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Multidisciplinary Design Optimization on Maximizing Long-Term Profit for an eVTOL Aircraft

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This is an EXAMPLE abstract.

I. Nomenclature

α	=	angle of attack
AR	=	aspect ratio
S	=	area
h	=	altitude
V_∞	=	airspeed
Q_n	=	normalized torque
R	=	rotor radius
RPM	=	X rotational speed in revolutions per minute
m_b	=	Y battery mass
$num.flts$	=	number of flights
L	=	lift
W	=	weight
T	=	thrust
D	=	drag
E_{avail}	=	energy available
E_{total}	=	energy total
C_m	=	pitching moment
C_r	=	rolling moment
SM	=	static margin
x	=	distance from nose

II. Introduction

III. Background

IV. Methodology

A. Problem Statement

Table 1 Optimization Problem Statement.

	Variable	Description	Quantity (primary)
minimize	-Profit		
with respect to	$-3 \leq \alpha_{wing} \leq 5°$	Wing Angle of Attack	1
	$3 \leq AR_{wing} \leq 13$	Wing Aspect Ratio	1
	$15 \leq S_{wing} \leq 30\ m^2$	Wing Area	1
	$-3 \leq \alpha_{tail} \leq 5°$	Tail Angle of Attack	1
	$3 \leq AR_{tail} \leq 13$	Tail Aspect Ratio	1
	$2 \leq S_{tail} \leq 4\ m^2$	Tail Area	1
	$2 \leq x_{tail,c/4} \leq 8$	Location of Tail c/4	1
	$0 \leq h \leq 2\ km$	Altitude	1
	$58 \leq V_\infty \leq 70\ m/s$	Speed	1
	$0 \leq Q_n \leq 0.6$	Normalized torque	6
	$100 \leq Range \leq 300km$	Range	1
	$* \leq R \leq *$	Rotor Radius	3
	$1900 \leq RPM \leq 3000$	Rotational Speed in RPM	6
	$500 \leq m_b \leq 700\ kg$	Battery Mass	1
	$0 \leq num.\ flts. \leq 200$	Number of Flights	1
		Total design variables	27
subject to	$L - W = 0$	Vertical Equilibrium	1
	$T - D = 0$	Horizontal Equilibrium	1
	$E_{total} \leq 10E_{avail}$	Energy Constraint	1
	$C_m = 0$	Pitching Moment	1
	$C_r = 0$	Rolling Moment	1
	$6\% \leq SM \leq 20\%$	Static Margin	1
		Total constraints	6

B. Design Structure Matrix

The design structure matrix is shown in figure [citation]. It visualizes the design optimization problem.

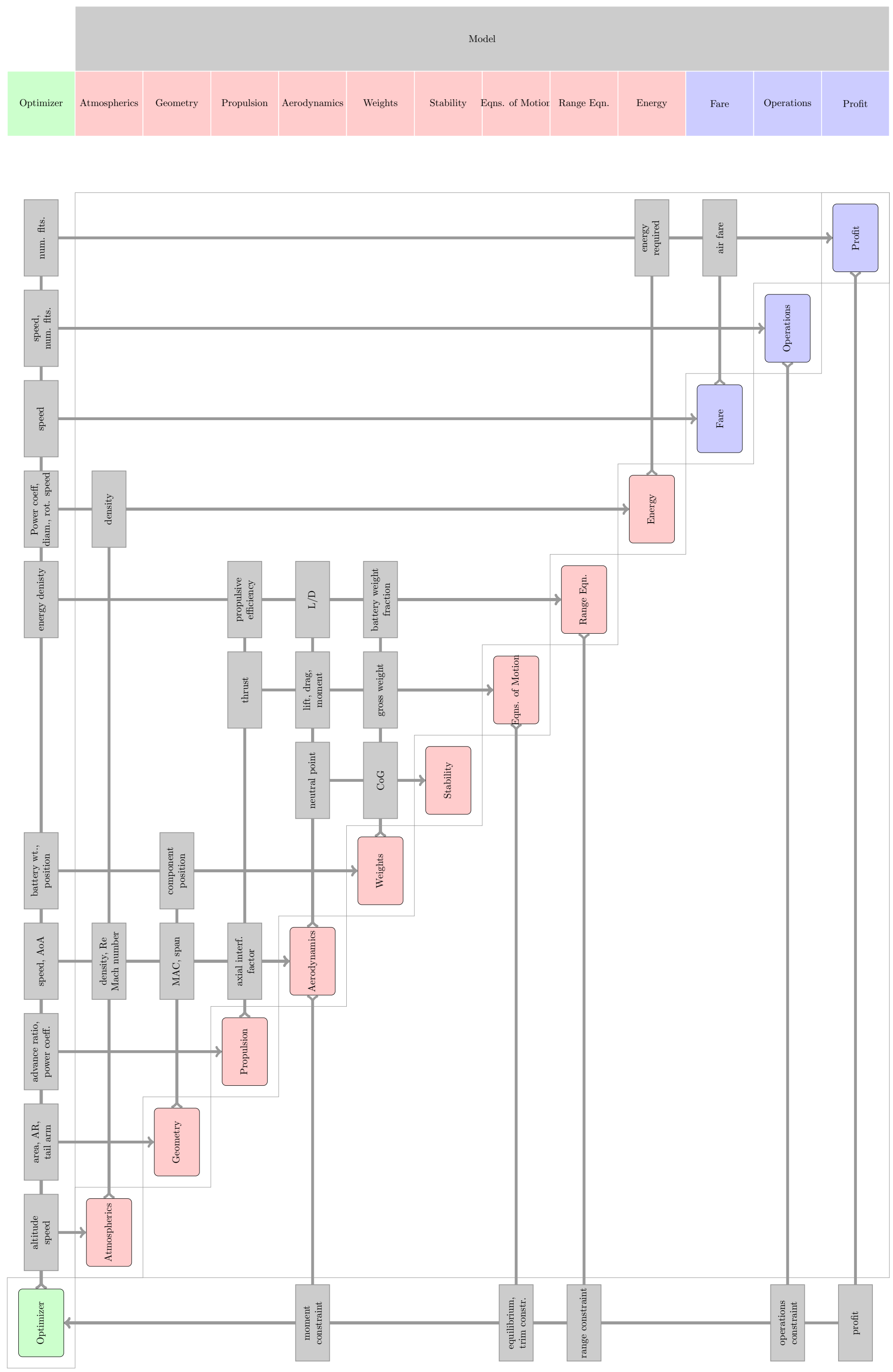

Fig. 1 Design Structure Matrix (DSM) for Optimization problem

C. Software Description

V. Models

A. Aerodynamics

The aerodynamic model is based on empirical formulae used to calculate lift and drag. To determine the lift and drag coefficient, standard 2-D airfoil analysis is employed that assumes linearity in the lift coefficient. In addition, in order to account for the section of the wing that is affected by the increased velocity of the slipstream due to the propellers, citedinproceedings includes a slightly modified formulation for the lift coefficient, which is shown in equation (1).

$$C_L = C_{L_0} + \frac{2r(C_{L_0}(1 + aC_b)^2 - C_{L_0}) * blown\ percentage}{span} \tag{1}$$

where r is the radius, a is the axial induction factor, and C_b is the blown coefficient factor. This model includes a simplified approach to include the effect of the axial induced velocity, resulting from the propeller slip stream. Including this effect in our analysis was deemed reasonable since we have multiple propellers along the wing with relatively large diameter. citedinproceedings$_2$*modelsthiseffectmorethoroughly*, *however*, *wedecidedthatforourpurposesalowerfidelityaerodynamicm*
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B. Propulsion

The propulsion model relies on the Glauert propeller theory, which is a high-fidelity model derived from general momentum theory. One of the main advantages of the Glauert model is that it includes the various losses associated with propeller motion. Since our aircraft is propeller driven, it was deemed appropriate to employ a high-fidelity propulsion model. The Glauert model is summarized by the following set of equations taken from citedisrael:

$$\begin{gathered} \eta = \eta_1\eta_2\eta_3,\ \eta_2 = 1 - \frac{4\eta_1}{\pi^3 J}C_P,\ \tan\varphi_1 = \frac{J}{\pi\eta_1\eta_2} \\ \eta_3 = 1 - \frac{\pi^4}{8}\frac{\eta_2^2}{C_P}\sigma\bar{C_d}f(\varphi_1),\ \eta_1 = 1 - \frac{2}{\pi}C_P\eta_2\eta_3\left(\frac{\eta_1}{J}\right)^2 \end{gathered} \tag{2}$$

where η_1, η_2, η_3 are the efficiencies associated with the losses due to the axial induced velocity, the rotational velocity and blade drag of the propeller, respectively. In addition, J is the advance ratio and C_P is the power coefficient. Lastly, σ,$\bar{C_d}$ and φ_1 are the blade solidity, the blade-average two-dimensional (2-D) drag and the the inflow angle between the propeller disk plane and the resultant cross-sectional velocity. Once the overall propulsive efficiency is determined it is easy to compute the thrust coefficient (C_T) and ultimately the thrust (T), which are related to the efficiency by the subsequent pair of equations:

$$\eta = \frac{C_T J}{C_P},\ C_T = \frac{T}{\rho n^2 D^4} \tag{3}$$

where ρ is the density and D is the blade diameter. While the Glauert model presented above accurately accounts for the losses associated with the blade motion, it assumes that the losses are solely due the aerodynamic action of the propeller. In reality, however, there is an additional loss resulting from the interaction between the air and the so called propeller boss citedaero. Unfortunately, there is no literature yet available that includes this effect in the Glauert model.

C. Performance

In this optimization problem we are only considering the cruise segment of the mission profile and therefore the net force acting on the aircraft has to be equal to zero to achieve steady level flight conditions. For vertical equilibrium, this means that the gross weight equals the lift generated from the wing and tail. It is important that the pitching moment generated from the separate lifting surfaces is equal to zero. To guarantee horizontal equilibrium, the cruise condition implies that the forward thrust generated from the propeller equals the parasitic and induced drag. The main reason that only the cruise condition is considered is that range is one of the constraints and the range equation for electric aircraft is only valid for steady level flight.

D. Weights and Stability

The model utilized for weights and stability is comprised of the equations outlined by Raymer's design reference citedraymer. Namely, the equations for general aviation were used to obtain output values for the aircraft's empty weight, center-of-gravity location, and neutral point location. This model was selected for the reason that it provides a high level of flexibility without sacrificing simplicity; moreover, it is based on Raymer's empirical estimations and so provides us with a way to consider the feasibility and reasonability of each weight estimate. Raymer's equations for weight-by-component were subsequently utilized to provide estimates for the aircraft's center-of-gravity (CG) and neutral point (NP), as outlined in equations (4) and (5).

E. Economics

The economics model is based on several formulae, including the Development and procurement costs of aircraft (DAPCA) equations and modifying them for an eVTOL aircraft. The main inputs are empty aircraft weight, maximum velocity, and the quantity of aircraft to be produced. The model outputs a total cost for the research, development, testing, and evaluation of the aircraft. To find labor costs for manufacturing, tooling, engineering and quality control, research was conducted to find the average hourly rate for each individual specialty. The engine production cost equation was removed and replaced with a battery and motor cost analysis, using a modern day value for cost per kilowatt-hr for the battery, and a standard market value for the motors.

F. Approach

VI. Conclusion

A. Summary

B. Significance

C. Future

VII. Individual Contributions

Appendix

References

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