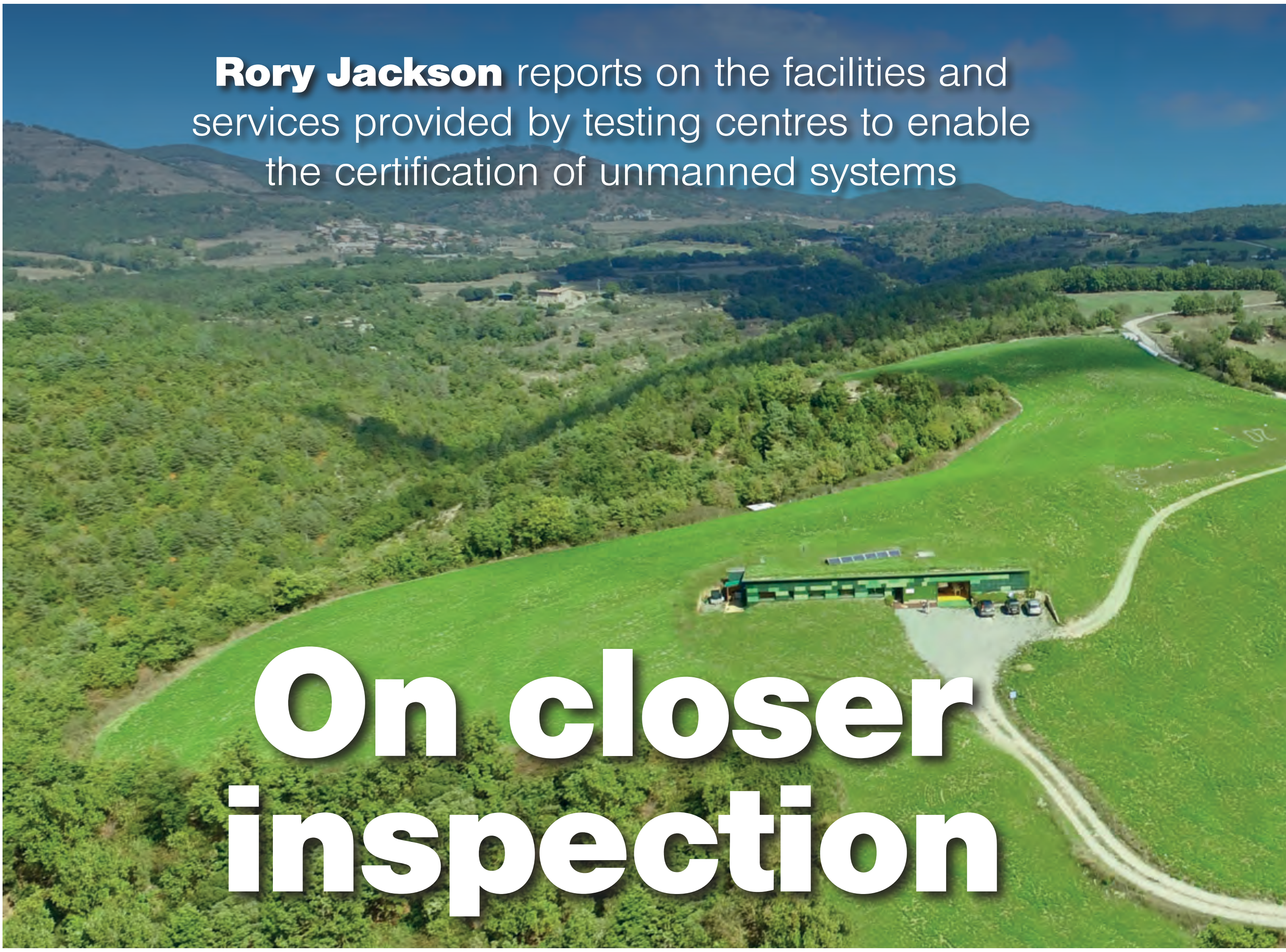
Rory Jackson reports on the facilities and services provided by testing centres to enable the certification of unmanned systems

On closer inspection



Between the successful development of a prototype UAV and its commercial availability, there is a critical set of flight tests to assess and confirm the system's ability to operate safely and to the parameters for the missions and environments its end-users require. A UAV's reliability, operating performance and avionics functionality can be evaluated across various flight test plans to examine its operating range, endurance, navigation accuracy, comms and control interfacing, autonomous capability, payload performance and failure modes.

While it is notable that flight tests for unmanned aircraft are not legally mandated in the way they are for manned aviation systems, many test centres have been established over the past several years. They are growing in popularity, as developers seek to take advantage of the ease and low cost of flight testing UAVs – especially in comparison to manned aircraft. This also helps avoid the potential safety and legal consequences of selling or operating a system that fails to perform as advertised.

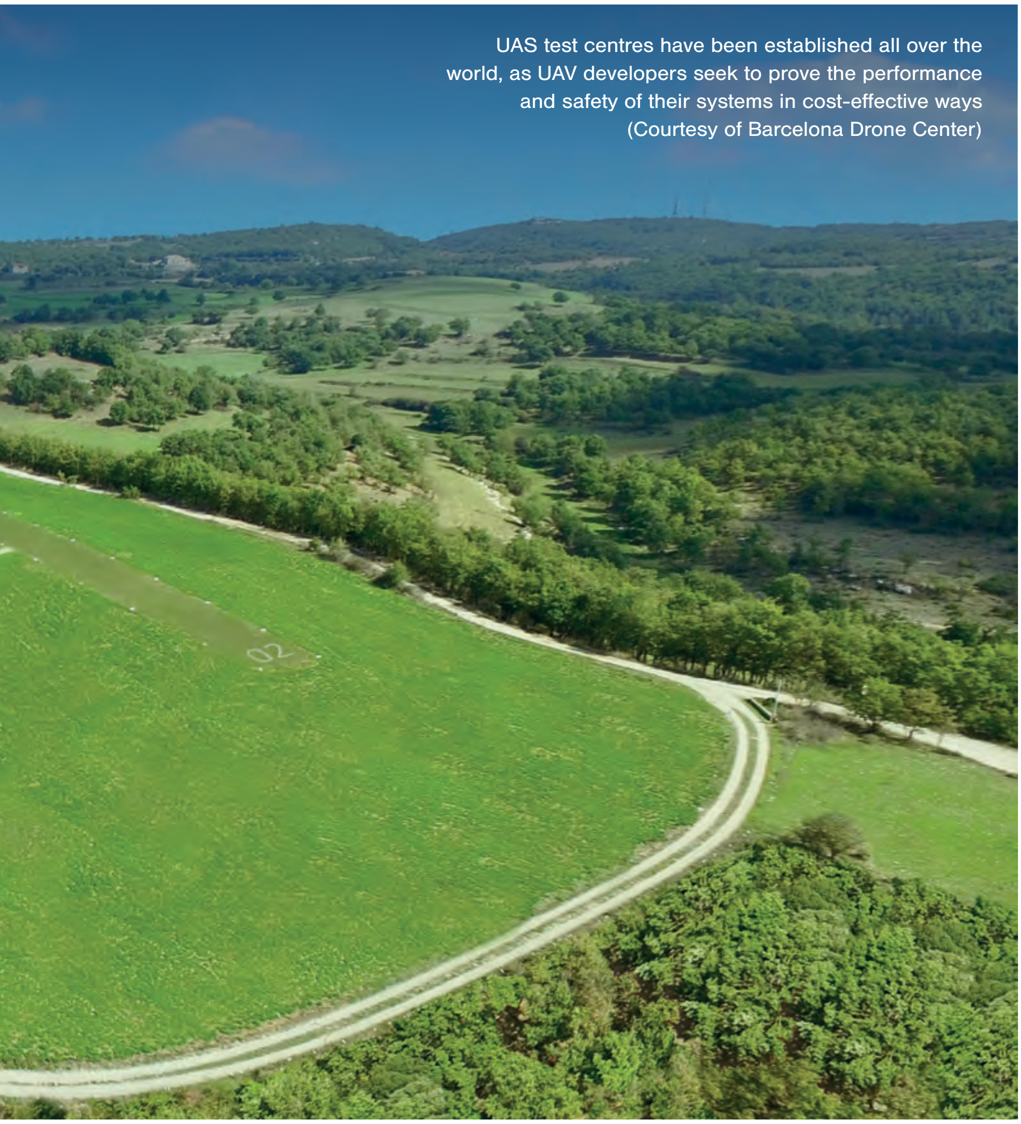
Variations in testing

Despite this ease and affordability, however, there are factors that make it challenging to apply the same testing plans used by manned systems to unmanned ones.

At a purely operational level, UAVs have far higher control sensitivities in the three axes than manned aircraft, owing to their smaller size and lower inertia. Also, given that they are remotely piloted via a radio link, there is no tactile force feedback at the operator's control station to gauge flying quality – as a manned aircraft test pilot would have. That makes it difficult to assess factors such as vibration and responses to buffeting.

The stability of flight testing paths is also challenging owing to factors such as a UAV's increased vulnerability to weather conditions and the greater susceptibility of onboard navigation systems to interference.

It is also more difficult to standardise test schedules and parameters across aircraft types and models, as some UAV models fly and function differently



UAS test centres have been established all over the world, as UAV developers seek to prove the performance and safety of their systems in cost-effective ways (Courtesy of Barcelona Drone Center)

Unmanned systems are susceptible to turbulence, making flight tests hazardous relative to manned aircraft tests (Courtesy of UAS Test Site, University of Maryland)

from each other, even in similar mission spaces. That is often due to wider variations in UAV configurations in terms of vehicle design and aerodynamics, as well as system architecture.

It follows then that as the UAV is remotely operated, any test and evaluation programme should include the ground control equipment and data links in addition to actual flight performance.

The complexity of a system tends to grow with a UAV's capability for autonomous flight, as the software and hardware requirements increase. The greater this complexity, the more precautions and data that are required within the test plan specifications for validating the safety of these systems and maturing them to the desired level of reliability.

It is also vital to have clear definitions of the roles of the crew in flight testing procedures. Not doing so might create misunderstandings over task ownerships, leading to a higher rate of errors owing to an excessive or insufficient number of contributors to the processes.

While different vehicles merit different models and approaches to team organisation, a few general roles are essential. First, there should be a flight test director or leader to coordinate and oversee missions, to ensure that the crew and the local airspace authority receive and understand all mission-critical information.

Also, the director should ensure that the proceedings of the test programme are comprehensively constructed, and appropriately modified and evolved as data is accumulated and evaluated.

The appointment of a safety officer is also key. Their responsibilities range from enacting all safety measures around the vehicle and during missions to taking over manual control of the UAV in the event of a failure mode.

These two people have primary prerogative over aborting a mission if either of them finds sufficient cause.

There should also be a ground control station (GCS) engineer or lead test pilot (the actual title is less important than

It is vital to appoint key roles in flight testing operations to ensure clear division of labour and a smooth flow of tests and data output (Courtesy of Qinetiq)

the function) who is charged with directly overseeing the sending of commands and receiving information from the UAV.

This officer should be the first point of 'active involvement' with the aircraft. That covers programming waypoints for autonomous flight tests, conducting pre-flight simulations, and overseeing ground tests and inter-operational adjustments to system architectures.

Appointing further personnel such as payload and comms engineers, and other crew to help with ground and air operations, should also be considered.

At first glance, the value of real-world testing may seem to be low when considering the advances in recent years in CFD software capabilities for gathering simulated data on design aerodynamics and operational effectiveness. Indeed, CFD may be used not only for design and development but also to examine propulsion, lift, aero-elastics, acoustics, icing-up of surfaces and other real-world concerns.

For some companies, however, running CFD tests and analyses remains prohibitively expensive and time-consuming compared with flight tests. Licencing fees, computing processor cores and power costs for running CFD software can rise over time with the number of data points gathered, whereas running actual flight tests tends to produce a flatter cost curve.

The accuracy of such simulations is also not guaranteed to perfectly predict or reproduce what the UAV will experience in actual flight.

These concerns might be mitigated over time as computer hardware becomes more powerful and less costly. However, the issue of operator liability will provide an incentive for simulation data – and the UAV specifications derived from them – to be validated at testing sites.

Risk assessments

In manned aircraft testing, it is standard procedure to carry out test hazard analysis, in which every possible risk is judged and rated for its probability and effects. Much like other manned flight test paradigms, however, the model needs to be adjusted to fit with unmanned testing.

The foremost safety concern is the risk to humans, yet there are no onboard personnel. Also, UAVs increasingly come with unique architectures and configurations – just look at the vast array of VTOL transition-capable UAVs to see the range of failure modes that could occur.

The chances and adverse effects of flight hazards are harder to anticipate when no aircraft resembling a given unmanned system has ever been flown before. Therefore the impact classifications should be reconfigured to fit the unique requirements and complexity of each UAV.

Electromagnetic effects should also be closely considered. UAVs are far more susceptible to errors from EM interference than manned aircraft, given their smaller size and the fact that they rely so heavily on RF connectivity with the GCS.

As a function of that, crews should pay close attention to what action the UAV is programmed to take when comms are lost. That may be an immediate and controlled descent to avoid flying outside test airspace, for example, or automated circling to try to re-acquire the lost signal.

Crews should also conduct extensive pre-flight ground tests that are consistent with the requirements for air traffic approvals.

It is also useful to draw up pre-agreed contingency plans in the event of an emergency. For example, if the

A range of ground tests should be conducted before each flight to ensure all systems are safe for testing (Courtesy of Northern Plains UAS Test Site)

Ground tests

Examining a UAV in a hangar or lab environment often marks the first time that all the different subsystems are assembled in a single, connected architecture. Before this, individual components will generally have been tested by their manufacturers or elsewhere.

Such systems integration tests often goes overlooked or is underdone as the design and development phases run on and crowd them out. It is critical therefore that, in addition to checking each system is functioning within normal parameters – before every flight, as well as the first – that all the microelectronics are debugged, soldered and reworked as needed.

Also, mechanical or material parts that need to be replaced can be fitted, and all avionics firmware updates installed.

Checking the data links – assuming there are primary and back-up links in the design – can first be conducted through a range check. This involves deliberately attenuating the output power of the links to see how much of the signal gets through. This should be conducted in the same environment as the flight test to improve the reliability of the results.

Also, verifying the procedures by which a back-up link takes over from the primary link, or how control may be passed from one GCS to another (if it falls within the test programme) is critical to ensuring safe control over the aircraft.

Testing the navigation systems tends not to be complicated, and can easily be conducted with the aircraft on the ground. The tests may involve no more than physically tilting a UAV in the various axes during a simulated flight mode to simulate pitch, roll and yaw, and checking that the output readings from the inertial navigation system match.

In addition to universal performance-focused testing, unmanned vehicles should be tested in their specific application (Courtesy of Nevada Institute for Autonomous Systems)

If checking the attitude control system as well, a similar test can be conducted to inspect the deflections of the elevators, ailerons and rudder. Verifying a UAV's ability to identify and recognise entry into waypoints is also a useful ground test for navigation. This can be simulated, or the vehicle can be towed behind a road vehicle to the waypoint coordinates to see when it 'arrives' at the designated location.

And although it may not be directly related to the condition of a UAV, checking the weather conditions before flying is advisable in order to ensure accurate data analysis when examining the flight logs after each mission. This should include the speed and direction of wind, degree of visibility, temperature, cloud ceiling and any rainfall.

Manual and autonomous flight testing

The first recommended step in actual flight testing is to carry out a manual flight, with the GCS engineer or lead pilot having direct control over the UAV.

This enables the test crew to ascertain that the aircraft has sufficient command capabilities and does indeed operate safely in the air and perform as expected. This maiden flight also acts as an effective control or comparison for the flights to follow that can be expected to use varying levels of autonomy.

All performance and specification results obtained during this flight should be compared with the benchmarks set by any simulated flights conducted so far. This ensures that any deviations between parameters such as position data, waypoint navigation or airspeed do not deviate unacceptably from expected values.

Naturally, flights in autonomous mode should then be conducted. Checks here on data such as the validity of the aircraft's orientation according to its inertial navigation unit, or its coordinates according to the GNSS, should be repeated to minimise the rate of errors and ensure reliable flight information.

It follows that from testing the GNSS data, the flight path taken by the UAV during autonomous testing should also be evaluated. It should match the path the UAV was directed to take by the GCS pilot (as well as the path taken during the pre-flight simulation, if one was run).

If a UAV is designed to offer differing levels or modes of autonomy, each one should be thoroughly tested in flight to continue verifying adequate performance by all onboard systems.

The lead pilot should also check that when switching from manual to autonomous mode, the flight controller and servos continue to operate normally. The rudder, ailerons and elevator should continue moving fully, whether directly controlled by the GCS pilot or not, within the space of each mission.

It also worth checking that when the autopilot computer is remotely deactivated, the microcontroller allows the UAV to be flown in manual mode again – with no loss of data accuracy in flight, navigation or information about power, and that there is no change in the performance of the data link.

Validating the flight-critical subsystems and handling qualities in manual and autonomous modes can be conducted over a multitude of flying patterns, airspeeds and crosswinds, and in visual range and beyond visual line-of-sight (BVLOS) – licences permitting. Such validation should ensure that there are no particular operations or environments that can lead to errors in system performance.

Mission testing

Naturally, given the wide range of UAV configurations being developed for different applications, markets and agencies, repeated testing of the vehicle's intended mission envelope is critical to ensuring that the feasibility of any such excursions are sufficiently evaluated.

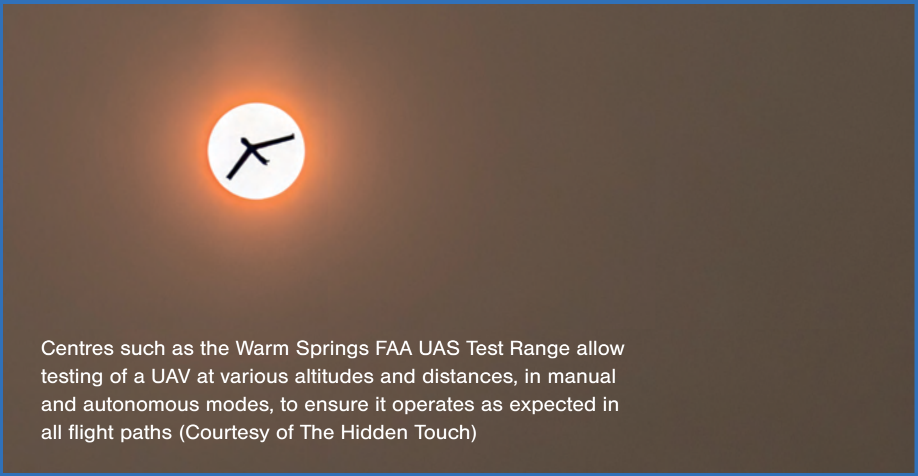
Some tests in this regard are the same across mission sets. Testing a UAV's ability to operate BVLOS missions for example are valuable in countless commercial, defence and civil applications.

Many end-users might for example want a UAV that climbs at 900 ft/minute in a given set of atmospheric conditions, in which case it is key to validate the craft's ability to safely achieve and hold that climb rate, whether manually or autonomously.

Others are more specific. An agricultural UAV, for example, would be expected to perform multiple flights with a payload such as a multi-spectral camera capable of producing digital surface models or normalised difference vegetation images, to prove its capability to acquire actionable information in a safe and timely fashion.

Alternatively, an aerial mapping system might need to be tested with any number of payloads to prove its compatibility with the flight computer and other interconnected systems, while then flying in the paths and patterns typical of mapping UAVs. These might be flying in lengths across a 50 x 50 m area or a long, winding flight for mapping a corridor such as a road or powerline. A UAV should autonomously maintain the necessary altitude and airspeed to capture the required detail for a consistent orthomosaic.

Tests of complex algorithms such as those for swarm navigation or extended aerial comms relay missions bear close attention as well, with repetition and extensive troubleshooting to confirm that they operate as needed. Testing with different antennas and other technology is recommended, to identify which systems produce the best overall configuration for achieving the stated objectives and simulation-defined parameters.



Centres such as the Warm Springs FAA UAS Test Range allow testing of a UAV at various altitudes and distances, in manual and autonomous modes, to ensure it operates as expected in all flight paths (Courtesy of The Hidden Touch) primary control link is lost, the aircraft can enter a holding pattern.

Alternatively, a back-up link – if a redundant 900 MHz link is designed in, as it is in many UAVs – can be used to conduct a controlled landing on a designated runway or other suitable terrain away from populated areas.

Such a landing may also be recommended if a problem in the autopilot or inertial navigation system is detected, or if an actuator fails, if structural damage occurs or if an engine failure is impending. While the solution might remain the same in each case, listing the risk scenarios remains key.

Delaying test missions is recommended if there are adverse weather conditions, such as rain or airborne dust, at levels above the intended environmental tolerances.

Pre-flight simulations

Access to accurate flight simulation is not only key to effective ground testing, it reduces risk by modelling flight patterns and anticipating potential failure modes.

Running simulations also allows system specifications to be set as targets for when the time comes to conduct real-world flight tests. Top speed, cruise and maximum endurance, among other key specs, can be identified in this way.

Furthermore, simulations can test the functioning of a UAV's embedded software to verify that the autopilot has been programmed effectively before flight.

Such a test might involve a computer simulating flight mechanical responses, setting flight paths anticipated during future tests and incorporating all processors, software systems and actuators. The GCS might be used as it would during actual flight, while the computer also models measured actuator commands and sensor errors.

That means the testing crew can train and familiarise themselves with their roles in real-world operations to reduce the probability of human error and improve the quality of data collected later.

Operations involving examinations of

Guide to testing (cont...)

Launch and recovery systems should be tested for consistent functioning and to ensure a UAV can handle their repeated use without damage (Courtesy of UAS Denmark)

System component validation

UAV flight tests are also conducted for individual systems. Validating new components in the air as well as on the ground with an unmanned system architecture is valuable for proving the efficacy of new product iterations in their working environment.

Testing a new subsystem in a more insulated enclosure than normal can be carried out to ensure that no overheating can occur during ordinary use. Stress-testing the system's power consumption by running it at maximum – for example, by using a telemetry system at its maximum data transfer rate to see if the batteries and motor can handle it for the required period of time – should verify that the power consumption and power plant fit with each other.

Repeated testing of launch and recovery systems such as catapults or nets is also critical to ascertain their survivability and that of the UAV's own components with repeated use.

Flying with simulated – or, time permitting, accidental – system failures can be vital to evaluating the performance of system redundancies. The failure of one or more motors on a multi-copter for example should be compensated for by the remaining motors, while a comms failure should trigger the activation of a back-up link.

As for the GCS, testing it should include verifying that all flight-critical data (including any warning notices) are clearly displayed and updated in a timely fashion. All control interfaces (including the touchscreen, mouse, keyboard and various joysticks) should move freely and elicit the proper response during manual flight, and the GCS itself should not contribute to any undue latency issues.


UAVs should be checked before every flight to ensure there is enough static thrust to ensure a steady ascent (Courtesy of Alaska Center for Unmanned Aircraft Systems Integration)

acceleration/deceleration, turn rate or other actions may require flight test modes to be programmed into the autopilot; running simulations for each test can help identify where such programming is needed. Without that, it may be impossible to breach the constraints designed for users to abide by for safety purposes, and effectively establish the absolute limits of a UAV's performance.

Engine checks

Power system tests for UAVs are less well-defined than those for manned aircraft engines, as they are far newer and less mature, with fewer records and established testing practices. In the case of battery-powered systems, monitoring current and voltage, and checking for appropriate charge, can suffice for pre-flight inspections.

For the two-stroke heavy fuel engines typical of tactical-grade UAVs, however, additional challenges may lie in placing monitoring equipment, owing to space restrictions. They too are often custom-made, with less supporting design data than is common for manned aircraft engines, and using COTS propellers of sub-optimal aerodynamic efficiency.

Other vital operating qualities such as levels of engine, coolant and gearbox oil should also be checked before each flight.

For fuel as well as electric vehicles, it is vital to check key propulsion variables, for example that the motor is generating power consistent with its rated rpm, and that the propeller produces enough static thrust to enable take-off and ascent.

For a prototype fresh off the assembly line, it may be recommended to run the motor at ground level, in a hangar or laboratory, in order to 'break-in' the system before attaching the propeller.

Electromagnetic interference

It is also worth testing the UAV on the ground for adequate EM shielding, as any defect here can cripple the control and comms feeds. Antennas, actuators, cable harnesses and other systems may be vulnerable if insufficient EM protection was added during the design stages.

The use of a controlled environment capable of producing or simulating the kinds of frequencies and energy levels a UAV might experience when flying near ships, airports or other complexes that produce EM emissions can be key.

In addition to emissions testing, critical EM issues can also arise between onboard systems. If 'noise' from an avionics or comms subsystem inadvertently enters the RF receiver, it will place extra demands on the power required for command and control signals to be received.

There is an agreed set of tests for intra-system EMI detection, perhaps the most important of which is an EMC SOFT (electromagnetic compatibility safety of flight test) operation. Such tests may be centred on operating a UAV's control surfaces at differing frequencies, transmitter power settings, antennas and engine revs (to account for engine system noise).

Fluctuations in the movement of the ailerons or elevators, such as overshooting or undershooting the commanded degree of movement, may be evidence of EM interference, and should be eliminated before flight testing for the sake of safety.

Payload testing

Although comms and autopilots need close scrutiny in mission tests, it is payload testing that bears the brunt of attention in UAV systems. Of course, other tests form the bedrock on which payload tests sit – without accurate navigation data, for example, the targeting accuracy of systems that use GNSS might be insufficient for mission effectiveness.

Information on altitude, pitch, yaw, roll and heading are also critical to supplement the limitations of GNSS coordinates in payload targeting. The update rate of all such data to the targeting computer should also be checked to satisfy that no lag can occur at some critical mission juncture.

In the case of a typical sensor payload, such as an electro-optic/infrared (EO/IR) system, ground checks such as checking that the telemetry feed operates effectively over the data connector linking the camera to the autopilot and data link hardware can be performed. All onboard systems should communicate with each other and the GCS effectively, particularly if the GCS operator is responsible for operating the payload during flight.

In other regards, the testing of a UAV's EO/IR payload is generally similar to that of a manned aircraft. On the ground and in the air, and in visual range and beyond it, the control sensitivity and image resolution should be tested to define parameters such as the minimum resolvable image particle differences or spatial frequency.

Comms relay payloads in particular should be tested for electromagnetic compatibility, given the emissive qualities of equipment used in such missions and the potential for their use in life-threatening situations.

Testing different forms of shielding or band pass filtering is recommended, as is testing over different flight patterns, all the available frequencies and with multiple transmission and reception antennas at the ground (or other endpoint of the relay test). That may help to home in on the optimal configuration to achieve the desired rate of transfer and delay to directly communicate or interface with an asset at BVLOS distances.


Test centres are often built on former airports or airbases, which offer ground infrastructure such as asphalt runways and hangars (Courtesy of Air Traffic Laboratory for Advanced Systems)

Testing centres

Testing centres are increasingly key to providing the necessary infrastructure and facilities for validating unmanned systems.

In many countries now, the take-off weight of a UAV, or operation of a prototype vehicle, is subject to considerable regulations and restrictions on where it can be deployed for evaluation. Such centres exist thanks to the appropriate licencing, as well as controlled ground and airspace.

These test centre-controlled pockets of sky stretch for thousands of kilometres in order to facilitate BVLOS testing, and thousands of feet up to enable testing a UAV's maximum altitude capability or its maximum climb or descent. As well as vast rectangular areas, long thin regions of airspace are common for corridor mapping tests as demand for this application grows.

Another advantage of specific UAV testing airspace is the unlikeliness of collisions, as no other users are generally permitted to fly at the same time. Also, such areas tend to be in unpopulated areas, minimising the risk of harm to people or property in the event of a crash landing.

Even so, when flights over populated areas are needed – to test for example how the primary data link and systems handle the EM emissions coming from a town, city or airport – this tends to be made easier by the airspace being located near such places, as well as through in-house certification procedures.

There are also often hangars on site for storage and pre-flight checks, and occasionally for testing indoor UAVs for their ability to navigate and move in a controlled fashion. Navigating with a roof, walls and possibly other obstacles around them is a useful quality for multi-copters intended for factory or warehouse operations.

For systems that do not rely on launch and recovery equipment, test centres built on airbases tend to supply the necessary ground-based infrastructure. There are runways of asphalt, concrete, gravel or grass at different centres, enabling taxiing, take-off and landing, and with varying degrees of lighting systems for night missions where needed. Launch pads for VTOL-capable systems that need clear space and solid ground are also common.

Test centres also often have laboratories for system adjustments. For electronic systems soldering stations, oscilloscopes and testers might be needed, as well as battery charging stations.

Camera systems meanwhile might need targets to enable pre-flight calibrations, or field targets for calibration in mid-flight. The use of different camera systems on a UAV payload can allow additional testing for UAV developers searching for lateral mission capabilities such as night missions with integrated IR and EO cameras.

Another factor is that if a UAV is damaged, having tools and materials on site such as saws, drills, additive manufacturing printers, CNC machines, carbon fibre tubes and spare propellers can enable rapid post-flight repairs and save a UAV's developer the time and expense of bringing their own.

The wide range of evaluations needed to satisfy the safety and reliability of an


Testing centres may offer indoor zones for UAVs built for warehouse or factory applications (Courtesy of Droneport)

Some examples of unmanned vehicle testing centres

BELGIUM

Droneport
+32 494 506 660 www.droneport.eu

CANADA

UAS Centre of Excellence
+1 418 669 5104 www.cedalma.com

DENMARK

UAS Denmark
+45 3071 3464 www.uasdenmark.dk

FRANCE

CESA UAV Test & Services Centre
+33 556 343 544 www.cesadrones.com

ITALY

Taranto-Grottaglie Airport
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MALTA

National Aerospace Centre
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NORWAY

Ocean Space Centre
+47 908 35 252 www.oceanspacecentre.no
Centre for Autonomous Marine Operations and Systems
+47 735 95535 www.ntnu.edu/amos
SINTEF Ocean
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Barcelona Drone Center
+34 9310 36034 www.barcelonadronecenter.com

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ParcAberporth Technology Park
+44 (0)1239 813910 www.wuase.com
Qinetiq Maritime Autonomy Centre
+44 (0)125 239 2000 www.qinetiq.com
Snowdonia Aerospace
+44 (0)1341 360 038 www.snowdoniaaerospacecentre.com
West Wales Airport
+44 (0)1239 811100 www.flyuav.co.uk

USA

Alaska Center for Unmanned Systems Integration
+1 907 455 2016 www.acuasi.alaska.edu
Grand Sky, Grand Forks
+1 701 499 2180 www.grandskynd.com
Northern Plains UAS Test Site
+1 701 777 6100 www.npuasts.com
Pendleton Test Range
+1 541 966 0281 www.pendletonuasrange.com
The UAS Flight Test Center, Physical Science Laboratory, NMSU
+1 575 646 9474 www.psl.nmsu.edu
Tillamook Test Range, Near Space Corporation
+1 503 842 1990 www.nsc.aero
University of Maryland UAS Test Site
+1 301 405 2057 www.uas-test.umd.edu
Warm Springs Unmanned Aerial Test Range
+1 541 553 3565 www.wsuas.com

unmanned vehicle is hardly surprising when considering the number of system components that have to be brought together to comprise a working UAV; it is even less surprising when considering UAV certification.

Manned aircraft have been subject to close regulation in their testing for years, but UAVs cannot follow their example, and must improvise in their pursuit of certifiability. While many sensible options for tests are clear, the necessary extent of testing is not.

When it comes to proving a radical new system, it can only be prudent to err on the side of more testing, not less.

Acknowledgements

The author would like to thank Jordi Salvador of Barcelona Drone Center, Nicholas Flom of Northern Plains UAS Test Site, Brett Kanda of the Nevada Institute for Autonomous Systems, Anjanette Riley of the UAS Test Site at the University of Maryland, Jakob Elmkær Hansen of UAS Denmark International Test Center & Cluster, Jesus Herrerra of Air Traffic Laboratory For Advanced Systems, Rob Walter of Qinetiq, Catherine Cahill of the Alaska Center for UAS Integration, Peter Dedrij of Droneport and Liz Stalford of the Warm Springs FAA UAS Test Range for their help with researching this article.