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Executive Summary of the Thesis

Conceptual and preliminary design of a double-wing hybrid-electric VTOL

Laurea Magistrale in Aeronautical Engineering - Ingegneria Aeronautica

Author: Andrea Romani

Advisor: Prof. Lorenzo Trainelli

Co-advisor: Prof. Carlo E. D. Riboldi

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1. Introduction

A growth of interest for urban air mobility is leading to a rapidly increasing development of this new sector of aviation. Along with UAM development, the need for hybridization of aviation field is becoming more and more dominant in the design process of new aircraft. Following the request for proposal of the client (*B Robotics W Srl.*), this work takes up the challenge of designing ***VELA***: a two seater hybrid-electric compact aircraft capable of vertical takeoff and landing operations, whose intended use is mainly for personal transportation over medium distances. The need to merge peculiar characteristics, such guaranteeing vertical takeoff and landing while remaining within strict sizing constraints, leads to the adoption of a peculiar design with a double foldable wing and 6 propeller, 4 embedded in the wings and 2 tiltable tail propeller.

2. Market Analysis

A careful scouting of the current competitor VTOL concepts and conventional airplanes and helicopters shows the pros and cons of each technology and design. Pure electric VTOLs, although being able to perform zero emission missions, have limited performance (especially range and endurance), large dimensions and high MTOW due to the low specific energy of batteries. Helicopters-like solutions are more compact but have worse performance with respect to airplane-like designs with superior performance, ease of ground movement but bigger size.

2.1. Certification

In the *Second Publication of Means of Compliance with the Special Condition VTOL* released in on 22 December 2022 [1], the European Aviation Safety Agency states all progress done since July 2019 and lists the means of compliance requirements to be certified under the VTOL special condition. For the purpose of this work the most relevant aspect is the definition of allowed VTO and VLND paths. Choosing a high enough transition altitude will allow ***VELA*** to have a correct clearance from nearby obstacles.

3. Mission Requirements

From a series of initial requirements given by the client, certification and safety standards, the sizing mission reported in Table 1 is defined, requirements are later refined after a series of preliminary studies and used as inputs during the initial sizing process as exposed in Section 5.

	End alt.	End dist.	Speed
VTO	250 m	0 km	2.46 m/s
Climb	1000 m	8.64 km	2.46 m/s
Cruise	1000 m	484.9 km	44.44 m/s
Descent	250 m	500.9 km	2.46 m/s
Loiter	250 m	500.9 km	37.9 m/s
VLND	0 m	500.9 km	2.46 m/s

Table 1: Mission Requirements

4. Initial Studies

Using preliminary methods such as steady flight equations and disk actuator theory initial studies are performed regarding: power estimation during VTO phase; analysis of cruise flight condition, with particular attention to cruise speed, wing surface, aspect ratio and weight sensitivity; hovering condition, in particular power estimation for this phase and estimation of jet blast from propellers. Most binding aspects are the power required for VTO (most power demanding condition) and jet blast velocity since it has to be limited not to cause damage and harm to ground structures and personnel. After a sensitivity study of these parameters with respect to number and radius of propellers, these limitation will result in the choice of adopting 6 propeller of 1.2 m diameters each. Moreover a series of regression of specific power and energy of ICE, EMs and batteries as well as weight fraction of different aircraft are performed to have a series of parameters to use in the initial sizing of the VTOL.

4.1. Concepts

Three main concepts have been developed. Each one is representative of a characteristic in terms of dimensions and configuration. The following comparison has the goal to make an assessment of pros and cons of each configuration with respect to the others. To work out a fair estimation of power required, all concepts are assumed to have a 1000 kg weight. Studies are performed using methods previously exposed as well as *OpenVSP* analysis. Most promising concept is the one in Figure 1.

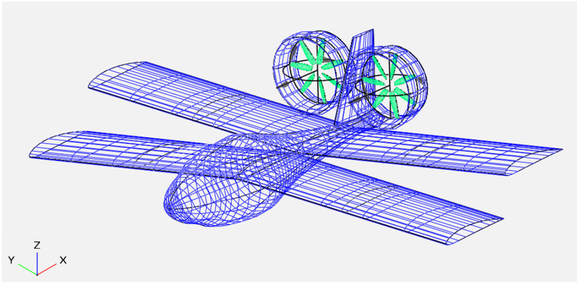


Figure 1: Version 2 concept

The idea behind this configuration, called Version 2, is to have a double wing to reduce span given required wing surface, on each semiwing a propeller of 1.2 m diameter is embedded and two more propellers (tiltable) are placed on the tail. During VTO/VLND phases wing propellers are exposed and tail propellers are pointed vertically, during transition phase the wing propellers close using a system of blinds or caps resulting in a clean profile for cruise and tail propellers align longitudinally to thrust the airplane forward. Tail propellers also replace the horizontal tail since they can be tilted to stabilize the airplane in all phases.

5. Preliminary Sizing

Sizing process has been carried out using a version of Hyperion®, a software developed by the Department of Aerospace Science and Thecnology of Politecnico di Milano and modified by the author of the thesis to take into account the peculiarities of the chosen configuration and mission including vertical takeoff and landing. Since ***VELA*** is an unconventional aircraft, regression models have to be adapted considering its peculiarities. A series of convergence and iteration models on empty weight and wing surface are implemented in order to reach a correct value of power required for all phases, correct constrains and final results in terms of weight and performance of the aircraft. After a further refinement of weight and specific power and energy of ICE, EMs, generator and batteries chosen in Section 6, obtained sizing input and output are reported in Table 2 and 3.

Data	Value
Cruise speed	44.44 m/s
Climbing/descending speed	36.01 m/s
Cruise Alt	1000 m
Loiter Alt	260 m
Loiter time	35 min
ROC	2.54 m/s
ROD	-1.77 m/s
Payload	250 kg
Range	500 km
VTO/VLND vert speed	2.54 m/s
Stall speed	30.35 m/s
Cruise high speed	77.16 m/s
Cruise (high speed) Alt	2000 m
ROC$_{max}$	4.06 m/s
VTO/VLND dist	250 m

Table 2: Input data

Data	Value
MTOW	1108 kg
Wing surface	20.33 m^2
Wing loading	534.6 N/m^2
Power loading	28.7 N/kW
Peak power	378.07 kW
MCP	302.46 kW
PGS power	152.91 kW
EMs power	302.46 kW

Table 3: Sizing output

6. Propulsion System

VELA adopts a serial hybrid electric propulsive layout, the power generation system (PGS) composed of ICE and a generator burns fuel to produce electric energy. This energy can be used, if needed, to directly move the electric motors but normally flows to the battery packs and recharges them during mission phases selected with an appropriate strategy. In the design mission the ICE turns on during climb, cruise, descend and first part of the loiter phase. The energy then flows from BP to a energy and power management system (EPMS) that regulates the energy flow and distributes it to the electric motors. Propulsive layout for the airplane is reported in Figure 2:

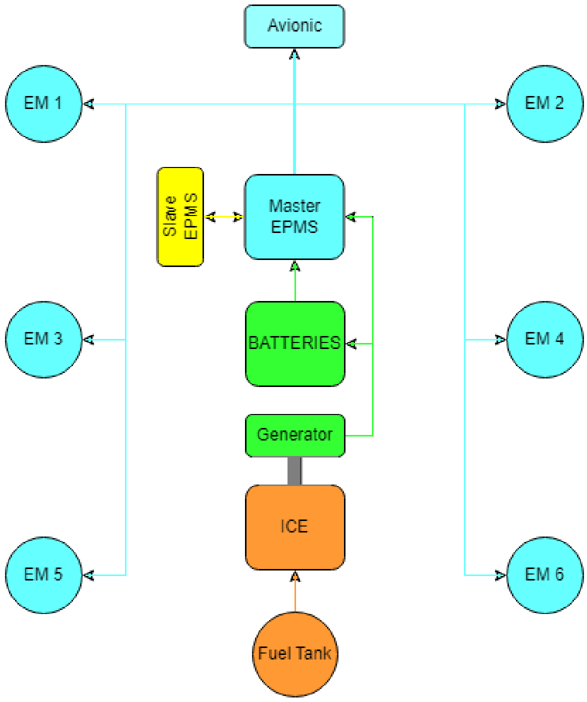


Figure 2: Propulsive layout scheme - **Orange**: Fuel flow; **Green**: Raw energy flow; **Cyan**: Controlled energy flow; **Yellow**: Auxiliary

Selected ICE, generator, EMs are respectively UlPower UL520T, Emrax 268 and Emrax 228 to satisfy sizing output. As for the batteries, specifications are reported in Table 4

Data	Value
Weight	5x40kg; 200 kg total
Specific Power	2000 W/kg
Specific Energy	200 Wh/kg
SOC$_{max}$	85%
SOC$_{min}$	25%
Charging time	3.5 hr to 5 min

Table 4: Battery specifications

7. Lofting

Every aspect must be taken into account to allow ***VELA*** to be as compact and small as possible wile at the same time granting comfort of users and enough space for the installation of every system. Constraints that guide the design of the VTOL under project are the following:

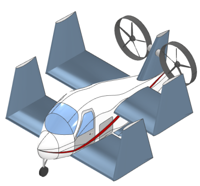
- Adoption of a double wing with low front wing and high back wing to allow for total length reduction and avoid downwash on back wing
- Tail motor ring placement to avoid interference between accelerated air stream from tail motors and back wing
- Passenger/Pilot cabin design granting comfort and appropriate view angles
- Battery compartment allowing battery swapping
- Baggage compartment to fit baggages of most size
- PGS compartment allowing easy access
- Fuel tank placement in root of back wing to grant a simple gravity feeding to ICE

7.1. Center of Gravity Study and Landing Gear Design

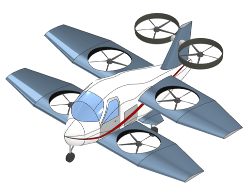
Considering the wing layout of the airplane, as a first estimate it is logic to place the center of gravity to have a small travel around the point in between the two wings. Highest, lowest, max afterward and max forward position of CG in operational (even considering an extreme case of taking of without one of five batteries) and maintenance condition are studied. A retractable trycicle landing gear is than designed to allow for airplane stability, equilibrium and manoeuvrability during all conditions.

7.2. Drawing and Total Dimensions

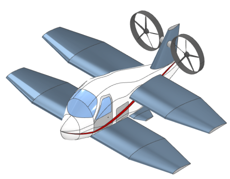
As a result from previous design choices and analysis, visual representation and total dimensions for ***VELA*** are reported below:



(a) Parked



(b) Vertical thrust



(c) Longitudinal thrust

Figure 3: ***VELA*** configuration in all phases

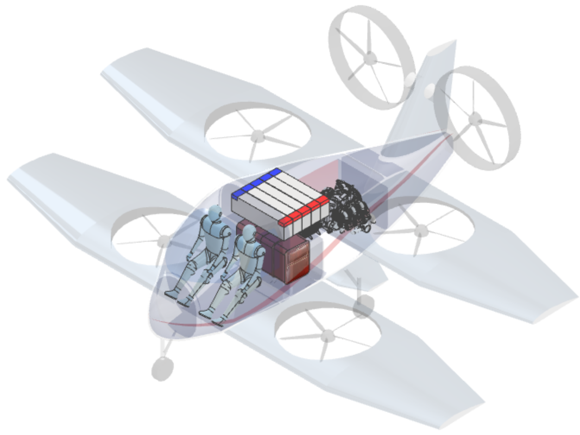


Figure 4: X-ray view of ***VELA***

Dimension	Value
Wing span	7.4 m
Wing root chord	1.6 m
Wings vertical spacing	0.76 m
Parked width	4.3 m
Lenght (nose to tail)	5.28 m
Max hight (wheel to folded tip)	2.895 m
Prop Diameter	1.2 m
MLG wheel spacing	1.6 m
MLG/NLG distance	2.64 m

Table 5: Relevant dimensions

8. Conclusions

This work consolidates the design and constitutes a solid feasibility study and initial sizing of ***VELA***. Thanks to its ability to perform vertical takeoff and landing, high transition altitude and remarkable range this air vehicle concept represents one of the safest, most comfortable and versatile alternatives in the UAM scenario. Moreover the compact design and foldable wing paired with a hybrid-electric propulsive system makes ***VELA*** unmatched when it comes to dimensions wile outperforming competing VTOL concepts.

References

[1] EASA. Second publication of means of compliance with the special condition vtol, 22/12/2022.