Skyports Offshore Renewables Deliveries

Technology in the Offshore Space

Document information

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Net Zero Technology Centre
Technology Driving Transition

Skyports
DRONE SERVICES

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Acronyms

Tag	Description
4G	4th Generation Wireless Broadband based on the cellular network
ACP	Airspace Change Proposal
ADS-B	Automatic Dependent Surveillance - Broadcast
AMSL	Above mean sea level
ANSP	Air Navigation Service Provider
AWS	Amazon Web Services
BVLOS	Beyond Visual Line of Sight
CAA	Civil Aviation Authority (UK)
CAP	Civil Aviation Publication
COTS	Commercial Off the Shelf
CTV	Crew Transfer Vessel
DFT	Department for Transport
DSM	Digital Surface Model
EASA	European Union Aviation Safety Agency
EC	Electronic Conspicuity
FAA	Federal Aviation Administration
GA	General Aviation
GCS	Ground Control Station
GNSS	Global Navigation Satellite System
IFR	Instrument Flight Rules
LAANC	FAA, Low Altitude Authorisation and Notification Capability
MLAT	Multilateration
MNO	Mobile Network Operators
OEM	Original Equipment Manufacturer
OSC	Operating Safety Case

Tag	Description
PAW	Pilot Aware
PoE	Power over Ethernet
RP	Remote Pilot
SSR	Secondary Surveillance Radar
SWAP	Size Weight and Power
TCAS	Traffic Collision Avoidance System
TDA	Temporary Danger Area
TMZ	Transponder Mandatory Zone
TOLP	Take-Off Landing Point
UA	Un-Crewed Aircraft
UAS	Unmanned Aerial System
UTM	Uncrewed Traffic Management
VFR	Visual Flight Rules
VTOL	Vertical Take-off Landing

Introduction

The offshore energy industry is a key player in the global energy landscape and is an essential source of power for the modern world. However, the industry faces unique challenges when it comes to supply chain management and maintenance operations due to the remote and inaccessible nature of offshore assets. To overcome these challenges, companies are exploring innovative ways to optimize their operations and reduce costs, and one such solution is the use of Unmanned Aerial Systems (UAS).

This report outlines the use of UA in the offshore energy industry and the potential benefits of their integration into current supply chain and maintenance operations. The report is based on a recent offshore drone trial carried out by Skyports Drone Services, which demonstrated the capabilities of their operational team as well as their aircraft system in executing various scenario flights simulating deliveries to offshore energy assets such as oil rigs and wind turbines.

The offshore flight trials by Skyports showcased the maritime capability of their operations team and their aircraft as well as the potential of their service to revolutionize the way in which offshore energy companies operate. The flight trials were completed as part of the Skyports Offshore Renewable Deliveries (SORD) project that was itself part of a wider project named Offshore Low Touch Energy RAS (Robotics and Autonomous Systems) (OLTER). The successful execution of various demonstration scenario flights showed that UAS could be used to deliver critical spare parts and supplies to offshore energy assets in a safe, efficient, and cost-effective manner. The trial has generated significant interest from offshore energy companies looking to integrate UAS into their logistics networks, with views to provide scheduled and unscheduled medical, spare part or time critical sample deliveries, as well as expanding operational service capabilities in low visibility or challenging weather conditions.

The client for this report, the Net Zero Technology Centre (NZTC), aims to develop and deploy technologies that reduce emissions and propel the energy industry towards a digital, automated, and decarbonised future. With this mission statement, the NZTC is particularly interested in the technological route to fully autonomous drone deliveries to offshore energy assets. This is of particular interest given these deliveries are currently carried out by large helicopters, which at the time of writing, are believed to be in short supply, with demand, and in turn costs, only increasing due to the current energy prices[1]. Coupling this with the fact that despite offshore helicopters operating under Instrument Flight Rules (IFR) in Instrument Meteorological Conditions (IMC), they still require good visibility to conduct an offshore landing as they have to be completed under Visual Flight Rules (VFR). An alternative delivery solution, less reliant on Visual Meteorological Conditions (VMC), could bring significant benefits to the offshore industry in this sense. Therefore, through this project we have looked to demonstrate how a fully autonomous UAS could significantly reduce the cost and risk associated with offshore operations by removing the need for human intervention, improving the speed and accuracy of deliveries, and reducing the environmental impact of offshore operations.

This report will explain how the Skyports offshore flight trial requirements were created, the results and findings of the trial, and the areas that require attention to allow commercial offshore operations to commence in the coming years.

[1] *“Only a Matter of time until offshore helicopter scarcity drives up prices” (2023) – Accessible at:* *https://www.energyvoice.com/oilandgas/north-sea/427798/only-a-matter-of-time-until-offshore-helicopter-scarcity-drives-up-prices/*

The SORD Project

The SORD project was a 6-month programme part of the Net Zero Technology Centre project OLTER. The project was designed to demonstrate how effectively state-of-the-art Beyond-Visual-Line-Of-Sight (BVLOS) UAS can operate in offshore environments to address a number of highly relevant, industry-developed, use cases. To demonstrate the offshore capabilities, a number of trial objectives were developed to replicate the needs of the offshore industry. For example, the trial aimed to demonstrate a target minimum flight distance, ability to operate in high winds that are regularly seen offshore, and the ability to land in restricted areas such as wind turbine hoist baskets.

The project aimed to deploy best-in-class BVLOS maritime delivery technology never before used in offshore environments, with the objective being to trial and identify improvements for a solution for offshore asset operation and maintenance (O&M) encompassing simulation and demonstration of a range of use cases, co-created with industry. This project culminated in an offshore test campaign in early February 2023. These flight trials included flagship technology demonstrations operating over a one-week period, under a range of conditions and environments demonstrating how the use cases could be realised with the new technologies Skyports and its actively engaged group of partners has developed. From these trials, a number of learnings were identified to improve the operations and ensure any future commercial offering fully meets the needs and safety requirements of all offshore industry stakeholders.

Offshore Trial Requirements

The SORD flight trials were aimed at demonstrating the capabilities of Skyports' drone technology for delivering goods and services to offshore assets, such as wind turbines and oil rigs. In parallel, the flight trials looked to identify and seek resolution to any shortcomings in the services currently offered by Skyports that would hinder commercial offshore drone operations. The flight trials simulated various delivery scenarios, including high-precision landing near high-value assets, and demonstrated several key features and technologies. In developing the flight trials, 7 testing requirements were identified with input on these taken from members of industry and from known use cases when completing offshore drone services.

Requirement 1: Enabling reliable communications between the UA and the Remote Pilot whilst operating outside of terrestrial communications networks (e.g. 4G or direct radio frequency systems).

Use Case: The UAS used in offshore operations is not fully autonomous, and therefore the remote pilot is required to always have an active communication link to the aircraft to manage emergency situations and to perform airspace deconfliction.

Solution to be demonstrated: The Skyports aircraft is equipped with an Iridium Short Data Burst Satellite communications system that sends short "text" messages via satellite (SATCOM). This enables the pilot to send discrete "pre-planned" commands to the UA as well as receive position reports and health information. The flight trials therefore aimed to demonstrate how the aircraft manages loss of terrestrial communications links and how it acts whilst being controlled via SATCOM.

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Use Case: The UAS used in offshore operations should be able to provide a regular and reliable service that is not regularly interrupted by the high winds, or low visibility conditions that are regularly experienced at offshore assets.

Solution to be demonstrated: The aircraft manufacturer claims it is capable of operating in crosswinds of up to 27 knots (14m/s), therefore this trial aimed to operate in high wind scenarios and validate how reliable an offshore delivery service could be using this aircraft. In addition, the trial aimed to demonstrate that the aircraft can operate safely in low visibility conditions.

Requirement 3: Accurate positioning information during landing, even in challenging environments where GNSS spoofing, or signal reflections, can occur.

Use Case: When delivering to offshore wind turbines, CAP437, the UK guidance for offshore helicopter landing areas, states the minimum size for a helicopter hoist basket is 4m by 4m. This is a much smaller landing zone for a drone compared to the land-based areas that are currently used (usually 10m x 10m), therefore the aircraft used offshore needs to be able to land with high accuracy.

Solution to be demonstrated: The landing logic of this system has a number of methods through which the aircraft can land. This trial aimed to utilise and demonstrate the high-precision Visual Landing Target (VLT) system, showing how the aircraft could safely operate to wind turbines with only a small 4x4m hoist basket available for take-off and landing. This VLT enables automated validation of the GNSS position, meaning the aircraft can land precisely without the need for manual intervention from the pilot, minimising the risk of damaging the offshore asset, or injuring a person located there.

Requirement 4: The aircraft used should have the ability to be tracked and monitored by existing airspace users.

Use Case: Other offshore airspace users, most notably helicopters, need to be able to recognise, and deconflict themselves from nearby UAS to reduce the chance of a mid-air collision.

Solution to be demonstrated: The flight trials aimed to showcase the aircraft's Automatic Dependent Surveillance-Broadcast (ADS-B) in and out capability, for which our aircraft has been approved by aviation regulatory bodies, such as the CAA (Civil Aviation Authority). ADS-B is a surveillance technology that enables aircraft to broadcast their identity, position, and other data to other aircraft and ground stations, which enhances safety and efficiency in the airspace. It is noted that many crewed offshore systems are not able to receive and process ADS-B in data, therefore our ADS-B out broadcast may not be picked up or acted upon by other airspace users. To counter this going forward, our future aircraft shall have a Mode-S transponder, a system which offshore crewed aircraft are able to detect as it feeds into the Traffic Collision Avoidance System (TCAS), which issues advisories to pilots in the event of two aircraft conflicting with each other.

Requirement 5: Mission critical systems on the aircraft operate nominally in the offshore environment.

Use Case: When operating any aircraft offshore, it is vital that it does not collide into the offshore asset, nor does it inadvertently injure staff on the asset during any phase of its flight.

Solution to be demonstrated: The aircraft used during the trials has high levels of redundancy across mission-critical components to ensure that in the event of one or more of these components malfunctioning or failing, the aircraft can continue to operate in a controlled manner. For example, the aircraft has a segregated power system, therefore if the forward motor batteries fail or run out, then the hover batteries will engage, allowing the aircraft to emergency land in a controlled manner.

Requirement 6: High operational efficiency allowing for fast response times.

Use Case: The drone operations should have a fast response time to deliver critical logistical packages. Many offshore assets play a key role in the energy supply chain, for example, Equinor’s Troll A contributes around a tenth of the total Gas supply in Europe. When an asset like this is inoperable, it is losing tens of thousands of pounds every minute.

Solution to be demonstrated: To ensure a quick response time, Skyports utilised a highly automated aircraft, therefore, to enable take-off, the Hub Operator for the aircraft simply needs to add the fully charged battery pod to the aircraft and press the “ready” button which initiates take off once the pilot is also ready. This capability allows Skyports to deliver urgent supplies, samples, or replacement parts very quickly when compared to conventional delivery methods.

Requirement 7: Aircraft and operational ability to fly safely at night to allow round-the-clock deliveries.

Use Case: Given offshore assets operate 24/7, malfunctions or problems can occur at any point and may require urgent spare parts or SAR services at any time, including during the night. Conventional offshore vessels, mainly helicopters, operate at night, therefore drone operations must be able to match this capability.

Solution to be demonstrated: The aircraft used during the trials does not rely on conventional cameras for navigation and oversight in operations, with the exception of when it is landing using the VLT.

Demonstration Objectives

The objectives outlined below were developed based on a survey Skyports conducted of potential stakeholders from various energy companies and organisations including Total, Shell, Equinor, Orsted and others. The aim of this survey was to collect feedback from key potential and current stakeholders on what they think the minimum viable product would be for an offshore logistical drone service as well as which use cases they have for drone deliveries today and in the future. Using this data, as well as the requirements identified above, we generated a number of test objectives to showcase in the demonstration. These test objectives (TO's) were an extension of the offshore trial requirements, further tuned towards the scope of the demonstration flights, with some clear measurable metrics developed to understand the success, or failure, of each objective.

Test Objective 01: Quick turnaround (< 90 secs) (A - B - A delivery flight simulation)

Test Rationale:

Requirement 6: High operational efficiency allowing for fast response times.

Test Description:

The objective of this test was to show how quick a turnaround on an offshore rig / wind turbine would be once the drone had delivered its payload. This objective was based on the need to ensure the aircraft is not stationary on a helideck for any longer than it needs to be, which in turn reduces the average downtime of the aircraft allowing an increased number of return journeys to be completed each day. In addition, a helideck operator often has other responsibilities on the rig, therefore if a drone delivery can be handled as quickly as possible this will allow the operator to complete their other tasks more quickly.

Test Procedure & Verification:

The aircraft was prepared for a 35km offshore flight from the airfield to return and land at a different location to where it had taken off. At the landing site the hub operator responsible for changing the payload would remove its payload, conduct a simple pre-flight check and press a green button situated on the starboard wing of the aircraft to let the remote pilot know the aircraft was ready to return. The time taken for this process was recorded by the aircraft's onboard computer, logging the moment the aircraft landed and took off from the simulated asset. An untrained operator was used for two of these tests to find out if training contributed to the turnaround time.

Test expected output:

The time for the aircraft to take off from landing should be consistently under 90 seconds. Since the ground handling consisted of a simple payload swap with the aircraft remaining ready to fly while on the ground, we expected the turnaround time to be minimal.

Test Objective 02: LTE - SATCOM automated switchover

Test Rationale:

Requirement 1: Enabling reliable communications between the UA and the Remote Pilot whilst operating outside of terrestrial communications networks.

Requirement 2: A UAS that can operate in conditions similar to those seen at offshore assets in the North Sea.

Test Description:

This test objective aimed to demonstrate, and stress test, the communications links used onboard the UA. Whilst both the LTE and Satellite communications systems have been used extensively onshore where LTE coverage is expected, the system has not regularly been used offshore. When operating offshore it is likely that the LTE system onboard the UA is able to connect intermittently where Line of Sight to onshore masts is achieved. This connection cannot be relied on at all times in the offshore space due to lack of coverage, and so the UA must be able to switch reliably between the LTE and SATCOM systems to ensure the RP retains communication to the UA.

Test Procedure & Verification:

During all flights offshore, the aircraft was logging its mission duration communicating via SATCOM and LTE and also the number of times it switched between the two systems. No other test-specific setup was required.

Test expected output:

The aircraft was expected to transition to SATCOM seamlessly when out of LTE coverage. It was assumed that the aircraft would make 2 transitions to SATCOM for when it left and entered the LTE coverage area.

Test Objective 03: > 70km range (2 x 35km) and extended endurance.

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Test Description:

The aim of this test was to showcase the current generation of aircraft's range and endurance over multiple cycles. Operating at the maximum range continuously and in higher wind conditions than normal will highlight any potential limitations to the OEM and operator. Despite the current generation of aircraft being limited in range by its almost 3-year-old battery technology, Skyports and its OEM are developing a new version of this aircraft with far superior range that will be able to service most offshore assets around the UK. By understanding the problems encountered with the old generation of aircraft during these offshore stress tests, Skyports will be able to tailor some of its development of its new model to operate in conditions similar to the North Sea effectively.

Test Procedure & Verification:

Similar to TO-01, the mission was split up into two 35km legs to simulate delivering cargo at an offshore asset and returning to the logistical hub on shore. By completing the trial in this way, the full mission cycle could be tested including using the hover motors for 2 take-offs and 2 landings on a single charge. To verify the objective had been completed, during each test the aircraft logged the forward and hover battery level, flight status as well as the timestamps of each log entry.

Test Expected Output:

The aircraft was expected to complete the long-range mission with at least 10% battery remaining as a reserve amount for any holds on diversions required during the mission.

[2] *"How far offshore can we build wind-farms" – Accessible here:*
https://www.sciencefocus.com/planet-earth/how-far-offshore-can-we-build-wind-farms/

Test Objective 04 (TO-04): Demonstrate rejected visual landing and return to base.

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Requirement 5: Mission critical systems on the aircraft operate nominally in the offshore environment.

Test Description:

The visual landing target is used to provide a second form of assurance in addition to a GNSS derived position. This ensures that the location in which the UA is landing is as planned. In the event that the target was not visible, and the aircraft wasn't forced to land on GNSS alone (for example at a landing site beyond the point of no return) the UAS would abort the landing automatically and initiate a return home to ensure the aircraft does not conduct an unsafe landing. Demonstrating this system ensures that the UA will not land unless forced to due to power exhaustion on unassured GNSS.

Test Procedure:

The rejected visual landing and return to base tests were completed by having the aircraft take-off as usual on an A-B-A mission similar to TO-01, remove the visual landing target (VLT) and wait for the aircraft to arrive at the destination. The aircraft would attempt to find the target, and once it had decided it could not it would return back to its take-off point and conduct a GNSS guided landing. The aircraft was programmed to not attempt a GNSS landing if the target was not found at the intended destination to ensure the RTB was demonstrated.

Test Expected Output:

The aircraft was expected to look for the target for no more than 10 seconds and switch flight modes to return to base. During the target acquisition less than 20% of the hover battery should be consumed to allow a successful landing at the take off point after the RTB.

Test Objective 05 (TO-05): Visual Landing Target System

Test Rationale:

Requirement 3: Accurate positioning information during landing, even in challenging environments where GNSS spoofing, or signal reflections, can occur.

Test Description:

As noted in TO-04, the VLT system is essential to ensure a safe landing on an offshore asset. Through this test objective and by demonstrating this function, we aimed to assure offshore operators that the UA can land both precisely and accurately.

Test Procedure & Verification:

During all offshore flights the aircraft was programmed to attempt a VLT system landing first, before attempting a GNSS landing if the visual target was not acquired. The accuracy of visual landings was recorded by the drone's flight computer logging the GNSS coordinates of the take-off point on the VLT and the landing point and comparing them.

Test Expected Output:

From operational experience on previous projects the drones centre point was expected to land within the VLT definitions on most landings. Furthermore, it was expected that the VLT landings would be more accurate than the GNSS landing system.

Test Objective 06 (TO-06): Quick response time (< 15 mins between client request and take-off).

Test Rationale:

Requirement 6: High operational efficiency allowing for fast response times.

Test Description:

This test aimed to demonstrate the response time of the system as well as the ground operator behind it. Response times are critical when the UAS is used to deliver urgent items such as tools or spare parts. By using publicly available data on rig oil production and the cost per barrel of oil some assets can generate up to £350 a second so downtime has an exceptionally high cost. In addition to delivery use cases, quick response times are critical when supporting search and rescue (SAR) operations which operate on a 15-minute notice period. Despite not pursuing assisted SAR operations through UAS in this project, demonstrating the operational feasibility is valuable.

Test Procedure:

To setup this test objective the hub operator and remote pilot were in a ready state with the aircraft in the hangar. Three predefined routes had been planned into the Ground Control Station (GCS) simulating the routes to multiple offshore assets. A visitor of the flight trials selected a route at random and the crew were timed on how long it took to get the aircraft airborne.

Test Expected Output:

Previously the time to deploy the aircraft had never been recorded but we expected the team have the aircraft ready and on the take-off point within 5 minutes of getting the delivery request. Following which the power up and initiation was expected to take 3 minutes.

Test Objective 07 (TO-07): 27 knot wind on departure.

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Requirement 5: Mission critical systems on the aircraft operate nominally in the offshore environment.

Test Description:

By testing the aircraft in multiple high wind scenarios, it would demonstrate how robust the system was throughout consistent high wind landings. This is relevant given the conditions offshore at both rigs and windfarms usually have harsher wind conditions than onshore.

Test Procedure & Verification:

Objective results were gathered by logging the wind speed the aircraft sensors detected at the top of hover to best represent the wind speed the aircraft was flying in during the transition. The results were taken on all flights where a wind speed was recorded.

Test Expected Output:

The expectation was that even in high wind conditions the aircraft continues to operate in a safe and stable manner, as per visual observations by the Skyports team from the ground.

Test Objective 08 (TO-08): Orbit (hold) manoeuvre.

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Test Description:

This test aimed to test the aircraft's ability to hold before continuing, for a reasonable amount of time, despite operating offshore and in harsh conditions. This was to replicate an instance where a helideck, or hoist basket, is not immediately available due to other helicopter operations ongoing, therefore the UAS may need to hold until the landing location becomes available. Alternatively, there may be scenarios where an emergency response aircraft, such as Helimed, may need access to the airspace in which the drone is operating, therefore during this time the aircraft would need to hold in place until Helimed have completed their tasking. In the flight trials, we aimed to simulate a Helimed operation requiring a section of airspace while the drone held itself in an orbit. Given these operations could take an undetermined amount of time, the longer the aircraft is able to orbit and hold in place, the better and safer the offshore operations could be.

Test Procedure & Verification:

The orbit manoeuvre was tested by an external observer requesting the RP to command the aircraft to hold. This manoeuvre was tested twice to simulate a busy helideck approach. These orbit commands were given during random flights as the aircraft was enroute to its destination.

Test Expected Output:

The expectation was for the drone to be able to hold for at least 5 minutes containing itself within the predefined volumes of the route while orbiting.

Test Objective 09 (TO-09): Return to Base Manoeuvre.

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Test Description:

Similar to TO-08, by testing the RTB in offshore conditions we aimed to prove the current generation UAS would be reliable enough to execute RTBs during commercial offshore operations. An example where this would be useful is if an unexpected weather front is detected that breaches the capabilities of the aircraft. In this case, it must be able to turn around and safely return to base. Similarly, if the aircraft is required to hold, as per TO-08, but the distance to complete the flight then becomes greater than the remaining battery range, then an RTB would also be required.

Test Procedure & Verification:

To test this capability the aircraft was commanded to RTB enroute to its destination.

Test Expected Output:

The expectation was for the aircraft to loop back on its original routing within 5 seconds of initiating the command from the GCS.

Test Objective 10 (TO-10): Demonstrate as many flights as feasible within a 7-hour operating shift.

Test Rationale:

Requirement 6: High operational efficiency allowing for fast response times.

Test Description:

This objective intended to reflect what would be expected of a drone operation servicing offshore platforms from a logistics centre. The aim was to not only stress the single system with constant flights, but also the ground operator, to show that it is possible to maintain a fast-paced offshore delivery service. Furthermore, this objective looked to identify any inefficiencies in our processes for re-launching the aircraft following a delivery. The 7-hour time was chosen as this allowed for multiple back-to-back flights to replicate the high activity scenario of receiving multiple deliveries at a rig or wind turbine.

Test Procedure & Verification:

To demonstrate the test objective, a single aircraft was to be used throughout the day with 3 battery pods available for the quick swapping of batteries. The routes planned were 35km battery swap routes to simulate a delivery to a more capable offshore rig that had charging infrastructure, and a 35 + 35km return route on a single battery pod. The onboard flight computer logged all of the flights of the day to verify that the results had met the objective's aims.

Test Expected Output:

Each flight was expected to take around 40 minutes for the 35km route, with around 5 to 10 minutes of additional ground time assumed between each flight. Within the 7-hour period a total of nine 35km flights were expected.

Test Objective 11 (TO-11): Full Night Flights

Test Rationale:

Requirement 7: Aircraft and operational ability to fly safely at night to allow round-the-clock deliveries.

Test Description:

An important criteria for the offshore operation is to be able to operate at night. This objective aimed to demonstrate the ability of the system and crew to operate successfully during the night hours and identify any problems or unidentified challenges associated with these operations.

Test Procedure & Verification:

The night flights were identical in planning to the normal 35km route out offshore. In terms of operation, the onboard lights are all switched on during day and night operations and so the only difference in procedure was during the landings. The VLT was illuminated by 4 spotlights 5 meters from each corner of the visual landing target.

Test Expected Output:

The aircraft was expected to complete the night flights no differently than how it would in daylight conditions. With the spotlights in place, it was also expected that the aircraft would complete the VLT landings successfully.

Test Objective 12/13 (TO-12 & TO-13): Simulated Helicopter Deck & Hoist Basket Landing

Test Rationale:

Requirement 2: A UAS system that can operate in conditions similar to those seen at offshore assets in the North Sea.

Test Description:

To land on offshore assets the system must be able to handle landing on a helicopter deck-sized landing area. The aim of this objective was to constrain the landings and demonstrate the consistency of the landing system by landing in a restricted area multiple times. Furthermore, TO-13 aimed to further constrain the landing area to demonstrate the ability to land on a wind turbine hoist basket. Hoist baskets are far more limited in size than helicopter decks, with CAP437 (UK regulatory guidelines) stating the minimum hoist basket size to be 4m x 4m.

Test Procedure & Verification:

Rather than have a physical helideck and hoist basket transported to the airfield just to demonstrate TO-12/13, the take-off and landing GNSS data was logged to be analysed post-trial to demonstrate the ability to land on either structure. This was believed to be as accurate, as having a visual definition of the helideck around the VLT or GNSS coordinate.

Test Expected Output:

The expectation was for the aircraft to easily satisfy TO-12 by always landing within an area smaller than 10x10 meters. From operational experience in previous projects TO-13 was expected to be satisfied as well. However, because of the nature and value of the assets we are simulating a landing on, we anticipated asset owners would prefer at least a safety margin of 50%. In this scenario landing on a 4x4m platform would require the drone to consistently land within 2x2m. With this in mind landing on smaller wind turbine baskets would be too difficult for the current generation of landing systems.

~~if safety margins of 50%~~

Trial Location and Routes

In order to complete these test flights, an appropriate location needed to be identified. Current U.K. regulations only allows BVLOS drone operations to take place in segregated airspace, meaning no other commercial or general aviation operations can be ongoing nearby to ensure the safety of their passengers. For drone operators, this means utilising a temporary or permanent danger area, which can be activated to ensure other aircraft operators stay clear of the drone operations. Creating a Temporary Danger Area (TDA) is a lengthy process and requires significant work and engagement with the UK CAA. Therefore, for these flight trials, Skyports used the existing Danger Area (DA) at Predannack Airfield. This DA is very large and can allow long-range, offshore operations allowing Skyports to validate TO-03. The DA also goes a significant distance away from shore, meaning the aircraft would be able to fly out of range of LTE, forcing it to transfer to SATCOM, meaning TO-01 could be tested. This feature also allowed Skyports to have a high chance of validating TO-07. While we cannot guarantee high-wind scenarios, by flying further offshore in this DA, encountering high-wind scenarios is more likely. Finally, this DA can be activated at night, allowing us to test TO-11. Given all other testing objectives were procedural, it was clear that this airfield would allow us to validate all objectives and provide evidence of each requirement.

The danger areas utilised in the flight trials are shown in Figure 1, numbered as D005A, D005B and D006B.

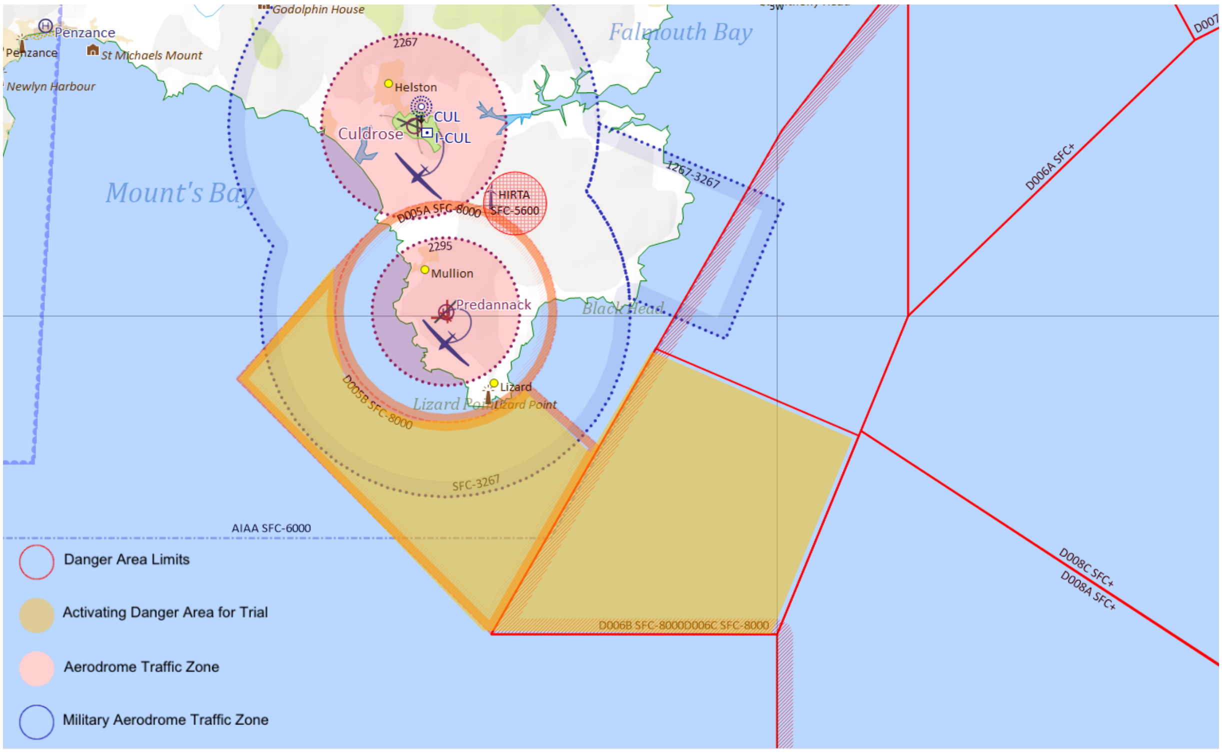


Figure 1: Wholeship Testing Range Danger Areas (Predannack, Helston)

Flight Routes

This subsection goes through the routes that were used during the tests to verify that the objectives had been complete. The project had a relatively short time frame, which meant that temporary danger areas could not be created for drone routes as they require at least 3 months just for the regulator's review. With this in mind, if the routings were to use an offshore asset, it would need to be within a predefined danger area like Predannack which at the time of writing doesn't exist in the UK. The best option, therefore, was to fly from the mainland offshore and back to the mainland. Shown below is the 35km route that was predominantly used as it satisfied the majority of the test criteria and maximised the airspace usage time.

Figure 2: Flight route used during SORD flight trials.

Figure 3 shows the LTE coverage for the Predannack Peninsula. This diagram represents expected LTE coverage, modelled by O_2, for user devices operated at ground level. The UA operates between 300ft and 400ft Above Ground Level (AGL), therefore, depending on signal propagation and reflection, coverage could still be found in the route's extremities. Even with the potential for increased coverage the Predannack Danger areas were deemed suitable to support demonstrations of TO-02.

Figure 3: Overview of LTE coverage during standard flight route

System Overview

The Swoop Aero Kookaburra Mk III was used during these flight trials. A summary of the operational limitations is detailed below. Skyports DS will not operate this vehicle beyond the limitations detailed below.

Table 1: Summary of UAS used during SORD flight trials.

Type	Hybrid – Powered Lift transitional platform (VTOL)
Max speed	68kt
Cruise speed	55kt
Max endurance	68 mins (forward flight limit at MTOW)
Max payload	3kg
MTOM/MTOW	17kg
Lighting	Navigational lights and a white strobe
Max. wind	27 kts (14 m/s) from any direction
Min. visibility	No minimum visibility limitations
Precipitation	Moderate rainfall (2mm – 10mm per hour)

Cloud ceiling	No limitation
Min. / Max. Operating Temperature	0°C / +45°C
Electronic Conspicuity	The UA is fitted with ADS-B IN and OUT, which can process uncertified ADS-B signals, namely SIL/SID=0. The UA ADS-B transponder transmits on 1090Mhz, this system can also receive other ADS-B signals from certified and non-certified sources, giving the widest range of visualised signals using the ADS-B protocol. The UA will not visualise Mode S only devices.

Results

The flight trials aimed to assess the capabilities and limitations of the current generation of BVLOS drones in various offshore scenarios, focusing on their uptime, endurance, adaptability, and response time. The trial objectives were based on a range of simulated situations, including quick turnarounds, automated communication switchover, endurance testing, landing manoeuvres, and response time tests. The trial results demonstrated the ability of the aircraft to successfully complete multiple objectives, although certain aspects such as quick turnaround time and response time still required some improvements. Overall, the trial showcased the potential of using drones for offshore operations and highlighted areas for further enhancement in future iterations. Table 2 outlines how each test objective was met.

Table 2: Summary of Test Objective Results

Objective Number	Objective	Results
TO-01	Quick turnaround (< 90 secs) (A - B - A delivery flight simulation)	78% percent of our turnarounds were within the 90 second objective, with some outliers caused due to SATCOM connectivity delays.
TO-02	LTE -> SATCOM automated switchover (dependent on offshore LTE coverage)	The system demonstrated a reliable automated switch over to SATCOM.
TO-03	70km endurance (2x 35km)	- 15x 70km Flights - 6x 35km Flights - 1x 50km Flights - 1x 75km Flights
TO-04	Demonstrate rejected visual landing and return to base.	4 out of 4 successfully demonstrated.

TO-05	Visual Landing Target (VLT) System	28/33 landings using the VLT System successfully acquired the target. The 5 Failed VLT's were at night when the camera failed to see the target due to low light.
TO-06	Quick response time (< 10 mins between client request and aircraft take-off)	Test completed twice. - First test: 15 minutes (delay due to SATCOM availability flag) - Second test: 6 minutes
TO-07	~27 knot (14m/s) wind on departure	No abnormal flight behaviour as a result of wind observed. - 2 flights in wind > 25 knots (13 m/s) (Gusting) - 8 flights in wind > 10 knots (5 m/s) - 13 flights in wind > 5 knots (2.5 m/s)
TO-08	Orbit (hold) manoeuvre	Manoeuvre successfully demonstrated twice.
TO-09	Return to base (RTB) manoeuvre	2 successfully executed RTBs with the aircraft performing the manoeuvres within the confines of the route plan.
TO-10	Demonstrate as many flights as are required and feasible within a 7-hour operating shift.	8 flights in a single 7-hour shift. We were airborne for 4 hours and 43 minutes and covered over 500km of distance.
TO-11	Full night flights	Flights were completed across two nights. Due to airspace access restrictions, around 4 hours of night flights were completed across those two nights.
TO-12	Simulated Helicopter deck landing	28 out of 28 landings within the confines of a simulated helicopter deck using the VLT system, and 6 out of 6 landings via the GNSS landing system were also completed within the definitions of a helicopter deck.

TO-13	Simulated hoist basket landing	28 out of 28 Landings within the confines of a simulated hoist basket using the VLT system, and 6 out of 6 landings on via the GNSS landing system were also completed within the definitions of a hoist basket.

TO-01 Results - Quick Turnaround (< 90 secs) (A - B - A delivery flight simulation)

The average turnaround time was 111 seconds, or 1.85 minutes. The average was greater than 90 seconds due to flights 6 & 8. The average turnaround time excluding these 2 results was 55 seconds.

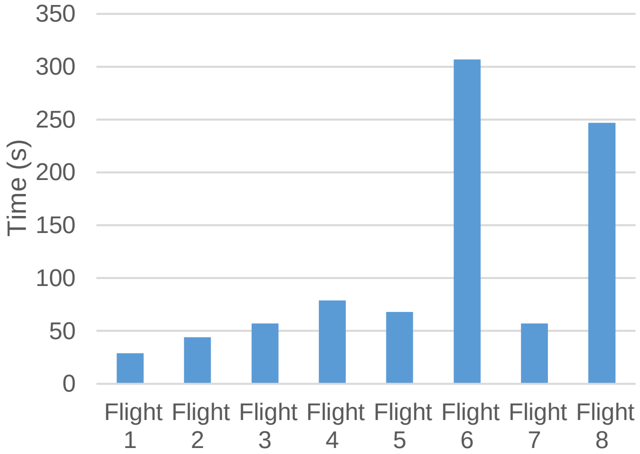


Figure 3: Quick Turnaround Time Results

An untrained hub operator was used for flight 3 and 5 and it made very little difference to the turnaround time. As shown in Figure 3, flights 6 and 8 both had longer turnaround times. The root cause of these delays on the ground was due to the drone relying on SATCOM to inform the GCS that the flight had been completed. The current generation of SATCOM equipment onboard the drone is the rock-block 9603 which sends updates between 10-60 seconds. Currently, the operating procedures of this drone require a low latency on take-off. Since the next generation of this system will have a latency of less than 5s by using the Iridium Certus 100 satellite service, this problem will soon be solved.

What does this mean:

With an average turnaround time of only 55 seconds, the utilisation of a helideck on an offshore asset can be greatly increased. If widely adopted, an onshore drone hub could in theory dispatch a new delivery every 2 minutes significantly boosting offshore connectivity to the mainland.

Our Learnings:

LTE signals close to the shore, or even on shore aren’t reliable. Relying solely on a solid LTE signal will cause delays in turnaround. Improvements in SATCOM latency to allow launches on SATCOM are required to reliably turnaround the aircraft quickly offshore.

TO-02 Results - LTE -> SATCOM automated switchover

The results were gathered by the aircraft's flight computer recording the number of SATCOM switches during flight, as well as the duration where communications were performed using SATCOM. The average time spent on SATCOM was 183 seconds per flight, approximately 8%. The average number of SATCOM switches per flight was 4.9 and the total switches were 162.

The results for each airframe differ significantly, KA341 spent around 10% of the total flight time on SATCOM, while KA337 spend 6%. Coincidentally KA341 switched to SATCOM an average of 3.7 times per flight vs 6.26 of 337.

What does this mean:

For TO-02, two conclusions can be drawn. The UA performs a switch between LTE and SATCOM communications systems much more often than expected during flight. This did not affect the ability of the RP to safely issue commands to and receive telemetry from the UA.

There is a variance in the performance of the communications links fitted to each UA. Whilst the test results do not provide data on a likely cause, it can be assumed this is down to variance in components on the UA that increase or decrease the sensitivity of the communications systems.

Our Learnings:

This test highlighted a variance in communication components on the UA that Skyports shall investigate further to ensure consistent performance.

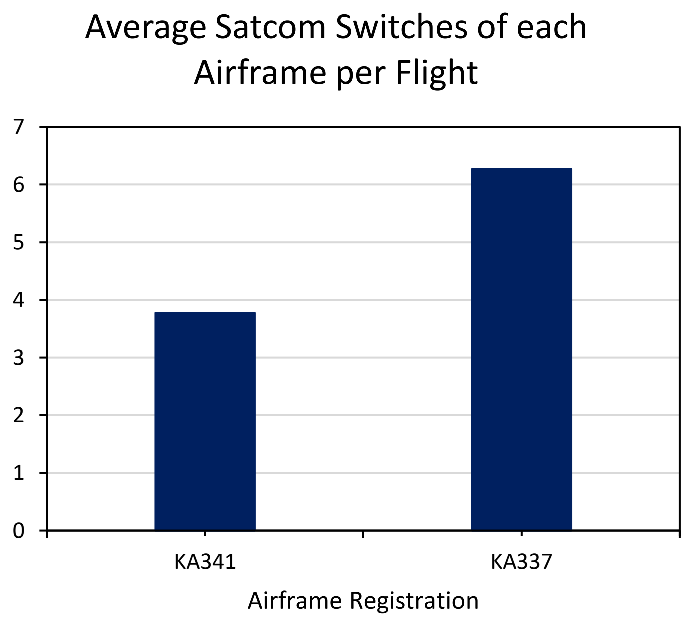


Figure 4: Average Satcom Switches of each Airframe per flight

TO-03 Results - 70km endurance (2 x 35km)

Test Objective 03 results were gathered by having the aircraft fly multiple 70km return routes to show the aircraft can consistently fly at the maximum range limitation offshore in the same way it can onshore. 18, 70km flights successfully took place during the trials.

The average battery level at the end of a long-range flight was 29%, far greater than the minimum reserve of 10% required by the operations manual. Another finding from the results was that the average battery level at the end of each flight when flying with an average wind of above 10 knots (5 m/s) was 22%. This was significantly lower than when the flights had an average wind speed of below 10 knots which was 33%.

Table 3: Average battery consumed in various winds

	Average wind speed (Kts)	Battery Percentage (%)
Average Battery Consumed in the 70km route	8.52 (4.3 m/s)	71%
Average battery Consumed with >10 knots wind	12.29 (6.3 m/s)	78%
Average Battery Consumed with <10 knots wind	6.83 (3.5 m/s)	67%

Figure 5 shows the battery percentage and airspeed throughout the flight that landed with the least amount of battery (13%). The airspeed has been included to better indicate what the aircraft was doing during the mission. During the initial transition from hover to forward flight the battery reduces at the greatest rate while increasing in airspeed and then reduces at a steady rate when cruise speed is established as expected. During the hover flight, around 1400 s into the mission, the battery percentage value did not follow the expected behaviour and produced what is thought to be erroneous values caused by temperature and EMF. This does not impact the safety of the aircraft or of the operation but is only a sensor issue to be investigated and resolved.

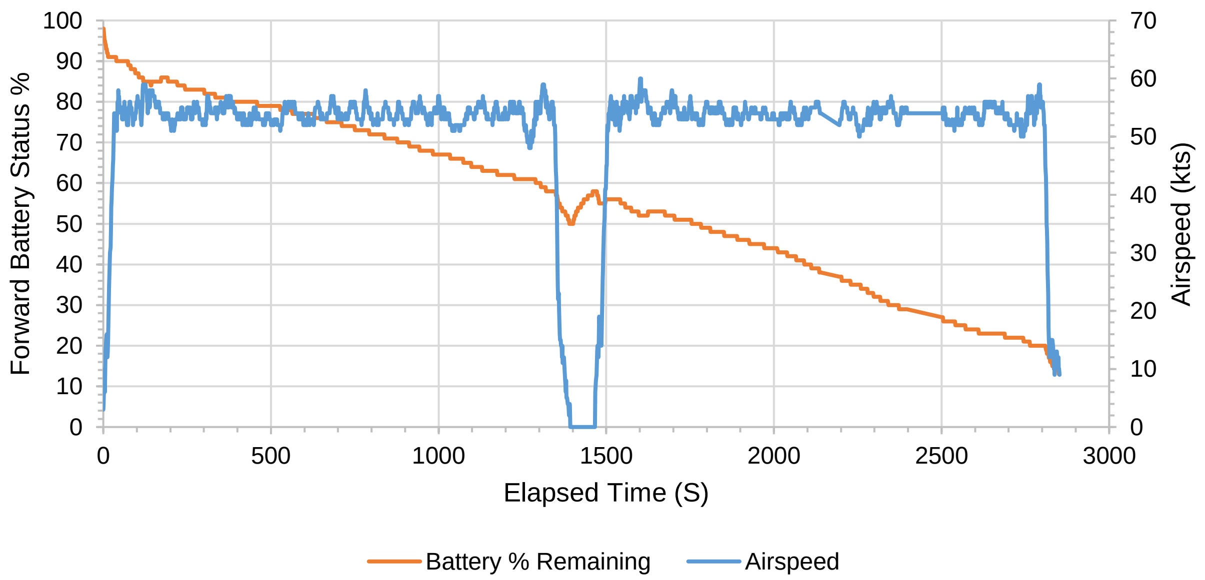


Figure 5: Battery Percentage and Airspeed throughout highest battery drained flight

What does this mean:

With the ability to consistently travel 35km, deliver a payload, and then return to base with safe charge levels still remaining, most offshore windfarms around the UK can be serviced with today's aircraft, even in the high wind conditions expected offshore.

Our Learnings:

During the first landing of a return trip the battery readings aren't reliable from the forward battery. Skyports shall investigate this further as accurate estimates of power remaining for the return trip is key to ensure safe operations of the aircraft.

TO-04 Results - Demonstrate rejected visual landing and return to base.

4 rejected landings were attempted and completed with the VLT removed. On average, during this target acquisition phase of flight 13% of the hover battery was consumed.

During the target acquisition, the drone spent an average of 9 seconds searching for the target while hovering before making the decision to abort and return to base as pre-planned in the mission planner. The other scenario that can be planned would be for it to conduct a landing using GNSS positioning during the landing, even if it did not identify a visual landing target. This procedure is used when the landing spot is too far from the next predefined landing point.

What does this mean:

The system has reliably demonstrated that if it has been instructed to only land if the VLT is acquired, it will loiter for 10 seconds before making an automated decision to return to base. This means that if the aircraft isn't assured that the landing point is correct through the GNSS coordinate and through the acquisition of the VLT, it will abort the landing and return home. In the offshore space this is critical as an incorrect landing location could cause damage to the offshore asset.

Our Learnings:

The rejected visual landing and return to base tests were demonstrated successfully, and Skyports is confident in using the manoeuvre in the offshore space.

TO-05 Results – Visual Landing Target (VLT) System

The image to the left shows the drone on the VLT. When landing, the average error to the centre of the VLT was 0.7m and the maximum distance error was 1.61m. The aircraft was able to acquire a visual target 28 times out of 28 during the day, demonstrating the reliability of the system even in lower visibility conditions that were present in the last two days of the flight trials. Figure 6 below shows the distances of each landing point from each take off point as a blue dot. The red square represents the aircrafts footprint for each landing to aid with visualisation of the results. It is important to note that despite operating in strong gusting winds at Predannack due to its proximity to the sea, offshore winds may play a factor in the landing accuracy of the aircraft, but this could not be tested within the scope of the SORD project.

What does this mean:

By having such high landing accuracy, this means that the aircraft could reliably and accurately land at offshore assets, where landing space can be limited, such as in a small wind turbine hoist basket.

Our Learnings:

Skyports is confident that the VLT system can provide accurate assured landings even in offshore conditions with lower than normal visibility.

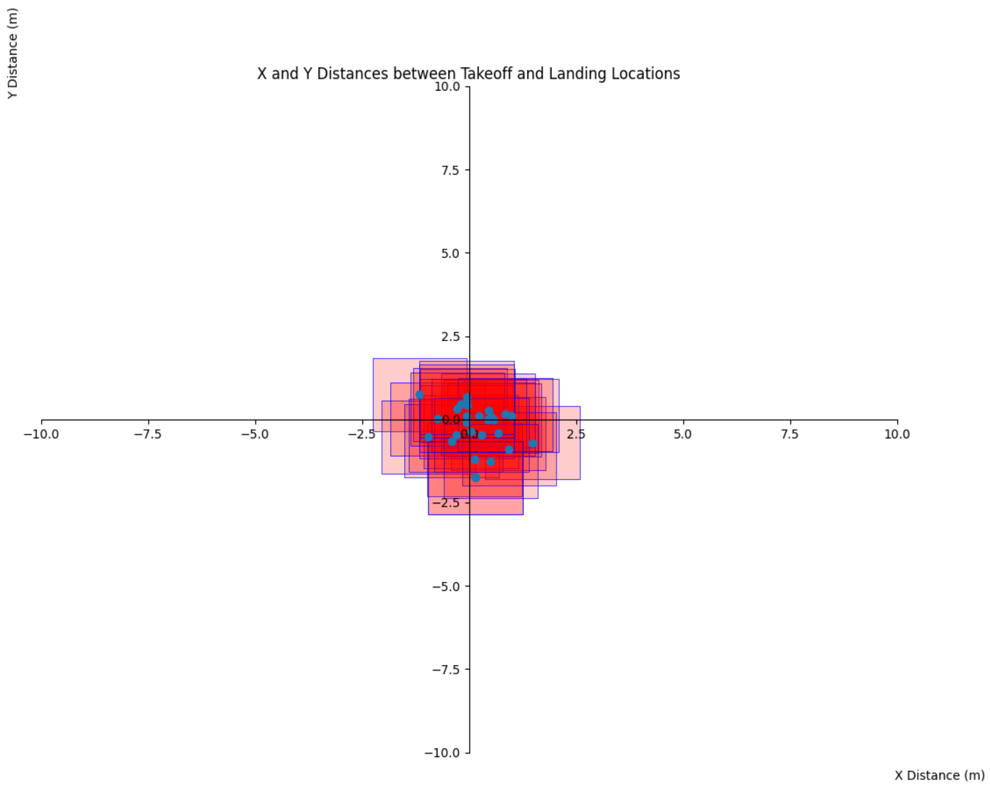


Figure 6: X and Y Distances between Take-off and Landing locations on VLT

TO-06 Results - Quick response time (< 10 mins between client request and aircraft take-off)

Table 5 presents the outcomes of the quick response time tests completed during the trial. Two separate response tests were executed, with Test 1 experiencing a significantly longer duration compared to Test 2. The primary contributing factor to this delay was the time required to establish a stable SATCOM connection.

Table 4: Aircraft Turnaround Time

	Test 1 (Minutes)	Test 2 (Minutes)
Total time to get the aircraft in the air	15.1	6.13
Operations Response time to deploy aircraft	3.21	2.96
Aircraft Power up and Initialization	5.10	3.13
Delays Acquiring SATCOM Signal	6.79	0

What does this mean:

The SATCOM delays experienced in Test 1 were the result of the drone requiring a stable LTE and SATCOM signal prior to launch. Throughout the other flights of the week, there was only one other flight delayed by not having a reliable SATCOM connection. While on the whole, a stable SATCOM connection was established quickly, implying this test objective has been met, this is a very small sample size and therefore further testing of this objective is required to come to a confident conclusion. Should successful tests be carried out in future, this would mean the delivery reaction time using a UA can be quicker than a traditional helicopter service. This could save offshore companies substantial costs if parts are needed immediately.

Our learnings:

SATCOM connection acquisition can result in extended wait times. Skyports will investigate if there is an alternative way to be connected to SATCOM before the pre-fight checks to ensure it doesn't act as a blocker in the deployment sequence or have the initial connection run in tandem with other parts of the startup sequence.

TO-07 Results - ~27 knot wind on departure

The sensors recorded that the average wind during transition for all the flights was 8 knots (4m/s). The top of climb is normally around 40m AGL, free from mechanical turbulence which would otherwise affect the results. To summarise, from the sensor data, 2 flights were completed with a wind greater than 25 knots (13m/s) during transition, 8 flights with 10 knots + (5m/s) and 13 flights with 5 knots + (2.5 m/s). These readings are based on the maximum wind detected on transition, not the sustained wind in flight.

By using the data feed from the battery sensor, the onboard log time, and the wind detected at height, trends have been generated in Figure 7 below. The general trend is that the greater the average transition wind, the more the hover battery was consumed, which is suspected to be the result of a higher time in transition which is also reported in the figure. The key output of this graph was that the transition wind increased the hover battery consumption significantly, and in future, the RP should be cognizant of the reported low-level wind. Additionally, observations of the aircraft operating in these high winds showed no safety issues or increased instability, therefore Skyports is confident that the aircraft can safely operate in high winds.

What does this mean?

By demonstrating multiple high wind operations, Skyports can be sure our aircraft have a high uptime during offshore operations compared to conventional mainland base flights.

Our Learnings:

Skyports recognise the importance of the low-level winds and how they affect the hover battery. Moving forward, the level of usage should be monitored in even higher winds, however it is not expected that this has a significant impact on the functioning of the aircraft, even if the hover battery was required in the event of a rejected visual target landing. This trial was deemed successfully completed.

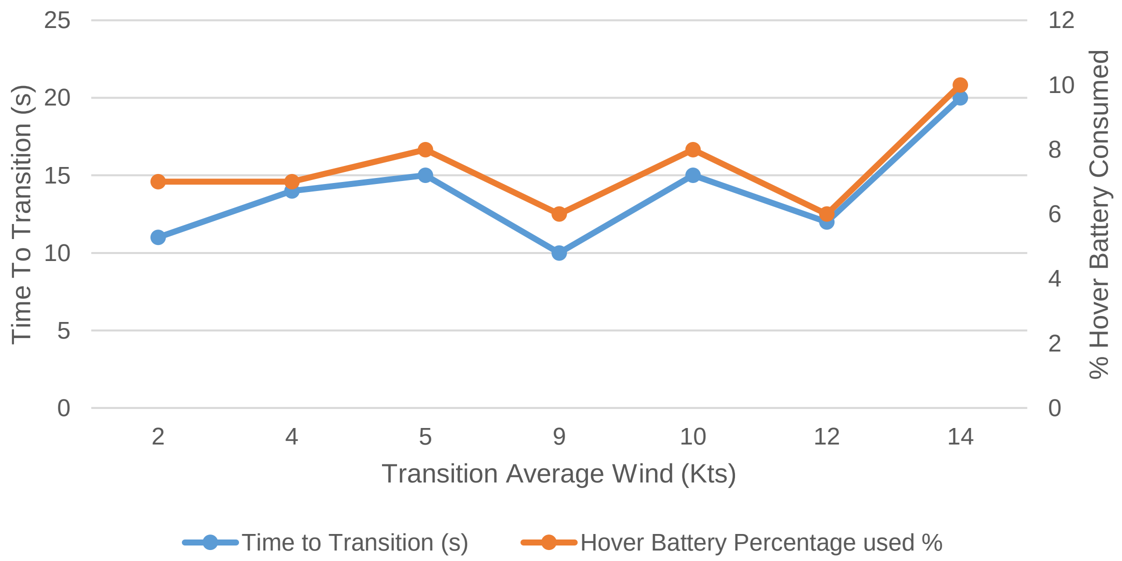


Figure 7:Time to Transition and Hover Battery Consumed at various transition wind speeds

TO-08 Results - Orbit (hold) manoeuvre

The orbit manoeuvre was tested by an external observer requesting the RP to command the aircraft to hold. This manoeuvre was tested twice to simulate a busy helideck approach. The 5 orbits took an average of 275 seconds to complete consuming 5% of the forward battery in line with standard forward flight battery consumption rates. The duration the UA can safely hold is dependent on the length of the route as well as the prevailing conditions.

What does this mean?

By demonstrating the aircraft can hold for a significant amount of time the integration with other operations, for example crew transfer helicopters, becomes simpler as the drone doesn't need to have the priority to land on the deck.

TO-09 Results - Return to base manoeuvre

The return to base command was tested 3 times by the RP executing the command from the GCS.

One of the RTB's was caused due to a caution flag on the GCS, initiated by a GNSS altitude mismatch for a sustained period. The pilot, following Skyports operational procedures, executed an RTB 35 seconds after the initial GNSS mismatch which was thought to be caused by a misreading sensor. On all RTB's the drone executed a loop to return along the route it came from. The aircraft commenced the RTB on average 2 seconds after the command was executed at the GCS. The RTB as well as an orbit manoeuvre is shown in Figure 8 below.

What does this mean?

This test was successfully completed, and the aircraft acted as anticipated. This therefore increased Skyports confidence in the aircraft to quickly RTB as and when required.

Figure 8: RTB and Orbit Manoeuvre during one of the tests

TO-10 Results - Demonstrate as many flights as are required and feasible within a 7-hour operating shift.

In total we completed 8 flights in the single 7-hour shift. The aircraft was airborne for 4 hours and 43 minutes and covered over 500km of distance. The results showed that the average time from having the aircraft ready on the ground until take off was 7 minutes 44 seconds.

The main cause of this delay was the time for the crew and pilot to be ready. This time on average contributed to 6 minutes of ground time. This crew readiness time also includes the time it takes to acquire an acceptable latency between the GCS and the aircraft. This wait time for a reduced latency signal occurred more often than usual at Predannack lasting on average 3 minutes.

Additionally, the second largest contributor to this ground time was the warmup period for the IMU. On 3 of the flights the outside temperature was too cold during start-up which was likely to have been caused by the aircraft being sat on the ground for too long. The average time for IMU warmup was 45 seconds. Finally, the avionics initialisation took on average 30 seconds per flight.

The other cause of downtime was for preparing the aircraft. This accounted for 76 minutes of downtime, averaging 9.5 minutes per flight. These delays were caused by pod replacement (walking to the hangar and back, 4 minutes each time), aircraft inspection, communication with Air Traffic Information and payload replacement.

What does this mean?

Being able to demonstrate a consistent service in an offshore environment shows that the logistical service can be reliable and therefore has a business case for offshore companies.

Our Learnings:

Each flight had approximately 17 minutes of downtime, a time which we expect to be reduced in future operations. This could be achieved by:

- Ensuring the replacement pods are stored close to the TOLP, reducing the time taken for the crew to walk back and forth.
- Ensuring pods are kept warm after being fully charged and whilst they are waiting to be placed on the aircraft.
- Investigating how to reduce the time taken to establish low latency communications between the aircraft and the GCS.

TO-11 Results – Full night flights

There were 280km of night flights flown, over 4 missions. During 3 of these tests the aircraft did not pick up the VLT and it executed a GNSS landing, however, on the last flight the UA detected the VLT and landed using the visual landing system. Figure 9 shows what the visual landing camera saw as it tried to acquire the VLT.

Four generator-powered spotlights were set up to illuminate the target during these tests shown in the figure below. There was no significant change in the setup that actually allowed the last test to acquire the VLT, and we attribute it to the correct environmental conditions occurring at that time of the flight. Overall, there were 161 minutes of night flying completed. One finding we discovered is that the aircraft is far more visible at night over long distances than in daylight thanks to its strobe and navigation lights. We consistently gained a visual of the aircraft 3 to 5 kilometres from the airfield, a difficult task in the daytime.

What does this mean?

This means that the current night flight set-up for visual landings is not wholly appropriate and adaptations need to be made to ensure the VLT is picked up more consistently at night. The aircraft can safely operate at night, and hub operators on the ground can observe it from a much greater distance due to the lights on the aircraft.

Our learnings:

An improved method for illuminating the VLT was tested successfully during these trials, as shown in Figure 10. This allowed the aircraft to successfully identify and land on the VLT, as opposed to when spotlights were being used on each corner. Going forward, as this improved method was only tested once, further tests shall be carried out to ensure it does allow for improved detection of the VLT for night-time visual landings. In doing this, Skyports could operate regularly and safely at night.

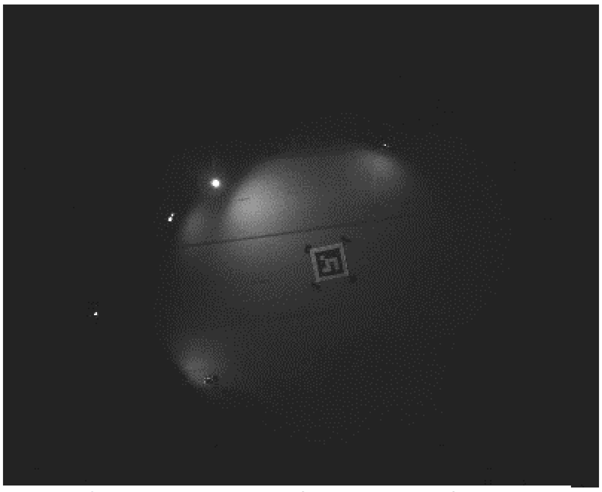


Figure 9: The Visual Target from the aircrafts landing system at night.

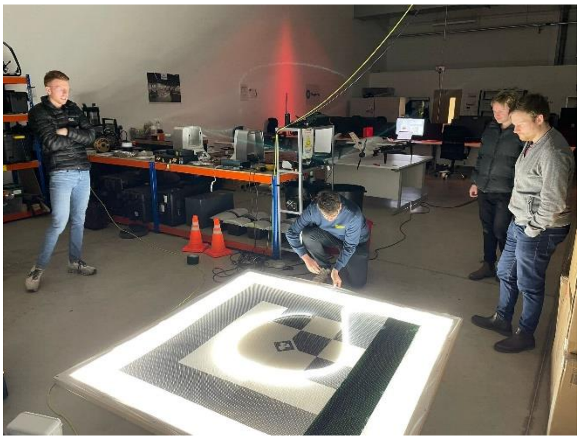


Figure 10: Developing an improved illumination method for the VLT

TO-12 & 13 Results – Simulated helicopter deck and hoist basket landing

Displayed on Figure 11 is the VLT landing data superimposed on a 10x10 helicopter deck and also in Figure 11 is the same VLT data imposed on a general hoist basket layout, approximately 10x6m. As the figures depicts, using the VLT as a primary guidance source for landing is accurate enough to allow helideck and turbine basket landings.

Our Learnings:

While these landings suffice for landing precisely on average wind turbine hoist baskets, some are as small as 4x4m. In this case, the aircraft would not land precisely enough to be safe, therefore even higher precision landings are required to be able to deliver to all offshore assets.

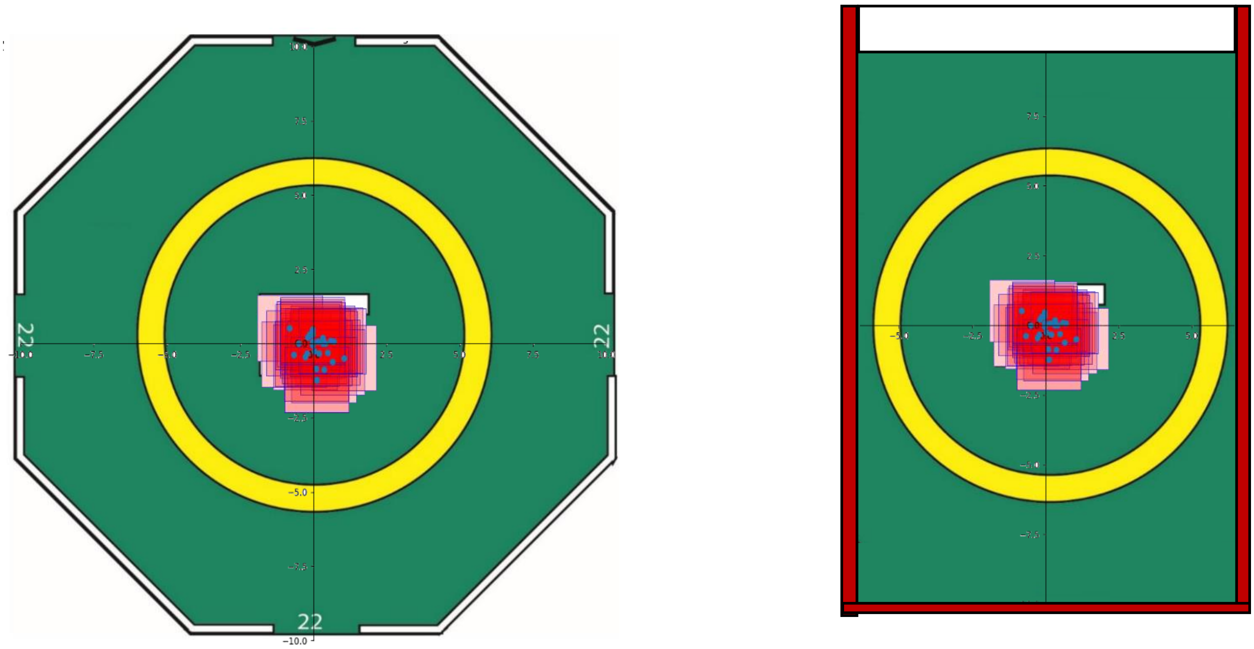


Figure 11: VLT Landing Data superimposed on a 10x10m Helideck (Left) and 6x10m hoist-basket (right)

Evaluation and Limitations

The flight trials completed were deemed a success by Skyports. Not only because a number of the trial objectives were met, but also because the testing identified a number of learnings to be further developed in future through future trials and offshore operations.

This section summarises the key learnings from the flight test results. As outlined above, there are some specific learnings that, if regularly applied in operations, would improve the service provided to any future offshore customers. These key learnings are listed below:

- TO1 – Lower latency SATCOM sensors built into the aircraft.
- TO5 / TO13 – Increased precision of aircraft landing.
- TO10 – Greater efficiency in preparing the aircraft between flights.
- TO10 – Easier access to TOLP from pod charging locations.
- TO11 – Improved illumination of the VLT during night operations.

The first learning was how Skyports can ensure the aircraft is able to utilise the Visual Landing Target (VLT) during night trials. The problem with the current system is the aircraft cannot see the actual definitions of the visual target at night. The root cause of this is that the OEM designed the system to primarily work in the brightest conditions associated with rural low infrastructure use cases such as in Africa. To maximise the contrast between light and dark in these scenarios, the sensor package includes a neutral density filter which decreases the camera exposure, acting like a pair of sunglasses. This makes it harder to detect the target in low-light conditions. There are two solutions to this problem - one more suited to a short-term implementation is to adapt the VLT with the addition of LED lighting strips around the side. Secondly, a more longer-term solution is to adjust the exposure of the camera or have a system to apply the sensor filter only in high brightness conditions. Figure 12 shows the direct changes we made straight after the SORD flight trials to improve the ability of the aircraft to detect the VLT at night.

Figure 12: Improvements made to the Visual Landing Target (VLT)

Figure 13 shows the landing data collected during the SORD flights. For the VLT landings, despite the take-off point changing daily as the infrastructure built was temporary, the script written to process this data used the take-off point as the datum to compute the absolute distances of the landing point from the take-off point. This corrects to account for variations in the absolute location of the target from day to day. The GNSS landings worked differently, as the GNSS target landing point was set pre-fight, and did not depend on the take-off point, therefore no compensation for absolution location changes of the TOLP was needed.

Superimposed on top of the VLT landing data points is a scaled offshore helideck found to the right of Figure 13, where the blue dots represent the GNSS coordinate of the landing location and the red squares represent the outline of the profile of the aircraft. Most offshore rigs can support aircraft of up to 1D (1 Rotor Diameter) of the helicopter, however, some are constructed to 0.83D (CAP437). The diagram shows a helideck sized to support one of the smaller offshore helicopters the EC135, with a deck diameter of 10m. The results demonstrate consistent landings far within the extremities of the helideck proving the landing systems' accuracy and precision.

To the left of that image are the GNSS landings, with the target GNSS coordinate as the datum. It is clear that the GNSS landings are at the moment the more accurate of the pair. In this current generation of aircraft landing systems, the VLT target acquisition serves as a second form of validation in the event that the GNSS position is inaccurate.

The final technical point for improvement was noted and explained in TO-01. The current generation of SATCOM equipment onboard the Swoop Kookaburra is the rock-block 9603 which sends updates between 10-60 seconds. Currently the operating procedures of this drone require a low latency on take-off. Since the next generation of this system, the Swoop Kite, will have a latency of less than 5s by using the Iridium Certus 100 satellite service, this problem will soon be resolved.

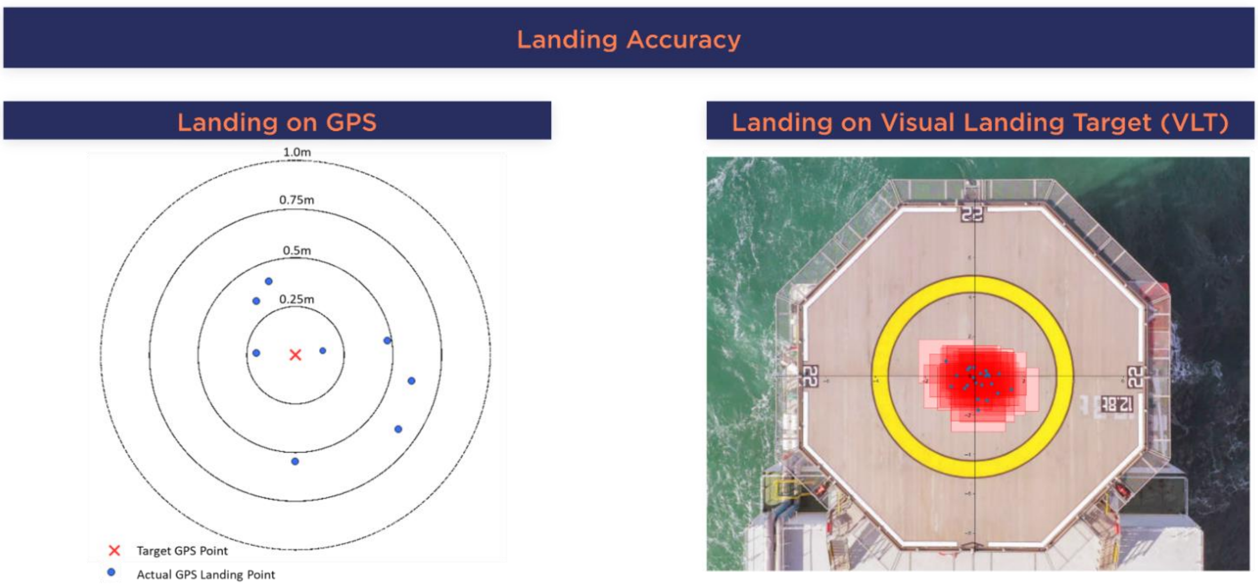


Figure 13: Aircraft Landing accuracy

Outside of these known improvements, some trial objectives require further assessment and testing in future projects. These are summarised below:

- TO-02 – Investigating the variance in communication components between different aircraft of the same model due to an increased number of LTE – SATCOM switchovers which took place when comparing KA-341 to KA-348.
- TO-03 – Investigate the accuracy of the battery charge readings during a landing and prior to a following take-off. It appeared that during testing, heat impacted the remaining charge readings logged by the flight recorder.
- TO-06 – Test whether SATCOM connection acquisition can be brought forward in the aircraft deployment sequence to reduce the chance of a slow connection delaying take-off of the aircraft once all other checks have been completed. This occurred twice during this phase of flight trials and so could delay aircraft departures more regularly should this become a commercial operation.

Conclusions and Future Work

Going forward Skyports shall continue to evolve its fleet and its capabilities to improve our performance in relation to the objectives above, as well as other known issues in relation to the offshore space, most notably operating in ever increasing levels of wind and rain, and in turn sea states. This will allow Skyports to provide a service more reliably to offshore companies, such as those consulted and involved in this project via the NZTC. Furthermore, as the test objectives are fulfilled by said improvements, the test objectives for future trials will evolve from what was proposed at the start of this project, encompassing increasing levels of automation.

Outside of the testing results, Skyports believes there are three key areas that require attention to allow commercial offshore operations to commence in the coming years. The beliefs are derived from operational experience, dealing with regulators, and engaging with airspace stakeholders. We have broken down these areas in the following sections, explaining the background to the improvements and how these shall improve the services we could provide to offshore companies in future.

- Increased Autonomy - The Path to Autonomy
- One to Many Drone operations
- Unsegregated BVLOS Flights using Transponder Mandatory Zones

Increased Autonomy - The Path to Autonomy

Autonomy is defined as the ability of a system to operate independently, free from external control or influence. However, to comply with safety requirements outlined in UK regulatory guidance material, such as CAP722, all uncrewed aircraft systems (UAS) must operate deterministically, meaning their responses to inputs are pre-designed and predictable.

Level 1 – Assisted Automation

CAA Definition

Lowest level of automation, systems which have been automated up to this level are used to support the remote pilot in performing the specified function.

Automated Functions

Some examples of Level 1 automated functions include:

- Automatic take-off.
- Automatic landing.
- Self-stabilising.

Level of Human Interaction

Human still required to manually control nearly all aspects of the aircraft and activate the automated functions.

Example Mission using Assisted Automation

Aerial photographer lining up shots manually. The photographer has control over the aircraft position at all times, as well as the camera angle and manually triggers the shutter using a button on the remote control.

Level 1 in an Offshore Environment

Level 1 automation UAs can be used to carry out one-off inspections of components on offshore assets. Using a UA could facilitate the inspection of components in hard-to-reach places and remove the need for a human to enter a high-risk environment. Assisted automation would help keep the aircraft stable in windy conditions, while the pilot focuses on angling the camera.

The limited automation of the aircraft places a high workload on the pilot, requiring them to position the aircraft suitably for the inspection, monitor environmental conditions and navigate around obstacles. This degree of pilot interaction makes Level 1 aircraft unsuitable for repeated inspection routines. Level 1 autonomy UA's are available to use in the offshore space today.

Level 2 – Partial Automation

CAA Definition

The level of automation increases to the point where a system may take over a particular function to relieve the remote pilot workload and allow focus on other tasks. Control and monitoring are shared between the remote pilot and the system, the interactions must be well understood by the human managing the operational tasks.

Automated Functions

All features in Level 1, in addition to:

- Following a pre-planned waypoint route.
- Detecting obstacles in the path of the aircraft, and coming to a stop to avoid a collision
- Carrying out set pre-planned actions, e.g. dropping a payload or taking a photo.
- Return to home functionality.

Level of Human Interaction

- Human required to initiate take-off, waypoint navigation and landing features.
- Human to monitor the aircraft health and external environment.
- Human to take manual control if required, e.g. safety compromised, technical malfunction, deconflict with other airspace users.

Example Mission using Partial Automation

A surveyor carrying out a roof inspection pre-plans a waypoint route over the inspection area. The path and altitude are determined by the resolution of data they require.

The aircraft follows the set waypoints automatically and takes photos at pre-set intervals. The path flown by the drone is more accurate than the operator could achieve manually, and the pre-set photo interval ensures that photo overlap and coverage are sufficient and accurate. This also allows the operator to focus less on controlling the position and attitude of the aircraft, and more on the quality of the photos and data being captured, resulting in a higher quality output.

During the mission, sensors on the aircraft detect a chimney that the operator did not consider when planning the route. The UA stops and hovers in place automatically to avoid collision. The operator activates the Return to Home function to recover the aircraft.

Level 2 in an Offshore Environment

Level 2 autonomy would be required to increase the scalability of operations on offshore assets. For example, a routine inspection of an asset could be pre-programmed and run daily. The UA's ability to navigate autonomously according to the pre-planned route would allow the pilot to focus on the inspection photos rather than positioning the aircraft.

Furthermore, inspections would be comparable as the flight paths would be identical each day.

A Level 2 UA would not, however, be able to complete its mission if external conditions change. For example, if a crane changes position and enters the inspection flight path, the UA may be able to detect the obstacle and halt to avoid a collision, however, it would not be able to continue its mission without interaction and repositioning from the pilot. Level 2 UA systems are available to use in the offshore space today.

Level 3 – Supervised Automation

CAA Definition

The capability of the automated system is expanded to handle the monitoring and response to changes in the environment. The key difference between this level of automation and lower levels is that the human is supervising the outcomes and intervening when required to manage the safety of the operation.

Automated Functions

All features in Level 2, in addition to:

- Ability to complete mission from take-off to landing with no pilot interaction.
- Ability to handle a wider range of scenarios autonomously e.g. technical faults, deconflicting with other airspace users.
- More advanced on-board decision-making based on a wider array of sensors, giving the aircraft a more comprehensive view of its state, e.g:
  - Aircraft performance and component health.
  - External environment, including weather conditions.
  - Other airspace users through electronic conspicuity or radar.
- This allows the aircraft to handle a wider range of scenarios autonomously, such as technical faults, navigating around obstacles and deconflicting with other airspace users.

Level of Human Interaction

Human is required to monitor aircraft performance during the flight and observe any automated actions the UA makes.

The pilot must also monitor events that the aircraft cannot deal with, depending on its equipage level. This may include interactions with air traffic control, and other aircraft without electronic conspicuity that the UA can detect.

The pilot is required to intervene by issuing a high-level command to the aircraft if safety is compromised. Commands may be “Return to base”, “Hold position”, “Navigate to alternative landing site”, but the pilot cannot manually control the position and attitude of the aircraft.

As the level of interaction with the aircraft during normal operations is minimal, "One-to-Many" operations become feasible, with a single pilot controlling multiple aircraft.

Level 3 in an Offshore Environment

Level 3 autonomy UAs would open up further scalability and use cases in an offshore environment. For example, deliveries to offshore assets could be implemented due to the aircraft's ability to respond to a greater number of scenarios, allowing it to navigate complex inter-asset conditions such as variable weather, other airspace users (e.g. HEMS) and service operation vessels without pilot interaction.

For this type of operation to be successful, it is essential for the pilot to have an understanding of their aircraft's capabilities and limitations, knowing when to intervene.

A delivery scenario with a Level 3 autonomy UA could proceed as follows:

One pilot is controlling five UAs delivering supplies to offshore assets. Take-off, navigation, landing, and delivery are fully autonomous and requires minimal interaction from the pilot.

A helicopter emergency medical service (HEMS) aircraft approaches the flight path of one UA without warning. The UA detects the aircraft using an onboard ADS-B sensor, and enters a hold manoeuvre, allowing the HEMS to cross its flight path safely.

The pilot contacts the HEMS and commands the UA to divert to a secondary offshore landing point due to continued HEMS operations around the destination landing site.

Level 3 UA systems are beginning to develop into the offshore space today. The challenging obstacle to progress towards frequent and reliable level 3 autonomy UA operations in the offshore space is RPAS regulation and policy.

Level 4 – High Automation

CAA Definition

At a high automation level, controlling the aircraft and monitoring the external/internal environment is entirely automated with no human oversight. The remote pilot does not receive flight information, instead, the remote pilot receives operational information of interest to ensure the system is meeting operational objectives.

Automated Functions

All features in Level 3, in addition to:

- End-to-end completion of the mission.
- Deconfliction with other airspace users.
- Navigating around obstacles.
- Navigating around areas of out-of-limits meteorological conditions.
- Interactions with air traffic control.

- Execution of contingency procedures.

Level of Human Interaction

The human operator will oversee the operations of multiple aircraft. They do not monitor any flight information as all decision-making at the navigation level is handled onboard the aircraft. Instead, operational information is fed back, e.g. mission status, time to complete the mission, and cancelled missions to ensure that operational objectives are being met.

The human operator may be able to issue very high-level emergency commands as a backup in the case of exceptional scenarios arising.

Level 4 in an Offshore Environment

Level 4 operations would continue to increase scalability by reducing human interaction, and safety by removing human factors.

More advanced sensors surveying the environment allow multiple UAs to simultaneously carry out automated inspections under the supervision of a single human controller, navigating a changing environment e.g. the movement of cranes, people or onboard structures, and replan its route to achieve its mission objectives. The remote pilot would only issue operational commands e.g. which areas should be inspected, and does not issue any flight commands.

Inter-asset delivery operations would scale further as human interaction is reduced. At this level of automation UAs shall be able to integrate safely with manned aviation, with detect and avoid (DAA) capabilities on par with those of crewed aircraft. The UAs would be able to navigate different airspace structures and communicate with ATC to request clearance without human intervention.

Level 4 autonomy UA systems are not found in today's offshore space. One of the main challenges to achieving Level 4 autonomy is having a sufficient level of data integrity for safe operations. As all flight decisions are made on-board, high levels of data integrity are required to ensure that the data is representative of the actual flight environment, and that the aircraft can therefore make the best decisions according to its situation.

Furthermore, any external data sources, e.g. weather data or ground-based radar data, would need to be to the same level of assurance as the UA.

This will likely require the use of certified sensors and processing software, adding significant cost to components and aircraft. Additionally, standards to be certified against have not yet been developed.

Level 5 – Full Automation

CAA Definition

At full automation there is no human involvement in the operation and human interaction is limited to providing high-level operational directives and observing resulting outcomes. No human intervention is possible as the operation outcomes are entirely within the scope of the machine.

Automated Functions

All features in Level 4, in addition to:

- Scheduling.
- Route planning.

Level of Human Interaction

High level operational instructions only.

Level 5 in an Offshore Environment

Full autonomy of Level 5 UAs would allow the human operator to be completely focused on the output of operations, e.g. inspection photos or delivery metrics.

A Level 5 inspection operation may involve the operator setting up a schedule for inspections of specific components. The UA would autonomously plan the route, and execute the mission, with the operator getting a notification when the flight is complete and photos ready for reviewing. The operator does not need to understand how to plan the route or control any aspect of the UA's flight.

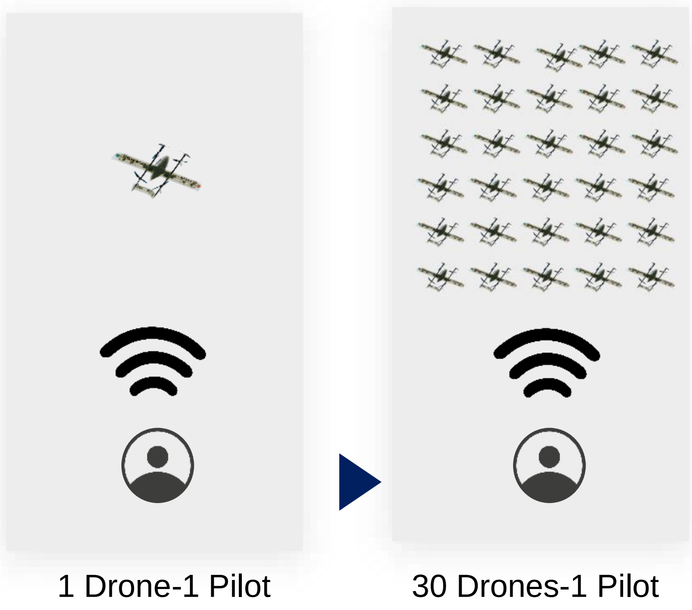
A Level 5 delivery operation would comprise of a human operator (not remote pilot) commanding a network of UAs between multiple offshore assets. High level commands are issued, for example prioritising specific deliveries, and the aircraft execute flights accordingly. The aircraft can communicate with ATC, requesting clearance to enter specific regions of airspace if required. Operational data is fed back to the pilot, e.g. percentage on-time deliveries, as opposed to any flight information.

Similarly, to level 4 there are no level 5 autonomy UA operations occurring in the offshore space. One of key challenges facing level 5 autonomous UAs is the lack of regulation covering pilotless operations. CAA regulations currently require one person to be responsible for an aerial operation, i.e. the remote pilot, and regulations will have to be developed to enable fully autonomous UAs.

The problem with pilotless autonomous operations is in how to regulate indeterministic autonomy. It is very difficult to show reliability and assure safety 100% of the time in unseen environments. Moreover, determining accountability for an erroneous decision made by an autonomous system remains undefined and is likely to require a substantial amount of time to resolve.

One to Many Drone Operations

The current regulatory environment that UAS are operating in fundamentally requires that all UAS must be under the command and responsibility of a remote pilot. Despite this, depending on the levels of autonomy found onboard the system, that same remote pilot can simultaneously oversee the command of multiple aircraft at the same time. As discussed in the levels of autonomy sections, by advancing DAA and UTM systems, the pilot can start moving away from acting in the loop to on the loop and eventually a symbiotic process involving a human and machine. In the loop meaning controlling the aircraft with direct commands with little assistance, on the loop where the aircraft completes the mission independently and the human monitors and a symbiotic process refers to a cooperative relationship between human and machine where both entities work together to achieve a common goal. As the technology moves further towards a human machine symbiotic relationship, more aircraft can be overseen by a single remote pilot. This will bring significant benefits commercially as hourly costs will reduce as less trained operators (in this case pilots) are in the loop.



The TMZ Blueprint

One of the key challenges in realising sustainable offshore BVLOS operations is the need to utilise shared airspace, with drone operations working alongside, rather than segregated from, other airspace users. In offshore environments this can include helicopter traffic, but also the offshore infrastructure and assets. Some of the approaches that have been adopted elsewhere, e.g., the use of segregated airspace would simply not be viable for offshore operations and are not scalable. To address this Skyports believe an integrated offshore airspace structure needs to be created in the form of a Transponder Mandatory Zone (TMZ) in order to create a safe airspace structure.

A transponder mandatory zone (TMZ) is an airspace structure where the use of a functioning transponder is required for all aircraft operating within that zone. A transponder is an electronic device that transmits an aircraft's identification and altitude to air traffic control (ATC) radar systems. The purpose of establishing a TMZ is to enhance the surveillance and tracking of aircraft within a specific airspace area. By requiring aircraft to have a functioning transponder, ATC can receive accurate and up-to-date information about the aircraft's position, altitude, and identification, which helps maintain safe separation between aircraft and improves overall airspace management.

Whilst novel in the context of drone usage, this approach leverages existing regulatory policy and frameworks to support the safety case development for UAS BVLOS operations. Both the UK and EU airspace regulators recognise the use of TMZs, and the UK regulator – the Civil Aviation Authority (CAA) – has developed guidance, recommending a TMZ is created *'when the establishment of a more restrictive classification of airspace is not warranted but additional measures to enhance flight safety are required'*. The guidance goes on to outline that the objective of the TMZ is to *'enhance the conspicuity of aircraft operating within, or in the vicinity of, complex, or otherwise busy airspace when the establishment of a more restrictive classification of airspace is not warranted, in order to maintain a balance between safe, efficient operations and fair, equitable access for all airspace users*.' The TMZ concept is also in alignment with the recently updated CAA 'modernised lower airspace strategy', shown in the Figure 15 below. There is a well-established airspace change and review process to support TMZ applications, and today, TMZs are used in locations such as airspace surrounding airports which experience high volumes of, or complex interfaces between, aircraft. They have also been successfully deployed over a number of years in other locations, including for example as mitigation for radar performance issues to maintain safe and secure airspace operations in the vicinity of the wind farms.

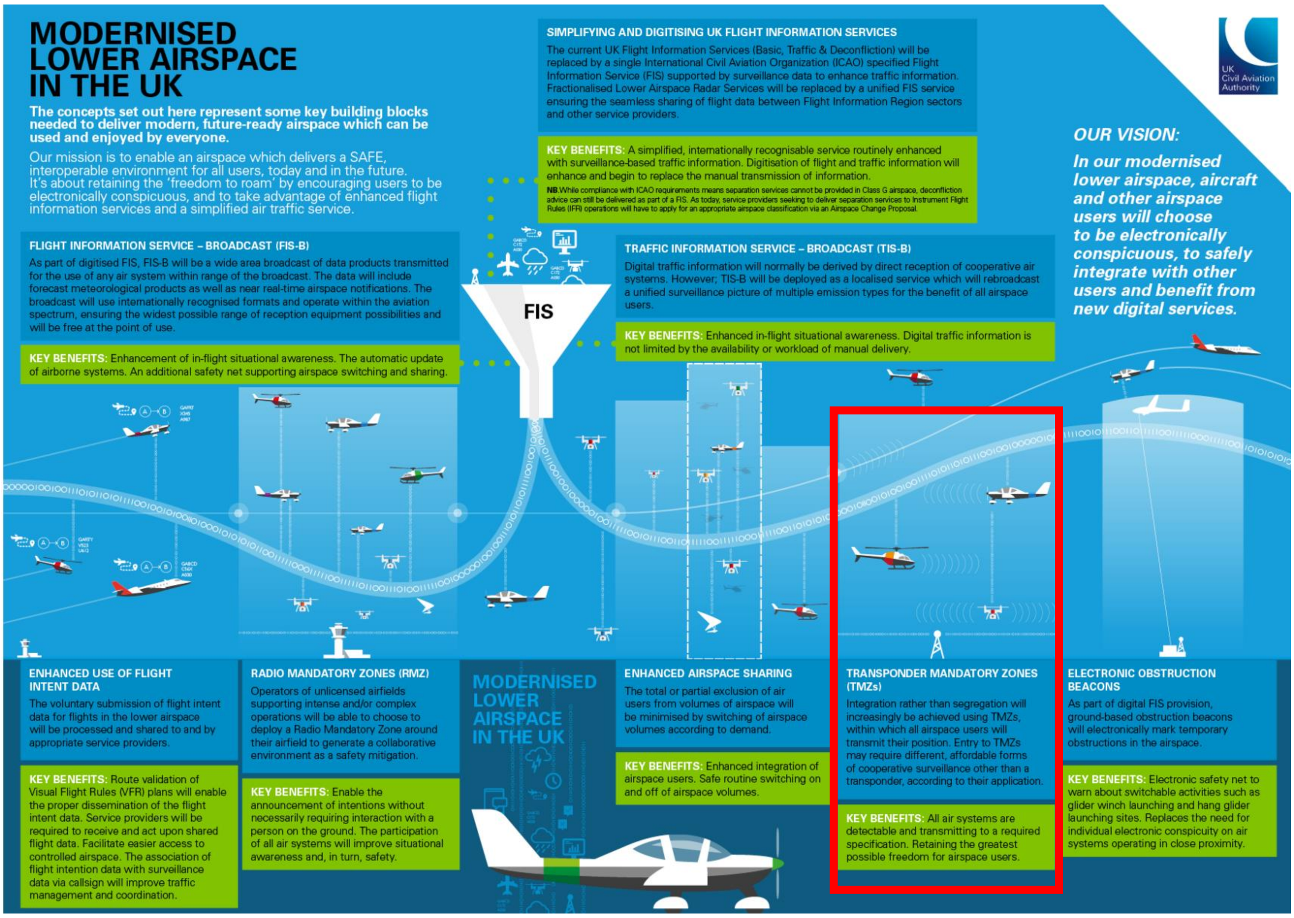


Figure 12. Modernised Lower Airspace in the UK, Source CAP1711[1]

At the time of writing BVLOS drone operations within a TMZ is a work in progress and hasn't been demonstrated outside of highly controlled test environment within a permanent danger area. Skyports are currently working with the UK and EU regulatory authorities to establish safe and secure TMZ's. This work has gained significant attention within the industry and in mid-2022, as part of a UK Government-funded CAA Innovation Sandbox project, Skyports established Project PROTEUS and are now working directly with the CAA and a partner company Air Navigation Solutions (ANSL), to create an operational safety case for BVLOS operations within a TMZ. Skyports hopes to prove the feasibility of such an approach and working alongside regulatory authorities and other stakeholders to establish the UK's first low-level BVLOS TMZ on the West Coast of Scotland as part of a pathway to full commercial operation offshore or onshore. Once established the BVLOS TMZ will enable crewed and uncrewed aircraft to operate together in the same airspace. There will be no impact on aircraft already carrying transponder technology, and users who do not wish to be conspicuous will be able to request access to the airspace structure.

The project is designed to sit within UK regulatory policy whilst using a modular service approach to generate wider expansion and use of the TMZ model and act as an enabler for the well-established U-space framework. Figure 16 demonstrates our proposed TMZ structure for the PROTEUS project with guiding principles and design criteria.

Figure 13: Skyports TMZ Project overview

The TMZ structure ensures that all airspace users are actively 'announcing' their position, however robust services and procedures, both at a tactical and strategic level, are required to enable an uncrewed aircraft (UA) operator working in a BVLOS environment to detect and avoid other aircraft. Firstly, in order to maintain separation, flights can be planned in order to avoid known aircraft routes and basic ground-based surveillance mechanisms can be employed to add further protections. At the next level - conflict avoidance – system-based algorithms can be used to track flight paths and identify potential conflict scenarios, alerting the UA operator in order that evasive action can be taken. At the highest level, automated onboard collision avoidance software can be utilised enabling the uncrewed vehicle to itself take collision avoidance decisions. Airspace modelling and design also play a crucial role in building up this multi-layered approach to safe operations.

The key requirement for BVLOS operations in a TMZ relates to situational awareness. Situational awareness is a long-standing aviation concept that originally applied to crewed flight. Put simply, in order to fly safely and reduce risks associated with human error, pilots need to maintain an overall awareness of what is going on around them, in terms of the aircraft, the airspace, other air traffic and related factors at all times. Pilots use highly developed situational awareness skills to keep passengers, ground crew, themselves, their craft and the payload safe, and this approach is replicated in uncrewed situations through a combination of people, processes and technology. At the heart of this approach is a Situational Awareness Platform.

Figure 17 introduces the different components of a suggested Situational Awareness platform, which effectively assimilates data from multiple sources, including ground sensing hardware, UAS telemetry and airspace management services, creating a single source of truth that provides a complete picture to enable in-flight decision-making in complex offshore BVLOS operations in TMZ airspace. At the time of writing Skyports works with a partner, OneSky to develop the end-to-end solution, which has been implemented globally into its live operations.

Figure 14: Components of a situational awareness platform to enable BVLOS operations within a TMZ

A successful situational awareness platform should enable: the submission of flight plans that can be deconflicted pre-flight, continuous monitoring of aircraft separation in flight, alerting in the event of a loss of separation, and a suite of post flight tools to support quality assurance audits.

Future Skyports Work

Going forward, Skyports aims to continue the progress made under the SORD project by expanding the testing regime and investigating how drones can be safely integrated into offshore airspace. To do so, Skyports envisages the following process to reach fully commercial offshore drone operations in the North Sea.

Phase 1 – BVLOS Drone Operations Demonstrations

This is the work completed under the SORD project, which demonstrated a highly automated, state of the art offshore UAS conducting a scenario based testing regime, mimicking that of real-life offshore requirements. This was completed in February 2022.

Phase 2 – Design and test a TMZ blueprint

In completing this phase, Skyports aims to achieve 3 UK firsts to solve the major blockers to commercial offshore operations:

1. Design and develop a standard audit system which validates that aircraft are capable of providing safe offshore operations. This would build on the requirements and objectives established through the first phase, as listed earlier in this report.
2. Design an airspace construct that, if fully implemented, would allow drones to complete permanent offshore operations in the UK and EU.
3. Demonstrate the procedures developed within the design airspace construct through 3 to 4 weeks of trial flying in a representative offshore environment, such as ship-to-shore operations.

The aim would be to complete this work over the course of 6 months, starting in Q2 2023.

Phase 3: Pilot Commercial Operations

This would aim to put the results and learnings from Phases 1 and 2 into a temporary commercial operation in the UK and EU, with high-integrity and high Technology Readiness Level (TRL) aircraft performing 6 months of scheduled or on-demand drone operations within a TMZ. These operations would also look to demonstrate higher payload deliveries and a certifiable Detect and Avoid system.

The aim is to start this work in Q2 2024, with the work taking 12-18 months.

Phase 4: Full Commercial Scale

By Q2 2025, Skyports aims to scale to commercially viable everyday drone deliveries in the UK and EU, with one-to-many operations in place to bring cost savings to offshore customers and improving the utilisation of Skyports staff. During this phase Skyports would offer both delivery and surveillance / SAR services to offshore customers, with highly autonomous drones providing services to even the most difficult to read offshore assets. The greatest challenge to achieve this is the required changes to current regulations. To achieve these changes in the required timescale, Skyports is working closely with the CAA to develop the safety criteria and acceptable risk levels of UA’s operating in unsegregated airspace within a TMZ under a new airspace structure called a TRA. A policy concept has been published recently when writing this paper called CAP2533, Airspace Requirements for the Integration of Beyond Visual Line of Sight (BVLOS) Unmanned Aircraft.

The phases outlined above are summarised in Figure 18 below.

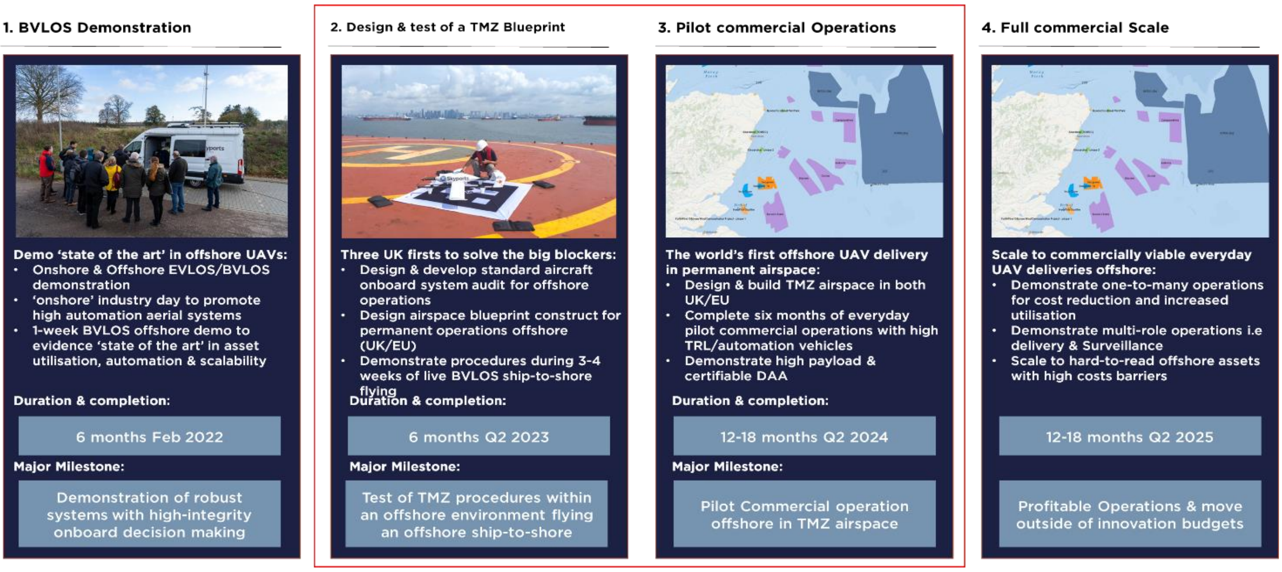


Figure 15: The future evolution of Skyports' offshore drone operations