Development and flight test of a UAV for Search & Rescue missions

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ABSTRACT

The number of SAR missions has been increasing strongly in recent years motivated by humanitarian crises, armed conflicts, geopolitical tensions, etc. In 2019, almost 100 people in average were rescued daily by the Maritime Rescue Service (SASEMAR) in Spain, and it is estimated that the total number of operations throughout Europe exceeded 500.000. Aurea Avionics has led the SABYR (Search and Rescue Autonomous System) project, co-funded by the Centre for the Development of Industrial Technology of Spain, that aims to increase the autonomy level of target detection in SAR missions, by the means of Artificial Intelligence onboard in an Unmanned Aircraft Vehicle. The AI algorithms make use of the video from the cameras onboard to detect people, vehicles, or boats and to guide a Class I Mini UAV to them autonomously. The flight test phase is a strategic step of the upmost importance for the success of the project. To accomplish the flight test phase properly, it is necessary to adapt the UAV to fit the specific needs of the project.

The overview of the motivation behind SABYR and the scope of the project are described in Section 1.0 INTRODUCTION. The main characteristics of the aerial platform are in section 2.0 AERIAL PLATFORM. Similarly, a high-level summary of the systems architecture can be found in section 3.0 SYSTEMS ARCHITECTURE. In section 4.0 TESTS CARRIED OUT PRIOR TO FLIGHTS, an overview of the procedure of ground tests is exposed. A description of the planning process of the flight tests, tailored for the case of SABYR, involving the AI-powered guidance mode is in section 5.0 FLIGHT TEST PLANNING. A brief description of the AI-powered mode is included in section 6.0 AI POWERED MODE CONSIDERATIONS. Finally, the results obtained during flight tests for some generic manoeuvres are included in section 7.0 FLIGHT TESTS.

1.0 INTRODUCTION

The number of SAR missions has been increasing strongly in recent years motivated by humanitarian crises, armed conflicts, geopolitical tensions, etc. In 2019, almost 100 people in average were rescued daily by the Maritime Rescue Service (SASEMAR) in Spain, and it is estimated that the total number of operations throughout Europe exceeded 500.000. Air assets, such as helicopters and traditional aircrafts are very useful tools due to their ability to cover large areas in short times, however the detection of stranded people, vehicles or castaways, shipwrecks and boats continues to be carried out to a great extent by human staff onboard or in ground facilities. The observers in charge of reviewing video feed, images and pictures in real time are under pressure, and acute levels of stress and fatigue is a common issue while performing these tasks, leading to suboptimal performance to find the target, and hence jeopardizing the presumed efficiency of the air assets. Moreover, the detection time – the timespan elapsed until the missing person, vehicle or target is found – is a key factor in rescue operations, as it is estimated that the probability of survival is reduced from 50% in 48 hours and to 20% after 72 hours.

Aurea Avionics has led the SABYR (Search and Rescue Autonomous System) project, co-funded by the Centre for the Development of Industrial Technology, under the Ministry of Science and Innovation. SABYR aims to increase the autonomy level of target detection in SAR missions, by the means of Artificial Intelligence algorithms that serve as guidance for a UAV to spot and follow people, vehicles, or boats autonomously. This solution would potentially help to conduct SAR missions in a more effective way, reducing operational expenses compared to traditional air means and shortening the searching time, thus increasing the survival probability. The information retrieved by cameras and sensors is processed by the AI algorithms in real time, and the outputs are sent to the autopilot to guide the UAV

The scope of the project includes the development of a UAV demonstrator and a new autopilot system along with the AI guidance system. On a final stage, SABYR project undertakes test flights, in which AI guidance algorithms generate the references for the autopilot.

2.0 AERIAL PLATFORM

SABYR's UAV's aerial platform is a Class I Mini Unmanned Aircraft under 5 kg of MTOW. The main characteristics of the aerial platform are summarized in the next table:

Parameter	Value
MTOW	4.5 Kg
Span	2.649 m
Longitude	0.923 m
Wing surface	0.8 m^2
MAC	0.44 m

Table 2-1. SABYR UAV characteristics

A three-view drawing of the UAV has been included in the next figure:

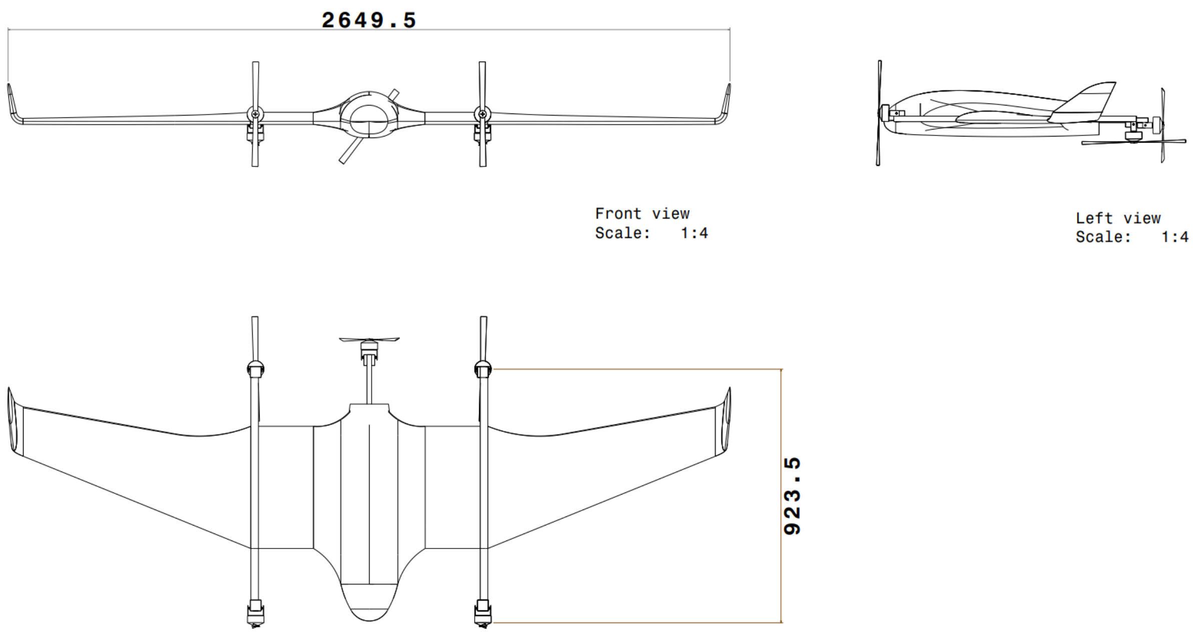

Figure 2-1. SABYR's project UAV

3.0 SYSTEMS ARCHITECTURE

Due to the lightweight nature of Class I Mini unmanned aircraft, onboard systems are very constrained in terms of weight, meaning that very strong Size, Weight and Power (SWaP) requirements apply for them. SABYR is in the weight range of less than 5 kilos of MTOW, so the onboard equipment must be minimal. Hence, in this type of aircrafts, redundancy-based robustness strategies are discarded to avoid penalizing the final performance of the system. To fill in the safety gap that this approach might cause, complementary safety requirements must be introduced, for example through specific procedures.

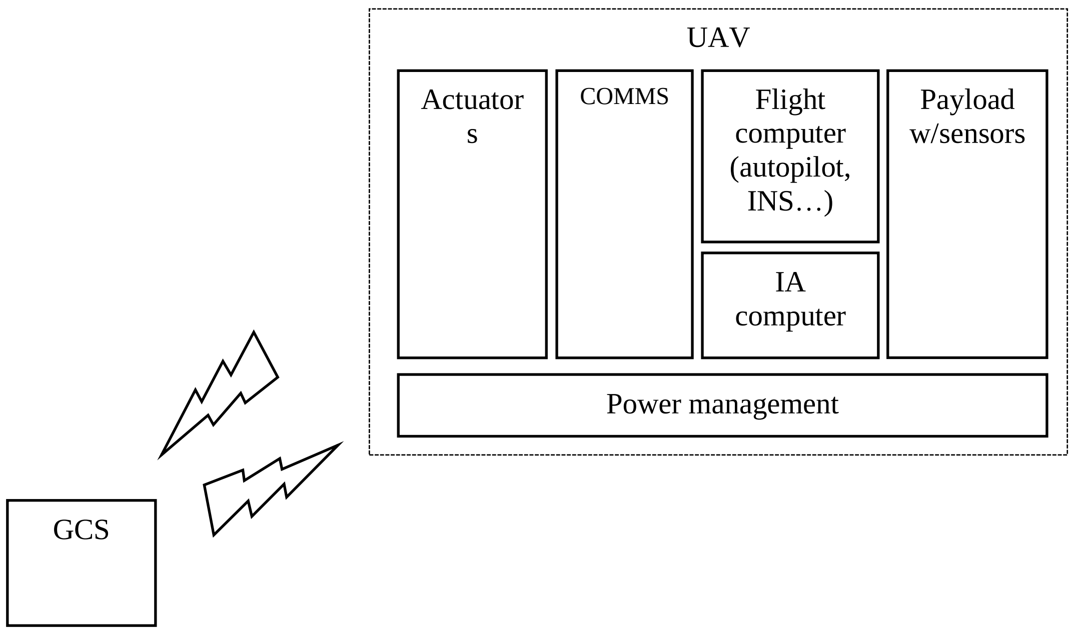

Figure 3-1. SABYR architecture

The basic subsystems are:

- Energy storage system
- Power management
- Engine and propulsion subsystem
- Flight computer, including the autopilot, ADS, INS, etc.
- Actuators
- Cameras
- Artificial Intelligence Computer
- Communications system
- Auxiliary systems: navigation lights, parachutes, etc.
- Ground Control Station

The behaviour of these subsystems must be checked during tests flights, as well as in ground tests.

4.0 TESTS CARRIED OUT PRIOR TO FLIGHTS

As a preliminary step to the development of flight tests, it is necessary to carry out a complete set of ground tests on the equipment and subsystems that compose the unmanned aerial system, either in the lab or on the field for tests that cannot be conducted in the laboratory (for instance, those relaying at some point in GPS navigation signals, among others). After that, only a subset of the tests will be then part of the flight tests and executed again in the air. The overall philosophy that shall rule the ground tests is to replicate the conditions found while flying.

The goal of this approach of conducting previous ground tests is to allow the early identification and detection of systems malfunctions, bringing three clear advantages at the same time:

1. It avoids all risks related to the flight of novel UAV platforms, novel systems architectures, or new equipment, specially taking into consideration the lack of equipment redundancy for Class I Mini UAVs in general and for SABYR's aerial platform in particular

2. It reduces and rationalizes the costs associated with flight campaigns.

3. It allows to mimic conditions that are difficult to find (i.e.: specific weather conditions) or manually introduce subsystem malfunctions to assess the overall impact on the UAS.

Essentially in SABYR, tests prior to flight campaigns have been split into software in the loop tests and hardware in the loop tests, with the aid of a simulation environment, and "on-the-field" tests. For the sake of brevity, a more in-depth description of this stage is omitted:

- Software in the loop (SIL): conducted in the laboratory with the aid of Aurea's proprietary simulation environment developed ad-hoc, it pursues the verification of the embedded software of the Flight Computer, as it conforms the most critical subsystem including the autopilot. The embedded software is forced to run in real time, while the physical components, as well as the dynamics of the UAV, the weather, etc. are simulated.

- Hardware in the loop (HIL): conducted in the laboratory with the aid of Aurea's proprietary simulation environment developed ad-hoc, it pursues a further and more realistic test of the embedded software of the Flight Computer and the onboard hardware, but also includes the whole UAV itself with the engine, actuators, payload, etc. In this case only the physics and dynamics of the UAV and weather are simulated. This setup allows the introduction of multiple realistic malfunctioning situations in subsystems, so many safety issues previously are addressed without risking the UAV.

- On-the-field tests: including all those tests that necessarily need to be performed either outdoors or on the field, such as those that imply the use of GPS signals, or RF COMMS V&V.

5.0 FLIGHT TESTS PLANNING

Manned aircraft flight tests comprise a set of tasks to be carried out on the aircraft in different flight configurations that shall be included in the operation manual, in order to ensure the ability to carry out a safe continuous operation throughout the whole flight envelope. The goal in an unmanned aircraft is essentially the same, although there are a set of particularities that make the set of tests necessarily broader.

The lack crew onboard means that system must include safety-critical elements among their subsystems that must be verified and checked during flight tests, as well as previously during ground tests, as we have seen before. The main additional test points are:

1. Verification of COMMS robustness
2. System check under automatic pilot control
3. System check under pilot assisted control
4. Verification of the stability of the aircraft against references given by the classic Flight Planner system
5. Verification of the operation of the mission planning system
6. Robustness of the measurements of the sensors. This shall be understood in a broad definition, as the autopilot shall be working properly even under corrupted or clipping data coming from the sensors, for example.
7. Verification of the aircraft stability and behaviour against references generated by AI algorithms, which replaces the Flight Planner in the AI-powered mode

The additional tests to be planned in this case are related to the absence of sensory perception of the pilot (sensors), aircraft pilot communication (COMMS) and the different modes of piloting the aircraft: automatic, assisted, and AI-powered.

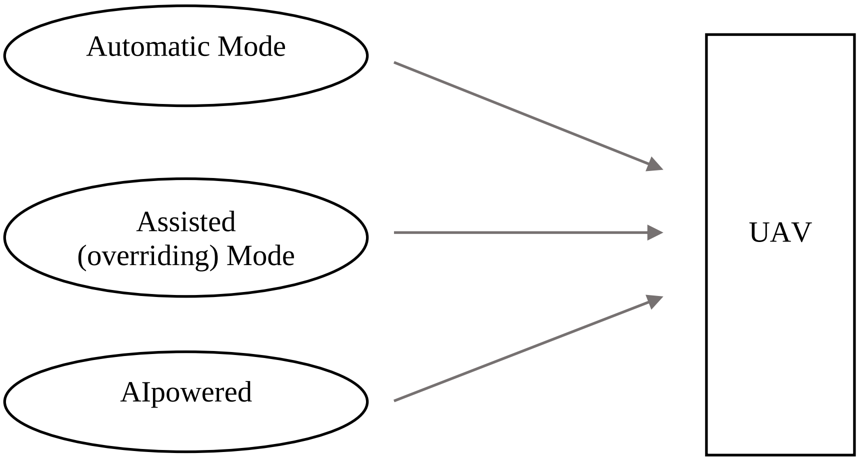

Figure 5-1. UAV flight modes

The emergency procedures to be included in the flight-testing procedures are:

1. Communications loss procedure
2. Pilot indisposition procedure
3. Sensor malfunction procedure
4. GPS Loss procedure
5. Structural failure procedure
6. Power loss procedure
7. Flight termination system activation

Flight tests for an unmanned aircraft must include tests to ensure stability, controllability, integrity, etc. of the aircraft, and additionally they must meet the safety requirements.

Flight tests are planned so that they are carried out in an isolated area and in a very small air volume in order to be able to undertake contingency actions if necessary. The volume will progressively increase when the aerial system demonstrates that it is safe to carry out more complex missions.

To increase the safety during the first phase of test flights, a three different COMMS links are part of the system: the “classic” two links (one allocated to telemetry and C2, and one exclusive for payload data, video, and command) and a third link. This latter is a short-range link that transmit the pilot’s orders directly to the control surfaces of the UAV and it is used in emergency situations exclusively, and works as a risk mitigator.

The airworthiness certification process for Light-Sport Aircraft regulatory framework (ASTM F2245) has been used as a reference. The tests will be accomplished following the order:

- Ground tests (engine, brakes, actuators, etc.)

- First flight (take off, basic behaviour and landing)
- Emergency procedures
- Automatic recovery in case of abnormal manoeuvres
- Stability and control (full envelope over all flight modes)
- Performance verifications (all flight modes)

During the execution of the test flights a card is fulfilled. The flight test card template is shown in the next image.

<table>
<tr><td>ID</td><td>Objetive</td><td>Test point</td><td>Flight number</td><td>Time (min)</td><td>Configuration</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">Test description:</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Observations:</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="5">Go/ No Go Criteria</td><td>Go/No Go</td></tr>
<tr><td colspan="5"></td><td></td></tr>
</table>

Table 5-1. Flight test card template

A Go/No Go criteria shall be defined for each test point.

6.0 AI POWERED MODE CONSIDERATIONS

SABYR’s AI algorithms has been developed and trained to detect and classify people or boats autonomously. A postprocessing layer uses the detection information to feed the guidance system and generate the references for the autopilot, replacing the “classic” Flight planner. The autopilot references are predefined and can be easily decomposed in simple commands. In order to guarantee the safety of the system, the test cases are defined to be representative of the worst cases – in the sense of references generated by the AI algorithms that, once fed to the autopilot, might cause a dangerous or degenerated behaviour of the aircraft – creating automatic sequences of references using the planning system.

Figure 6-1. AI powered mode process

7.0 FLIGHT TESTS

In this paragraph the results obtained during flight tests for some generic manoeuvres are described and the behaviour of the more relevant variables has been plotted. The complete testing plan and results is not included for the sake of brevity.

7.1 Climbing test

This test shows the behaviour of the aircraft against changes in commanded altitude. The initial altitude is 1000 and the final altitude commanded is 1050m.

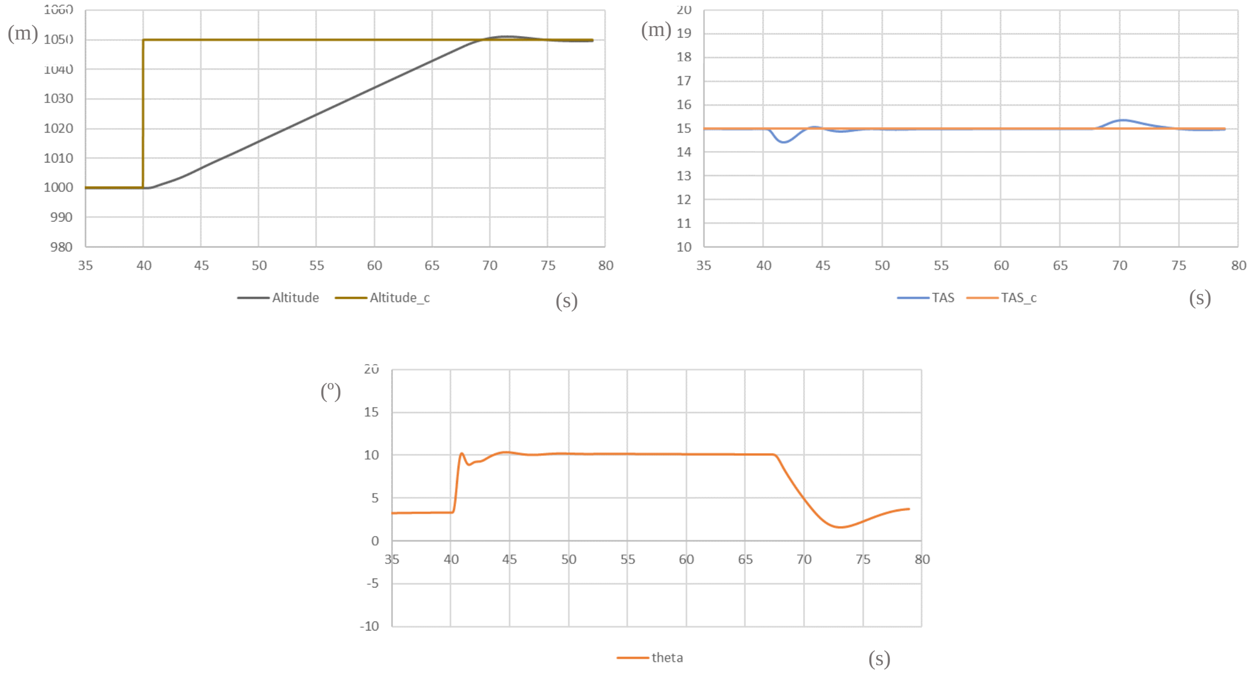

Figure 7.1-1. Altitude, TAS and pitch angle in climbing test

These graphs show the evolution of altitude versus commanded altitude, true airspeed (TAS) versus commanded true airspeed and pitch angle (theta). The actual altitude follows the reference with a constant slope and small overshoot. The effect of altitude change is small, producing a throttle demand during the rise until second 70. The pitch angle increases to ten degrees during the ascent and then it stabilizes around its trim position.

7.2 Acceleration test

This test shows the behaviour of the aircraft when under commands of speed increases. The initial speed is 15m/s and the final target speed is 18m/s.

The graphs below show how the speed increases quickly and reach the final value in 2 seconds, with small oscillations. The pitch angle evolves slowly adjusting its value to the new balance position in order to keep a constant altitude.

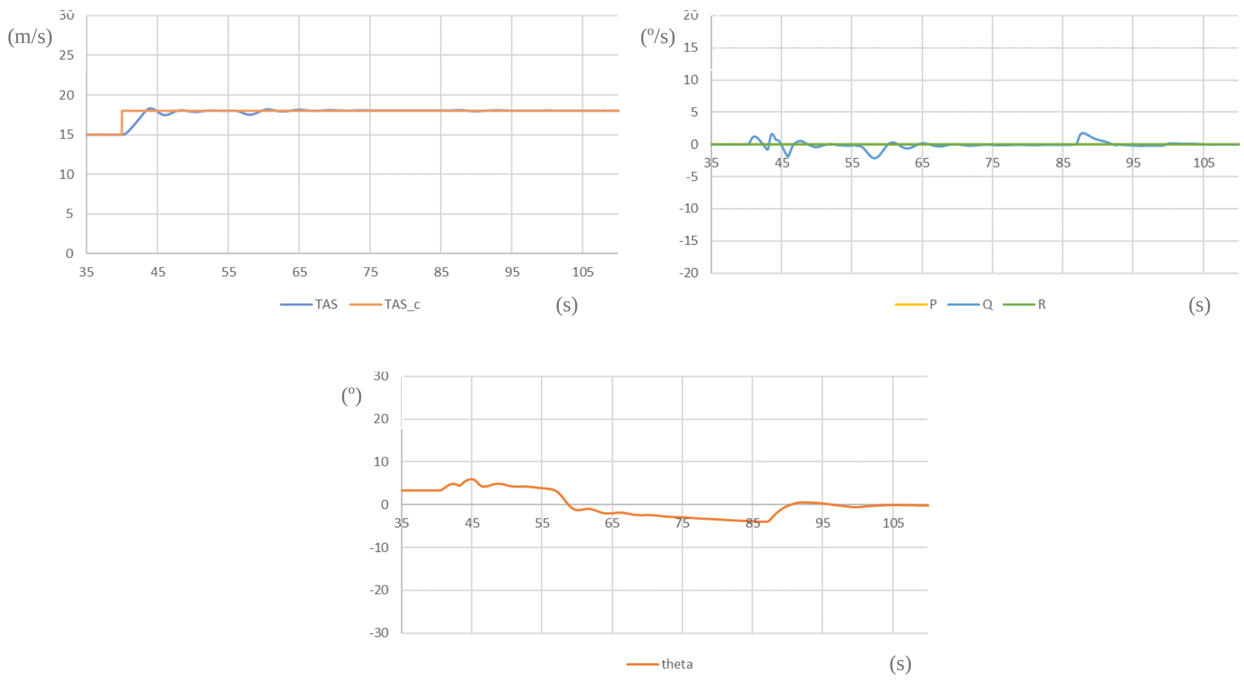

Figure 7.2-1. TAS, angular velocity and pitch angle in the acceleration test

7.3 Roll angle test

This test shows the behaviour of the aircraft against changes in roll angle. The initial altitude is 20 degrees and the final roll angle commanded is -20 degrees.

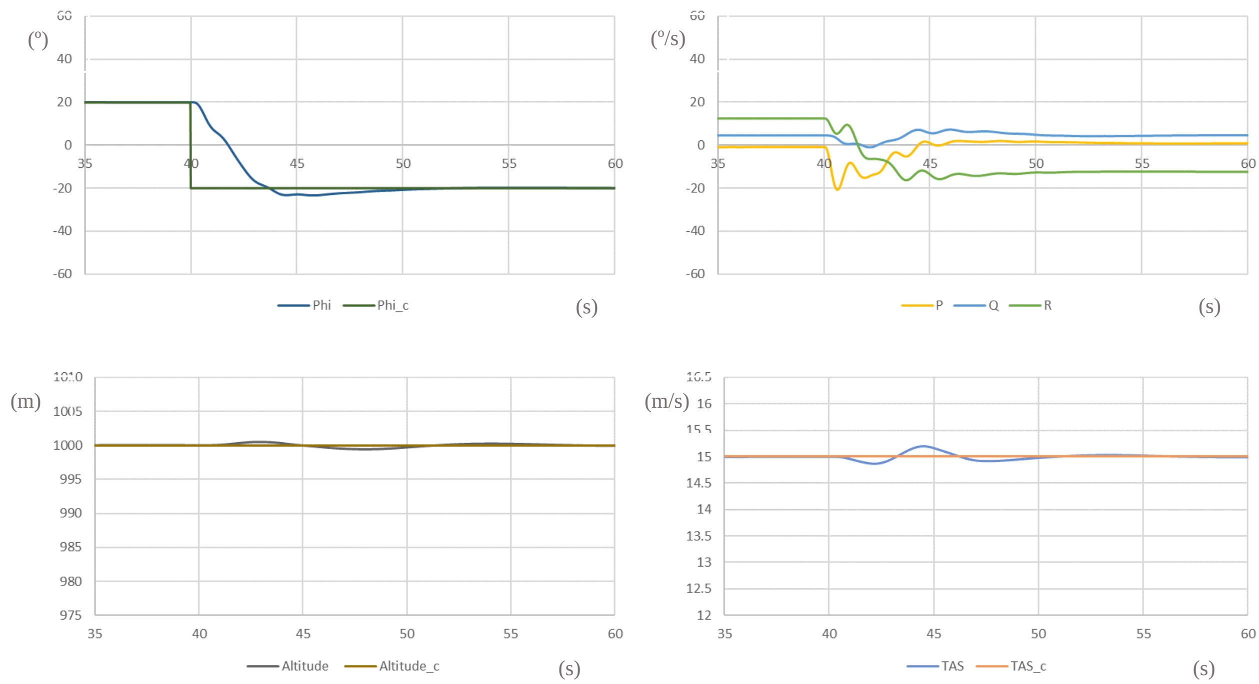

Figure 7.3-1. Roll, angular speed, altitude and TAS in the roll angle test

These graphs show the evolution of roll angle versus commanded roll angle, angular speed (P, Q, R), altitude versus commanded altitude and pitch angle (theta). The aircraft starts this test since an orbit and perform an orbit in opposite way. The effect of altitude change is small, and altitude remains approximately constant. The variation over the speed is small along all the manoeuvre.

7.4 AI powered Mode test

If the system works with the AI powered mode on, the algorithm is constantly trying to detect elements in the picture in real time. In case of a positive detection, the algorithm waits for the pilot to validate the target, and then starts to track it and generates references to the guidance system, so as the UAV get closer to it improve the quality of the images and send the target's GPS coordinates to ground.

In this test the system has detected a boat and the pilot has confirmed the target. The aircraft gets closer to the boat and orbits above its position.

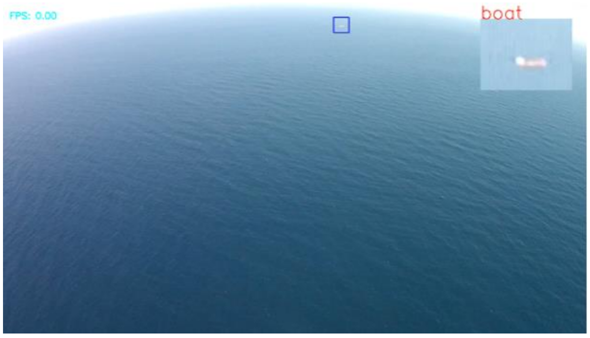

Figure 7.4-1. Target confirmed

When a target is validated, the aircraft goes towards it and track it. In the eventuality of the target is stopped, then the aircraft orbits around it at constant altitude.

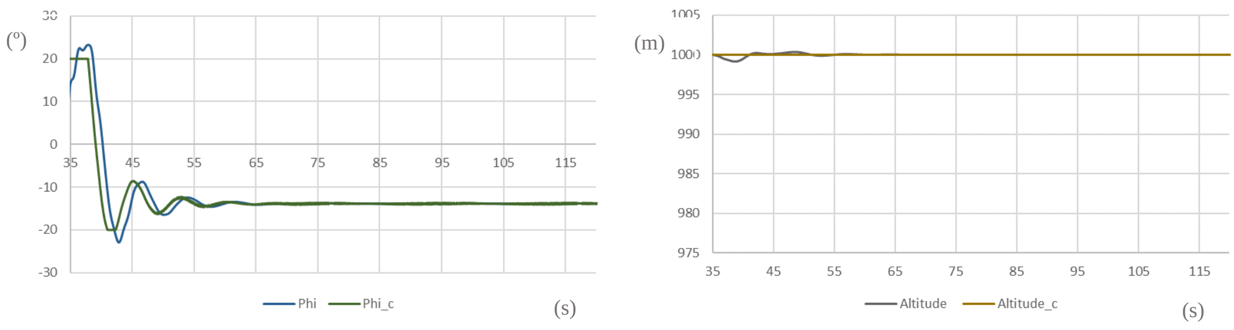

Figure 7.4-2. Roll and altitude in the AI-powered mode test

These graphs show the behaviour of actual and commanded roll and the behaviour of the altitude. The reference altitude remains constant, and the actual altitude shows small deviations with respect to commanded altitude.

The graph below shows the trajectory followed by the aircraft during this test.

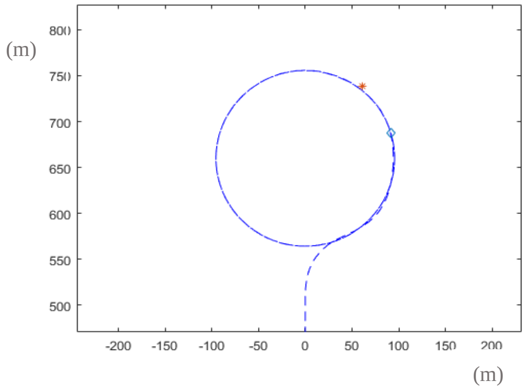

Figure 7.4-3. Trajectory in the AI-powered mode test