Final report

1. Project details

Project title	ADD2Wind
File no.	64020-2009
Name of the funding scheme	EUDP
Project managing company / institution	Aalborg University
CVR number (central business register)	
Project partners	Loxar, European Merchandise Group, Aeroscout, Ørsted, Siemens Gamesa, Vestas and Vattenfall.
Submission date	2020-0910 February 2026

2. Summary

Project summary

The purpose of the project:

This project develops and demonstrates the feasibility of an air cargo delivery service from shore to offshore wind turbines using unmanned helicopter aircraft. Packages up to 40 kg containing parts for maintenance can be delivered directly to the turbine nacelle offshore in most weather conditions and with the wind turbine still spinning.

Results, conclusions and perspective

- Demonstrated airborne delivery to an offshore-type wind turbine using unmanned helicopter drones.
- Developed and integrated a payload winch, delivery bags, and sensor systems for safe and precise delivery.
- Obtained multiple BVLOS flight authorizations in Denmark and Switzerland, including for offshore operations.
- Conducted operational analysis and business case studies with industry stakeholders.
- Gained insight into the regulatory process, highlighting key barriers to commercial drone operations.

The results show that air cargo delivery to offshore wind turbines is technically feasible and operationally promising, especially for ad hoc maintenance deliveries. Although offshore flights were not completed within

the project, key system capabilities were validated and readiness for real-world deployment was significantly advanced.

Going forward, the results will be shared with relevant companies to enable further development and commercialization. The technology is expected to improve turbine uptime, reduce vessel dependency, and enhance crew safety, ultimately lowering maintenance costs in the offshore wind sector.

Projektresumé

Formålet med projektet:

Dette projekt udvikler og demonstrerer gennemførligheden af pakkeleverancer fra land til offshore vindmøller ved hjælp af ubemandede helikopterdroner. Pakker op til 40 kg indeholdende dele til vedligeholdelse kan leveres direkte til nacellen offshore under de fleste vejrforhold og med vindmøllen stadig i gang.

Resultater, konklusioner og perspektiv

- Demonstrerede luftbåren levering til en offshore-type vindmølle med ubemandede helikopterdroner.
- Udviklede og integrerede et hejssystem, leveringsposer og sensorsystemer til sikker og præcis levering.
- Opnåede flere BVLOS-flyvetilladelser i Danmark og Schweiz, herunder til offshoreoperationer.
- Gennemførte driftsanalyse og forretningscase-studier med industripartnere.
- Opnåede værdifuld indsigt i godkendelsesprocessen og identificerede centrale barrierer for kommerciel dronebrug.

Projektet har vist, at luftbåren levering af reservedele til offshore vindmøller er teknisk mulig og operationelt lovende, særligt til ad hoc vedligeholdelsesopgaver. Selvom offshoreflyvninger ikke blev gennemført i projektperioden, blev centrale systemfunktioner valideret, og teknologien bragt tættere på anvendelse i praksis.

Resultaterne vil blive delt med relevante virksomheder for at fremme videreudvikling og kommercialisering. Teknologien forventes at kunne forbedre møllers oppetid, mindske afhængighed af fartøjer og øge sikkerheden for mandskab, og dermed reducere vedligeholdelsesomkostningerne i offshore vindsektoren.

3. Project objectives

The ADD2wind project has five main objectives, focusing on developing and demonstrating an airborne package delivery service to offshore wind turbines using unmanned helicopter drones. The project aims to reduce maintenance time, increase planning flexibility, decrease dependency on weather conditions, and improve crew safety, which collectively reduces maintenance costs.

1. **Economic Feasibility**: Conduct an operational analysis of an unmanned air cargo service to offshore wind turbines, including flight operations, revenue models, logistics, and service demand.

2. **Technical Viability**: Demonstrate that the B330 aircraft with the right sensors and payload mechanisms can safely and repeatedly operate over long distances and close to wind turbines, delivering packages to the nacelle.

3. **BVLOS Permission**: Obtain permission for operations beyond visual line-of-sight (BVLOS) according to new EU regulations, aiming to reach TRL 9.

4. **Flight Delivery Tests**: Conduct multiple flights to Anholt Wind Farm, Horns Rev 3, and Kriegers Flak in various weather conditions, delivering multiple payloads.
5. **Operational Plan Development**: Develop an operational plan for integrating air cargo service, mitigating perceived risks through a joint manned/unmanned concept and visual documentation of successful flight operations.

These objectives aim to demonstrate that the concept is technically, commercially, and legally feasible. In the project, we were able to argue that economic feasibility is realistic, although we did not manage to completely determine this point. The technical viability was demonstrated through integration of both sensors, computers, winch and hook on the aircraft and demonstrated through flight test. Also, the interaction with a turbine was demonstrated. We also obtained BVLOS permission in Denmark and in Switzerland, including for offshore flights. We also conducted delivery flights to a wind turbine, but unfortunately not offshore. For the operational plan development, we realized during the project, that this is somewhat more complex and difficult than expected due to the diversity in the offshore industry.

4. Project implementation

The project had four main components; business case of spare parts delivery (WP2 and 10), technological integration (WP3 and 4), regulatory integration (WP8), and test flights (WP5, 6, 7, and 9.

The business case was studied from two angles, from the perspective of the wind farm owner/operator and from the perspective of the drone service provider. For the former, Siemens conducted a study on the actual need by tracking components deliveries over a period of time. This was done relatively late in the project, and did not depend on any other results from the project. For the latter, Loxar conducted a series of interviews and discussions with a number of stakeholders in the industry. This was done early in the project. It was the intention to continue with a more tangible development of a commercial service once flight testing had demonstrated the potential. However, due to the exceedingly long processing time for flight authorizations, the project did not evolve to a point where this was possible.

For the technological integration, the necessary computer and sensor unit was developed and integrated throughout the project along with the winch and hook. A significant part of the effort went into this development. The payload bags were also developed throughout the project, with a couple of different versions along the way. The technological integration went as planned.

The regulatory integration has been very challenging and a continuous source of distress. This is almost solely due to the exceedingly slow processing of applications at the aviation authorities. The regulation is reasonable clear and uniform in Europe, and the project consortium has a good and detailed knowledge on this topic. Therefore, writing applications, although requiring a significant effort, has not been a major challenge. A total of 5 authorizations were applied for (and granted). They are listed under chapter 5, WP8. It is noteworthy that the first authorization took more than a year and a half, even though the authority only billed the project 10 working hours.

This has had a significant impact on the project. The delays meant that some work could not be done for long periods of time, that the people employed on the project had their employment terminate before test flights could be conducted, that continued costs such as insurance exceeded what we originally planned for. Consequently, some WPs and milestone simply could not be achieved as planned.

It should be noted that this project is not singular in this respect. The slow pace of aviation authorities is notorious throughout Europe. There are also huge differences between nations. For instance, FOCA in Switzerland, although not fast by any means, it still about 3 times faster than the Danish authority.

The test flights hinge directly on authorizations to operate. Consequently, we have not been able, within the time frame and resources of the project, to conduct all flight tests and demonstrations. We did achieve to deliver a payload to an actual offshore-type turbine, although not actually located offshore. We also demonstrated the feasibility of the technological integration and the ability to control the aircraft during the physical interaction with the turbine.

We did not achieve any offshore flights.

5. Project results

WP1: Project Management and Dissemination

The project management was carried out by the project lead partner, Aalborg University. As an external service, Energy Cluster Denmark was hired to take care of some facilitation processes, economic controlling and dissemination of the results.

Throughout the project, the project partner had monthly status meetings and for most periods, also longer physical meetings every three months. Due to the distance between the participating persons, the frequent online meetings added great value to the project coordination.

In general, there was great progress in the beginning of the project with high effort and frequent deliveries. During the first half of the project, we developed working prototypes of the hoist and hook system, the delivery bag and the flight systems. During this period, we also handed in the application for the BVLOS flights. Due to very long and quite inscrutable process at the Danish air traffic authorities, the project was derailed in the second half. This resulted in multiple changes to the time plan and budget, and ultimately also cancellation of several milestones.

Project Progress and Challenges

The ADD2wind project has made significant progress but has also faced some challenges. Test flights were planned and everything was ready, but unfortunately, liability insurance was not obtained, which prevented the flights. On the positive side, flight permission was obtained from the Danish Transport Authority, which is an important step forward.

In January 2025, test flights were planned for week 5. Preparations start on Monday, and flights are scheduled to take place from Tuesday to Thursday, when the turbine is available. Peder has sent the bags, and Jakob has been hired for one week in January. There will be a secondary drone for footage, and Markus is preparing the drone for winter flights. A meeting with ECD board members was also mentioned.

In October 2024, a change request was submitted, requesting an extension of the project's end date to March 31, 2025. The change was necessary due to delays with offshore flights to Anholt, Kriegers Flak, and Horns Rev 3. It was decided to abandon offshore flights and instead focus on test flights to an onshore turbine of the offshore type in Tim. The project will also use extra time to disseminate the results to relevant stakeholders in the industry.

In August 2024, a change request was submitted, describing the necessity of obtaining flight permission for offshore flights. The application was in the final phase of approval with the Swiss Transport Authority, with an expected response in mid-October. Subsequently, the Danish authorities would formally approve the flights, which would take a few weeks. Flights to Anholt were planned for early December. Due to the long processing time, it was not possible to conduct flights at Horns Rev 3 or Kriegers Flak, and the associated milestones were deleted. The project's end date was moved to December 2024.

In June 2024, an annual report was submitted, describing the project's purpose and activities over the past 12 months. The project has worked on developing and demonstrating the feasibility of airborne package delivery from land to offshore wind turbines using unmanned helicopter drones. Test flights and drop tests were conducted, and several prototypes of delivery bags were made. There has been sporadic contact with Anholt Offshore Wind Farm, and analyses of potential flights to Horns Rev 3 and Kriegers Flak have been conducted. Flight permission has been a major challenge, but the final permission is expected to be obtained in September or October.

In June 2024, another change request was submitted, requesting to extend the project's end date to December 31, 2024. This change was necessary because the application for flight permission for the remaining flights was sent to the Danish Transport Authority in February, and it is expected to take up to six months to obtain the permission. Additionally, changing contact persons at Siemens Gamesa delayed the delivery of CM7 (elementary case study), which was also moved.

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The budget remained largely unchanged, even though offshore flights were abandoned. Funds were allocated for travel in 2025 to visit companies in Denmark, the Netherlands, Germany, and the UK. Flight permissions for offshore flights were almost obtained, but it was decided to continue the process to inspire and help others with similar needs.

Press:

The ADD2wind project has received significant media attention across various platforms. Articles have been published on Ingeniøren.dk, Tekniskfokus.dk, Dkvindkraft.dk, Pro.ing.dk, Metal-Supply.dk, Altomteknik.dk, Energy-Supply.dk, Energiwatch.dk, and more. These articles highlight the project's innovative approach to using helicopter drones for delivering spare parts to offshore wind turbines. The coverage emphasizes the successful test deliveries, the potential for drones in the energy sector, and the collaboration between major industry players. Additionally, the project has been featured in print media, including Ingeniøren and Søfart, further showcasing the project's milestones and technological advancements. The widespread media coverage underscores the project's significance and its potential impact on the renewable energy industry.

Digital:

- Ingeniøren.dk: Helikopter-drone skal flyve reservedele ud til havmøller
- Ingeniøren.dk: Helicopter to fly spare parts out to offshore wind turbines
- Tekniskfokus.dk: Verdens første testleverance understreger droners potentiale
- Dkvindkraft.dk: The world's first test delivery underlines the great potential of drones in the energy sector
- Dkvindkraft.dk: Verdens første testleverance understreger droners potentiale i energisektoren
- Pro.ing.dk/Gridtech: Test viser positive takter fro droneleverancer til vindmøller
- Metal-Supply.dk: Se videoen: Droneleverancer til vindmøller runder milepæl
- Altomteknik.dk: Verdens første testleverance understreger droners potentiale i vind-industrien
- Energy-Supply.dk: Se videoen: Droneleverancer til energisektoren runder milepæl
- Energiwatch.dk: Testflyvninger viser potentiale for droneleverancer til vindmøller
- Energywatch.com: Danish firm to build flying crane for wind turbine installation
- Energiwatch.dk: Nordjyder vil bygge flyvende kran til vindmøller
- MesterTidende.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- ElectronicSupply.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Fremtidenslogistik.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Jernindustri.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Metal-Supply.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Soefart.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Energy-Supply.dk: Droner transporterer mølledele op til 80 kilometer fra kysten
- Energywatch.com: Four wind giants team up to haul spare parts via drone
- Energiwatch.dk: Fire vindkæmper vil sammen fragte reservedele med droner
- Es.aau.dk: Verdens første testleverance understreger droners store potentiale i vind-industrien

Print:

- Ingeniøren: OFFSHOREDRONER STORE PENGE AT SPARE VED UBEVANDET FRAGT PÅ HAVET Helikopterdrone skal flyve reservedele ud til havmøller (sektion 2, s. 6)
- Søfart: Droner transporterer mølledele op til 80 kilometer fra kysten (Sektion 1, s. 16)

WP2: Operations analysis

Business case

Objective

- Assess the potential benefits of implementing low-payload (30 kg) cargo drones in offshore operations.
- Transport and lift Tools/EQ from onshore warehouses and SOVs to offshore WTGs.

Hypothesis: Improved operational efficiency:

- For planned lifts, the vessel would spend less time at each turbine.
- For ad hoc lifts, the vessels would not have to deviate from their planning and avoid extra fuel consumption.

Types of cargo transfers

During annual service, cargo transfers can either be planned in advance or take place ad hoc. Cargo may include various items such as safety kits, troubleshooting kits, tools, spare parts, oils and other materials and personal bags. For planned cargo lifts, the vessel visits turbines according to a schedule to drop off cargo expected for annual service. The number of bags per single lift vary between 1-5, with a total mass ranging between 20-350 kg. For ad hoc cargo runs, the vessel is requested to revisit a turbine on the same working day to deliver additional/missing cargo. The number of bags per single lift vary between 1-4, with a total mass ranging between 2-30 kg.

Initial conclusions based on field data

An SGRE internal assessment was done to determine what portion of offshore cargo transfers currently carried out by crane can be replaced by drones, considering a payload of 30 kg. The figure below displays the mass distribution of single cargo lifts to the nacelle.

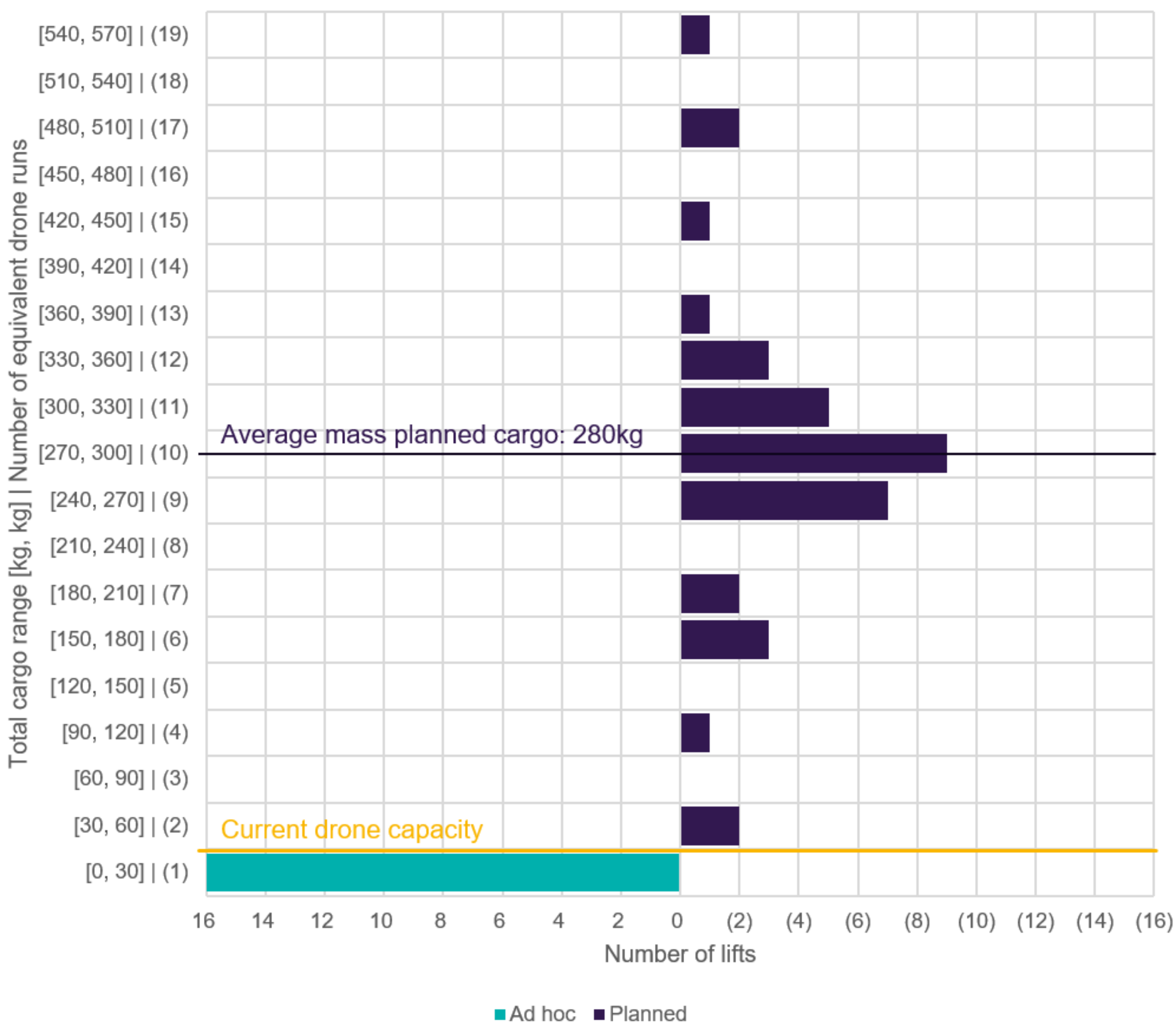


Figure 1 Mass distribution of lifts (via the Nacelle Service Crane)

The x-axis shows the number of occurrences for lifts within a certain mass range. The y-axis shows the total mass ranges (which is based on the drone's payload), and the equivalent drone runs needed to carry out the same lift. This is with the assumption that it is possible to split the cargo into ≤30 kg portions. Based on the data, the initial take-aways are:

- The average total mass of planned cargo lifts is approximately 280kg, while the ad hoc runs were all under 30kg.
- The average lifting time of planned cargo from the TP to the nacelle is approximately 21 minutes.
- **There is potential value for planned runs.** Some lifts were within the current drone's limits, so a portion of planned cargo packages could have been pre-delivered using drones. However, the mass of the individual (essential) cargo pieces was unknown so it is unclear which cargo pieces can only be lifted by crane due to its mass exceeding the drone's payload.
- **There is an immediate value for ad hoc runs.** All ad hoc cargo requests recorded were within the drone's capacity. This allows for a more opportunistic use of time; if required maintenance is observed that was not planned, it can perhaps be handled at that moment instead of having to plan a separate maintenance visit.

High-level business case to transport cargo ad hoc by drone vs CTV/SOV

The costs to charter a cargo drone depends on the contract conditions. To simplify the case, this section only makes a comparison between owning a drone and using maritime assets to transport cargo for ad hoc re-quests.

The estimated cost of drone ownership shown and comprised of, but not limited to, the following elements:

CAPEX	83k	• Drone • Infrastructure and compliance • Regulation compliance cost
OPEX	99k	• Maintenance • Pilot salary • Fleet management and IT • Insurance • Battery and electricity/fuel cost

To deliver cargo for ad hoc requests, CTVs and SOVs are estimated to have an annual additional cost range of 50-143k and 23-136k, respectively. It is assumed an additional cost since the vessel is generally already on charter for the site.

These costs are based on the need to transit from the cargo storage location to a WTG. The operation mainly consists of fuel cost considering assumptions about:

- Requests per day (assumed to be 1 in this case based on survey data)
- Return distances between pick-up and drop-off locations.
- Corresponding transit and push-on/DP duration
- Fuel consumption in relevant operating modes

- EUA price (currently only applicable to SOVs)

The previous sections compare the cost to transport cargo either by drone or by the onsite maritime asset. The value of being able to deliver ad hoc cargo will be improved turbine availability while preserving the O&M schedule, however, this is difficult to quantify. This can be estimated by carrying out a campaign to compare O&M operations with and without a drone available onsite.

Conclusion and Recommendations

- Based on initial assessment, cargo drones with a payload of 30kg are currently best suited for ad hoc transport of tools / EQ of smaller weight that are otherwise transported by CTVs or SOVs.
- Drones may not (yet) be suitable to be used as a complete alternative to service-crane-based lifting during annual service due to the restricted payload capacity, endurance and the large number of lifts required.
- **Use ad hoc tool runs as an entry point to the offshore market. Let users become familiar with the technology. Then, upgrade where possible to include planned cargo as a service.**

Key considerations

- As OWFs move farther offshore (>65km), they will be serviced from SOVs rather than CTVs.
- Larger-payload and drone fleet sizes are more feasible for transport from onshore warehouses than vessels due to available storage/deck space.
- As WTGs grow in size, the distance between them will increase as well. Therefore, the focus should be increasing endurance rather than payload capacity.
- Much larger-capacity drones with greater endurance needed to maximize amount of cargo pre-delivered to WTGs.
- Note about taking everything (even though you might not need it because *if* you do end up needing it then it's a lot of hassle to get it.

Impact analysis

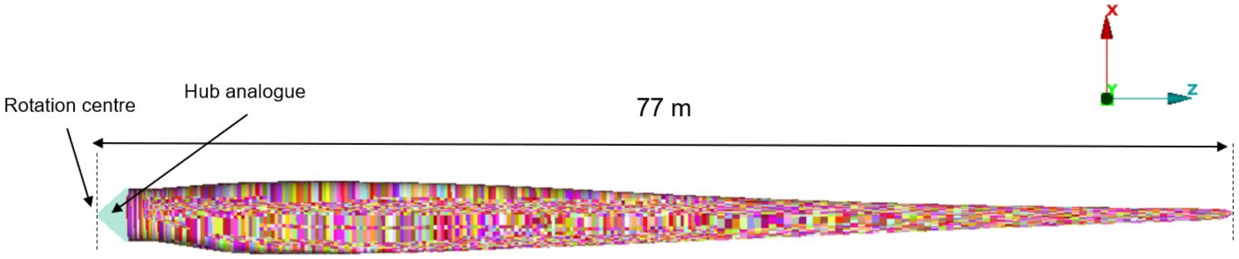
Background

During service of wind turbines in a offshore wind farm Siemens Gamesa Renewable Energy (SGRE) intend to use unmanned drones of an estimated size of 1.5*0.5 m with a total weight of ~110 kg. The drones will carry cargo to and from the roof of the wind turbine nacelle. This analysis conducted by FS Dynamics aims to determine potential damage caused by a drone impact to the leading edge of a wind turbine blade.

A transient impact analysis with a drone analogue impacting a B75 blade operated at 10.8 rpm will be presented in this report.

Blade Model Overview

The blade model used in the drone impact analysis is presented below. The blade and hub has a total mass of 28 500 kg and a moment of inertia about Y-axis of 2.37E7 kg*m2.

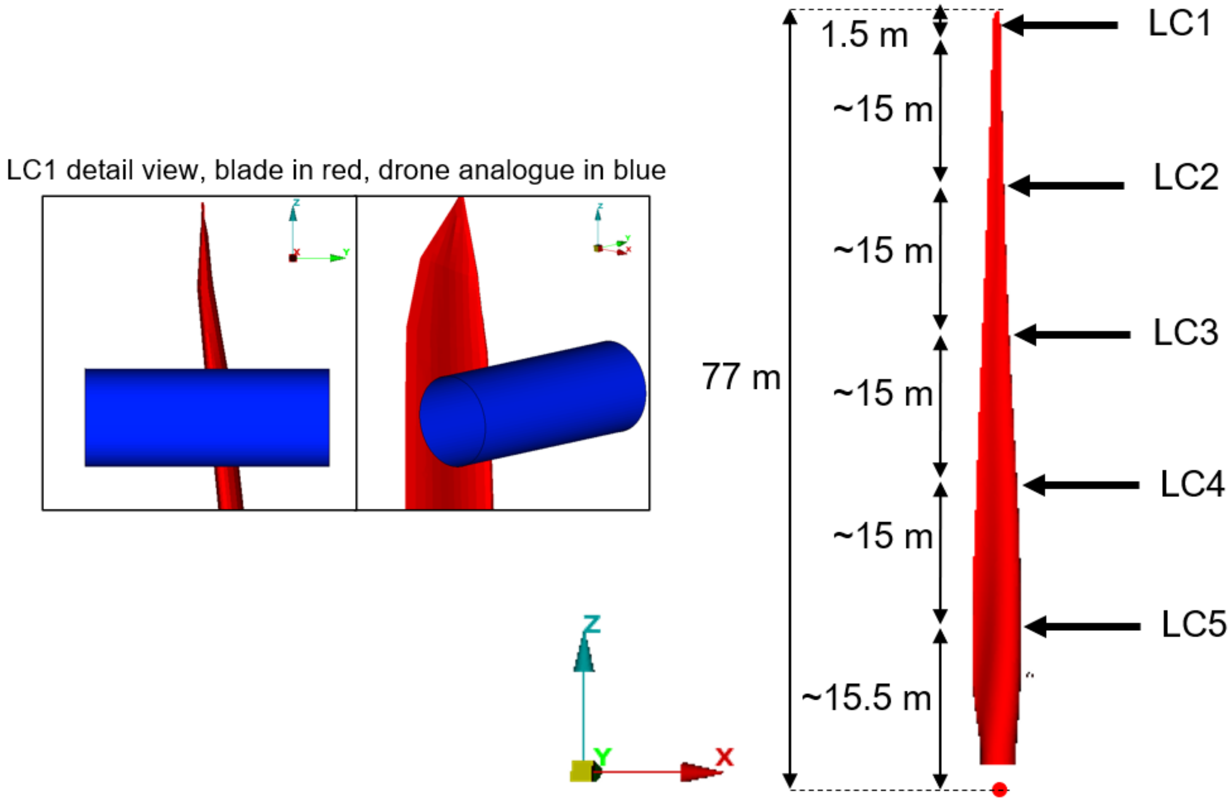


Load Cases

Five different impact positions were considered, called LC1 through LC5. The blade initial angular velocity is 10.8 rpm giving a tip velocity (77 m radius) of 87.1 m/s. The angular velocity is given by SGRE and is based on blade zone: 22, blade: B75, turbine: SWT-7.0-154 incl. PowerBoost functionality.

The approximate impact velocity for the different loadcases is hence:

LC5: 18 m/s, LC4: 35 m/s, LC3: 51 m/s, LC2: 68 m/s and LC1: 85 m/s



Results and Conclusions

Five load cases and impact positions with and without material failure criterion were analyzed. The result with and without material failure show basically the same final outcome.

For LC1 the impact will likely result in complete separation of the blade tip.

LC2 is the impact where the highest amount of both strain and kinetic energy is transferred to the drone. During the impact the outer skin is damaged and the drone is stopped by the inner spar. When the drone gets rapidly accelerated by the blade a shockwave is established in the blade with propagates towards the hub and tip. When the shockwave reaches the tip it starts deflecting quite a lot. The risk of separating the tip for loadcase 2 is however relatively small. The analysis without failure indicates risk for delamination in an approximate 2 m region but the area will be reduced due to softening effects from damage and failure.

LC3-LC4 show local fibre failure risk in a small region and delamination risk in a ~ 1 m region from the impact location. Low to no blade separation risk.

LC5 will likely result in very local fibre damage damage but the blade will not separate. Delamination in a ~ 0.5m region from the impact location is likely.

It is not possible to draw any definitive conclusions from the hub loads, the loads need to be evaluated by SGRE. The loads are however not much larger than the centrifugal loads also without considering wind loads. It is therefore unlikely that the drone impact will damage any other component than the blade itself.

	Reaction force [kN]				Reaction Moment [kNm]					
	Initial centrifugal load		Absolute max relative		Initial centrifugal load		Absolute max relative		Type of blade damage	Comment
Loadcase	Radial	Axial	Radial	Axial	Radial	Axial	Radial	Axial		
LC1			**78**	**74**			**416**	**0**	Complete blade tip detachment	
LC2			**215**	**244**			**1937**	**0**	Large penetration/ rupture of leading edge of blade	Stiff impact due to contact between drone and leading edge spare
LC3	**811**	**0**	**195**	**173**	**701**	**0**	**1148**	**0**	Large penetration/ rupture of leading edge of blade	Stiff impact due to contact between drone and leading edge spare
LC4			**329**	**203**			**974**	**0**	Large damage of leading edge of blade	
LC5			**221**	**180**			**770**	**0**	No element failure but likely local fibre damage and delamination	

WP3: Sensor and payload integration

This WP has two main components; the sensor integration and the payload winch integration.

Computer and Sensor Unit (CSU)

The Computer and Sensor Unit is a collection of sensors, PSU, OBC, and assembly mechanics. The unit was located in the front of the aircraft, seen here during the assembly of the flight campaign equipment.

The CSU consists of a main carbon plate placed horizontally, to which all other components are attached. To provide rigidity and shield the more vulnerable components, an aluminum frame covers a large part of the down-facing side of the carbon plate. The unit is attached to the aircraft with four hardpoints via two metal spring dampeners.

The CSU was designed to carry as many of the necessary sensors and computer equipment as possible. It has a mass of around 4.5 kg, slightly wider than the aircraft fuselage, and is placed some distance in front of the aircraft to establish a proper CoG. It is mounted on two metal spring dampeners. Accelerator measurements during the campaign in Nov 2022 in Switzerland indicated that vibrations are at an acceptable level but not as reduced as we had hoped.

A detailed list of CSU components and images are available in the Finale Report.

Winch and hook

From the beginning of the project, it was clear that it would be necessary to hoist or winch payloads down to the turbine. Specifically, placing the payload bag on the metal floor in the heli hoist. For this, a hoist was needed. The project was aiming for 25 kg payloads, so the winch design requirement was 50 kg payload. To achieve this, a relatively large Maxon motor was selected with an appropriate gearing that allowed a winch-up speed of 50 kg at 25 cm/s. The winch also has a locking mechanism that allowed for locking the payload in place during flight without excessive use of electric power.

A fully operational winch and hook was designed, implemented and used during flight operations. The details of this design along with images and renderings are presented in the Final Report.

Safety features

A major concern from both the aircraft operator and the wind turbine companies was the physical contact between the hook/payload and the heli hoist guard rails. It was considered a possibility that, regardless of design, the hook/payload may get stuck, leaving the aircraft tethered to the turbine. To mitigate this risk, some safety features were implemented and approved by the project group as appropriate and sufficient. The details of these are provided in the Final Report.

WP4: Payload delivery bags

Conceptual Design

Development of first concept drawing of bag and mold for the outside plastic bottom. Concept drawings from first to last attached.

3.2 Material Selection

Selection of optimal material and method to weld the bags to make them waterproof and with good strength-to-weight ratio, durability, and resistance to environmental factors.

Different foam types were selected and tested to find the best foam for shock absorption of the load in the bag.

Drop tests were performed and analyzed in collaboration with Aalborg University.

3.3 Prototype Development

From project start to finish, 6 concept drawings and several prototypes were created.

3.4. Testing and Validation

Prototypes were tested according to EN 1492-1 and ISO 21898. The prototypes were filled with plastic granules and a pressure test with 4:1 safety factor was performed for 6 hours.

Subsequently, a tensile test was performed where 70 pulls with 6:1 safety factor and finished with a pull to determine the breaking strength.

Aerodynamic testing was also conducted during the flight test.

3.5. Compliance and Approvals

The bags are designed, produced and tested in compliance to relevant parts of 1492-1 and ISO 21898 and certified by Dekra.

Dekra has witnessed the test and issued a certificate.

3.6. Implementation Strategy

The bags have been produced and will be marketed via catalog and website and sold for commercial use.

3.7. Conclusion

The bags were designed, produced and tested with satisfactory results.

Test flights where the drone delivered the bag to an onshore Narcelle were also conducted with success

The bags were aerodynamically stable during the flight test.

WP5: Anholt wind farm interaction

The first wind farm to be used for test flight was Anholt wind farm. To facilitate this, both Grenaa Port and the wind farm itself had to be ready for these operations. This included logistics, timing, facilitation by the port and wind farm crews, rescue service in case of water landings, air integration with any traffic in and around the wind farm, integration with the wind farm emergency response plan, and insurance requirements.

All of the above was carried out in 2020 to 2022 to the extent possible without knowing the actual dates and conditions for flights. A meeting with both wind farm crew and harbor master was conducted, agreeing on the operational conditions for both the port area to be used, the turbines to be used, and the crew necessary at the wind turbine for conducting test flights. Dansk Søredningsselskab was identified as an appropriate and capable capacity for recovery of the aircraft from the water. Air integration would be done by having high conspicuity of the aircraft (using an ADSB mode St transponder) combined with prearrangement with Ørsted (the wind farm owner), the appropriate tower for ATC, and NOTAM based on the operational authorization. Integration with wind farm ERP was done by adapting the relevant emergency procedures for the air operation (such as turbine impact and water landing) with the wind farm ERP procedures. Insurance was addressed by combining the learnings from the Siemens and FS Dynamics impact simulation (which demonstrated the worst-case scenarios resulting from the aircraft impacting the rotor blades as full operational load) with the cost of partial or complete renovation of a damaged turbine. It was mutually agreed between Ørsted, Aeroscout, and AAU that the insurance coverage provided by Allianz for the operations would be sufficient.

WP6: Horns Rev 3 wind farm interaction

This WP was intended to be heavily based on the learning from WP5. However, since the project did not achieve any operations, this WP6 eventually only included discussion during meetings on how to adapt the WP5 setup to Horns Rev 3.

WP7: Kriegers Flak wind farm interaction

Same as WP6.

WP8: Flight permission and compliance documentation

A total of five authorizations were granted for the project. These are the following:

Date applied	Date granted	Country	Type
Dec 9, 2021	March 22, 2023	DK	Rural BVLOS in ARC-a, HCA Airport, B1-100 and B330 aircraft.
Oct 19, 2021	June 9, 2023	DK	Rural VLOS in ARC-b, all of DK, B1-100 and B330 aircraft.
Apr 1, 2024	Nov 14, 2024	CH	Rural EVLOS in ARC-b, Aeroscout test area, no backup pilot.
Apr 1, 2024	Nov 14, 2024	CH	Offshore BVLOS in ARC-a, intended for cross-border.
Nov 17, 2024	Jan 17, 2025	DK	Rural EVLOS in ARC-b, based on cross-border article 13.

Details on the 2021–2023 DK authorizations

The first set of applications for flight authorizations was submitted to TBST (the Danish NAA) in the fall of 2021. After several months, TBST responded with a request to handle the application as an Article 13 cross-border. This would require resubmitting the application to the Swiss authorities since Aeroscout was the operator of the aircraft. This was soon changed back to a Danish application since Switzerland had not yet, at that time, fully implemented the SORA. A full year passed after that, and not much happened. This was also the reason for conducting an additional flight campaign in Switzerland in the fall of 2022. Finally, the campaign #1-#4 drew nearer, the NAA issued permission. First, for BVLOS at HCA Airport, and subsequently for VLOS in all rural areas in DK.

In total, the permission was for both the B1-100 and the B330 aircraft and for VLOS and BVLOS operations. The test flights were conducted with the B1-100 aircraft only.

Details on the 2024 CH/DK authorizations

In the planning for the offshore flights, it became clear that a new flight authorization would be necessary for two reasons: First, Aeroscout decided not to have a backup pilot during flights. This was an integrated part of the Operations Manual, which thus needed to be changed. Also, this made flight EVLOS, requiring a change to ConOps. Second, BVLOS operations over water were not covered in the first BVLOS permission (it only included the airspace north of HCA Airport).

Consequently, a revised application (revision of OM and ConOps) was submitted to TBST. A month after the submission, it became clear that this time, an Article 13 procedure had to be carried out. This meant that Aeroscout had to apply in Switzerland first and, upon receiving permission there, would submit this permission to TBST for a cross-border authorization. The humorous element of applying for offshore BVLOS operations in Switzerland did not affect the application.

Authorization was granted by FOCA (Swiss NAA) in Nov 2024. At that time, the Anholt Wind Farm was no longer available for the project, and operations could not be switched to another wind farm with short notice. Therefore, to reduce the complexity of the cross-border application to the Danish NAA, only the EVLOS part of the authorization was submitted to TBST.

Authorization for VLOS operations in DK was granted in January 2025.

Compliance documentation

For operational authorization, four types of documentation must be provided: Operations Manual (OM), Concept of Operations (ConOps), Specific Operations Risk Assessment (SORA), and additional documentation, such as aircraft manual, emergency response plan, training manual, etc.

For each of the above authorization, a full set of documents was provided. Such a set constitutes hundreds of pages, and must be adapted to each specific operation. Most of this documentation is proprietary to Aeroscout and is therefore not shared as part of this reporting. This documentation was largely written in collaboration between Anders la Cour-Harbo, Markus Birrer, and Carlo Zgraggen.

WP9: Preparation and execution of offshore flight cargo delivery

A total of 12 campaigns were planned in the project (see application). One additional campaign, number #3a, was added during the project. Only four of the original campaigns were completed, and all four were combined into a single week of operations in June 2023. All four campaigns were successfully conducted and yielded the expected results. A promotional video is available here demonstrating the delivery of a payload bag to the Siemens 6 MW turbine at Tim.

The Nov 2022 campaign (#3a)

A campaign was conducted in November 2022 in Switzerland. The purpose was to prepare for campaign #3 and #4 in Denmark, since, at that time, we still had not received operational authorization, and it did not look like that was going to happen any time soon.

The goal of this campaign was to deliver a payload to a heli hoist mock in scale 1:2. This was built from wood and plastic fencing to visually and physically resemble a real heli hoist, as we would encounter it in Tim. It was constructed at 2 m altitude to allow a safer and easier approach and delivery of the payload bag.

More details of and images from this campaign are available in the Finale Report.

The campaign started with a number of flights to test the safety features of the winch, which consisted of 1) emergency separation of the slung load using shears, 2) unspooling the entire tether, and 3) normal release using the hook. All three methods were tested and approved for flight.

The June 2023 campaign (#1 – #4)

The early campaigns in the project were initially planned to take place in 2022. However, due to the exceedingly long delay in obtaining flight permissions in DK, this was not possible. Two actions were taken to attempt to circumvent the challenge:

- A new campaign (#3a) was added to test both sensors, winch, and general liability close to a nacelle. This campaigns was conducted in Switzerland, where Aeroscout already had permission to operate. This was carried out in November 2022.
- Campaigns #1 through #4 were combined into a single flight week in June 2023.

It was initially believed that it would be good to fly on a turbine in small incremental steps for several reasons.

- Aeroscout did not have experience with such operations, and operating with a few meters of a high structure at 100 m requires extreme care.
- It was not known to what extent the magnetic field of the nacelle would affect the avionics in the aircraft. Two tests of this were conducted in a prior project, OPAL, and both indicated that it would probably be fine, but not conclusively.
- AAU flew a DJI M600 over the same nacelle (the same turbine as used in the June 2023 campaign) and recorded the magnetic field.
- AAU flew an Aveox T50 aircraft close to a smaller wind turbine at Aalborg Port to observe both magnetic field effects and turbulent wind effects.

- Given that we would eventually be physically interacting with the turbine, we found it best to rehearse emergency procedures related to various types of unplanned physical interaction, such as a stuck hook or coming too close to the rotor blades.

It was eventually decided that the incremental steps could be conducted in just one campaign, and campaigns #1, #2, and #3 were carried out on June 19 and 20, 2023. In addition, some of the concerns regarding navigation and guidance over the heli hoist were addressed in the preceding campaign #3a. Two payloads were delivered to the Tim turbine using the fully sensored Aeroscout B1-100 aircraft.

A detailed account of the conducted flights is available in the Finale Report.

WP10: Air cargo service operations

Early in the project, Loxar investigated how short-to-turbine deliveries could become business case. This was done by a combination of

- Mapping all offshore wind farms with distances, operators, methods of maintenance, etc.
- Interviews with a number of stakeholders, including wind farm owners, maintenance companies, individual technicians, spare parts warehousing, etc.
- Discussions with manned airborne offshore flight services from EMG, Ørsted, and Siemens.
- Participation in an accelerator program to boost investor networking.

The conclusions from this effort where three-fold:

- There is a huge potential for the business case in the sense that the market is large and increasing, and that virtually everyone agrees that airborne delivery solves a number of challenges and has the potential to increase revenue for wind farm owners.
- Due to the scattered nature of current maintenance services and both installation and maintenance contracts, it is by no means obvious how the general concept can be commercialized. If a particular way of providing an airborne service makes sense for one windfarm, it is useless for another, because the maintenance setup varies significantly.
- The people/department who pay for maintenance (and thus stand to have economic gain) are generally not the same people who bear the risk if maintenance is not done correctly or in time. Consequently, the risk/gain setup is skewed, making it rather difficult to introduce a fundamentally new approach to maintenance.

From the start of the project, a manned/unmanned combined service appeared to be interesting. We have generally good feedback on this concept, although it was difficult to crystalize the idea without more tangible input from stakeholders, which again hinged on the ability to demonstrate flight operations. Therefore, the manned/unmanned concept remains a feasible approach, but yet unproven.

6. Utilisation of project results

From inception, the company Loxar was intended to be the main driver for commercialisation of project results. Loxar has been started by AAU staff Anders la Cour-Harbo and Simon Jensen, and had already been pursuing the concept of spare parts delivery for a couple of years prior to project start.

Before and during the project, Loxar pursued a number of opportunities for financing and demonstrating delivery capabilities, including several companies in Denmark, the UK, and Germany. This included manufacturers of wind turbines, offshore maintenance operators, investors, and others.

However, due to the relative slow progress in the project combined with the general reluctance in the industry to adopt new methodologies, Loxar was unable to procure sufficient financing (which due to the nature of the concept is considerable), and during the fall of 2024, Loxar decided to cease operations and release any commercializing opportunities to other entities.

To this end, the Final Report details much of the learnings from the project, including details not included in the present report. The purpose is to disseminate what is hopefully useful knowledge to anyone who would be interested in pursuing the spare parts delivery business.

To further advance this, the project group has identified a list of companies that will be contacted after April 1, 2025, and offered both the Final Report and an online meeting to further transfer knowledge.

The identified stakeholders are

Company	**Point of contact**	**Role**
Kymati	Michael Voith von Voithenberg	CTO
Stromkind	Andreas Desch	CEO
Avilus	Niclas Bähr	COO
Upteko	Benjamin Meinertz	Product Director, Partner
Flying Basket	Thomas Markert	Head of Operations
Airflight	Travis James Mathers	COO
EnBW - Offshore Challenge	Vincenz Schneider	Project Lead
Ampelmann	Thijs van't Geloof	Business development
Malloy Aeronautics	Ben Long	Business development officer
FlowCopter	Uwe Stein	Technical Director
ACC	Claes Drougge	Director of the board
DSV	Mathias Vinter	Head of Drone Excellence
TU Delft	Daniele Ragni	Assoc Prof

In addition to this, EMG wants to pursue commercialization of the winch and hook as a separate product.

7. Project conclusion and perspective

The ADD2wind project has demonstrated that airborne delivery of spare parts to offshore wind turbines using unmanned helicopters is both technically feasible and operationally promising. The integration of payload delivery systems, successful test flights to an offshore-type turbine, and the achievement of BVLOS authorizations represent substantial progress. While some of the original milestones could not be fully realized—primarily due to delays in regulatory processing—the project has laid the groundwork for future development and deployment of unmanned air cargo services in the offshore energy sector.

The insights gained into both technical integration and operational challenges are highly valuable. The learnings from business case exploration, payload development, and regulatory navigation have not only informed our own efforts but are also being actively shared to support future industry initiatives. Looking forward, there is significant potential in developing drone-based logistics as a complement to existing offshore service infrastructure. Especially for ad hoc deliveries, drones can improve turbine availability and reduce vessel dependency.

With increasing turbine sizes and longer distances from shore, the need for flexible and scalable logistics will only grow. The technology and know-how developed in ADD2wind can be leveraged to meet this need, whether through public-private partnerships, new commercial ventures, or as part of a hybrid manned/unmanned service concept. The project's results, though not without obstacles, have provided a clear path forward and a strong foundation for others to build upon.

Following the conclusion of the ADD2wind project, the immediate next step is to transfer knowledge and results to stakeholders who may pursue further development or commercialization. This includes sharing the Final Report and offering follow-up discussions with identified companies and organizations. In parallel, the consortium aims to continue supporting regulatory progress and explore new funding or partnership opportunities to advance offshore drone logistics, either by enabling new demonstration campaigns or by further developing key components such as the winch system into standalone products.

8. Appendices

- YouTube channel with test flight videos:
  https://www.youtube.com/@uas-ability-aalborgunivers3967/videos

- Image gallery from this project, and others
  https://droneresearchlab.smugmug.com/

- Link to Final Report
  https://lacourfamily.dk/ADD2wind_Finale_Report_April_1_2025.pdf