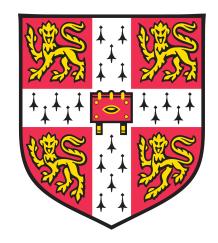
University of Cambridge Department of Engineering

MASTERS PROJECT REPORT





Propulsion Systems for e-VTOL Aircraft

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Abstract

Abstract here..

Nomenclature

Control Volume Analysis

Control volume numbering as below.

- 1. Upstream flow conditions $(V = 0; p_{01} = p_{atm}; A_1 large)$
- 2. Exit flow conditions $(V_2 = V_x; p_{02} = p_{atm}; A_2 = A)$

2.1 Assumptions

- Upstream velocity $(V_1 \approx 0)$ and pressure $(p_1 = p_{01} = p_{atm})$
- Flow velocity small, hence assume incompressible and Bernoulli applies
- Control volume (CV) large enough such that $\dot{m}_1 V_1 \approx 0$
- Jet leaves propulsor straight and parallel meaning jet exits CV through A_2 with p_2 but all other CV surfaces experience p_{atm}
- Assuming flow area is equal throughout, exit velocity V_2 must be equal to axial velocity V_x , hence stage loading can be written as $\phi = V_2/U$

2.2 Calculations

Steady flow momentum equation (SFME) gives

$$T_p = \dot{m}_2 V_2 - \dot{m}_1 V_1 + A_2 p_2 - A_1 p_1 \tag{1}$$

Assumptions therefore give

$$T_p = \dot{m}_2 V_2 + A_2 (p_2 - p_1) \tag{2}$$

Considering a near isentropic process

$$\mathcal{I}ds = dh - \frac{dp}{\rho} \tag{3}$$

$$\therefore \Delta h_0 = \frac{\Delta p_0}{\rho} \tag{4}$$

Now using Bernoulli to define Δp_0 , given $V_1 \approx 0$

$$\Delta p_0 = p_{02} - p_{01} p_1 \tag{5}$$

$$\Delta p_0 = \frac{1}{2}\rho V_2^2 + (p_2 - p_1) \tag{6}$$

Peak jet efficiency when $p_2 = p_{atm}$

$$\therefore \Delta p_0 = \frac{1}{2}\rho V_2^2 \tag{7}$$

As $p_1 = p_2$, SFME becomes

$$T_p = \dot{m}_2 V_2 = \rho A_2 V_2^2 \tag{8}$$

Hence design exit velocity can be determined by fan geometry and required thrust

$$V_2 = \sqrt{\frac{T_p}{\rho A_2}} \tag{9}$$

2.3 Geometry

Fan geometry can be varied using a sensitivity analysis to obtain desirable values of flow coefficient (ϕ) and stage loading (ψ) . From previous design these are approximately (at mean line)

$$\phi = \frac{V_x}{U} \approx 0.7 \qquad \qquad \psi = \frac{\Delta h_0}{U^2} \approx 0.3 \tag{10}$$

Fan speed Ω is predetermined by the choice of motor assembly (electric motor, electric speed controller (ESC) and battery voltage)

Relating the above coefficients to the geometric parameters r_c and r_h

$$\phi = \sqrt{\frac{T_p}{\rho \pi (r_c^2 - r_h^2)}} \cdot \frac{2}{\Omega(r_c + r_h)}$$
(11)

$$\psi = \frac{T_p}{\rho \pi (r_c^2 - r_h^2)} \cdot \frac{2}{\Omega^2 (r_c + r_h)^2}$$
 (12)

These sensitivity analyses, along with consideration of available space and a desire to reduce weight as much as possible (minimize fan radius), resulted in approximate fan radii being determined.

This is not an optimum this is to design within the constraints applied to the problem.

$$r_c = 55 mm$$
 $r_h = 25 cm$ (13)