

DAS Departamento de Automação e Sistemas
CTC Centro Tecnológico
UFSC Universidade Federal de Santa Catarina

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

*Relatório submetido à Universidade Federal de Santa Catarina
como requisito para a aprovação da disciplina:
DAS 5511: Projeto de Fim de Curso*

Willian de Medeiros Galvani

Florianópolis, Junho de 2017

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

Willian de Medeiros Galvani

Este relatório foi julgado no contexto da disciplina

DAS 5511: Projeto de Fim de Curso

e aprovada na sua forma final pelo

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 photography and mapping. It entails the gathering of requisites, design, prototyping, 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.

List of Figures

Figure 1 – Orthomosaic. source: Indonesian Redcross/OpenAerialMap	10
Figure 2 – Coordinates system and relevant variables.	13
Figure 3 – Zagi 12 airfoil.	15
Figure 4 – Zagi 12 characteristics	15
Figure 5 – Zagi 12 characteristics	16

List of Tables

Contents

1	INTRODUCTION	8
1.1	Motivation	8
1.2	Objectives	8
1.3	Structure	8
2	AERIAL MAPPING AND PHOTOGRAMETRY	9
2.1	The need for mapping the land	9
2.2	Aerial Mapping	9
2.3	Aerophotogrammetry	9
3	THE REQUISITES	11
3.1	Objective	11
3.2	Requisites	11
3.3	Functional Requisites	11
4	FLIGHT MECHANICS AND DESIGN	12
4.1	Brief Introduction to Flight Mechanics	12
4.2	Fixed-Wing Mechanics	12
4.2.1	Flow deflection and Newton's laws	12
4.2.2	Increased flow speed and Bernoulli's principle	12
4.2.3	Airfoil Shape	12
4.2.4	The Coordinate System and Nomenclature	13
4.3	VTOL Mechanics	14
4.4	XFLR5	14
4.5	Design	14
4.5.1	Preliminar Design	14
4.5.2	D	15
5	THE ELETRONICS	17
5.1	Propulsion	17
5.2	Batteries	17
5.3	The Control Surfaces	17
5.4	The Flight Controller	17
6	THE CONTROL STRUCTURE	18
7	CONCLUSIONS	19

1 Introduction

1.1 Motivation

Technology and automation 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,
im-
provement
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 practicality 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 electro-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 performance 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 its tuning.

2 Aerial Mapping and Photogrammetry

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 Babylonia².

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.

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

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. 
- 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

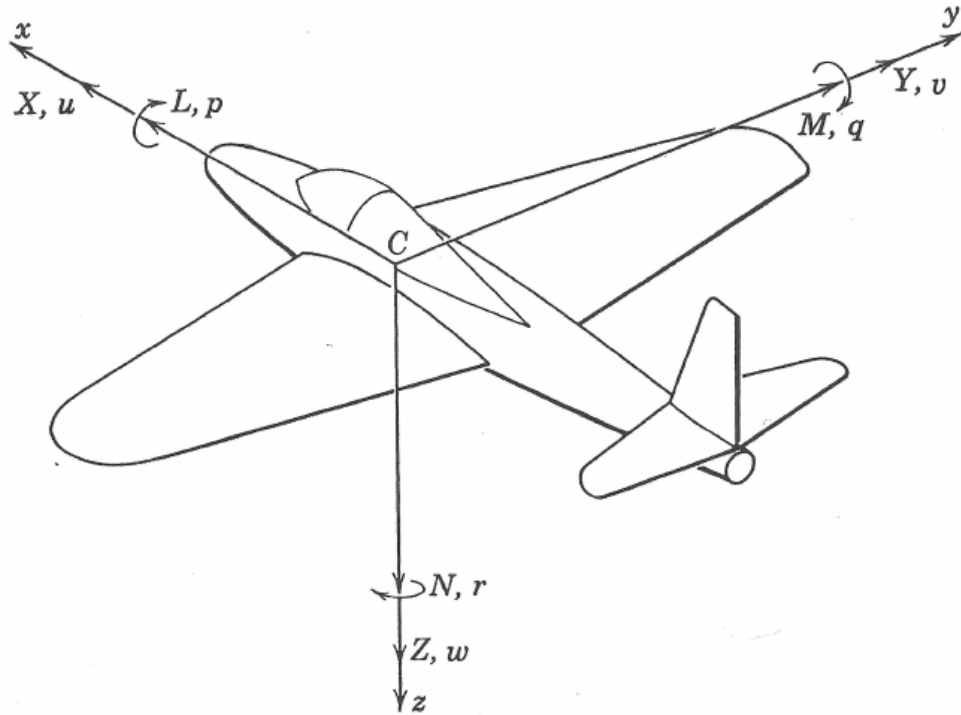


Figure 2 – Coordinates system and relevant variables.

the drag (air force pushing against 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 *yaw*, *pitch*, and *roll*.

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 Lifting 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 structure, 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

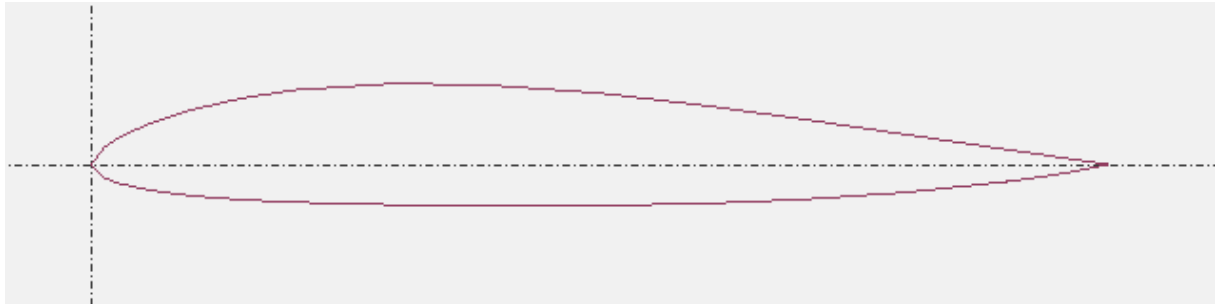


Figure 3 – Zagi 12 airfoil.

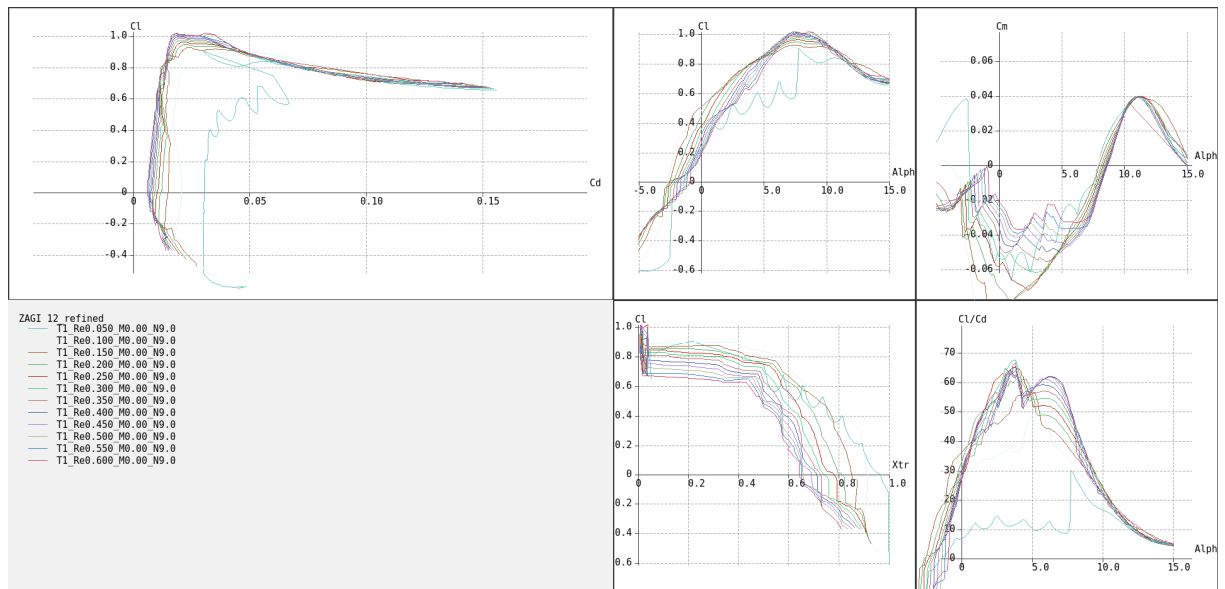


Figure 4 – Zagi 12 characteristics

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.

4.5.2 D

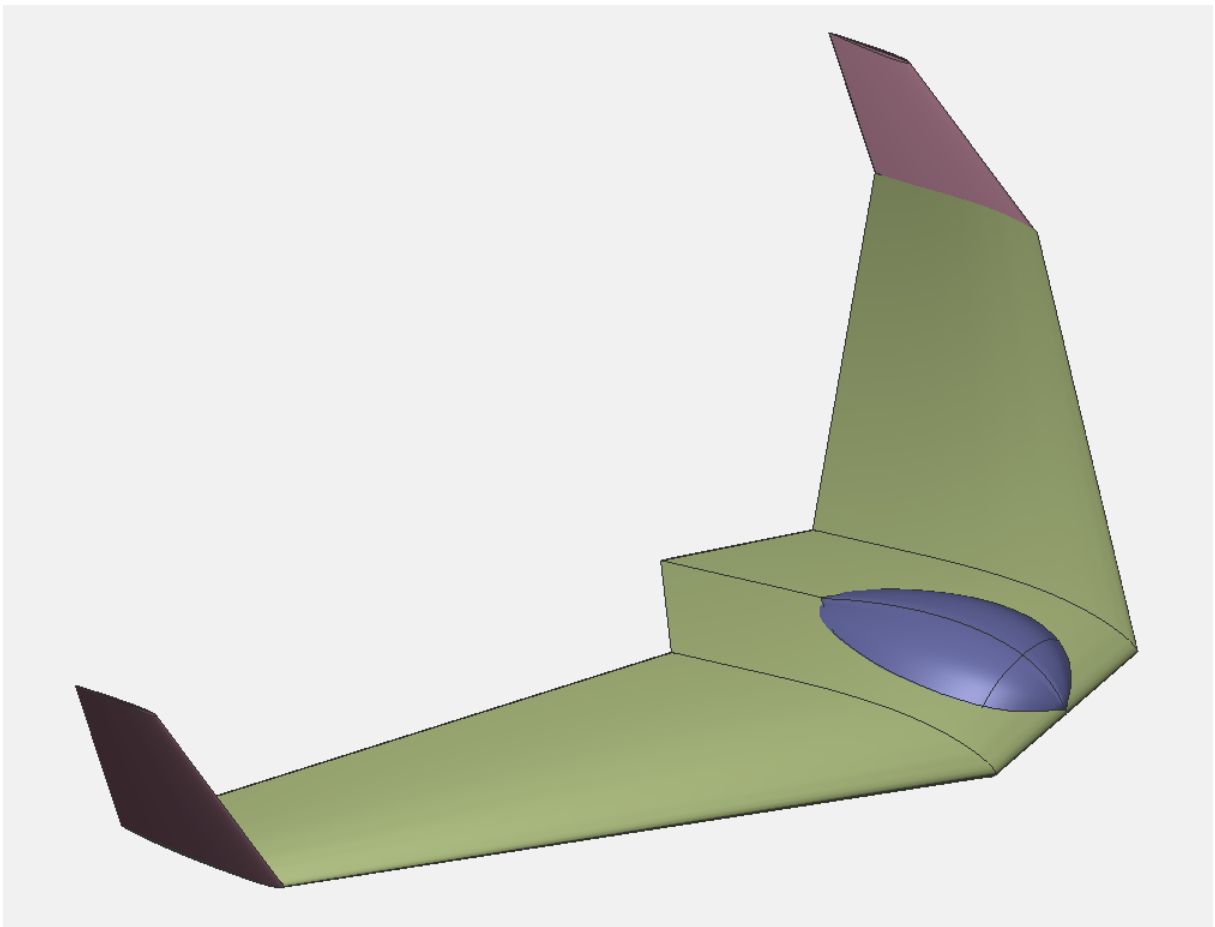


Figure 5 – Zagi 12 characteristics

5 The Eletronics

5.1 Propulsion

5.2 Batteries

5.3 The Control Surfaces

5.4 The Flight Controller

6 The Control Structure

7 Conclusions