokes, we have a far larger valve area, and our intake porting is unrestricted. We can double the power of small four-strokes derived from the likes of handheld power tools; at the same time, our rotary valve engine overcomes the problem of detonation associated with running a conventional four-stroke on heavy fuel.

"You might be able to optimise a poppet valve four-stroke to match our performance on gasoline but, using four valves per cylinder, that would be a bigger, heavier engine – and you wouldn't get it to run on heavy fuel. A two-stroke can be even more compact and light for a given power output, but again running it on heavy fuel is a challenge."

DF70 performance

The RCV combustion system is ideally suited to heavy-fuel operation. Lawes reports that, once it's at running temperature, it runs identically on kerosene/JP8 or gasoline, producing similar power and running without misfire over the same range of air-to-fuel ratios.

He notes that the VRV offers inherently good throttle response, and that the DF70 can run to at least 14,000 rpm without issue, but there has been no call to develop it to go beyond the current 8500 rpm peak power speed.

That speed is in turn a function of the propeller speed requirement in a typical fixed-wing UAV application using direct drive. The DF70's peak torque speed is 6500 rpm while running on JP8 heavy fuel; maximum power at 8500 rpm is 4.2 kW (5.6 bhp). From 71.251 cc that amounts to 79 bhp/litre.

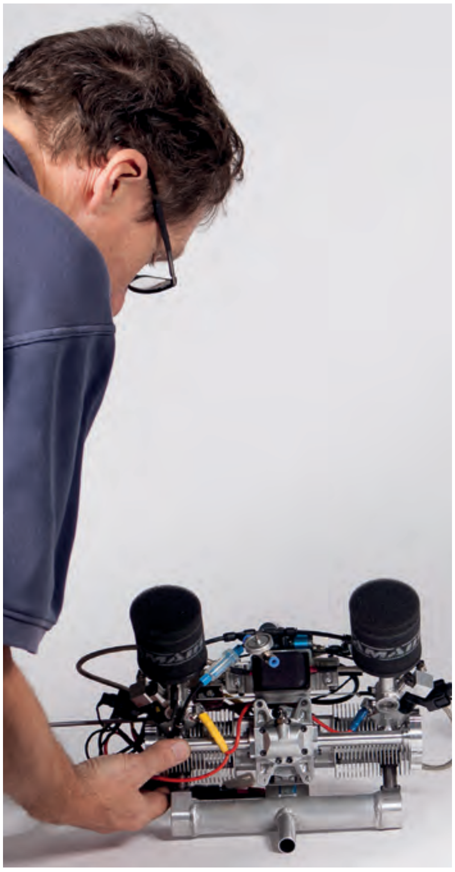
Peak power is normally used only for take-off and subsequent climbs with fixed-wing craft cruising at partial load, at about 4000-5000 rpm, for the best fuel efficiency. Clearly, fuel consumption is partly a function of the craft under propulsion – in particular the propeller it is using – but a representative figure from the dyno is 300 g/kW/h (0.54 lb/hp/h).

Engine life between rebuilds is limited by the rating of the bearings, which is 400 hours at maximum load. The base engine is only 263 mm wide, 70 mm high and 120 mm long. It weighs 2.7 kg (5.95 lb) complete with management system and exhaust (excluding only the propeller, cowling and any generator). Producing 5.63 bhp, it is thus very close to the 1 bhp per lb target set by DARPA.

To improve power density further, weight-saving materials can be used: magnesium for the crankcase and titanium for the fasteners, for example. So far, only a few lightweight-specification engines have been supplied.

Currently RCV offers only port injected gasoline and kerosene engines, with Mason noting that the engine runs on diesel fuel, still using spark ignition, but with a 5% drop in power and higher fuel consumption. Practical diesel operation would call for a costly development programme that awaits a user prepared to fund it.

The DF70 produces commendable power for an engine of its size



RCV Engines

RCV Engines (RCV) was established in 1997 and currently employs seven people, with Eric Hill the managing director, Keith Lawes the technical director and Dr Brian Mason the commercial director. It is located on the edge of the New Forest in Dorset, England, within the premises of Manutech Manufacturing.

Manutech assists in the production of prototype engines. Airframe integration is handled on behalf of RCV by HFE in Arizona and NW UAV in Oregon, the latter acting as a dealer for these UAV engines.

Once the DF70 is at running temperature it runs identically on kerosene/JP8 or gasoline, producing similar power without misfiring

Attending DSEI is a must for anyone involved in the military supply chain

Security review

Our round-up of some of the highlights from the 2015 Defence and Security Equipment International exhibition

Every two years, the defence and security industry gathers in London for the DSEI show. It attracts more than 30,000 visitors and 1500 exhibitors ranging from UAV suppliers and ground station software vendors to sensor makers and sensor fusion algorithm developers, plus conference contributions from leading aerospace companies.

If you couldn't make it this year, here's a selection of the editors' picks.

Following our report in *UST* issue 3 about Spectracom's Geo-PNT combined master clock and GPS/GNSS inertial navigation system, at the DSEI show the company's director of solutions architecture, Hironori Sasaki, said, "The Geo-PNT is an innovative and efficient solution for applications that require precise data as well as an accurate time reference.

"We see it as more applicable to secondary systems [surveillance systems, radars, steerable antennas, communications systems] where understanding your attitude at any given point and the orientation of your platform or sensor is critical, even when operating in GPS-denied environments."

Weighing 750 g and measuring 120 x 100 x 55 mm, the Geo-PNT contains a GPS/GNSS receiver, an inertial measurement unit and an extremely accurate clock that acts as a reference for both time and frequency. The clock can be either an oven-controlled crystal oscillator, or a much more accurate chip-scale atomic clock (CSAC) regulated by the radioactive decay of a rubidium isotope.

In the event of a lost or jammed GPS signal, the Geo-PNT can keep track of position, velocity and attitude using the IMU and the time signal from the CSAC or oscillator.

In the Geo-PNT, precise time and frequency signals are available as 1 PPS (one pulse per second), IRIG-B (unmodulated Inter-Range Instrumentation Group B) time code, NTP (Network Time Protocol) over Ethernet, 10 MHz and NMEA TOD (National Marine Electronics Association Time Of Day) messages as standard formats.

Spectracom's modular designs allow for additional formats and protocols as needed for custom applications. The Geo-PNT can also support SAASM GPS for military applications that require anti-spoofing resistance.

Radar, comms transmitters and other ISR systems also need a precise frequency reference from the clock, as Sasaki explained. "Those devices transmit or receive at a very specific frequency, and fluctuations in frequency have negative effects on the performance of the overall system," he said.

"So they rely on devices like this to

The Geo-PNT contains a GPS/GNSS receiver, an IMU and highly accurate clock

provide an exact frequency reference."

When a GPS signal is available, it provides a reference signal to 'discipline' the oscillator in the clock, which means using a tracking loop to match the clock output signal to the GPS input signal.

As satellite navigation signals are central to Spectracom's work, the company has developed a range of GNSS simulators (the GSG product line) to mimic satellite signals, and tools for developing new products and to assess the effects of interference, including jamming. "You can create an interferer and simulate the effects of that on the GPS receiver, so it is really testing the robustness of your system," Sasaki said.

Ceramic bearings manufacturer

CEROBEAR is new to the unmanned vehicles sector but has a firm foothold in sensor gimbals, which require thin bearings that accommodate low-speed precision movements. The company also offers advanced bearings for aerospace and industrial high-tech applications in general.

The company's general manager, aerospace Europe, Bernd Reuter, and aerospace project engineer Katharina Norta outlined the case for hybrid bearings, combining steel rings with ceramic ball or roller elements. The aerospace industry has shown some reluctance to use non-metallic materials in bearings because of concerns over the difficulty in detecting wear debris with magnetic plugs. However, Reuter stressed that such worries are misplaced.

"It has been proved," he said, "that the ceramic elements are not the weakest link of any bearing. If wear starts, you will always pull material out of the rings, which will then be detected."

Hybrid technology offers longer bearing life for applications in marginal lubrication conditions such as in helicopter transmissions, which must run for 30 minutes after lubrication failure. Reuter said CEROBEAR wants to extend this 'run dry' endurance to a matter of hours.

He said bearings survive much longer after lubrication failure if they combine metal and ceramics, because the ceramics are chemically inert. "There are no free electrons on the outside of the atoms," he explained. "And then you have no cold welding between the two materials."

Norta pointed out that in applications where there are extreme temperatures or out-gassing problems – in space, for example – ceramic and hybrid bearings can be run at low speeds and loads without lubricant.

At higher speeds and loads, lubrication is advisable even for hybrid or ceramic bearings, she said, because without it there is direct contact between the race and the rolling element. "So failure is ▶

CEROBEAR says hybrid steel-ceramic bearings offer longer bearing life in applications such as helicopter transmissions

not due to fatigue or anything, but wear. You get increased radial play, the shaft moves too much and at a certain point the customer decides it has failed.

"So it is always recommended to use a lubricant. But if you compare all-steel, hybrid and all-ceramic bearing dry running, the hybrid and the all-ceramic have better properties – lower friction, longer lifetime and less wear," she said.

Working with customers, she explained, enables faster development cycles and the design freedom to incorporate features such as flanges, threads and anti-rotation devices, offering faster installation and easier handling. Developing applications in partnership with customers brings further benefits. "We bring the bearing knowledge, they know their system," Norta said.

German start-up Dedrone has developed a system to detect unmanned aircraft in flight. The system, DroneTracker, combines established graphics processor unit (GPU) technology with microphones and two types of camera, all of which can be connected via Ethernet.

The system uses a combination of sensors for detection. An Ultra HD (UHD) camera can pick up images up to 100 m distant, and the image recognition algorithms running on an array of GPUs in a Tegra K1 processor from Nvidia can identify and track objects in the air. This provides four high-performance ARM Cortex-A15 cores running at 2.3 GHz with an array of 192 GPUs for the image processing.

A standard HD camera is used to identify areas of the field of view for the UHD camera to analyse for movement by subtracting the background image. The HD camera not only provides real-time video of the incident, but records the video as well, and the system can be configured for 720p resolution for faster UAVs or 1080p for more detail, and also operate in a low-light mode for monitoring at night.

Regarding the two microphones, the DroneTracker uses one to pick up the identifying frequencies of a UAV's brushless dc electric motor, at 13 kHz to 40 kHz, via a fast Fourier transform in the processor. The other microphone monitors the background noise around the tracker itself, and subtracts this from the first signal for more accurate measurements.

Dedrone has added tighter integration with existing security monitoring systems via SNMP networking capabilities to notify staff if a UAV is approaching a facility or restricted area.

The Ethernet port also connects the DroneTracker to the cloud, which is said to allow the system to learn faster and for detection to improve continuously. The HD camera operates in temperatures from -20 to +70 C and, as it is intended to be mounted on the exterior wall of a prison or stadium, it is housed in an IP54 enclosure made of weather-resistant and dust-proof plastic.

Dedrone's DroneTracker uses a combination of GPUs, microphones and two types of camera

Cella Energy's managing director Stephen Bennington provided more insight at the show into the company's hydrogen gas generator for UAV fuel cells, on which we reported in our previous issue.

The storage material is a chemical hydride in pellet form that releases the gas when heated to about 120 C. When Cella's gas generator which contains the Cella material is connected to a fuel cell, it can provide three times more electrical energy per kilo than lithium-ion batteries. "We can provide extremely lightweight power," Bennington said.

The gas generator is a pressure vessel containing printed circuit boards with pellet heaters etched onto them. The pellets are embedded in an insulating polyamide foam matrix, and heating them one by one produces a controlled flow of hydrogen. Thermal management is complex, with much work going into minimising heat transfer by radiation, convection and conduction, Bennington said.

With no moving parts, there is little to go wrong and, with no hydrogen gas in the system before first use, it is safe to transport. "Our material is not air-sensitive, so if you breach the containment nothing happens," he added.

The generators are sealed, but units can be returned for refilling.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HighEye's HEF30 UAV now supports a 4 kg payload and has a three-hour flight time

Bennington said the technology will benefit from economies of scale. "If we can sell thousands of units – which is what we anticipate doing, many thousands – then the price goes down to tens of dollars per cartridge," he said.

Cella is also working with Safran on bigger systems to provide onboard back-up power for aerospace.

Dutch UAV supplier HighEye has redesigned its HEF30 UAV platform to double its range and integrate video and secure communications. The 20 kg platform now supports a 4 kg payload and a three-hour flight time from the petrol engine and with a larger fuel tank, while the noise signature from the engine has been reduced.

A single IP-based encrypted data link to the ground station has also been added, along with an integrated ADS-B Out Mode S transponder, video converter and payload power outputs of 5, 12 and 24 V. The designers have also added two heat exchangers to remove excess heat from the payload electronics.

Lockheed Martin has updated its hand-launched UAV platform to provide all-weather operation, a longer range and integrated sensors. The Desert Hawk 3.1 upgrade extends the 60-minute flight time to 2.5 hours, and features an integrated electro-optic, infrared and laser-illumination payload rather than separate systems.

The 3.7 kg craft has a wingspan of 23 cm and a top speed of 50 knots. It carries a 1 kg payload and includes autonomous GPS navigation, an RF signal geolocation module and a gimballed 360° turret for the sensors. Updates to the landing software create a controlled stall so that it can land more accurately in an area of about 2 sq m.

Selex ES launched its Falcon Shield system to counter threats from small commercially available UAVs. At DSEI, capability manager Steve Williams said the modular, scalable system integrates radar, cameras and electronic warfare capabilities to detect, track and identify such threats, leaving the decision on using the defeat mechanism to the operator. "This defeat mechanism is where we think we are class-leading," he said.

Reluctant to be drawn on whether Falcon Shield can take control of a hostile UAV, although a section of the promotional video showed a small quadcopter apparently being forced to land, Williams emphasised the need to avoid unintended consequences. "The whole premise of the system is to minimise collateral [damage], and that is only possible with intelligent mechanisms of defeat," he said, declining to go into further detail.

We asked whether Falcon Shield uses digital commands or analogue jamming. "We are looking to use all the capabilities we have within the company to deliver a robust capability," Williams replied, emphasising Selex's expertise in developing UAVs and control systems, and long experience in electronic warfare. ◻

The upgraded Desert Hawk from Lockheed Martin comes with an all-weather endurance of 2.5 hours


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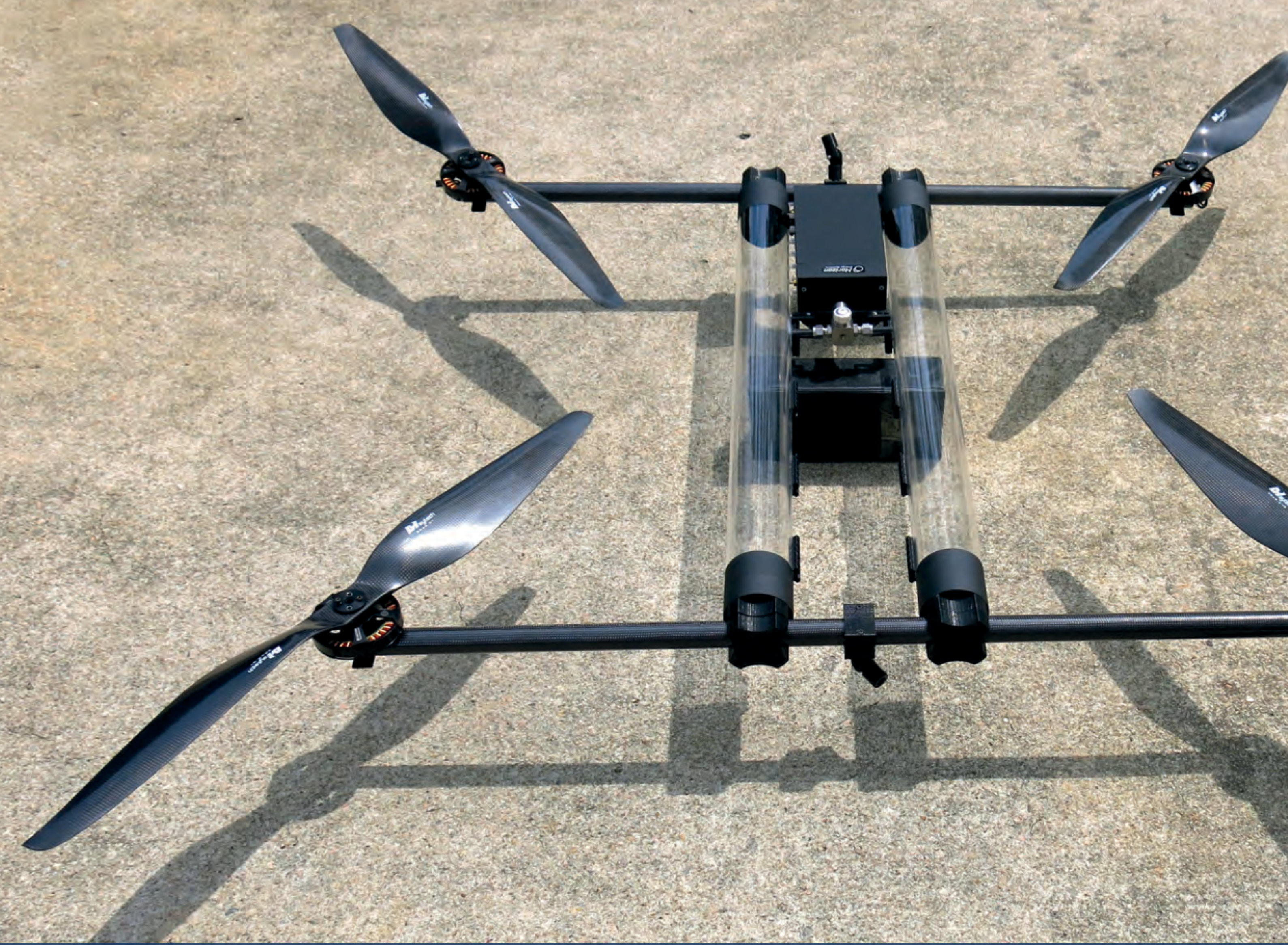


Chemistry lessons

Will Roney reports on developments in fuel cell technologies, and the promise they hold for unmanned systems

Unmanned systems are being deployed in a range of applications that appears to be growing almost exponentially – from the depths of the world's oceans to the reaches of outer space. A critical challenge with all of these systems though is to supply them with enough fuel energy to give them the payload-carrying capability and endurance to carry out their assigned tasks, and to do so within an overall vehicle design that of necessity has to feature a range of compromises.

Although petroleum-based fuels are popular because of their high energy density compared with batteries and other power sources, oil is a material that will ultimately run out and will therefore become increasingly unaffordable for all but the most efficient propulsion systems. This generally means a highly industrialised product, unlike the unmanned vehicles of today.

Renewable energy sources such as biomass and solar have yet to prove their reliability in providing uninterrupted (or readily replenished) energy for unmanned use. There is also the issue of energy per unit vehicle mass, which is critical in the design of aerial vehicles in particular, where weight is at a premium.

These issues signal the growing importance of using fuel cells to power unmanned systems.

In its simplest form, a fuel cell consists of three basic elements – the anode, cathode and the electrolyte (a substance that ionises when dissolved in a suitable

The fuel cell-powered Hycopter stores its hydrogen in its frame structure rather than specific fuel tanks. The craft will be available in early 2016 (Courtesy of Horizon Energy Systems)

> Fuel cells are far more efficient than fossil fuels and have a higher energy density. They also tend to be modular units, making for easy installation

ionising solvent such as water).

The anode oxidises the hydrogen fuel using a catalyst, often a platinum powder, by removing an electron (oxidation) to leave a positively charged hydrogen ion. The hydrogen ions are drawn through the electrolyte after the reaction. At the same time, electrons are drawn from the anode to the cathode through an external circuit, producing direct current. At the cathode, hydrogen ions, electrons, and oxygen react to form water

The advantages of fuel cells are that they are far more efficient than fossil fuels and have a higher energy density. They also tend to be modular units, making for easy installation, they are considered to be zero-emissions devices, and they produce very little vibration that could affect other parts of an unmanned system such as a camera or video unit.

On the downside, however, they can prove relatively expensive and complex compared with battery or solar power alternatives, and require specialist design and assembly to make them integral to the unmanned system; they can need specialist maintenance procedures too. In addition, the risk of the system becoming contaminated means they need filters and cleaners to ensure that the materials used are of the best quality, which have to be accounted for in their cost.

Hydrogen is not naturally abundant so it must be obtained through water electrolysis or by reforming hydrocarbons, defining it as an energy carrier rather than an energy source. There is also no distribution infrastructure yet for hydrogen for fuel cell use, and issues with hydrogen handling mean special safety precautions must be adopted when dealing with it. Methanol toxicity (where CH_3 is the fuel) and flammability mean that storage and transport will always be a key aspect of the overall support network.

Fuel cell integration into the unmanned vehicle, however, is key. The issues that need to be addressed are those that designers wrestle with on a daily basis – where is the energy to be produced, how is it to be stored and delivered to the power unit, and how is the power system going to be contained within the vehicle? What is the impact to the vehicle in terms of weight or cost?

Gaseous hydrogen storage

The notion of gaseous hydrogen storage as a design feature to fuel UAVs recalls the designs of the first airships, from the Zeppelins of World War I to the Hindenburg and the British R101 in the 1920s and '30s. Their time ended after a number of disasters, but recently there have been steps to mimic the concept, in such diverse applications as passenger carriage right down to the smallest of UAVs.

The challenges with dealing with hydrogen, particularly in its gaseous form, are twofold – its flammability and the volume needed to provide meaningful fuel energy. In a properly sealed system, there should be no problems with fire risks, but the issue of gaseous volume is a tricky one.

With the extra structure needed to encompass the fuel in this state, there is the possibility that the design compromises needed for flight cannot be achieved. This is owing to the balance needed between providing enough space for the gaseous fuel and keeping the weight of that structure to the absolute minimum so that any advantages in using this method are not marginalised.

The advantage with storing gaseous hydrogen within the structural framework of the UAV, instead of in specific fuel tanks, is that the more traditional 'silo-based' design philosophies, such as aerodynamics, structures and mass coexist in a less distinct way. This allows an overall more efficient system to be designed that makes best use of the advantages of gaseous fuel cell technology.

Where this concept has been

A typical fuel cell for a UAV (Courtesy of Energyor)

proven to work, smaller UAVs can achieve longer durations, and in conjunction with higher efficiency fuel cells, flights of up to four hours are possible, against the matter of minutes previously achievable. This concept has been demonstrated at test facilities looking into this technology, although with a payload of about 1 kg the flight time has been reduced to about two-and-a-half hours, which for the size of UAV under test is still a considerable advantage.

The ability to scale up this technology into bigger and bigger systems will be challenged by being able to maximise the volume of gas across the structural weight needed to carry it. There is effort now to try to succeed in this.

The potential over batteries of a gaseous storage system is already being demonstrated, even though current prototypes are having to use commercial off-the-shelf gas pressure vessels and tubular frames. With bespoke materials and design though the potential for further design gains are possible.

Supporting this design of UAV is the world's highest power density fuel cell, at around 1 W/g for sub-kilowatt systems. It is more efficient than a traditional fuel cell, and has far fewer of the peripheral

Combined with higher efficiency fuel cells, flights of up to four hours are possible, against the matter of minutes that previously could be achieved

parts that are typically used to manage water and gases in the cell; instead it uses algorithms to manage the chemical reactions inside the cell precisely. Similar to the level of maturity of the integrated gaseous structure, this is also currently in development.

Despite the potential advantages with a gaseous-fuelled UAV, one problem this UAV system could face are the restrictions on transporting battery technology around the world. One way of circumventing these regulations is by using a process of electrolyser-based hydrogen manufacturing in situ, using pure water.

This replenishment of hydrogen, in up to 30 minutes, is faster than the several hours taken for battery charging using solar power, notwithstanding the logistics of manufacturing the hydrogen in situ and that a solar panel, while easier to use, will take longer to charge. With charging rates like that, the focus is then on fuel production rather than battery capability.

PEM fuel cells

Proton exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells, were developed in the automotive industry. The possibilities of using such a system in unmanned ground vehicles is a direct carry-over from the commercial world.

Essential parts of PEM fuel cells are the membrane electrolyte assembly (MEA), and bipolar plates to separate the MEAs. The MEA consists of two electrodes: the anode and the cathode. These are porous carbon electrodes that are each coated on one side with a small amount of platinum catalyst and separated by a proton exchange membrane.

Bipolar plates, also known as flow-field plates, are positioned on either side of the MEA. They help distribute gases and serve as current collectors.

The plates contain a fine mesh of gas channels, through which hydrogen gas is directed to the anode, and air flows through the channels to the cathode. At the cathode, the oxygen in the air forms water with the protons that come through the membrane and the electrons coming from the external circuit.

The airflow removes this water, which can then be redirected to provide system cooling, although this cooling is sometimes achieved by humidifiers. The design of the bipolar plate is critical for the correct operation of the fuel cells.

A single fuel cell consists of the

The US Navy is testing different fuel cell technologies in its Large Displacement UUV Innovative Naval Prototype, which will start trials in California in 2016 (Courtesy of USN Office of Naval Research)

membrane electrode assembly and two flow-field plates. A single fuel cell delivers typically a voltage between 0.5 and 1 V, which is too low for most applications so, as with batteries, individual cells are stacked to achieve a higher voltage and power. This is called a fuel cell stack.

PEM fuel cells do not require corrosive fluids, like some fuel cells. They only need hydrogen, oxygen from the air, and water to operate.

The power output of a given fuel cell stack will depend on its size. Increasing the number of cells in a stack increases the voltage, while increasing the surface area of the cells increases the current. One 10 kW full stack measures 190 × 270 x 520 mm, and weighs 35 kg. A stack is finished with end plates and connections for ease of use.

Advantages include a fuel cell stack power density as high as 1000 W/kg with a potential for automated cell fabrication and assembly, which brings about a true potential for low-cost stack manufacture.

Drawing elsewhere from industry to provide commercial off-the-shelf fuel cells can also have an effect on UAV efficiencies and performance. One recent test flight using this technology achieved the world's longest multi-rotor UAV flight, flying for 3 hours, 43 minutes and 48 seconds, beating its own previous world record of 2:12:46.

This extended duration translates into a more attractive flight system that will go a long way to meeting the demands of customers who are always looking for additional capabilities.

Based on fuel cell system technology similar to that used in the automotive industry, specific attention has been paid to operation in ambient temperature extremes (high and low), high altitudes and environments where significant airborne contaminants such as dust are present.

> Battery power allows a typical UUV cycle time of only three hours, however a fuel cell will increase the time at station depth

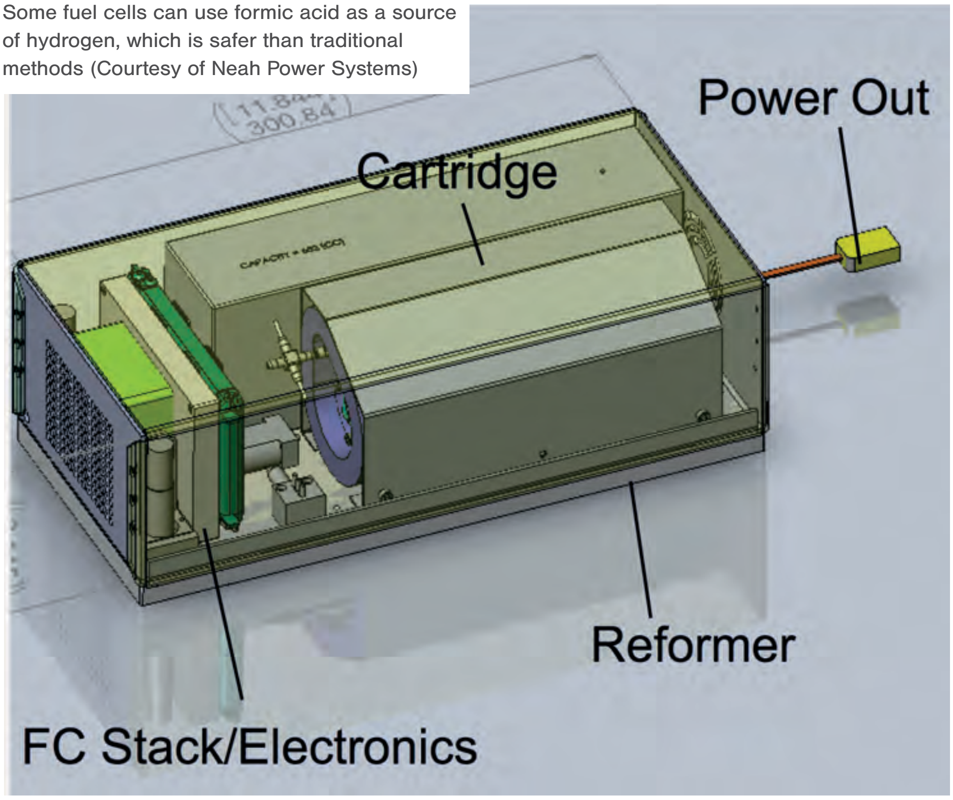
Underwater systems

The design compromises in autonomous unmanned underwater vehicles are not as critical as those with UAVs, since being in water mitigates the issue of weight when sub-surface. This allows the list of potential applications to grow as fuel cell technology develops, the extra capability driving bigger and more effective unmanned sub-surface systems.

By having a wholly independent UUV, the operator is able to release it from its support vessel without the risk of having a tethered vehicle in rough weather. Most operators and UUV manufacturers are therefore looking for ways to increase autonomy and time at station depth to achieve a more cost-effective performance.

With battery power, a typical mission allows a cycle time of only three hours: an hour down to station, an hour at station then another hour back up to the support vessel for recharge. However, a fuel cell system increases the time at station depth, how much longer depending on the amount of fuel carried – often enough for months of autonomous operation. This additional storage can be accomplished by adding separate containers or increasing storage pressure, or both.

Typical modern UUV fuel cells are designed to operate with a minimal amount of system components, the complexity from extra parts outweighing the advantage they can provide. This will supply a more reliable and cost-effective power and energy system over a more complex system. A consequence of this is that with a fixed-volume fuel cell sized for a given power level, the reactant



Some fuel cells can use formic acid as a source of hydrogen, which is safer than traditional methods (Courtesy of Neah Power Systems)

> One common feature in the fuel cell market is the in-situ production of hydrogen from water, which can be stored in tanks without additional compression

storage becomes the critical variable, making its storage the principal structural design challenge.

These fuel cells minimise parasitic load losses while providing rapid electrical transient response. This means that power is available as soon as it's needed, and at an increased level of efficiency. The cell itself operates at greater than 50% efficiency when consuming compressed oxygen rather than compressed air, accentuating the ability to scale power output with fuel cell stack size while separately scaling energy output through reactant storage sizing.

Systems such as this also use a bifurcated approach that separates power output from energy output. This is the distinguishing difference between fuel cells and batteries. Batteries provide a high specific power (kW/kg) while fuel cells provide a high specific energy (kWh/kg). It is the high specific energy resulting from this bifurcated approach that provides a three-hour mission cycle, which become eight hours or more, and that simply depends on vehicle layout by minimising system inefficiencies.

It is becoming clear however that the dominating factor in establishing optimum specific energies are the hydrogen and oxygen storage tank systems contained on board a UUV, but for most applications a simple compressed gas storage arrangement should suffice.

One common feature in the fuel cell market is the remote, in-situ production of hydrogen from water. Modern electrolysers operate in the reverse way to a fuel cell and can generate hydrogen, at pressures of up to 250 bar, by breaking water molecules into their constituent parts. The resulting hydrogen and oxygen reactants are then stored in tanks without additional compression and supplied to the UUV for consumption in its fuel cell.

This technology is already allowing mission durations of the order of months, rather than weeks. We can see this in the search for answers to the mystery surrounding the disappearance of flight MH370, with UUVs operating in the southern Pacific week in week out. It is this sort of technology that will make operations like this routine.

Reformer technology

One constraint on the adoption of fuel cells from the automotive industry is the use of hydrogen as a fuel. Compressed hydrogen, when used as a fuel source in unmanned ground vehicle systems, has safety issues, so the safety systems and processes that as a result need to be in place tend to limit the take-up of fuel cells.

There are also high costs associated with expanding the infrastructure necessary for buying and distributing compressed hydrogen to consumers. Similarly, typical industrial-scale storage fuel cell installations require an on-site hydrogen generation plant, the infrastructure of which can add significant cost to the unmanned ground vehicle system being used. As it is, given that the likely use of unmanned ground vehicles would be either the military or other government agencies, their existing non-public infrastructure would have to be improved.

One alternative to the in-situ production of hydrogen is a 'reformer' that allows on-site or point-of-use generation of

> For unmanned vehicles, the opportunities for local 'reforming' allow a measure of independence from any national grids producing hydrogen

Relative energy densities of fuel materials

Power source	Theoretical energy density (Wh/kg)	Theoretical energy density (Wh/l)
Lithium-ion	200	704
Lead-acid	30-40	60-75
Formic acid	1700	2086
Hydrogen (at 5000 psi)	33,333	833

hydrogen using formic acid (HCOOH). Although it is not a fuel, the use of formic acid to provide a source of hydrogen allows other, more volatile fuel sources such as gasoline to be discounted.

When used at 85% concentration, formic acid is less dangerous than pure hydrogen, although there are still safety procedures to be followed. When heated, it produces carbon dioxide and water, and then, when exposed to catalysts, it decomposes into hydrogen and carbon monoxide.

Formic acid is pumped from a cartridge using one of two metering diaphragm-driven pumps– one supplies the correct amount of formic acid for hydrogen production, the other supplies fuel through a heat exchanger to the catalytic burner to provide a continuous heat supply to the reformer. After exiting the heat exchanger, the reformate is mixed with a small amount of air and passed through a preferential oxidation reactor to bring the trace carbon monoxide content down to less than 10 ppm, which is a target of this development.

The reformate is then passed to a fuel cell stack to produce electrical power, with anode off-gases being vented to the atmosphere; the air supply for the catalytic burner is provided by a small blower. The hydrogen produced by this process can then be used by a variety of fuel cell types – solid oxide fuel cells, proton exchange membrane and so on – for either grid-scale power or unmanned automotive power.

The production of hydrogen in this way is a lot safer than traditional methods. Consequently the safety systems needed to protect the manufacturer can be reduced in line with the relative risk of production.

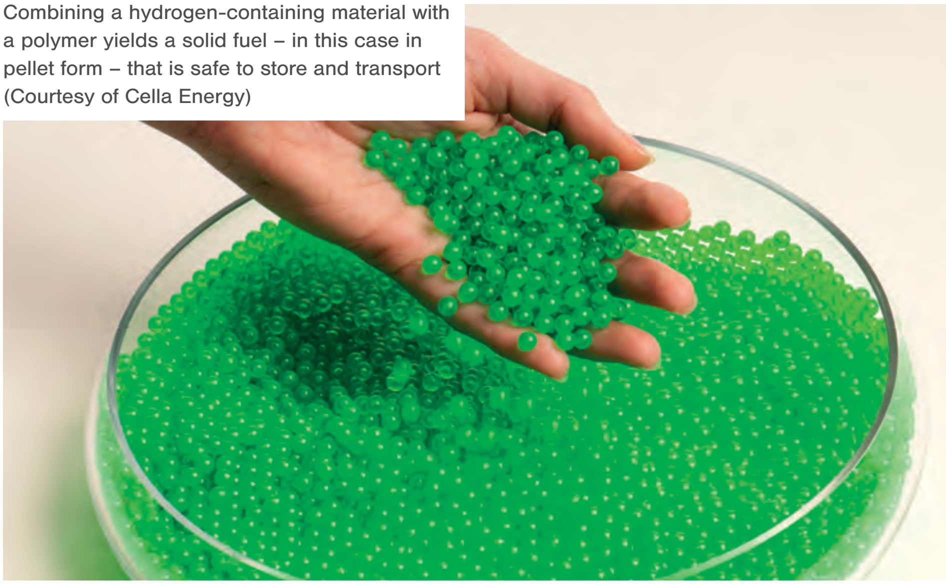
For unmanned vehicles, the opportunities for local 'reforming' allow a measure of independence from any development in the national energy grids producing hydrogen. Despite the need for safety procedures in reforming hydrogen for unmanned use, the overall advantages in producing fuel this way are still more attractive than relying on battery power.

Hydrogen pellet technology

Hydrogen is not the easiest material to transport or use in a leak-free system to allow useful power to be extracted from it. To do so typically entails compressing it to 700 times atmospheric pressure or liquefying it at temperatures close to absolute zero for both transport and use.

There is however a process that produces a solid hydrogen storage material that looks and feels like a plastic. It has a low toxicity and, although flammable, is no more dangerous than gasoline.

The current developed process takes a material with a high useable hydrogen content by weight, and turns it into a hi-tech composite by combining it with a polymer. The resulting material then forms a microporous plastic-like solid that can be pressed, shaped or extruded into any form and to fit any space. The advantage with this is that



Combining a hydrogen-containing material with a polymer yields a solid fuel – in this case in pellet form – that is safe to store and transport (Courtesy of Cella Energy)

Some examples of fuel cell manufacturers

Canada

Energyor Technologies
+1 514 744 6122 www.energyor.com

Germany

DLR – German Aerospace Center
+49 220 360 12474 www.dlr.de

SFC Energy (EFOY)
+49 896 735 920 www.efoy-pro.com

Singapore

Horizon Energy Systems
+65 625 039 49 www.hes.sg

UK

Cella Energy
+44 (0)1235 43 7740 www.cellaenergy.com

USA

AMI's Ultra Electronics
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Hydrogenics – Fuel Cell Power Systems
+1 905 361 3660 www.hydrogenics.com

Infinity Fuel Cell & Hydrogen
+1 860 688 6500 www.infinityfuel.com

Neah Power Systems
+1 425 424 3324 www.neahpower.com

Oorja Fuel Cells
+1 510 659 1899 www.oorjafuelcells.com

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UltraCell
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the 'fuel' can fit the volume needed, rather than the other way around – a key advantage, particularly in the aerospace sector.

Each gramme of it produces up to a litre of hydrogen gas, giving it a very high specific energy and making it ideal for mobile or portable applications where weight is crucial, such as in unmanned aerial or space vehicles.

It can also be packaged into cartridges which, when combined with a fuel cell, have two to three times the specific energy of a lithium-ion battery. In comparison with an alternative hydrogen production plant using a pressure of up to 700 atmospheres, it produces the fuel but without the same safety concerns or cost of infrastructure.

It can be moulded into pellets as well, to form a solid fuel but which has the properties of a fluid, making it far easier to transport it in large quantities and offering the prospect in the future of it being as easy to use as hydrocarbon fuels are now.

The principal advantages of this pellet system are that it does not need high pressures such as those for storing gaseous hydrogen, does not need cryogenic temperatures for the storage of liquid fuel, has a high specific energy (energy per unit weight), is a stable solid at room temperature and the pellets are not the only forms this fuel can be shaped into. The process can allow solid fuel to be fitted into any potential spare volume in a vehicle, which can have benefits in systems such as UAVs.

The future

When paired, fuel cells and battery technology can be seen as symbiotic: an advance for one can encourage the development of the other. However, the use of batteries alone in unmanned systems can only go so far. Their capability in unmanned systems is ultimately limited, owing to the comparative difficulty of recharging them on or close to an unmanned vehicle.

The advent of advanced fuel cells however is starting to remove these limitations, and there is a world full of chemicals waiting to be converted into zero-emissions hydrogen close to the vehicle, if not in it. However, it must be remembered that the ease of providing solar recharging may outweigh the requirements for faster hydrogen-based charging at this time.

It is exciting to see that the structural design of UAVs is moving in the direction of highly optimised systems that blur the barriers between traditional functions. This has produced long-duration UAVs capable of gaseous storage, producing ever-longer flight durations and providing the unmanned systems industry with solutions that are not tied to traditional methods of refuelling.

Granted, there are still technical challenges to overcome, such as the ability to generate hydrogen locally and/or to provide suitable methods of storage. However, history shows that where there is a technical challenge, there will be people to provide the solutions needed.

Acknowledgements

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UAV shows on both sides of the Atlantic are attracting a growing number of visitors

Transatlantic trade

Here's our review of some of the more interesting developments on show at the Commercial UAV Expo and InterDrone events in Las Vegas and the Commercial UAV Show in London

More than 1500 people attended the first Commercial UAV Expo in Las Vegas, where the 120 exhibitors showcased cutting-edge solutions including airframes, components, sensors, software and services.

Interdrone meanwhile is billed as the first global-scale conference for the builders, flyers and buyers of commercial UAVs; it drew nearly 3000 attendees and saw a clutch of new product announcements.

In London, the Commercial UAV Show attracted more than 2300 attendees, and the 85 exhibitors covered the whole range of UAV activities, from small platforms to large lifters and the latest camera, gimbal and mapping technologies.

Commercial UAV Expo

At the CUAV Expo, thermal imaging system specialist FLIR announced that it has updated its latest airborne camera with data collection and in-flight controls for unmanned systems.

The Vue Pro thermal imaging camera has a resolution of 640 x 512 pixels, and is intended for unmanned aircraft, adding a simplified interface providing power and data links through a single ten-pin mini-USB connector to save space and reduce the weight to 120 g.

Adding a Micro SD card interface allows for collection of 8-bit thermal imaging video in either motion JPEG (MJPEG) or H.264 formats, as well as 14-bit still images for mapping and survey applications. The data can be accessed after the flight directly from the card or via the USB interface.

FLIR has also added an accessory port to give users direct control of camera functions such as changing the colour palettes of images, starting and stopping recording, and the camera's e-zoom, while the platform is in flight. MAVLink compatibility and an RS-232 serial interface allows the camera to interface easily with the standard flight control systems used for mapping, survey, and precision agriculture missions. It also

FLIR's Vue Pro camera comes with data collection and in-flight controls

Aeryon's SkyRanger is to have TrellisWare's MANET radio technology integrated into it

means the images and video can be automatically stamped with the location of the UAV.

"Vue Pro builds on the original Vue and puts even more thermal imaging functions and greater flexibility in the hands of small UAV operators," said Jeff Frank, FLIR's senior vice-president for product strategy.

The camera can be set up via a Bluetooth wireless link to an app running on an Apple or Android smartphone.

UAV maker Aeryon Labs has teamed up with TrellisWare Technologies to provide low-latency, high-reliability video links from its unmanned aircraft.

TrellisWare's mobile ad-hoc network (MANET) radio technology will be integrated into the Aeryon SkyRanger as an airborne communications relay node. "Through our work with TrellisWare we are acting as an airborne node on the TrellisWare network, providing 'over the horizon' line-of-sight comms links," said David Proulx, vice-president of product and marketing at Aeryon Labs. "The maximum distance between any two nodes on the Trellisware MANET is 26 miles."

The 8 Mbit/s TrellisWare IPv4 and IPv6-compatible network allows eight channels of video to be viewable by every user with an enabled Android device or PC, and has an audio latency of under 275 ms for a single hop and under 400 ms for four hops. In addition, the network allows the terminals to extend the UAS control link via these hops.

The TW-600 Ocelot embedded module provides pin-header interfaces for analogue audio, USB data and module control, as well as simultaneous voice, video streaming and position location information. In the network, Ocelot has the ability to act as a network relay to send and receive IP data. The 2 W module measures 3.4 x 2.1 x 0.9 in and weighs 3 oz. It works on the 1775-1815 MHz and 2200-2250 MHz bands.

SkyRanger is a quadcopter that can be operated remotely or autonomously via a programmed flight path, and all the payloads have independent stabilisation and are 'hot swappable' for quick changes while in operation. A smart battery and charger means flight time and battery minutes are displayed at all times, and the system returns home and lands automatically if user-configurable limits are reached.

It also includes intelligent fault handling that automatically detects potential problems by monitoring battery levels, in-flight wind speeds and other system and environmental conditions, and has a configurable automated response behaviour such as the return-home-and-land routine.

InterDrone

At InterDrone, Qelzal showed its Qelsafe aircraft avoidance system, which it says uses brain-inspired engineering for a different approach to helping UAVs detect other aircraft. Its vision sensors subtract the static background from the image to highlight movement.

"One of the key things we have is special vision sensors that work on the millisecond scale, but to use them you need different processing than conventional machine vision," said Olivier Coenen, Qelzal's co-founder and CEO. It works using a regular CMOS sensor with additional processing, which reports changes in the world, and which is similar to how our eyes work.

Qelzal's system reacts 1000 times faster than a conventional system. This is achieved by making use of the sparse inputs obtained from the vision system using a conventional computer for the processing. Brain-inspired hardware may come later in the future to further speed up complex processing.

To compete with conventional machine vision Qelzal targeted a market such as that for UAVs with specific needs and constraints where one cannot simply add more computational resources because the UAV payloads are limited by size, weight and power.

The Qelsafe system is Qelzal's first product that detects low-flying aircraft in a range of difficult lighting conditions, for example when a plane is in front of the sun.

The Qelsafe avoidance system works in a similar way to human vision

The Altus LRX uses a variety of rotors for lift, stability and responsiveness

Altus Unmanned Aerial Solutions has launched a long-range version of its unmanned platform.

The Delta LRX has three times the flight time of the existing platform: 25-35 minutes at 27 mph with a 3.5 kg payload, using a patented 'stagger-prop' technology. This uses a combination of large and small diameter rotors mounted to different motor types running at different speeds in a wingspan of 180 cm.

Low-rpm motors with large diameter propellers provide the bulk of the lift efficiently, while high-rpm motors driving shorter propellers provide stability and responsiveness. These are powered by a 22,000 mAh lithium-polymer battery.

These multi-rotors are in an 'X-8' configuration to give high tolerance to wind and buffeting. The X-shaped arms with rotors above and below also enable the aircraft to continue safe flight after individual and even multiple motor failures.

The LRX has also been upgraded with dual autopilots, each with its own IMU and GPS antenna, and each monitors the other's system health, telemetry and accuracy. These are configured in a master-slave arrangement.

It also includes Altus' patented ballistic emergency parachute, which is able to catch the weight of a falling multi-rotor from as low as 25 ft.

Commercial UAV Show

At the CUAV Show, UK start-up Altitude Angel announced that it is using cloud computing to provide a highly responsive database of the movement of UAVs and any obstacles they might face anywhere in the world in order to minimise any collisions.

The team has extensive experience of building scalable systems for the Internet of Things, where data from millions of sensors has to be collected and acted on in real time. The system already contains tens of millions of ground hazards (ranging from power infrastructure to schools), and also pulls in airspace restrictions, weather and space data such as solar flares that can affect the operation of a UAV, all of which is continuously monitored.

The technology requires each UAV to have a unique identifier, which can be provided securely by Altitude Angel or another trusted source, which is then tracked by the system using the craft's GPS. Communication to the cloud is either directly from the UAV or via a mobile phone connected to a remote ground station. Every flight is automatically assigned a globally unique reference number, and operators can optionally associate their own additional data to help monitor the activity of the craft.

The company aims to provide updates on potential risks from other craft (including manned aviation), obstacles and weather to the operator or to the UAV directly with sub-second response times. The cloud infrastructure has built-in fault domains that can switch over within 1 s to minimise risk associated with server outage, while there is triple redundancy on the storage and dual redundancy on the computing resources to ensure that there is always data available to the UAV or operator.

Any software or hardware vendor in the world can make use of Altitude Angel's system to improve the situational awareness of their UAV or UAV fleet, and easily integrate advanced capabilities including collision mitigation and avoidance.

The prototype system is currently being tested, and the company plans to release its application programming interface (API) to makers of fixed-wing, rotary and hybrid UAVs for free to integrate with the control, autopilot and GPS sensors. This could potentially allow the system to instruct a UAV to avoid a restricted area, take evasive action, loiter in one place or even ground it safely to avoid it becoming a risk to people or other aircraft.

The company is also working on an API that would provide a virtual beacon for every UAV with an ID that could be accessed by other navigation systems to provide a collision detection infrastructure.

BAE Systems has developed a prototype collision avoidance system for unmanned aircraft. It uses a single high-resolution 5 megapixel CMOS camera with a high-quality Schneider lens, backed by a dual-core microprocessor running up to 2 GHz with a Gigabit Ethernet connection. It deliberately avoids the use of graphics processing units (GPUs) and quad- or octa-core processors as these are not certified for use in critical avionics systems.

One core of the Intel i5-class processor is dedicated to running the motion detection algorithm via the camera (running at 5 Hz), which can detect and track objects up to 4 km away. This gives a reaction time of 10-15 s at a closing speed of 500 knots. The system identifies objects in the air – against the background of the sky – and tracks them. Objects that move like aircraft are tracked, while others such as birds are ignored, although there is an alternative use for the system to detect possible imminent bird strikes on passenger aircraft.

The other processor core can be used for weather detection using the camera running at 1 Hz. This algorithm is driven by the colour of the clouds, and can track cloud features, particularly rain and ice, up to 15 miles away. This can give the unmanned system or a remote operator more information for taking evasive action.

One issue for installing cameras around an unmanned aircraft is the weight. Holes in the airframe to mount them actually increase overall weight, as the holes have to be supported, so three arrays of 30 sensors is lighter than five separate arrays of five sensors, for example.

The system is also being combined with an onboard map database of safe areas to land in real time. This takes into account the glide path and any potential known obstructions, and tells the image array where to look for temporary obstructions such as vehicles, people or animals that may be in the way.

All this was part of the Astraea European project that finished in September 2015.

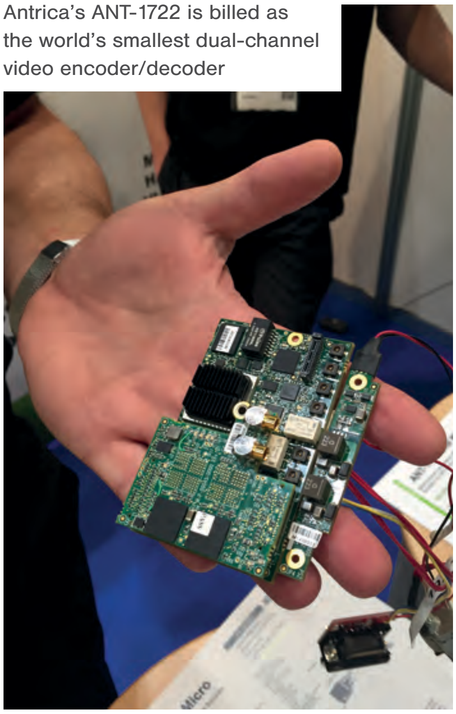
Vulcan UAV has developed a prototype craft, the AirLift 2, which it says will have a flight time of up to 30 minutes with a 30 kg payload, making it suitable for heavy-lift applications such as wire pulls for power line replacement, maritime search and rescue, bathymetric Lidar, and transporting ground-penetrating radar and other heavy sensors and payloads into hard-to-reach places.

The design includes a new generation of 8 kW brushless motors from KDE, which use KDE's new self-adjusting bearing system aimed at significantly increasing the lifetime of the motors beyond the current 50-100 hours. The aircraft is powered by four 22,000 mAh 12s lithium batteries.

The AirLift 2 platform is undergoing test flights towards the end of 2015, with certification testing in 2016.

Antrica has launched a multi-channel video encoder for airborne and ground unmanned system encoding and streaming applications over IP. It is billed as the world's smallest dual-channel H.264 HD/SD encoding or decoding solution, weighing less than 43 g.

The ANT-1772 Micro consumes less than 4 W of power for 1080p30 encoding plus simultaneous PAL/NTSC encoding. It provides simultaneous low-latency streaming of two sources from HD-SDI and analogue composite video signals, together with two-way serial data, audio and Micro SD card recording onboard.

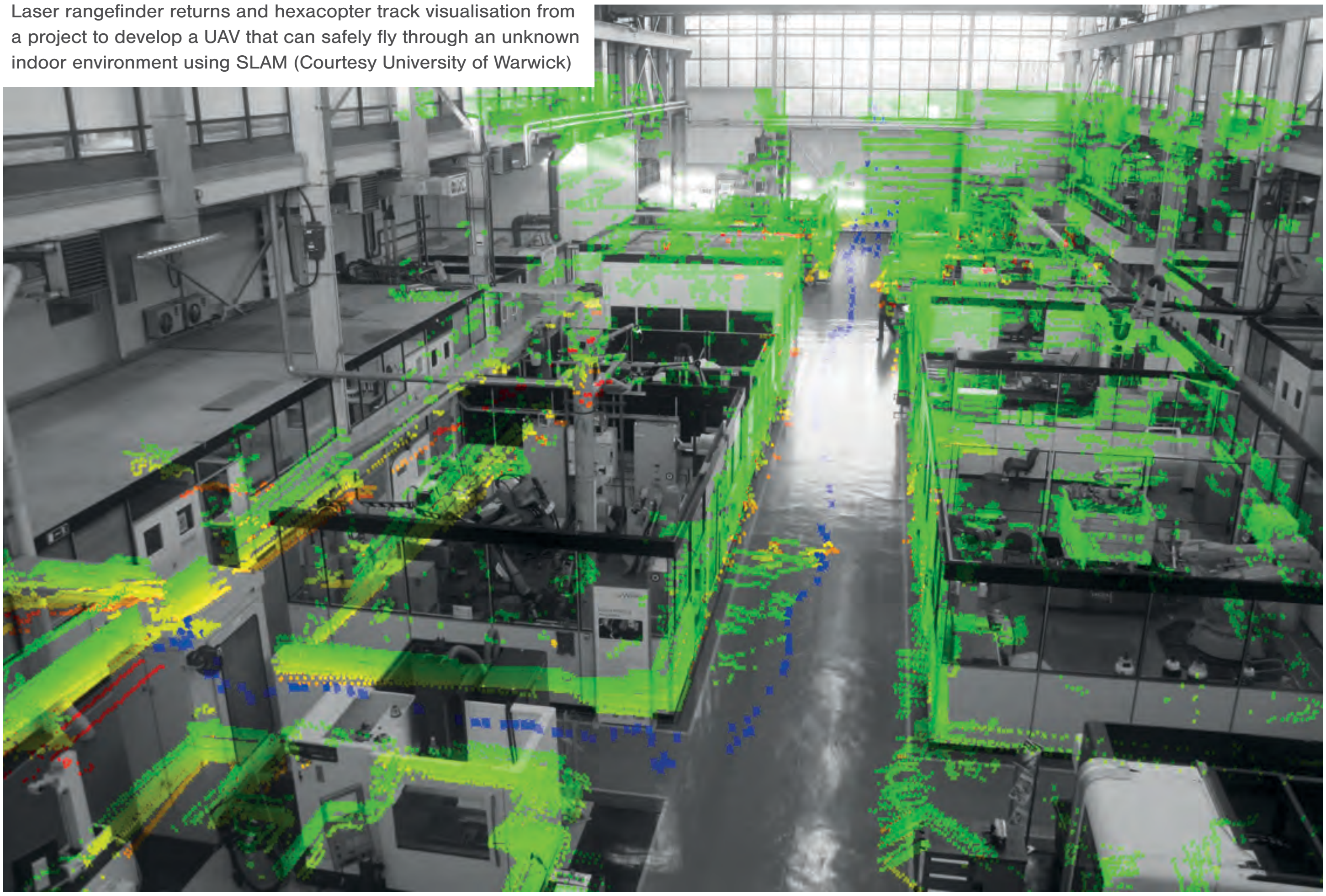

Antrica's ANT-1722 is billed as the world's smallest dual-channel video encoder/decoder

The 45 x 45 x 18 mm board can be integrated easily into a UAV design and offers extended temperature and voltage range for operation. As well as encoding, the unit can act as a hardware decoder with HD-SDI, Micro HDMI and composite outputs.

"Antrica has been providing an extensive range of video encoding and decoding solutions to a variety of applications and markets for over 15 years, but this is Antrica's first solution specifically designed for the UAV market and meets new standards for miniaturisation," said Les Litwin, sales director of Antrica.


Vulcan UAV says its AirLift 2 will carry a 30 kg payload and have a flight time of up to 30 minutes

Laser rangefinder returns and hexacopter track visualisation from a project to develop a UAV that can safely fly through an unknown indoor environment using SLAM (Courtesy University of Warwick)



The way ahead

Peter Donaldson reports on an emerging technique for enabling an unmanned system to find its way safely around an unknown area

Simultaneous localisation and mapping (SLAM) has been called a chicken-or-egg problem, but that particular conundrum has been solved – there were eggs for millions of years before chickens evolved. SLAM is a much harder problem though, because it requires an unmanned vehicle to enter an unfamiliar area, create a map from sensor data – and at the same time use it to find its way around that area without crashing into anything.

Requiring a vehicle to proceed from the doubly uncertain state of not knowing where it is or where any landmarks are might seem perverse in an age of satellite navigation and digital maps, but autonomous systems that must operate underwater, indoors, underground or in environments otherwise deprived of navigation signals and reliable maps face exactly this problem.

The term SLAM was first coined 20 years ago, at the 1995 International Symposium on Robotics Research, so the technology has had time to mature somewhat. Furthermore, because there are SLAM features in the latest version of iRobot's Roomba autonomous vacuum cleaner, it may be said to have been partially domesticated, but there are still applications out there 'in the wild' that demand smarter, faster, more reliable and less computer-intensive algorithms than are yet available – and there is no one-size-fits-all solution. So now is a good time to look at the state of the art.

As well as the dual uncertainty about the position of the autonomous system and surrounding landmarks, SLAM algorithms also have to cope with measurement errors inherent in devices such as wheel odometers, inertial measurement units, radars, sonars, laser rangefinders and so on. With an active range measurement device, such as a laser rangefinder, Lidar or sonar, a measurement might be caused by a beam reflecting off an obstacle, but might also be an error caused by crosstalk in the circuits, the beam reaching its maximum measurement range, a moving obstacle, multi-path interference and so on, all of which must be allowed for.

There is also the knotty problem of data association – the assignment of observations to landmarks. In general, multiplying the number of observations by the number of landmarks gives the number of possible associations; choosing the wrong data associations though can be disastrous.

As a vehicle moves though its environment making observations, it will observe the same landmarks multiple times, so the computer must have a reliable means of telling whether it is seeing one landmark from two different angles, for example, or two different landmarks – with no map other than the one it makes as it goes along. This is hard enough in laboratory conditions, but real-world landmarks have a habit of looking different from different angles, compounding the problem.

Mathematics of uncertainty

SLAM relies on the mathematics of uncertainty pioneered in the 18th century by English clergyman Thomas Bayes, whose work was edited and published by his friend Richard Price and developed by French mathematician Pierre-Simon Laplace. Bayesian mathematics deals with probabilities, recursively refining the probability that observed effects have a particular cause. In SLAM, the unknown

With its 'intelligent visual navigation', which uses information from a laser sensor, the Roomba 980 brings SLAM technology to domestic appliances (Courtesy of iRobot)

The mathematical tools at the heart of SLAM algorithms are known as filters, all of which have their strengths and weaknesses

cause is the autonomous system's real position in space, and the effect is an observation it makes of a landmark at a particular relative range/bearing combination at a particular time.

This echoes Bayes' original thought experiment in which he sought to deduce an unknown (the position of a ball on a table) from a series of observations – the relative positions of other balls rolled subsequently onto the table. Crucially, he started with the hypothesis that the original ball was equally likely to be anywhere on the table.

In his thought experiment, Bayes could not see the table and so relied on an assistant to report whether each new ball landed to the left or right of the original. If all the balls landed to the left, he could be confident that the original was near the right-hand edge of the table, and vice versa. If there was an even left-right split, he could be pretty sure the first ball was in the middle. With each new report of a relative position he made a more educated guess about the position of the mystery ball, and used that as the starting point – the prior – for the next guess, using this recursive process to increase his confidence in the estimated position, which he called the posterior.

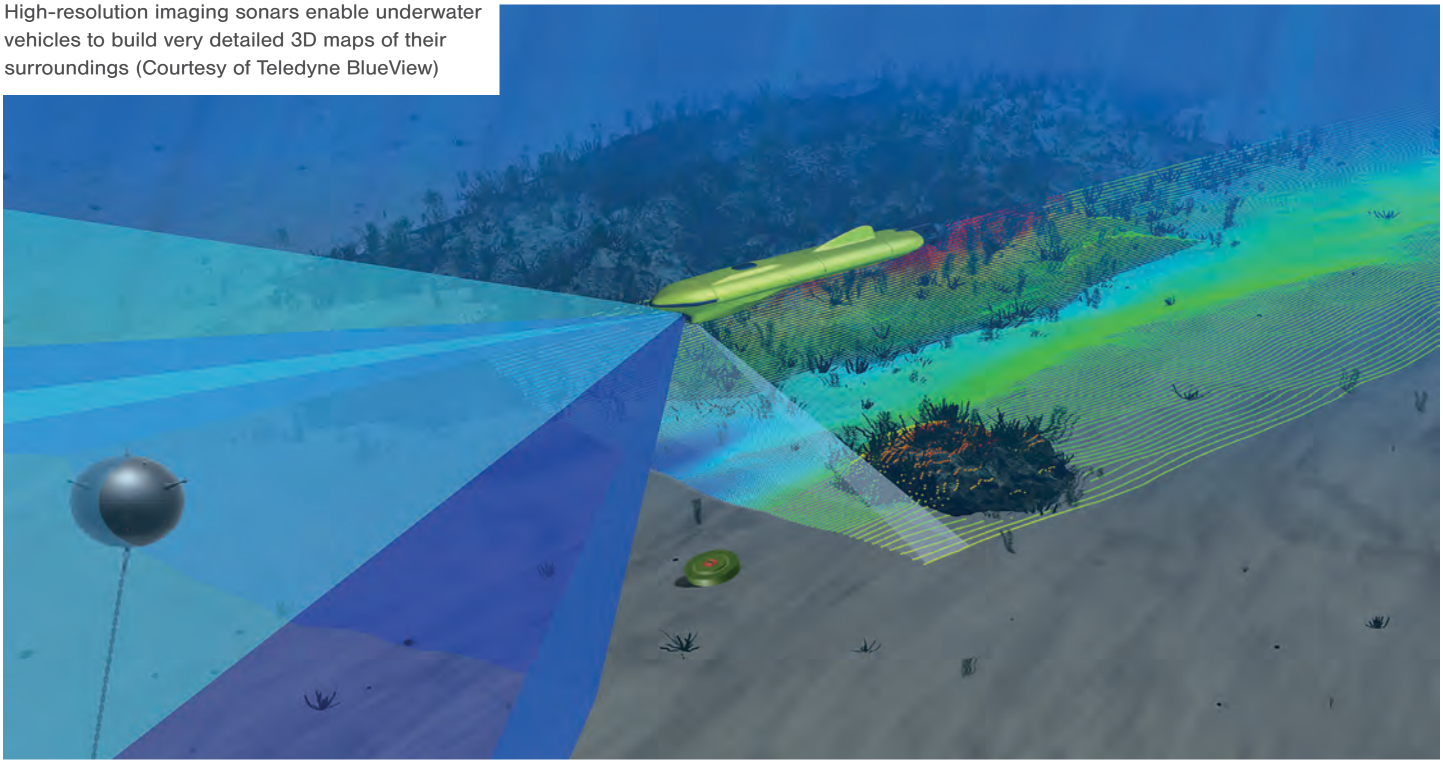
The mathematical tools that refine this process, and which all SLAM algorithms have at heart, are known as filters, and include several varieties of Kalman filters (including information filters) and particle filters, all of which have their strengths and weaknesses. Kalman filters are used in an enormous variety of applications, particularly in the areas of guidance and control.

Crunching vectors

As the autonomous system moves and takes observations, the SLAM algorithm defines four key parameters for a given instant in time, which can be called 'now'.

The first is the state vector, meaning the vehicle's location and orientation (also known as its pose). The second is the control vector, which is the command applied in the previous instant to drive the vehicle to where it is now. Third, it defines a vector that describes the position of a landmark, which is assumed not to move. Lastly it defines an observation from the vehicle of where that same landmark is now. It also builds up a history of vehicle locations and control inputs, the set of all landmarks and the set of all landmark observations.

Although this requires a lot of number crunching, the estimated positions of all these landmarks correlate because of a common error in the estimate



High-resolution imaging sonars enable underwater vehicles to build very detailed 3D maps of their surroundings (Courtesy of Teledyne BlueView)

of the vehicle's location. This means that even though the absolute positions of the landmarks may be uncertain, their positions relative to each other are known quite accurately. And the more these correlations grow with new observations from different locations, the more accurate the solution.

Then, by effectively turning the problem on its head and assuming it knows with certainty where the landmarks are, the SLAM algorithm can produce increasingly accurate estimates of where the vehicle is in relation to them.

This is another aspect of Bayesian logic, in that it can predict a system state, such as a vehicle position, from an observation and predict that it will make a particular observation based on a 'known' system state. For example, "If I can see that tree 10 m that way then I must be here", or "If I am here then I should be able to see that tree 10 m that way". This is a prime example of an ability that comes naturally and easily to humans but not to machines.

In 2006, robotics scientists Hugh Durrant-Whyte and Tim Baily wrote, "The most important insight into SLAM was to realise that the correlations between landmark estimates increase monotonically as more and more observations are made. Practically, this means that knowledge of the relative location of landmarks always improves and never diverges, regardless of robot motion."

A key insight into SLAM was that knowing the relative location of landmarks always improves and never diverges, regardless of robot motion

Refining the Kalman filter

An algorithm such as a Kalman filter-based SLAM algorithm can be thought of as a mathematical model of how some portion of the real world works and, like all models, it has to make some simplifying assumptions, which are embodied in its main components.

In a Kalman filter, these include a matrix that describes how the autonomous system's pose changes over time if it is not deliberately altered by a control input or affected by 'noise'. (For example, a UGV sitting on a flat, stable surface won't go anywhere, but a helicopter might be blown by the wind.)

A second matrix – the motion model – describes how control inputs change the system state, while a third – the observation model – describes how to map the state to an observation, or predict an observation from a known state. Also included are random variables representing likely process and measurement errors or noise.

Crucially, Kalman filters assume that the measurement errors they must account for and the distribution of probable system states (landmark locations and the autonomous system's position) follow a 'normal' bell-curve distribution on a graph, also known as a Gaussian distribution. They also assume that the motion and observation models are linear functions.

However, the real world is always much more complex: the curve might look like a bell that has been hit with a hammer and have a very irregular shape, while vehicles might respond to commands or environmental disturbances such as gusts of wind in a non-linear fashion. In these circumstances, assumptions of linear responses and normal distribution can lead to large errors; Kalman filters do not cope well with non-linear functions.

The best choice of algorithm for a particular environment depends on factors such as the time available for processing

Cheating non-linearities

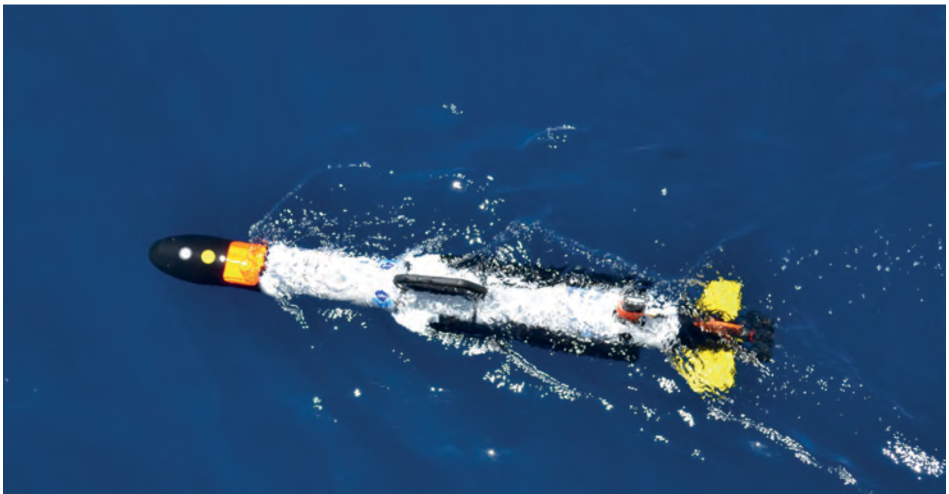
The Extended Kalman Filter (EKF) gets around this with a technique called local linearisation, which essentially involves fitting a straight line as closely as possible to an awkwardly shaped distribution curve, passing through the mean point and then proceeding as an ordinary Kalman filter would. This works quite well in practice if most values are fairly close to the mean, but not so well if they don't, and it also means that new linearising calculations have to be carried out at every point in time, adding to the processing overhead.

Local linearisation is only a partial solution, however, as the EKF can still be tripped up by large non-linearities. It is also relatively slow in computing large maps with lots of landmarks because every measurement the vehicle makes affects everything else, so update calculations can take a lot of time.

A variant called the Compressed Extended Kalman Filter (CEKF) gets around this to an extent by storing information from a small local area, then transferring it to the rest of the map at a lower total processing cost than an EKF.

The strangely named Unscented Kalman Filter (UKF) simplifies things by basing its calculations on a carefully chosen set of sample points from the original bell-curve distribution of probable positions for the autonomous system. One technique involves running them through a non-linear function such as one that describes the way the system responds to a motion command, and computing an updated bell-curve distribution to provide a new best estimate of where the autonomous system is. The UKF is much more accurate than the EKF, but is also slow to update when dealing with large numbers of landmarks.

The information filter is another variant of the KF, one that avoids linearisation problems by using information vectors and information matrices. It can provide more accurate position estimates, and is considered more stable than the EKF, but it can run into computational trouble during update steps when applied to non-linear systems.



Cut off from GPS and potentially all external sources of navigational information, UUVs such as this one are likely to rely heavily on SLAM in the future (Courtesy of NOAA)

Distorted bell curves

All varieties of KF, however, can only deal with Gaussian distributions; to deal with more chaotic real-world probability distributions – those that look like badly dented bells – SLAM algorithm developers are turning to particle filters.

Sampling techniques are very good at choosing representative samples from Gaussian distributions, so particle filter algorithms take advantage of this by using 'importance sampling', a technique that allows sampling from a normal bell curve overlaid on the messier distribution of interest, attaching a higher weighting to samples from areas where the two are very different.

Every sample can be seen as a state hypothesis – a possible state the system may be in regarding the unmanned ▶

vehicle's probable position after a non-linear response to a command or that of a landmark after an observation, for example. To determine the probability that the true state is within a small region, the algorithm looks into that region and counts the samples. The more there are or the higher their weighting, the higher the probability that the true state lies within that area.

One disadvantage with this approach though is that a very large number of samples might be needed to represent the probability distribution properly if there are large areas of uncertainty, which imposes high computational costs.

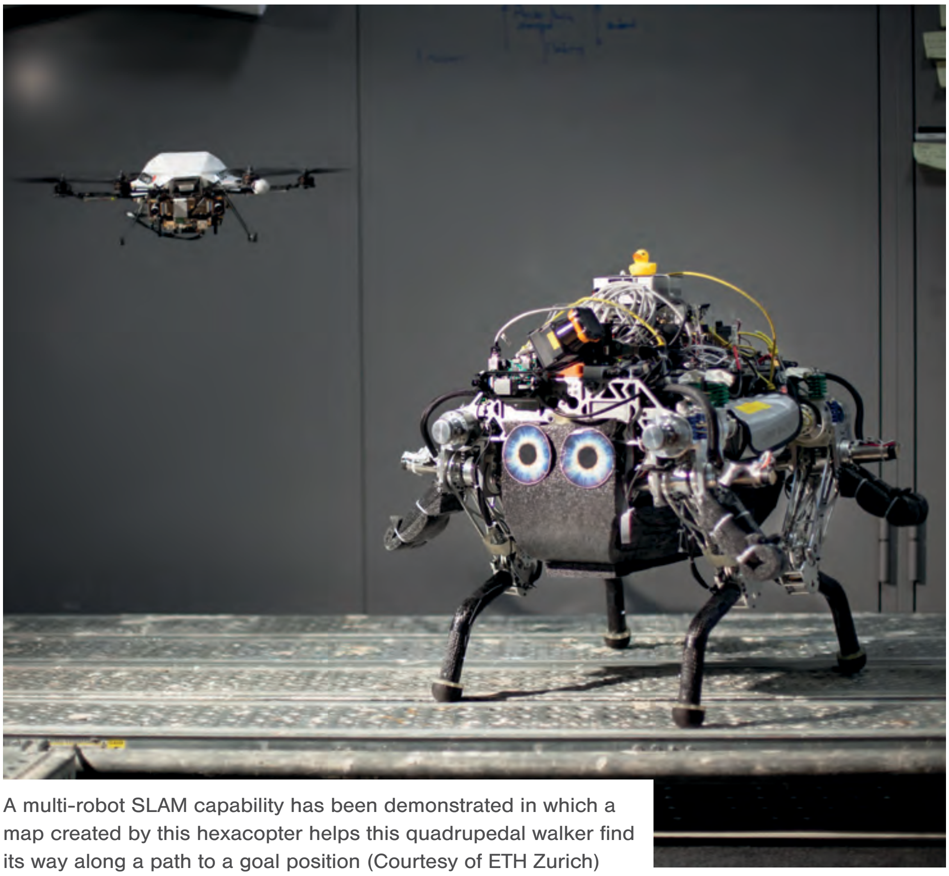
As this extremely brief glance at different flavours of SLAM algorithm suggests, the best choice for a particular environment depends on several factors including hardware limitations, the size of the environment the autonomous system must map and navigate, and the time available for processing. Large areas with many landmarks still present problems, which can be addressed by making smaller sub-maps and stitching them together later, but this relies on robust data association, which is another important area for improvement, according to a recent academic review of current approaches to SLAM.

Multi-system SLAM

A lot of current r&d work is focused on multi-vehicle SLAM, in which pairs or larger teams collaborate to find their way around an unknown environment. For example, a team from the Autonomous Systems Laboratory at ETH Zurich, Switzerland, has developed collaborative navigation in which a small UAV helps a four-legged walking robot.

In one demonstration, available on video, the walker must find and follow a safe path from the start area to the goal position. Before the quadrupedal robot takes a step, a hexacopter with a camera flies over the mission area to track visual features for SLAM, produce a consistent map of the landmarks and create a high-resolution elevation map of the environment.

The walker then prepares to navigate with the help of the hexacopter data, analysing the elevation map for slope steepness, local roughness and maximum step height. Based on the resulting 'combined traversability map', the team's navigation planner finds a path to the goal position.



A multi-robot SLAM capability has been demonstrated in which a map created by this hexacopter helps this quadrupedal walker find its way along a path to a goal position (Courtesy of ETH Zurich)

> A lot of current r&d work is focused on multi-vehicle SLAM, in which pairs or larger teams collaborate in an environment

The quadruped produces accurate estimations of its state by fusing signals from position encoders in its joints and an inertial measurement unit, and processing image data for localisation. It also continuously updates the elevation map with measurements from its laser rangefinder, checks the route for safety, and senses and avoids new obstacles.

A video of this shows the walker safely navigating along a narrow raised metal path, around tight turns, avoiding a box placed in its path after it started its journey and down a ramp to the goal position. Because the walker was provided with an initial map by the hexacopter, some observers might consider that it did not conduct a real SLAM task; however, the overall system formed by the pair of autonomous systems did.

Cooperative search and rescue

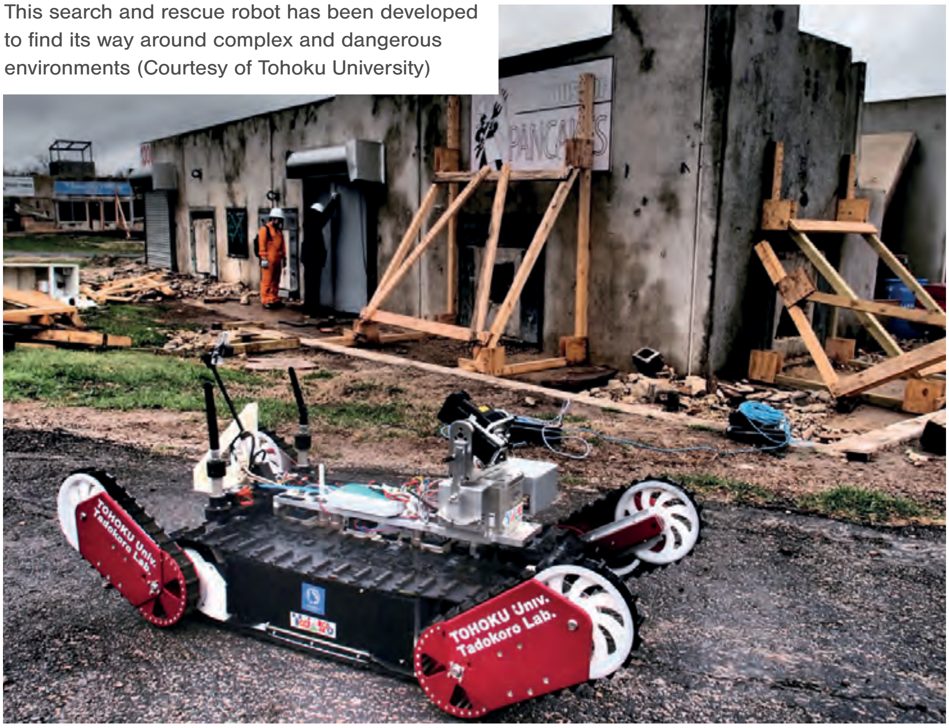
Urban search and rescue operations attending a natural or man-made disaster could benefit greatly from teams of autonomous systems that can cooperate effectively using SLAM to find their way around, building their own maps as they go and then merging them into a more comprehensive map when they meet, or get close enough to communicate.

To merge their maps accurately, of course, each system needs to know its own poses accurately in relation to the coordinate system of the shared map. Using particle filter-based SLAM algorithms in each system, this has been shown to work efficiently with up to six vehicles.

For example, a team in Germany from the Nuremberg Institute of Technology and Julius Maximilian University in Würzburg has demonstrated a SLAM approach applicable to multiple autonomous robots, which uses 2D Lidar sensors to build a dynamic representation of the environment. The team's SLAM algorithm uses signed distance functions, which are increasingly useful in machine vision because they contain the distances to the imaged surface for each 3D 'voxel', which is a kind of video pixel in 3D space, enabling the algorithm to estimate the sensor's pose efficiently.

In a successful 'loop closure' experiment carried out by the team, a single autonomous system – a rescue robot named Simon and equipped with a Hokuyo UTM-30LX Lidar – found its way around the first floor of a building and back to its starting point, a task made more difficult because the environment contained few distinctive features and several laser-unfriendly glass surfaces, and in which the start and end points were close together. In a second single-robot experiment designed to test the team's SLAM framework, reference laser frames from a data repository at the University of Freiburg were used, along with an image of the resulting map to validate the output of the software.

This search and rescue robot has been developed to find its way around complex and dangerous environments (Courtesy of Tohoku University)



To test its software with multiple robots, the team used a package called the ROS Simple Two Dimensional Robot Simulator installed on a PC with a quad-core processor to provide the simulated robots with artificial laser data. Starting at the same time, the four virtual robots – one for each processor core – successfully explored a labyrinth and built a map of their surroundings.

The team's next multi-robot SLAM experiment involved Simon and Georg, two real autonomous robots that explored separate parts of the same building, again using Lidars as their principal sensors. To validate accuracy, both robots' trajectories again contained loops that had to be closed. Both arrived back at their starting points at the same time and confirmed that the drift errors were very small.

In April 2015, the team also entered the robots for the RoboCup Rescue German Open competition, and won. In future work, the plan is to analyse the accuracy of the estimated trajectories using knowledge of the robots' real positions (known as exact ground truth) and to carry out a detailed timing evaluation.

Experiments like those described above strongly suggest that SLAM techniques will enable teams of robots to cooperate with one another and with humans to take on difficult and dangerous tasks, such as searching inside damaged buildings for casualties after major incidents. SLAM also promises greater robustness for military systems that currently rely on satellite navigation systems that could be attacked with jammers or even anti-satellite weapons in future conflicts. SLAM will be valuable even when GPS or other navigation systems are available, thanks to its ability to build and update maps and obstacle databases 'on the fly'.

As it's still only 20 years old, SLAM can't be described as fully mature yet, but it is getting smarter and potentially more useful by the day. Like many of today's advanced technologies, progress in SLAM comes from a deeper understanding of mathematics and logic expressed in software rather than hardware. Thomas Bayes and Pierre-Simon Laplace would be astonished to see where their logic has led – probably. ◻

"Now, here's a thing"

Many unmanned systems rely on mobile communications networks to operate their onboard systems, navigate, and send and receive information from their operators (writes Stewart Mitchell). There has been growing concern, however, over the global coverage, security and reliability of the current generation of networks, 4G, which could leave vehicles vulnerable to hacking or loss of control in parts of the world without network coverage.

It is timely therefore that mobile comms engineers have begun developing the next generation of networks, aptly named 5G, which is designed to address most of these issues.

How it will do so comes down fundamentally to using a much wider range of frequency bandwidths than those in 4G. With 4G, these are all under 6 GHz, whereas 5G will use frequencies from less than 1 GHz up to and beyond 40 GHz, allowing far more data to be transferred across each frequency, at a higher speed and much further. In theory at least, it will also provide uninterruptible coverage to more than 99% of the world, with latencies as low as 1 ms.

Making the networks secure will be achieved by embedding security codes in each bandwidth of the spectrum. The codes will be allocated to each device using a particular frequency according to their unique IP address. As the codes will be cloud computer-generated, there will be no physical host on the network for hackers to attack, meaning that the comms server will have no software identifier to re-code or interfere with.

> Security codes will be allocated to each device on a particular frequency according to their unique IP address

With its embedded security, overage and capacity, 5G will offer unmanned systems the potential to perform mission-critical services such as autonomous trade of goods and public transport.

When countries signal a desire to use autonomous vehicles on a commercial basis and trade with other countries, governing bodies will assign the operating companies a specific frequency on the 5G network to operate their fleet. Each vehicle will have to incorporate software that abides by local laws of the countries in which the vehicles are operating, but this should be a relatively straightforward task.

5G's development is underway in parts of the world including Asia and Europe, and is set to be implemented worldwide in 2020. So far, trials at a local level have demonstrated a data transfer capacity of up to 1 Tbyte/s at a range of 100 m.

5G will offer unmanned and autonomous vehicles clear advantages in efficiency, security and safety, and it will not be long after its implementation that it will allow some of the world's largest forms of goods and personnel transport to be completely unmanned.

Also, if a bandwidth has been allocated to a company operating a UAV then any other devices such as mobile phones that were on that bandwidth will be automatically moved off it. However, any such devices using 5G will be able to jump automatically between bandwidths, depending on their service supplier, the device's power and the service requirements of the device. This will determine the allocation per device, but something to consider as well is the tiny amount of data comms devices such as mobile phones actually require.

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