Future ScanEagle UAVs will use a new two-stroke engine from Orbital. *(Photo: Insitu)*

Core workout

With good power-to-weight ratios, smooth operation and fuel-efficient performance, the two-stroke engine is attractive to small UAV developers. **Peter Donaldson** talks to industry about recent advances in the technology.

Achieving the best combination of performance, reliability and affordability is a particular challenge for developers of small UAVs and their powerplants. Airframers need to form close relationships with engine suppliers to ready such vehicles for longer missions, while carrying increasingly sophisticated – and costly – payloads.

This was certainly a high priority for Insitu when it chose Orbital to develop the powerplant for its next generation of birds from the nest that hatched the ScanEagle and Integrator. 'Propulsion modules are absolutely vital to the reliability of our aircraft,' Don Williamson, director of the ScanEagle product line for Insitu, told *Unmanned Vehicles*.

The Orbital engine is to go into ScanEagle Block 2, with Williamson describing it as an evolutionary development of the original, which has accumulated more than 800,000 operational flying hours. 'We will take the lessons we have learned from the ScanEagle platform and the emerging technologies from the rest of our product lines and merge them,' he said.

NEW FEATURES

ScanEagle Block 2 will have new avionics and GPS modules, as well as a ground support infrastructure that is common with that for the larger Integrator, and includes the launcher, SkyHook recovery system, GCS, software and user interface suite.

'What that does for our customers is allow them to make a single investment in the infrastructure and, perhaps as important, a single investment in their operator training,' added Williamson.

The single-cylinder, two-stroke Orbital engine will be designed to have a maximum power rating of 2kW, an increase of 0.5kW over the current ScanEagle engine, although it will run at approximately the same maximum continuous power setting as before, giving it an easier life, according to Kevin Beloy, the platform's propulsion manager and technical lead for Insitu's work with Orbital. It will also provide significantly more electrical power.

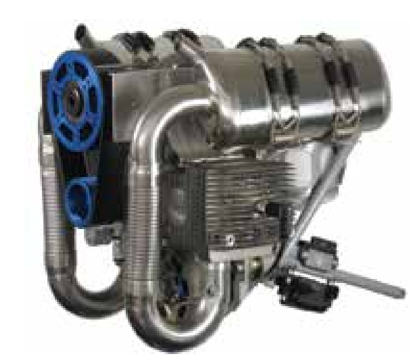
Williamson described progress on the propulsion system front as phenomenal. 'We have really enjoyed our relationship with Orbital. We find them to be a world-class partner, and the plan that we embarked upon two years ago is on schedule.'

FIRST FLIGHT

The first engine arrived at the company's premises in Bingen, Washington, in August. 'We are in the process of getting that engine set up on our test stand,' he told *UV* at the time. 'Over the next couple of weeks, we will commence the bench testing here at Insitu, which will really be an extension of all the work that Orbital has done – this engine development already has over 1,000 hours on the bench.'

Mating of the engine with the airframe will take place over the next couple of months, with flight testing scheduled to begin shortly afterwards. 'We fully expect to have our first Orbital flight in a test environment in this calendar year, and expect the engine to be released in 2015 and fielded no later than 2016,' continued Williamson.

Integrating the engine with the airframe is critical to reliability. 'It is not always immediately obvious how complex this is,' he added. 'When people think about engine reliability they often focus on the engine itself, and, really, it's much more than that. Everything from fuel management and fuel delivery, the oil and lubrication system, lubrication schedule, the ignition system, the metering of the fuel and air into the engine – all of that – is being considered as part of our partnership with Orbital so that we have a fully reliable propulsion system in all operating environments.'



Hirth's S1215 UAV engine is an air-cooled, fuel-injected, two-stroke, horizontally opposed 'boxer' powerplant. *(Photos: Hirth)*

DESIGNING FOR TURBULENCE

Extremes of heat and cold, dust and, at high altitude, thin air are all aspects of the environment that can stress the propulsion system, as is turbulence.

'In turbulent conditions, something that can be overlooked is the fact that you have to pick up fuel from a fuel tank or lubrication oil from an oil tank – being able to manage that so it is always available for the delivery systems is a very important job to consider,' said Beloy.

There is even more to worry about in bumpy air. 'There are things like wiring, vulnerable wires and lines that are routed through the airframe and you really don't want them to rub or chafe.'

Geoff Cathcart, chief technology officer and director of engineering at Orbital Australia, also emphasised the importance of a systems approach. 'It is not the engine technology that results in the improvement, it is the development and integration of the complete propulsion system,' he told *UV*.

Orbital's research has highlighted the need for bespoke fuel and oil supply systems, and the company has designed custom delivery modules for the Insitu application.

'The design of these systems is not trivial and, again, requires an integrated approach to the design and development of the propulsion system,' he continued. 'By engaging with Insitu at such an early stage of the programme development, we have been able to take an uncompromising approach to the system integration in the ScanEagle, which has resulted in a design that incorporates features to handle the complete operating envelope of the UAV in a robust package, as well as unprecedented redundancy and onboard monitoring.'

The single-cylinder F33 is a 28hp two-stroke with advanced management, an integrated throttle servo and a 3kW starter generator.

Insitu confirmed that it will be making use of the new engine's multi-fuel capability, accessible by loading the appropriate maps onto the Flex Argon ECU. 'It is a very simple process to install that firmware,' explained Beloy.

MAKING COMPROMISES

Cathcart outlined what he sees as the most important technologies that go into an efficient and reliable multi-fuel engine. 'For SUAS applications with high endurance requirements, in the 3-15hp range, I think the small, spark-ignited two-stroke engine is ➤

hard to beat for the best compromise [in] power-to-weight ratio, fuel efficiency, cost and reliability.

'For a multi-fuel engine, however, there needs to be an effective method to control combustion phasing for different fuels. The octane rating or effective cetane rating [the propensity of the fuel to self-ignite and combust] of the various gasoline blends to different forms of kerosene differs significantly, and therefore trying to control the combustion with a passive system I believe is not possible.'

He continued: 'An electronically controlled direct injection system is the only way to accomplish efficient, safe and reliable operation for the varying fuel properties under all conditions. In addition, you need to have the best atomisation possible of the fuel so that the fuel injection timing is optimised around what the combustion control requires.'

He also emphasised that a highly atomised fuel charge is vital for cold starting with the less volatile heavy fuels, such as JP5 and JP8, as well as reliable running throughout the engine's operating temperature range.

Small engines that power long-endurance UAVs must work reliably and autonomously over a wide range of conditions, including extremes of temperature and turbulence. *(Photo: Insitu)*

TWO STROKE

Direct injection (straight into the cylinder, rather than via the air inlet tract) is also needed on two-stroke engines, explained Cathcart, to improve fuel efficiency at low power settings and particularly in the cruise. 'We typically see an improvement of 30-50% in fuel economy in these operating conditions over a wide range of propeller speeds.'

Minimising the deposits left by combustion by-products is also important for reliability, particularly in two-strokes because they have to mix lubricating oil with their fuel. Cathcart pointed out that many engines in the field suffer from excessive deposit build-up, reducing performance and even leading to engine failures – a problem that the use of heavy fuels can exacerbate.

'To combat this, not only do you need a clean burning combustion system, but also some technology in the lubrication system, including special oil formulations and lubrication circuits,' he said. 'Finally, all of this needs to be coupled with a sophisticated engine management system which not only adjusts the calibration to allow the engine to operate on the different fuels, but also has self-compensation for the range of operating conditions, including altitude, ambient temperature, cylinder head temperature, generator output, etc. This type of technology is more likely found on today's highly complex automotive engines than traditional general aviation engines.'

Cathcart noted that specific fuel consumption (SFC) figures in the order of 0.5-0.55lb/hp/hr can be achieved over a wide range of typical propeller curves for engines producing between 3 and 15hp.

Cars with diesel engines enjoy much greater fuel economy than their gasoline-powered counterparts, and inevitable design compromises in multi-fuel engines mean that no great differences in either economy or power are apparent between gasoline, JP5 and JP8.

MULTI-FUEL COMPROMISES

'When we design a multi-fuel engine, we need to design for the "heaviest" fuel to be used, as we only change the calibration, and no hardware, for the range of fuels the engine operates on,' he told *UV*. 'There is a small reduction in fuel consumption when operating on gasoline due to the ability to achieve best calibration for fuel economy due to the higher octane rating of the fuel, and this is typically in the range of 3-5% improvement compared with the heavy-fuel calibration. The results on JP5 and JP8 are basically identical.'

Moving up the power scale, Austrian engine house Göbler-Hirth Motoren produces UAV two-stroke engines ranging in output from 8 to 100hp for fixed-wing and VTOL applications. The 8hp 4102 and 15hp S1212 engines serve the SUAS market, while the 28hp F33 and 50hp S1215 power fixed-wing machines, whether runway- or catapult-launched. The latter and the 60hp heavy-fuel HF3503 are found in a growing range of VTOL vehicles including the Saab Skeldar, the Sistemi Dinamici/AgustaWestland SD-150 Hero and the Indra Pelicano.

Hirth propulsion engineer Dietrich Kehe reports a growing market, particularly in civil applications where endurance levels need a step-change improvement from electric motor-driven solutions, he told *UV*. It is two years since the company announced that it was developing a new family of engines based on its 8hp model 4012 horizontally opposed (the 'boxer' configuration) air-cooled two-cylinder engine, emphasising advanced control systems and improvements in resistance to electromagnetic interference (EMI) and to protect electronic systems from engine-generated interference, a property known as electromagnetic compatibility (EMC).

'We have been focused on upgrading our 100cc boxer [the 4102] with an advanced engine management system with closed-loop engine control and a CAN bus interface with the vehicle flight computer,' said Kehe. 'This new engine [the 4103] also has an advanced ignition system, shielded harness and shielded ECU for EMI/EMC.'

Hirth's family of small engines, he continued, will use common engine management systems and be compatible with Hirth's iPower technology to enable them to run on heavy fuels.

While the primary focus has been on the 8hp and 15hp engine, Hirth is also looking at a 25hp four-cylinder boxer engine to minimise engine vibration levels to improved camera stability on UAVs that currently use a 25hp twin-cylinder boxer engine, he told *UV*.

SFC varies across applications, engine sizes, fuel types and type of fuel system used, such as electronic fuel injection – usually assumed to mean an indirect system – or direct injection. 'It can vary from up to 480g/kWh for an EFI engine at WOT [wide open throttle] down to 320g/kWh in the best cruise point on a direct injected engine.'

CONTROLS AND MATERIALS

Kehe includes advanced fuel injection systems that both improve fuel efficiency and enable spark ignition engines to run on everything from automotive gasoline to jet fuel among the most important developments in two-stroke engine technology of recent years.

He also pointed to advanced engine management systems and the CAN bus, a data bus standard with its origins in the automotive industry that enables the flight computer to monitor engine parameters such as cylinder head temperature, exhaust gas temperature and fuel consumption as well as more precise control of engine speed via an electronic throttle. He also cited integrated starter generators and reduction drive systems.

Advanced materials are increasingly used to save weight throughout the propulsion system, with Kehe picking out such examples as carbon-fibre propellers and engine mounts and the use of permanent (rare earth) magnets in generators. He also pointed to coatings that help minimise the formation of deposits when spark-igniting heavy fuels.

With good power-to-weight ratios, smoothness, plus increasing fuel efficiency, reliability and multi-fuel flexibility, the two-stroke engine looks set to remain at the heart of many small UAV propulsion systems for the foreseeable future. UV