UNMANNED systems TECHNOLOGY

Critical intelligence for land, sea and aerospace engineers

Traffic signs

Why sense & avoid is moving to ground-based systems

It's all in the blend

Focus on advances in composite materials

Wing-folding wonder

How the PteroDynamics X-P4 exploits some innovative VTOL-transitioning technology

UST 41 : DEC/JAN 2022
41
9 772056 982005
UK £15, USA $30, EUROPE €22

Read all back issues online
www.ust-media.com


22


36


46


54


62

This UAV's unique VTOL-transitioning technology gives it advantages over other VTOL systems. **Rory Jackson** explains how it was developed

Transition elements

The professional UAV industry has spawned a multitude of approaches to producing safe and robust VTOL-transitioning systems. Most have taken the route of a multi-copter hybrid, such as those from Alti Transition (*UST* 8, June/July 2016) with vertically disposed electric motors on fixed booms. Other manufacturers have developed tiltrotor aircraft, such as those from Quantum Systems (*UST* 14, June/July 2017) and Wingcopter (*UST* 24, February/March 2019), or tail-sitters from the likes of Martin UAV (*UST* 15, August/September 2017) and UAV Works (*UST* 32, June/July 2020).

And the innovations continue. Take the case of US-based PteroDynamics, which has developed a unique VTOL-transitioning solution in which transversely folding wings move a UAV's electric drives from a forward-facing arrangement for flight to one that points upwards for hovering.

The company says the system, called the Transwing, has various advantages over other VTOL systems for fixed-wing UAVs, from better aerodynamics and agility to greatly reduced mechanical and software complexity, as well as a far smaller ground footprint relative to its in-flight dimensions. It is used on its flagship aircraft, the X-P4 UAV, which is on track for delivery to the US Navy next year. There is also a smaller version, the X-P2.

The X-P4 is a 4 m wingspan all-electric aircraft, with a nominal MTOW of 75 lb (34 kg) and a maximum endurance of 3 hours when cruising at 45-50 knots (52-58 mph). It offers a 6.8 kg nominal payload weight (within a 28 litre payload volume), although up to 11.8 kg can be carried if the end-user is happy to sacrifice battery packs and hence range and endurance.

Company history

The Transwing technology was invented by Dr Val Petrov, founder and CTO of PteroDynamics, who moved to the US from the former Soviet Union in 1990 while still a PhD student, specialising in control theory and non-linear dynamics.

PteroDynamics' transitioning architecture is computationally simple and allows a high aspect ratio wing (Images courtesy of PteroDynamics)

The Transwing uses its four electric motors in cruise, forward flight and transitions between the two

Although he spent much of his subsequent professional life in investment management, he took up aeronautics as a hobby, mainly through remote control (RC) planes and helicopters.

"I spent more than 20 years flying RC, and I'd always wanted to combine my planes and helicopters into a single aircraft," he recounts.

"I especially wanted to combine a high-aspect ratio wing, which is ideal for highly efficient and fast forward flight, with a VTOL capability. But long, thin wings make aircraft hard to control when they're anywhere near the ground, especially with crosswinds that can 'catch' and pull them around. That's why most VTOL-transition engineers opt for relatively short wings, despite being less aerodynamically efficient for flight."

Dr Petrov ruminated on this until 2016, when he began conceiving a way to fold his aircrafts' wings (partially influenced by the Sto-Wing technology patented by Grumman for the F4F-4 Wildcat) using a rearwards-folding element to direct its propellers upwards.

After building parts for a prototype from balsa wood, he iterated many blueprints of wing-folding until arriving at one he thought would work. He constructed the mechanisms, installed them in the 3 lb aircraft (along with rudimentary RC electronics and controls), and found to his shock that it transitioned from vertical take-off into forward flight without any issues.

Recognising what his technology was capable of, he hurriedly patented it and sought partners to start a company. A new prototype with a slightly improved transitioning mechanism was built and entered testing in mid-2017, which accomplished about 200 flights before crashing because of an aileron servo failure.

"We've built prototypes of many different MTOWs and wingspans, and found that the Transwing technology scales without any difficulties," Dr Petrov adds. "The first 4 m wingspan prototype was critical to proving that: if we were prone to any wind stall on larger wings, it would have shown up in one of its test flights. Instead, transition and flight were performed perfectly, with high controllability at all speeds and power outputs."

The company began pitching its design to potential customers in 2018, shortly after Matthew Graczyk joined as CEO. The following year, the US Navy asked to test a Transwing aircraft, awarding PteroDynamics a contract for the Blue Water ship-to-ship logistics project soon after; the X-P4 was subsequently designed around this requirement.

Vice-president of engineering Tim Whitehand joined PteroDynamics in early 2020. He is a seasoned engineer and aviator experienced in the design, build and testing of numerous unmanned and optionally piloted experimental aircraft, and worked to establish a team of engineers focused on maturing the company's technologies, processes and capabilities. ▶

To transition between cruise and VTOL, a linear actuator moves a clip with two pushrods up and down the centreline of the UAV

System architecture

Numerous key technologies have been combined in the X-P4, with three patents already granted and five more pending that formalise and globally protect PteroDynamics' subsystem designs.

As Graczyk explains, "A lot of big UAV companies have dozens of patents, but they are on individual components, like perhaps the method and design of lowering packages from a hovering aircraft. Our principal patent family covers the entirety of the Transwing aircraft design, including the articulating wings, the design of the propulsors on the wing, and how the wings rotate with a symmetrical dihedral."

While the company takes a modular approach to its aircraft designs, anticipating that different use-cases will require different airframes, aerofoils and tailplanes, a few key features currently stand out.

These include a high aspect ratio wing and a vee tail with a largely composite hull. In addition to the 4 m wingspan, the fuselage measures about 2 m long.

2.2 kWh of energy is stored in COTS lithium-ion batteries that sit in the four wing-mounted propulsor nacelles, along with the electric motors and ESCs, and a CAN bus running data between the nacelles and the fuselage-mounted autopilot. Lightweight COTS wiring harnesses with locking connectors run between these systems, although the company's roadmap includes r&d into optimising cables and plugs for sealing and EMI shielding.

"At no turn have we opted for any exotic parts in this vehicle," says Whitehand. "We use traditional, well-proven materials, design methods and COTS components. System integration, controls development and automation are where we see the most opportunity for innovation.

"Keeping the powertrain in the wings may seem unusual but it yields great inertial relief, air cooling and a simplified structure, because the back tips of the nacelles act as landing struts."

Whitehand notes that the four electric motors together can deliver up to 10 times the necessary power for cruise. So, while all four are used in VTOL, with a peak climb rate of 1000 ft/minute and more, the X-P4 will typically shut off two motors during cruise, with their propellers passively folding back (pushed by airflow) and sitting tightly against the aerodynamic profile of the nacelles to lower power consumption and drag.

"The high available power means we could fly comfortably at altitudes above 10,000 ft, but we've not tested that out," he adds. "As interesting as it would be for us to find out, it's not exactly a priority for customers."

Several hundred test cycles of sub-components have been performed, with final qualification testing for the US Navy planned for 2022.

The Transwing

In a Transwing aircraft, each wing attaches to the fuselage via a rotary hinge – each hinge is set at an angle – with an actuation system for deploying and stowing them.

While each hinge sits on a winglet-like protrusion on either side of the forward fuselage, the actuator (a linear worm-

▶

Each pushrod connects to the inner-rear section of its closest wing to achieve the transverse folding and unfolding movements

The Quattro autopilot and ground interface solutions from Applied Navigation are used in X-P4s for defence users

drive servo) sits further back, near the tail, and when powered moves a clip with two external pushrods that act on the inner-rear sections of either wing. The wings thus pivot about the hinges, to fold against the fuselage or unfold into their flight angles.

"The hinges need to withstand the loads imparted during transition, and meet key stiffness requirements to be able to manage during both hover and flight," Whitehand says. "The wings are passively locked into place after take-off by way of a secondary wing interlock, so that the actuator isn't needed for holding the wings in place.

"The worm drive was chosen to be as lightweight and reliable as possible, with an efficient and accurate encoder to allow us to tightly control its position.

"As Val's tests have proven, we can safely fly the X-P4 in all modes of transition, because when the wings fold in it just behaves like a quadcopter. So although we're relying on a single electromechanical device, it doesn't constitute a point of outright failure in the traditional sense."

The disposition of the hinge (and thus the angle of rotation between the two extremes of wing positioning) can vary between Transwing aircraft designs. While the X-P4 has been designed with high robustness and controllability of transitioning for the US Navy (with ongoing tests validating these), future r&d will examine how the aerodynamics change during transition, to see if there is an optimal angle from that perspective.

"While we've had hundreds of real-world tests, developing robust aero and performance estimation is a key ingredient to maturing the technology," Whitehand says. "And while most of our analysis currently relies on proven first-order methods and empirical data validated through testing, selective CFD and wind tunnel tests will play an important role in taking advantage of the differentiating aspects of the technology."

As mentioned, the Transwing system has some key advantages over other, better established VTOL-transition systems. The most visible is compactness: as the wings fold tightly along the fuselage, the craft's footprint is greatly narrowed when landing (from 4 m wide to about 1.2 m). X-P4s can thus be stowed in cases or compartments without having to be disassembled, just as Grumman's Sto-Wing maximised the number of F4F-4s that could fit on an aircraft carrier.

Furthermore, the folding of the wing makes for a much more stable VTOL. As mentioned, a larger aerodynamic surface means a greater impact from crosswinds and gusts whenever fixed-wing aircraft try to land or take off.

That could pose severe issues for tail-sitters, or for tilt-wing UAVs such as NASA's Greased Lightning, as large landing pads could be needed to avoid endangering technicians during recovery. Dr Petrov notes here that the X-P2 by contrast has been flight-tested amid 55 mph gusts, and performed VTOL autonomously to well within safe levels of stability.

Whitehand says, "The Transwing design has a very broad transition envelope. A lot of tiltrotors and tail-sitters, like helicopters, have to climb to a certain altitude before switching to forward flight, creating numerous constraints on speed, power, angle of attack and so on.

"By contrast, we're very tolerant of multiple outbound and inbound transition profiles, speeds, weights and external disturbances. We can start transitioning into cruise almost immediately after launching, and we want to expand that envelope over the next 6 months so that customers have a broad flight envelope to work with."

As mentioned, since wing length contributes little to ground footprint or near-ground instability, a high aspect ratio wing can be designed to maximise flight efficiency and hence endurance.

Dr Petrov adds, "Since we use the same propulsors on the wings for both VTOL and forward flight, we don't need to carry the dead weight and severe parasitic drag that hybrid multi-rotor planes have to in their VTOL systems, or the added points of failure that tiltrotor servos pose.

"That means we gain not only endurance and lift-to-drag ratio, but also airspeed, since we can devote more power to forward propulsion. Based on my calculations, I am confident that we will soon break the world speed record for a VTOL UAV [currently 150 mph/240 kph, set by Wingcopter in 2018]."

There is tangible value in this, as Whitehand explains. "We've found that flying faster is a huge differentiator among customers looking into last-mile aerial logistics. Among industrial or defence users who need, say, a critical repair tool or replacement part for broken-down vehicles or machinery, moving fast is much more important than being able to fly far.

"For those users, a 3 hour flight endurance is surplus to requirements; instead, we could carry a 15 lb payload at 75 knots for 1.5 hours. Right now, we estimate our dash speed to be 150 knots with variable-pitch propellers, and once we've incorporated some further things in our r&d pipeline, we'll be able to get all the speed these customers will ever need."

Modular mission systems

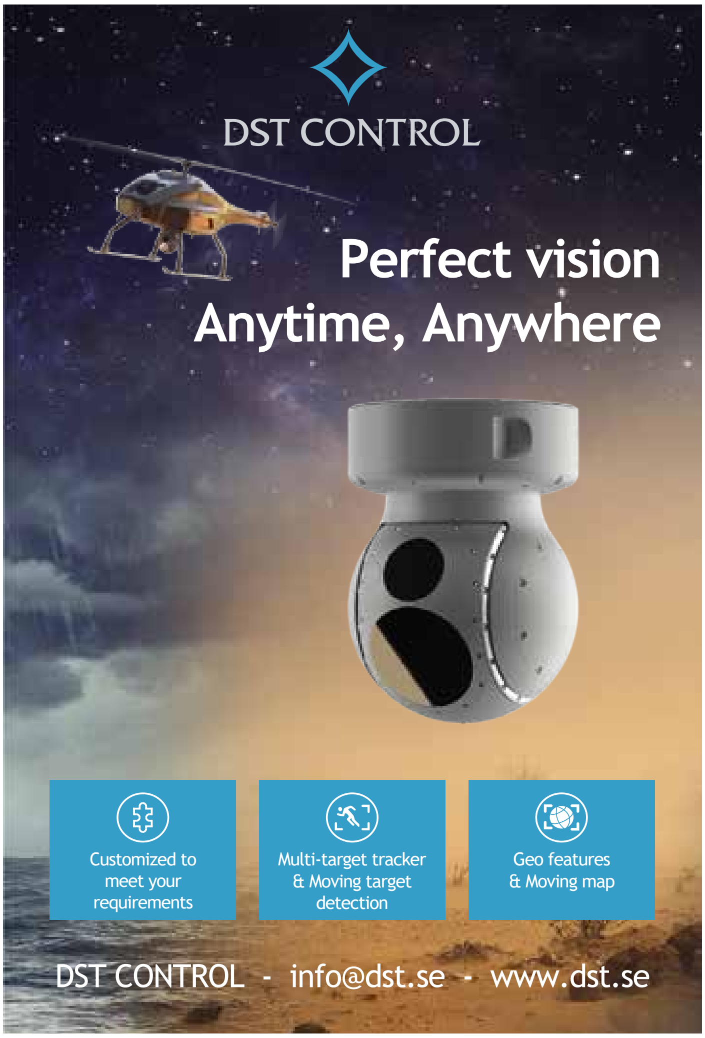
As mentioned, the initial customer for the X-P4 is the US Navy, for the Blue Water Maritime Logistics programme. More specifically, the Military SeaLift Command (which handles military transport and replenishment) needed a fast, reliable, easy-to-use aircraft with high tolerance to hazardous weather conditions, to ferry repair tools and parts to ships.

"Those parts and tools are typically delivered by H-60 and V-22 aircraft, which are incredibly expensive and high maintenance, even though 90% of the time they're carrying payloads of 50 lb or less for these missions," Graczyk says.

"After showing what our aircraft could do for them, we signed the contract in June 2021 to deliver three X-P4s in June 2022 as demonstration units, which might be extended to more units and larger variants in a follow-on contract."

Vice-president of business development Chris Corgnati notes that the reliability, speed and carrying capacity of the X-P4 also mean that PteroDynamics sees commercial ship-to-ship and shore-to-ship logistics as highly applicable for it and successive

▶



PteroDynamics has tested (and keeps in store) a wide range of BLDC motor and propeller pairings, to mature and optimise the full range of its UAVs' flight envelopes

UAVs. Similar repair logistics missions could be provided for armies, air forces, oil & gas platforms and remote industrial facilities, as well as delivering emergency medical products or aid packets.

"Mapping or intelligence missions might seem straightforward and less urgent than all these delivery and relief operations, but we can certainly do them," Corgnati adds "We can adjust the wings and tailplane to trade off between speed, endurance, payload stability and so on."

To carry all the different items across these missions, a payload bay is installed in the front as standard. A single hinge under the nose allows this section to swing open, to reveal a square-shaped 1 cu ft volume for installing packages. If needed, this section can be turned into a mounting point for a retractable camera gimbal.

"We want even the most inexperienced personnel to be able to use the aircraft," says Corgnati. "The payload is housed internally to maximise aerodynamic efficiency. Access requires no tools, and all airframe components are retained without having to be removed."

Flight control and avionics

The VTOL-transition systems we have previously featured in this magazine rely largely on complex algorithms for transitioning that took enormous development time and rigour.

PteroDynamics has a strikingly different story. As Dr Petrov discovered in the maiden test flight of his balsa prototype in 2016, the Transwing transition approach requires very little of the UAV's autopilot in terms of sensory inputs, processing load and control outputs.

"I made that first flight and transition with a $10 KK2.1 flight controller," he recounts. "I programmed it with a really simple gain scheduling algorithm, to handle the gradual change of controller laws from a quadcopter configuration to a comparatively simple fixed-wing configuration. It's a linear change from one set of rules to the other as the wings unfolded, and that was all – and it worked."

Specifically, the strength of the autopilot's PID control feedback loop (much like those typically used in distributed-lift UAVs) is linearly reduced by the position of the worm drive, rather than a hard, binary switch, as the wings unfold into their fixed-wing angle.

"All the flight controller needs to know is when it's supposed to transition," Dr Petrov adds. "It doesn't physically need to look at the altitude or airspeed, and we know from hundreds of test flights that the transition will be very benign and controllable, without any significant loss or gain of altitude. The most common effect is some loss of speed as the aircraft decelerates during inbound transition, or speed gain during outbound transition."

Therefore, the main purpose of the flight controller is not to handle any complex transition algorithm, but to ensure an appropriate robustness of flight autonomy and hence consistent endurance for the end-user.

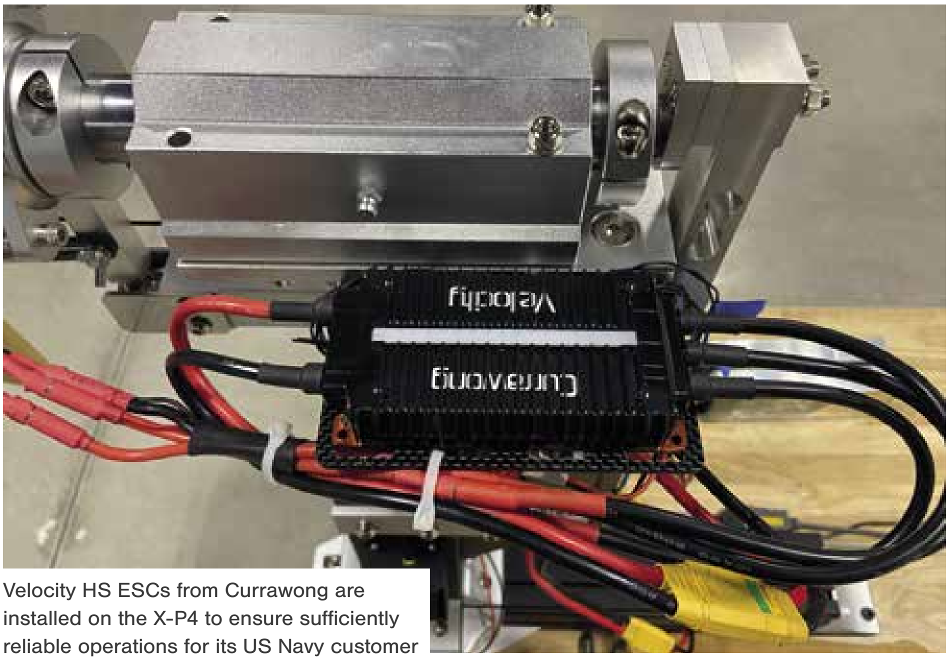
"We have developed a Matlab model of our aircraft to better understand the interactions between the aerodynamic and propulsion forces, hinge flexing and feedback control actions during the transition regime," Dr Petrov comments.

"We have analysed multiple implementations of this model spanning a range of sizes and weights up to 5000 kg MTOW. We concluded that the transition flight envelope is robust and independent of the size and weight of the aircraft, even with the simple linear controller gain scheduling. We have also developed RealFlight models of the X-P2 and X-P4 to test the flight regimes using the Ardupilot SITL environment and the native RealFlight stabilisation systems."

To date, PteroDynamics has flown Transwing aircraft using three different flight controllers: KK2.1, Ardupilot and Applied Navigation's Quattro FMS.

"While the simple KK2.1 controller was sufficient to stabilise our aircraft, we have progressed to other, more mature flight control systems that enable

One of PteroDynamics' propulsion testing rigs



Velocity HS ESCs from Currawong are installed on the X-P4 to ensure sufficiently reliable operations for its US Navy customer

higher levels of reliability, customisation and automation," Dr Petrov says. "We continue to work closely on this with our control partners Applied Navigation, KH Unmanned and Aerial Robotics Australia."

For commercial users, PteroDynamics typically uses Ardupilot systems such as the X2.1 777 board from Mayan Robotics, as it is an open source solution with a large community of developers providing ways to adapt and tune different algorithms to work with the hardware.

"The additional code we've written on top of Ardupilot's master branch is actually very minimal. That's enabled us to fly the aircraft in different ways and leverage the broader Ardupilot ecosystem where we've needed to, thereby supporting a wide range of peripheral devices," Whitehand notes. "It also means our commercial customers can easily make use of other Ardupilot add-ons for whatever niche missions or manoeuvres they want to carry out."

While some among people in the defence services are increasingly interested in open source technology for its community-driven agility, many are still dubious of having such transparency in their subsystems. For those users, including the US Navy, PteroDynamics has integrated Applied Navigation's Quattro autopilot to operate the X-P4.

"Applied Navigation implemented our flight control modules and gain scheduling into the Quattro," Whitehand says. "What that gets us compared with the very flexible, open source Ardupilot is a far more powerful hardware architecture that can support the kind of peripherals we need in order to deliver the X-P4 to a government or military customer, or easily scale up the aircraft for similar customers who might want to carry more weight.

"Applied Navigation also provides the Vigilant Spirit operator interface, which many US defence-sector customers are experienced with. And I understand Applied Navigation was also recently approved for BVLOS operations in Spain, which we feel has further validated our choice to go with the Quattro in the defence market."

The radios and antennas are also installed throughout the fuselage, rather than in the routinely mobile wings. For standard-issue comms, dipole omnidirectional antennas enable data uplinks and downlinks over the 900 MHz and 2.4 GHz bands.

"We've played a bit with our ground planes and antenna positioning, and we're confident now that we have solid comms over a 10 mile distance, which is far more range than we need," Whitehand says. "That said, we have the backbone to accept any IP mesh radios, satcom and more powerful links, along with pretty much any transponder systems end-users might want. It's just a matter of being certain what they want, before going through the lengthy FCC licencing process to fly them."

Propulsion

As indicated, the X-P4 features four propulsor nacelles, each of which contains a BLDC electric motor, an ESC and a lithium-ion battery pack with about 550 Wh of energy. Each nacelle has a battery panel (held in place by two screws) for removing and replacing the battery packs, although the team is looking at ways to recharge the plane without having to change the batteries.

Various motor-propeller combinations have been trialled (and are kept on the engineering team's racks) to identify ideal combinations of speed and torque for different mission requirements. Although T-Motor motors are used at the moment, the efficient air-cooling inherent in the propulsors' design, and their modularity, means others can be used, providing they supply the power output necessary for all stages of flight.

"The X-P4 uses about 7-8 kW to hover, and when we're cruising at 65 knots or so the motors draw about 1.8 kW with fixed-pitch propellers," Whitehand says.

"If we're dashing at 75 knots though, power consumption is about 2.5 kW, and naturally, when we're transitioning, there's a power curve that varies between the values for hover and cruise. For example, if we're inbound, we can do a low-power extended flare approach, or if an end-user's coming in hot and wants to do a quick stop, then obviously that's going to be sharper and more power-intensive."

Petrov adds, "There is a slight trade-off here, in that we want to use powerful motors for take-off, hover and landing, but when we're cruising we don't really need high power at all. Switching to electric variable-pitch propellers in the future will not only boost prop efficiency, it will allow us to use less powerful motors during VTOL. It will also save on manufacturing and operating costs, which is why variable-pitch is a significant item on our roadmap.

"Another area we're looking into is small asynchronous motors. A lot of efficiency losses in permanent magnet BLDC motors come from the demagnetisation of their iron cores, so if we can have an asynchronous motor where we control the strength of the magnetic field, we could significantly improve efficiency in forward flight.

"The only problem there is that, currently, no-one really makes three-phase AC induction motors at the right SWaP for our requirements, but it's something we're keeping an eye out for.

"We're also working with GM Propellers and Mejzlik on improving the performance of our current fixed-pitch propellers.

▶

Specifications

PteroDynamics X-P4
VTOL-transitioning UAV

Wingspan: 4 m
Length: 2 m
MTOW: 34 kg
Payload volume: 28 litres
Standard battery energy: 2.2 kWh
Standard payload capacity: 6.8 kg
Maximum payload capacity: 11.8 kg
Maximum endurance: 3 hours
Maximum speed: 280 kph
Cruising speed: 105 kph
MTBF: At least 100 hours

Some key suppliers

Autopilot & controls:
Applied Navigation
Autopilot & controls:
KH Unmanned
Autopilot & controls:
Aerial Robotics Australia
Autopilot & controls:
Mayan Robotics
Aerodynamic analysis consultation:
Flighthouse Engineering
Mechanical design consultation:
Flighthouse Engineering
Airframe r&d:
Tumbleweed Composites
Fuselage manufacturing:
Composites Universal Group
Wings and vee-tails:
Ultimate Composites
Folding propellers: GM Propellers
Additional propeller consultation:
Mejzlik
Electric motors: Hacker
ESCs: Currawong Engineering

PteroDynamics X-P2
VTOL-transitioning UAV

Wingspan: 2 m
Length: 1.03 m
MTOW: 10 kg
Payload volume: 3 litres
Standard battery energy: 0.7 kWh
Standard payload capacity: 2.2 kg
Maximum payload capacity: 3.1 kg
Maximum endurance: 2 hours
Maximum speed: 150 kph
Cruising speed: 95 kph

Some key suppliers

Autopilot & controls:
Applied Navigation
Autopilot & controls:
Mayan Robotics
Airframe manufacturing:
Vibe Composites
Folding propellers: GM Propellers
Electric motors: T-Motor
ESCs: Mezon

Because the Transwing uses the same propulsion system for VTOL and cruise flight, any fixed-pitch system will be a compromise, but a variable-pitch propeller set-up would solve that. We would be very excited to find a group interested in developing that with us.”

Whitehand adds, “We are also exploring things such as different propeller solidities and acoustics. Our customers aren’t necessarily looking for those right now, and using unusual propeller designs can add risk, but we want to know how to add efficiency so that we’re ready when the market demands it.”

Barring some unexpected leap forward in the commercialisation of new, high-density battery chemistries, PteroDynamics expects to use some form of hybrid power unit in the future for customers requesting longer flight times, greater carrying capacities or just reduced downtime. Gasoline, heavy fuel and hydrogen systems alike are open for consideration, including IC engines and fuel cells. Microturbines suited to the X-P4’s weight class, efficiency requirements and MTBF remain rare.

Meanwhile, the electric motors are controlled by Currawong Engineering ESCs, chosen for their long life and reliability. Whitehand and Dr Petrov emphasise that ESCs often come up as the highest-risk components during UAV failure analyses, being routinely subjected to surges that can break them and hence the powertrain.

Aero

The shape of the X-P4, particularly its high aspect ratio wing, outwardly resembles a glider more than an archetypal high-speed aircraft. Initial designs of its profile were calculated and conceived based on first engineering principles and available bodies of empirical data.

“We are putting more resources into the analytical modelling of the Transwing to identify opportunities for optimisation and establish a strong technical basis on which to scale the technology; however, we place a high priority on flight testing to support our claims,” says Whitehand.

Structural design and materials

The structural design of the X-P4 is largely driven by experience-based decision-making combined with selective use of FEA and mechanical testing. Airframe materials and mechanical architectures were selected with a heavy emphasis on manufacturability and cost.

Its airframe is made predominantly from a minimum gauge (thinness) composite sandwich structure using carbon, Kevlar and fibreglass. Core materials include low-density closed-cell polyethersulfone foam and balsa wood. High-load

The X-P4's wings come from Ultimate Composites, the nacelles from Composite Universal Group

The company is continuing its r&d into different subsystems and larger versions of its UAVs, for defence as well as other uses

elements such as the wing hinge are machined from 6061-series aluminium, and 3D-printed SLS materials are used throughout the aircraft.

The company works with a few partners for airframe manufacturing. Whitehand explains that for the X-P4, the fuselage and nacelles are manufactured by Composites Universal Group in Oregon, US, which was chosen for its exceptional track record on numerous manned and unmanned aviation projects and its adaptable and pragmatic approach to aircraft manufacturing.

X-P4 fuselages and nacelles are manufactured using traditional vacuum bag open-mould methods using out-of-autoclave (or 'out-of-oven') resin systems. The wings and tails are manufactured by Ultimate Composites in Queensland, Australia, which has an innovative clamshell moulding process using pre-preg carbon and a proprietary foam-moulding process to produce wing structures with a high specific strength.

"We involved our manufacturing partners early in the design process of the X-P4, giving them the opportunity to steer the design according to their wisdom and experience," Whitehand says.

The materials and methods used to manufacture the X-P4 are currently geared towards low-volume, labour-intensive methods to allow rapid in-process changes. "As the X-P4 matures though, the manufacturing methods will evolve to high-volume, low cycle time processes," Whitehand says. "The foundation for those has already been baked into the X-P4's design."

Future plans

PteroDynamics is pressing on with the final r&d phases for its US Navy customer, with specialised test stands being completed for cycling the X-P4's subsystems individually to the required standards.

As indicated, future models for navies and elsewhere might use a range of technologies, and the company is expanding its capabilities to that end, having moved its headquarters for r&d and production to Colorado Springs at the end of July 2021.

"We're in ongoing discussions with two very large US defence primes about teaming opportunities," Graczyk adds. "We're now doing feasibility studies into a 12,000-plus lb MTOW Transwing craft, a 5000 kg version, and another with a 250 kg payload to support those opportunities. We are also in further talks for a range of cargo and intelligence operations across the US Department of Defense, and a project solicitation from a large international defence prime.

"More recently, we've been contacted by one of the largest commercial shipping companies in the world, which is looking for something largely identical to the X-P4 for maritime logistics."