MAAMA

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1 Introduction

MAAMA; the Multi-purpose Autonomous Aerial Monitoring Aircraft. In the past years there has been a significant interest in the design and operation of small UAVs as evidenced by the various conferences and scientific journal contributions dedicated to UAVs. However, most UAVs are dedicated to performing one specific task. A real challenge is at hand in designing an unmanned aircraft that is capable of performing a variety of missions ranging from hurricane research to traffic control to sea rescue assistance.

2 Project objective and design requirements

The project objective of the MAAMA is best described as:

"Design a small autonomous aircraft that is capable of performing a variety of sensing and monitoring tasks under severe weather conditions"

The design specifications of the MAAMA are:

Design Parameter	Value
Dimensions	Span < 5m, Length < 4m
Payload	8 kg
Payload bay capacity	10 liters
Deployment time	< 20min
Endurance	5 hr
Range	100 km
Loiter speed	<40km/h (Changed to <72 km/h)
Cruise speed	>120km/h
Operating altitude	100 m – 3000 m ISA
Autonomous flight	Take-off, mission and landing along prescribed track
Total life cycle	> 1000 flights, > 2000 hrs

Table 1 : Design parameters of the MAAMA

3 Concepts and trade-off

Exotic concepts were thought-off but discarded at the start of the conceptual design phase. Two main concepts were seriously considered; a co-axial helicopter and a fixed wing aircraft.

The power required for a co-axial helicopter was found to be considerably larger than that of fixed-wing aircrafts. The RPM of the helicopter blades has to drop below 1000 for optimized power which would make the helicopter less maneuverable, more unstable and have possible problems caused by vibrations. Helicopters have more complex systems than those in aircraft, which translates into an increase in weight and decreased robustness. Furthermore helicopters are inherently longitudinally unstable.

The main advantage of using helicopters is to cope with the low loiter speeds required for traffic monitoring and search and rescue operations. The loiter speed required was increased with analytical proof that a fixed wing aircraft can capture images of a fixed target by encircling it at a maximum velocity of 72 km/h. The helicopter concept was thus discarded.

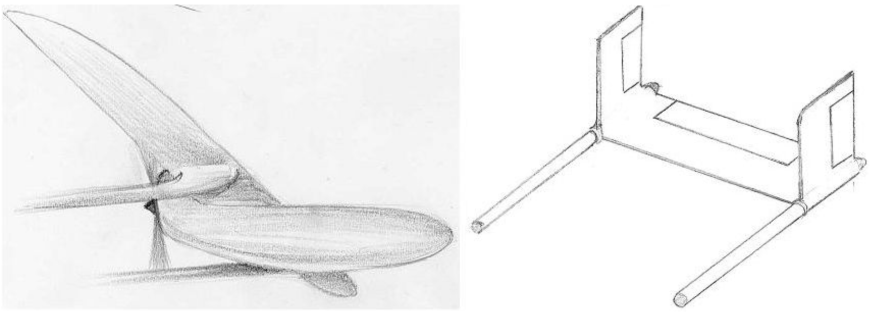

Figure 1: Sketch of conceptual design

After opting for the fixed wing-aircraft concept, different configurations were considered. The chosen configuration was one with a push-propeller mounted above the center line of the fuselage, and twin tail booms attaching a U-tail to the main wing.

4 Final design

In the design of the UAV, many important aspects are taken into account. In this section each of these aspects are briefly treated.

Aerodynamics

The UAV operates at low Reynolds numbers, in the order of 105. Because of that, the flow over the wings will be mostly laminar and as a consequence, occurrence of separation becomes more probable. At low Reynolds numbers, the performance of the lifting surfaces decreases. To partly overcome this problem, a thick airfoil, namely the NACA 4315 (see figure. 13.3), was used for the main wing. For the horizontal tail, the most important requirement is to have the horizontal tail stall after the main wing. A symmetric airfoil, namely the NACA 0015, was therefore used for the horizontal tailplane. To calculate the aerodynamic characteristics of the complete aircraft, the Vortex Lattice Methods (VLM) were used. The model used is given in figure. 2

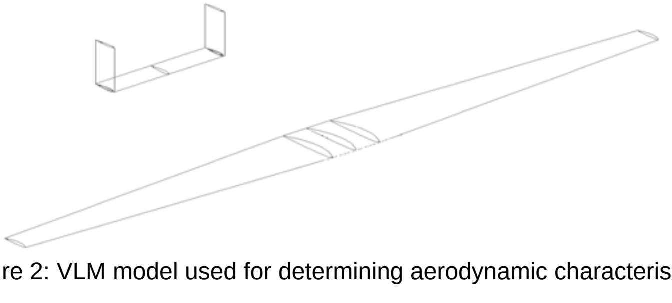

Figure 2: VLM model used for determining aerodynamic characteristics

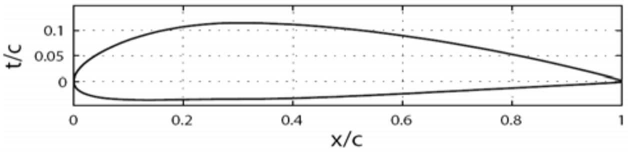

Figure 3: NACA 4315 airfoil

The effect of the propeller on the aerodynamics was also considered. The Propeller slipstream was found to increase the lift produced by the horizontal tail by approximately 25%. Table 1 summarizes the geometrical characteristics of the main wing.

Parameter	Value
Aspect ratio	15
Wing area	0.95m2
Taper	0.4
Airfoil	NACA 4315

Table 2: Wing characteristics

Stability and control

To ensure static longitudinal stability, the center of gravity limits and limits imposed by aerodynamic characteristics were calculated. For calculating the dynamic stability of the aircraft, a VLM model was made, as shown in figure 4. The side of the fuselage was modeled as accurately as possible to take into account the fuselage contribution and wing fuselage interaction. All but the spiral motion were found to be damped. However, it is not uncommon that the spiral motion is a little bit divergent.

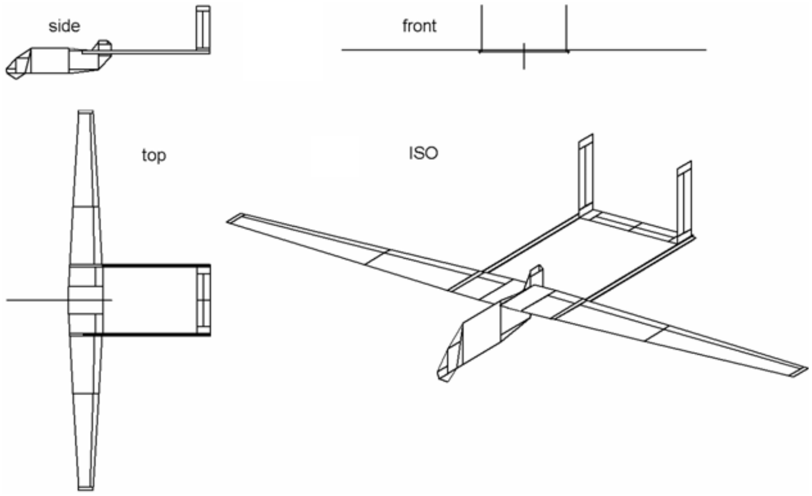

Figure 4: Tornado model of MAAMA

Structures and materials

The fuselage, wing and empennage of the UAV is made out of carbon fiber which is fatigue resistant and has a high specific strength (which makes the aircraft relatively lightweight). Besides sustaining the general flight loads, the structure of the UAV is designed to endure impact from debris and accelerations of over 11gs due to hurricane gusts.

Figure 5: Wing structure

The wingbox is depicted in figure. 13.5. The skin and the webs carry mostly shear stresses so they are made out of -45/45 plied laminates (due to a high shear modulus of this configuration). The stringers on the other hand sustain tensile stresses so they are made of 0/90 plies (since they have a higher Young's modulus). The fuselage structure is constructed in a similar manner.

It should be noted that the skin of the wing is thicker from the connection of the tail booms to the root of the wing. This is done due to the high loads which could be transferred through these booms from the aerodynamic forces on the empennage (see figure. 6).

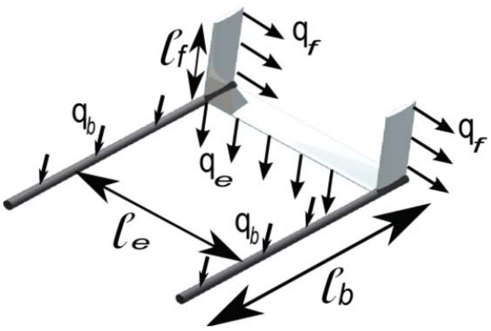

Figure 6: Loads on empennage

The UAV's main wings were analyzed for aeroelastic stability. It was determined that the flutter speed was 200 km/h. figure 7 shows the flutter model.

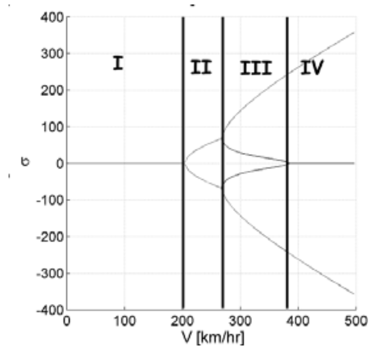

Figure 7: Flutter diagram

Launch and recovery

To minimize the drag during mission, the aircraft can takeoff without a landing gear, by means of a catapult. The catapult cart grabs the aircraft at strong points on the wing to minimize structural impact. For recovery, the aircraft can fly into a net. To make sure the aircraft can land under severe weather conditions, the aircraft is fitted with a laser guidance system.

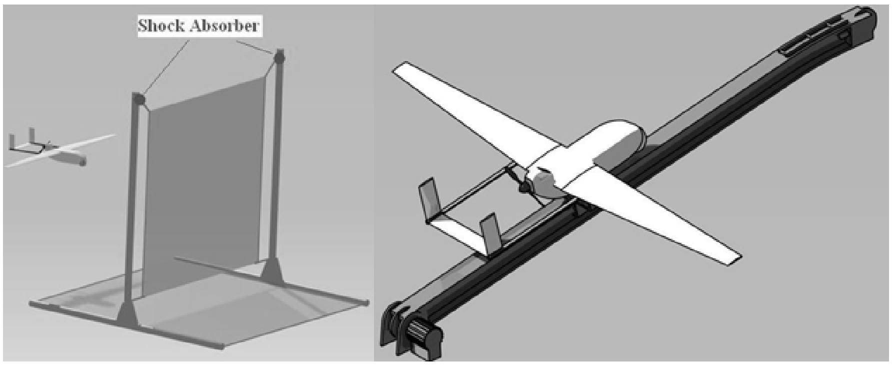

Figure 8: Recovery(left) and launch(right) of the MAAMA

During normal missions for which the extra drag by a landing gear is not important, a landing gear can be screwed on the fuselage and normal runways can be used. Thanks to the powerful engine, the aircraft can take off and land within 500 meters.

Figure 9: Landing gear

Remote Sensing

The UAV is equipped with a visual and infra-red gimbal camera. The tracking device in the infra-red camera offers the possibility to detect a target in the sea even under stormy weather conditions. To distinguish different objects in the water, a method called the Bayesian approach is used. This method is based on dividing the pixels on the IR image in three different classes.

- skin
- covered skin (clothing and hair)
- background (water)

These then can be merged to obtain a high contrast image containing the human and the background. The method can be used under different weather condition as can be seen in figure 10. The contrast in the IR image is high enough to distinguish separate objects from the background.

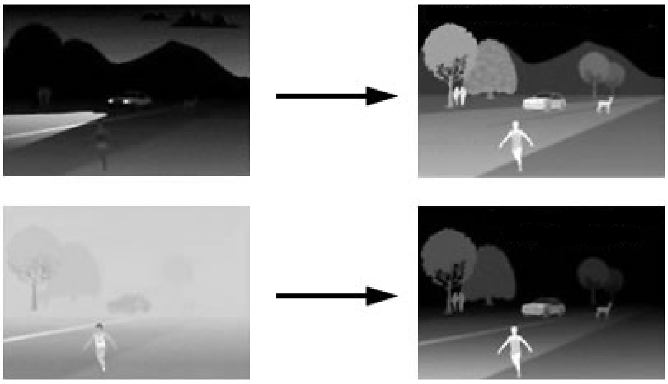

Figure 10: Detection of human at night (top) and in foggy weather (bottom)

The IR camera is important for the SAR mission, but the visual camera is used in traffic monitoring. Loitering at an altitude of 150 m, a high resolution quasi live video is delivered to the traffic control authorities to gain insight of the situation.

Simulation build up

To build up a complete simulation of a flight into the hurricane four main elements (hurricane model, aircraft response, and autopilot and flight path) are needed. These elements all provide their own information based on inputs from other blocks. Because of this interlinking of elements a loop is created which can be run for a specific amount of time steps. This loop can be seen in figure 11.

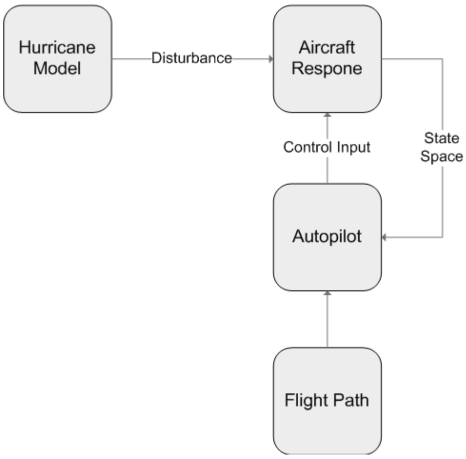

Figure 11: Simulation build up

The hurricane model and the autopilot are discussed below, while the aircraft response is based on the linearised equations of motion using the control and stability derivatives obtained from using the VLM model.

Hurricane Model

To have an idea about the hurricane environment and the effect it has on the aircraft, an idealized hurricane model was created. This model used a convective scheme based on subcloud-layer entropy equilibrium. First a radial cross-section, giving the wind speed and directions, was created. Secondly, using this cross-section a threedimensional model was made. Finally, gusts were added to this model of sustained winds and the hurricane was given a groundspeed. The final model was used in determining the flight path and gave a first estimate of the gust wind speeds and the loads caused to the aircraft structure.

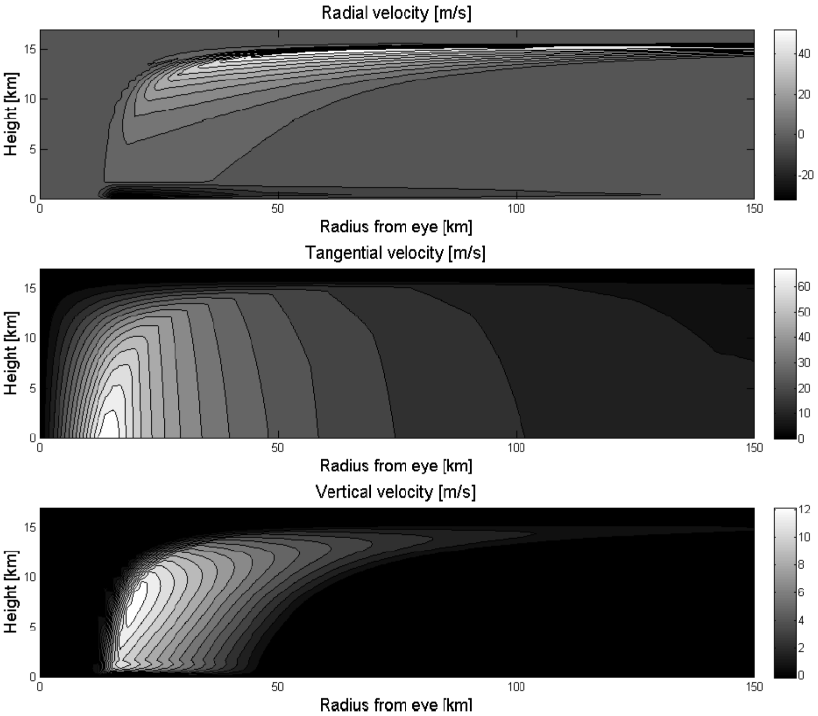

Figure 12: Velocity profile of hurricane model

Auto-pilot

To perform a successful simulation inside a hurricane, an autopilot is needed to keep the aircraft on track and make it fly to the eye of the hurricane. To design the autopilot the following approach was chosen:

To represent the aircraft dynamics the linearised equations of motion in the state-space format are used.

Reduce the system from a MIMO (multiple input multiple output) system to SISO (single input single output) systems.

PID (proportional integral derivative) controllers were designed for the SISO systems.

A PID tuning program was created in the Matlab environment. An example of the results obtained with this program is shown in figure. 13.13.

The optimized SISO controllers are combined in the full MIMO model.

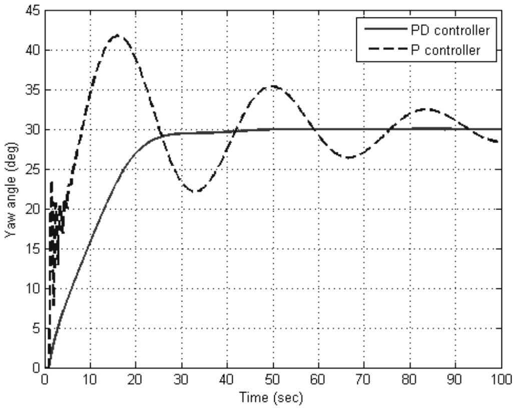

Figure 13: Response to yaw angle step input

Figure 13 shows the response of the yaw angle when a step input of 30 degrees is given on the desired value for the yaw angle. The P-controller is derived from a root-locus analysis and optimized to a PD-controller with the help of the PID tuning program.

Simulation results

In figure 14 the result of the simulation can be seen. By implementing a flight path which consists of three parts, a complete hurricane research mission simulation is created. First the aircraft flies towards the hurricane, which it does by pointing the thrust vector towards the eye (by using the autopilot). Once it is in the eye the UAV starts loitering in a spiral to obtain the atmospheric data needed for the mission. These two parts are shown in figure 13.4. Returning to the landing zone is also part of the simulation and is done in an identical manner.

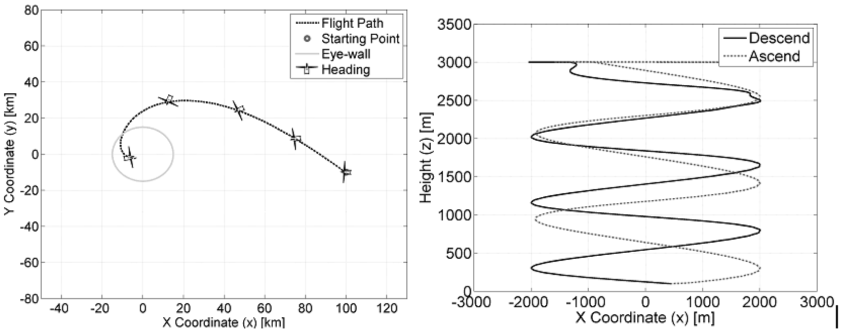

Figure 14: Simulation of flight path. Flight to eye-wall (left) ;
Flight within eye-wall(right)

5 Summary

Figure 15: Final design, rendered to scale.

The MAAMA is a robust and a very stable platform that can handle high structural loads caused by severe weather conditions. It is fully autonomous, able to take-off, perform a mission and land just by using a pre-set flight path. The control system is optimized to react effectively to inputs by adjusting the gains using a tuner for its PID controller. The MAAMA can be launched and recovered from ships or narrow areas using a catapult launch and net-recovery system. Its ability to fly into a hurricane makes it useful for atmospheric research, while its capability of loitering for 5 hrs makes it an asset in sea rescue and traffic monitoring operations.