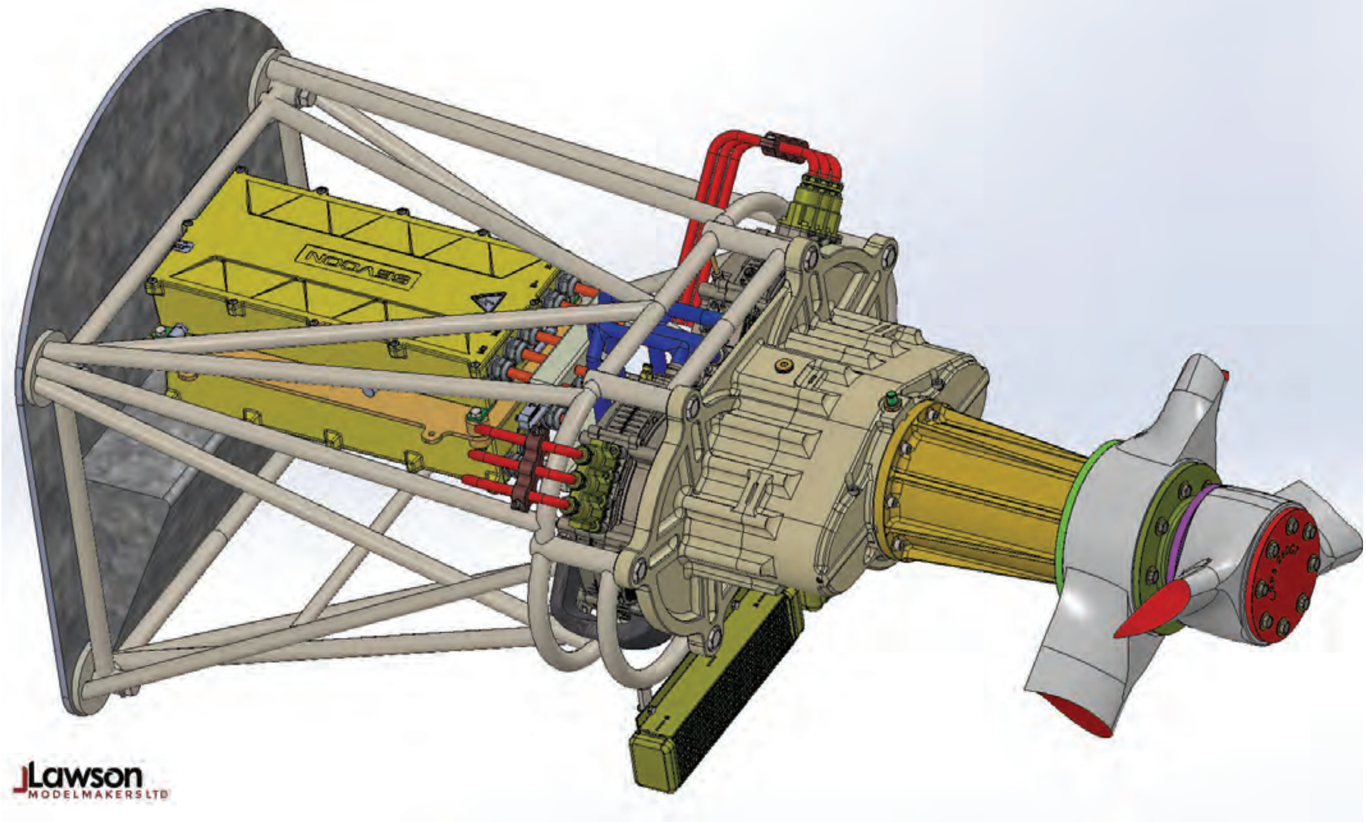


Above An overview of the CRPS 260GT and mounting frame that will be used to install the system in a Harmon Rocket in place of its existing Lycoming IO-540

Electric propulsion – light aviation's future

LAA member and electric powerplant pioneer **Nick Sills** explains the benefits of contra rotating propellers with electric motors…

Over the past five years a small British company, Contra Electric Propulsion Limited, together with several industry leading companies, has developed and ground tested the concept of electrically driven contra rotating (CR) propeller propulsion for light aviation. This article describes the project to date and the numerous benefits of CR over single propellers. It also illustrates the completion of the R&D phase with the manufacture of a 250hp continuous, 400hp max power system for flight testing in Condor Aviation's Harmon Rocket later this year. The system, known as the CRPS 260 GT, is intended as a direct replacement for combustion engine systems.

The feature in July's issue of *Light Aviation*, together with TL 3.28, admirably introduced the basic considerations of using electric propulsion in light aircraft and highlighted some of the benefits and complexities of moving from internal combustion to electric propulsion. However, an important component of the propulsion system, the propeller, was given only brief consideration.

Contra rotating propulsion systems

Most aviators understand that it is the propeller that dictates the performance of their aircraft as much, if not more than, the prime mover, but there is little scope for further improving the design and performance of modern combustion-powered propellers. The recent development of high-performance electric traction motors, however, offers the opportunity to make drastic improvements in propeller technology. These motors make it possible to design and build simple and affordable contra rotating propulsion systems (CRPS) eminently suited to many types of light aircraft.

The CRPS format offers unique and enormous performance benefits over a single propeller format, even if that single propeller is driven by an electric motor.

Of course, contra rotating propeller systems are not new and were used to upgrade the performance of piston and turboprop military aircraft for decades, but it is the torque curve of modern electric motors that is the game changer here for civil aircraft. Maximum torque is available right from zero rpm to the base speed of the motor and this eliminates the need to use variable pitch propellers.

Although at first glance combustion-powered and electric CR propeller systems might appear similar, there are very significant differences. Combustion driven CR systems normally comprise of two identical variable pitch (VP) propellers, often quite widely spaced due to their complex mechanical construction, and controlled by torque (propeller pitch). In complete contrast, electric driven CR propellers are fixed pitch, closely spaced and the front and rear propellers are substantially different in design. They are designed to absorb the same power at the same rpm. Power (thrust) is controlled directly by propeller speed.

Another major difference is that, unlike combustion engines, electric motors run equally well in either direction, so can offer reverse thrust in aircraft requiring this facility. However, normal fixed pitch propeller aerofoils do not work efficiently running backwards, so for aircraft requiring reverse thrust, we designed our propeller blades with symmetrical aerofoils on their outer diameters. As far as we know this is a unique solution.

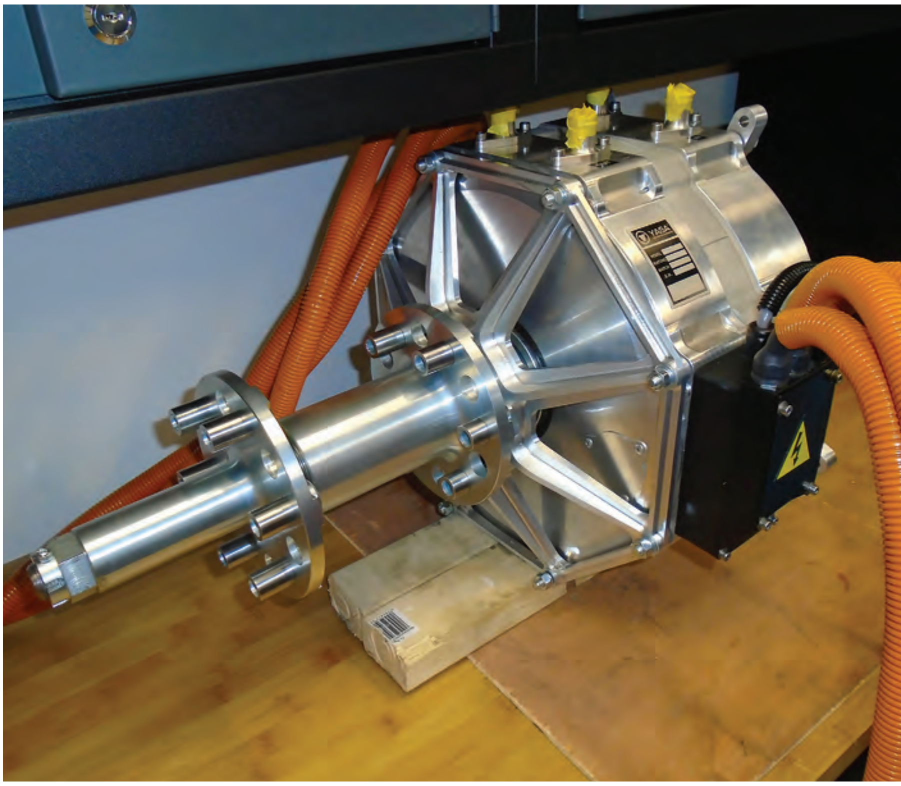
Complex gearboxes

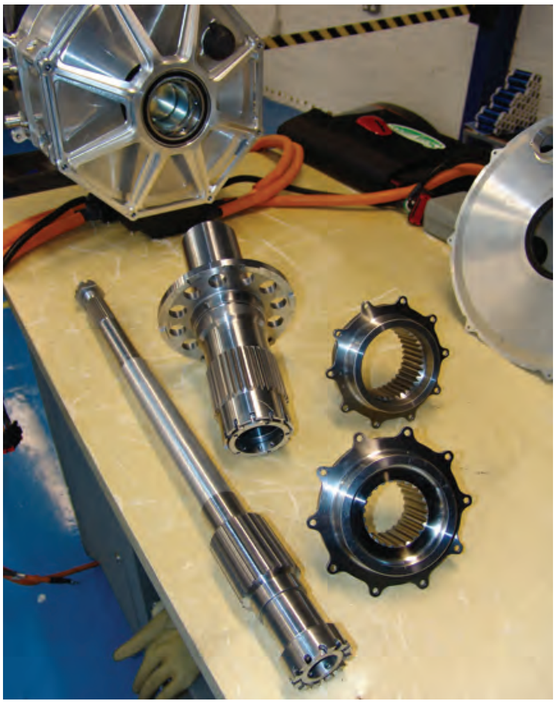
Most combustion driven CR systems used a single powerful engine, such as in the Seafire 46/47, Avro Shackleton and Short Sturgeon types, with complex gearboxes to drive the two CR propellers and govern pitch. There were exceptions, such as the Fairey Gannet, which used two independent Mamba gas turbine engines to drive the two propellers.

Electrically driven CR systems will invariably use two independent motors and, as all other components are also duplicated, they will be classified as true 'twin engine' systems.

Over the last five years we have designed and tested various fixed pitch contra rotating propeller designs in collaboration with Hercules Propellers Limited and automotive electric powertrain experts, Potenza Technology Limited.

The photographs below illustrate the design and construction of a twin electric motor CRPS 225 assembly built to test the propellers. Together they give 140kW (180.7hp) continuous and 225kW (301.7hp) peak power at 2100rpm.





Above The two DD500 Motors bolted together with twin CR propeller hubs.

Left YASA DD500 motors, bearing assemblies, some of the coaxial shaft components and the two splined motor power transmission couplings prior to assembly.

Left below: The complete CRPS 225 assembly together with its cooling system mounted in its purpose designed heavily instrumented test frame.

Right: Propellers are machined to exact parameters from CAD models with the aid of a purpose designed CNC machine and then hand finished.

The contra rotating propeller pairs were designed to absorb the same power at the same rpm. This meant that each of the pairs were quite different from each other in terms of diameter, pitch, blade area and chord. Algorithms dictating the design of the propellers were generated during an 18-month R&D programme known as Novel Contra Rotating Propellers for Electric Aircraft, assisted by NATEP (National Aerospace Technology Exploitation Programme) funding. The propeller sets were manufactured by Hercules Propellers from laminated beech wood blocks using a 'loss process' of manufacture, which ensures each propeller pair was made to exact dimensions, rather than using 'one size fits all' mass produced moulded or cast production methods.

In order to test the propeller designs in both static and under simulated take-off conditions, the CRPS unit and test frame were mounted to the rear of an electric vehicle equipped with a 420Vdc, 28kWh capacity battery pack, twin inverters, cooling and performance monitoring systems. During mobile tests the 'pilot' had control of the vehicle steering and wheel brakes, the 'co-pilot' controlled the motor power, propeller rpm, rotational direction and emergency systems through a handheld control panel.

During static tests the control panel was operated remotely through a 25m umbilical.

The test programme was carried out on Gloucestershire Airport's runways to examine and record the performance of fixed pitch contra rotating propeller assemblies at different speeds, different power settings, with one or the other propeller at different speeds, in reverse and also to examine failure modes. Data recorded included rpm, torque, thrust, acceleration, power consumption, battery, motor and inverter temperatures, ground and air speed, air temperature and weather conditions. Videos showing some of the tests can be seen on the company's web site. *www.contraelectric.com*

CR propeller propulsion

In a series of static tests at 135kW (181hp), thrust generated by the electric CR system was measured at 470kg forward and 320kg reverse. This data was compared with that of the Lycoming IO-360 powerplant and VP prop performance in a static Falcomposite Furio aircraft at max power – also 135kW. The aircraft was anchored by a load cell to take the measurements and recorded 310kg forward thrust. Though not a truly scientific test, the result was indicative of the difference in performance of single and CR propeller propulsion at the same power.

An encouraging start to the mobile programme was to record the extremely rapid acceleration of the 1180kg mass vehicle (including pilots) to 63kt in 120m using 135kW power in simulated 'take-off' runs. Compared to the same mass piston aircraft (Falcomposite Furio) at the same horsepower with a single VP propeller, this was less than half the distance to achieve Vr of 63kt in 300m with the Furio. Even allowing for differences in profile drag and wheel rolling resistance, this is an undeniably indicative result.

Perhaps the most significant single benefit of the CR format for light aircraft is the total elimination of yaw. The graphs (right) show that each propeller generates significant torque when operated individually but the net torque with both propellers in contra rotation is effectively zero.

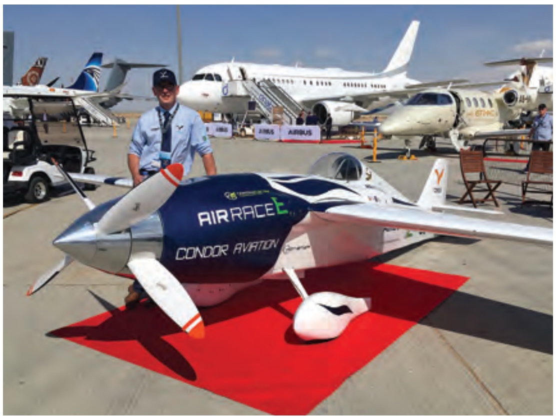
Eliminating propeller induced yaw can raise the efficiency of the propulsion system (compared to using the same horsepower with a single propeller) by up to 7% in flight and completely eliminates the four 'swing' forces (torque reaction and asymmetric airflow in nose wheel aircraft and asymmetric blade effect and gyroscopic effect in taildraggers) at take-off – greatly improving handling and safety. Analysis of the ground test data confirmed the performance of the CR propellers to be sufficiently encouraging to warrant flight testing the system so, as an engineering exercise, Condor Aviation and Contra Electric Propulsion converted a Cassutt race aeroplane from piston to electric CR. The CRPS 225 system you see in the test car was installed in the aircraft to see what was possible. The aircraft was exhibited by Airbus at the Dubai Air Show in support of the new Air Race E formula.

Is there an immediate future or requirement for electric propulsion in GA?

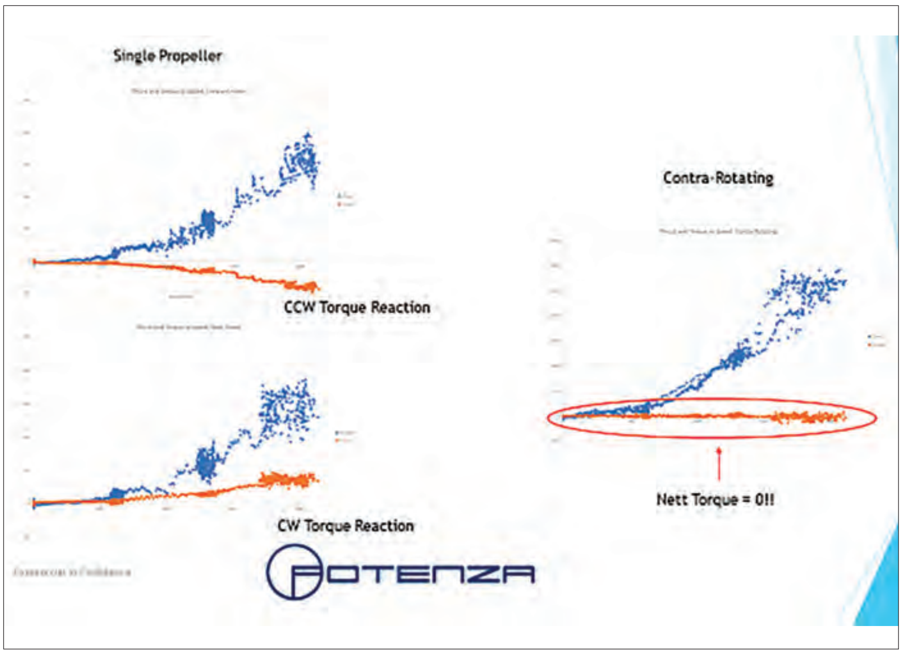
As illustrated in the *Light Aviation* article, there are already a small number of basic electric propulsion systems entering the market suitable for microlights and training aircraft. In addition, companies such as MagniX and Siemens (now

Above Safety was an optimum priority when test driving the electric contra prop unit.

Above right CRPS 225 including power electronics, inverters and cooling in the Cassutt.



Right Electric CR Cassutt race plane at Dubai Air Show.



Below Torque (orange data) generated by the counter clockwise (CCW) and clockwise (CW) rotating propellers (causing yaw) and the two contra rotating propellers together nullifying torque (no yaw).

RR) have developed motors up to 500kW (670hp) for single propeller commercial applications but their high cost and the marginal performance benefit over conventional combustion systems inhibits their use in most private light aircraft. At present the range of a battery powered electric system, compared to a combustion system of the same gross weight, is about 1/6th – not ideal for touring – but there are significant benefits in far lower operating costs, emission free flight and reduced noise.

Over the years, a considerable number of companies have approached CEP Ltd asking when an electric contra rotating propulsion system was likely to be available to test in their specialised types of aircraft. Several Alaskan float and ski-plane operators have stated that upgrading their piston powered aircraft with a similar power electric CR system which offers yaw free thrust, can go to full power almost instantly (giving STOL performance) and provides full reverse thrust on demand, would constitute the 'Holy Grail' of propulsion systems to them in their operational environment.

Dream machine…

Modern sky divers using wing suits and other aerodynamic devices, crave to jump from ever higher altitudes to extend freefall time. Existing piston carriers struggle above 10,000ft and turboprop carriers are very expensive to operate. This sport's dream machine would be C182 type aircraft with a rapid ascent (sub 10 minutes) to 15,000ft, very low operating costs and rapid turn-around times (recharge/battery swap) allowing 10 flights a day or more.

High performance aerobatic aircraft fitted with electric contra rotating propulsion could undertake completely new aerobatic manoeuvres, impossible with single propeller systems. A factor not lost on one particular high-end designer who commented that he could already see a new sports aircraft design emerging.

These three sectors represent a fleet of some 16,000 aircraft worldwide and have provided the market incentive for CEP Ltd., to proceed through design to manufacturing the first pre-production CR system. In the majority of cases, operators say they are willing to sacrifice range and endurance for extreme performance – a 20 to 30-minute endurance is more than adequate in many applications.

The first systems will therefore use pure battery energy sources, rather than more complex hybrid solutions. Most operators have said that a 200kW (250hp) continuous power rating would be sufficient for their needs with 75-100kW (100-125hp) nominal at cruise. However, a feature of some electric motors is that they can operate for short durations at significantly higher powers than their continuous rating. Two YASA P400 RHC motors capable of providing a combined 200kW (250hp) continuously, providing 260kW (325hp) for 10 minutes and 320kW (400hp) for one minute, were therefore chosen to power the CRPS 260 GT unit.

In the non-aviation sector, there are some 8,000 sports, utility, emergency services and military air boats operating in the USA, many using combustion powered contra rotating propeller propulsion systems. Increasingly, operators are seeking new quiet and pollution free systems to meet evolving environmental and noise reduction legislation. For these applications, CEP Ltd. are considering upscaling a CRPS to 1mW (1341hp).

The benefits of electric CR compared to single prop combustion systems

Above: The first UK Falcomposite Furio is under construction, albeit Lycoming powered, but a CRPS powered variant is on Nick Sills' wish list.

- Twin 'engine' safety and classification.
- Yaw free thrust.
- Axial loading only to airframe/firewall (negligible radial loading).
- Rapid full power response on demand.
- Full reverse thrust (with reverse capable prop set)
- Increased air speed. Up to 0.1 Mach (75mph) above single prop max speed).
- Smaller propeller disc diameter at same power.
- Simple mechanical construction.
- No exhaust or pollution.
- Virtually silent motor operation.
- High energy efficiency.
- No engine warming, shock cooling or spool up time.
- Recharge using ground power, wind or solar sources.
- No change in power output at sea level or high altitude.
- No liquid fuel.
- Offers aerobatic a/c unique manoeuvring capabilities.
- Negligible 'engine' vibration.
- Propeller noise reduction by desynchronising propeller rpm.
- Very low maintenance.
- TBO extended beyond 5,000 hours.
- No weight change during flight.
- Pilots do not require 'twin engine' licence rating to operate coaxial systems.

The CRPS 260 GT system

YASA Motors Ltd., which manufactured the motors used to develop the CRPS 225 propeller test system, have unfortunately discontinued its production. A survey of motors worldwide shows no other motor is commercially available with a similar architecture to YASA Motors' DD500 series. This motor had a large central clear annulus of 110mm suitable for installing a central coaxial shaft assembly and drive splines, ideal for producing a simple CR system by bolting two motors in line and operating them in opposite directions.

All future CRPS designs will use a power transfer box to house the coaxial shaft assembly and be driven by parallel twin electric motors running in opposite directions. This arrangement does have the great advantage that all propeller and aerodynamic loads can be carried by the power transfer box casing, so that the motors play no part in the structural assembly. This will make the certification process more straightforward – a number of different off-the-shelf automotive developed and extensively tested motors can therefore be specified.

The power transfer box houses the coaxial shaft assembly, power transmission gears and shafts, thrust and roller bearings, oil and cooling systems and is stressed to +/-10G. Two YASA P400 RHC electric traction motors, each rated at 100kW (125hp) continuous and 160kW (214hp) peak running at up to 7,000 rpm are mounted to the rear of the power transfer box. Two contra rotating fixed pitch propellers (cut down) are shown to the front.

Note: NASA too is relying on the efficiency of contra props on its autonomous helicopter *Ingenuity* for the challenging atmosphere on Mars. When the Perseverance Rover mission lands there on 18 February 2021, the 1.2m, 1.8kg *Ingenuity* will be the first flying vehicle ever to operate on another world.

Funding woes

The UK Government's ATI Innovation Funding Service claims to be highly supportive of SME (small and medium sized industry) proposed aerospace development projects. A recent application for assistance with the development of the electric CRPS 260 GT propulsion system (aimed at introducing affordable fixed pitch contra rotating propeller technology into the UK light aviation and GA sector) was refused on a financial technicality and scored zero points out of 70 for application content. Much of the application content is repeated in this article and I would invite comment from LAA members who have attempted to acquire grant funding. nick.sills@contraelectric.com.

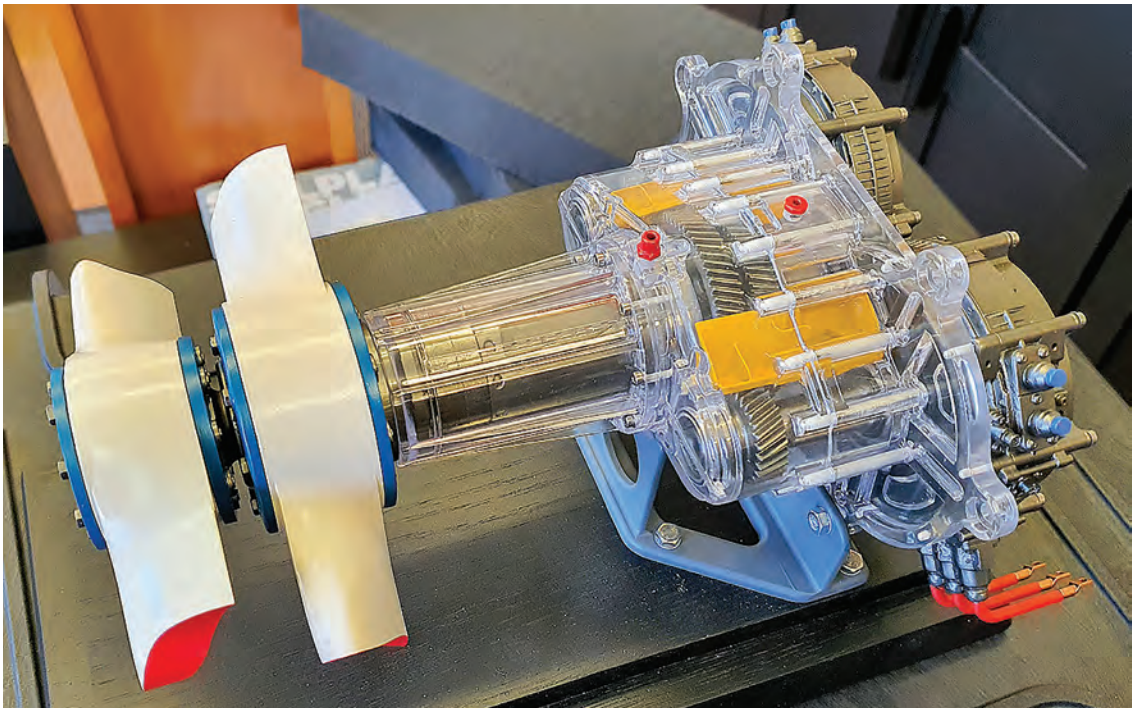
Conversations with many SMEs about their success in gaining grant funding for light aviation projects, makes depressing reading. I would urge the LAA to consult with its members and perhaps approach the ATI to relax the competition rules that blatantly discriminate against SME's.

Without ATI assistance, manufacturing the CRPS 260 GT system in the UK is not financially attractive. Production has therefore been moved overseas, which is regrettable for the UK light aviation manufacturing sector.

An early supporter of Electric CR, Ian Whittle, did warn me that his father's experience was that UK Government Aviation Authorities often smothered developments by small companies rather than support them. It seems little has changed! ■

General specification

Dimensions: The complete assembly with twin motors, propellers and cooling services will weigh 125kg and principal dimensions of 950mm total length, 725mm width 400mm depth.
Power transmission unit: Designed by John Lawson, one of few experts in this field, the unit takes all the aerodynamic loads and is designed to allow independent operation of the two motors and propellers.
Propellers: Matched contra rotating fixed pitch pair operating at up to 2,700rpm. Diameter 1800mm front, 1740mm rear.
Electrical system: Two liquid cooled Sevcon Gen 4 size 10 inverters/controllers drive the two motors and will be powered by two 22kWh X 800Vdc battery packs with 12C discharge capability and full battery management systems (BMS).
Performance: It is expected that the Harmon Rocket test aircraft will have a super STOL performance allowing take-off (nil wind) within 100m, initial climb rate of 6,000ft/min and top speed exceeding 220kt. Service ceiling would exceed that requiring oxygen or pressurisation.
NOTE. A single fixed pitch propeller offers aircraft a relatively narrow speed range efficiently, but a fixed pitch CR pair offers a considerably wider speed efficiency range. In most applications an electric CR system matched to a specific aircraft will out-perform a same horsepower combustion engine even with a VP prop at both slow (take-off and climb) and high-speed cruise.



Left A quarter scale engineering model of the CRPS 260 GT unit. The power transfer box is fitted with transparent casings to show the internal components.