AIRTuB project

Activities & results

2019-2023

Partners:

Eneco

DEMCON | unmanned systems

FUSION ENGINEERING

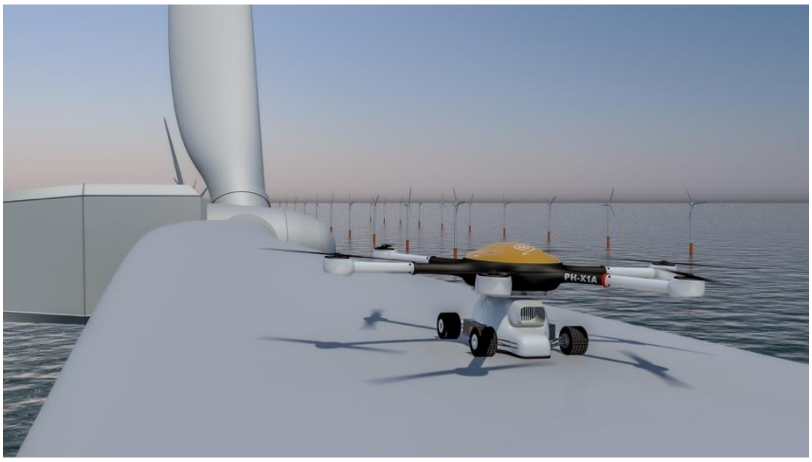
HZ UNIVERSITY OF APPLIED SCIENCES

nlr

Scalda

Overall report
Workpackage 2 & Workpackage 3

Date: 2023-02-20



Version 1.0

Authors:

Jos Gunsing, HZ UAS

Martin Joosse, NLR

Fedor Ester, Demcon Unmanned Systems

Tim Koning, Fusion Engineering

Overall report AIRTuB Workpackage 2 & Workpackage 3

1. Project details

- **Participating persons for each partner**
  - HZ WP leader:
    - Edward Mouw
    - Gillie Maas
    - Leo Blok
    - Joshua de Jong
    - Ronald Eijlers
    - Peter van der Heide
    - Gerben Huiszoon
    - Jos Gunsing (MaromeTech; outsourced activity)
    - Martijn Crombeen (Crombeen Robotics)
    - Other colleagues involved
  - Scalda (formally outsourced activity in WP2 & 3):
    - Ronald Schroevers
    - Kasper de Feijter
    - Other colleagues involved
  - NLR
    - Martin Joosse
    - Arjan Hanema
    - Marco de Boer
    - Several colleagues from NLR Drone Centre
    - Rob Remmerswaal
  - Demcon
    - Fedor Ester
    - Barth Vrijling
    - Adam Swiderski
    - Other colleagues involved
  - Fusion Engineering
    - Robert Crone
    - Abhishek Chatterjee
    - Tim Koning
    - Other colleagues involved
  - Eneco
    - Bart VandeHoek
    - Sandro di Noi
    - Stef ten Katen
    - Harmen Wijnja
    - Jeroen Achterberg
    - Michiel Spoor
    - Other colleagues involved

2. Final report on the contents of the project

- **Summary**
  - WP2 & 3 results:
    - System architecting/interfacing between partners WP2/3 and WP1 (sensor development)
    - Development of flight controller esp. for handing of drones in gusty wind condition
    - Development of lidar system for path planning along leading edge (scanning with laser line scanner external damage sensor package) and landing on windturbine blade (internal damage ultrasound sensor package plus crawler and drone)
    - Development of several drones for different purposes in different stages of the project
    - Development of crawler; several generations from feasibility models to 2 prototype versions
      - Carrying internal damage sensor
      - Crawler connected to drone; can be disconnected
    - Demonstrations/presentations (Marknesse November 24, 2022)
      - A small drone equipped with dedicated landing gear for landing on a curved windturbineblad; the landing was automated with a beacon
      - Testbed#2 with NLR flightcontroller and equipped with the TU-D laser scanner and inspecting a segment and the leading edge of a windturbineblade by flying accurately and stabile short distance above the blade
      - The AIRTUB drone (mass 60kg) with NLR flightcontroller and equipped with 15kg payload crawler, after landing the crawler disconnected and left the drone.
      - NLR also facilitated as an authorized operator also the flight with Testbed#1 that was specified and built by NLR
      - Demo flight with testbed#1 equipped with fusion flight controller
      - Demo/film with lidar/path planning equipment
      - Crawler with internal damage sensor (ultrasonic device) demo on turbine blade; crawling while inspecting internal damage.
      - Short presentation

Fig 1. Final AIRTuB event November 24, 2022 at Marknesse

Introduction:

- WP2 & 3
    - In the early stage of the AIRTuB developments the key question for developing the equipment was:
        - How small and how precise should the relevant defects be measured?
            - The size and accuracy determine the size (volume/mass) of the sensor system
        - When the first ideas were generated in WP1 with respect to size and accuracy of the sensor the size of the drone and the size of the crawler could be determined.
        - Meanwhile concepts could already be developed in WP2/3 and feasibility models be designed/built and tested
    - In WP2 and WP 3 HZ, Demcon, NLR and Fusion Engineering worked closely together in order to develop a drone with dedicated equipment plus crawler. In WP3 we work closely together also with WP1; TU Delft and another department of NLR to integrate:
        - Drone plus external damage sensor package
            - laser line scanner
                - Leading edge inspection
        - Drone plus crawler
            - Crawler carrying internal damage sensor package (ultrasonic sensor)
                - Structural damage sensor

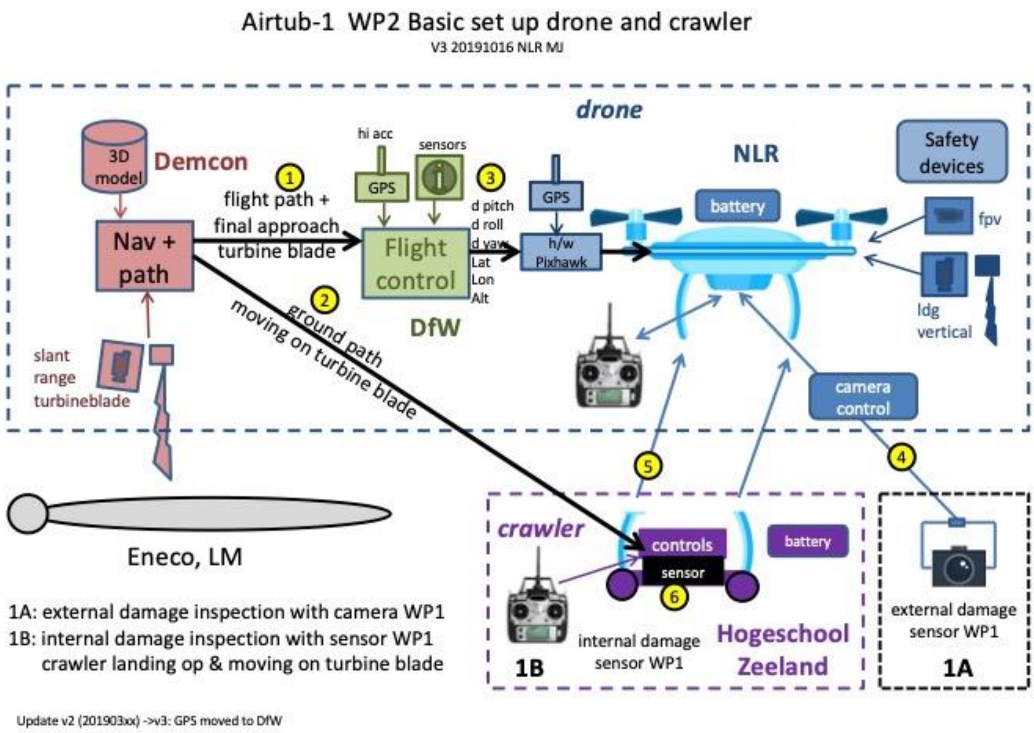


Fig.2. Basic architecture drone-crawler-external damage sensor package

- For navigation purposes Demcon developed a lidar for making a scan of the blade and leading edge contour. In combination with the GPS data a flight path can be generated along the leading edge and towards a landing area.

Fig.3. Lidar sensor for navigation path planning purposes (Demcon Unmanned Systems)

- Fusion is involved in developing a flight controller which is specially equipped to deal with heavy wind gusts, which is evidently an advantage when flying close to and /or lading on a wind turbine blade

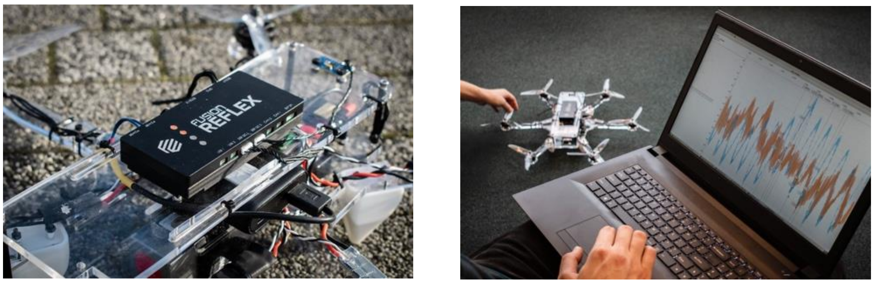


Fig.4. Flight controller for gusty wind conditions (Fusion Engineering)

- The crawler will be developed by HZ and Scalda in such a way that it can operate completely independently from the drone. In an earlier stage it was thought that the drone would be carried by the crawler when travelling on the blade but this is a too big risk/challenge. The drone will be equipped with a landing gear with locking devices to hold the crawler/external sensor package safely during flight/landing and take off and which enables easy/safe release and pick up of the crawler. Several feasibility models have been developed top test critical functions

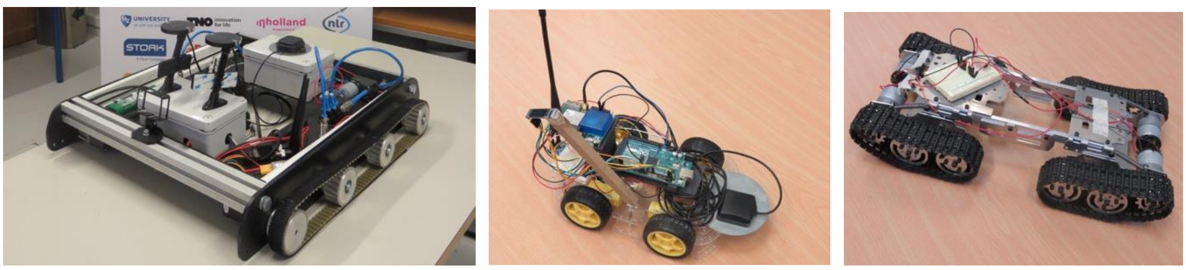


Fig.5. Feasibility models for crawler development (HZ UAS and Scalda)

- Several drones have been chosen and built by NLR to fulfil the requirements for flying with the laser line scanner and with the crawler/sensor package. In both cases the lidar sensor is designed to be combined with several types of flight missions/drones. This also accounts for the Fusion Flight controller.
    - The flight controller development was on the critical path. For risk mitigation purposes we also had the possibility to apply conventional flight controllers

Fig.6. AIRTuB and testbed drone with laser line scanner (leading edge erosion damage TU Delft) (drones: NLR)

- Test equipment was developed by Scalda in order to test the crawler on a wind turbine blade under several circumstances for testing at the Kaap, Vlissingen
- Test wind turbine blade available at Marknesse
- As final results of the project we demonstrated following prototypes:
    - 1 operational big drone; up to 60kg MTOM
        - Flying and landing with crawler
    - 2 operational drones; 15-20kg MTOM
        - 1 Flying with conventional flight controller and laser line scanner
        - 1 Flying with Fusion flight controller
    - Lidar sensor and software for flight path generation
        - Demo with help of film
    - 1 crawler stage 2: able to carry sensor package
        - Inspection demo on blade
    - Test equipment:
        - Mobile platform with 2 deg of freedom 22 m windturbine blade (tilt and pitch); available at the Kaap
        - Static 22m wind turbine blade at NLR, Marknesse
        - Both wind turbine blades were supplied by LM Windpower

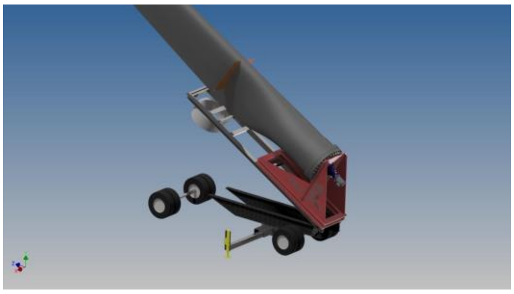
 

Fig.7. 22 m Windturbine blade: sketch for mobile platform (Scalda) and static test rig at Marknesse (NLR)

- Eneco has had the role of the asset owner and would originally also supply test time on onshore and offshore wind turbine farms apart from also supplying partical information to check the use cases with and also data for WP4 and WP7 . Due to lead time issues the tests on the onshore and offshore wind turbines could not be performed
- Especially with WP1 a close cooperation is necessary. The WP leaders from WP1 and WP2/3 participate in each other's WP meetings to keep the communication lines short.

-

WP1 General

- The WP leaders from WP1 and WP2/3 participate in each other's WP meetings to keep the communication lines short.

- **WP 1.2. up to 1.6**: mainly impact on WP1.4 architecture of sensor package
  - HZ is involved in these WP's for reason that both the internal and the external damage sensor packages the sensor package has to be integrated in the crawler and drone so packaging in terms of volume/sizes, masses, center of gravity, communication protocols (both hardware and software) are important discussion items; also range and ways of operation of the sensor package are important issues to get agreement on. At this moment the designs are more or less complete and we are finetuning the interfacing both mechanically and electronically. The designs plus software message protocols will be detailed in the next months. The overall architecture and use cases are known
  (e.g. scanning or step inspection; how to deal with the involved forces, necessary for sensing, between sensor and turbine blade)

- **Objective/goal**
  - WP2 & 3

  Results with respect to project
    - Successful cooperation NLR, Demcon, Fusion Engineering, HZ and Scalda incl. MaromeTech (WP leader Jos Gunsing)
    - redesign and tests of several drones
    - Integration of Fusion flight controller in testbed drone (delayed, not tested in big drone)
    - Successful design and test with outdoor and indoor navigation modules; indoor for test purposes (indoor flying has less legal restrictions)
    - Lidar test near wind turbine blade successful

- Successful design and test of vacuum devices for blade holding/clamping mechanism
- Phase 2 crawler; tested under drone and tested on blade including sensor package while holding and moving
- Scalda realized a mobile platform with tilt and pitch function for the available 22m wind turbine blade at De Kaap; on a second hand trailer a support is being built such that the blade can safely be:
    - Pitched over 360 degrees
    - tilted/rotated over an angle of over 30 degrees
    - Moved to other nearby locations such as inside/outside De Kaap
- involvement of students:
    - HZ
        - Overall 90 + students involved
    - Scalda
        - Overall approx.. 30 students involved
- Involvement of other university of applied sciences
    - Avans University of Applied sciences has joined the project with the minor Aerospace Engineering & Maintenance during autumn 2020 and 2022 and several involved student groups delivered a working demo of the motion and clamping mechanism for the crawler (demo January 2021) ; in January 2023 they delivered a lot of test results for the crawler stage 2 plus several proposals for further improvement

Fig.8. Students involved in projects (HZ UAS, Scalda and Avans UAS)

- **Way of working**
    - WP2 & 3
        - In general:
            - Regular meetings
            - Contacts in between
            - Discussion and work distribution leading to :
                - Use cases
                - Requirements
                - Functional decomposition
                - Risk analysis
                - Risk mitigation actions
                - Sharing results
                - Combined testing
            - Working towards demonstrator model which means
                - Lean interfacing between modules /functions
                - Each function can operate and communicate independently

- This will not lead to an optimal product but to a demonstrator in time which helps to determine the requirements and the specifications for a real product

- HZ:
  - technical lead for WP2 and WP3
  - development of crawler with teacher/researchers and students
  - Scalda (officially subcontractor role; in practice: partner):
    - Development and technical support for crawler
    - Development, building and test for mobile wind turbine blade tilting and pitching platform
- NLR
  - Development and test of large drones
  - Development of landing gear for curved blade incl suction system
    - Including Automated landing with beacon

- Demcon
  - Development of path planning with help of lidar system
- Fusion Engineering
  - Development of robust flight controller which is also able to deal with strong windgusts with help of innovative control algorithms
- Eneco
  - Supply of data with respect to wind turbine performance and maintenance
  - Availability of and access to on- and offshore wind turbines for test purposes related to the AIRTuB project

- **Results/deliverables:**
  - WP2 & 3
  - **WP2:** General
    - HZ has a technical leading role in WP2 and WP3 and has a direct contact line with WP1 in order to integrate the internal and external damage sensor packages in the drone and/or crawler

  - **WP2.1.** Definition of use cases
    - use cases for flyby and on-the blade inspection available

  - **WP2.2.** Definition of architecture
    - The gross distribution of functions/modules/building blocks of drone, crawler including lidar sensor and flight controller is available

  - **WP2.3.** Design of experimental set-up
    - Several demo models of lidar sensor/path planning and for the fusion flight controller
    - Several feasibility models have been realized for drone and crawler including lidar sensor and flight controller test; also several test set ups for feasibility and prototype tests based on 22m wind turbine blades are available both static (Marknesse) and movable (with pitch and tilt)

  - **WP2.4.** Development of experimental set-up

Based on results several steps have been taken to come to a definite drone and crawler prototype version including the lidar sensor and flight controller;

- **WP2.5.** Lab testing, optimization and redesign
    - Many tests have been carried out with drone/crawler, lidar sensor and flight controller
- **WP3**
    - The on- and offshore tests have not been taken place;
        - Delays due to covid 19 measures
        - Delays in the development of the Fusion Flight Controller
        - Instead: big demo event November 24 2022 in Marknesse where all the functionalities have been demonstrated

- As final results we demonstrated following prototypes:
    - 1 operational big drone; up to 60kg MTOM
        - Flying and landing with crawler
    - 2 operational drones; 15-20kg MTOM
        - 1 Flying with conventional flight controller and laser line scanner
        - 1 Flying with Fusion flight controller
    - Lidar sensor and software for flight path generation
        - Demo with help of film
    - 1 crawler stage 2: able to carry sensor package
        - Inspection demo on blade
    - Test equipment:
        - Mobile platform with 2 deg of freedom 22 m windturbine blade (tilt and pitch); available at the Kaap
        - Static 22m wind turbine blade at NLR, Marknesse
        - Both wind turbine blades were supplied by LM Windpower

Fig.9. Mobile platform with rotatable/pitchable 22m blade

- **of the project itself**
    - WP2 & 3:
        - Fusion:
            - Flight controller shows strongly improved control in gusty wind conditions (demo in windtunnel with small drone)
            - Demo with NLR testbed#1
        - Demcon:
            - Demo of lidar sensor including path planning software
        - NLR
            - Several testbeds

        - Landing on blade
        - Inspection of blade with laser line scanner
    - AIRTuB drone 60kg
        - Flying and landing with crawler including release of crawler
- HZ: prototype/demonstrator of crawler able to:
    - Crawl over blade including sensor package carrying out inspection while clamping with vacuum to the turbine blade
        - Teleoperated
    - Crawl in and out drone payload carrying gear (combined with landing gear) including safe connection drone-crawler operated from crawler

- **possibilities for spin-off and follow-up activities**
    - WP2 & 3
        - HZ/Scalda
            - Strengthening of combined research and education of Scalda, HZ and also UCR (discussion started)
            - Involvement of MKB companies in wind turbine maintenance
            - Further contribution to AIRTuB2 and other projects in the field of maintenance and robotization in the energy transition field
-

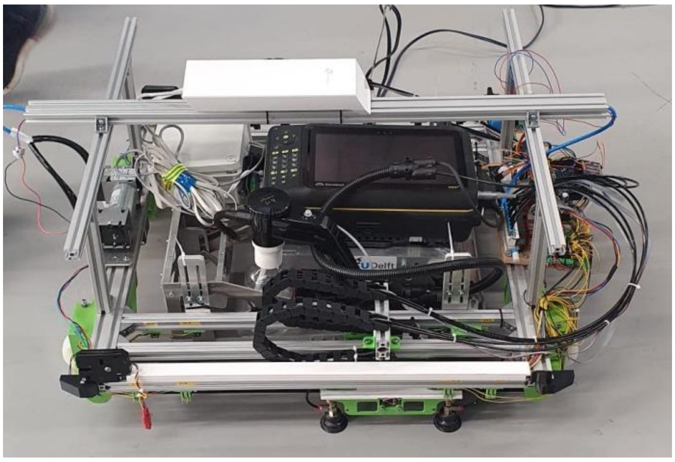


Fig.10. Crawler (HZ UAS/Scalda) including external damage sensor (TU Delft)

        - NLR
            - Experience with big drones
                - Possibilities for offshore applications
                - Development & operation
                    - High accuracy landing and flying was investigated, this knowledge can be used in other projects.
                - Knowledge that has been gained by the development and flying of the heavy drone can be used in other projects were a heavy drone or heavy payload (15kg) is needed.
            - Further contribution to AIRTuB2
-

Fig.11. Drone with crawler on landing platform and crawler/sensor package on 22m wind turbine blade

- Demcon
    - Application of path planning HW and SW also for other autonomous flying, sailing or driving equipment
    - Further contribution to AIRTuB2

Fig.12. Lidar for navigation path planning (Demcon Unmanned Systems)

- Fusion Engineering
    - Application of dedicated flight controller also for other (autonomous) flying equipment suppliers/applicants
    - Further contribution to AIRTuB2
    - Remark photo of a test with a small drone in windtunnel; upper with Fusion Reflex; lower with conventional flight controller; response to strong windgust from left

-

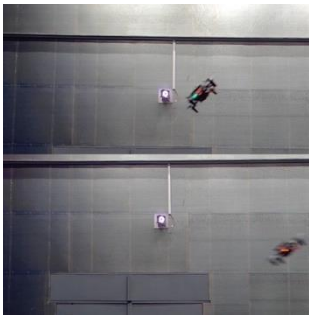


Fig.13. Effect of Fusion Engineering Reflex flight controller in wind tunnel with heavy windgusts; reduced position deviation; quick response

        - Eneco
            - Further involvement/contribution in/to AIRTuB2

- **Discussion**
    - **Conclusion and recommendations**
        - WP2 & 3
            - A drone, crawler including sensor package have been developed and demonstrated successfully.
            - A lidar sensor including path planning ahs developed and demonstrated successfully.
            - A flight controller has been developed and demonstrated successfully.
            - In a follow up project we would have a plan B scenario available for critical developments (in our case the Fusion flight controller development)
                - No new technology on the critical path of the project that has to be developed by a partner without a track record.
                - Proven technology on critical path/ interesting new technology to be developed on a parallel track
            - Strongly dependent on the internal sensor development a development of drone and crawler towards lower mass and volume will be possible ; mission time and agilty (=also safety) will benefit from this.
            - Further development of crawler to be able to crawl on the leading edge for internal damage inspection and for leading edge repair i.e. new layer on eroded areas . An other addition can be the detection of loose Leading Edge Protection shells

3. Execution of the project

- **The problems (technical and organizational) that occurred during the project and the way in which these problems were solved**
    - WP2 & 3
        - Covid 19
            - Especially in spring 2020 hardly any prototyping and experimental work could be carried out due to the lockdown of HZ and Scalda. The delay is still present
        - Execution of actual inspections/tests on offshore windturbine blades
            - Scope of project limited ; still the feasibility of the individual modules has been carried out and several of them also in combinations:
                - Drone/external damage sensor(Laser line scanner)
                - Drone/crawler: flight and release of crawler
                - Crawler/internal damage sensor (ultrasound)
- Flight controller development
    - For the development of the drone and being able to fly a partner had to deliver an advanced flight controller. To detect and resolve errors in these new systems and to make the airworthiness (needed for a permit to fly) plausible, an extensive testing phase is required. This part was originally underestimated by this partner.
    - For the typical AIRTuB operation an additional positioning system and inspection systems developed by other partners were needed. Also this required an extensive testing phase.

    - This resulted in hard deadlines for the delivery of equipment by partners. Those deadlines were not met. This has been reported and time schedules were rescheduled, finally a scope change of the project was needed (see below).
- Blade holding/clamping mechanism
    - On a small scale the blade holding mechanism with vacuum application works for the drone But it has not been proven on a scale sufficiently to deal with a big (and moving) crawler in more severe wind conditions including wind gusts; the work in the next year will focus on these issues to make sure that the effectiveness will be proven. In September 2021 test will be carried out with a phase 2 crawler (both upgraded mechanics/electronics and Software) in parallel other holding/clamping mechanisms will be engineered and tested as backup solutions
- Small mass budget for crawler functionality
    - The sizes required from the sensor package WP1 are big (sensor package of 500x500x500 mm at a mass of max 10kg) ; the size will be smaller than this; estimate 300x300x600 with a slightly bigger mass. The impact will be discussed with NLR
    - Total mass budget for the crawler functionality is 5 kg including the attachments for the sensor package and the possibility to work with vacuum plus the attachment mechanism with the drone; the mass will probably be higher than the aimed 5 kg; still under discussion.

- **Explanation of changes to the project plan**
    - WP2 & 3
        - Delays w.r.t. Covid 19; estimated 3 to 6 month
    - The development of the flight controller had too much delay and stopped the development of the drone. Extensive knowledge support by NLR was provided to this partner and an extra test bed was made with which this partner could determine an initial tuning for the flight controller. At the end of the project, the flight controller was not yet ready to be built into the drone and tested by NLR. Ultimately, NLR equipped the drone and a second testbed with its own conventional flight controller to be able to demonstrate a flight (limited conditions) with the inspection systems.
        - As a result, it was not possible to carry out all the originally planned work so that an inspection could be carried out. A scope change was necessary and was accepted by RVO (1 Sept 2022).

- **Explanation of the differences between the budget and the costs actually incurred**
    - WP2 & 3
        - **Applicable for reports on partner-level**

- **Explanation of the way of spreading knowledge**
    - WP2 & 3
    - Active involvement in September 1, 2020/August 31, 2021:
        - Masterclass Offshore Wind, Innovation in Maintenance
            - September 30, 2020
        - 2020 Zephyros annual congress/webinar:
            - Zephyros/AIRTuB/Mars4Earth
            - September 16 2020
        - Demo-session crawlerplatforms
            - AVANS, HZ and Scalda
            - January 28 2021
        - Demo session Event windturbine blade maintenance
            - Zephyros/AIRTuB, Mainblades, NLR, HZ, Scalda

            - July 22 2021
        - Demo Session Crawler, De Kaap, Vlissingen September 22, 2022
        - Demo Session AIRTuB, at NLR Marknesse, November 24, 2022

- **Explanation PR project and further PR possibilities**
    - WP2 & 3
        - AIRTuB Crawler at events
            - Visit of minister Robbert Dijkgraaf to Scalda, HZ and UCR
                - Pitch for minister Robbert Dijkgraaf at JRCZ (Joint Research Center Zeelandl Scalda, HZ and University College Roosevelt, Middelburg. November 14, 2022
            - Opening of JRCZ (Joint Research Center Zeeland Scalda, HZ and University College Roosevelt), Middelburg. December 15, 2022
            - Several events at De Kaap, Vlissingen. Autumn 2022
        - The AIRTUB project and the drone in development for this project is one of the use cases used in presentations to inform (national and international) visitors and customers of the capabilities of the NLR dronecentre, the link to offshore wind energy and developing & operating a large drone.
        - The AIRTuB project shows also the potential and necessity in complex applications of and thus contributes to the PR with respect to:
            - Dedicated flight controller for dealing with gusty wind conditions
            - Dedicated lidar sensor for inspection drone path planning and automated landing

Fig 15. Final AIRTuB event November 24, 2022 at Marknesse , all WP teams , public plus demonstration models near static 22m wind turbineblade test rig