EXPLORING SHAPE ASYMMETRY FOR PROPULSION EFFICIENCY

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INTRODUCTION

The growing interest in unmanned aerial vehicles (UAVs) is due to their deployment in various sectors such as commercial, industrial, civilian, and military. However, the limited capacity of on-board energy storage considerably restricts their flight duration, affecting their overall applicability. The propulsion system of the UAV is one of the key factors in its total energy use.

METHODS

General hovering equation for propelling system in gaseous or liquid medium in presence of gravity :

$$F_g = F_L + F_{dd} - F_{du} \qquad (1)$$

where F_g - gravity force; F_L - motor force; F_{dd} - drag force for movement down ; F_{dup} - drag force for movement up;

Substituting the known equations for force of moving mass $F = ma$
and drag force $F_d = \frac{1}{2} C_D \rho A V^2$

$$mg = ma + \frac{1}{2} C_{Dd} \rho A V^2 - \frac{1}{2} C_{Du} \rho A V^2 \qquad (2)$$

where C_{Dd} - drag coefficient for pulling down action = 1.4;
C_{Du} - drag coefficient for pulling up action = 0.4;

Cycle time:

$$t = \frac{1}{f}$$

where f - reciprocating frequency of asymmetrical shape;

Speed and acceleration, in terms of frequency, take the following form:

$$v = xf; \quad a = xf^2;$$

where x - cycling amplitude of asymmetrical shape in meters;

After plugging all in equation (2) and evaluation, we get the hovering frequency threshold equation for machine using reciprocating asymmetrical slim shape (RASS) for propulsion (See Fig.1):

$$f_{rass} = \sqrt{\frac{2mg}{(C_{Dd} - C_{Du})\rho A x^2 + mx}} \qquad (3)$$

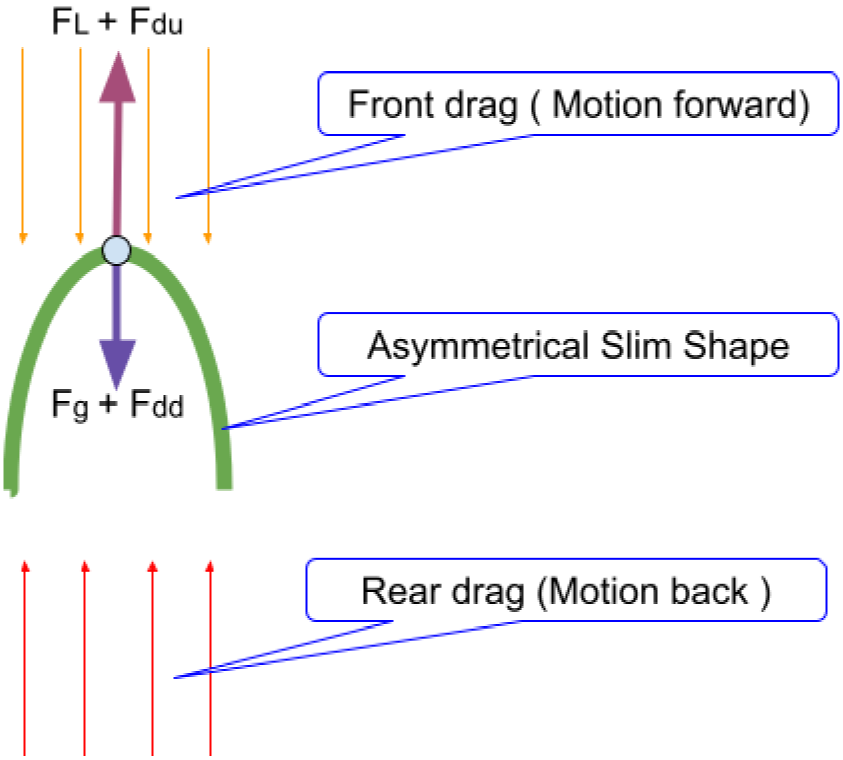

Fig. 1 Acting forces on asymmetrical slim shape

Now let's calculate the comparative efficiency of rotor and RASS .

For rotor machines, lift defined by the known equation:

$$F_L = \frac{1}{2} C_L \rho A V^2 \qquad (4)$$

Hovering condition is:

$$F_g = F_L$$

where F_g - gravity force; F_L - lift;

Substituting with known equations:

$$mg = \frac{1}{2} C_L \rho A V^2 \qquad (5)$$

As long as rotor has different lift efficiency along the radius, integrating (4) gives the total lift of the rotor machine :

$$F_L = \int_0^r \frac{1}{2} C_L \rho A V^2 dr \qquad (6)$$

Substituting V = $2\pi r f$, where f - rotation frequency, and solving gives us the following:

$$F_L = \frac{2}{3} \pi C_L A \rho f^2 r^3 \ ; \qquad (7)$$

Hovering rotation frequency threshold:

$$f_{rotor} = \sqrt{\frac{3mg}{2\pi^2 C_L A \rho r^3}} \ ;$$

Energy consumed by the rotor machine per 1 second:

$$P_{rotor} = E\cdot f = 2\pi r F_L f = \frac{4}{3}\pi C_L A \rho f^3 r^4 \qquad (8)$$

Energy consumed by the rass machine per 1 second:

$$P_{rass} = E\cdot f = Fxf = \frac{2mg}{(C_{Dd} - C_{Du})xf\rho A} \qquad (9)$$

RESULTS

Now we can do comparative estimations of the two type machines' efficiency with real physical parameters.

Assuming m = 1 kg, r = 0.5m, x = 0.1 m, $A_{rass} = \pi r^2 = 0.78\ m^2$,
$A_{Rot} = 0.015\cdot A_{rass}$, $\rho = 1.3\ kg/m^3$, g = 9.8 m/s^2, C_{Dd} = 1.4, C_{Du} = 0.4, C_L= 0.1 .

Threshold hovering frequency for asymmetrical slim shape system:

$$f_{rass} = \sqrt{\frac{2\cdot 1\cdot 9.8}{(1.4 - 0.4)\cdot 1.3\cdot 0.78\cdot 0.1^2 + 1\cdot 0.1}} = 13.34\ Hz$$

Energy consumed by the asymmetrical slim shape machine per 1 second:

$$P_{rass} = \frac{2\cdot 1\cdot 9.8}{(1.4 - 0.4)\cdot 0.1\cdot 13.34\cdot 1.3\cdot 0.78} \simeq 15\ W$$

Threshold hovering frequency for rotor system:

$$f_{rotor} = \sqrt{\frac{2\cdot 1\cdot 9.8}{2\cdot 0.1\cdot 0.1\cdot 1.3\cdot 0.5^3}} \simeq 44\ \text{Hz}$$

Energy consumed by the rotor machine per 1 second:

$$P_{rotor} = \frac{4}{3}\cdot 3.14\cdot 0.1\cdot 0.01\cdot 1.3\cdot 8.5\cdot 10^4\cdot 6\cdot 10^{-2} \simeq 42W$$

DISCUSSION

Form factor efficiency of the whole half of a streamline shape (bird wing) calculated here as a difference in drag coefficients of the streamline shape exposed to incoming flow of gaseous or liquid medium.

Let us assume 1.4 - existing drag coefficient of the half of a hollow streamline body exposed to the incoming flow by a hollow part at front (bird wing moving down).

Now assume 0.4 - drag coefficient of the half of a hollow streamline body (bird wing) exposed to the incoming flow by streamline part at front (bird wing moving up).

Form factor efficiency of asymmetrical slim shape (non transformable) = 100 - 0.4/1.4* 100 ~ 70%. Hovering energy efficiency $P_{rass} / P_{rotor} \sim 0.35$. That means we can expect the energy efficiency of a RASS machine exceeding 200% that of a rotor machine.