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A Fixed-wing UAV Capable of Vertical Take-off and Landing for Aerial Mapping and Photogrammetry.

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DAS 5511: Projeto de Fim de Curso

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DAS 5511: Projeto de Fim de Curso

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Curso de Engenharia de Controle e Automação

Prof. Ubirajara Franco Moreno

Orientador

Fly, you fools!

J. R. R. Tolkien

Abstract

This work proposes the usage of a VTOL (Vertical Take-Off and Landing) fixed wing aircraft for aerial photograpy and mapping. It entails the gathering of requisites, design, protyping, and testing of the proposed UAV.

Palavras-chave: otimização sem derivada, poços de petróleo, simulação, sintonia automática .

Abstract

Aerial mapping is one task that got revolutionized by the arrival of drones on the latest years. The manual job of taking pictures, printing and assembling them together was changed into putting coordinates into a software, and the pictures into another after the flight.

Depending of the task at hand, the operator can chose a multicopter for smaller areas, or a fixed-wing aircraft for larger ones. Both categories have their quirks: While multirotors are precise and can take-off/land virtually anywhere, their autonomy suffers as they generate all their lift by using propellers, Fixed-wing aircrafts, on the other hand, can cover large areas quickly with a smaller power consumption, but are harder to position, and require larger areas for take-off an landing.

This work prososed an aircraft in between these two worlds. The prototype designed is a tail-sitting fixed-wing aircraft, able to take-off as a multicopter and transition into fixed-wing mode for more efficiency, enabling it to cover larger areas while needing a small area for take-off or landing and no additional apparatus for take-off.

results!

Keywords: derivative-free optimization, oil well, simulation, automatic tuning.

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1 Introduction

1.1 Motivation

Technology and auomation have been changing and improving a lot of tasks on last few decades. One of the tasks is aerial mapping, which started with balloons, then manned airplanes, and now, for smaller areas, is done mostly with drones

citation needed, improvent needed

1.2 Objectives

The final objective of the work is to have a working prototype of a VTOL fixed-wing UAV able to autonomously take off vertically, transition into fixed-wing mode, follow a planned path taking pictures, transition into hover mode, and land autonomously. It's planned to have a smaller prototype to test and tune the hover mode before testing the larger, heavier and more powerful final prototype, for safety and practicity reasons. The possible on-board electronics will be briefly described and one of them chosen. An overview will be given of the control systems in place and their tuning. The requisites for the job will be gathered, and the eletro-mechanical structure designed and built around it. It's expected that the prototype fulfills the hole between rotating-wing and fixed-wing aircraft by being able to land in tight spaces, but having a perfomance close to that of fixed-wing aircrafts.

1.3 Structure

This report is structured in 5 chapters. Chapter 1 gives an introduction to the report. Chapter 2 describes the fields of aerial mapping and photogrammetry. Chapter 3 explains the requisites imposed on the aircraft. Chapter 4 delves into the flight mechanics and the UAV's mechanical design. Chapter 5 shows the electronics involved. Chapter 6 shows the control structure and it's tuning.

2 Aerial Mapping and Photogrametry

2.1 The need for mapping the land

The first known map (actually a painting of a city) dates up to the 7th millenium BCE,[1], while the oldest surviving world maps are from 9th centursy BCE Babylonia[2].

In the past, maps were used mostly for localization and navigation [citation needed], and were made without special tools, mainly by sight. During the Age of Exploration, new tools such as the sextant and magnetic compass helped improve accuracy, while remaining as a navigational tool.

On the last centuries, maps began being used to precisely map properties, natural landscapes, and cities. Mapping properties, for example, requires high dimensional accuracy, hard to get with regular tools. This is usually the job of land surveyors, professionals who use a multitude of tools, such as total stations, robotic total stations, GPS receivers, retroreflectors, 3D scanners, radios, handheld tablets, digital levels, subsurface locators, drones, GIS, and surveying software.

2.2 Aerial Mapping

Aerial mapping consists of using photographs taken from the air, usually with the camera facing straight downwards, correcting the perspective transformation, and assembling them into an orthomosaic, as seen on Figure 1.

2.3 Aerophotogrammetry

Aerophotogrammetry takes the job on step further. By knowing the cameras lens intrinsics, software are capable of matching a number of pictures, detecting features on the environment, and locating the point used to take each of the pictures. With this information, it's possible to rebuild in 3D most of the environments, enabling the operator to interact with the area as a 3D mesh. By using precise GPS information(such as RTK/PPK data, or total stations) or known landmarks, it's possible to accurately measure distances, areas, volumes, angles and elevations, simplifying the surveyors' job.

Aerophotogrametry can also rebuild in 3D buildings and other structures,

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1 Stephanie Meece (2006). "A bird's eye view of a leopard's spots. The Çatalhöyük 'map' and the development of cartographic representation in prehistory". Anatolian Studies. 56: 116. JSTOR 20065543.

2 Kurt A. Raaflaub; Richard J. A. Talbert (2009). Geography and Ethnography: Perceptions of the World in Pre-Modern Societies. John Wiley & Sons. p. 147. ISBN 1-4051-9146-5.

Figure 1 – Orthomosaic. source: Indonesian Redcross/OpenAerialMap

3 The Requisites

3.1 Objective

The final objective of the work is to have a working prototype of a VTOL fixed-wing UAV able to autonomously take off vertically, transition into fixed-wing mode, follow a planned path taking pictures, transition into hover mode, and land autonomously. It's expected that the prototype fulfills the hole between rotating-wing and fixed-wing aircraft by being able to land in tight spaces, but having a perfomance close to that of fixed-wing aircrafts.

3.2 Requisites

For the design, a few conditions have been imposed by the available material and desired performance:

- The flight time should be between 1 and 2 hours.
- The cruise speed must be around $15m/s$.
- The batteries used will be 6s lithium-polymer packs of XXXXX mAh. capacida
- The motors should preferably be the ones already in use at the company, MK3538, Mk3638, or MK3644
- The UAV must be able to take of and land autonomously.

3.3 Functional Requisites

4 Flight Mechanics and Design

4.1 Brief Introduction to Flight Mechanics

Flight mechanics deal with a vehicles interaction with propulsional, aerodynamic, and gravitational forces.

In order to achieve proper flight, a vehicle needs an upwards force, and means of maneuverability.

4.2 Fixed-Wing Mechanics

In fixed-wing aircrafts, the force responsible for cancelling the gravitational pull and keeping the vehicle aloft is the lift generated in the wings.

In a simplified explanation, two main principles are responsible for generating lift:

4.2.1 Flow deflection and Newton's laws

Most wings have an angle of attack (to be hereafter called α) such that $\alpha > 0$, which means the air passin through it gets deflected down. According to Newton's second law, an opposite force is necessary on the wing. This force is the generated lift.

4.2.2 Increased flow speed and Bernoulli's principle

Bernoulli's principle states that within a steady airflow of constant energy, when the air flows through a region of lower pressure it speeds up and vice versa. Implying there is a direct mathematical relationship between the pressure and the speed, meaning if one knows the speed at all points within the airflow, on can calculate the pressure and vice versa. For a cambered airfoil (where the chord at the top is longer that the chord at the bottom) the/home/will/Pictures/Screenshot from 2017-11-13 11-03-27.png air needs to take a longer path, moving faster, thus lowering the pressure on the top, and generating lift.

4.2.3 Airfoil Shape

How much lift is generated depends on the chosen airfoil. An cambered airfoil (longer chord on the upper surface than in the lower one) generated lift even when the angle of attack α is zero. Simmetric airfoils need a positive angle, and the lift is generated by deflecting the air downwards. Other properties that depend on the airfoil shape are

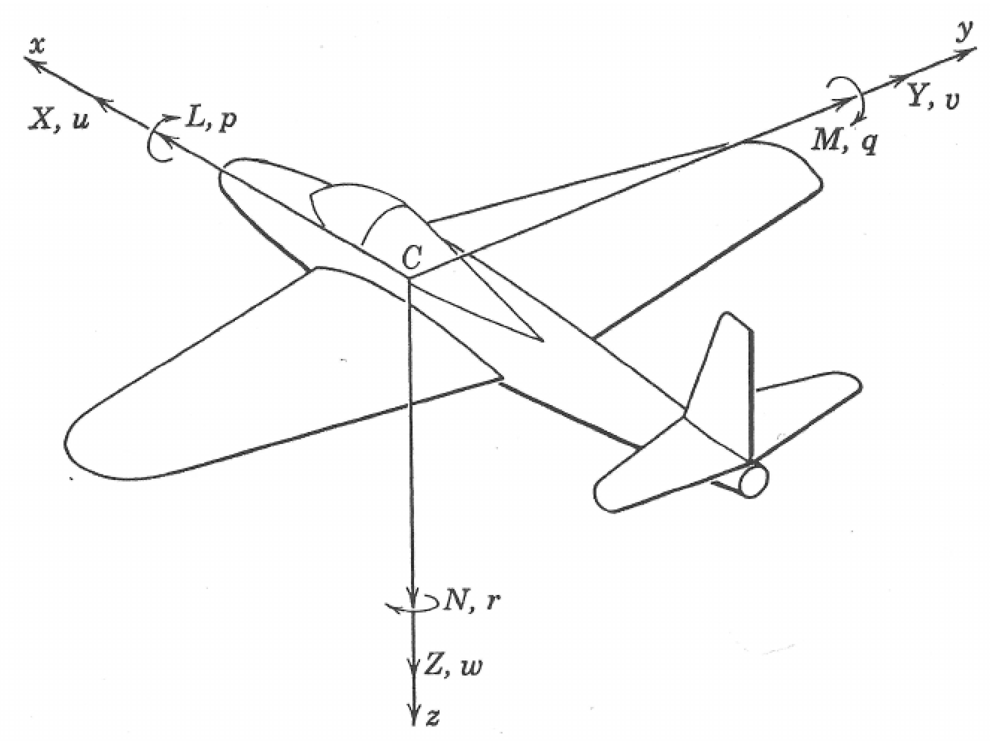

Figure 2 – Coordinates system and relevant variables.

the drag (air force pushing agains the direction of movement) and angular moment it generates on the aircraft.

4.2.4 The Coordinate System and Nomenclature

The coordinate system, when dealing with the fixed-wing mode, is as shown in figure 2

Where:

- x, y, and z are the coordinates, with the origin in the vehicle's center of mass.
- u, v, and w are the linear velocities in each of the x, y, and z coordinates, respectively.
- X, Y, and Z are the components of the aerodynamic force in each of the x, y, and z coordinates, respectively.
- p, q, and r are the linear velocities in each of the x, y, and z coordinates, respectively.
- u, v, and w are the linear velocities in each of the x, y, and z coordinates, respectively.

- Although not indicated in the figure, the variables ϕ, θ, ψ represent the angular rotations, relative to the equilibrium state, about the x, y, and z axes, respectively. Thus, $p = \dot{\phi}$, $q = \dot{theta}$ and $r = \dot{\psi}$ where the dots represent time derivatives.

  ϕ, θ, and ψ can also be referred, respectively, as *roll*, *pitch*, and *yaw*.

4.3 VTOL Mechanics

4.4 XFLR5

XFLR5 is an analysis tool for airfoils, wings and planes operating at low Reynolds Numbers. It includes:

- XFoil's Direct and Inverse analysis capabilities;
- Wing design and analysis capabilities based on the Lifiting Line Theory, on the Vortex Lattice Method, and on a 3D Panel Method.

  This tools enables the iterative design and analysis of multiple aircraft configurations.

elaborar aqui

4.5 Design

The chosen design is the one of a flying wing, a fuselage-less made of a wing, propulsion system, and control surfaces. The reasons are because of a simpler and sturdier mechanical strucutre, besides the possibility of the VTOL configuration

4.5.1 Preliminar Design

As a starting point, a wing with a central hub and 2 semi-wings ending in symmetrical winglets was designed. The ZAGI12 airfoil was chosen due to it's good soaring capabilities and low stall speed . citation needed

With the airfoil chosen, It's characteristics were calculated with the aid of XFOIL, an airfoil analysis tool built into XFLR5.

These characteristics plots can be seen on figure 4.

It can be noted that the point with the highest Cl/Cd ratio, the theoretical point with better lift to drag ratio, and therefore best gliding performance. It's also notable that the airfoils moment "pulls" it into this better Cl/Cd ratio, allowing the aircraft to fly into this ideal condition without deflection of the control surfaces

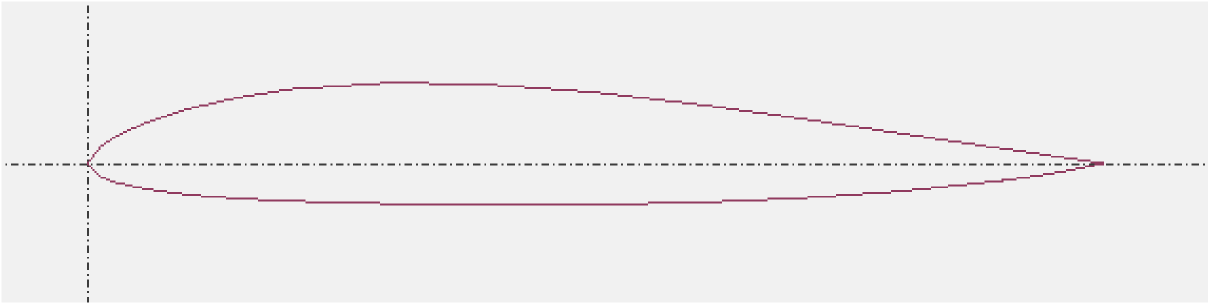

Figure 3 – Zagi 12 airfoil.

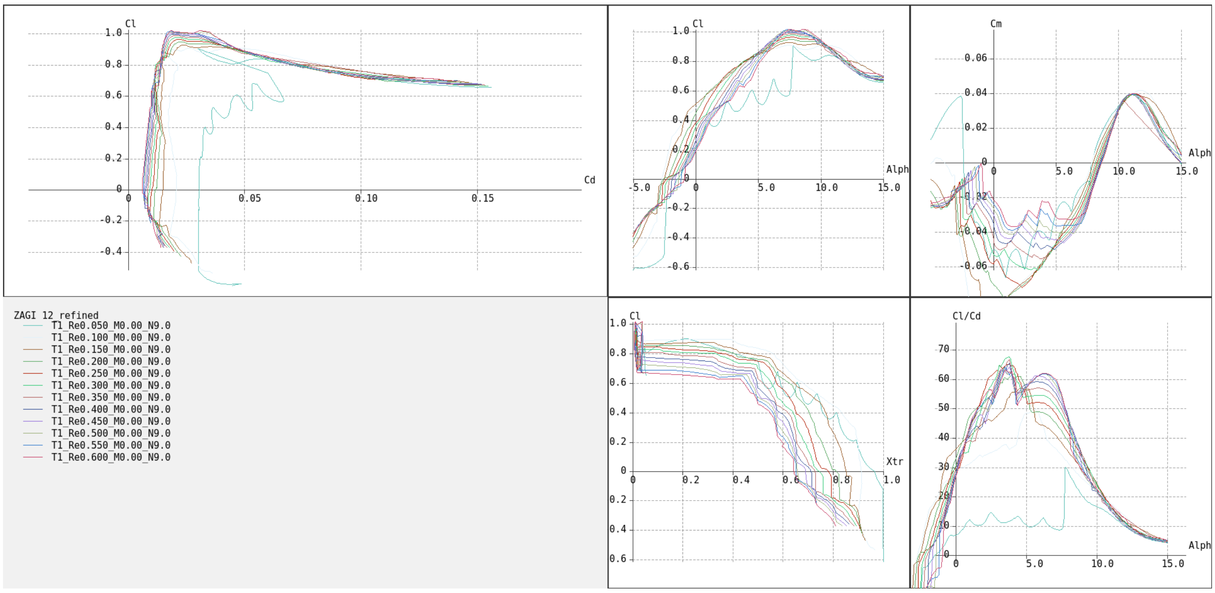

Figure 4 – Zagi 12 characteristics

With that data, the main body was conceived, as seen in the figure 5. With this CAD tool we can then analyze the performance of the aircraft as a whole. This gives us the same data as the airfoils', but for the whole craft, as seen in figure 6.

Some data can be infered from these graphs. From 4 it can be seen that the highest C_l, or Lift Coefficient, is obtained around $\alpha = 8\,\text{deg}$, which, possibily by design, is also the zone with a higher C_l/C_d, or *lift-to-drag ratio* maximizing the gliding distance. It's also notable tat the $C_m \times \alpha$ plot crosses 0 around the the same $8\,\text{deg}$, meaning the profile is always trying to point at that angle.

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4.5.2 D

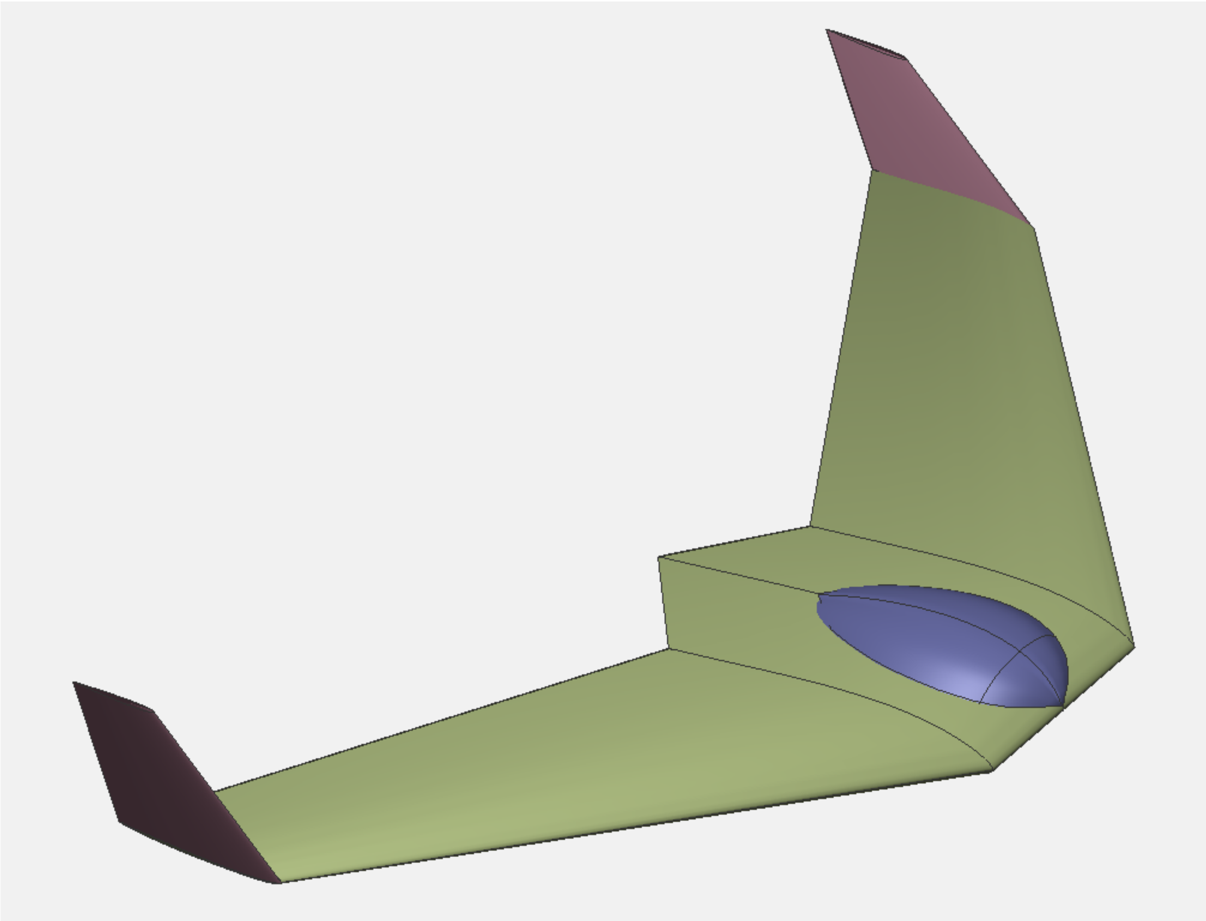

Figure 5 – First concept of the aircraft.

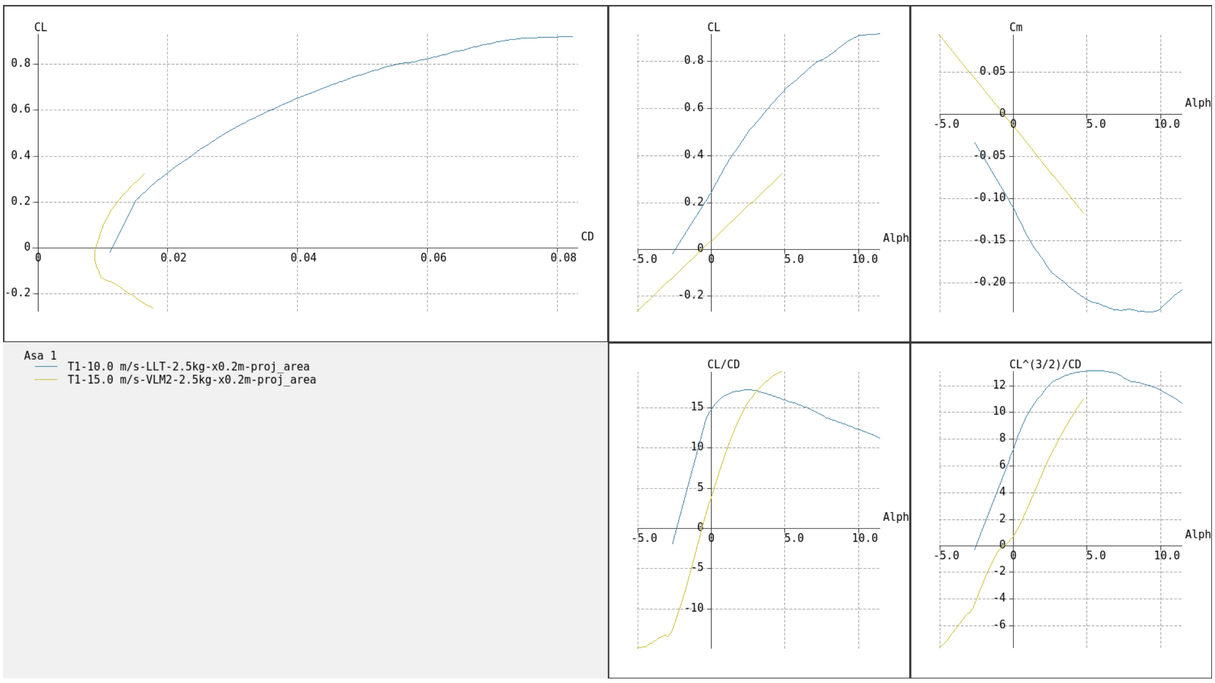

Figure 6 – Flight characteristics of the preliminar aircraft design.

5 The Eletronics

In order for the aircraft to fly and navigate autonomously, onboard electronics are required, for both actuation, power source, and navigation. Some of the used electronics was already available, and was chosen for this reason.

5.1 Propulsion

Due to the familiriaty and availability, the Mikrokopter Mk3538 Motor was chosen, paired with E-Max Simon 60A escs.

Experimental curves for the motor are available at Mikrokopter's website, and the relevant ones are reproduced on Figure 7. Each motor should give, on 25 V, at least 2.2kg of static thrust.

5.2 Batteries

The Batteries are also the ones already in use by the company, .

tamanho da bateria?

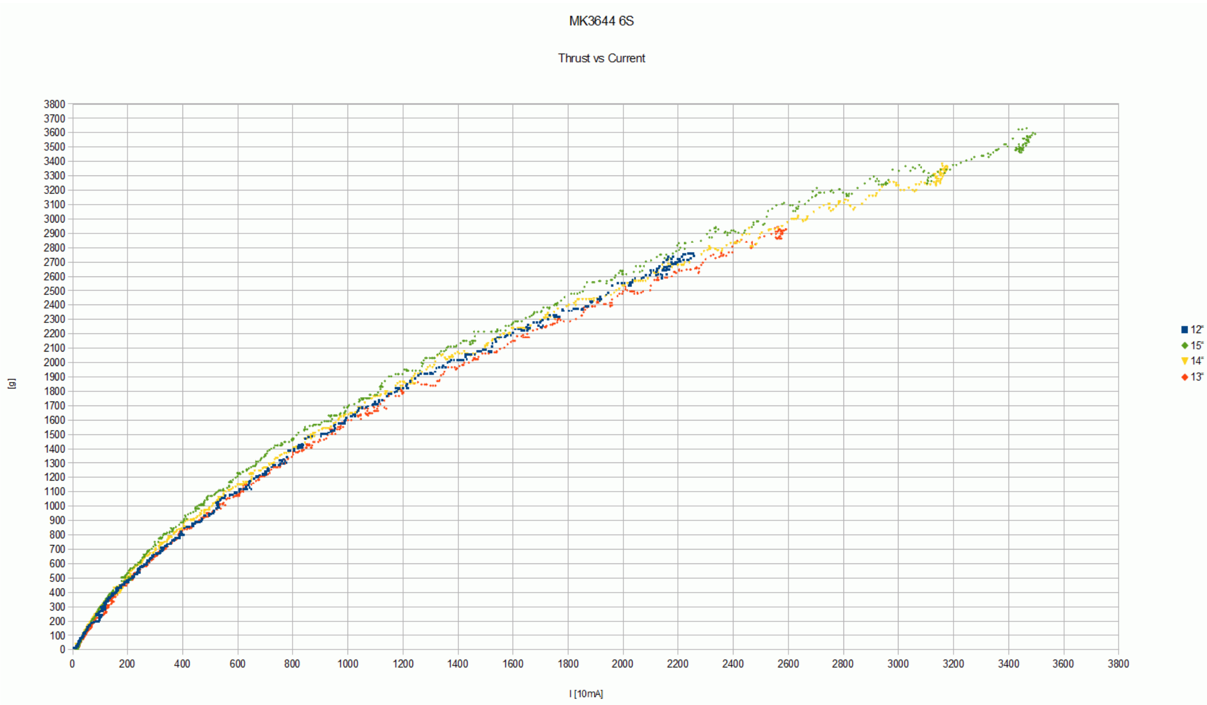

Figure 7 – First concept of the aircraft.

5.3 The Control Surfaces

The control surfaces must be slightly larger than usual for a flying wing, as on a tail-sitter a reasonable ammount of air must be deflected on hover situation, while on most wings a steady airflow is assumed.

5.4 The Flight Controller

The Flight Controller is a PixHawk, running latest Beta release of ArduPlane, where there's experimental support for tail-sitters.

6 The Control Structure

The control Structure used is the one of ArduPlane, in hover, or tail-sitter mode, the ArduCopter stabilization system is used, while in airplace/fixed-wing mode, Arduplane's controllers are used. Both will be discussed and explained in the following sections.

6.1 On Airplane Mode

On Airplane mode, the aircraft is always moving forward, towards the X axis, position control depends on defining a route and pointing the aircraft in order to remain on it.

6.1.1 Roll and Pitch Control

The roll and pitch control loops (seen on Figure 8) are responsible for keeping the aircraft on the desired orientations on the X and Y axis. Usually, roll is controlled by turning the elevator up and down, while roll is controlled by the deflecting the ailerons. On this aircraft, however, there are only two control surfaces, such that the output of both controllers are summed (mixed, and is usually used in the RC world) in order to control both axis at the same time. While at first they look like a classical P+I+D controller, there are some small changes:

- There's a feedforwar controller trying to cancel the current angular rate $\dot{\phi}$
- The Derivative and Integral terms and scaled to the airspeed, and the controller's ouput aswell. This is because as the aircraft moves faster, less deflections is necessary for the same movement of the body.

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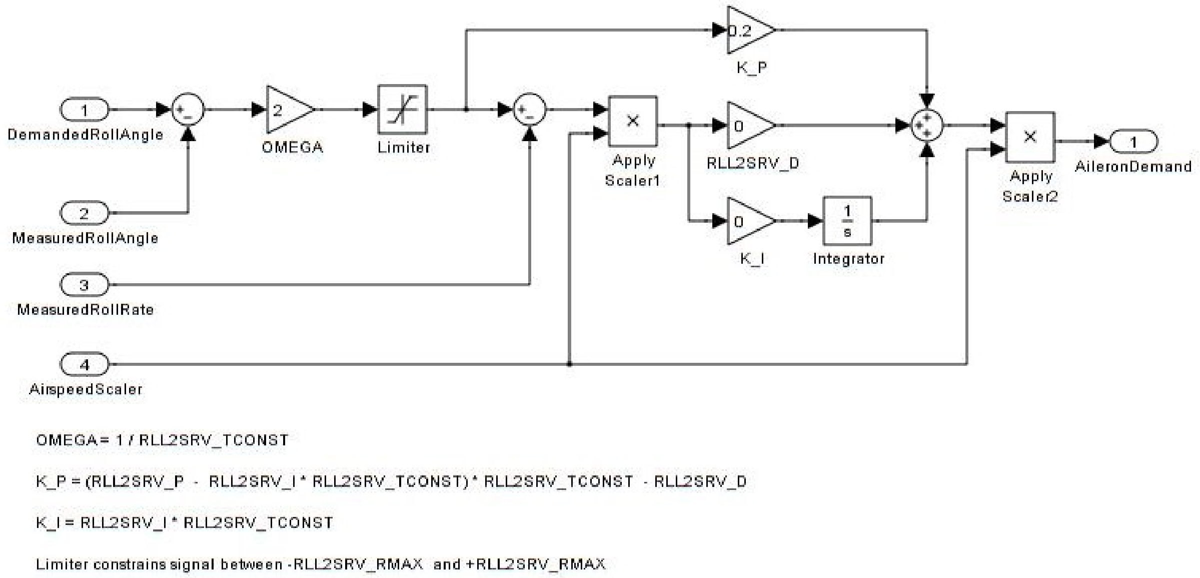

Figure 8 – Roll control loop.

6.1.2 Yaw Control

The Yaw Control loop controls the angle around the Z axis, ψ. This is usually used for landing only, and is not used on this aircraft on airplane mode. It can, however, be seen on Figure 9. Like the D and I terms on the roll axis, the controller's output is again scaled with the square of the AirspeedScaler factor. dafuq?

6.1.3 Navigation: L1 Controller

Since a fixed-wing aircraft usually can't fly in-place, waypoints can be used in two general ways, the aircraft can fly around it in circles, or hit it and then follow to the next one.

In order to circle it, a PD controller is used

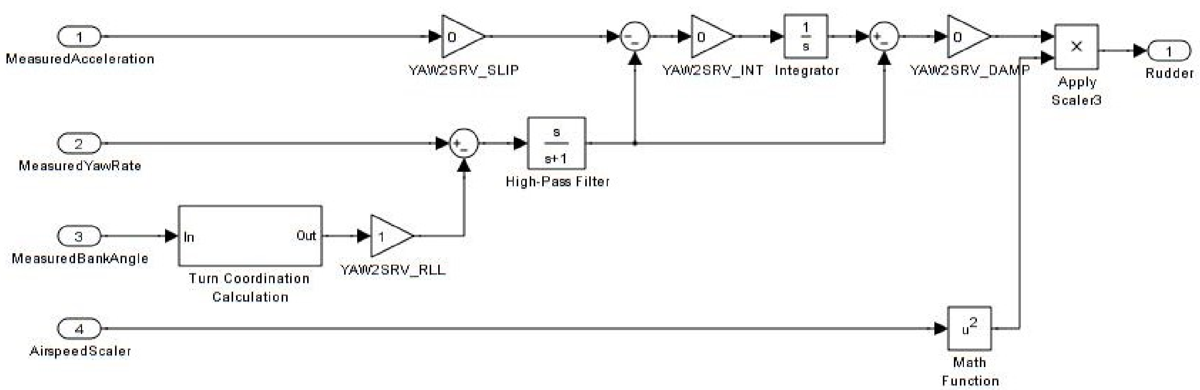

Figure 9 – Yaw control loop.

7 The Prototype

8 Conclusions