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While attractive, the idea of taxing robots that replace human labour ignores the complexities of defining them for tax purposes

Fake it to make it

The development of unmanned systems is undergoing a seismic shift, and its consequences are immense. The technologies to handle data from billions of devices around the world in the Internet of Things are also fundamentally changing the way unmanned systems are developed.

Just as computational fluid dynamics software running on supercomputers has supplanted wind tunnels, so data centres with thousands of processors and petabytes of data storage now simulate not only the software in vehicle controllers but the sensors, the vehicle and even the city it drives around. Simulation can even model the paint on a vehicle bumper and the impact that has on the performance of the radar system hidden behind it.

This combination of virtual models from the chip to the city allows a design to be operated in a simulation for millions of miles before it ever hits the road or takes to the sky, giving developers and regulators confidence that an unmanned platform has been tested in as many scenarios as possible. This also opens up more opportunities for developers of the models themselves, the city environments and the test software (see page 84).

But that capability comes at a price. Petabytes and even exabytes of data storage will be needed to handle the data from cameras, Lidar and radar sensors along with all the comms between hundreds of virtual vehicles in a city model.

What is certain is that the world of unmanned systems development will never be the same again.

Nick Flaherty | Technology Editor

Editorial opportunities

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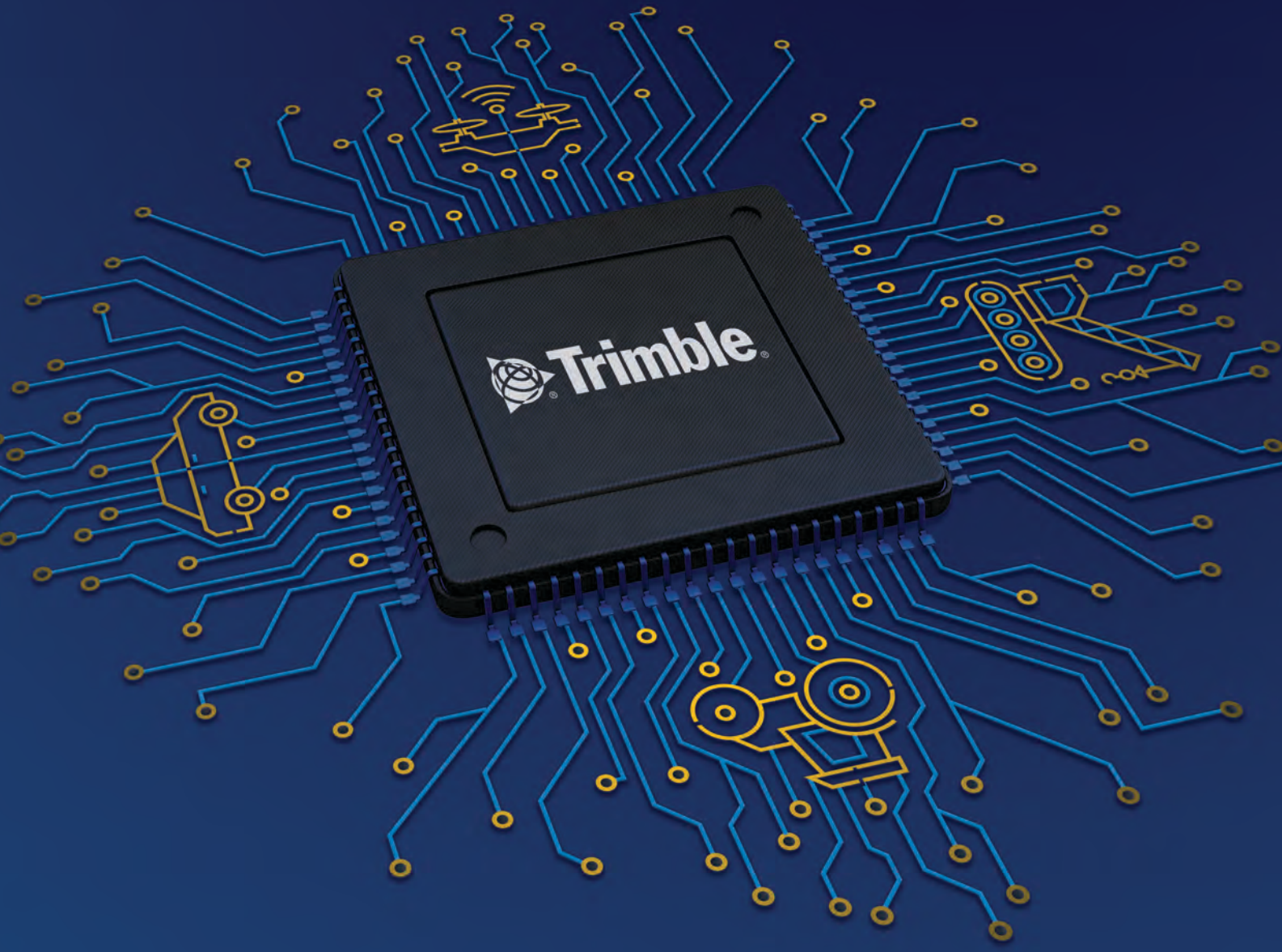
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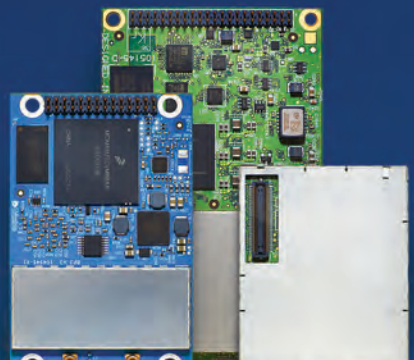
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Platform one

Mission-critical info for UST professionals

The Magma unmanned aircraft has no moving control surfaces



Future of flight control?

Airborne vehicles

Engineers at the University of Manchester and BAE Systems have developed a prototype aircraft that can be manoeuvred using supersonic air rather than control surfaces (writes Nick Flaherty).

The Magma UAV demonstrated two flow control technologies that can be used for platform designs in the future.

The first takes air from the aircraft's engine and blows it supersonically through narrow slots around a specially shaped feature on the tailing edge of the single wing to control the aircraft. This wing circulation control technique removes the need for moving control surfaces, allowing the airframe to be lighter and simpler.

The second technique, fluidic thrust vectoring, controls the aircraft by blowing air jets inside the nozzle to deflect the exhaust jet and generate a thrust that can be directed as an additional control mechanism.

The wing circulation and fluidic thrust vectoring exhaust control devices were made from metal using an additive manufacturing process that achieved a wall thickness of 0.5 mm.

The technologies could also improve an aircraft's stealth, as they reduce the number of gaps and edges that currently make aircraft more observable on radar.

"This is part of a long-standing effort to change the way aircraft can be controlled, going all the way back to the invention of wing warping by the Wright brothers," said Bill Crowther, leader of the Magma project at The University of Manchester.

"We made our first fluidic thrust vectoring nozzle from glued-together bits of plastic nearly 20 years ago, and tested it on a hairdryer fan. BAE Systems is 3D-printing our components out of titanium, and we are flight testing them on the back of a jet engine in an aircraft designed and built by the project team."

UAV recharges during flight

Airborne vehicles

Florida-based Aergility has unveiled a design for a UAV that uses a patented form of managed autorotation to recharge its batteries during flight (writes Rory Jackson).

"The Atlis is essentially a cross between a multi-copter and a gyroplane," said James Vander Mey of Aergility. "It takes-off like a multi-copter, using some battery electricity to power the eight electric motors.

"After the transition into forward flight, which is powered by a rear-mounted gasoline engine, the flight controller adjusts the aircraft's pitch, roll and yaw attitude via the speed of the electric motors. And it does that in a way that the rotors operate near autorotation."

Doing that means the amount of power collectively consumed by the electric motors is either zero or near zero throughout horizontal flight. The battery pack is recharged during flight by driving the pitch upwards slightly past the autorotation point to have the motors being driven by the airstream (thus using them as generators).



Aergility's Atlis is a cross between a multi-copter and a gyroplane

A 25% scale model was on display at the company's stand at AUVSI Xponential 2019, and the full-scale UAV is expected to have a 385 kg MTOW, while offering 180 kg of payload and fuel capacity, a cruising speed of 160 kph and a fuel consumption rate of 15-19 litres/hour.

"We've been developing this for four years, and have a year's worth of testing this physical model. We had to develop a flight controller from scratch because of all the lessons we're learning as we develop it," Vander Mey said.

Development of the full-size prototypes is expected to begin later this year. It will take roughly 18 months to complete the engineering, tooling, construction and initial flight testing.

Kit boost for SLAM codes

Control systems

Digital signal processing specialist Ceva has launched a software development kit (SDK) to accelerate the development of simultaneous localisation and mapping (SLAM) algorithms on its hardware (writes Nick Flaherty).

The Ceva-SLAM SDK combines the hardware, software and interfaces required to enable an efficient SLAM implementation into a wide range of autonomous control systems. It includes a detailed interface from a processor core to offload the SLAM blocks to the Ceva-XM6 digital signal processing (DSP) core.

These building blocks support both fixed- and floating-point processing to extend the device's battery life. They include capabilities for image processing such as feature detection, feature descriptors, feature-matching and linear algebra with matrix manipulation and linear equation-solving.

This enables a full SLAM tracking module to run on the Ceva DSP at 60 frames/second with a power consumption of only 86 mW. The SDK can also be used with Ceva's NeuPro machine learning accelerator cores.

It also includes the Ceva-CV standard library of OpenCV-based functions for vision processing, optimised for the Ceva-XM and NeuPro. This uses pre-optimised kernels for target applications, speeding up development.

The Ceva-VX software handles all the system resource requirements, including data transfers, memory transactions and kernel execution, abstracting the system architecture and automating frame handling.

There is also a real-time operating system scheduler that handles task prioritisation and switching, as well as a link driver that manages the comms channels and system drivers to abstract the CPU-DSP interface and enable automatic task offloading from the CPU to the DSP.



The Almaz-Antey VTOL interceptor is based around a gas-operated shotgun

Taken down by a 12-gauge

Airborne vehicles

Guided weapons supplier Almaz-Antey has patented an anti-UAV aircraft built around a 10-shot semi-automatic shotgun (writes Peter Donaldson).

The tail-sitting electric VTOL interceptor UAV is a 23 kg, 3 m span fixed-wing, twin-motor canard design, and was originally designed by a student group at the Moscow Aviation Institute (MAI).

The shotgun is a gas-operated Molot Vepr 12 that is patterned on a Kalashnikov assault rifle. It is carried within a fuselage that appears to be an aluminium alloy lattice reminiscent of the geodetic structure of a Wellington bomber used by the RAF in WW2.

This structure surrounds the shotgun from the muzzle to the rear of the action, and continues to the trailing edge of the wing. The 10-round magazine protrudes from the underside of the aircraft.

The weapon has had its stock and pistol grip removed, and is mounted in a recoil-absorbing/damping mechanism which appears to include a coil spring attached between the rear of the receiver and the fuselage structure.

Despite this mechanism though, the flight control system must be able to compensate for recoil, which is significant in 12-gauge shotguns. Autopilot compensation for muzzle blast interference with the canard foreplanes is also likely to be needed.

The trigger is operated by a servo, and there is a cut-out in the structure to allow spent cases to be ejected. It is not clear at the moment though whether there is a servo to cycle the gun's action in the air to clear a jam or a misfire, or if there are any means of operating the safety lever remotely.

Aiming is via a first person view camera on the nose, just above and behind the gun muzzle, although MAI implies that automatic target tracking software linked to the autopilot is included.

"The device takes shots in the automatic mode, continuing to fly along a given course, and if the target is not hit, the UAV can continue moving behind the object," the institute said.

The camera sends imagery to the operator via what appears to be a Chinese Inchang mushroom transmit antenna mounted on a stalk on the right-hand side, ahead of what seem to be the batteries.

These probable batteries are in two large, wedge-shaped packs mounted on either side of the fuselage ahead of the gun's magazine, and provide a claimed 40-minute endurance. They power two tractor propellers ahead of each wing's leading edge. Hacker A100-8 motors have a speed constant of 196 rpm/V.

Four crossbolts hold the carbon fibre wings to the fuselage, and two control surfaces on the trailing edge of each wing serve either as flaperons or the outer surfaces as ailerons and the inner ones as flaps.

The all-moving canard foreplanes that provide pitch control pivot through the structure behind the gun muzzle, while two large vertical stabilisers incorporate the fixed landing gear and the rudders.





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The Shelley autonomous Audi TTS being tested at Thunderhill Raceway Park in the US

Prior experience required

Driverless cars

Researchers at Stanford University have developed a way of controlling autonomous cars that integrates prior driving experiences to boost safety (writes Nick Flaherty).

Its machine learning algorithm is based around road-tyre friction data. It has been tested on a racetrack using Niki, an autonomous Volkswagen GTI, and Shelley, an autonomous Audi TTS. The system performed about as well as an existing autonomous control system and an experienced racecar driver.

"We want autonomous vehicles to work in many scenarios, from normal driving on high-friction asphalt to fast, low-friction driving in ice and snow," said Nathan Spielberg, a researcher in mechanical engineering at Stanford. "We want our algorithms to be as good as the best skilled drivers – hopefully better."

Instead of just relying on real-time evaluation of the environment, the new algorithm includes data from recent manoeuvres and past driving experiences, including trips Niki took around an icy test track near the Arctic Circle.

The road-tyre friction data dictates the limits of how hard the car can brake, accelerate and steer in order to stay on the road in emergency scenarios. If engineers want to safely push an autonomous car to its limits, such as having it plan an emergency manoeuvre in icy conditions, this data is essential; unfortunately it is highly variable and often difficult to predict.

The neural network for the controller integrates data from past driving experiences at Thunderhill Raceway in Willows, California, and a winter test facility that provided 200,000 physics-based trajectories.

"With the techniques available these days, you often have to choose between data-driven methods and approaches grounded in fundamental physics," said Christian Gerdes, professor of mechanical engineering at Stanford.

"We think the path forward is to blend these approaches in order to harness their individual strengths. Physics can provide insight into structuring and validating neural network models, which in turn can leverage massive amounts of data."

In comparison tests, Shelley first used a physics-based autonomous system, preloaded with information about the course and conditions. When compared on the same course during 10 consecutive trials, Shelley and a skilled amateur driver generated comparable lap times.

The researchers then loaded Niki with the neural network system. The car performed similarly, running both the learned and physics-based systems, even though the neural network lacked explicit information about road friction.

In simulated tests, the neural network outperformed the physics-based system in both high-friction and low-friction scenarios. It did particularly well in scenarios that mixed these two conditions.

"With so many self-driving cars on the roads and in development, there is a lot of data being generated from all kinds of driving scenarios," said Spielberg. "We wanted to build a neural network because there should be some way to make use of that data.

"If we can develop vehicles that have seen thousands of times more interactions than we have, we can hopefully make them safer."



UAV systems will be tested in urban environments as part of the UTM system over the next few months

City safety system due

Airborne vehicles

NASA is entering the final stage of testing its Unmanned Aircraft Systems Traffic Management (UTM) platform (writes Nick Flaherty).

UTM is an essential element in allowing safe beyond visual line of sight (BVLOS) operation of UAVs. NASA has been working on the technology for operations in a city, at an altitude of 200-400 ft, and the challenges of BVLOS in urban areas.

The system is based on the digital sharing of each user's planned flight details, giving them all the same situational awareness of airspace, rather than relying on ADS-B transponders to identify a UAV.

Tests in spring 2018 focused on technologies that will help keep UAVs at safe distances from each other and flying in their designated zones, detecting and avoiding other UAVs over moderately populated areas.

The final tests, from May to August this year, will study how the UTM system can integrate UAVs into urban areas. This has to address obstacles, various weather and wind conditions, reduced lines of sight, reduced ability to communicate by radio and fewer safe landing locations.

It will use more localised weather predictions in flight planning, cellular phone networks for UAV comms and data from cameras and radar to allow UAVs to manoeuvre around buildings and land when necessary.

For example, every UAV will need to know how to make a safe landing under unpredictable conditions, for example to make way for a fire department UAV responding to an emergency.

These landing spots can be pre-programmed but there's no way of knowing ahead of time if there will be a parked car or people standing there. One technology being tested allows a UAV to use its camera to detect pedestrians or vehicles and, if necessary, move on to the next safe place.

After August the research will be transferred to the Federal Aviation Authority to issue implementation guidelines.

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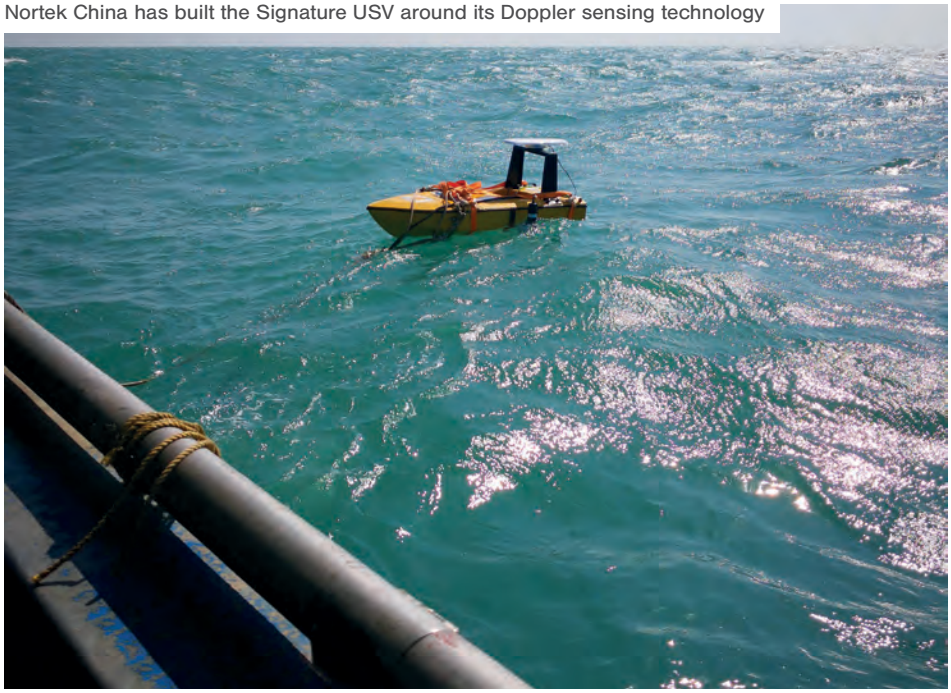
Instrumentation systems supplier Nortek has developed its own USV called the Signature VM that has an integrated Doppler sensor to measure water current and direction (writes Nick Flaherty).

Nortek develops acoustic Doppler instrumentation such as Doppler Velocity Logs, which are used for subsea navigation, and Acoustic Doppler Current Profilers (ADCPs), to understand physical processes in the oceans, rivers, lakes and laboratories.

For surveys in Asia, Nortek China has built the Signature around an ADCP sensor and a COTS controller. It has an industrial personal computer as the main controller and uses a remote control technique called Remote Desktop to communicate with all the instruments installed.

That means the vehicle allows users to carry out hydrology and water quality measurement while simultaneously obtaining water samples.

Nortek China has built the Signature USV around its Doppler sensing technology



The Signature VM measures 2 m x 70 cm x 40 cm and has two propellers that produce 80 lb of thrust. It can be controlled by a remote operator or programmed to sail by itself. The layout of the vehicle can be adjusted according to user requirements.

The next step in its development is to add a more powerful controller.

Quick-change power unit

Airborne vehicles

HFE International has updated its DA150 twin GenPod propulsion to streamline its integration into UAV airframes (writes Rory Jackson).

"We have a lightweight aluminium back plate on the GenPod, which is meant to be permanently affixed to the front or rear of the airframe," said HFE's Rob Shoemaker. "There are two latches on the top of the plate and a hook underneath to hold the engine pod system securely to the airframe.

"That enables a UAV manufacturer or technician to remove the whole engine unit from the airframe easily and quickly, for maintenance, inspection or repairs."

The ECU, fuel pump, ignition and other key components sit in the back of the GenPod, and have circular connectors for integration with an airframe's electronics. The DA150 also comes with dual decompression valves, which HFE has designed-in to reduce the size requirements of the starter/generator.

"That saves space, because otherwise we would need a very large alternator, which would limit the range of airframes the system could be integrated on," Shoemaker said.

The system displaces 150 cc and has a 500 W alternator as well as one spark plug per cylinder. During start-up, the power management unit will open the valves, and close them as soon as the engine is running at normal operation.

The updated DA150 GenPod comes with dual decompression valves to save space



USV-CAN servos unveiled

Airborne vehicles

Hitec Commercial Solutions has launched servo actuators for UAV designs that use the CAN bus (writes Rory Jackson).

"These servos specifically communicate in UAV-CAN," said Hitec's Shawn Spiker. "We've worked with engineers versed in the UAV-specific variety of CAN to come up with a standard protocol by which these servos can be plugged into a flight controller and immediately begin communicating data on position feedback, current, voltage and other information the servo can provide.

"There are multiple variants of the CAN protocol, but UAV-CAN works seamlessly with Ardupilot and PX4."

Among the UAV-CAN-compatible servos is Hitec's MD-series, which use 32-bit programmable digital circuits and magnetic encoder position sensors. The overall UAV-CAN servo line-up ranges in weight from 11.9 to 400 g, with torque ranging from 1.8 kgf-cm to 162.2 kgf-cm respectively.

> We've come up with a standard protocol so that they can begin communicating immediately



Hitec's servos are designed to communicate with UAV-CAN

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UGV has pulling power

Ground vehicles

Researchers at the Istituto Italiano di Tecnologia (IIT) in Italy have demonstrated a small hydraulic quadruped ground robot that can pull a 3.3 tonne aircraft (writes Nick Flaherty).

The HyQReal is 1.33 m long, 90 cm tall and weighs 130 kg. It is protected by an aluminium roll cage and a skin made of Kevlar, glass fibre and plastic, with custom-made feet made in special rubber for high traction on the ground.

A 48 V battery pack powers four electric motors connected to four hydraulic pumps. These use new actuators that were co-developed with Moog and allow the platform to be operated without the need for an umbilical line to provide power or control signals.

The robot has two computers on board, one dedicated to vision and the other to control, which are closely coupled to the new Moog hydraulic technology. The IIT adapted its locomotion control framework that it has developed over the past decade.

A new hydraulic system has allowed the IIT system to pull a 3.3 tonne aircraft



The system has been tested by pulling a 14.4 m Piaggio P180 Avanti passenger aircraft that weighs 3300 kg.

The long-term goal of the HyQReal project is to create the hardware, software and algorithms for robust quadruped vehicles for rough terrain that can be tailored to applications such as disaster response, agriculture, decommissioning and inspection.

"Pulling a plane allowed us to demonstrate the robot's strength, power autonomy and the design," said Claudio Semini, project leader at the IIT's Dynamic Legged Systems lab.

Pan-brand tether system

Airborne vehicles

Elistair in France has launched its fourth generation of tether system to provide power and comms to a UAV (writes Nick Flaherty).

The Ligh-T version 4 provides unlimited flight time to 20 of the most popular commercially available UAVs via a 230 m power line to a tether station on the ground.

The first version was released back in 2015 and has been used by police forces, private security and at industrial sites for surveillance. The feedback from these deployments fed into the design of v4, with Plug and Fly Air modules that support individual UAVs such as DJI's M200 V2, M200 V1, the Inspire 1 and 2, and the Yuneec H920. Data transfer is handled through a micro-tether attached to the main power line.

The micro-tether weighs 10.5 g/m and uses a newly developed dual-mode tether management system that controls the micro-tether's tension via a motor while allowing the user to manually wind and unwind it in case there is a power outage.

Housed in a rugged case with an open and accessible interface, the system is easily transportable so that it can be deployed quickly at a site such as a stadium. The T-Monitor software application has also been updated to allow full remote monitoring of the tether station's state during each flight.

Elistair's system allows quick deployment of a UAV at a site such as a stadium



Unmanned Systems Technology's consultants



Dr Donough Wilson
Dr Wilson is innovation lead at aviation, defence, and homeland security innovation consultants, VIVID/futureVision. His defence innovations include the cockpit vision system that protects military aircrew from asymmetric high-energy laser attack. He was first to propose the automatic tracking and satellite download of airliner black box and cockpit voice recorder data in the event of an airliner's unplanned excursion from its assigned flight level or track.

For his 'outstanding and practical contribution to the safer operation of aircraft' he was awarded The Sir James Martin Award 2018/19, by the Honourable Company of Air Pilots.



Paul Weighell
Paul has been involved with electronics, computer design and programming since 1966. He has worked in the real-time and failsafe data acquisition and automation industry using mainframes, minis, micros and cloud-based hardware on applications as diverse as defence, Siberian gas pipeline control, UK nuclear power, robotics, the Thames Barrier, Formula One and automated financial trading systems.

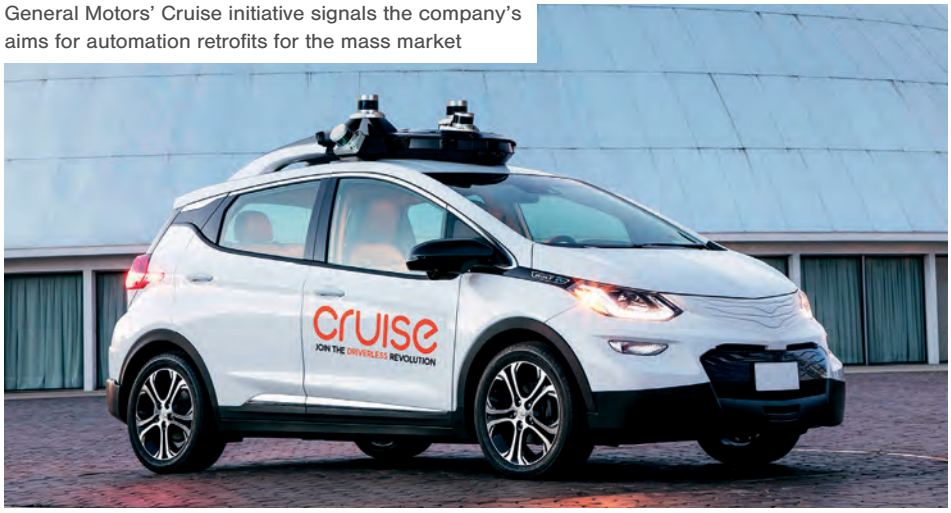


Ian Williams-Wynn
Ian has been involved with unmanned and autonomous systems for more than 20 years. He started his career in the military, working with early prototype unmanned systems and exploiting imagery from a range of unmanned systems from global suppliers.

He has also been involved in ground-breaking research including novel power and propulsion systems, sensor technologies, communications, avionics and physical platforms.

His experience covers a broad spectrum of domains from space, air, maritime and ground, and in both defence and civil applications including, more recently, connected autonomous cars.

General Motors' Cruise initiative signals the company's aims for automation retrofits for the mass market



Mass retro roll-out

Driverless cars

General Motors has applied for a US patent for a system for retrofitting automation to vehicles that were not originally designed for it (writes Peter Donaldson).

The idea is to enable the roll-out of autonomy much quicker and less expensive than through purpose-designed autonomous cars alone. While UGV kits have been developed for many vehicles going back at least to the DARPA Grand Challenge series, the fact that GM is doing it as part of its Cruise initiative and is aiming it at mass-market vehicles is significant.

The patent application details the system, subsystems and preferred embodiments with some variations. Core elements are a sensor suite, a central computer and interfaces for the steering, brakes and throttle, and the user.

With forward- and rear-facing cameras in a roof-mounted module, the sensor suite also includes radar and sonar sensors in the front valance, a GPS receiver and an inertial measurement unit.

While the autonomy software resides in the central computer, the heart of the system's ability to be adapted to existing vehicles is in the interfaces to the car's controls, which are controlled by the central computer.

GM's preferred embodiment of the throttle interface takes advantage of drive-by-wire technology by feeding an electronic signal into the throttle body.

The throttle interface includes a driver circuit that produces the throttle signal that imitates the accelerator pedal, for example, and a switching relay that allows the throttle interface to switch between the outputs of the driver circuit and the accelerator pedal.

The brake interface might include both a brake actuator and a pedal sensor. The actuator might consist of a rotary electric motor that presses the brake pedal by winding a steel cable around a spool, tightening the cable. This is an implementation that would also allow a human driver to add more brake pressure.

The steering interface also responds to inputs from the central computer, preferably applying torque to the steering column with one or more electric motors, with a means of disengaging them in case of a malfunction.

It could also include steering position and strain sensors, the latter providing a means of detecting when the human driver is trying to turn the wheel.

In all cases, the software would be designed to manage smooth transition between human and computer control.

AUVSI USDPS

Industry

Unmanned systems offer defence and security organisations a range of opportunities to trim their operating costs while removing personnel from potentially hostile environments, as well as gathering intelligence and reconnaissance data on such environments at a distance.

Advances in artificial intelligence, autonomous fleet management and machine learning are also poised to offer significant force multipliers for armed forces willing to invest in and work towards technological change.

Given these opportunities and technological advances, the Association for Unmanned Vehicle Systems International (AUVSI) is set to host USDPS (Unmanned Systems – Defense. Protection. Security) on August 20 and 21 at the Marriott Wardman Park convention hotel in Washington DC.

The event will bring military leaders, strategic experts and defence industry supply chain actors in contact with unmanned system developers.

It will also provide a forum for establishing connections, sharing concepts and gaining critical insights into how unmanned systems have evolved – and will continue to do so – to help security forces keep the peace in a time of rising hostilities and shrinking defence budgets.

The USDPS schedule includes a number of breakout sessions and solution showcases.

These will communicate to attendees the kinds of advances in defence-critical areas such as autonomy, artificial intelligence and UAV threat-tracking and mitigation.

They will also provide updates on how strategically important UAS, USV and UUV projects are progressing in their technological capabilities and degrees of maturity.

For more details go to **www.thedefenseshow.org/home**

InterDrone

Industry

The International Drone Exhibition & Conference (or 'InterDrone') remains one of the largest UAV trade shows in the world, and is returning to the Rio Hotel in Las Vegas from September 3 to 6 for its fifth iteration.

At the time of writing, more than 130 UAS manufacturers, suppliers and solution developers were listed to attend, with many more expected to have signed on by the end of the summer. As ever, the exhibition floor is expected to play host to a huge number of new product launches, orders, investments and r&d partnerships among start-ups and major aerospace and robotics corporations from around the world.

The conference programme is set to feature keynote addresses from organisations such as the FAA, NASA and Unicef on how UAVs are being adopted and integrated to better meet the needs of countries and markets around the world.

Also, specialised 'enterprise tracks' will offer insights into how UAVs can be used in critical industries such as construction, mining and infrastructure inspection.

In addition, panel discussions of critical technological advances in urban air mobility, energy storage solutions and UAS traffic management will offer insights into the forces that will shape the years ahead for unmanned aircraft.

For more details go to **www.interdrone.com**

UAS Summit & Expo

Industry

The UAS Summit & Expo is one of the longest-running annual events for experts and stakeholders in unmanned aerial technology to gather and discuss the latest in research, development and innovation in UAVs and their subsystems.

The event is to be held in the Alerus Center, near the research offices of the Northern Plains UAS Test Site in Grand Forks, North Dakota, on August 27 and 28. It is expected to feature speakers from government and defence authorities, who will discuss updates on regulations for unmanned aircraft and integrating them into the national airspace, among other keynote addresses and panel discussions.

Outside the conference hall, the exhibition room will host a number of global aerospace contractors, research institutes and other key players in the unmanned aerial space who are looking to share their latest innovations and connect with others seeking to advance the cause of unmanned systems across the world.

For more details go to **www.theuassummit.com**

UST diary

Paris Air Show
Monday 17 June – Sunday 23 June
Paris, France
www.siae.fr/en

Autonomous Ship Technology Symposium
Tuesday 25 June – Thursday 27 June
Amsterdam, The Netherlands
www.autonomousshipsymposium.com

ExpoDronica
Thursday 27 June – Friday 28 June
Madrid, Spain
www.expodronica.com

Unmanned Systems – Defense. Protection. Security.
Tuesday 20 August – Wednesday 21 August
Washington DC, USA
www.thedefenseshow.org

UAS Summit & Expo
Tuesday 27 August – Wednesday 28 August
Grand Forks, ND, USA
www.theuassummit.com

InterDrone
Tuesday 3 September – Friday 6 September
Las Vegas, USA
www.interdrone.com

DSEI
Monday 10 September –Thursday 13 September
London, UK
www.dsei.co.uk

Interaerial Solutions and Intergeo
Tuesday 17 September – Thursday 19 September
Stuttgart, Germany
www.interaerial-solutions.com

UAV Technology
Monday 30 September – Tuesday 1 October
London, UK
www.uav-technology.org/ustmag

Commercial UAV Expo Americas
Monday 28 October – Wednesday 30 October
Las Vegas, NV, USA
www.expouav.com

Advanced Engineering
Wednesday 30 October – Thursday 31 October 209
Birmingham, UK
www.easyfairs.com/advanced-engineering-2019/advanced-engineering-2019/

Unmanned Systems Canada
Wednesday 30 October – Friday 1 November
Ottawa, Canada
www.unmannedsystems.ca

The Commercial UAV Show
Tuesday 12 November – Wednesday 13 November
London, UK
www.terrapinn.com/exhibition/the-commercial-uav-show

TUS Expo
Tuesday 14 January - Wednesday 15 January 2020
Rotterdam, The Netherlands
www.tusexpo.com

UMEX
Sunday 23 February – Tuesday 25 February 2020
Abu Dhabi, UAE
www.umexabudhabi.ae

Oceanology International
Tuesday 17 March – Thursday 19 March 2020
London, UK
www.oceanologyinternational.com

Japan Drone
Wednesday 25 March – Friday 27 March 2020
Chiba, Japan
www.japan-drone.com

DRONE Berlin Exhibition
Tuesday 26 May – Wednesday 27 May 2020
Berlin, Germany
www.drone-berlin.de



Early experience with the PackBot gave Frost an appreciation of how robust military UGVs have to be to operate and survive in the real world (Photos courtesy of FLIR Systems)

Ground force

The general manager of FLIR's unmanned ground systems group explains his engineering philosophy to **Peter Donaldson**

Sometimes, having a budding electronics engineer around the house can be a major test of parental tolerance.

"I used to booby-trap the house with alarm systems," says Tom Frost, now 45 and general manager of FLIR Systems' unmanned ground systems division, recalling a childhood in which the engineering bug bit early.

"That would drive my mom wild because I would alarm the door to my room, and the drawers in my bureau all had different alarms on them that would sound off. I even tapped the phone system," he confesses.

He credits his father as his early inspiration, recounting that he taught him to be hands-on and creative, both in playing around with electronics and making things in the back yard. "Sometimes it was building a wooden deck, sometimes it was building a circuit or an alarm system, even playing around with robotics by then, trying to build different things, some of which were successful, some of which caught fire!" he says.

His interest in computer programming also came early, and he was able to pursue it through high school and university. "I liked software because it was an area where you could innovate very quickly," he says.

"You could solve some very difficult problems in interesting ways, but I always lamented the fact that I would write these pieces of code that I was quite proud of but could never really show them to anybody.

"I didn't like my creations being captive in the computer. Robotics to me was a way to make the code live in the real world."

Career inspiration

The trigger for his choice of a career in robotics was an article in *Discover* magazine about Rod Brooks – later one of the founders of iRobot – and his work at MIT with his small, legged robots Attila and Genghis and the 'subsumption architecture' he was developing to give them what Frost calls a sense of life.



Smaller and lighter than the PackBot, FirstLook is designed to go into dangerous places so that soldiers don't have to, and is built to survive being thrown into a room

Subsumption architecture, Frost explains, is an approach to layering different levels of autonomous behaviours into very simple robots. The specific layering sequence of simple behaviours such as returning to the charger when the battery is low causes more complex behaviours to emerge in the robots through the interaction of the simpler ones in response to the priority rules the programmer gives them in different circumstances.

Having earned his bachelor's and master's degrees in computer engineering, with a focus on robotics, Frost joined iRobot in 1998. (In 2016, iRobot separated its civil and military businesses, the latter becoming Endeavour Robotics, which FLIR Systems bought in February 2019.) He was attracted by the idea of learning from Rod Brooks and getting to grips with developing robots for real-world applications.

He regards Brooks, along with his fellow iRobot founders Helen Grainer and Colin Angle, as mentors from whom he learned a lot about how to create successful products during the process that led to the military PackBot and the Roomba robotic vacuum cleaner.

> I didn't like my creations being captive in the computer. To me, robotics was a way to make the code live in the real world

"Early on, we were trying to come up with product concepts that would make iRobot successful," he says. "We had multiple failures and concepts that were just not going to make any sense sales-wise before we found success with the PackBot and the Roomba. What I came away with is that you need to design a solution that matches the price point of the customer."

It was with the PackBot, however, that he had what turned out to be an even more profound formative experience. The company was in the late stages of developing the PackBot, under a programme known as Tactical Mobile Robotics sponsored by the US Defense Advanced Projects Research Agency (DARPA), when 9/11 happened.

Lessons from Afghanistan

Frost was the PackBot's programme manager at the time, and led a team to carry out search and rescue duties in New York. "It was the first time we used the DARPA prototypes, which hadn't been tested thoroughly in the real world, and applied them to a real operation."

He had only just returned to iRobot's Burlington, Massachusetts, facility from the rubble of the World Trade Center in New York when the US military's Rapid Equipping Force asked iRobot to send a team to support the hunt for Osama bin Laden in the mountains and caves of Afghanistan.

As a civilian engineer, he flew to Bagram Air Base with the US Army and spent the summer of 2002 deploying the robots with various forces, using them to search caves, bunkers and compounds, so that the soldiers didn't have to go in first, he says.

He learned a lot from what he calls walking in the boots of his customer. As the PackBot was designed to be carried by a soldier, Frost made a point of marching around the air base with the soldiers in 112 F heat with the robot in his backpack. He also learned about how tough the robots themselves had to be to keep working through rough handling, a lesson subsequently applied to the 5 lb FirstLook throwable reconnaissance UGV.

There were also engineering

lessons to be learned, particularly about running repairs and improvisation, even cannibalising equipment left over from the Russian occupation.

"We had four robots over there and it was my job to keep them running," he says. "It was also my job to improvise additional accessories that we thought the mission needed. We were finding discarded Russian equipment lying around the base that we pillaged for components."

One breakdown forced Frost to call Burlington for help. "I sent an email back to my team that effectively said, 'Look, I'm the only one here. The robot is down. These are all the issues. All I have is a DeWalt drill and these tools, what do I do?'

"And they sent back an email that said, 'You know that DeWalt drill? Take it apart. Take resistor 80 off the circuit board and take this component off that and solder these in so you can keep the robot running.' It was a very Apollo 13 moment."

Frost returned from that summer in Afghanistan with a new appreciation for what the military does and what soldiers and their equipment have to endure. These days he is based in Chelmsford, Massachusetts, where his responsibilities leave little time for hands-on engineering, he admits.

"I have a glass wall here in my office, and all day long I can see the robots zipping by, autonomously navigating through our building as the guys are checking out the new designs," he says.

Layered autonomy

Layering in additional levels of autonomy is one of the most exciting things his team is working on at the moment, he says, as it gives them an advanced simultaneous localisation and mapping (SLAM) capability, for example. SLAM has long been held back by the size and cost of the sensors, and of the computers required to process their data and run the algorithms, he adds.

"Now we are doing that with sensors that are tightly integrated into the robot; they are part of the rugged chassis. We are doing it with the computer built into the robot, and we are doing it at a price that is affordable."

Another strand of development he points to is bringing UGVs and UAVs together, linking them through a common command and control system so that they can combine more effectively.

A more immediate matter is a major US Army programme called the Common Robotic System Heavy (CRS-H), for which FLIR is taking part in the second competitive 'fly-off' with a design based on the company's Kobra reconnaissance platform.

Primarily an explosive ordnance disposal robot, the CRS-H must be able to neutralise vehicle-borne IEDs, meaning it must be powerful enough to break into a car but light and compact enough to be easily transportable, and manoeuvrable enough to navigate tight spaces in buildings and climb stairs, for example. FLIR's Kobra-based solution weighs about 500 lb and fits into the back of an SUV.

Frost expects to learn whether they have won the tender sometime in the early summer, and much will depend on how well he and his team have followed the philosophy of engineering that he developed in the light of his experience in Afghanistan: "It's not enough to just to solve the problem, you've got to make it easy to use, and you've got to make it rugged and reliable for the real world."

Tom Frost



Tom Frost is the general manager of FLIR Systems' unmanned ground systems group. He began his education at Hereford High School in Maryland, then went on to Lehigh University in Bethlehem, Pennsylvania, where he earned bachelor's and master's degrees in computer engineering with a focus on robotics, followed by an MBA from MIT.

He joined iRobot in 1998, where he held a number of key positions including software developer, project manager for the DARPA project that developed the PackBot, director of engineering for government and industrial robots, PackBot programme manager, unmanned maritime systems programme manager, vice-president of strategy, and general manager of the defence and security unit.

He remained at iRobot until 2016, when the military business was separated out as Endeavor Robotics, where he served as president before it was bought by FLIR Systems earlier this year. He now reports to Roger Wells, who heads FLIR Systems' unmanned systems and integrated solutions division. Seven people report directly to him, and together they manage about 140 people.

In the early days of the Afghanistan War, Frost spent six weeks in-theatre with the US Army's Rapid Equipping Force, pioneering the military's use of ground robotics in a combat environment and better understanding the military's needs.

He serves on the National Advanced Mobility Consortium's Board of Directors as a senior robotics executive, where he addresses the opportunities and challenges facing robotic technology developers.

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Peter Donaldson explains the approach behind developing this versatile UGV, which is aimed initially at firefighting duties

Blazing a

While many unmanned vehicle platforms are intended to take on multiple roles, starting with a particular job in mind is a good way of focusing development efforts, building relationships with potential operators and learning about the challenges presented by the environments in which they work.

Tecdron has taken this route with its TC800-FF UGV (formerly known as the Sentinel), a 540 kg tracked vehicle capable of carrying an 800 kg payload and withstanding the heat that comes with operating close to wildfires and burning buildings, to help keep human firefighters at a safe distance. Other sectors the company has in mind include the construction, nuclear power and military markets, so versatility has been very important from the start.

Tecdron emphasises that, although the TC800-FF has a degree of autonomy in the form of path-following capabilities, it is primarily intended as a remotely operated platform designed to help firefighters and other emergency responders with dangerous, difficult or physically demanding tasks.

Its electric motors and rubber tracks enable it to operate inside buildings, where its compact size allows it to pass through doorways (it measures 156.4 cm long by 65 cm high by 77 cm wide), and its battery pack provides a maximum endurance of 6 hours.

While the TC800-FF is a clean-sheet design, it incorporates lessons learned from the development and fielding of the Scarab TX with the Paris Fire Brigade, and has been developed in response to a follow-on tender from the service.

CEO Jean-Charles Mammana explains, "When we submitted our response to the tender, the TC800-FF's conception phase was being finalised. We took their requirements and specifications into consideration in order to design a robot that would more than meet their expectations.

"We put on paper everything we had learned from our previous experiences with firefighters, and started from scratch to design a more powerful and more reliable platform."

He emphasises, however, that Tecdron works with many fire brigades across France as well as overseas, and each one has its own more or less specific



Compactness and the ability to climb steps as well as negotiate rough ground put limits on the overall size of the vehicle, and made tracks preferable to wheels (Courtesy of Tecdron)

trail



The TC800-FF's primary purpose is to keep firefighters out of harm's way. Carrying a hose and a water cannon into risky situations is one of its tasks (Courtesy of Tecdron)



The Apollo PE monitor from Akron Brass is the primary firefighting tool and is fed by a hose attached to a fire engine or other water source (Courtesy of Akron Brass)

way of using its robot for tasks such as direct firefighting, transporting response equipment, evacuating casualties, smoke extraction and gathering information using suites of sensors including cameras. In each case, the company offers the same basic platform, onto which different mission equipment and accessories can be integrated.

Effectors and sensors

The main effector dedicated to fighting fires is a modified Apollo PE monitor – a steerable nozzle – from Akron Brass. It is mounted on an adapter plate that is secured to the main aluminium payload deck using quick-release pins that can be inserted and removed without tools, and which are secured to the plate using wire tethers to prevent them from getting lost.

The monitor is fed by a hose attached to a fire engine or other water source and passes through a guide bracket on the rear of the payload deck that keeps it safely behind the vehicle. Mounted on an electrically powered turret, the monitor can be remotely aimed in both azimuth and elevation, and is fitted with a remotely operated valve to start and stop the flow of water.

Mounted above and behind the monitor on its own pedestal is a dual camera system from Exavision in a rugged dual axis pan and tilt head. The system is from Exavision's Omnicam range, and can be equipped with a 640 x 512 element uncooled thermal imager with either a lens of fixed focal length or one with an optical zoom, and either a colour CCD camera with a 36x zoom or a full HD CMOS camera with a 20x zoom.

Uncooled thermal cameras have become essential in firefighting operations because they can penetrate smoke to reveal the seats of fires and measure temperatures accurately to show up areas approaching ignition temperature. These can then be targeted with hoses to slow or halt the spread of a fire.

Alternatively, a high-flow ventilator fan system, such as the Easy 2000 from Leader, can be installed for removing smoke and cooling large enclosed spaces such as car parks, warehouses, factory production lines and exhibition halls. On the TC800-FF, the fan's standard mounting skid is fixed to an adapter plate that is attached to the payload deck (instead of the monitor) using the quick-release pins. Each payload is fixed to the payload deck via its own custom-built adapter plate,

With the nozzle closed down to create a jet of water, the Apollo PE provides greater range (Courtesy of Tecdron)



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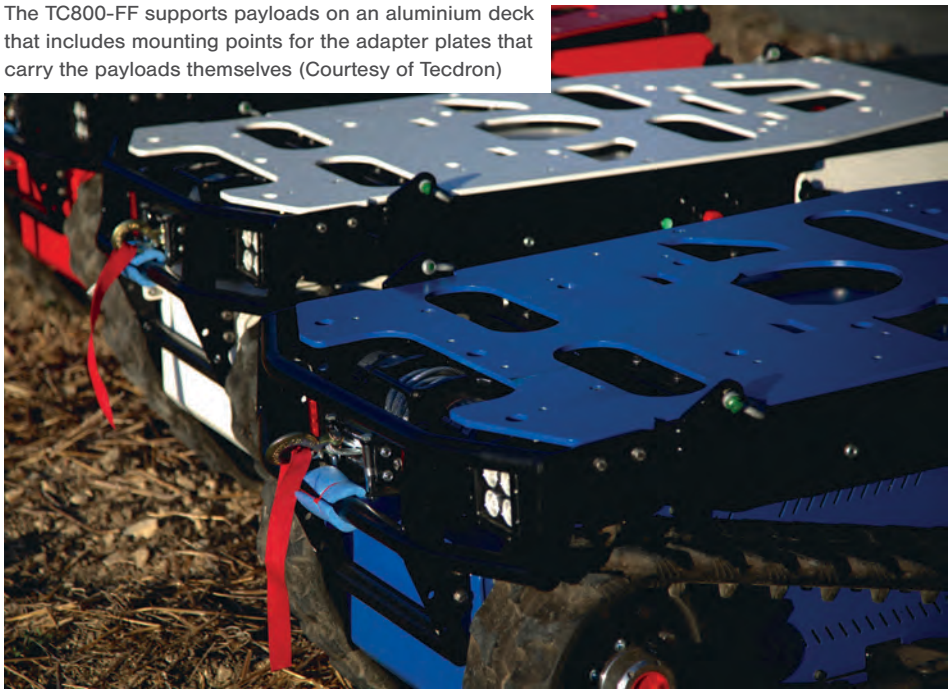
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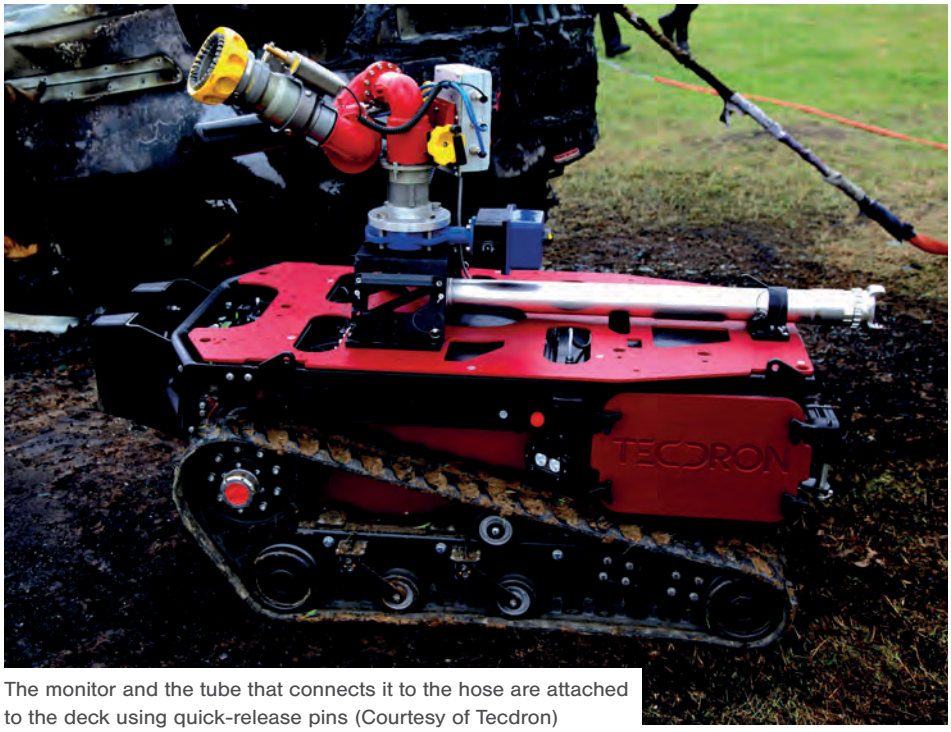
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The TC800-FF supports payloads on an aluminium deck that includes mounting points for the adapter plates that carry the payloads themselves (Courtesy of Tecdron)





The monitor and the tube that connects it to the hose are attached to the deck using quick-release pins (Courtesy of Tecdron)

speeding up the process of swapping between them.

Driven by an integral 20.8 hp Honda GX630 petrol engine, the Easy 2000 can flow 220,000 m^3 of air per hour with its 85.55 cm-diameter propeller, and its 18 litre fuel tank can keep it running for a little over 3 hours. On its skid mount, the fan system weighs 178 kg.

When configured for evacuating casualties, the TC800-FF can carry bottles of medical gases on the main payload deck with a stretcher mounted above them on brackets fixed to the corners of the deck. The robot can also tow other vehicles including cars or push people carriers aside using rubber-tipped bumpers mounted to the chassis on steel brackets, and also mounts a winch at the front below the payload deck.

Design and testing

Mammana says, "The TC800-FF and the Scarab TX may look alike but that's all they have in common." Highlighting the key differences between the Scarab TX and the TC800-FF, he points to the latter's brushless DC motors, new batteries, a new structure and mechanical architecture, and embedded software developed in-house to enable Tecdron to offer options and services both within and beyond firefighting.

One of the most important design criteria was the ability to carry heavy loads. This drove the selection of a tubular steel chassis and of tracks rather than wheels to distribute the load evenly through the structure and onto the ground respectively, as well as the choice of the motors.

The design process from which the hardware architecture emerged was guided by a thorough review of what Tecdron had done before and of customer feedback on earlier vehicles, the Scarab TX in particular. "We entirely reworked the platform in order to improve its performance and reliability, and used new technologies," says mechanical engineer Romain Chaumier.

This phase lasted about six months and included drawing the chassis in SolidWorks CAD software, and calculating and simulating parameters such as rolling resistance – an important determinant of the energy required for propulsion – using the simulation capabilities in SolidWorks.

From starting the first drawings to completing the assembly of the first prototype took Tecdron almost a year. A subsequent testing and refinement phase lasted about six months, during which the engineering team checked that the TC800-FF complied with firefighters' needs.

Simplified manufacture

The manufacture of earlier platforms such as Scarab TX relied heavily on machining processes, which Mammana says were costly and not well-suited to the technical constraints that apply to the TC800-FF.

"Machining is perfect for creating

small and complex steel parts, but in our application we need big, simple parts for the frame that are not easy to machine because of the huge amount of material that has to be removed," he says.

The new vehicle's structure is made using what he describes as "boilermaking processes", which essentially involves cutting standard profiles of S235-grade steel tubing to length and TIG-welding them together to form a tubular spaceframe chassis. To save weight, the outer casing is fabricated from aluminium alloys, with milled components made from 2017 grade while those that require welding are 5083 grade.

Not only are these processes less costly, Mammana says, they make the chassis structure simpler and more accessible. They also allow fewer parts to be used, which makes assembly, disassembly and maintenance much easier.

The chassis and component housings are manufactured in mechanised welding by Tecdron's local partners in France, and the vehicle is completed at the company's La Rochelle headquarters.



The TC800-FF is based on a steel tubular frame chassis and aluminium bodywork, and its rubber tracks are driven by electric motors that draw power from a lithium-ion battery (Courtesy of Tecdron)

Another major decision was in the area of motors and power transmission, where Tecdron made the change from brushed to brushless DC motors. Brushless motors are more complicated to implement than brushed motors, but for a given size they provide much



more power, and if their speed, torque and temperature limitations are respected they have an almost unlimited life and need little or no maintenance.

The extra complication arises from the need to apply current very precisely to each phase of the rotor's windings as it rotates. To provide that, the controller needs to know the rotor's angular position throughout its rotation, information that is provided by a Hall effect sensor. Brushed motors, by contrast, need no sensors or synchronisation to run, only a constant electrical supply.

New electronic architecture

The TC800-FF also has a new electronic architecture, both in terms of hardware and software.

Tecdron developed its own embedded computer that monitors the operation and health of all the vehicle's major components. The computer continuously analyses and controls more than 50 parameters, including speed, torque, inputs, outputs and so on, and makes adjustments in real time to protect the vehicle and its onboard systems.

It also keeps the operator in the picture by sending alarms over the comms link whenever one of these operating limits is reached. For example, if motor temperature exceeds 130 C, the robot stops then sends an alarm. The limits for the battery and electronics are 60 and 75 C respectively.

Mammana says this has enabled them to make sure everything is working properly and to program in safety measures that prevent components from exceeding predetermined limits to avoid damaging them or compromising their reliability.

The embedded computer also offers other advanced functions including a data logger, remote network access and a closed-loop motor control system. The data logger records everything the robot does in operation and, says Mammana, timestamps all the measured values against the computer's real-time clock, which records the data every 100 ms or whenever an event occurs.

Tecdron's raison d'etre

Based in La Rochelle on the Bay of Biscay in western France, Tecdron specialises in mobile land-based robotic vehicles for indoor and outdoor applications. As well as designing and producing bespoke robotic platforms for customers ranging from small and medium-sized enterprises to large multinationals, the company also develops others that it markets under its own brand name.

Tecdron's firefighting UGVs fit into the second category. These include the Scarab TX, its first fully operational vehicle introduced in 2016 that was developed from several prototypes tested in cooperation with the Paris Fire Brigade. Subsequently, the Amsterdam Fire Department bought a Scarab TX and operates it with payloads and sensors including a water monitor (a remotely steerable nozzle for a fire hose), a smoke extraction fan, a Lidar and a stretcher holder.

Tecdron's CEO Jean-Charles Mammana arrived in late 2016. He is a software engineer with more than a decade of experience in robotics with companies including warehousing firm Scallog, SoftBank Robotics, and Gostai Robotics, a robot manufacturer and AI house.

He wanted to change the company's direction towards developing a wide range of options and services as well as integrated robotic platforms, the first focus of which is the TC800-FF, and is now looking for distributors for them.

The data gathered and recorded by the logger comes from multiple temperature sensors, which are mounted externally on the vehicle as well as inside the motors, batteries and electronic components. There are also voltage and current sensors on the motors, brakes and batteries, and rotary speed sensors on the motors.

The system also gathers data from the TC800-FF's GNSS and inertial sensors so that every one of its routes can be recorded and played back. The data logger has a continuous recording capacity of several months' worth of operations.

All the data it logs can be exported via the comms link, which can use the vehicle's onboard wi-fi router or a 3G/4G cellular network as the bearer, and fed into diagnostic software tools that Tecdron has developed to determine whether any components will need maintenance.

This remote network access also enables the TC800-FF's software to be updated or patched over the air, removing the need to return it to Tecdron. "This is useful if a client discovers a bug and needs a fix as fast as possible or wants a new feature, such as the ability to handle a new device," Mammana says.

He adds that Tecdron can access a number of the robot's key parameters, such as speed and power limits, and enable certain features over wi-fi.

"These parameters are specific to each robot, and are not affected by software upgrades," he says. "That means we can have one core software suite for all our TC800-FFs and adapt their features for individual clients."

In-house computer

Tecdron developed the computer's open architecture to support the integration of a wide range of external devices and advanced services such as the data logger, remote diagnostics and the remote software upgrade capability, Mammana notes. He adds that Tecdron needed fast computer hardware capable of handling all the devices connected to it in real time, and with very low energy consumption, so it chose an embedded

processor with two 32-bit cores running at 240 MHz.

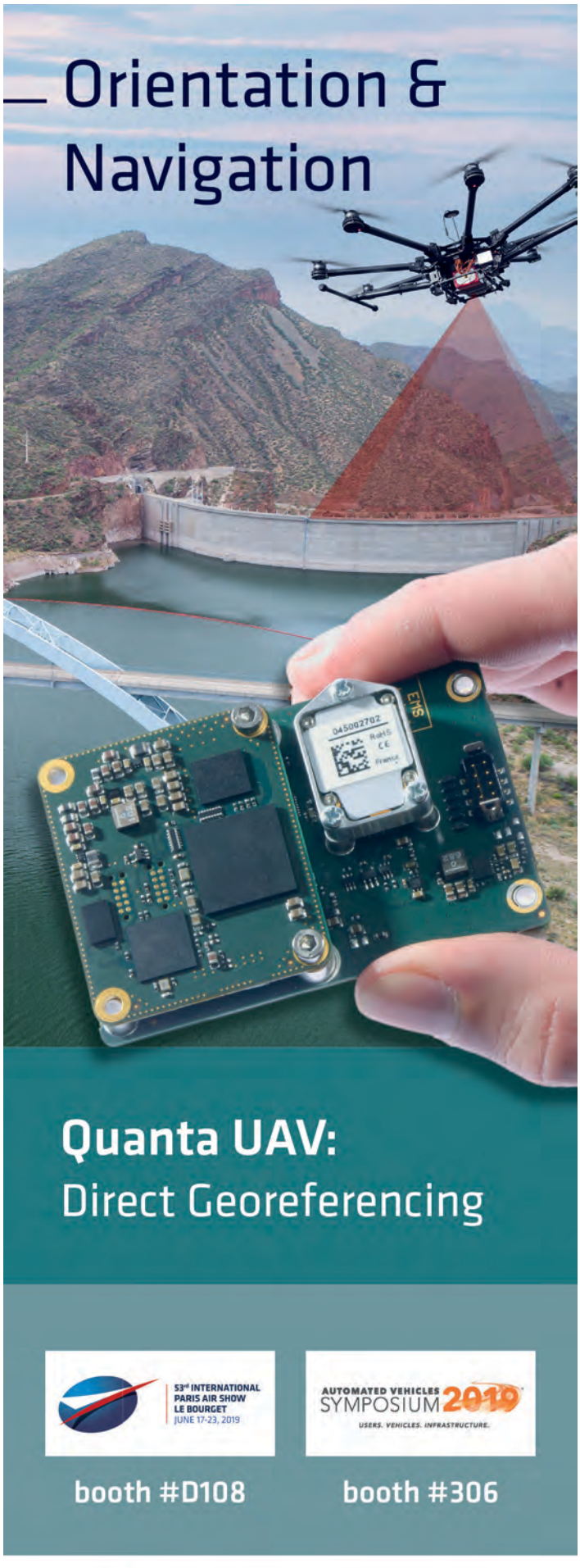
This processor runs the first of the two layers in the TC800-FF's software architecture, which manages all the low-level platform devices and computer security. The second, higher layer is only needed to run complex algorithms such as those to enable autonomous navigation, for example, and is handled by a separate standard computer connected to the embedded processor.

As well as wi-fi and 3G/4G, the embedded computer supports most widely used network interface and data bus standards. These include Ethernet for IP data, CAN for comms between microcontrollers, for example, RS-232/485 serial interfaces, ADC and GPIO for voltage selection, SPI for short-distance comms in embedded systems, and I2C and 1-Wire for low-level comms between small sensors and other devices.

This variety makes it easier to integrate a wide range of payloads. The system also provides industrial-grade safety with, for example, protection against over- and under-voltage conditions.

The basic comms fit is a WPA2 wi-fi system that is used mainly for piloting over short ranges and for data uploads and downloads during maintenance. Tecdron has also built up a network of partners specialising in high-performance and secure radio systems operating in the 868 MHz, 2.4 GHz and 5.1 GHz bands, and the company can offer point-to-point and mesh networking systems with ranges greater than a kilometre. These can be integrated on demand according to the environments in which customers need to operate.

The company chose to develop its own software instead of going down the commercial or open source route partly to avoid licencing problems, but mainly because open source robotics software is either not considered reliable enough, like Arduino, or is not embedded, such as the Robot Operating System (ROS), Mammana says.





The weight-bearing wheels and track tensioning system are attached to a box-section steel tube mounted on the side of the chassis (Courtesy of Tecdron)

Closed-loop motor control

The closed-loop motor control system is designed to increase the accuracy and precision of the robot's movements, particularly when operating with a heavy load over rough ground. That makes control of the robot easier and more comfortable for the operator, Mammana says. "In practical terms, it gives a lightweight feel to piloting the robot."

Like all tracked vehicles, the TC800-FF steers by manipulating the tracks so that they move at different speeds or different directions. A gentle left turn with the vehicle moving forwards, for example, would involve slowing the track on the left side while maintaining speed or even accelerating the track on the right. Similarly, turning the tracks in opposite directions with the vehicle stationary would turn it on the spot.

The motor controllers are supplied by Roboteq, which says it offers equipment that can implement a variety of control schemes. In closed-loop speed mode in brushless motors, for example, the Hall effect sensor is used to measure the motor speed, and if the speed changes because of a change in load the controller adjusts the motor's power output to compensate.

In closed-loop position modes – including position relative, count position and position tracking – the controller uses the sensor to compare the angular position of the axle with a desired position.

In the position-relative mode, the motor moves from a starting position to a destination position using a controlled acceleration, velocity and deceleration.

Count-position mode works in a similar way, but the motor can be commanded to go to any count position value using a controlled acceleration and velocity profile. In position-tracking mode the motor goes to the commanded position as quickly as possible.

The TC800-FF can be equipped with two types of track, one optimised for range/endurance, the other for performance on rough terrain and low-traction surfaces, which Mammana likens to summer and winter tyres for a car.

Each continuous rubber track is driven by its own motor via a reduction gearbox and a sprocket mounted at the front of the chassis. There are four pairs of weight-bearing wheels per track, with the front and rear pairs being larger than the two sprung pairs in between, while a single pair of wheels on each side support the top run of the track.

All of these are attached to a box-section steel tube mounted on the side of the chassis. The rear wheels are bolted to this tube via slotted plates that enable operators to adjust track tension.

The decision to develop the computer in-house was also driven by the desire to offer greater versatility, more reliability and the ability to respond more quickly to requests from customers.

"Our computer now matches our exact requirements in terms of applications," Mammana says. "We have direct control of it and the new developments we want to carry out software-wise. We don't have to rely on a third party anymore."

Energy supply

When it came to the energy system, Tecdron chose a bespoke solution from specialist battery supplier Neogy. It designs batteries for electric vehicles, both ground-based and airborne, and the 48 V system supplied for the TC800-FF consists of two CE-certified 25 kg lithium-ion batteries tailor made for the TC800-FF, a battery management system (BMS) and an internal comms system that enables them to interact with each other and with the UGV.

"Given the extreme constraints related to the robot's engagement during firefighting operations, it is essential that its batteries offer a very high level of safety against shocks, vibration, temperature, humidity and misuse," says electrical engineer Richard Breuiller.

The TC800-FF's batteries feature nickel manganese cobalt lithium-ion cells connected in series and parallel. The BMS manages the status of both batteries together, and displays information on the run time and battery life remaining in percentage terms.

It also protects the cells from overload and deep discharge, provides over-

current protection, implements safety procedures in case of excessively high or low temperatures and balances the state of charge across all the cells.

A charging port on the back of the vehicle can be used to recharge both batteries without removing them, or individually when removed. The first method takes around 4 hours and 20 minutes, while the second takes less than 3 hours and 10 minutes, Breuiller notes.

The quoted maximum run time of 6 hours, says Breuiller, is achievable under ideal conditions. He emphasises that several factors influence the running time in a given mission, including the weight of the payload the vehicle is carrying, the nature of the ground over which it is travelling and the operator's driving style.

"We've worked with a judicial officer to have the running time certified, under operating conditions that were representative of those under which firefighters use the TC800-FF," he says.

For example, with a 500 kg payload, the running lights on and in steady-state, non-stop driving it can keep going for more than 4 hours and 15 minutes, he says, adding that exhausted batteries can be quickly swapped for fully charged ones in the field, as they are mounted in drawers on the vehicle. The drawers are behind waterproof side covers at the rear of the UGV, and are secured using knobs that screw on and off without the need for special tools.

Normally, the power that the TC800-FF delivers and the speed at which it travels are limited by its software to 12 kW and 3 kph, to maximise the reliability and longevity of its components. However, it can deliver up to 26 kW at 3.8 kph and travel at up to 6 kph if necessary.

"The worst-case scenario is when we ask the TC800-FF to rotate on its own axis with its 800 kg maximum payload and on a surface with a high level of grip, such as tarmac or concrete," Breuiller says.

Although the Paris Fire Brigade and other customers asked for a 500 kg payload capacity, Tecdron decided to build in a significant margin, which led to the TC800-FF's 800 kg capacity.



Capable of working with a variety of radio systems, this remote control device is one of several options for managing the vehicle (Courtesy of Tecdron)

Mammana explains, "Moving a huge payload is in itself quite easy, but moving it for several hours is much more difficult. We want to offer a robot that can handle its maximum payload throughout its battery endurance without malfunction."

Navigation and control

The TC800-FF's primary navigation sensor suite integrates a GNSS receiver from SBG Systems that processes both GPS and GLONASS signals supplemented by an inertial measurement unit. The navigation algorithms the vehicle uses are programmed into the embedded computer, and operators can control it via an OpenStreetMaps interface.

Tecdron also offers several options for direct remote control, including rugged remote control (RC) units, smartphones and tablets that can display images from cameras and other sensors.

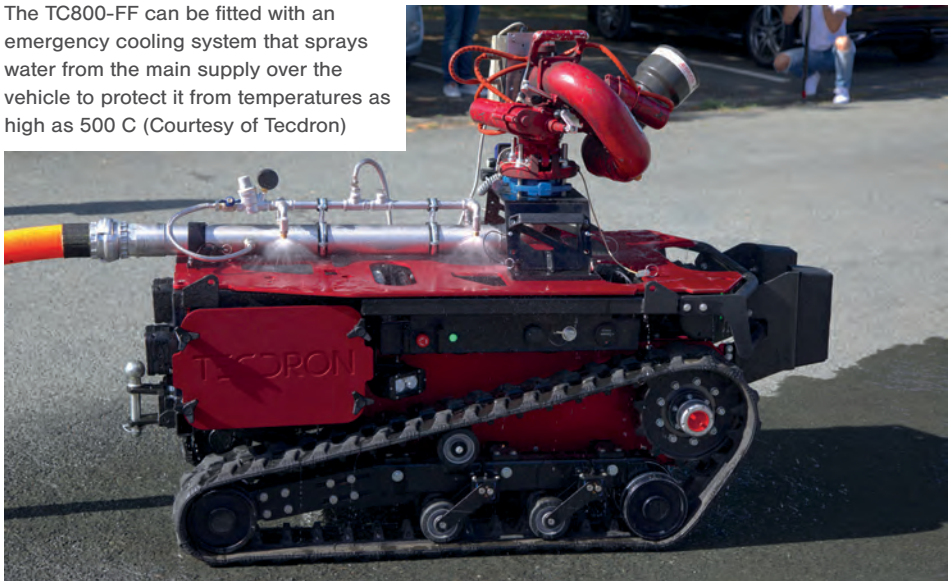
Semi-autonomous mode allows operators to have the robot follow a firefighter from point A to point B carrying a load, for example, then repeat the route by itself for as long as required. As yet, the TC800-FF does not have collision avoidance capabilities, but Tecdron is working on that.

In either mode, and by default, if all comms are lost or there is no new command within a given time, the TC800-FF stops moving immediately. However, its software will act autonomously by turning the water nozzle to a protective position to save it from fire, for example.

In firefighting, the TC800-FF would typically be used in RC mode for tasks such as attacking fires underground, or where there is a high risk of explosion or exposure to dangerous chemicals, gases or radiation. For jobs like these, the vehicle would be fitted with a remotely aimed nozzle fed by a hose that serves as a water cannon, a thermal camera and other sensors appropriate to the specific risks that the firefighters anticipate.

Another example would be the use of an extractor fan on the vehicle to clear smoke from the site of an incident.

Firefighting is among the most demanding applications to which the UGV can be put, as that obviously exposes it to very high temperatures, water, other fire extinguishing and suppression media along with general dust, grit and dirt.



The TC800-FF can be fitted with an emergency cooling system that sprays water from the main supply over the vehicle to protect it from temperatures as high as 500 C (Courtesy of Tecdron)

What's more, the nature of the missions sees the UGV being sent into situations that are too dangerous for people, such as fires in tunnels, mines or underground parking structures for example, and onto sites where there are serious risks of explosion, such as warehouses or petrochemical plants.

Mechanically, all the key components such as the motors, batteries and electronics are sealed into enclosures that protect them from fluid and dust/grit ingress to the IP66 standard. Also, the batteries are housed in double enclosures (internal and external) to provide an extra layer of passive thermal protection. Software-related protection measures are embodied in the monitoring system to let the operator know the robot's exact state of health.

Mammana says, "It is very important for firefighters to know the robot's limits and where they can send it. By the temperature of its motors, its batteries, the current draw and voltage – even the amount of power available – it gives them a clear vision of how they can use the robot during the mission.

He adds that the TC800-FF will also adjust automatically to the state of its components, reducing its power and/or activating its onboard cooling system if one of its motors gets too hot, for example.

Staying cool

To protect it in the hottest environments to which it is likely to be exposed, the TC800-FF is fitted with an active cooling system of Tecdron's own design.

This consists of a set of pipes and nozzles that draw water from the main hose that feeds the main water cannon and sprays it onto the vehicle's most critical components. These include the computer enclosure, the battery boxes, the electric motors and the tracks.

Tecdron emphasises that this system can be adapted to different vehicle and mission system configurations, and either one nozzle or several can be positioned to spray water onto selected components, including the effectors and sensors.

The length of time for which this system can protect the TC800-FF obviously depends on the water supply, but Mammana says they have tested the cooling system at ambient temperatures up to 500 C, and that after 20 minutes the robot's average temperature was less than 45 C.

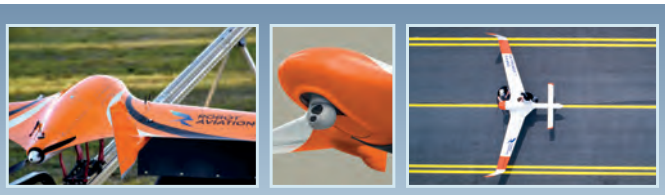
In total, Tecdron has completed more than 700 hours of testing with the TC800-FF. Mammana says that most of this has been carried out under extreme conditions, including temperatures exceeding 500 C, for long periods over complex test routes and with the maximum payload.

The measures taken to ensure it can survive and operate in such environments are also likely to enable it to handle other demanding jobs. Mammana says Tecdron has some customers in the defence and nuclear sectors for different applications, and anticipates more within months.

Datasheet

Payload: 800 kg
Maximum power: 12 kW
Maximum torque: 2000 Nm
Dimensions: 156.4 x 65 x 77 cm
Incline: 45°
Side incline: 40°
Obstacle clearance: 30 cm
Traction force: 12,500 N
Weight: 480-500 kg depending on accessories, 1300 kg all up with maximum payload
Speed: 3.5 kph
Endurance: 4-6 hours
Charging time: 2-5 hours (depending on the charger)
Electrical power: removable lithium-ion batteries
Control system: radio and/or wired
Monitoring: real-time robot monitoring (temperature, power, voltage), data logger
Pulling power: 200 m of fire hose containing water
Sealing: complies with the IP66 standard
Command interface: remote control and/or rugged tablet and/or smartphone (Windows, Android, iOS)

Some key suppliers
Monitor (water cannon): Akron Brass
Camera system: Exavision
Fan: Leader Group
Batteries: Neogy
Motor controller: Roboteq
GNSS: SBG Systems



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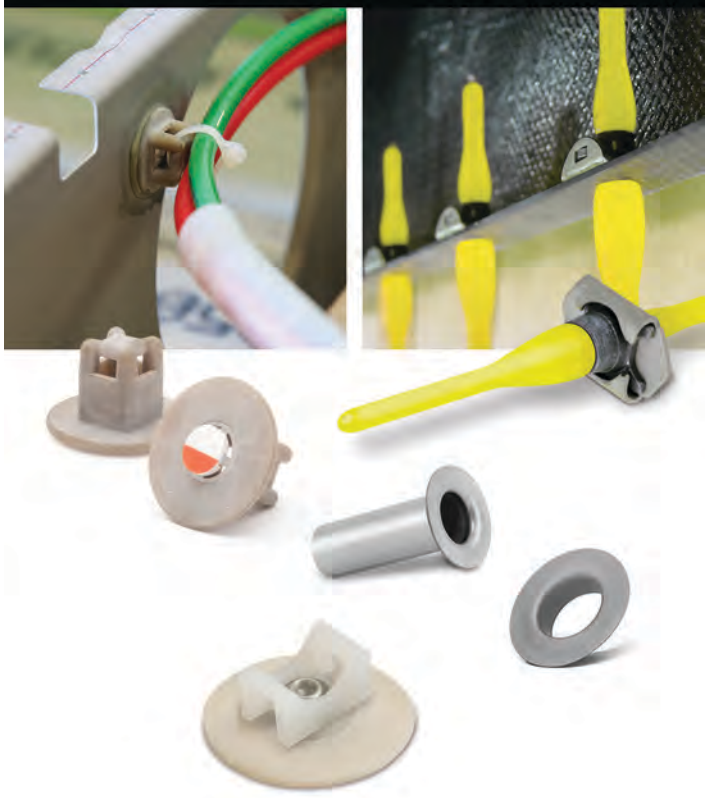
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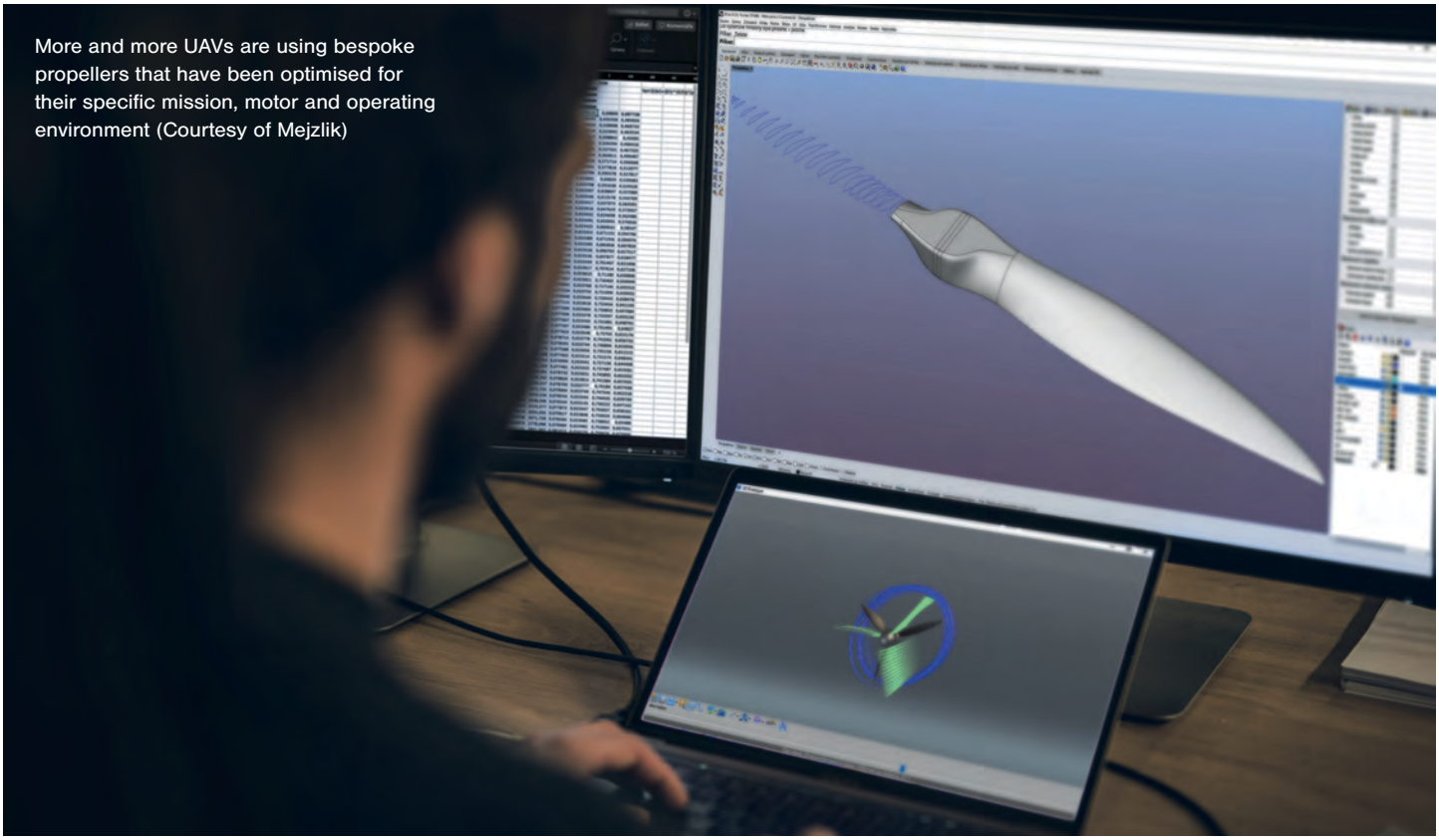
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More and more UAVs are using bespoke propellers that have been optimised for their specific mission, motor and operating environment (Courtesy of Mejzlik)

Made to order

Advances in materials, design and analysis are enabling UAV propeller suppliers to provide solutions tailor-made to a given application. **Rory Jackson** reports

Over the past few years, propeller manufacturers across the UAS industry have expanded their focus towards the production of customised designs. That is partly because of the increasing maturation of UAVs and the growing competencies of their operators, who might approach a prop developer with a CAD model and ask them to provide the manufacturing, testing and analysis of the design.

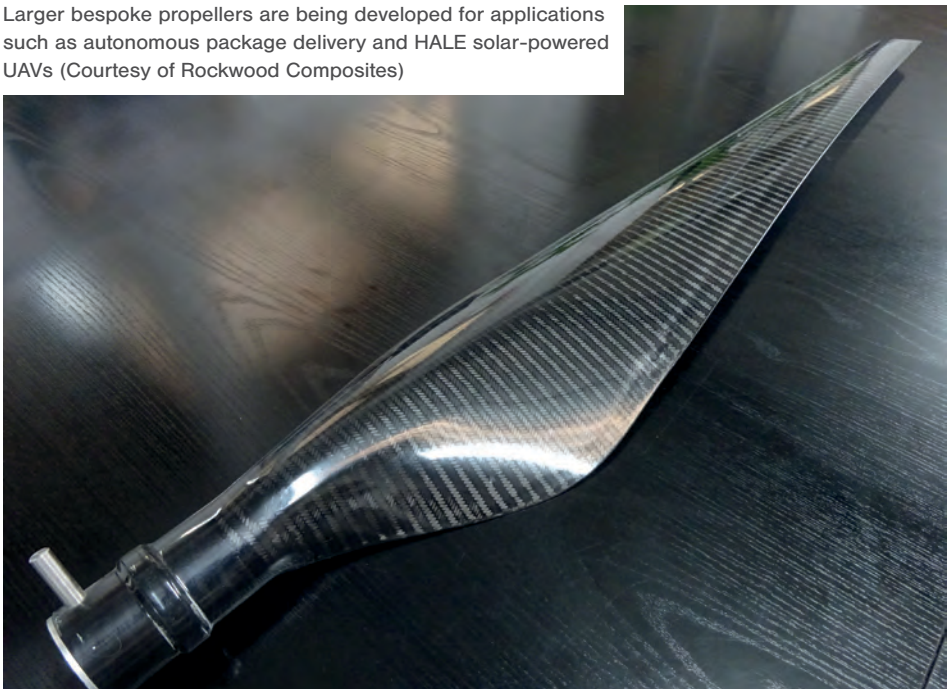
More and more manufacturers and users of small UAVs are also now aware of the value of using COTS propellers that have been designed and tested for airfoil and chord distributions appropriate for multi-rotor and fixed-wing UASs. Although such design considerations can drive up manufacturing costs, they are a key evolution among bulk producers of props the world over, as they come to understand more closely the unique air densities, power requirements, and operating conditions of UAVs versus those of RC hobby aircraft.

At the same time, new markets such as aerial package deliveries, HALE pseudo satellites and self-piloted urban air taxis are spurring the development of larger propellers with customised geometries to serve their unique requirements.

Each of these new types of UAS is different in terms of their flight envelopes, operations and potentially in their environments – none of which can realistically be served with COTS propellers in the way that small 'prosumer' UAVs can. Autonomous HALE craft and air taxis in particular cannot use existing COTS props, not least because of the expense and safety requirements.

Development of robust and efficient propellers is critical for ensuring these vehicles can stay aloft safely and for longer. And since greater endurance can be translated into heavier payloads (or more passengers), an efficient propeller allows these new types of commercial operators to cater to more customers, for longer.

Requests are therefore growing for propellers that are customised to suit specific parameters such as their aircraft's mission, motor and environment. Even manufacturers of particularly high-end COTS propellers are now updating their bulk-produced designs with a modicum of aerodynamic analysis and testing to ensure a balance of efficiency between lift and hover, given that the



Larger bespoke propellers are being developed for applications such as autonomous package delivery and HALE solar-powered UAVs (Courtesy of Rockwood Composites)

optimal pitch varies depending on the power requirement.

Among such manufacturers, carbon composite is emerging as the industry-standard material, thanks to its high strength-to-weight ratio and the wide range of carbon prepreg suppliers around the world.

Fibre glass and wood continue to be used intermittently – wooden props can be particularly useful for oil and gas inspections, where ATEX certification mandates non-explosive, low-friction materials. However, carbon fibre tends to be preferred among UAV designers seeking to meet a weight target.

Some of the changes in propeller manufacturing being spurred by the new UAV markets might be obvious. As ever-larger autonomous (and typically electric or hybrid) aircraft are developed for heavy-lift duties and transporting passengers, propeller blades must be made far bigger than those the UAV manufacturers typically work with, to provide the necessary lift for ascent, hover and descent in these urban applications.

For a typical two-bladed UAV propeller to provide such lift, the speed of the motor would need to be quite high, but as the rpm and diameter of the propeller increases, the speed of its tips rises to close to the speed of sound.

That exponentially increases drag (without a corresponding increase in thrust) and creates noise and structural problems, so the larger propellers must come with more blades to generate sufficient lift without relying on high motor speeds. That could mean further increases in their material costs, however, and adding more blades generally means extra weight and surface area for the propeller, creating more drag that the UAV and its motors have to contend with.

Propeller design and analysis

There are various blade parameters to be taken into account when analysing a propeller for a particular UAV and its end-use. These include the blade diameter, airfoil, pitch, chord and blade count.

There is a growing understanding of just how many factors influence the effectiveness of a propeller in a given application. Approaches to propeller analysis and design, such as using modelling software for blade elements, momentum and fluid dynamics can show all the ways a propeller can be optimised.

The parameters listed above can be explored in further detail, for example by examining the way pitch and chord are distributed along the length (or 'twist') of the blades. Hub diameter should also be considered, as the hub should be as small as possible while still providing a strong core for the propeller.

And once the vehicle and mission parameters have been detailed by the customer, the designer can input factors such as engine power, rpm, air density and the forward speeds the UAV will be moving at (including if the craft will spend more time hovering than moving).

Alternatively, the customer and designer might choose to omit such parameters in order to achieve a simpler and quicker simulation run time, if having a shorter overall lead time takes precedence over a thoroughly optimised propeller design.

Propeller designers can then calculate a range of useful qualities to define the eventual shape the bespoke prop should take. These can be found by using established (and increasingly popular) CFD software such as SolidWorks or STAR-CCM+, or by way of in-house simulation capabilities and amassed data on UAV propeller characteristics, or a combination of both.

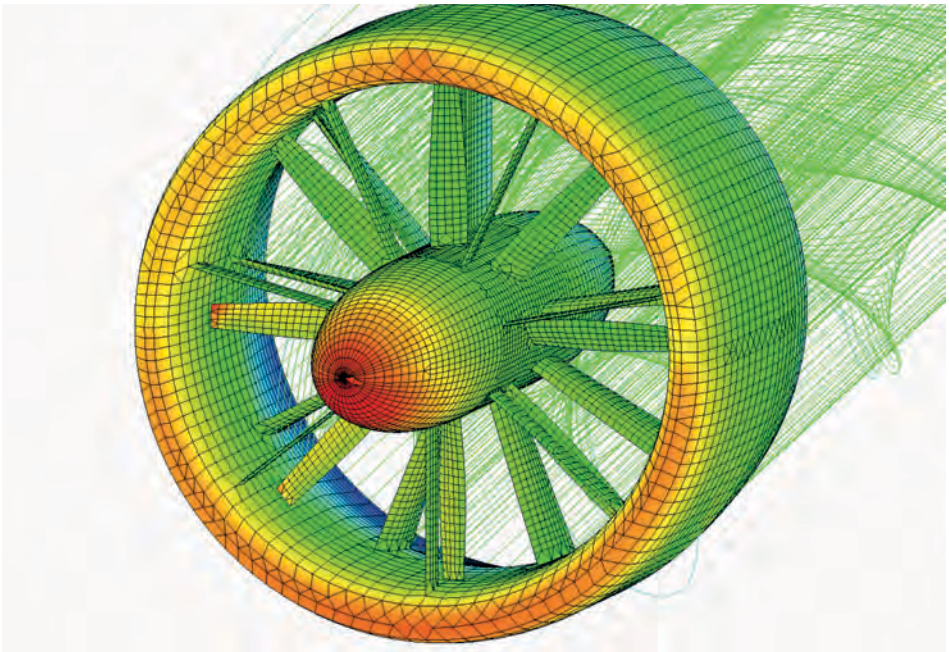
For example, a propeller's optimal helix angle – the angle between its plane of rotation and its effective pitch (the actual path the blade 'cuts' through the air) – can be determined, thus enabling significant optimisation for the prop's intended use.

In another case, a propeller with a low pitch and low helix angle will suffer minimal drag but might provide low thrust. Alternately, one with a deep pitch and large helix angle would provide powerful thrust but induce potentially significant drag.

The solidity ratio – the ratio of chord length to pitch – can also be analysed. This gives a measure of how much of a propeller's disc area is taken up by solid material versus air. Increasing it, by increasing the blade chord or the number of blades for example, can increase the power imparted by the prop to the air.



The great majority of UAVs now use propellers made from carbon composite, although wood and fibre glass still find some use (Courtesy of Sensenich)



Software is available for running aerodynamic analysis, as well as structural and fatigue analyses of propeller designs (Courtesy of DARcorporation)

These variables and others, such as estimates of lift and drag forces, can be more accurately gauged as propeller designers amass more and more test data (such as from wind tunnels) to refine their models.

Combining these with data from engine and motor manufacturers – or, for companies that manufacture motors as well as propellers, their own data – means accurate calculations of critical values such as thrust, power and torque coefficients are possible.

These are important for modelling properties such as a propeller's real-world efficiency by seeing how much thrust it generates compared with how much power it 'consumes', as well as its losses at the tips and hub, and its static thrust while hovering.

Alongside aerodynamic analysis, it is increasingly common among manufacturers to perform structural and fatigue analyses on their propellers, as these will also influence the prop's aerodynamic performance as well as its lifespan.

It is also worth noting that judicious FEA simulations by the manufacturer can help predict which segments or areas along the blades can be expected to show signs of wear over time. That can help with the safety case for their vehicles (and therefore the case for regulators to accept increasing urban integration of UASs) if they are informed in advance of where any damage is most likely.

Through FEA software such as Nastrel or Femap, propeller designers can identify the effects of aerodynamic, centrifugal and gravitational loads on the blades and hub, for example by seeing if the highest stress levels are experienced at the blade tips, blade roots, trailing edges or elsewhere.

They can also model where cracks might appear and how they might grow over time, depending on the expected frequency of use and service life of the prop. That can be used to further improve the structure or to inform the vehicle's operators for future safety inspections.

Modelling technology also allows users to simulate the effects of the prop's material in FEA, be it carbon composite, thermoplastic or aluminium alloy, as the balance between a material's cost and its properties (such as durability or flexibility) will still typically influence design choices. Software can also account for the roughness or smoothness of a blade surface, which can vary according to how much the end-user is willing to invest in quality of manufacturing.

After simulation, it is increasingly common for propeller manufacturers to conduct tests on prototypes of the modelled design. These vary between companies, and include combinations of test stands, acoustic chambers and wind tunnels, either in-house or those from third parties.

And although additive printing is





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still far from ideal for bulk production, it is now widely used by propeller manufacturers for rapid prototyping of new designs, in thermoplastic or printed composites with chopped fibres.

Acoustic optimisation

Real-world testing is vital for ascertaining qualities that computer simulations can occasionally fail to predict. For example, testing propellers for balanced weight across their shape is common for preventing weight-related oscillations of the prop during flight.

Greater attention than ever is being paid to the noise generated by propellers. This is as much due to the correlation between noise and inefficiency (and vibration) as it is a function of the expansion of commercial UASs into populated airspace and the need to reduce noise pollution.

By using an anechoic chamber and one or more sound sensors, a propeller manufacturer can measure the variations in noise level at different revs, from either a single propeller-motor pairing or several of them. This latter set-up could more accurately capture the overall noise from a multi-rotor system.

Many rounds of testing might follow, depending on the UAV's flight envelope and configuration. If the acoustics from a multi-rotor delivery UAV for example are being tested, sound sensors might be placed downstream of and perpendicular to the propeller's airflow. That would test the noise heard by civilians as the UAV flies over them or lands next to their offices or dwellings.

Carrying out tests of just the engine or motor is also vital for determining how much noise is being contributed by the propeller alone. Again therefore, it is important that UAV manufacturers know which other propulsion components they need before seeking a propeller optimised for their application.

Testing and reducing propeller noise will be even more important for autonomous urban air taxis, as the passengers may be very close to the



Propeller hubs must provide a strong core for the blades while also being carefully analysed to ensure they do not create unnecessary losses (Courtesy of KDE Direct)



Many UAV propeller manufacturers now have their own test stands, facilities and other equipment (Courtesy of Xoar International)

props for hours at a time. Modelling and testing propeller vorticity and noise is vital for determining how the wake of the blades might beat against the cabin windows and windshields, as any growth in the urban air taxi market will depend on passenger comfort as well as safety.

A comprehensive testing regimen for urban air taxi propellers could therefore mean having multiple rounds of tests with several different prototypes, with different blade counts (although the optimal blade geometry might vary, as the solidity ratio increases with blade count).

While a two-bladed propeller emits only two acoustic pulses per rotation (compared to three and four for a three-bladed and four-bladed prop respectively), collectively they are louder than the noise per rotation of propellers with more blades, assuming the same overall lift is being generated from each prop.

While more blades might theoretically mean more drag and manufacturing expense for the propeller, if the same thrust can be maintained while making the ride less stressful for air taxi passengers, it will become increasingly important for propeller and aircraft manufacturers to develop (or partner with) teams with large-scale acoustic testing facilities.

In addition to acoustic testing, air taxi propellers might benefit from some form of real-time integrity testing to ensure they are working well enough to assure passenger safety. For example, some helicopter blades have multiple fine-wire filaments woven into their layers, with an electrical circuit continuously passing through it to confirm integrity. Should the smallest crack occur, the circuit is broken and the monitoring system can then activate an alert.

Such tests are rare for unmanned aircraft propellers that are already in use.

Some manufacturers and users might X-ray props to identify internal damage, but generally a propeller is replaced as soon as signs of wear or fatigue are suspected.

Design innovations

The past few years have seen new solutions and approaches to blade configuration emerge, particularly with regard to reducing propeller noise and vibration. For example, while winglets on the tips of propeller blades were being hypothesised as feasible only two years ago, these days they are a common sight on multi-copters.

A winglet blade will induce less drag than a 'flat' blade of equivalent material volume, and generate less noise, as the shorter distance between the blade hub and its tip means the effective tip speed is kept further from the speed of sound without sacrificing lift.

This shorter hub-tip distance also decreases the risk of injury from accidental blade contact. However, as this technology is still fairly new, real-world data for modelling and optimising the exact performance characteristics of wingletted propellers might be hard to come by, compared with conventional planform props.

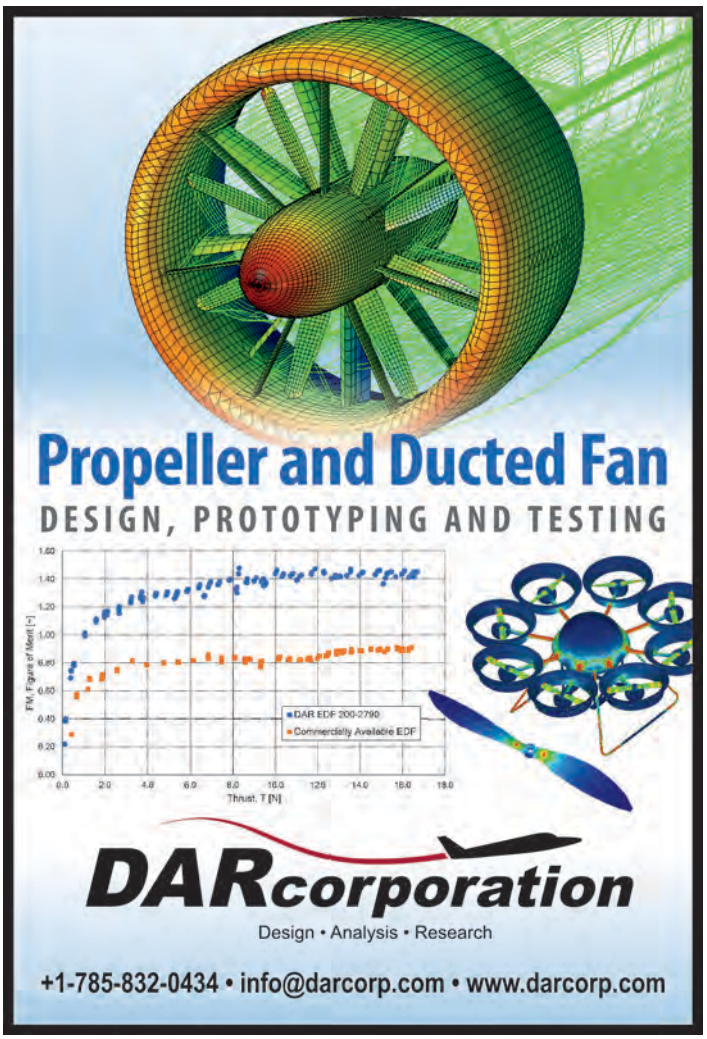
Also surging in popularity is the use of hub-less, rim-driven propellers for UUVs. Here, the outer sections of the propeller blades are mounted to a ring that is directly driven by a motor in the rim. This typically means the ring is integrated inside a permanent magnet rotor, with the motor stator encircling it.

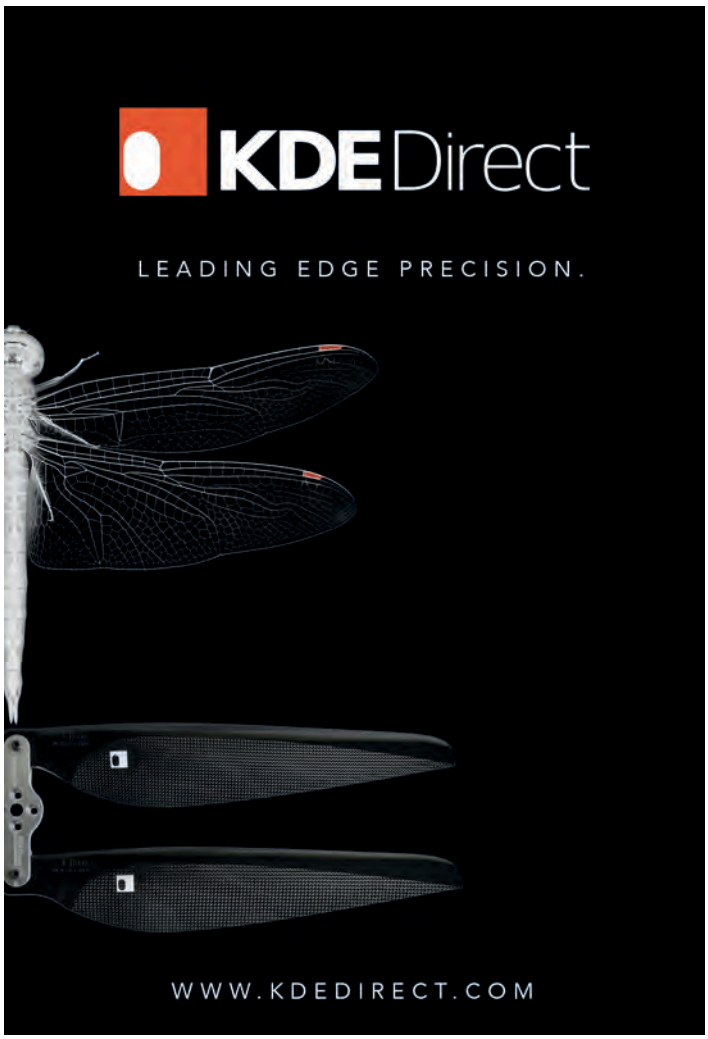
With the tips of these hub-less thrusters pointing into the centre of rotation, tip speed – and therefore 'noise' and vibration – are greatly reduced compared with typical hub-driven propellers for AUVs and ROVs. These rim-driven thrusters are also simpler, more reliable and more energy-efficient, as they eliminate the need for a shaft or gearbox.

Such mechanical simplicity also means the thrusters can be more easily configured for azimuthing. As a result, even USV designers and autonomous shipping developers are becoming more interested in these thruster-propeller systems, for the 360° directional control and station-keeping abilities they can provide for complex surveys and manoeuvres, compared with conventional thrusters limited to pointing off the stern of their vessels' hulls.

Their design was a rare offering a few years ago, often being additively printed to capture their then-unusual geometry. As demand has risen though, justifying the case for bulk production, they are now widely available in a range of sizes and power ratings, and in metals and injection-moulded plastics.

We might see further innovations for aerial props in the future. For example, studies have been conducted in the past two years into UAV propellers with







Belt-driven variable-pitch propellers can provide highly efficient propulsion, but for some UAVs a direct-drive VPP would be preferable (Courtesy of Hawk Aviation Technology)



Passive VPPs have specific pitch angles embedded into the hub to optimise propeller efficiency without needing complex hydraulic or mechanical arrangements (Courtesy of Aerovate)

serrated trailing edges, for multi-copter and fixed-wing flight.

Results from modelling and testing propellers with sawtooth serrations indicate that they produce no particular aerodynamic advantages over conventional trailing edge designs. However, the findings show that they produce less noise, with greater reductions coming from larger, sharper 'teeth'.

Further testing is needed though, as some findings suggest that at very high revs the serrations might actually generate more noise than smooth trailing edges, and might be best suited to low-to-medium revs.

The serrated trailing-edge approach is a biomimetic design, inspired by the serrations on bird feathers. Biomimicry is also spurring explorations into other blade shapes, including some designs that imitate cicada wings or maple seeds for example.

Speed tests and anechoic chamber tests have been run on propellers with geometries and volumes matching these shapes. Results so far indicate that they can generate equivalent thrust to conventional propellers with the same power input, but with reduced wake regions, tip vortices and therefore less noise.

For all the technological advances made in their designs, however, fixed-pitch propellers will often be a compromise between two optimal geometries. A fixed-wing aircraft's propulsive efficiency relies on a steeper pitch during take-off and ascent than in cruising flight, owing to the higher power output needed at those times.

Variable pitch

Variable-pitch propellers (VPPs) provide for this by hydraulically, mechanically or electrically rotating the blades until the optimal pitch is reached. Multi-copters consume more power in hover than in motion, and might similarly benefit from integrating VPPs, as some new designs have done.

A key drawback with these propeller types though is their complexity. Using a VPP introduces several potential points of failure, and fitting six or eight of them on a heavy-lift multi-copter could pose too much of a public safety risk in national airspace.

For electric or hybrid-powered fixed-wing UAVs, however, electric VPPs have continued to develop. Belt-driven electric VPPs are now available for users seeking to increase the energy efficiency of their systems, by having a motor running at lower revs than its propeller.

For HALE systems, which need to maximise endurance and consume as little energy as possible, a belt-driven VPP could save input power and alter pitch to suit the thin operating atmosphere.

Such systems are not ideal for maximising flight speed though, so defence and special forces UAVs for example might be better off using more conventional direct-drive electric VPPs, to ensure surveillance payloads can be launched at short notice for instance.

Passive VPPs have grown in popularity over the past few years. They are mechanically simpler than most other VPP configurations, and operate by having the hub system embedded with a specific take-off pitch angle and cruising pitch angle. Actuation between the two is triggered by changes in air resistance on the blades as the craft changes airspeed and altitude, transitioning between ascent and cruise.

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the specific aircraft's flight profile, and works as a turnkey replaceable system, rather than needing a dedicated internal architecture to provide hydraulic or mechanical actuation of the blade pitches. They are also often designed to fold back mechanically – a quality that has proven increasingly useful for tiltrotor UAVs.

Most tiltrotor UASs are now configured to use three or four rotors for take-off and landing but only one or two for cruise. By folding back the propeller blades and switching off their motors, they are kept from interfering with the airflow, and the vehicle saves significant power and operating costs.

As with fixed-pitch propellers, the past few years have seen passive VPP manufacturers developing and maturing larger form factors of their technology. Wind tunnel testing is enabling the optimisation of diameters far above the 60 cm typically seen with these systems – upwards of 100 cm in some cases – with additional design work to produce lighter hubs (using less metal) to compensate for the weight increase that comes with larger blades.

Ongoing research is also being conducted to develop passive VPPs with four or more blades, to suit the larger unmanned aircraft coming onto the market. Data continues to be gathered for the ever-growing tiltrotor UAV market, in the interest of optimising passive VPPs between vertical lift, stationary hover and horizontal cruise on a single aircraft.

Acknowledgements

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The tide is turning

USV developers are ditching hull-like designs in favour of those that can remain more stable in a range of weather conditions. **Rory Jackson** reports

For a long time, the design of USVs has been geared towards conducting hydrographic and topographic surveys for various industries. Partly as a result of this, the development of unmanned watercraft these days is influenced less by boat manufacturers and more by the hydrographic surveyors who operate them. And just as UAVs need to minimise vibrations to avoid generating blurry imagery, so USVs must cope with being buffeted by waves or other boats if they are to generate actionable survey data.

The shapes and capabilities of the vessels are therefore being designed more and more around stability and controlled manoeuvrability in a range of weather and maritime traffic conditions. Even in applications outside surveying, USVs are being built to hold their position and be resilient to external sources of motion or damage.

Coastal surveys

Florida-based Sea Robotics is close to completing the prototype of its newest platform, the battery-powered SR-Surveyor M1.8, which was unveiled publicly in April 2019 after about eight months of development. Although the company's USVs have typically been larger than the new craft, which measures 1.83 x 0.91 m, Sea Robotics' engineers sought to scale down its technologies and competencies to suit this vessel.

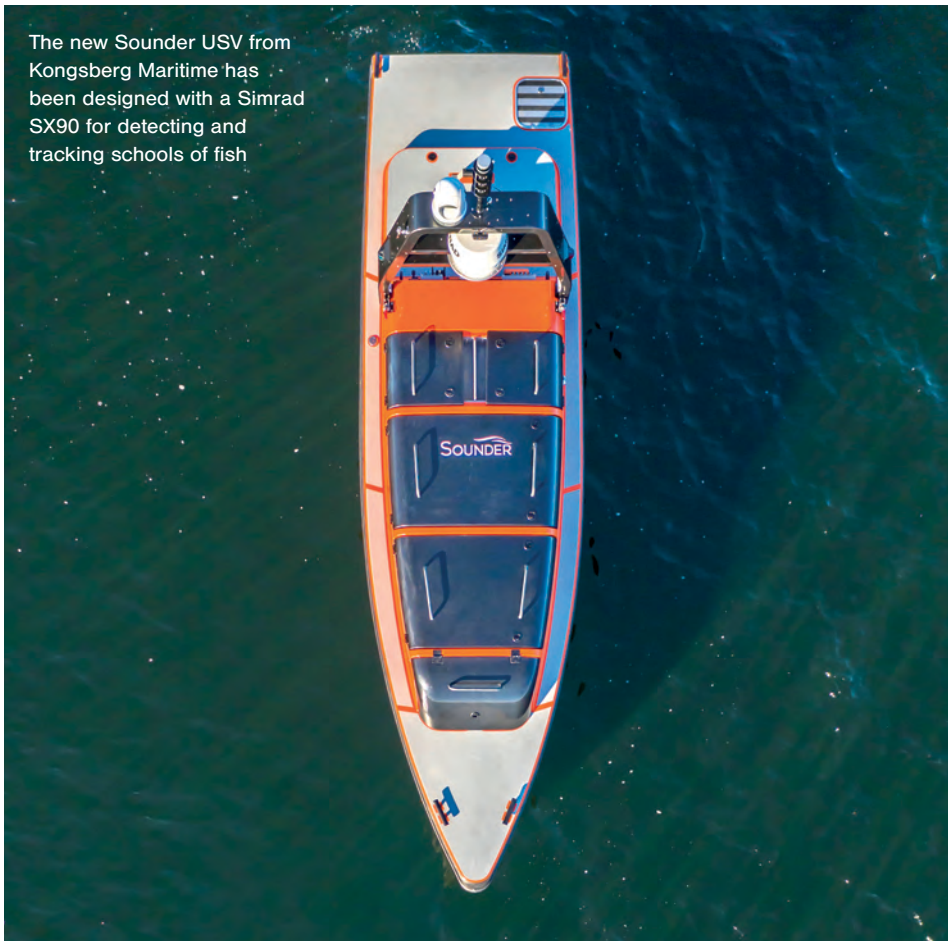
"We've identified an increasing demand for man-portable bathymetry units that can operate in shallow waters or remote areas," says Geoff Douglass, the company's development manager for USV platforms.

"To support multi-beam echo sounders on a vessel which can provide around a day's worth of endurance, boats usually have to be much larger than the M1.8, in order to support the right battery capacity or fuel weight. Our next-smallest vessels are 2.5 to 3 m long, going up to 7 m long in our production series."

The M1.8 has a catamaran shape to provide additional stability and station-



The SR-Surveyor M1.8 is powered by a customised lithium-ion battery, with specifications suited to support the USV's required performance and sensor architecture



The new Sounder USV from Kongsberg Maritime has been designed with a Simrad SX90 for detecting and tracking schools of fish

keeping for gathering sonar imagery amid waves and wind. Also, for vehicles of its size class, surveys tend to be conducted at speeds of between 3 and 5 knots, and at such speeds a catamaran design tends to provide the right hydrodynamic efficiency and stability, as well as the necessary balance for controlled pitch and roll.

"When you're engineering a system to run on batteries, you really have to prioritise efficiency, and optimise everything around that," Douglass says. "And, somewhat uniquely for a catamaran USV, we don't hang anything between the two pontoons.

"We have an acoustic doppler current profiler (ADCP), an EdgeTech 6205 side-scan sonar and other sensors, all fared into the hull. That allows us to have a 1.8 m hull that can move at up to 7 knots and survey for up to 6-8 hours."

Under the rear of each pontoon is a 1 kW BLDC thruster to provide the craft's speed and endurance.

> We've identified an increasing demand for man-portable bathymetry units that can operate in shallow waters or remote areas

The payload bays are essentially 'buried' into the pontoons. For example, a well for integrating ADCPs or DVLs is on the forward part of the left pontoon.

This design approach was originally used for another Sea Robotics USV, the Hycat. That vessel was developed in partnership with YSI, Hypack and Sontek for water quality inspections, and was fitted with a Sontek M9 ADCP for current profiling, discharge measurement and bottom tracking installed in the well.

On the forward well of the M1.8's right pontoon, an AML micro SV sensor is typically installed to provide sound velocity measurements for the EdgeTech sonar. Other motion compensation for the sensors (and for navigation referencing) is provided by an SBG Systems Ekinox INS.

At the top of the forward main hull, a Velodyne Puck Lidar can be installed for terrestrial mapping. "We designed



The SB100 from GPA Seabots is less than a metre long, and is designed to be easily portable and deployable in harbours and marinas at short notice

this USV really for coastal, infrastructure inspections – inshore pipeline surveys, habitat mapping and inspections of bridges, piers and under rigs – and the Lidar gives a 360º view of data points," Douglass explains.

"To power all these sensors, we use a lithium-ion battery that we've had customised for this vessel and mission profile. COTS power solutions are never going to be optimal for an unmanned system like this, with its own mission, power requirements and performance profiles. So we specified a particular discharge rate, weight, form factor, chemistry and other specifications we wanted to package the M1.8 around, and the battery supplier made it for us."

In another offshore autonomy development, TASA, the largest fishing company in Peru, has ordered one of Kongsberg Maritime's new Sounder USVs to provide surveying and research capabilities for the company's fisheries.

The 8 m-long craft comes with a Simrad SX90 'fish-finding' sonar that operates over a 20-30 kHz band using an FM signal with filters for enhancing fish school detection, definition and tracking at a range of up to 8 km.

A 125 hp Steyr diesel engine gives the craft a top speed of 12 knots, with an operating speed of 4 knots, at which the USV can operate for up to 20 days, while communicating data back to the operator over a maritime broadband radio link or Iridium satellite connection.

Marina and harbour inspections

GPA Seabots has designed a USV that measures about 95 x 65 x 31 cm, to provide inspections and survey around marinas and harbours that are congested with boat traffic.

The SB100 was developed particularly for industries needing a one-man portable survey and measurement tool that could be transported and deployed at a moment's notice. As a result, the craft weighs only 12 kg.

"This compact craft has its instrumentation integrated to obtain data in marinas, canals, swamps, lagoons and sheltered waters," says Pau Sarsanedas, founder and CEO of GPA Innova, the parent company of GPA Seabots.

"For example, a harbour master might urgently need to measure the depth of the mouth of a harbour, so they can't wait for a manned survey boat or team of divers.

"We're based in Barcelona, and the law there says you need at least five divers and a great deal of costly equipment for safety. Alternatively, a single person can quickly deploy the SB100 and control its operations and sensors from its rugged GCS."

Typical sensors include a 450 kHz single-beam sonar with a 100 m range integrated on the front of the craft between the two pontoons, a side-scan sonar for seabed mapping, an FPV camera for visual inspection and real-time control, and a 360° fisheye lens camera that records the vehicle's surroundings during surveys.

"The panoramic camera means you don't lose any detail of what's happening around the SB100 as you survey. When you're back in your office, you can review that footage and see if there was anything affecting the vessel or the water above the surface that might inform how you analyse your survey data," Sarsanedas says.

"That data is also delivered to the GCS in real time, so the user sees the sonar imagery as the operation proceeds. And the programmable autopilot allows them to map out the survey path, so they can concentrate on the image feed, with the real-time FPV-based manual control being available if they see something that merits deviating from the planned route for closer inspection."

The SB100 typically comes with real-time kinematic GNSS integrated, so that waypoints accurate to 1 cm can be plotted. That enables automated inspection paths to be very close to moored boats, jetties and other objects, and it has a multi-constellation satellite capability to keep a constant position fix.

Operations are carried out at a cruising speed of between 3.6 and 5.4 kph, with a top speed of 9.36 kph. Propulsion comes from a pair of 135 W Blue Robotics thrusters behind each pontoon that provide 5 kg of thrust and full 360° rotation in the *z* axis. The thrusters and sensors are powered by a 14.8 V, 20 Ah battery pack as well as PV cells integrated atop the pontoons.

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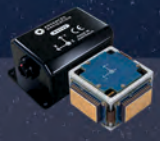


UAV













	ORIENTUS	SPATIAL	SPATIAL DUAL	MOTUS	SPATIAL FOG	SPATIAL FOG DUAL
Heading	0.5°	0.2°	0.1°	0.05°	0.05°	0.01°
Pitch & Roll	0.2°	0.1°	0.1°	0.03°	0.01°	0.01°
Positioning	-	20 mm (RTK)	8 mm (RTK)	-	8 mm (RTK)	8 mm (RTK)



ADVANCED NAVIGATION

POSITIONING EVERYWHERE

AutoNaut has unveiled a 3.5 m version of its solar-powered, wave-propelled craft, initially for users seeking a maritime comms relay platform



Telecoms

AutoNaut, having developed and matured its main 5 m-long USV roughly two years ago (as detailed in *UST* 12, February/March 2017), has launched a 3.5 m version of the wave-propelled craft, aimed primarily at providing a mobile maritime comms hub.

"The advantage of the 3.5 m variant is that it is more straightforward to recover at sea – that can be done with the 5 m too but the 3.5 is lighter and has a single-point lift," says Pete Bromley, managing director at AutoNaut. "Recovery and launch are therefore quicker and safer."

While the 5 m version has more carrying capacity for power and sensors, and therefore more versatility, the 3.5 m craft is designed to be more focused on missions such as comms relay, after AutoNaut's clients started asking for a more 'deployable' long-endurance USV built around a single primary sensor.

The 3.5 m AutoNaut's lack of an engine or propellers for propulsion means acoustic sensors can transmit and receive with minimal interference, and its wave-powered control system enables it to hold station between two points needing it as a relay.

Bromley notes, "Station-keeping is sometimes a challenge for renewably powered USVs – be they sail-, wave- or solar-powered – but the AutoNaut can continuously circle a given waypoint within a radius as little as 25 m. We've now conducted missions of several weeks in length but there is scope to go for many months at a time."

The AutoNaut 3.5 is currently rated to perform for three months or more, potentially providing comms between two moving points, such as separate scientific research or maritime prospector vessels, or between a moving vessel and a shore base.

"Originally, the early prototype and pre-production AutoNauts were in fact all 3 or 3.5 m long," Bromley says. "We scaled up to 5 m for the first production model because that allowed us to concentrate on ensuring mechanical robustness and providing versatility to early adopters. After much sea-trialling and a wide range of missions with the 5 m craft, we then brought the lessons we learned back into the 3.5."

Such lessons helped to inform the layout of the internal architecture so that the 3.5 m version's designers could make the best use of the space. And the wave propulsion system was designed to be fundamentally scalable, meaning most of the changes between the two unmanned craft simply involved miniaturisation of the hull and the propulsion system's architecture.

The 3.5 m version integrates 170 W solar panels onto a hull that is built from fibre-epoxy composite, with structural PVC foam sandwiched into the internal structure for additional buoyancy. The PV cells charge two 90 Ah lithium-ion batteries, which supply the 40 kg (or 270 litres) of payload volume the USV can carry, and the standard UHF line-of-sight comms system it comes with.

Defence and security

The Accession USV is a project funded by the European Regional Development Fund and developed by UK company Unmanned Survey Solutions (USS).

The financial backing was awarded through Marine-i, an EU-funded programme for promoting marine technological innovations. The project was given the green light for development in April 2018, and around nine months of design work followed.

Like many unmanned vehicles being developed, the vehicle is based around a modular framework, but rather than simply having one or two swappable payload bays, the Accession's hull is

designed as a system of replaceable cartridges or 'pods'. That means it can be modular in terms of its carrying capacity for systems such as payloads, avionics or power banks.

The Accession also has a reverse-bow design, a shape increasingly adopted by vessels for heavy weather, to make it more stable when taking images of coasts, seafloors or marine infrastructure.

"You can have a bespoke length of, say, 3.5 m, and then the stern detaches and you can integrate an extra 75 cm or 150 cm length of hull," says James Williams, director of USS and managing director of Swathe Services, which supplies maritime survey technologies.

"As well as more batteries or payloads, users can add a diesel generator to ramp up their Accession's endurance. As a result, the 3.5 m version runs for about 12 hours as standard, the 5 m version for about eight days.

"Also, if required, a user could obtain just one USV and then half-a-dozen different payloads through Swathe Services, which they'll be able to use in any combination of as many or as few as they want," Williams says.

The company's method for joining the USV's different sections is currently proprietary and cannot be disclosed, but Williams says it should take survey operators roughly 30 minutes to replace a mid-section of the vessel if a different operation needs to be carried out.

That would include unplugging the USB connections for power, as well as Ethernet connections for data, but otherwise the pods are designed as turnkey systems. In operation, the main system batteries can be recharged while the mid-section is swapped out.

The USV has largely been designed to work as a force multiplier with a mothership such as a 12 m port authority catamaran, or a bigger vessel needing a more nimble, long-endurance survey tool.

As well as providing a high degree of payload modularity and thus a range of survey possibilities, the company sees a major application of the craft as a launch-and-recovery platform for UAVs.



The Accession USV is made from three detachable sections, with the middle part customisable across different sizing options

If required, a user could obtain just one USV and then use several different payloads in any combination – as few or as many

"Swathe Services also represents Planck Aerosystems, which has developed the capability to launch and recover UAVs from moving platforms, whether that's flatbeds or UGVs on land or boats, or USVs in motion across water," Williams explains (and as featured in *UST* 25, April/May 2019).

"The US military is taking great interest in that platform, and even looking into developing tethered versions, and we are integrating Planck's Shearwater UAS into our USV to provide an unmanned force multiplier across air and sea."

That might also include integrating a UAV charging station into a future mid-section pod of the Accession, potentially to charge the Shearwater from the onboard diesel generator.

"Of the nine months we spent on developing the craft, most of that time was spent on modelling, to place sensor combinations sensibly and prevent bubble-wash – which can harm sensor performance on a lot of USV designs, especially sonars – and to ensure that we had the design right before building the moulds for bulk production."

Heavy industry

The Apache 6 USV from CHC Navigation is a 40 kg vessel measuring 1.8 m in length, and is built largely from carbon composite with anodised aluminium and stainless steel. It can carry up to 60 kg of payload, and operates at speeds of between about 7.2 and 9 kph, with a maximum speed of 12.6 kph.

"We've done a lot of survey work for the Macau bridge, which connects Hong Kong to mainland China, and the Apache is also often used to perform inspections on hydroelectric dams," says PJ Walker, managing director at CHC Navigation UK.

"We have also carried out a water volume survey at the Dorothea Lakes in North Wales, the site of a former slate mine, which ranges from 5 to 70 m deep. That was particularly tricky because the environment in the water has unusual 'thermal climb' properties, with sudden changes in water temperature – if you don't select and calibrate your echo sounders correctly, the sonar will think it's found the bottom, when really it's just found a different density of water."

Key to its ability to conduct survey work for heavy industry infrastructure and projects was it being designed and optimised around a Norbit multi-beam echo sounder, which is integrated into the underbelly of the central hull section.

Development of the Apache 6 was originally spurred by CHC Navigation customers who were familiar with the craft's smaller predecessor, the Apache 5, but who wanted a USV that could provide a higher quality data set. The Norbit sensor was selected for meeting the specs to provide that, but its weight and power requirements – typically 9.5 kg and 60 W respectively on the standard Norbit – meant creating a larger USV than the 160 cm-long Apache 5.

The standard version of that sensor operates at a frequency of 400 kHz and covers a swathe of 7-210°. It has a range of up to 275 m from the craft and a range resolution accurate to within 10 mm. An Ethernet link is used to interface with the Apache 6's onboard processor.

Its trimaran shape was chosen for stability during data gathering in turbulent waters with 2-3 m swells. However, the outboard riggers are removable in case the operator is working in reasonably calm waters or needs a narrower hull shape for navigating tight spaces or busy areas.

It also typically comes with an 8 W Lidar sensor with a 360° FOV, mounted on a bracket atop the hull for gathering 3D image data above the surface (and below) in the 'roll' axis.

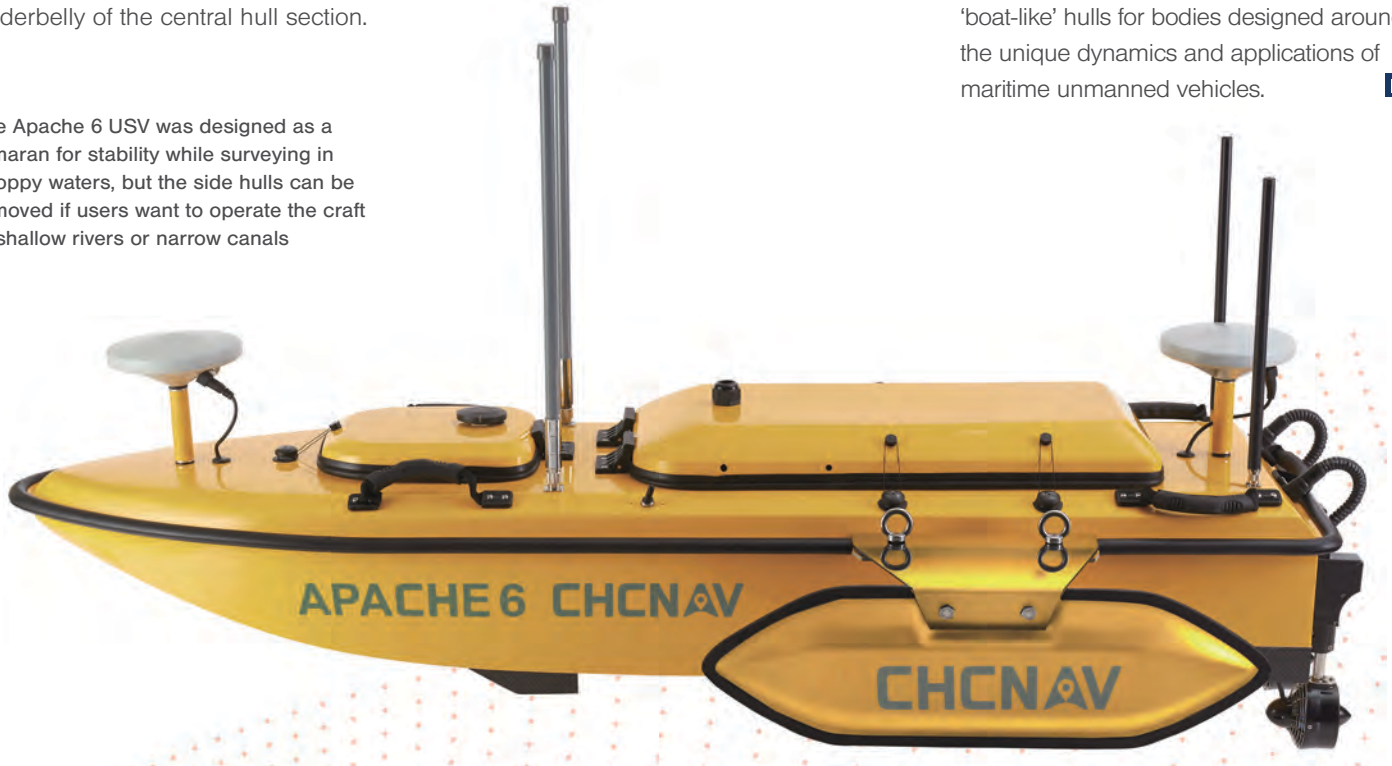
"The USV has two covered bays. The front one is for installing processing computers for sensors, while the larger, rear one is for the lithium-ion batteries and the main processing computer for navigation and telemetry," Walker adds.

In order to view, analyse and dynamically react to surveyed data in real time, the USV comes with a complex comms architecture. Although mission routes can be plotted and automated beforehand through the vehicle's CHCNAV Auto Planner software, a 1 GHz remote command link is supplied via an omnidirectional antenna over a 1 km range.

Imagery is supplied to the GCS over a live 5 GHz data link with a 0.8 km range, and for surveys further away or for redundancy a 900 MHz connection with a 1.5 km transmission range is also integrated.

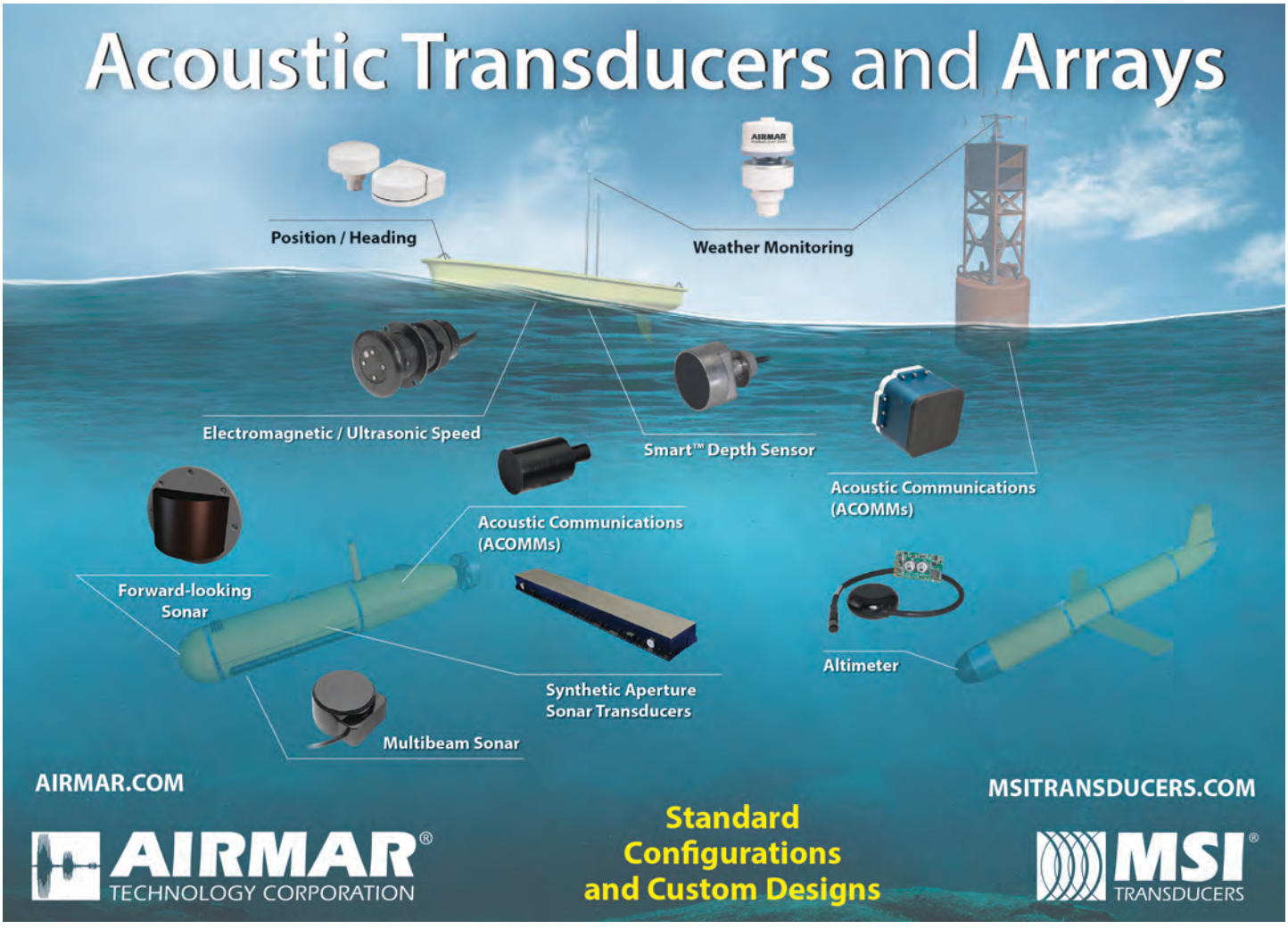
Conclusion

As in the air and on the ground, USV designs are becoming more diverse as manufacturers identify how best to cater for different users and mission profiles. As technological progress, climate change and user awareness grows, the years ahead will probably see even more configurations abandoning traditional 'boat-like' hulls for bodies designed around the unique dynamics and applications of maritime unmanned vehicles.



The Apache 6 USV was designed as a trimaran for stability while surveying in choppy waters, but the side hulls can be removed if users want to operate the craft in shallow rivers or narrow canals


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News from the Windy City

Rory Jackson presents the first in a two-part round-up of the product highlights at this year's exhibition, held in Chicago

The world's largest exhibition and conference for unmanned technologies, AUVSI Xponential, was held this year from April 29 to May 2 at the McCormick Place convention centre in Chicago. More than 700 companies from around the world showcased their platforms and inventions for autonomous vehicle systems, with hundreds of new solutions being launched, and new markets and industries being represented.

KDE Direct attended the show to unveil its 13218XF-105, a new motor aimed at heavy-lift applications. As Leslie Koegler explained, "This motor can provide up to 68 lb of thrust, and is the largest in our product line-up."

The motor measures 150.2 mm across, weighs 1.915 kg and integrates 36 stator poles and 42 permanent magnets, as well as a shaft measuring 69.2 mm. The input voltage range runs from 22.2 to 60.9 V to enable compatibility with power sources from a 6S lithium-ion battery to a 14S system, and the motor has a kV rating of 105 rpm/V.

The company also launched the KDE-UBECUVC, a universal battery eliminator circuit for fixed-wing and multi-rotor UAVs. This weighs 90 g, and is capable of regulating voltages from 14.8 to 60.9 V with active braking, down to a selectable 5, 6, 8 or 12 V. It has six JST pin-out channels and one high-power output lead.

Sarcos Robotics unveiled a commercial variant of its snake-like



KDE Direct's 13218XF-105 motor provides up to 68 lb of thrust



The Guardian S snake-like UGV is now available commercially

Guardian S UGV, which was originally developed several years ago for defence operators to perform remote inspections of pipes, culverts and other tight spaces too small for typical inspection robots.

"It's completely wireless, uses no tether, and the tracks have rare earth magnets underneath, so it can climb ferromagnetic surfaces," said Scott Archer.

"The onboard radios communicate over 2.4 GHz, 900 MHz and mesh wi-fi networks. Communicating with the UGV when it's deep in a pipe or a similar place can vary. Sometimes, a wi-fi link is maintained without issue; sometimes an antenna needs to be positioned at the opening of the pipe, but we've yet to lose connectivity completely."

The UGV is equipped with six 4K cameras with digital zoom and autofocus that are positioned around its body, and they can perform surveillance for up to 12 hours or operate over distances of 4.8 km. They are powered by three lithium-ion batteries with a collective energy capacity of 147 Wh.

Picatinny rails are installed to allow payloads to be integrated. Payload capacity is up to 4.5 kg if travelling horizontally; 2.25 kg if the UGV has to climb vertical ferromagnetic surfaces.

The Guardian S extends to a maximum length of 132 cm, weighs about 8 kg, and has a top speed of 2.25 kph (or 0.97 kph for the magnetic version when moving up or down a vertical surface) if no payload is added.

Although tethers are not required for power or comms, the company offers them for easier retrieval. Commercial applications for the vehicle currently include mine surveys and infrastructure inspections in industries such as oil and gas, power grids and urban infrastructure.

Maxx Products displayed a new range of four UAV servos from Innoflight Tech.

"You can program these servos, for example to run at constant current," said Baoyou Wang. "That ensures the servo never overheats owing to excess current, which goes towards overall UAV safety.

"At full load, they have been tested to last 300 to 500 hours, and the servos integrate magnetic coded potentiometers in their brushless DC motors for consistent and accurate position sensing."

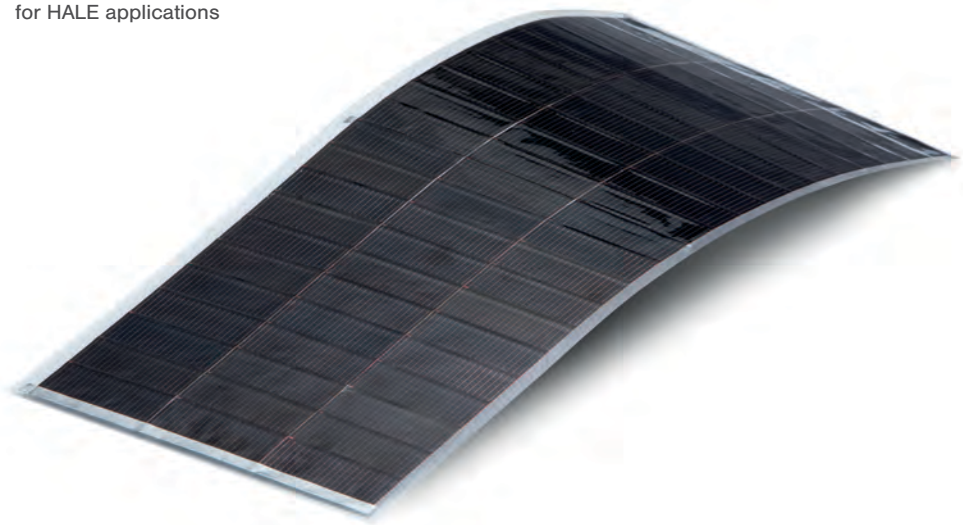
The largest in the series, the SM40035F, measures 120.2 x 100 x 51 mm and produces up to 400 kg/cm of torque, on a power supply of 12-24 V DC. The smallest, the ST3514F, measures 44.1 x 40 x 20 mm and gives 35 kg/cm of torque, with 4.8-8.4 V of input power.

All four are housed in CNC-machined, IP67-rated aluminium housings and use titanium gears, with comms options including PWM, UART and CAN bus.

Alta Devices unveiled the AnyLight for HALE, its newest HALE solar module for integrating onto high-altitude UAV wings.

"It's a complete product for stratospheric solar aircraft, where the module's design, integration and packaging have been geared towards power and aerodynamic efficiency at

The AnyLight solar module, for HALE applications



20,000 m," Aarohi Vijh explained.

"It uses our Gen4 AnyLight solar technology announced last year, which is based on our single-junction PV cell technology. The packaging design has been optimised and characterised to support multi-year lifetimes.

"The packing factor – how densely you can pack the PV cells into a given wing area – has been maximised as well, as that influences how much power you're carrying."

Alta uses an overlapping design for interconnecting solar cells, which enables close to 100% use of wing area for cell integration. The company has a proprietary modelling suite built around circuit modelling software Spice, and atmospheric radiative transfer simulators for electrical layout and simulating the performance of the solar array in different conditions, including variations in environment, damage, temperature and illumination.

Gladiator Technologies has developed a processing firmware suite called Velox, which is installed in all the company's digital IMUs, gyros and GNSS-INSs.

"With Velox we have created a high-speed processing solution that can achieve up to 10 kHz speeds for sampling and data output," said Eric Yates. "It also enables a 350 Hz bandwidth, and message latencies of less than 200 μs."



Gladiator Technologies' LandMark 60LX IMU

The company is also close to completing development of its LandMark 60LX IMU, which will have a 28 μ*g*/Hz accelerometer and a 4°/h in-run bias stability gyro. It will weigh 125 g, measure 50 x 45 x 34 mm, and typically consume 550 mW. The new system is expected to be released shortly.

"The 60LX MEMS IMU has exceptionally low-noise accelerometers and gyros," Yates said.

"Velox is also a key feature, offering high-speed processing and filtering duties. Users can configure output rates, bandwidth, baud rate and other settings to meet their particular system requirements, although we've found that most users prefer to configure for faster speeds and higher bandwidth."

Southwest Antennas is launching a new line of circularly polarised omnidirectional antennas. The Turbo Cloverleaf range is designed with unmanned systems and multi-antenna MIMO applications in mind.

As Adam Krumbein told us, "They are going to be available for the S and C bands, and the circular polarisation can help establish a good link between the GCS and air vehicle, since polarisation mismatch isn't there to cause comms issues, as it often is with vertical and horizontal antennas. With circular polarisation, the relative angle between the UAV and GCS no longer affects the comms link."

The antennas in the Turbo Cloverleaf range are available as left- or right-hand circularly polarised, and are typically 110-130 mm in height.

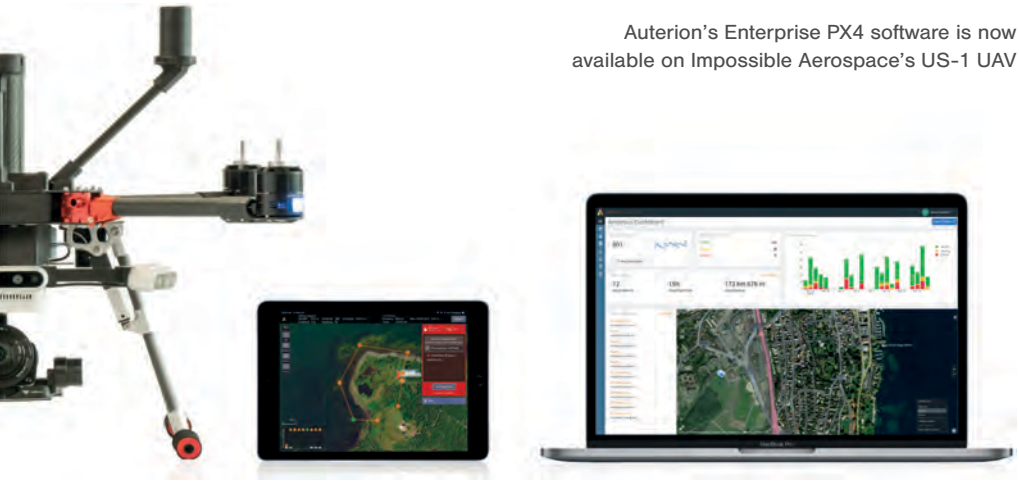
Auterion attended the exhibition to announce the latest integrations of its software solutions, including the installation of the Auterion Enterprise PX4 onto Impossible Aerospace's quadrotor UAV, the US-1.

"The US-1 can fly for two hours on electric battery power alone," said Dr Lorenz Meier. "The PX4 is the flight control and avionics software running on the drone. The full system also runs Auterion Ground Station on a GCS tablet.

"The software is based on the open source QGroundControl software architecture. The UAV is connected by LTE to Auterion Cloud Insights, which provides fleet management, automatic log analysis and management, pilot management, and real-time predictive maintenance if there is a problem with the vehicle."

Meier added that the open source nature of Auterion's software means that integration requires minimal time and work, and that some aspects of Impossible Aerospace's technology already use very similar software. That therefore reduces the amount of new learning required by manufacturers and test pilots.

"By integrating our software onto



Auterion's Enterprise PX4 software is now available on Impossible Aerospace's US-1 UAV

Impossible Aerospace's systems, we learned a lot about the safety aspects and other requirements of working in the emergency services sector. It has ramifications on the specifics of how the vehicle should behave, the ways in which missions need to be planned, and what constitutes desirable failsafe behaviour," Meier noted.

General Electric's autonomous avionics hardware platform is also due to use Auterion's software. That GE system will be provided for aircraft in a range of commercial and government projects, and Auterion will provide ongoing support in terms of firmware updates, software maintenance and cyber security to both GE and Impossible Aerospace.

TaiSync attended the show to display its newest data link products, the latest of which is its line of ViuLinx wireless modules, which have been designed with Ethernet, HDMI and USB functionality.

"It is a video, telemetry and RC combination link, and has an HDMI input on the aircraft-side unit and one for the ground unit, with a USB interface for the ground unit as well," said Yan Li.

"Telemetry is communicated through a UART interface, and remote operation occurs by PPM or S-bus interface. The system is designed to be integrated with the PX4 autopilot ecosystem, so it's available with the QGroundControl software for GCSs.

"We also support Ethernet interfacing, including one input for the air unit and one for the ground unit," he said.

The ViuLinx air unit measures 77.8 x 47.3 x 23.5 mm, and weighs 97 g. The ground unit is 130 x 90 x 28.5 mm in size, but the weight has not yet given.





Bell's Nexus urban air mobility vehicle



TaiSync's ViuLinx data link units have Ethernet, HDMI and USB interfaces



Both units are tested to operate between -20 and +55 C, and communicate over 1.4-1.495 or 2.4-2.495 GHz bands.

The overall system offers downlink throughputs ranging from 2.3 Mbit/s to 12 Mbit/s, as well as BPSK, QPSK or 16-quadrature amplitude modulation.

Bell showcased a full-scale model of its Nexus urban air mobility vehicle, with which the company hopes to begin commercial operations by the mid-2020s.

"We are actively working with regulatory agencies, testing components and sub-components, and developing our production vehicle to meet that commercial operation target," said Sam Bryk.

"The configuration here, with six rotors, is a concept vehicle but it's what we're currently developing towards. The initial vehicle will probably reflect something very close to this, depending on factors such as wind tunnel data, flight test data and regulatory requirements."

Bell has partnered with Safran, which will provide the single gas turbine engine for the craft's powertrain, and the electric motors to be powered by that engine.

Inertial Labs presented several key improvements for existing inertial systems and unveiled a new dual-antenna inertial navigation system, the INS-DL. The system is compatible with all major multi-frequency constellations as well as SBAS, DGPS and RTK.

The INS-DL can be configured with different Kalman filters depending on the type of vehicle on which it will be used. These include algorithms to process inertial data and output actionable motion readings for UAVs, UGVs, UUVs, gimbals, helicopters and automated guided vehicles.

"It also integrates an IMU that has a 1 milli-*g* accelerometer, and gives 3°/h in-run bias stability gyroscopes," said Jamie Marraccini. "We evaluate and use GNSS receivers from many companies, and as well as testing for vibration and shock, we aimed for cost optimisation to keep the price of the INS-DL roughly 50% below the market average."

The company also demonstrated the next-generation variant of its single-antenna GPS-aided INS-P, which integrates a GNSS receiver from Novatel and a gyro-compensated fluxgate compass.

Marraccini added, "The INS-P has many configurable inputs and outputs in order to work directly with different UAV airborne equipment such as Cobham's Aviator UAV 200 Inmarsat terminal."

For surface and underwater autonomous and unmanned vessels, Inertial Labs also presented new multi-functional motion reference units, which are ABS-certified and are fully compatible with most commercially available DVLs. They are designed to measure output position, heading, pitch, roll, heave, surge and sway parameters for unmanned surface and underwater vehicles.

MicroLink Devices solar arrays on an Airbus Zephyr S wing



MicroLink Devices attended Xponential to discuss its continuing collaborations in the HALE UAV sector.

"We are the only solar cell provider for the Airbus Zephyr S platform, and the UK's Ministry of Defence has bought three of those from Airbus," said Ray Chan. "We deliver solar sheets to Airbus, and they carry out the sheets' integration into the Zephyr's wings."

MicroLink's solar cell is a triple-junction structure: an (Al)InGaP/GaAs/InGaAs inverted metamorphic PV cell. The cell has a power density of 300 W/m^2 at AM1.5 (roughly ground-level atmospheric thickness), or 382 W/m^2 at AM0 (zero atmospheric thickness), with rated efficiencies of 30% in the former and 28% in the latter.

"We're looking to improve those figures wherever possible as the HALE market grows. We're now supplying solar arrays to the BAE Systems PHASA-35 aircraft as well," Chan added.

GPS Networking exhibited its GPS Indoor Testing Solution (ITS), which is designed to enable UAV manufacturers to test or demonstrate newly integrated GNSS receivers from indoor (or other GNSS-denied) facilities.

"The key part is the GPS re-radiating kit," said Steven Waite. "We receive the GPS signal through a roof-mounted





Exploded view of the Reference Technologies Hummingbird XRP



WiBotic's Edge wireless UGV charger

L1 antenna, run it through a cable, then amplify and radiate it out of a passive antenna.

"All the satellites the roof antenna sees can then be picked up from a user's workshop, doing away with the risk of bad weather or other environmental hazards when a user wants to test a new satellite navigation system."

Operating the ITS does first require an experimental licence from the Federal Communications Commission, which can be obtained through the FCC's website. The standard ITS kit comes with a re-radiating amplifier with 0-23 dB variable gain and a 50 ft LMR 400 cable, although custom lengths are available on request.

WiBotic exhibited its WiBotic Edge, a variant of its wireless charging technology aimed at factory UGVs.

Able to serve multiple robots, Edge devices can be placed throughout a facility to enable 'opportunity charging' of batteries for short periods of time wherever a robot routinely pauses, for example when loading. That minimises the overall number of UGVs in a factory, since each one can spend more time in service.

"In this configuration, the UGV just needs to pull up to an Edge device but doesn't need to make contact," said Josh Pan. "Charging starts automatically and continues for as long as the robot stays in that location – there is no need for it to navigate into a docking station or take time disengaging from the charger.

"Our technology is also robot-agnostic, permitting interoperability across a variety of robot and battery types. Precise alignment and docking are not necessary to permit efficient and safe wireless charging. Receiver components on the robot can also be customised and weatherproofed if a customer requires."

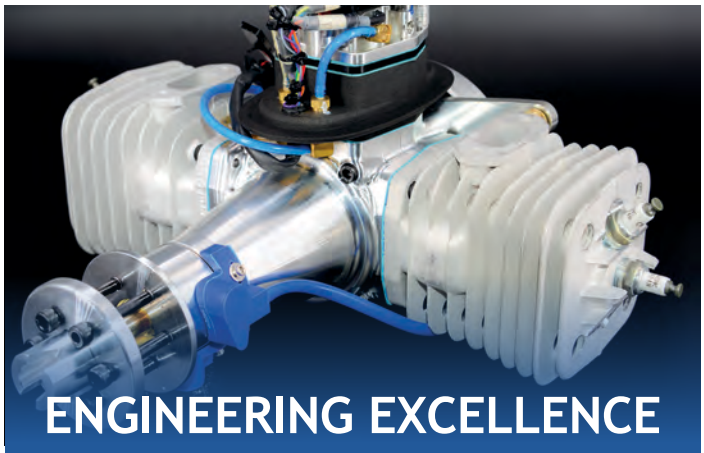
The WiBotic Edge has four fastener holes for securing it to a wall, avoiding the need for floor space. It contains an internal power supply, transmitter circuit board and transmitter antenna. Alternatively, the system can be mounted in the floor to provide unobtrusive charging as a robot drives over it.

The company now offers a range of off-the-shelf systems, for charging at power rates of 90, 125, 250 and 300 W, or more.

Reference Technologies displayed the latest version of its Hummingbird XRP (eXtended Range & Payload) unmanned aircraft, which has a range of updates over the version exhibited at the previous AUVSI, including having been modified from a hexacopter to an octocopter configuration.

"When we came out with the hexacopter, we found users wanted more lift and longer durations, so we added two more rotors to provide an extra 36 kg of thrust," said Allen Bishop.

"To fit these extra motors around the original 61 cm diameter though, we needed a larger circumference, so



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the vehicle's diameter was increased to 76.2 cm. That also provided more cooling through the centre of the fuselage from the counter-rotating propellers in the duct."

The outer propellers are 70 cm in diameter and produce 18 kg of thrust each. The overall thrust produced is about 171 kg in normal operation, enabling missions such as 41 kg of cargo being carried for one hour, or flying with a 9 kg gimbal for nine hours.

The new Hummingbird also integrates an SP-180 Wankel rotary hybrid engine from Sky Power (as detailed in *UST* 25, April/May 2019) to provide gas or multi-fuel propulsion from the central duct and electric power to the eight electric motors.

"That engine provides us with 13 kW at our 48 V supply. Achieving that kind of power density has been the main barrier to the successful development of a UAV like ours," Bishop added.

uAvionix exhibited a number of new products for unmanned aviation safety and airspace integration, including its new 70 g SkyLink command and payload control (CNPC) data link solution, which the company hopes to have certified in the near future.

"One of the requirements we see for BVLOS development is a TSO-certified command-and-control link," said Ryan Reed.

"We are currently certifying our truFYX GPS and Ping200X Mode-S transponder, so we are building on our certification experience and bringing that to the SkyLink. It is designed to be used in enterprise UAVs, leveraging its 10 W transmitter to achieve a range of 75 nautical miles line of sight."

One aspect of certification includes environmental testing and performance. To that end, SkyLink has been designed to operate in temperatures from -45 to 70 C, and is being tested to the DO-160G standard for salt, fog and humidity resistance.

"On the software and hardware development side, you have to meet



The SkyLink command and payload control unit from uAvionix weighs 70 g

design assurance levels. To achieve that, DO-178C Level C software and DO-254 Level C development and testing processes are applied, and any change goes through a robust review process," Reed explained.

The company also displayed its new MicroLink 2 x 2 MIMO data link radio, which transmits at a 200 kHz bandwidth over the 902-928 MHz ISM band. It weighs 16 g, measures 31 x 26 x 9 mm and consumes a maximum of 1.7 W.

Lemo has launched a new line of lightweight plastic circular connectors as part of its SP series.

"These use a patented push-pull system derived from a solution originally developed for, and used in, the medical market," said Julie Carlson. "As more small UAVs are being developed, manufacturers are increasingly demanding connectors that are plastic but also watertight, so the SP series is designed to block the ingress of water."

Lemo has tested the new models to meet IP68 ingress protection for withstanding submersion in up to 1.5 m of water, as well as dust, sand and dirt. The specifications for the connectors will be released later this year.

UAV Factory has developed a version of its Penguin C aircraft, the Penguin C-Mil, for an undisclosed US Department of Defense (DoD) customer, which has been approved for supply by the Defense Logistics Agency (DLA).

"The biggest requirements for getting DLA approval were a higher level of encryption for the command-and-control link, and including a magnetometer for acting in GNSS-denied environments," said Josh Brungardt. "These were critical functions to minimise the risk of the DoD customer losing the asset during field operations, or keeping a rough idea of where it is if a retrieval mission is needed."

Some electronics upgrades and internal modifications for higher heat tolerances were also performed over the six-month development period, in line



UAV Factory has developed a military version of its Penguin C



The OTUS U170 gimbal from DST Control

Midwest Digital's Soliton Zao-S digital encoder is designed for H.265 broadcasts



with the user's specified requirements, although further details were unavailable at the time of writing.

"Designing-in the extra ruggedness for higher internal temperatures was perhaps the biggest challenge of all the different modifications'," added Konstantins Popiks of UAV Factory. "In general, pusher aircraft configurations can't easily be adapted to additional cooling requirements, so to make a UAV compliant with higher temperatures we needed a lot of creativity from our engineers and a lot of testing."

UAV Propulsion Tech, a component supplier, attended the show to display a number of new systems from various UAV companies. Of particular note was gimbal manufacturer DST Control's new OTUS U170.

"It's a 170 mm-diameter gimbal that integrates EO/IR and a laser rangefinder with a 100 μrad destabilisation. It also has a vibration isolation mount consisting of a series of elastomeric components in an aluminium frame for further improving the quality of video recordings and the reliability of the structure in high-vibration environments," said Bob Schmidt.

The IR camera on the OTUS U170 is available with a 3x true optical zoom lens, and the laser rangefinder is capable of measurements up to 3 km. The gimbal is available with Ethernet, H.264 video streaming, KLV metadata, onboard video recording, advanced video tracking and multi-image blending as options.

It consumes less than 40 W of power, with 20 W being typical. It weighs about 2.3 kg and comes with an RS-485 port for user control.

UAV Propulsion Tech was also showing US company ePropelled's new 12 kW Gwynt series of starter-generators, which are rated to a minimum of 95% power efficiency.

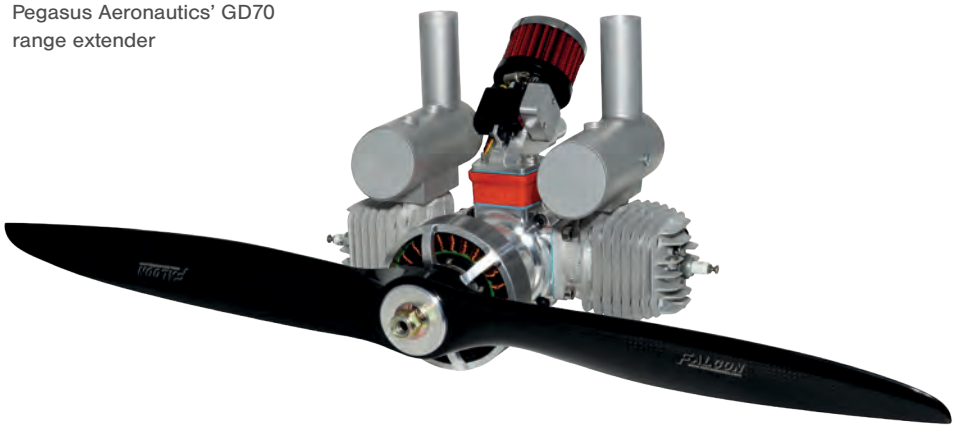
"A significant attraction with these is their maximum temperature capability. They can operate at up to 200 C, which is higher than most starter generators, and without damaging the magnets – an issue that rare earth magnets are typically sensitive to," Schmidt noted. "They have some patent-pending techniques for keeping the electrical parts of the generators cool."

Fuel pump manufacturer HP-Tech's latest brushless motor gear pump formed part of the UAV Propulsion Tech display as well. The system comes in versions compatible with kerosene or gasoline, and uses a 'smart pump' to measure fuel pressure and control the speed of the pump and gearset to maintain flow to the engine without needing a return fuel system.

"That's common in automotive systems because they don't recirculate fuel, and it means the UAV needs only one fuel line going between the engine and the fuel tank. The fuel pump needs less power because it's only sending what the engine is using, rather than continually pumping what's required at wide-open throttle," Schmidt added.

Midwest Digital AV was on hand to discuss its Soliton Zao-S digital encoder, which is designed for H.265 audio video mobile broadcasting. The Soliton Zao-S streams over multiple standards including 3G, 4G-LTE, wi-fi and satellite solutions.

"This bonded cellular technology is designed using our patented RASCOW algorithm to allow the Zao-S to provide audio and video transmission to receiver software and the cloud," said Brian Falatovich.



Pegasus Aeronautics' GD70 range extender



The Force 3U rugged server enclosure from Crystal Group

"RASCOW is written to dynamically adjust the video frame rates, and therefore the data load, according to the condition of the network. The data transmitted is also AES 256-encrypted. One of our tests took place at 30,000 ft, at 600 mph, with a satellite input while achieving a strong constant video output of about 2 Mbit/s."

The system weighs about 410 g, measures 123.5 x 78 x 35.5 mm and can be integrated into heavy-lift UAVs conducting camera broadcast work. Applications for the Zao-S include sporting and entertainment events, news, law enforcement and first response.

Pegasus Aeronautics showcased its newest propulsion system, the GD70 range extender. An air-cooled 70 cc two-stroke, it features an electric generator designed directly into the crankcase, being integral with the engine behind the propeller mount.

"We have been building gas-electric power units for a while now, but increasingly we've been asked to implement gas-electric power generation in a direct-drive configuration," said Matt McRoberts. "So the GD70 is gas-direct as opposed to gas-electric."

The system has a dry weight of 3 kg, and the engine can produce up to 4.5 kW, with the generator typically producing 500 W of auxiliary power, or up to 1000 W depending on the cooling capabilities of the power management unit (PMU).

"We've also worked on the fuel injection of this engine to make it more efficient, broadly by integrating it more closely within the physical engine unit than what you'd see in most conventional two-stroke approaches," McRoberts added.

"Part of that comes from our design that condenses far more electronics into the physical engine than usual to get more sensor data, which the power management system leverages to generate power and time the fuel injection more efficiently.

"That also allowed us to reduce the amount of wiring between the electronics and the PMU, which goes towards significantly lowering maintenance costs and improving long-term reliability, as wiring harnesses tend to be a notable source of failures on UAV engines."

The GD70 is tested to STANAG 4703 and IP67. Interfacing for starting, throttle, diagnostics and all other comms can be conducted through PWM, serial or CAN connections.

Crystal Group displayed its newest offering for rugged unmanned vehicle computer enclosures. Its Force 1U, 2U and 3U servers are designed with a modular system of bays to enable customisation for UAV engineers' specific processing requirements.

"Our Force servers can be designed with architectural templates that best suit the operational environment and performance requirements, such as air or liquid cooling, and dust filters," said Toni Hogan. "With multiple bays of flexible size, end-users can select whatever components they want to integrate, such as an eight-port switch or multiple drive options.

"Each Force unit also comes with a 'sanitise' function, for when any and all mission-critical information needs to be wiped from the drives in a matter of minutes. We developed that feature at the request of the US Department of Defense, as an additional security factor on a current military program."

The servers come in depths of 19, 22 or 25 in, and in variants up to three racks in height, powered by single or dual Intel Xeon processors.

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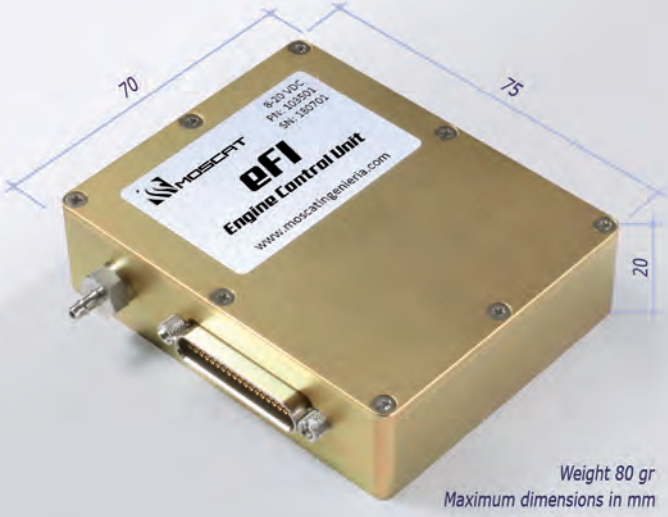
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The UAVE is a four-stroke, two-cylinder boxer that originated from a design intended as a range extender for electric vehicles (Author's image)

Rory Jackson reports on how a range extender system inspired the design of this four-stroke UAV engine

Range of options

It is not unusual for motorcycle engine and component manufacturers to move into developing propulsion systems for unmanned aircraft, applying expertise from one area to the other. Italian company Robby Moto Engineering is the latest organisation to follow this trend. Surprisingly though, the UAVE, Robby Moto's first solution offered principally for UAV propulsion, is not a two-stroke engine nor does it come in a form factor suitable for motorcycle integration.

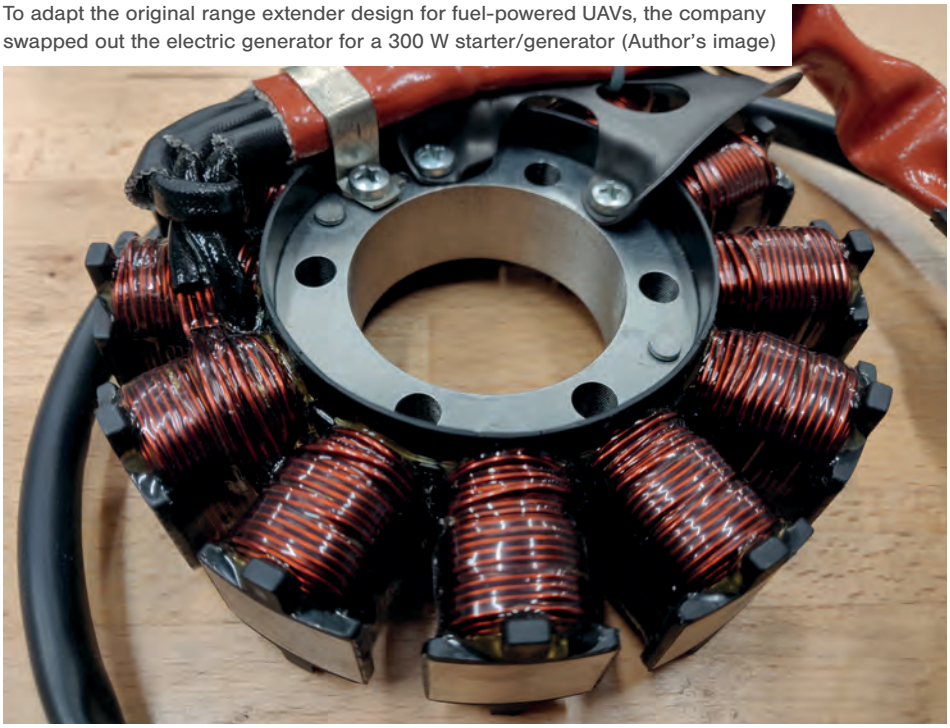
The choice of a four-stroke design stems largely from the fact that Robby Moto has more than 25 years of experience in developing parts and designs specifically for four-stroke motorcycle engines, which have achieved significant success in motorsport competitions. The company has gone on to produce complete four-stroke engine systems for motorcycle and aeronautical use, which continue to be developed and matured as design technologies advance.

Design philosophy

The UAVE is a 23 kg two-cylinder boxer four-stroke engine, and is based very closely on the company's RES (Range Extender System), a design originally conceived as a hybrid power unit for electric automotive powertrains.

The RES was developed in collaboration with the Polytechnic University of Milan. It consists of a four-stroke boxer twin engine with an electric generator on the rear of the IC engine that is directly driven by the crankshaft.

To adapt the original range extender design for fuel-powered UAVs, the company swapped out the electric generator for a 300 W starter/generator (Author's image)



The engine was conceived by the company's founder Roberto Papetti, with engineer Filippo Marino as lead designer and fellow engineers Marco Costa, Mattia Durantini and Luca Narcisi providing the project's CFD, ECU and prototype production work respectively.

Papetti's key principles for the development of the RES centred on making the system small and light enough to be swapped into a battery-electric 4 x 4 road vehicle, in place of where a spare tyre might sit beneath the back seat. With this emphasis on convenience, Papetti and his team wanted to ensure a low cost for each unit.

As a result, heavy emphasis was placed at each design stage on minimising the cost and weight of each part, making the engine as quiet as possible, and keeping the form factor within the rough dimensions of a vehicle tyre.

At the same time, Papetti's investigations into unmanned aircraft propulsion led him to notice that even the largest multi-rotor electric UAVs were significantly constrained in their payload capacities, the main cause being the low power densities and large physical footprints of present battery technology.

"We then suspected that our RES could be applied to electric multi-rotor UAVs to extend their endurance, because the power density of the system was far higher than what could be achieved with battery packs of equivalent size and weight," Papetti says. "These suspicions were confirmed by running simulations and comparing the two in terms of their power-to-weight ratios."

The company also determined that the RES could alternatively be used for a non-electric UAV's propulsion.

This alternative configuration, now called the UAVE, was created by modifying the RES' crankshaft, replacing the RES' generator with a starter/generator, designing new cam profiles and programming the ECU to operate the engine at 5000 rpm (instead of the RES' 4000 rpm operating speed).

The starter generator is a 300 W, 12 V system that provides start-up power for the engine and is also designed to supply the onboard battery for powering the UAV's electronics – other than these changes, the RES and UAVE are mechanically and operationally identical. The company now promotes the former for electric UAVs, the latter for fuel-powered UAVs.

As Papetti notes, "Our company's experience lies largely with four-stroke engines and components from the race motorcycle field, and two-stroke UAV engines suffer from a few key problems in our view."

The first, he says, is excessive fuel consumption, which adversely affects the ability of UAVs to run missions of more than four or five hours. Increasingly it is the primary factor that UAV designers rail against in their discussions with engine companies.

"Two-stroke engines also experience increasing difficulties at higher altitudes, as their efficiency is significantly affected by air density, air temperature and humidity, unless their spark timing and compression ratio are strongly mechanically regulated," Papetti adds. "That limits their applicability for major UAV uses such as defence and police surveillance."

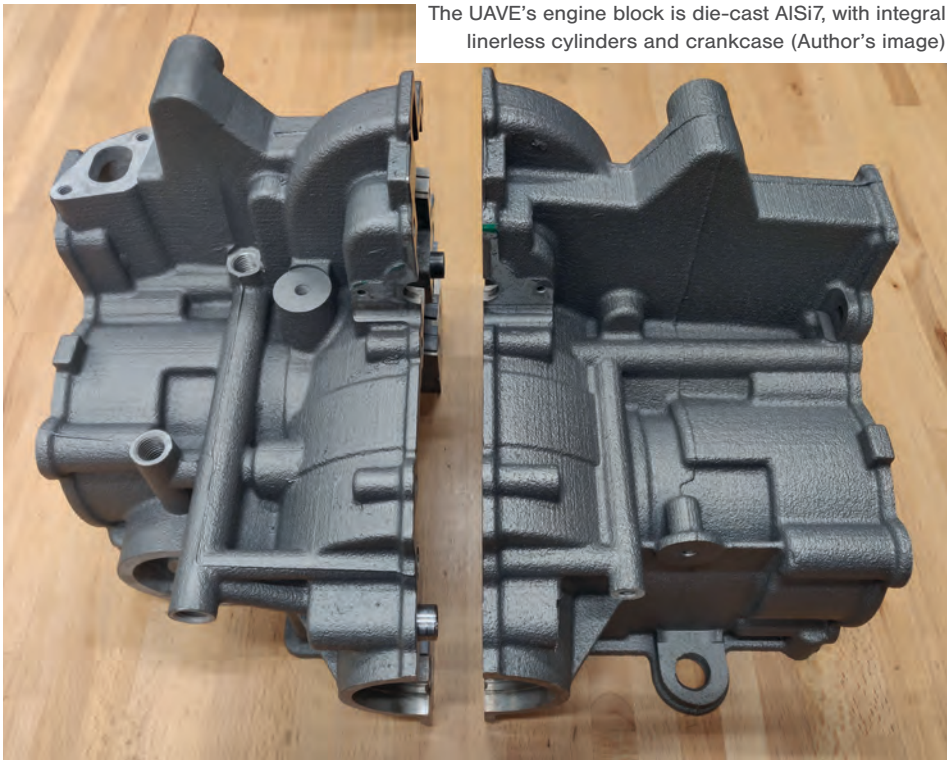
Marino notes, "Also, the volumetric efficiency is affected by fluid density and temperature. Two-strokes need to fill two chambers with air – above and below the piston – meaning two separate volumetric efficiency levels, and these both worsen with altitude."

"Four-strokes have only one chamber to fill with air though, so the volumetric efficiency changes less with altitude. Also, the exhaust gas clearance in two-stroke engines suffers problems owing to the external air density causing waves of pressure in the exhaust tubes; four-strokes experience this problem far less because of their different architecture."

Engine components

As well as being designed for small size and low weight, the preliminary phase of development was also driven by the recyclability of component materials, in order to improve the suitability of the RES for 'green' automotive purposes.

The need to abide by environmental quality was balanced against the need to keep production costs down, and materials were selected to optimise that balance, along with the



The UAVE's engine block is die-cast AlSi7, with integral linerless cylinders and crankcase (Author's image)



A gear on the front crankshaft section drives the distribution gear for camshaft timing, as well as a smaller gear for driving the oil pump (Author's image)

Company history

The offices and workshops of Robby Moto Engineering are located in Casalmaggiore, in the Italian province of Cremona. The company was founded by Roberto Papetti in the early 1990s, and since 1993 it has had a significant presence in motorsport, developing specialised titanium engine components for motorbike championships.

By the late 1990s, Robby Moto had moved from just designing and prototyping engine parts to developing and manufacturing full engine designs for companies such as Benelli and Suzuki.

Amid ongoing projects and collaborations in motorsport, the company conducted studies into endothermic cooling and light aviation prototypes for four-stroke engine designs in 2003 and 2007 respectively, with further studies and developments in aviation and nautical propulsion systems following.

aforementioned weight constraint.

Most of the UAVE's and the RES' components are therefore made from recyclable and lightweight materials wherever possible. The crankshaft, con rods, camshafts, rockers, gears, pistons, timing chains, springs and fasteners are all made from steel. The oil sump, cylinder head covers, airbox, timing chain tensioner shoes and cooling water manifolds are made from additively printed thermoplastic – principally for easy prototyping – using an on-site printer.

Most of the other major components have been made from aluminium, to help reduce weight and by extension fuel consumption.

While the oil sump and cylinder head covers might typically be made from aluminium, thermoplastic parts have been used in both the RES and the UAVE to reduce overall weight. The thermoplastic has a density of roughly 1000 kg/m^3, compared with the density of aluminium, which is about 2700 kg/m^3.

This thermoplastic, rather than rubber reinforced with steel wires, was also used to manufacture the cooling water manifolds, as the latter method would have been less environmentally friendly.

The result of these constraints are what give the UAVE its 23 kg weight, compared with the 36 kg of the RES with its electric generator integrated. It measures 530 x 320 x 290 mm (or 560 mm long, rather than 320 mm, if the electrical generator is present).

The engine block is made in two halves from die-cast AlSi7 aluminium, and serves as a monobloc for the cylinders and crankcase. Each of the two cylinder heads is also made from die-cast AlSi7, and these sit atop the horizontally opposed linerless cylinders, which have a Nikasil coating. These materials were selected to save on weight and manufacturing costs.

While four-stroke engines might typically use a monolithic crankshaft, Robby Moto opted for a three-part version after determining that this would reduce manufacturing and assembly costs. The engine's operating power and torque were also deemed low enough – 25 kW and 47 Nm at 5000 rpm respectively – to make the 'composite' crankshaft design approach possible.

The three parts are the rear crank, front crank and central section. All three have been machined from blocks of 18NiCrMo5 steel to optimise for material weight, cost and recyclability, and are subsequently carburised to reduce wear over time.

Both the rear and front crank sections incorporate a crank journal about 60 mm long and 30 mm in diameter, as well as a counterweight and bearing journal. In order of contact with or proximity to the counterweight, the rear crank holds a phonic wheel for speed measurement and a distribution gear to drive the timing of the two camshafts.

The central part provides a coupling for each crank pin, and has been designed to keep the rear and front cranks constrained against the torsion and bending loads created during operation.

The UAVE also has two plain bearings on the propeller-side crank, as well as a single plain bearing on the rear crank close to the starter/generator. In the RES configuration, there are two plain bearings on the rear crank, close to the generator, and one on the front crank.

To ensure proper lubrication of the bearings and the crank journals, a network of ducts for oil flow is drilled through the crankcase and the rear and front cranks. The main oil input points are located at the two main bearings (the ones found on each shaft section closest to the journals), and the centrifugal force of the shaft's movement delivers the oil to the con rod big ends via the inside of the crankshaft.

To do that, the oil exits from the crankshaft interior through ducts on either side of each crank pin's circumference. The oil then lubricates the plain bearings between the crank pins and con rod big ends, as well as between the crank journals and the holes in the central part.





Robby Moto's RME Avio division

The RME Avio division of Robby Moto Engineering was set up in 2006, as a result of the company's increasing competence in aircraft propulsion systems and Papetti's interest in transferring and applying his team's experience in thermodynamics and fluid dynamics to light aircraft (such as those Papetti flew in his spare time).

The first project to come out of this division was the RAP 98-90i, a four-stroke boxer engine, configurable for fixed-wing and rotary aircraft. This 72.5 kg, 2715 cc four-cylinder design measures about 660 x 653 x 453 mm, with a bore and stroke of 98 and 90 mm respectively. It features a patented oil-to-air cooling system as well as an all-aluminium structure and an 11:1 compression ratio.

When the RAP's ECU is programmed for a fixed-wing aircraft, the engine has a maximum speed of 3000 rpm, a peak power output of 77 kW at 2750 rpm and a maximum torque of 275 Nm at 2420 rpm. Set for a helicopter, the top speed is 3500 rpm, maximum power is 88 kW (at 3400 rpm), and torque peaks at 270 Nm, at 2300 rpm.

After talks in 2013 with the Lombardy Aerospace Cluster of aviation engineering companies in northern Italy, the company began developing its TEPS (Twin Engine Pack System) twin independent four-cylinder engine integrated into a single unit for helicopters. The total displacement of this 130 kg patented engine is 5400 cc, with a 3600 rpm top speed, 88 kW rated maximum power output (at 3400 rpm) and 270 Nm peak torque (at 2300 rpm).

The similarities in performance between the four-cylinder RAP and the eight-cylinder TEPS come largely from the latter being principally conceived and designed as two independent RAP units built together for redundancy, sharing a common crankcase.

The Avio division used many of the same design points in the TEPS as the RAP, including the same Heron cylinder design with the same bore, stroke and compression ratio. The aforementioned oil-to-air cooling system was also implemented.

Although TEPS was envisioned for use in helicopters with MTOWs of 600 kg for two-seaters or 1000 kg for four-seaters, the Avio division has recently conducted a study into a use case for the engine in stratospheric flight. This configuration sees the engine being used for take-off and landing for a HALE-type unmanned aircraft, which would operate for several days at a time at altitudes of between 16.76 and 18.28 km.

When operating at low altitude, the HALE UAV would fly with only one TEPS block active (as intended with the system's design), and at high altitude the craft would have the other TEPS block activated. One block is calibrated for use with high efficiency at altitudes from sea level up to 30,000 ft. The other is calibrated for use between 30,000 and 60,000 ft.

In its final configuration, the HALE craft is envisioned as having integrated PV cells for power at high altitude. The end goal will be to offer the craft for applications such as telecoms, environmental surveys and maritime traffic radar, at far lower cost than satellites.

Further development of both engines' use cases are planned following further dyno tests this summer.

The shaft sections are held in the central crank section using an interference fit of about 0.1 mm. As the design team modelled the dimensions of this fit, they were concerned that the torsional forces being transmitted through the crankshaft, combined with the bending forces generated from the con rods, could cause wear and even misalignment of the crank journals and the central part over time.

Finite element modelling (FEM) was used to simulate the worst-case scenario here. By importing the .step files of the UAVE's crank section models from SolidWorks into Abaqus, the team conducted assessments for stress, fatigue and slippage at a range of crank angles at maximum torque.

This made up most of the FEM work carried out for the engine, and enabled the team to predict the torsional loads and bending moments imparted throughout the crankshaft during engine operation. From these it was determined that, even when the interference is at its minimum level possible, the crankshaft geometry should still not change.

Owing to the extended length of the RES' rear crank (199 mm), it is used as a mount and direct drive for the 'operative' part of the engine's configuration. That is, when configured as the Robby Moto RES, a conical coupling is used to mount the rotor of the electric generator on the end of the rear crank.

In the UAVE, the front crank measures 247.5 mm long in order to enable propeller mounting on the front of the engine. The rear crank is 198.2 mm long to mount the distribution gear for driving the camshafts, as well as the starter/generator.

Each of the two con rods is about 140 mm long, or 103 mm between the centres of the small and big ends. As the crankshaft is made in three sections, this negates the need for a split in

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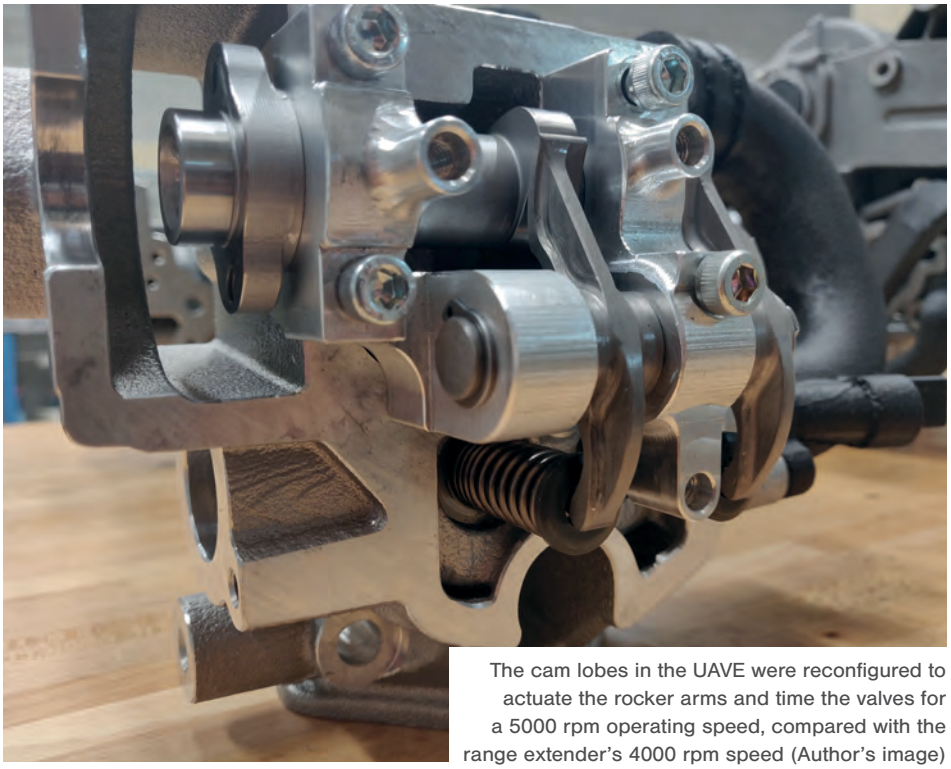
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The con rods are made as single components, as the three-section crankshaft makes it unnecessary to design them with a split (Author's image)





The cam lobes in the UAVE were reconfigured to actuate the rocker arms and time the valves for a 5000 rpm operating speed, compared with the range extender's 4000 rpm speed (Author's image)

the rod design, so the rods have been manufactured as monolithic parts, machined from 39NiCrMo3 steel. This was another decision made to save on manufacturing costs and assembly time.

"We have a range of different machines in-house, but we cut mainly from metal blocks for prototyping the crank parts and con rods," notes Marino. "When we move towards scale production, we will probably switch to other fabrication methods more suited to bulk manufacturing, such as forging for example, as well as other materials that we will select later. All the engine components have been designed to be ready for mass production."

No bearing is used between the piston pin and the interior of the con rod small end. Instead, smooth movement is facilitated as oil runs through a lubricating hole drilled into the top of the small end, which runs through to the piston pin. That oil comes from the big-end bearing, as a 1 mm groove in the top of it allows it to flow up to the small end, exiting from the bearing at 5 bar of pressure and a flow rate of about 180 g/s, and running up to the pin.

This then lubricates the 20-or-so μm space between the two parts. FEM of the con rod's design has been conducted in Abaqus to assess for static strength and fretting, as well as a fatigue analysis run in MatLab, to minimise the risk of the rod failing or slipping.

Operation

The UAVE and RES share almost all the same components but have different cam profiles and ECU parameters so that they can be adapted to different operating conditions.

As mentioned, the UAVE's operating speed is 5000 rpm, with a maximum of 8000 rpm given, although that may be subject to change following new rounds of dyno tests starting this June. The system's highest torque level of 61 Nm is achieved at 2700-2800 rpm.

In RES configuration, the engine's peak power output is 20 kW, which is reached at roughly 4000 rpm. If the operator runs the engine at this speed they will have 47 Nm of torque to drive the generator.

The brake-specific fuel consumption of the engine is 168.19 g/kWh at 4000 rpm in RES configuration, and 226.82 g/kWh at 5000 rpm in UAVE configuration. In a drive for efficiency, the compression ratio for both versions has been set at 14:1.

Each cylinder has an intake valve measuring 28 mm in diameter, and an exhaust valve 23 mm across. The valves are positioned atop each cylinder head, with a valve angle of 0° for design and

Datasheet

Robby Moto UAVE
Boxer type
Stroke: 72.0 mm
Bore: 61.4 mm
Displacement: 499.98 cc
Gasoline fuel, RON 95+
Naturally aspirated
Aluminium alloy structure
Linerless with case hardening treatment
Three main bearings, plain
Steel crankshaft, three sections, two pins
Steel monolithic con rods
Aluminium pistons, three rings
Two valves per cylinder
One plug per cylinder
Port injected
Liquid cooled
Engine management system
14:1 compression ratio
Maximum rpm, 8000

Some key suppliers

Castings for crankcase, heads, and other parts: SBA Pozzato
Machining for crankcase, heads, and other parts: in-house
Bore coating: Cylinder Line
Crankshaft: in-house
Camshafts: in-house
Con rods: in-house
Oil pan: in-house
Tappets: in-house
Rockers: in-house
Pistons: Pistal Racing
Rings: Pistal Racing
Piston pins: Pistal Racing
Circlips: Pistal Racing
Valves: Scarpa & Colombo
Valve seats: in-house
Valve springs: Mollificio Legnanese
Gaskets: Lariete
Ignition system: EFI Technology
Spark plugs: NGK
Fuel injectors: Bosch
Engine management system: EFI Technology
Sensors: Bosch
Data acquisition: AIM
Electronic boards: EFI Technology
Wiring: EFI Technology
Throttle: Bosch
Oil pumps: in-house
Oil filter: UFI
Alternator: Ducati Energia
Airbox: in-house
Intake manifold: in-house
Wiring loom: EFI Technology
Propeller: GT Tonini
Voltage regulator: Ducati Energia
Oil: Motul
Surface treatments: SET
Surface treatments: Lafer
Heat treatments: SET
Metals: TAU Metalli
Metals: SCAM
Dynos: Borghi Saveri
Machine tools: Mazak
QC equipment: Mitutoyo
Design software: TopSolid 7
Testing software: Midas NFX
Testing software: Abaqus CAE

manufacturing simplicity. Extensive CFD studies were carried out to optimise for air-fuel flow and exhaust flow around these parameters by Marco Costa.

He modelled the fluid dynamics using a combination of TopSolid 3D, STAR-CCM+ and STAR-ICE, an add-on to STAR-CCM+ developed in 2017 for in-cylinder simulations.

For operating and timing the valvetrain, the crankshaft's distribution gear drives the main timing gear, and the latter has roughly twice the circumference of the former in order to turn each camshaft once for every two crank rotations.

A pair of shafts extend from the front and back of the main timing gear. Each has a sprocket mounted to drive one end of the steel timing chain, and the other end of the timing chain drives a sprocket on the back end of the camshaft, with one camshaft in each of the two banks.

The tension and positioning of each timing chain is maintained by two pairs of thermoplastic tensioner shoes, which are installed in the top and bottom of the chamber and run between the distributor and the cams.

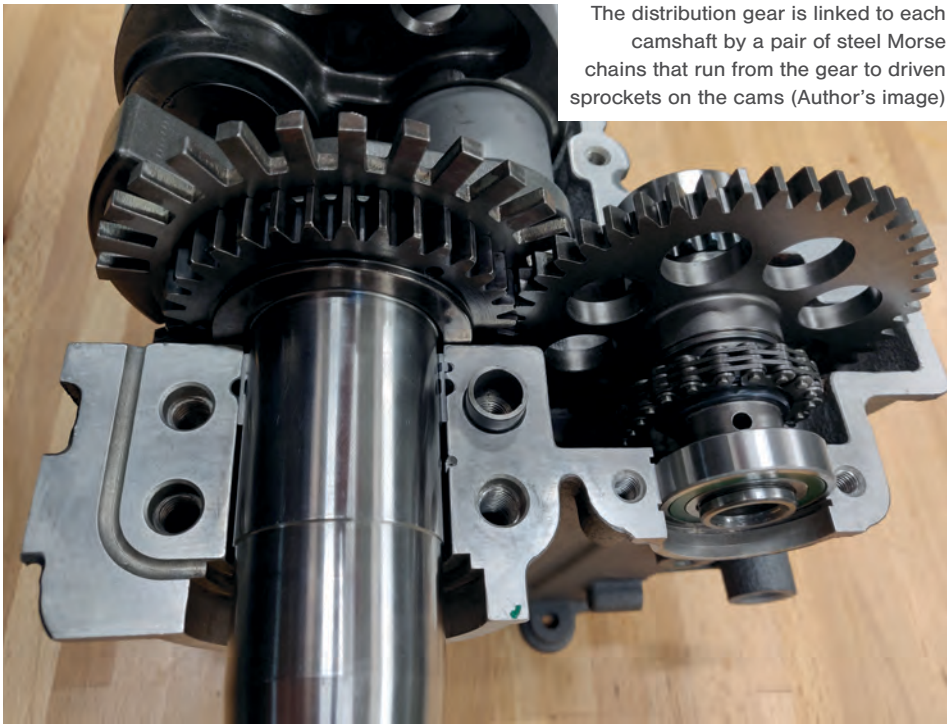
"The cam doesn't act directly on the valve, and we don't use pushrods," Costa explains. "The cam lobes act directly on the rocker arms, and they push the valve stems down, to give the valvetrain a small overall footprint in the cylinder head and to keep the engine width compact."

Marino adds, "The UAVE's cam profile is completely different from that of the RES, to help the UAVE 'breathe' better and obtain its peak power at 5000 rpm instead of 4000 rpm. For example, the UAVE has a sharper acceleration for the valves' openings and closings, which is enabled by changing the cam lobe shape.

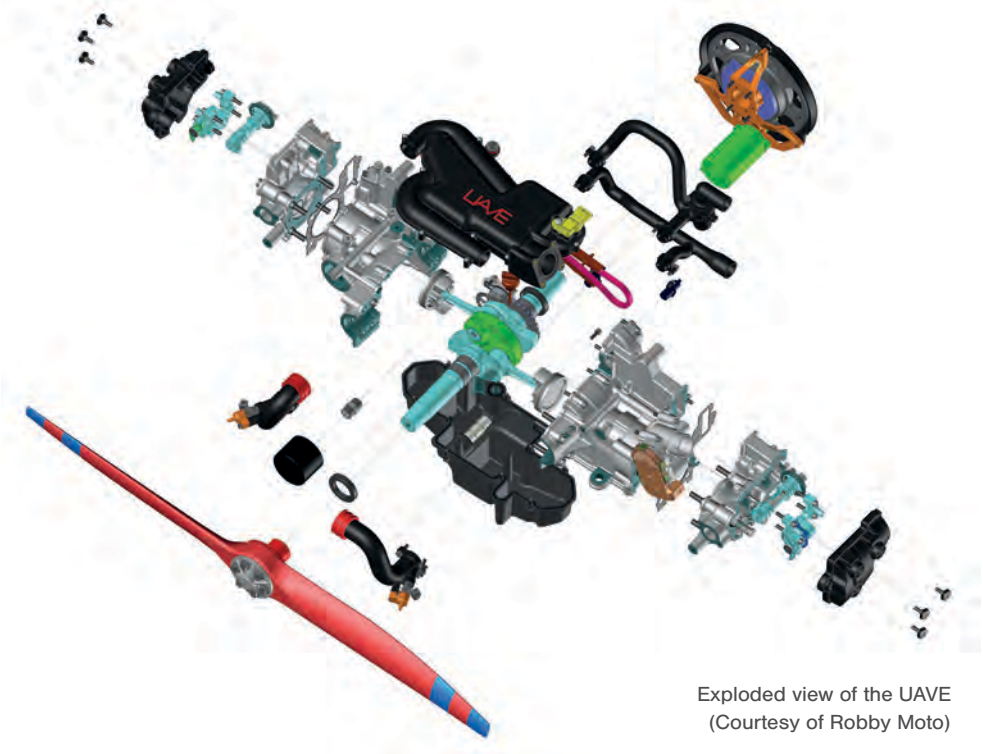
"Also, the RES' intake valve lift is 8 mm and its exhaust valve lift is 7.5 mm, whereas the UAVE's intake valve lift is 8.4 mm and the exhaust valve lift is 7.7 mm."

Each cylinder has a single 8 mm spark plug, with a coil manufactured by ACDelco and supplied by EFI Technology, using an inductive discharge ignition system.

"In a four-stroke engine you have a spark every two rotations, and its



The distribution gear is linked to each camshaft by a pair of steel Morse chains that run from the gear to driven sprockets on the cams (Author's image)



Exploded view of the UAVE (Courtesy of Robby Moto)

rotational speed is typically 4000-5000 rpm, so the fast charging times of a capacitive system are unnecessary," Costa says. "CDI is common among UAV engines mainly because it is useful for two-strokes."

The UAVE is port injected, with two EV 14 injection valves from Bosch integrated onto the manifolds situated at the lower front corners of the engine which feed into each cylinder. These top-feed conical injectors spray fuel at an operating pressure of 3 bar, up to a 5 bar maximum.

The engine's injection, ignition and throttle systems are controlled by the ECU. "We use the EURO4 PPC from EFI Technology as our ECU," says ECU engineer Mattia Durantini.

The EURO4 measures about 165 x 95 mm and uses a 32-bit CPU (specifically, a 40 MHz PowerPC unit) with 32 kbytes of RAM, 512 kbytes of flash storage and a further 8 Mbytes for additional data logging.

An electronic throttle body (with a redundant throttle position sensor) from Bosch is integrated on the top-right of the airbox and controlled with what is called a speed density strategy. This uses data inputs on manifold air pressure (MAP) from a Bosch Pressure Sensor Combined PST 1/PST 3 unit, and on crankshaft speed from the phonic wheel mounted between the distribution gear and the forward counterweight, to maintain the fuel-to-air ratio.

The injection system is controlled and timed using inputs from these two sensors as well as a lambda sensor and a magnetic camshaft speed sensor. Ignition timing is managed using inputs from the lambda, crank and cam sensors.

The injectors are also corrected using sensors for water and oil temperatures, for example to provide additional fuel to compensate for the colder temperatures at start-up. An oil pressure sensor is used to control the oil pump to ensure the pressure does not drop too low and risk lubrication failure.

The ECU provides a CAN bus that serves as the sole comms and control link from the various engine sensors to the aircraft. A 12 V supply connects the ECU to the ignition coils, fuel injectors, throttle and lambda sensor, with an additional 5 V link to the MAP, oil pressure and throttle position sensors.

Conclusion

Following further dynamometer tests this year, Robby Moto plans to conduct experimental flight testing for the UAVE. Findings from these will be used to continue maturing the engine's capabilities and, if past projects are any indication, to inform the company's future projects in the aerospace and automotive sectors.

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The FlyOx has been developed to deliver aid to disaster-hit areas, flown remotely or autonomously

International aid worker

Nick Flaherty looks at an aerial platform developed to deliver food and medicines to areas hit by disasters

Anyone who has watched news footage of such events will readily appreciate that there are major issues with delivering aid to disaster-hit areas. Take-off zones may be many miles distant, and almost by definition there are usually no suitable places to land. Flying into such areas can be extremely hazardous, even for experienced pilots, so organisations such as the World Food Programme have been looking at unmanned aircraft to solve these and other problems.

However, the specifications for such an aircraft are quite challenging. It needs to carry a payload of at least 200-500 kg to feed a minimum of 95 adults, and have a range of at least 100-500 km.

One approach is to fly over a crisis area and supply aid from an unmanned aircraft at a low height. Inspired by the design of firefighting aircraft (see sidebar), this requires a considerable change to the cargo system, for delivering the aid as well as quick re-stocking.

Spanish company Singular Aircraft has therefore adapted its amphibious UAV with a modular design that can trade off the space for cargo with fuel tanks, balancing the range requirements with the need to deliver as much aid as possible in each mission.

"When the World Food Programme asked us to transport sorghum [a cereal crop], we saw that it is capable of withstanding a drop from a plane, so we wanted to give them the option to do that," says Luis Carrillo Lostao, founder of Singular Aircraft.

"We therefore chose a firefighting version of our amphibious UAV. Getting a plane into dangerous situations has risks for a pilot though, so we thought, 'Why not use an autonomous aircraft?'" Enter the FlyOx.

Using the firefighting version as the base of the design provides a load capacity of 1500 kg with 300 litres of fuel, or a payload of 720 kg of food with 2200 litres of fuel – enough to fly a round trip of 2200 nautical miles over 24 hours.

Design

The FlyOx is designed to be operated autonomously or remotely. However, this means that under current regulations it cannot travel long distances; it has to be transported wherever needed in a standard 40 ft (12 m) shipping container.

That in turn means the airframe is constrained by the size of the container. The aircraft is also designed to be dismantled easily so that it can be transported safely around the world in the container. It can then be reassembled in a few hours.

While the base design of the aircraft was established in 2015 by Singular for firefighting, it had to be extensively modified to fly supply runs into disaster areas. The water tank has been replaced by a specialist cargo system that is linked into the autopilot, while new cargo loading and refuelling systems have been developed.

The cargo system consists of a series of slots that can carry either payload or fuel, depending on the mission requirements. This ability to trade off fuel and payload is necessary, as the aircraft may have to fly from another country into a war-torn region.

"We are able to deliver 1000 sets of rations through 1000 km without refuelling. If you reduce the range to 520 km we can deliver 3000 rations," says Lostao.

The system is designed to be flexible enough to balance the different range requirements with the need to maximise the payload delivery, and to make it easy to refill both the cargo and the fuel.

The cargo bay can be refilled in two ways. One option is to use the doors under the high wing. These feed directly into the top of the cargo bay, allowing boxes of rations to be almost thrown into the aircraft by hand, without the need for particular placement. Each box weighs 13 kg and carries a day's rations for one person.

There are two lateral cargo doors under each wing, each 700 mm wide, the biggest size the team could fit without obstructing the crossbeam of the aircraft. The restocking takes 20 minutes, the same as refuelling.

If the whole bay is dedicated to cargo, the aircraft can be raised on a jack, the bay door opened and a pallet of aid lifted in. Closing the bay doors secures the pallet.

The range and cargo capacity can be varied depending on the mission requirements



> Using GPS and the autopilot mission plan, or a trigger from a remote pilot, a simple solenoid opens the bay doors. The cargo then falls to the ground

Operation

In operation, the aircraft flies low over the drop zone, using cameras to monitor the ground. Using GPS and the autopilot mission plan, or a trigger from a remote pilot, a simple solenoid opens the bay doors. The cargo then falls to the ground.

Agencies such as the UN are using pilots to remotely monitor the aircraft to ensure that the drop zone is clear, although that would also be arranged with staff on the ground. A ground station has been developed to support this type of remote operation with the aircraft flying autonomously, in preference to just flying the aircraft remotely.

The rations themselves are carried in a rugged box that will survive the drop. Smaller, 50 kg, sodium sacks can also be carried. These fit easily though the doors and are packaged in a three-layer bag that can also withstand the drop.



The loading doors can be seen under the high wings of the FlyOx. These allow the cargo bay to be refilled in 20 minutes with up to 3000 ration packages

The rugged boxes can also be used for medicines that have been tested to show that they survive the drop. This allows more specific deliveries of drugs to health centres and hospitals in a matter of hours rather than days.

Normally, a large or sensitive load such as drugs would be delivered using a parachute, but that can lead to them landing in the wrong place depending on the wind patterns. Direct drops are more accurate.

The bay doors can be triggered using the mission plan on the autopilot or through the FlyOx's system bus. Once the system is armed, it can be triggered by a message over the radio link or a coordinate from the GNSS navigation sensor.

This can take 1-2 s, but with the aircraft moving at 45-70 m/s then even if the signal is 2-3 s late, that is a difference of 120 m from the target. But as Lostao says, "If you are delivering food or medicine that's not much.".

However, the release of the cargo has a major impact on the operation of the aircraft, which has to be taken into account by the autopilot or remote operator. Releasing the 1850 kg of cargo all in one go equates to a change of 40% in the weight of the 2200 kg aircraft, which means it could jump 4-5 m into the air in less than a second.

The FlyOx's centre of gravity is deliberately designed to account for that, but it can still be challenging for a remote operator. The best way to handle it is to have fully autonomous operation, with the autopilot adapting to the new configuration to maintain altitude and speed, correcting the angle of attack and power, and usually reducing the speed on the return leg as the weight is so much lower.

Once the FlyOx returns to base, the landing is always autonomous.

Configurable fuel load

The FlyOx has a fuel capacity of 2.3 m^3 in two tanks by each wing, but this is configurable, as space in the cargo bay can also be used for fuel to extend the range.

Tanks carrying 300 or 600 litres can be added in the bay, reducing the cargo capacity. There are four divisions in the bay, and 'slices' of thin fuel tanks can be added or removed as required.

The extra 600 litres provide a range of 500 nautical miles or 5 hours of flight time. However, the fuel can also count as payload, delivering fuel to a disaster area, although the aircraft has to land to deliver it. The tanks can also hold chemicals for crop spraying, giving the platform more flexibility.

One challenge with the design of the systems in the aircraft is that aid organisations and different countries use remote pilots who are trained on a range of different systems, usually based around particular autopilots.

Singular Aircraft has therefore developed most of the components of the FlyOx with a clear interface to a range of autopilots. "That was because we saw that customers, mainly governments, already had their people trained to a particular system, so they don't need so much training," Lostao says. "With our system the pilot knows he is flying a different plane but the basics are the same."

The level of autonomy is for the customer to decide, whether it be fully autonomous, fully manual or something in between. "We developed everything in-house up to the control law from

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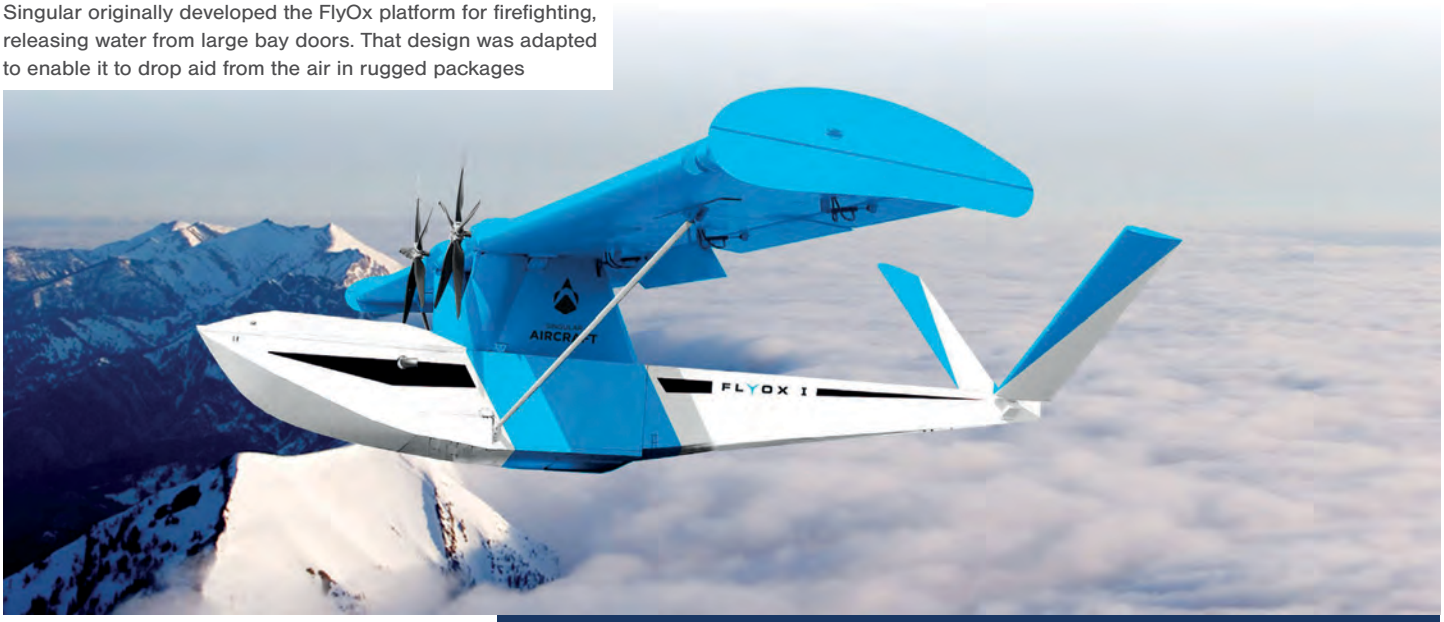
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Singular originally developed the FlyOx platform for firefighting, releasing water from large bay doors. That design was adapted to enable it to drop aid from the air in rugged packages



the autopilot. The bus system, electronic control unit for the engines, the power management, 17 separate boards – all that was designed, produced and programmed by us," Lostao says.

"I don't want to develop autopilots, as they are off-the-shelf systems and are changing frequently from the technological perspective. Also pilots need to be very well trained in the system."

The system architecture allows the team to integrate any type of autopilot on the market into the aircraft.

"We took control of all the systems and subsystems in the plane, and got just the vector for the autopilot, so now we can install whatever autopilot the customer asks for. There are different ones from Canada, Spain and China," Lostao says.

"The core functionality of the plane is not the autopilot though, or the energy equations, it's the main subsystems such as the hydraulics and power management," he adds.

The same is true of the comms systems. "The radio links are off-the-shelf, as every country asks for a different frequency," he explains.

The architecture is such that an autopilot is not actually necessary. "You can put a direct input to our systems in the plane via the radio link; you don't need the autopilot," Lostao says.

This comes with problems though, as pilots have struggled with remote operation during testing, says Lostao. "One plane was working properly, but it crashed because the pilot was a couple of seconds behind what the plane was doing."

The problem was the latency for the pilot. This is a maximum of 0.1 s, which

Heritage of the FlyOx airframe

The air-freight version of the FlyOx evolved from a design developed for firefighting. This came about from conversations in airports between Luis Carrillo Lostao, founder of Singular Aircraft, and an experienced pilot and his colleagues. After a friend was killed in a firefighting operation, Lostao and the others started to talk about using an autonomous aircraft.

An amphibious craft made a lot of sense for firefighting, as it could land on water to refill its water tanks, rather than going back to an airport. This led to the design of an airframe that could land on a lake or river and then open its bay doors to scoop up water.

The original proposal centred on night-time firefighting operations because pilots are often not allowed to fly then for safety reasons. As a result, the FlyOx was automated, using IR and EO cameras as the main sensors.

The problem is that landing autonomously on water is not easy, and it is even harder in the dark. Most of the problems pilots have with landing on water comes from the glassy nature of the surface – they don't realise exactly where it is so they can't establish where to land safely.

Another problem is that the water's surface is never at the same level, so a vertical radar is used to provide an accurate height. This adds a second control loop to the one used by the cameras.

That then has to be integrated with the control systems for safely opening the bay doors and refilling the water tanks, then opening the doors to release the water at the correct location to fight the fire.

This then led to the development of the version described here for aid agencies such as the World Food Programme.



The FlyOx uses two, three-blade propellers to get the maximum range and cargo capacity



Singular developed its own ground control station to assist with remote operation of the aircraft in difficult environments

prevents the pilot getting a good feel for the aircraft, he says. Pilots trained on instrumentation, with IFR, are a little better at the remote operation, as they are used to relying purely on the instruments. "If you are a VFR [visual] pilot it's even worse," Lostao says.

So Singular developed and built its own ground control station (GCS) based around standard tablet computer technology so that the aircraft can operate fully autonomously, and the pilot becomes the mission controller rather than flying it directly. "We manufacture our own GCS because the equipment we have found so far lacks security or is way off in pricing," Lostao says.

The GCS, coupled with the autopilot of choice, allows the remote operator to be the mission manager, selecting waypoints and the drop point, rather than flying under constant remote control.

The GCS technology is also used for a pilot training module (PTM), a one-sixth scale version of the FlyOx. The stability and control performances of the PTM are the same as for the full-size aircraft, with the same power-to-weight ratio and controls, so that the pilot experiences exactly the same performance.

Future plans

The FlyOx has been tested in the US but it is Africa that offers the most immediate opportunities.

Kenya for example is opening up its regulations for commercial UAV operations, following the lead of Rwanda. Astral Aviation in Kenya has set up a subsidiary called Astral Aerial Solutions, which will use the FlyOx.

Astral is starting a pilot programme, and that will be followed by an application for certification and then regular commercial cargo operation, for example to deliver spare parts to oil and gas companies and for e-commerce deliveries.

It is also working with UN agencies to operate in areas hit by natural disasters and famines for more effective delivery of food and medicines.



Deep-sea diver

Rory Jackson explains how this AUV was designed and engineered to survey some of the deepest parts of the world's oceans

Following incidents such as the disappearance of Malaysian Airlines flight MH370 in March 2014, governments and rescue organisations around the world have realised that the technological capabilities for deep-sea search and recovery need to be better. As a result, Teledyne, which has produced and operated the Gavia AUV for 20 years (via its subsidiary Teledyne Gavia), has witnessed a growing demand for a UUV that can dive and survey much deeper than the typical 1000 m rating for AUVs.

The company therefore began designing its largest AUV yet, capable of operating down to 3000-6000 m, and in a separate development it won a tender from an undisclosed customer in late 2017 that closely matched what the design team at Teledyne Gavia was already working on. The terms of the tender gave the company 18 months to deliver what would eventually become the Teledyne SeaRaptor.

"18 months is a short cycle for design, production and delivery, when you consider that the lead times for many AUV components are around six to nine months," says Stefan Reynisson, general manager of Teledyne Gavia and project manager for the SeaRaptor.

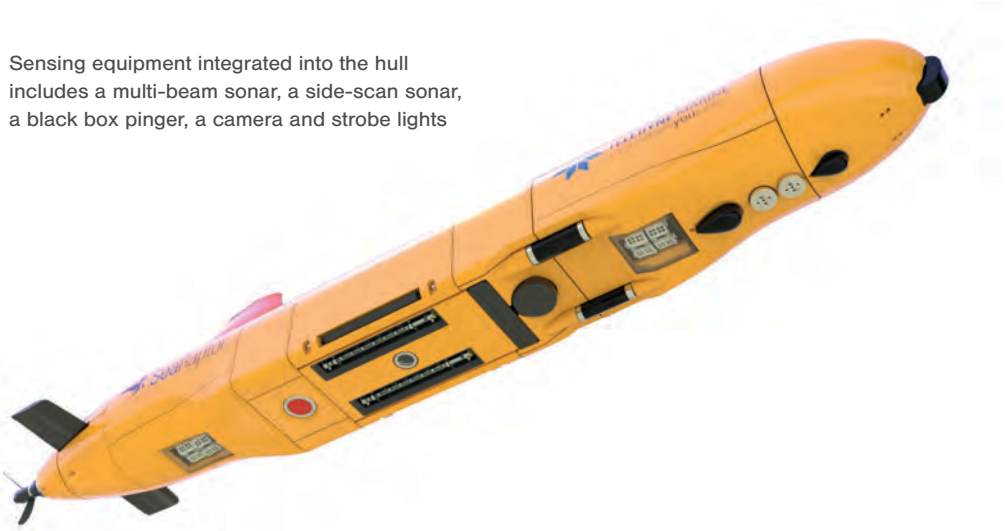
"But we had a very good idea from the outset of what we wanted to achieve with the SeaRaptor, and leveraged a lot of our experience with the Gavia AUV to accelerate its development."

That meant using much of the same software architecture as the Gavia (particularly for autonomy and mission planning), with the principal development work for the SeaRaptor focusing on establishing the new vehicle's mechanics, electronics and sensor architecture.

"For example, we actually had to



Teledyne has developed the SeaRaptor for surveying down to 6000 m below sea level, in applications such as search and recovery of wreckage on the seafloor



Sensing equipment integrated into the hull includes a multi-beam sonar, a side-scan sonar, a black box pinger, a camera and strobe lights

do many iterations of the PCBs and parts like that, because you learn more at each iteration and can make improvements," Reynisson says. "We had preliminary design reviews, critical design reviews and set-up reviews, and several sensors were changed during the process as new sensors would come along that fitted the mission of deep-sea search and recovery better."

Technical development predominantly took place in Iceland (where Teledyne Gavia's main facilities are located), by an r&d team of 10 engineers headed by Dr Hordur Johannsson, chief engineer at Teledyne Gavia.

The result is an AUV that is 5.5 m long, 630 mm in diameter and weighs 1-1.2 tonnes in air (depending on configuration). It is available in versions rated to 3000 or 6000 m, and has multiple payload bays along the hull.

The main propulsion comes from a single thruster that can be actuated 25º to port or starboard, with two dive planes on the AUV's sides which are independently controlled for roll compensation and ascent and descent.

The SeaRaptor's standard battery module provides 13 kWh (with 16 kWh optional) and typically incorporates 16 independently pressure-tolerant lithium-polymer battery packs – four groups of four packs connected in series.

Each pack weighs about 8 kg in air and uses a wet-pluggable connector to enable individual packs to be quickly unhooked and replaced between missions.

"Each pack is nominally about 29 V, so we connect them in series to push them up to 116 V, to optimise for the propulsion system," Reynisson notes. "We then have multiple DC-DC converters to provide different voltages for different sensor needs, to handle a varied sensor selection so long as buoyancy and internal volume constraints are adhered to."

The BMS has monitoring sensors for each cell to log for battery health and optimise charging, discharging and power balancing across the power module. A range of sensors and technologies from other Teledyne Marine subsidiaries (such as Teledyne Benthos, BlueView and Reson) have also been integrated to assist with different stages and circumstances of the AUV's operations.

Pre-survey steps

Before the SeaRaptor can be deployed, it is programmed with its tasks using similar mission planning (and post-mission analysis) software to that developed for the Gavia AUV.

It is operated via the Gavia AUV Control Center software, a chart-based interface program in which the vehicle operator plans out a mission based on sea charts, with inbuilt route-planning templates that allow the user to set up a 'lawnmower' type back-and-forth survey pattern or long-line surveys. The user's selected or customised routes can also be copied or transplanted into other sea coordinates for mission repeatability.

"Although we were able to leverage that software we needed to write new functionality for the Control Center, to account for some new sensors and mission parameters such as the descent mechanism," Reynisson says.

"We were lucky enough that, with the modularity of the Gavia, we'd also made the Control Center a bit modular, which made implementing the software changes easier."

As an example of the changes, Reynisson notes that the Gavia AUV typically uses a single-beam obstacle avoidance sonar to detect any obstructions in its path. Upon detection, the Gavia will either 'fly' over it or stop, if the former action is not feasible.

For the SeaRaptor's detect-and-avoid capability though, the company integrated a forward-looking multi-beam sonar Teledyne BlueView. "This is BlueView's M450-130-D6, a 450 kHz 2D imaging sonar, with a 130° FOV

and 6000 m depth rating," Reynisson explains. "Rather than just detecting obstacles, it performs bottom-tracking, allowing the SeaRaptor to plot terrain up to 100 m ahead, and engage in terrain-following behaviour long before any obstacle can endanger the system."

In addition to programming a route and the sensors to be used, the operator must plan how to reach the survey site, both in terms of transporting the AUV to the correct part of the ocean and considering how to handle the dive down to 3000 or 6000 m.

To transport the SeaRaptor to the location of a new deep-ocean survey mission, Teledyne has developed a special, 20 ft-long storage container.

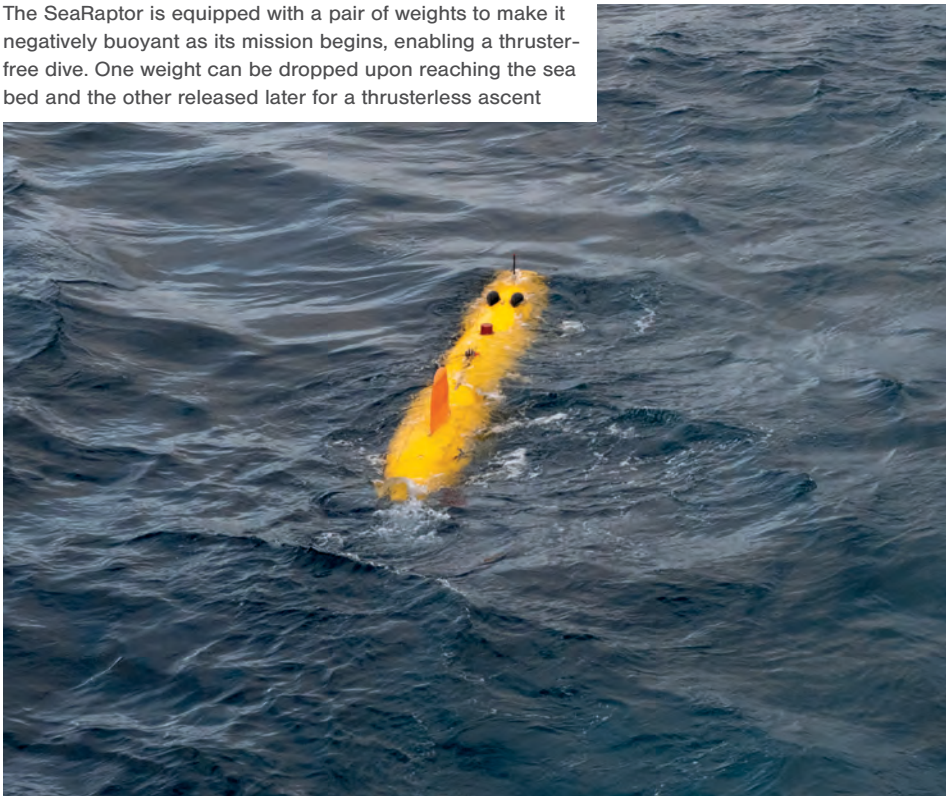
Initially, this enables easy ferrying such as by train and ship to whichever part of the ocean is above the survey site. However, the container was also designed according to the parameters of a manned mission vessel owned and operated by a Teledyne Gavia customer, so that it could sit on its operations deck and work within the existing infrastructure.

"And given the vehicle's dry weight of a tonne or more, it's not something two people can haul out, so we installed a launch slipway of hydraulically driven wheels to 'push' the SeaRaptor out for deployment, after a side-door along the length of the container is opened," Reynisson says.

"Inside that container, the AUV has maybe 5 in of space on each side. We have more flexible storage solutions for other potential users, but this initial storage and launch solution was designed to sit permanently on that customer's ship."

After the AUV is pushed out from the container, an A-frame hydraulic winch equipped with a Mermac D docking head (originally designed for launching and recovering ROVs and towed systems) is connected to the centre lift point of the vehicle and lowers it into the water.

Given the safety concerns of working in the weather conditions and sea states of deep-ocean regions, this sequence of launch systems is automated, to ensure that personnel can stay off-deck as the SeaRaptor is deployed, to counter the risk of injury or damaging the craft.



The SeaRaptor is equipped with a pair of weights to make it negatively buoyant as its mission begins, enabling a thruster-free dive. One weight can be dropped upon reaching the sea bed and the other released later for a thrusterless ascent

Diving and sensing

Teledyne Gavia has integrated a release mechanism from Teledyne Benthos into the SeaRaptor that allows a weight to be attached temporarily to it. That allows it to descend to its required depth without having to use the drive thruster.

Given that the operating speed of the vehicle is about 3 knots (5.5 kph), not having this option would mean consuming significant power to reach the seafloor, without generating any survey data along the way.

The mechanism, the VR Series, can be triggered acoustically or by various commands. It can be released at a particular depth or after a certain time into the mission.

The SeaRaptor actually has two of these releases, allowing it to release a second weight later in a mission to make the vehicle more positively buoyant and enable a thruster-free ascent.

The VR Series release takes between 5 and 10 s to unlock, and the released weights are made from materials such as steel that will dissolve in the ocean, to prevent pollution.

"A lot of that weight carry-and-release system is customisable depending on how the end-user might want their SeaRaptor to descend and surface, but the operator needs to be careful, because unlike other AUVs you're starting with something that's negatively buoyant," Reynisson cautions. "So if you don't have a good hold on the SeaRaptor it'll drop down into the ocean depths."

Once it has reached the seafloor, it will begin the pre-programmed survey operation, autonomously following the user-commanded route using a combination of USBL updates (or LBL updates, mission duration and costs permitting) and dead reckoning.

The greater payload capacity and power supply of the SeaRaptor compared with the Gavia enables the integration of more demanding systems, such as the recently launched SeaBat T-50S multi-beam echo sounder from Teledyne Reson, a sensor

which, at 460 x 102 x 90 mm, was too large to fit into the Gavia's hull.

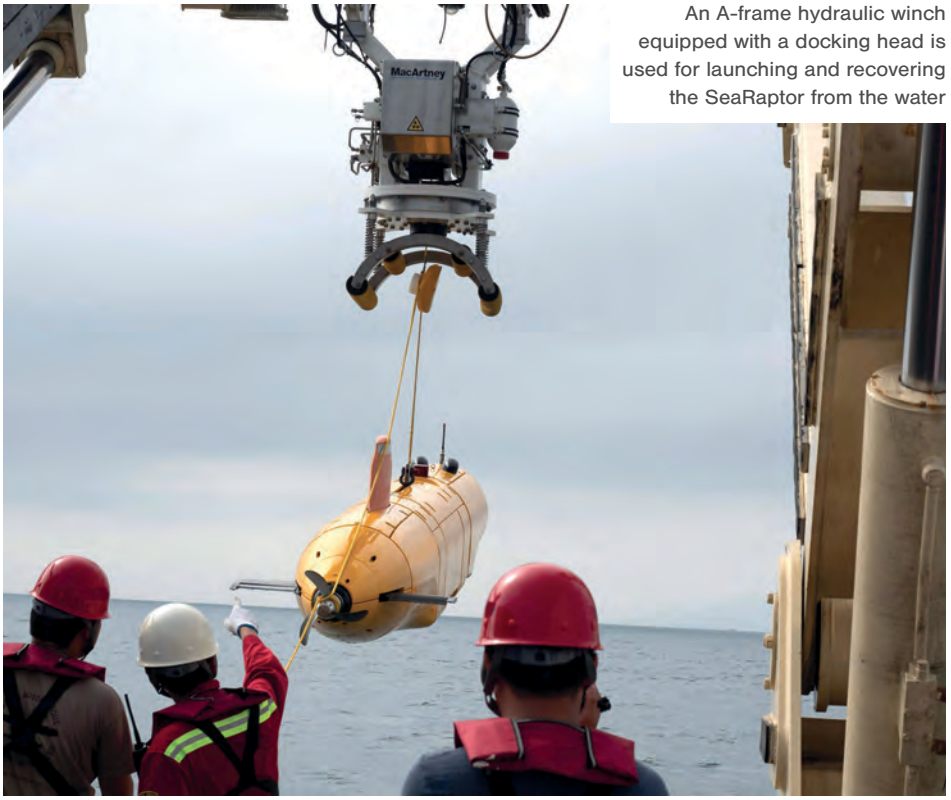
With an operating power requirement of 150 W (and a peak draw of 300 W), the T-50S can be integrated into the SeaRaptor with little issue, while typical AUVs would struggle owing to their smaller size and batteries. When set at 200 kHz, the T-50S can survey up to 575 m away from the vehicle across a swathe of up to 165°.

If an item of interest is then found at a distance from the AUV, the SeaRaptor can later be commanded to navigate closer and use the T-50S at 400 kHz. This roughly doubles the image resolution, therefore helping to identify the nature of the object, be it an airline wing section, a coral reef or a tail section where a black box might be found.

"For this particular deep-ocean search-and-recovery application, we worked with Teledyne Benthos to modify one of their existing USBL systems to act as a new sensor for the SeaRaptor," Reynisson adds.

"The result was a black box pinger locator, which will acoustically detect range, bearing and elevation from a ping. But instead of that being a USBL navigation system from a ship-side transducer, the customer will use this to listen for a pinger, for example from an airliner's black box."

In addition, the SeaRaptor is fitted with acoustic pingers for its own use. If a 'critical state' is detected, such as a malfunction detected by the BMS or a sudden loss in mobility, they are powered on automatically so that a recovery vehicle can locate it.



An A-frame hydraulic winch equipped with a docking head is used for launching and recovering the SeaRaptor from the water

Recovery and post-processing

As mentioned, the 'ascent' weight allows the SeaRaptor to return to the surface without needing to use its thruster. Unlike the descent weight though, this one is typically integrated within the hull, to prevent it interfering with the vehicle's hydrodynamics during a survey.

While returning to the surface, the AUV's quad-core CPU can process the hundreds of gigabytes of survey data using Teledyne CARIS Onboard post-processing software, although this processing can also be carried out in real time during a mission. The CPU typically processes the data at a 'one-for-one' rate – one minute to process a minute's worth of multi-beam echo sounder images.

Upon surfacing, the SeaRaptor can be set to deliver its coordinates to the operator's vessel or GCS via Iridium, wi-fi or any other user-specific comms link, and loiter in that position to avoid running into any surface traffic.

In its initial design specification, the SeaRaptor releases a buoyant flotation section from the centre of its hull with a 30 m Kevlar line linking it to the AUV. This float is recovered by the crew, the line is attached to the A-frame, and the AUV is hoisted back into its container, using a rotatable snubber ring to lock on and prevent the vehicle swaying in the air (similar to methods used in ROV recovery).

After recovery, the operator can download the processed data via a wi-fi link, although Teledyne Gavia is developing a removable hard drive option to speed up this phase.

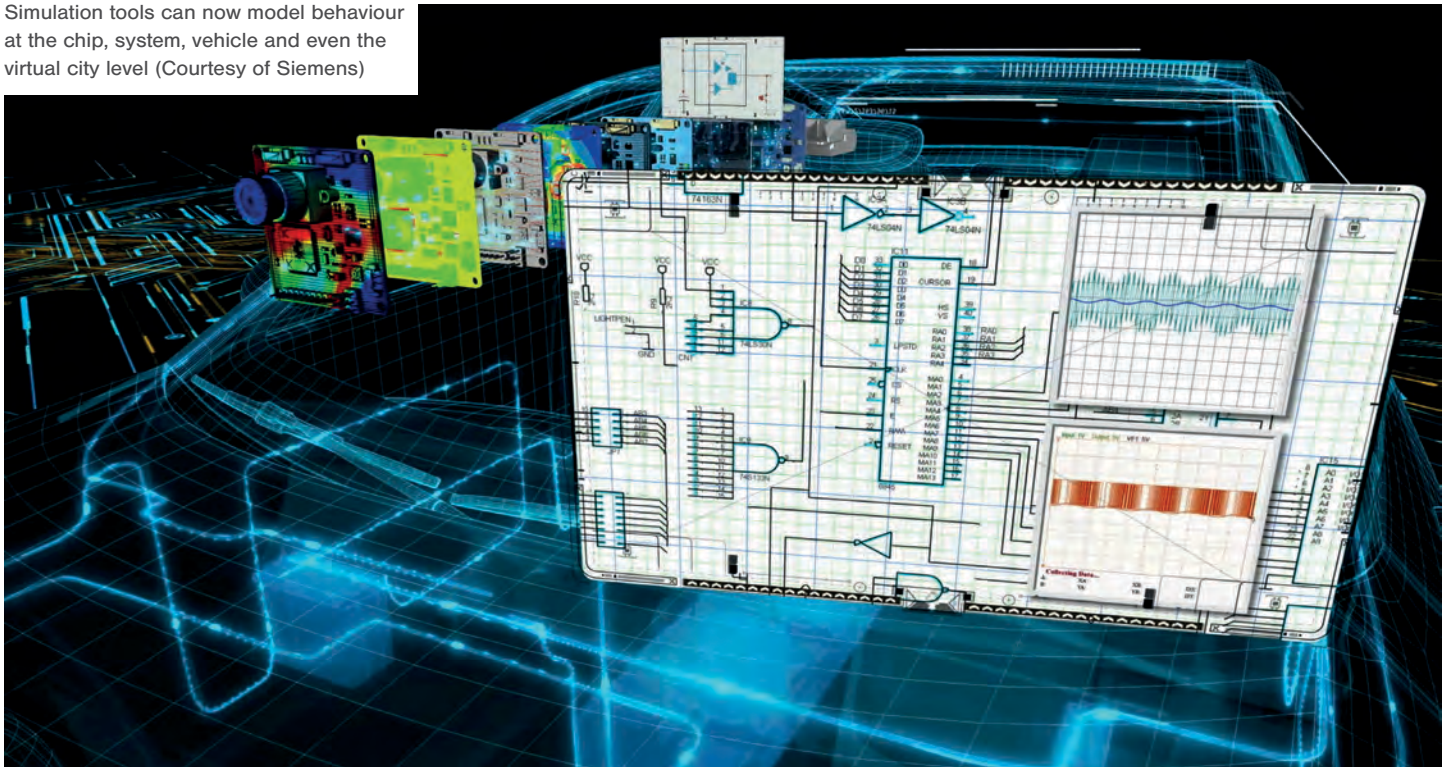
Various maintenance procedures can then follow. Batteries are charged or swapped out, control surfaces are checked for seaweed, and heavy freshwater rinsing is performed.

"Rinsing is critical because the SeaRaptor uses so many different materials – titanium, aluminium, stainless steel – which can react adversely with each other, so you need to rinse off the salt, and care for the connectors and O-rings," Reynisson comments.

"We also integrate 'sacrificial anodes' that will take on the corrosive element if there's any ground between the materials – those may need to be swapped out and investigated for the cause of corrosion."

Conclusion

The company continues to develop the various technologies across the SeaRaptor system to account for the different environments, launch-and-recovery requirements, and mission profiles of the fast-growing market for deep-ocean UUV engineering.



Simulation tools can now model behaviour at the chip, system, vehicle and even the virtual city level (Courtesy of Siemens)

For all practical purposes

The development and testing of unmanned systems is being boosted by recent advances in simulation technology, writes **Nick Flaherty**

Improvements in processor performance, and the availability of massive amounts of that processing power in data centres, has allowed unmanned systems to be simulated in detail as standalone designs and within simulated environments. This in turn is allowing virtual models of unmanned vehicles, and the underlying real hardware and software, to be tested in thousands of different scenarios.

This is also becoming essential in the certification process, as regulators look increasingly at using the virtual environments to demonstrate the functional safety of vehicle designs. That is then leading to the creation of 'golden models' against which systems will be tested.

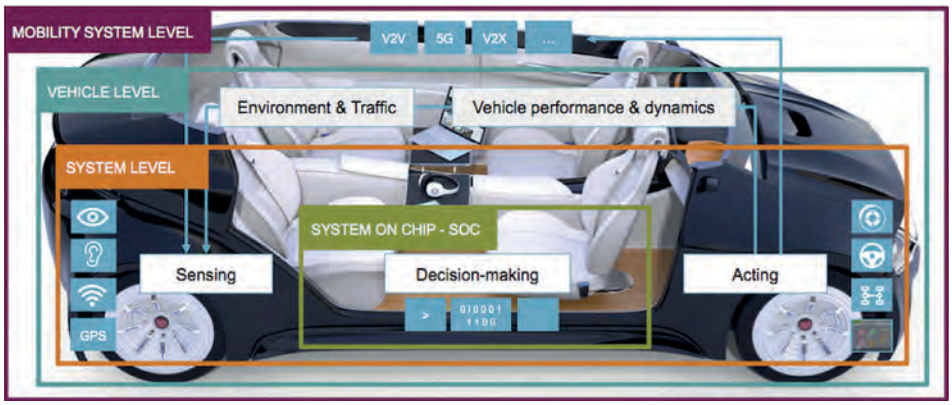
Digital twins

Traditional driving simulators are combined with tools for developing models, system architectures, wiring harnesses and complex control software. All of this leads to the ability to create a virtual model – a digital twin – of an entire vehicle, whether it is a driverless car or a UAV.

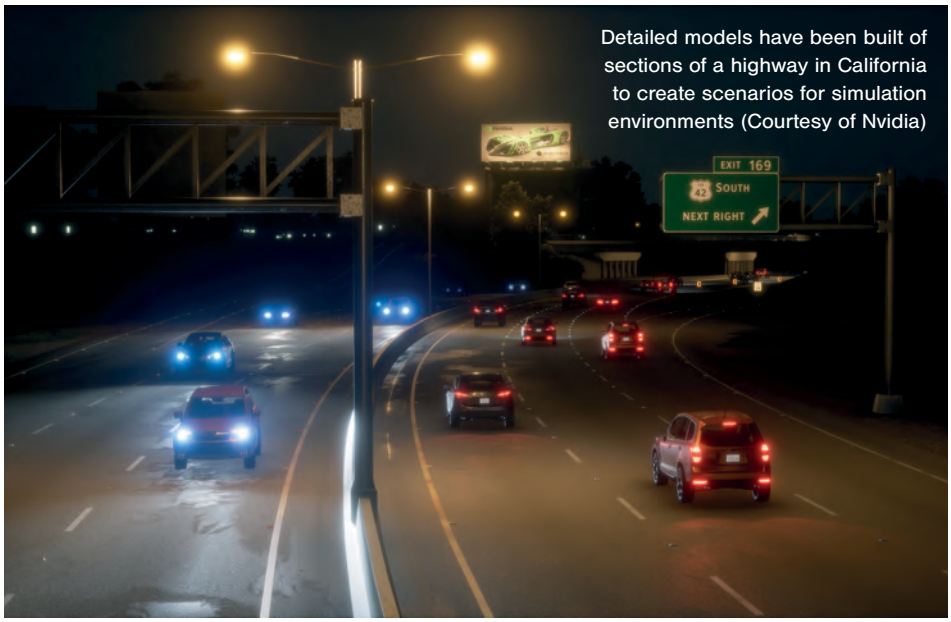
The digital twin can be built using behavioural models at the chip level, through the vehicle and even up to the virtual city model level. Behavioural models, as the name suggests, provide the behaviour of a device or vehicle and so are simpler and therefore run faster than the fully-fledged design.

The value of a digital twin is that it can be used to explore different design options, and test those options using verification tools. The behavioural model can then be replaced with the full design and revalidated to ensure that the design that will be made into a chip, board or vehicle corresponds to the original intention. That allows the detailed development and testing to start long before the chips and boards are available.

That is essential, as the complex devices for the driverless vehicles planned for the next few years will have billions of transistors and take 12 to 18 months to design, produce and test. At the same time, regulators will want to see millions of miles of testing – which can take years – so starting as early as possible is vital.



A digital twin of a driverless car has a number of layers of models, from the chip through the vehicle design to the comms network (Courtesy of Siemens)



Detailed models have been built of sections of a highway in California to create scenarios for simulation environments (Courtesy of Nvidia)

That means the verification tools are also key – the test vectors that are used are being constantly updated to ensure they provide the maximum possible test coverage. These are used throughout the design process to provide a way to distinguish between the suitability of different designs.

The actual chips, boards and embedded software can then be used instead of the design models, and added as hardware in the loop in the data centre. Again, the test vectors ensure that the final integration of the hardware and software accurately reflects the performance predicted by the original behavioural models.

The power of this approach is that it can be extended to wider systems: models of vehicles can be implemented in a digital model of a city. The vehicles can travel though the environment, interacting with each other and models of other road users and pedestrians, with software instrumentation allowing visibility of data that would otherwise be hidden in the system.

These digital models can be connected by models of wireless links that interact with models of the buildings, trees and street furniture to test out the connectivity, allowing the effectiveness of protocols such as IEEE 802.11p, 4G and 5G wireless to be assessed. All of this is possible without having to build a single board.

The advent of low-cost cloud computing allows all these models to be combined. One challenge though is that the models exist across many parts of the supply chain.

Some chip makers will have the behavioural models and high-level designs of the graphics processing units (GPUs), which act as domain controllers around the vehicle as well as running the machine learning frameworks for image identification and sensor fusion. Others will have the models of processors or wireless transceivers.

Tier One suppliers will have models for the sensors, platform electronics, printed circuit boards and embedded software. The OEM car maker will have the detailed model of the vehicle, from the powertrain to the modelling of the passengers and the environment they are travelling in.

Other suppliers are now delivering city-level models that allow for traffic flow optimisation, analysis of noise and many other factors. These can use software engines to model roads, trees, other cars and pedestrians to create traffic scenarios. They are all physics-based, using the reflective properties of the models to see how the radar, camera, Lidar, ultrasound and other sensor models respond.

For example, the model of a radar sensor will include a model of the emitter, a model of how the radio waves are reflected by wet or dry trees, and what happens with multiple reflections – all within the digital twin.

One way to manage the complexity of such digital twins is not to run them in real time. As the interactions are all synchronised, a scenario can be played out and replayed, tweaking different parameters in each model.

This can use different levels of validity to explore particular areas of interest. To test sensor fusion in a controller, for example, a simpler parameterised model of the radar can be used.

To test the performance of the radar, other models can simulate the electromagnetic impact of the paint on the bumper of a vehicle on the radar signal. Different paint colours have different effects, so as a result



The Constellation system combines two Xavier GPUs and two Turing accelerators generating 320 TOPS of processing power for simulation (Courtesy of Nvidia)

the radar wave has different shapes. This can be exported to a specialist electromagnetic simulation tool to use the exact shape for validating the radar system's performance.

Other tools will simulate the wiring harness, for example. The harness is the central component of a vehicle, and is usually one of the first parts of the vehicle to be designed.

The simulation models include the cable types, whether copper, optical or even wireless, as well as the data transfer. Most recently, these models have started to focus on optimising the network traffic from one processor to another within the vehicle. This assists in choosing between distributed or centralised controller and sensor fusion architectures to achieve the desired performance and cost levels.

Raw sensor fusion with a single, large processor and cheap sensors can be tested against multiple processors with more expensive sensors and simpler wiring. Other tools then generate key performance indicators (KPIs) to determine the performance of a subsystem. These KPIs can be used by the OEM or a Tier One supplier to ensure that the module meets the overall requirements.

Testing AI systems

The emergence of autonomous systems takes away the operator (the driver), who took care of unexpected situations – also called corner cases in system verification and validation. Now the system designer has to demonstrate that all the possible scenarios the vehicle will face have been addressed, and this is strongly driving the use of simulation.

This is increasingly difficult with machine learning (ML). There are two approaches to validating ML systems that are based on neural networks (NN) trained using millions of data points.

Some OEMs use an end-to-end NN implementation, feeding in data to generate actuator outputs. This is regarded as a very risky approach though, as the system developer never knows when the system is fully trained – that is, has reached a specified level of safety.

There is also the risk of false training via over-fitting to a data set, such as a specified safety level. That means the NN meets every test situation with a different specific pathway to meet the specification, but fails to generalise.

The NN then becomes a huge virtual look-up table that cannot cope with unexpected situations. The more complex the NN, the larger the number of nodes, and the less easy it becomes to control this over-fitting.

The other approach is to use physics-based models, which measure everything. That leads to massive amounts of operational data, which can be difficult to process.

These physics-based synthetic models also carry the risk of missing data, as models tend to be ideal and similarly cannot cope well with fast-changing, dirty and, especially, chaotic systems.

The consensus is that both approaches will be needed for effective verification and validation. That's because it will be necessary to trace what has been tested to prove the developer did a thorough job – for example, out of the 10 million scenarios that were simulated, the fatal scenario was not part of the test suite.

Machine learning can also be used to test the performance of a particular model. For example, a software tool can generate 1000 synthetic scenarios, run the models through those scenarios and measure the results against the critical KPIs. The ML algorithm can then be used to generate further variants of the scenarios to dig deeper into the controller, generating more variants to optimise particular parameters and then measuring the KPIs against recorded data.

This has been integrated into the ISO 26262 safety-critical design process, but it means having to document millions of test scenarios, which is a massive data challenge. That has led other tool suppliers who have a long heritage in large data management to produce development and test environments that make these documents transparent and traceable.

The simulation and test of vehicle-to-vehicle and vehicle-to-infrastructure (V2V and V2I, commonly called V2X) links is also a key element, and that has to correlate closely with the real-world systems.

One challenge with simulating these links is the fidelity of the models. For example, not all wireless packets will arrive at the vehicle, so probabilistic models with limited quality are

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needed, rather than fully accurate models. The level of fidelity required in the V2I model then depends on the use case and the environment, which then links back to the scenarios used for modelling.

At the digital city level, these models are huge but they already exist. Developers of smart city software already have detailed models of infrastructure, traffic flows and roadside units, along with maps to identify where a car can drive – all based on real-world, infrastructure-based sensors.

These tools can then be used to generate traffic that behaves realistically, to test the interaction of the digital twin model of a vehicle with the environment, complete with the different wireless links.

Detecting vehicles and lanes in the reference example about designing a visual perception system (Courtesy of MathWorks)



Standardisation

The sheer complexity of the simulation and verification environments highlights the challenge going forward. So far, many companies have developed their own tools, but the complexity is growing at such a rate that this is no longer viable. Standardisation is therefore needed, but the debate is at which level.

There can be standard interfaces between tools at the application processing interface level, but they may not be able to cope with the various levels of fidelity of the different models. There are working groups around the world looking at how this can be achieved.

There is also a need to standardise the scenarios – how they are set up and what they test. At the moment, many unmanned system developments are replicating the development of the same scenarios, seeing this as core intellectual property built up over time.

Scenario definition is critical, as are the interfaces to the scenario databases, so that vehicle developers can share scenarios to improve the quality of the ML algorithms.

At the validation stage, there is value in having a shared set of data. Ride-sharing companies say they test a set of 2 million scenarios with a closed-loop improvement cycle, which drives down development costs as well as potential liability costs.

There is also the regulatory environment. Singapore for example is a key testbed for this technology, and has built a $75 million digital twin of itself called Virtual Singapore. This will allow regulators to test vehicles and their levels of performance in the virtual environment before they allow cars in particular areas. Scenarios based around the models of these areas would be a key part of the initial permission.

No regulator has a set of test cases yet, but that is expected to come. This is highlighted by the fact that the EuroNCAP car safety lab is part of the certification process for combined virtual and physical testing of systems for 2020.

Hardware in the loop

There is a lot of continuity in the transition from a high-level model simulation, through a detailed model in the loop and then hardware in the loop (HIL). This hardware can be a physical controller that replaces the model in the simulation or even the entire vehicle.

For example, a development team can disconnect the sensors in the vehicle and feed the scenarios directly into the vehicle bus to achieve full proving-ground testing without leaving the lab.

In this case the scenario definition gives the sensor input, the trajectory of the vehicle and a robot 'driver' on the seat of the car or in the controller. The robot driver allows the same scenario to be replayed on a physical testing ground with the same control data, which provides consistency throughout the test process.

Integrating the hardware into the simulation environment is key. The simulation environment and scenarios are used to test and validate the systems being put into the cars using a process that is safe and repeatable to enable test and validation.

This is being used for simulating perception systems, mapping, localisation and the sensors around the vehicle, also called the 'safety force field'. This simulates the camera, Lidar and radar inputs, and feeds them into the actual hardware running the sensor fusion and control software.

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This validates the systems that will go out on the road up to the various levels of autonomous operation, including full autonomy on any road at Level 5 with redundancy through a second hardware controller.

For Level 5 operation the simulation plays a huge role. It allows the developer to jump to the most dangerous intersections in the world and create a suite of the craziest environments to test the system, which simply isn't possible in the real world.

One open platform is being developed around the GPUs used in many unmanned vehicle designs. This has two hardware controllers based on production GPUs, in a data centre linked to a server that provides the simulation environment.

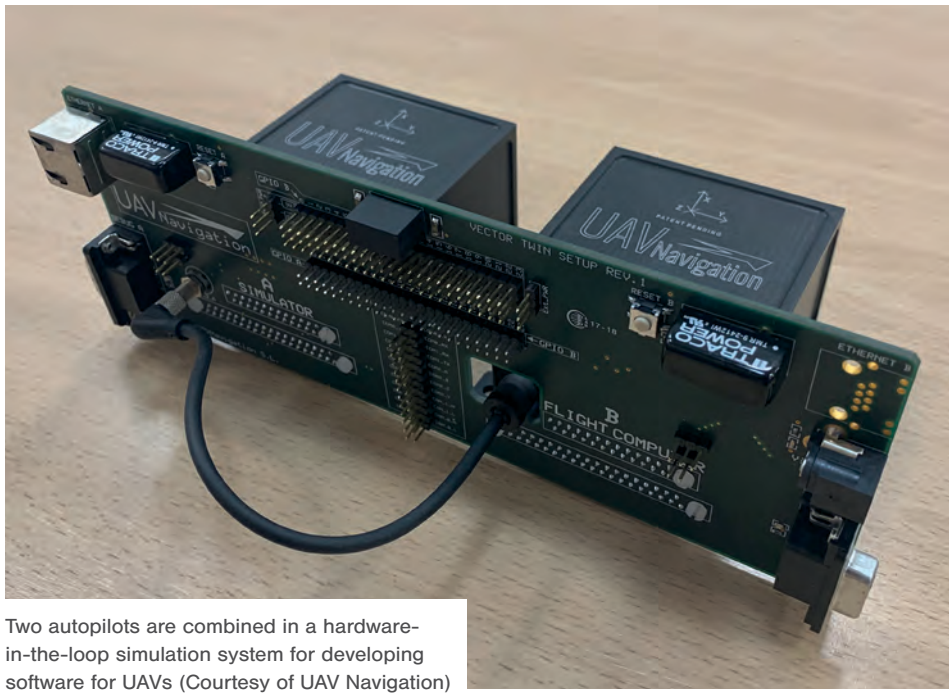
It uses software tools from the computer gaming world to create the virtual maps and environments, allowing developers to create random trees and roads with potholes, and changing the time of day or the weather, to provide a wide range of scenarios for testing the responses of the controller.

These can be linked to the vehicle models, which have many thousands of parameters. This allows 100 nodes in the data centre to run automated tests in different environments 24 hours a day using real-world data, rather than having to have 100 cars driving around with safety drivers.

The platform supports regression testing so that when new code is added to address a failure, the previous tests are run to ensure that the responses are improved. Again, this is a significant data management challenge in tracking all the environments, the sensor sources, the test vectors and the results.

The platform is also scalable so that the controllers based on the latest GPUs can be dropped in to replace the current hardware and all the same tests run with the same scenarios in the same environments.

However the data challenge is huge. Four, 4 MP camera sensors would generate 4 bytes per pixel at 30 frames per second, generating around 2 Gbytes each second. At 60 mph, the simulation generates 120 Gbytes per mile.



Two autopilots are combined in a hardware-in-the-loop simulation system for developing software for UAVs (Courtesy of UAV Navigation)

The 100 nodes running for 24 hours would generate 17.28 Pbytes – 17.28 million Gbytes – each day, just for the image sensors, let alone radar and Lidar. A million miles of simulation, which is a small part of a validation suite, would require 120 Pbytes of storage for just one vehicle.

Hardware in the loop for UAVs

HIL can also be used in the development and testing of UAV systems, and in a number of ways. Simulation of an airborne platform is usually carried out in exactly the same way as for a ground vehicle, but the differences come with the hardware in the loop.

This can be used for testing the end controller as well as developing the flight control software, rather than using a purely software simulator – especially helpful when customising an autopilot for a specific UAV platform.

One HIL approach is to use the autopilot hardware both as the simulation environment and as the HIL test system. A simulator can run on an autopilot board, providing 200-250 mission parameters, such as the GNSS positioning data, altitude, speed and so on for any type of unmanned aircraft, both rotary and fixed wing. The system also simulates an electrical model of the sensors, the output to servos, switches – essentially all the items connected to the autopilot.

The output from the simulation autopilot is then fed via a custom interface board to an identical autopilot board, with the software being tested via links to the ground control system. This allows developers to adjust the simulation environment to explore different scenarios.

That means the same processor is used for flight control as well as the simulator, so there is consistency.

The only thing outside this combined dual autopilot system is the control of the mission, and that is addressed using a 3D representation built around a third-party model. This allows an engineer to have additional feedback to see the orientation of the simulated craft, and see how it is 'flying' via a PC connected to the GCS. This then allows the engineer to change the scenario, for example by introducing noise or offsets on the sensors, or forcing the servos into a certain position.

Some examples of simulation & testing providers for autonomous vehicles

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The results of these changes can be analysed using the flight control computer, with all the standard telemetry links.

These approaches address perhaps 95% of the testing, and provide a higher level of reassurance that test flights will be successful. That is especially important for custom platforms, where there may be only one or two versions.

Traditional simulation tools are also a key part of the development and test environment. Development tools that were previously used to develop control loops now have to include ML techniques. In the past they used a block-based graphical interface to develop the algorithms, automatically produce code optimised for a particular processor or GPU, and provide the test vectors to validate the code running on the actual hardware.

This is much harder with ML algorithms, which have to be trained and with reinforcement learning where the algorithms keep taking in new data to constantly improve their accuracy. That means the algorithm development tools are moving more to simulation environments, taking in external real-world or simulated data as part of the software validation process.

Summary

The development of autonomous systems has driven a boom in the use of simulation technologies of all kinds. Being able to model a vehicle or even part of a city with all the different elements though is a huge computing challenge. The emerging market for common scenarios for testing, and more widely available test data with the associated test vectors, will speed up the validation of controllers and sensor systems.

The prospect of golden scenarios and test environments for regulatory approval is another significant potential move that would also speed up the development and testing process.

All of this requires a new generation of frameworks rather than individual tools. The ability to manage huge amounts of data effectively as part of a safety-critical design process will be vital, and that will reduce the number of suppliers to a handful. The differentiation in the simulation and test process will then sit with the development of the scenarios and the efficient analysis of all the test data being produced.

Acknowledgements

The author would like to thank Danny Shapiro at Nvidia, Mattieu Worm at Siemens, David Pinta and Luis Garcia at UAV Navigation, Chris Hayhurst at MathWorks and Andy Luo at TotalSim for their help with researching this article.

The UK's National Oceanography Centre has proved the ideal venue for the Ocean Business show













Putting to sea

Rory Jackson reports from this hands-on show with details of the latest technologies for marine autonomy

Hosted at the National Oceanography Centre in Southampton, England, Ocean Business 2019 drew together over 330 companies and 5000 visitors from more than 60 countries, to exhibit and discuss the latest in marine innovation and operations – with unmanned systems taking prominence as organisations aim to reduce costs and risks.

SBG Systems presented its new Horizon-grade IMU, the company's first fibre optic gyroscope (FOG) inertial sensor, as part of its Navsight Marine line of inertial navigation solutions.

"Low dynamic applications, urban canyons and large bridge crossings can push the limits of what MEMS technology can provide," said Ludovic Bazin, adding that Horizon has been designed to fill this gap by addressing the most demanding survey applications, for which MEMS IMUs are insufficient.

The Horizon IMU provides roll and pitch measurements accurate down to 0.007°, real-time heave measurements to 5 cm (or to less than 2 cm using delayed heave algorithms) and heading to 0.01°.

"That performance is a result of Horizon's closed-loop FOG technology, and it can be further improved in post-processing using our Qinertia software," said Bazin.

The Horizon module is currently intended for surface applications such as hydrographic survey USVs. It comes in an IP68-rated enclosure, measures 150 x 168 x 215 mm and weighs 4.9 kg.

As mentioned, the Horizon IMU is integrated in the Navsight product line, with a direct interface to the same topside processing unit used by the NavSight Apogee and Ekinox IMUs.

The topside unit measures 227 x 156 x 63 mm, weighs 1.9 kg, and consumes up to 7 W when coupled with an RTK GNSS receiver as well as an Horizon IMU.



SBG Systems' Horizon-grade IMU (right) is IP68-rated and weighs 4.9 kg



The Dynautics Phantom AUV is rated down to 30 m

Marine unmanned electronics company Dynautics launched its Phantom AUV, development of which began following an order in November 2018, with its first sea trial taking place 105 days later.

"The system successfully completed an autotuned roll manoeuvre within 2 s, and roll was controlled to within less than 1°," said Dr Henry Robinson. "The vehicle was developed largely from a blank sheet, and engineered to meet the customer's particular list of requirements for an AUV for tight control in shallow waters rather than heavy payload capacity or deep diving."

Dynautics undertook the r&d and design work, with the Phantom's blueprints being completed within the first month of the development schedule, at which point the hull drawings were sent to be machined by a third-party manufacturer over the subsequent eight weeks. The r&d team was able to adapt its Spectre autopilot, which has been developed over 20 years, with only minor changes needed to meet the specific mission requirements.

"No significant alterations were needed for the autonomy – the Spectre's algorithms are designed for versatility, so it can be used by anything from a 20 m USV to this 1.3 m AUV," Robinson said.

This version of the Phantom is rated down to 30 m, although it has been pressure tested to 50 m depth and is estimated to be fit for 100 m. It travels at up to 5 knots, can operate for up to an hour at a cruising speed of 4 knots, and weighs 11 kg in air. The design is intended to be flexible and modular to allow for multiple payloads and missions.

SeateChrim exhibited an AUV antenna system designed to double as an ice drill, for AUVs operating under ice floes and in need of rapid surfacing (for comms, transmitting survey data or gaining a GNSS position fix).

"You can attach this system to the hull and power supply of your AUV, to provide mounting, power and also a forward push of the drill into the ice," said Vladimir Stoyanov. "Tests have shown it to take 4 minutes to drill through a layer of ice 2.5 m thick."

The drill motor drives the shaft for a drilling speed of 1-1.4 cm/s, boring holes roughly 35 mm wide in the ice, and the upper part of the drill contains an Iridium antenna for transmitting data via satellite to the AUV operator. The system can be mounted atop the middle of an AUV's hull, in a vertical- or forward-pointing configuration, depending on the propulsion system.

Swift Engineering presented its latest UAV, the Swift 021, which is intended as the successor to the Swift 020 VTOL-transition tailsitter, the company's first UAV (detailed in *UST* 16, October/November 2017).

"We've made some improvements, primarily to the main centre body, replacing the moving landing gear with static landing struts, and including design changes for manufacturability and to improve ease of operation, set-up and dismantling," said Ryan Chase.

"These were done in order to increase stability on uneven surfaces when landing and taking off, to reduce overall weight, cost and complexity, and increase overall efficiency in operations."

In addition, the larger centre body is meant to provide easier integration of new subsystems and payloads without requiring a redesign of the airframe. Like its predecessor, the Swift 021 can still land and take off vertically, independent of runways, is operated by one person and fits within confined spaces such as ship decks that can accommodate its 4 m wingspan.

Software changes have also been made, with Pixhawk and QGroundControl now compatible with the Swift 021.

Significant engineering work has also focused on reducing the amount of wiring throughout the inside of the hull, to streamline the vehicle's electronics and reduce their weight.

"We're also looking to integrate additional payloads, including the Nighthawk EO/IR from NextVision and the Sony A7R for still-shot photogrammetry applications," Chase said. "There are other payloads as well, including a methane sensor for oil and gas inspections – they'll all be within the 1 kg weight range."

The Swift 021 is designed to perform missions such as fishery surveys, linear infrastructure inspections including pipelines, railways and power lines, and monitoring for piracy and other illegal activities on the oceans.

Further specifications for the Swift 021 are expected to be published later this year.

Swift Engineering also showcased its Remora towed pH sensor and low-cost commercial-grade buoys for citizen scientists, researchers and academia focused on aquaculture and water quality monitoring.

Three prototypes of the Remora system have been built and lab-tested so far, producing measurements of 0.002 accuracy and 0.0001 precision on the pH scale after only one calibration.

Riegl's UAV-mounted Lidar mounted on its RiCopter-M UAV





SubCtech's battery provides 41 kWh

Marine battery manufacturer SubCtech showcased one of its latest projects, a large AUV battery that is now in series production and can be customised to the requirements of a specific UUV.

"The PowerPack has been developed to API17F and Mil-Std-810G, for shock, vibration and other safety factors that are critical to preventing battery failure and vehicle loss when submerged far from the operating station," said Stefan Marx.

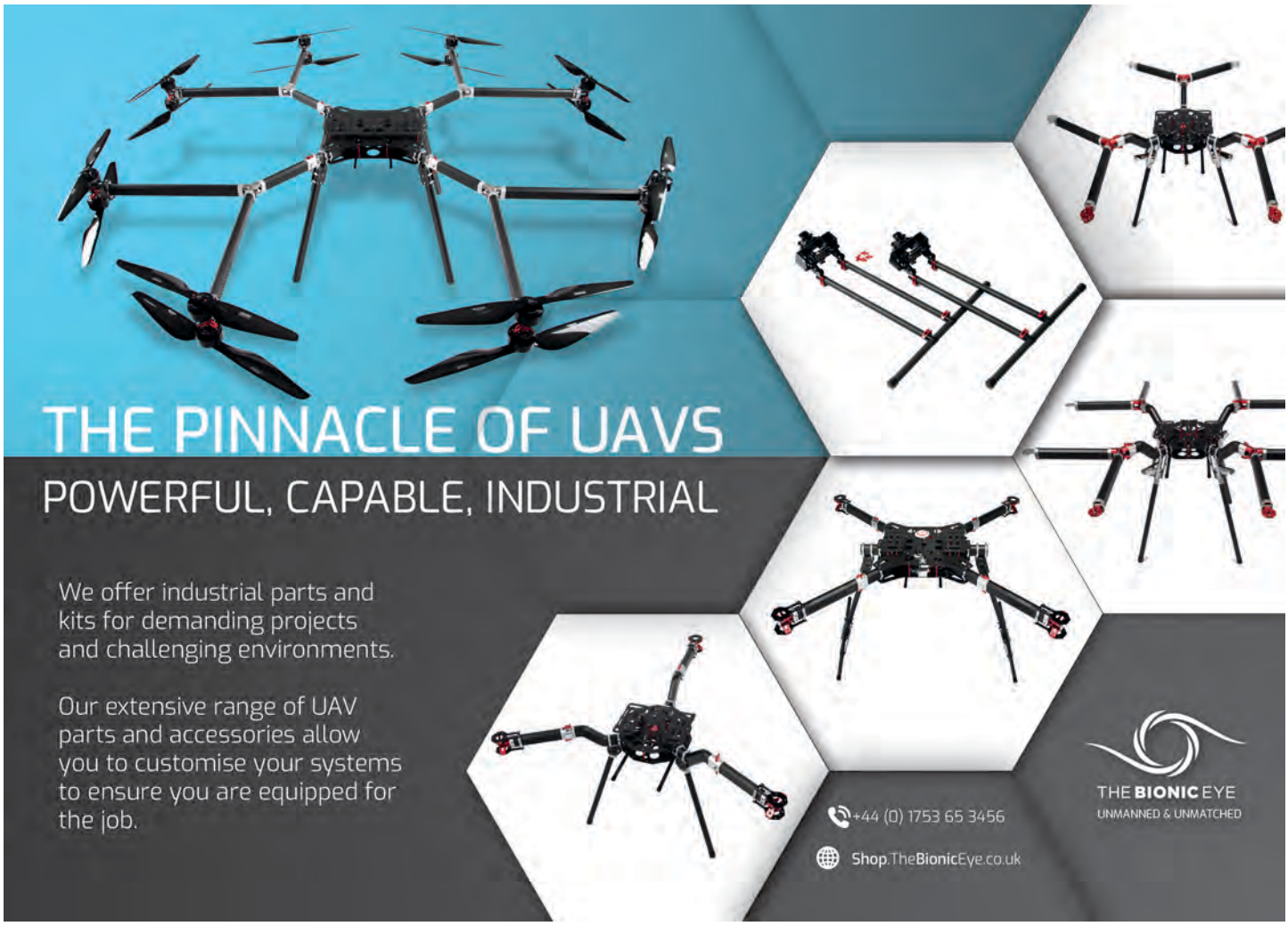
"The company commissioning the battery had a number of clear specifications right from the start. Accordingly, this battery model provides 41 kWh within a form factor 1.8 m long and weighing 200 kg in air when installed in its pressure housing."

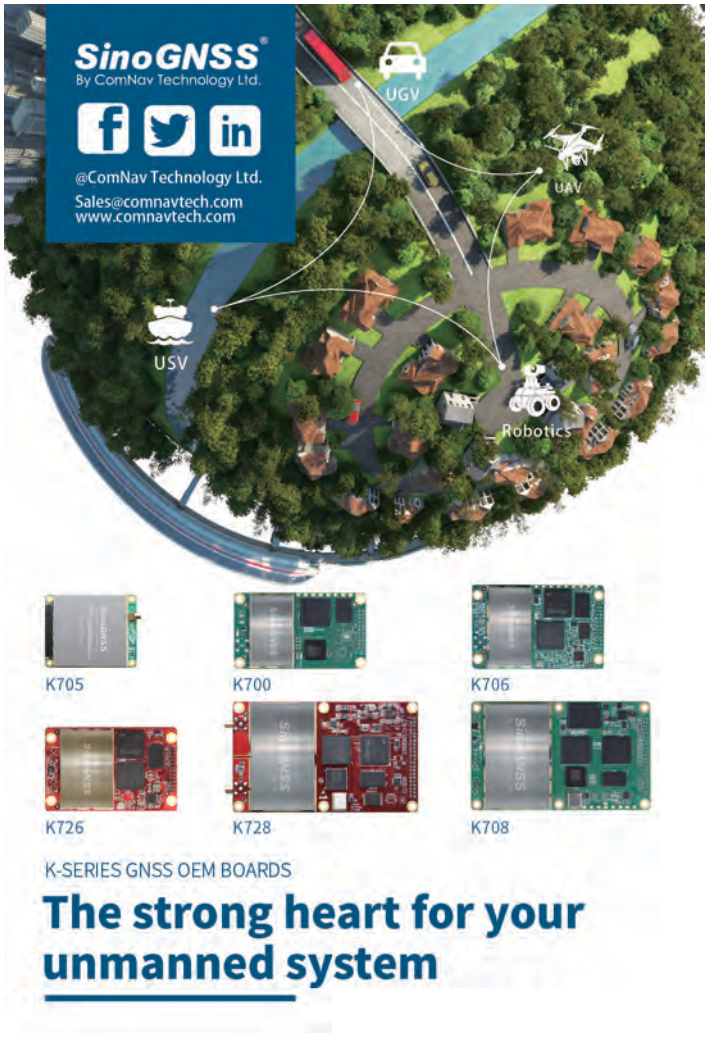
The PowerPack battery provides 10 kW over a 150 V supply typically, but the architecture can also be configured for 400 and 600 V connections, with energy storage of up to 200 kWh. The system is passively cooled, with piping to the AUV housing as the sole thermal management connection.

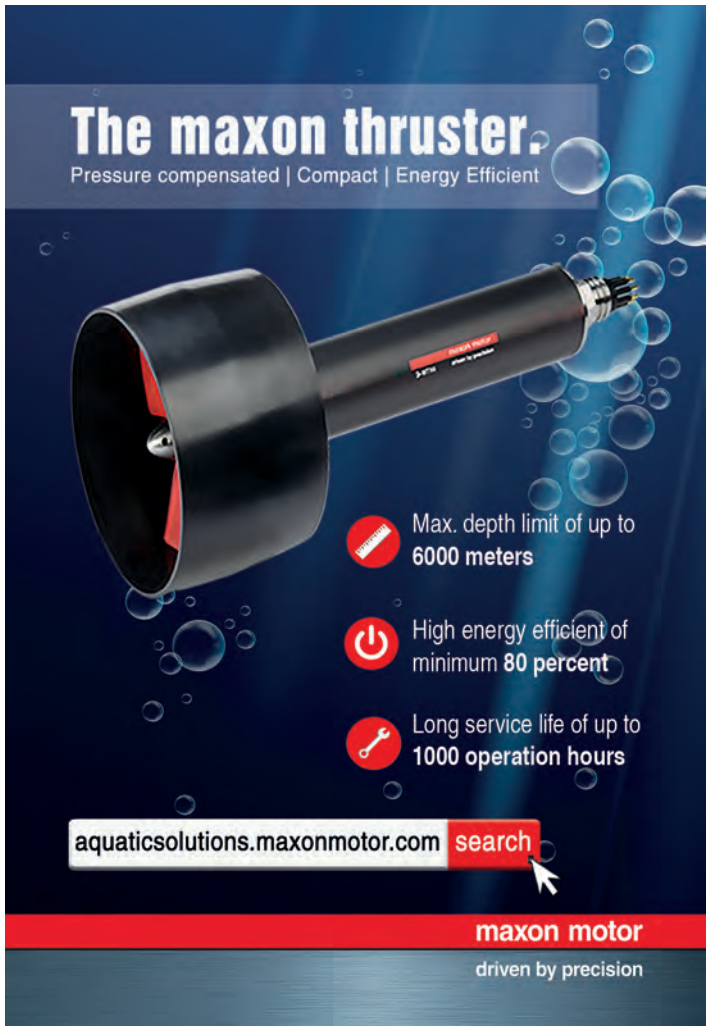
"With our battery designs, active cooling is generally not required until you get above 50 kW, and no AUV yet requires that much power," Marx said.

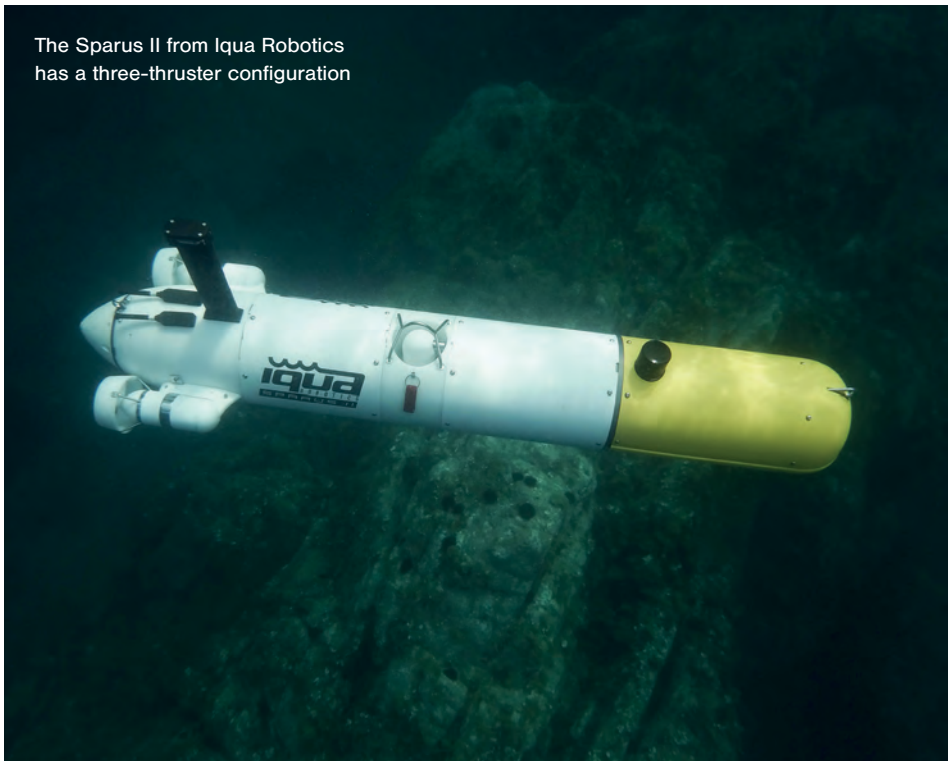
Lidar manufacturer Riegl displayed its range of newest solutions for UAV-based marine surveys, with at the forefront the VQ-840-G laser scanner for hydrographic and topographic data gathering.

As Dr Martin Pfennigbauer told us, "This system was designed to succeed our BDF-1 bathymetric scanner. It weighs less than 15 kg, which was a key target for ensuring it could be used on heavy-payload UAVs, and we designed it to achieve a pulse repetition rate of up


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The Sparus II from Iqua Robotics has a three-thruster configuration

to 200 kHz and water penetration of up to 1.5 Secchi depths.

"This requires a suitable wavelength for the laser to penetrate into the water: ours operates in the visible green range of the light spectrum. And we had to select a highly sensitive receiver with a significant aperture to collect as much of the echo signal as possible – which is very weak as it returns from the seafloor – otherwise you wouldn't be able to produce useful bathymetry measurements.

"Robust signal processing algorithms are also as important as these sensitive optoelectronics."

The system typically consumes 110 W and features an integrated GNSS-IMU and camera for geo-referencing and fusing of bathymetry data with additional sensor inputs.

The company also showcased its latest unmanned aircraft, the RiCopter-M UAV, an eight-rotor system designed to serve as a carrier for the VQ-840-G and other Riegl laser scanners. The aircraft has a maximum payload capacity of 15 kg and a MTOW of 40 kg, with a 20-minute endurance when at full carrying capacity.

CHC Navigation launched its P2 series of GNSS modules, and exhibited them at the show for applications such as unmanned maritime system navigation.

"In the UK, we also run a network of RTK base stations, supplying real-time kinematic correction signals to our customers," commented PJ Walker.

"Much of the work on the P2 series was borne out of our experience of developing and optimising that network, and we'd long had requests for something suitable for larger USVs in need of accurately geo-referenced survey data from various different payloads."

The P2 unit comes with 336 channels and compatibility with GPS L5, GLONASS L3, Galileo E6, BeiDou B3, as well as the older GNSS constellations, along with the latest QZSS and SBAS functionality. With RTK, longitudinal positioning is 8 mm +1 ppm RMS, and latitudinal position is accurate to 15 mm +1 ppm RMS.

In addition to the standard version, the P2 Pro version comes with a dual-antenna input for generating heading data, while the P2 Elite integrates additional 4G and UHF modems for broader comms functionality and redundancy.

The P2 measures 162 x 120 x 53 mm and weighs about 1 kg, with a typical power consumption of 2.7 W running off a 9-36 V DC supply.

Iqua Robotics displayed its latest unmanned subsea survey vehicle, the Sparus II AUV. It comes with an open ROS architecture to enable users with scientific, academic and industrial applications to write custom behaviours into its autopilot for specific missions and operations.

As Natalia Hurtos told us, "It differs slightly from the typical 'torpedo-type' AUV design in that its three-thruster configuration allows it to hover at a single point underwater, which is useful when you need to gather concentrated imagery from a specific part of the seabed."

Two of the thrusters sit on opposite sides of the rear section of the AUV for forward propulsion up to 3 knots (as well as manoeuvring), with a vertically oriented thruster mounted into a tunnel in the centre of the aluminium and acetal hull for hovering. All three are made in-house.

"It also has an 8 litre payload capacity – about 7 kg in air – within the nose, to ensure flexibility in the types of sensors users can install and the types of missions they can carry out," Hurtos said.

"We integrated the cameras, multi-beam sonars and side-scan sonars. The system is open and simple, which allows customers to integrate equipment themselves."

The Sparus II has a maximum endurance of 8 to 10 hours, and when surfaced it uses a wi-fi connection to transmit and receive commands, as well as a GNSS antenna and an indicator light fixed atop the rear hull.

Septentrio displayed its range of maritime GNSS solutions, including the AsteRx-U multi-constellation, multi-frequency receiver, which is used on iXblue's DriX USVs and major dredging ships around the world.

"The advantage with the AsteRx-U comes from its compatibility with all



Silicon Sensing MEMS IMUs



The Impact Subsea ISS360 is said to be the smallest imaging sonar currently available

satellite constellations and the major marine correction services such as Veripos Apex and Marinestar by Fugro," said Laurent Le Thuaut. "While compact in size, the AsteRx-U supports all wireless comms available today as well as UHF radio."

It measures 174 x 166 x 53 mm, and weighs 1.5 kg. It features the company's latest algorithms for interference detection and mitigation, multi-path rejection, and for maintaining tracking accuracy amid increased mechanical vibration or ionospheric activity.

"The AsteRx-U Marine is an offshore-focused product, with particular development attention given to accuracy and reliability in difficult environments," Le Thuaut explained.

"For example, to mitigate multi-path errors we have an in-house database containing thousands of records of field GNSS measurements, so we can leverage that to correct the observed satellite signals."

Silicon Sensing is working on a series of new IMU products for maritime navigation, to be released after mid-2019.

"A lot of our marine users have been requesting additional information to be output from these new products," said Andy Hughes.

"These include pitch, roll and heading measurements alongside the normal angular rate and linear acceleration measurements.

"Enabling that is a matter of working on the mathematical operations and Kalman filter necessary for pitch, roll and heading derivation from the compensated sensor inputs, which will also include magnetometers and barometer measurements. That means the Kalman filter has to be optimised to reduce the sources of errors that can degrade the derived roll, pitch and heading measurements."

The company is also developing new sensors for use in future generations of its IMU, with the aim of working towards a product that would be capable of gyro-compassing without the need to rely on magnetic sensors.

Impact Subsea exhibited its ISS360, which at the time of writing is the smallest imaging sonar available. It is about 72 mm long and 43 mm in diameter, while weighing roughly 400 g in air and 300 g in water.

"It is a scanning sonar that provides imagery to a range of about 90 m away from the host vehicle," said Ben Grant. "Uniquely for scanning sonars it does not use slip rings to couple the transducer to the electronics.

"The transducer is fully inductively coupled to the electronics, which means it can keep scanning and never wear out. That removes the maintenance requirement to return to the manufacturer for new slip rings to be fitted, which is an issue with most scanning sonars these days."

The sonar also has integrated gyroscopes, accelerometers and magnetometers to provide heading, pitch and roll, and assist in imagery clarity by compensating for them. That helps to reduce any blurring of image data if the host vehicle rotates quickly.

"The size of the system made development challenging," Grant said. "The electronics take up a very small area inside the enclosure, with three PCBs, each six layers thick, and miniaturising everything in the boot end required complex and rigorous design work."

“Now, here’s a thing”

Proposals to put a specific tax on robots, promoted by luminaries including Bill Gates, are confused and likely to be counterproductive (writes Peter Donaldson).

The idea is attractive because it seems to address the problem of a shrinking tax base caused by robots replacing tax-paying humans in the workforce. However, it overlooks the real relationship between taxation and government funding, and ignores the complexities of defining robots for tax purposes.

The orthodox view is that taxes fund government spending, but that isn’t true for currency-issuing governments. They spend by issuing currency, their every payment is made with new money, and they don’t wait for tax revenue to come in before they spend.

Taxation therefore removes some of that money from the economy to prevent inflation. Also, the obligation to pay tax in the government’s currency creates a base level of demand for it.

Likewise, government ‘borrowing’ in its own currency, in the form of interest-bearing bonds, does not fund government spending. Instead, it is a means of taking money out of circulation while providing safe assets for the financial sector.

The orthodox view only applies to governments that don’t issue the currencies in which they tax and spend. These include the members of the Eurozone. However, the EU as a whole is a currency issuer and owns the European Central Bank – the source of the euro.

> Not only would robot taxes not do what their proponents say they would, they are also aimed at the wrong problem

This description of how governments finance themselves is central to modern monetary theory, an approach to economics that is presenting an increasingly powerful challenge to the mainstream.

Robots can be hard to define for tax purposes. Most of us think of them as computer-controlled mobile machines, but many computerised entities that replace human labour are just software.

There’s a risk then that unmanned vehicles would be disproportionately affected by robot taxes because they are easily identifiable as robots and therefore easy to target.

Unmanned systems are creating new markets though their ability to go places and do things that manned systems cannot do safely and economically, so a tax on robots could hurt the development of these new fields of activity and the jobs that depend on them.

The effects of a robot tax on government spending power would differ between countries that issue their own currencies and those that don’t.

In a country with its own currency, they would discourage the adoption of robotics without affecting the government’s spending power. In a nation without its own currency, such as a member of the Eurozone, tax receipts would add to the government’s spending power, but they would shrink as their discouraging effect on robotics took hold.

Not only would robot taxes not do what their proponents say they would – increase government spending power – they are also aimed at the wrong problem.

The real damage to the economy from the destruction of jobs, and the attendant human cost, would come from the collapse in income for millions of people, leaving them with little or nothing to spend. That would be disastrous for capitalist economies that run on sales.

It isn’t technology in general or robots in particular that is destroying well-paid secure jobs and threatening livelihoods, it’s economic policy driven by political priorities. The solution lies in finding ways to embrace the productivity of robots and to distribute the fruits of their labour fairly. Such solutions can only be arrived at through politics and economics.

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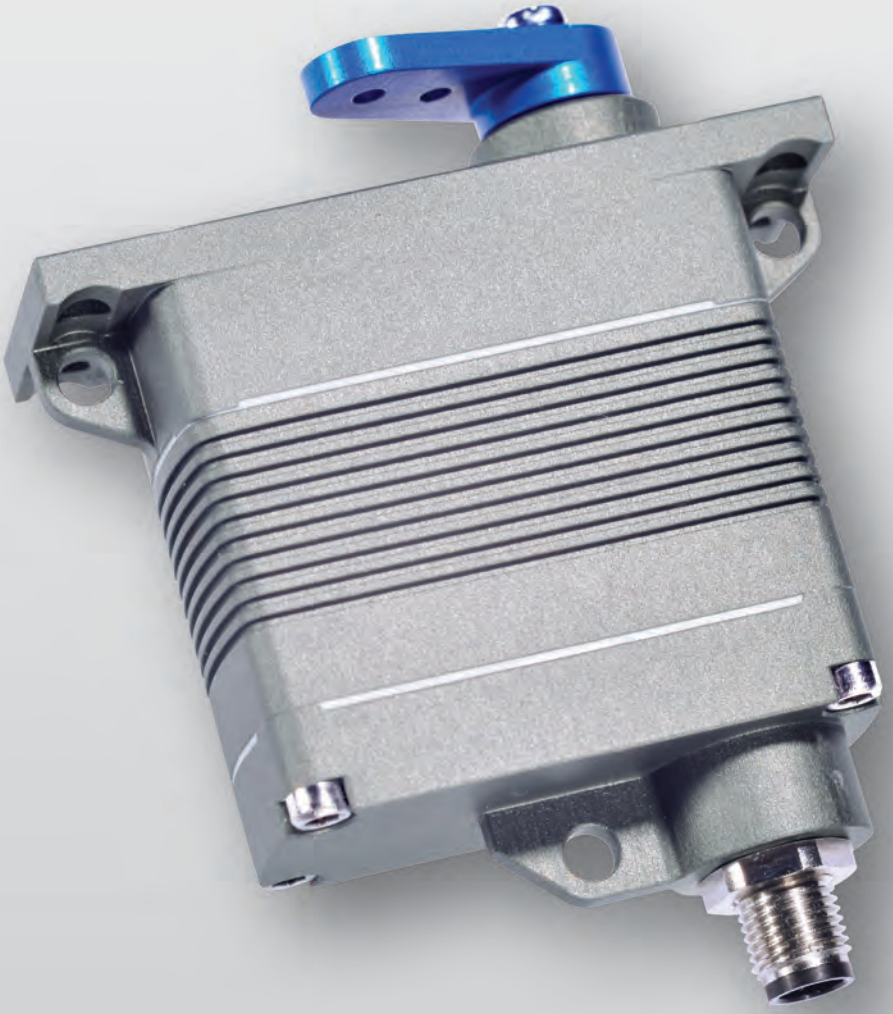
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