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RESEARCH ON DESIGN METHOD OF PETROL-ELECTRIC HYBRID DRIVE SYSTEM BASED ON MDO FOR A NOVEL VTOVL UAV

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Abstract

In this paper, the MDO method is used for optimizing design of a VTOVL UAV's Petrol-Electric Hybrid Drive System.

Firstly, a novel VTOVL UAV has been described in detail on the tailless aerodynamic shape and Petrol-Electric hybrid drive system. For optimizing design, those positions which are relevant to optimize the centre of gravity for UAV are labeled on a UAV sketch.

Secondly, the method architecture of optimizing design for UAV's drive system has been designed based on MDO. The MDO module is composed of Objectives, Constrains, and Functions, and so on. The optimizing programme has been illustrated in detail.

Finally, the optimizing design experiments have been done and a lots of data was obtained for finishing UAV concept.

Results presented in the paper show that the method architecture of optimizing design for UAV's drive system agrees well with the experience data.

1 Introduction

Recently, aircraft designers are making an effort to create a novel VTOVL (Vertical Take Off Vertical Landing) UAV which be able to take off and landing as easy as rotate wing UAV and has the capability of fly resembling fixed wing UAV. The UAV may conveniently take off and landing from many worse places such as mountain area, islands, and narrow boat deck and has twice flight velocity and duration so that it can be employed widely in lots of application of reconnaissance, search and rescue, and long-distance freightage required fast.

The paper is organized as follows: Section 2 explains in detail the configuration and Petrol-Electric hybrid drive system of a novel concept VTOVL UAV. Method of optimizing design for UAV's drive system based on MDO is presented in Section 3. Section 4 presents the optimizing design experiments data. Section 5 summarizes the conclusions.

2 The Novel VTOVL UAV Concept

2.1 UAV Concept

A novel VTOVL UAV has been designed by our team and is illustrated in Fig.1.

Fig.1 a Novel VTOVL UAV

The UAV has a novel tailless aerodynamic shape with large aspect ratio wings. There are two large-sized fan which embedded in UAV's wings and used for providing lift when the UAV takes off and landing. A small-sized fan is assembled in forepart of the UAV for providing mainly trim lift in order to achieve pitch control. A medium-sized fan is fixed on after-body of the UAV for providing thrust during the whole flying travel. When the UAV makes a level flight, three fans shut down except the Push Fan.

Whole four fans must be controlled harmoniously for stabilizing UAV's flying.

2.2 Petrol-Electric Hybrid Drive System

To take advantage of the weight, cubage, energy resources, and power, the UAV employ the Petrol-Electric Hybrid Drive System (illustrated in Fig.2) for driving UAV's four fans,. Two Lift Fans and a Push Fan are driven directly by turbine engine with fuel, while a Trim Fan is driven by electromotor. When the UAV makes a level flight, a certain amount of extra fuel will be consumed to drive electric generator for charge up the battery which supplies electricity to the electromotor of the Trim Fan.

When the UAV's essential parameters (such as weight, cubage, and power) are fixed, it is expected for the UAV to achieve the optimized time which takes into account both level flight and hovering flight, by allocating the weight proportion between battery, fuel, and fuel used for charging.

The position of UAV's centre of gravity is simultaneously checked to ensure that UAV has an enough safe margin for flight control.

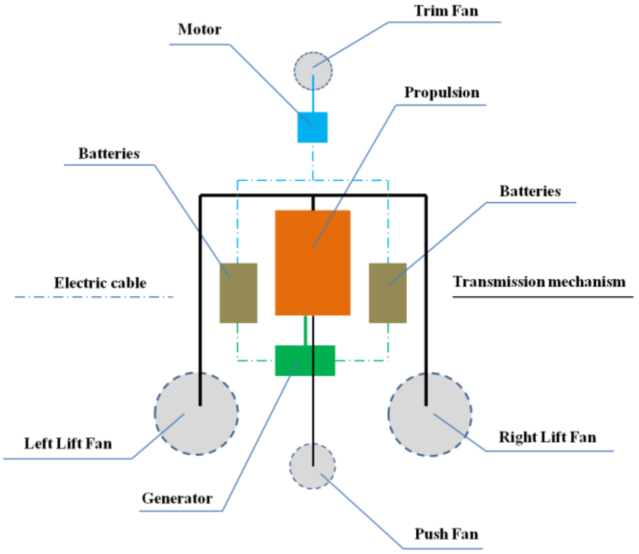

Fig.2 Petrol-Electric Hybrid Drive System of UAV

2.3 The centre of gravity for UAV

In Fig.3, the model of the above optimization problem is shown. Those positions which are relevant to optimize the centre of gravity for UAV are labeled on a UAV sketch.

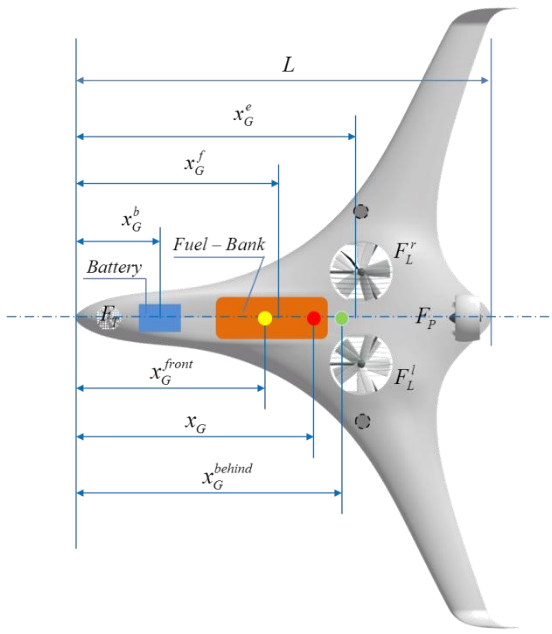

Fig.3 Position marking for Centre of Gravity of UAV

3 Method Architecture of Optimizing Design for UAV's Drive System

3.1 Model of MDO

There are many optimization problems about the Petrol-Electric Hybrid Drive System of the UAV such as the power allocation, coordinating positions, and selecting drive way between Lift Fans and Trim Fan. But it is only paid close attention to the optimization problem of the variable weight (fuel) and invariable weight (battery) of UAV's energy resources. The MDO module is adopted following equations:

Objectives:

$$\begin{cases} \text{Objective1: maximize } \overline{T}_{total} \\ \text{Objective2: maximize } \overline{x}_G^{T-L} \\ \text{Objective3: maximize } K_V \end{cases}$$

Constrains:

$$\begin{cases} V_b + V_f \le V_0 \\ G_b + G_f = G_0 \qquad G_b \in [G_b^{\min}, G_b^{\max}] \\ x_G^T - x_G^{front} \ge 0 \qquad x_G^{behind} - x_G^L \ge 0 \end{cases}$$

Functions:

$$\begin{cases} V_b = K_{VG}^b \cdot G_b \qquad V_f = K_{VG}^f \cdot G_f \\ T_{level} = K_T^f \cdot \left(G_f - G_{f_0} - G_{f-b}\right) \\ G_{f_0} = k_{rg} \cdot G_f \qquad G_{f-b} \in [k_{f-b}^{down} \cdot G_f, k_{f-b}^{up} \cdot G_f] \\ T_{hover} = K_T^b \cdot \left(G_b - G_{b_0}\right) + K_T^{f-b} \cdot G_{f-b} \\ \overline{T}_{total} = \left(k_{lT} \cdot T_{level} + k_{hT} \cdot T_{hover}\right) / T_{\max} \\ x_G^T = \left(G_b \cdot x_G^b + G_f \cdot x_G^f + G_e \cdot x_G^e\right) / \left(G_b + G_f + G_e\right) \\ x_G^L = \left(G_b \cdot x_G^b + G_{f_0} \cdot x_G^f + G_e \cdot x_G^e\right) / \left(G_b + G_{f_0} + G_e\right) \\ \overline{x}_G^{T-L} = \left(k_{tx} \cdot x_G^T + k_{lx} \cdot x_G^L\right) / L \\ K_V = \left(V_b + V_f\right) / V_0 \end{cases}$$

Optimization:

$$\begin{cases} \left[G_b, G_f, G_{f-b}\right]_{50}^{T} = \arg\max_{G_b, G_f} \left\{\overline{T}_{total}\right\} \\ \left[G_b, G_f, G_{f-b}\right]_{20}^{x} = \arg\max_{\left[G_b, G_f, G_{f-b}\right]_{50}^{T}} \left\{\overline{x}_G^{T-L}\right\} \\ \left[G_b, G_f, G_{f-b}\right]^{opt} = \arg\max_{\left[G_b, G_f, G_{f-b}\right]_{20}^{x}} \left\{K_V\right\} \end{cases}$$

It is worth mentioning that $\left[G_b, G_f, G_{f-b}\right]_{50}^{T}$ means the top 50 sets of the weight allocations for maximizing $\overline{T}_{total}$ and G_{f-b} means the weight of extra fuel consumed by turbine engine for charge up the battery.

3.2 Architecture of Optimizing Design

In this paper, the scheme of the MDO module used for optimizing the variable and invariable weight parameters of UAV's energy resources is illustrated in Fig.4:

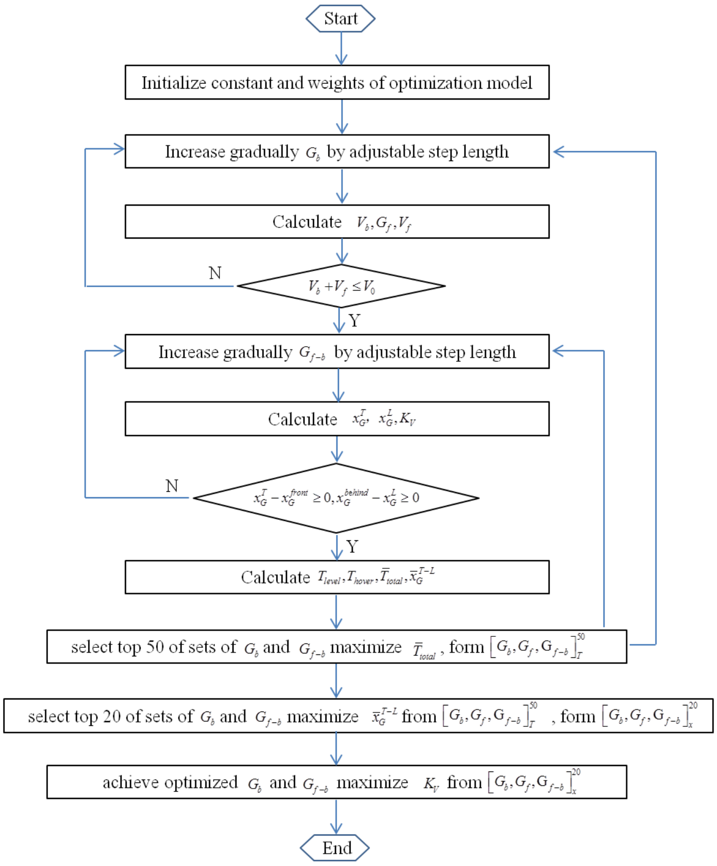

Fig.4 Architecture of Optimizing Design for UAV

3.3 Programme of Optimizing Design

In this paper, the optimizing programme uses MDO method, which is illustrated as follows:

Programme: Optimizing Design for UAV's Drive System

Initial $G_b, G_f, G_{f-b}, G_{\max}^b, G_{\min}^b, V_b, V_f,$
$K_{VG}^b, K_{VG}^f, G_0, V_0, k_{f-b}^{up}, k_{f-b}^{down}, M, N$
$T_{level}, T_{hover}, T_{total}, \overline{T}_{total}, K_T^f, K_T^b, K_T^{f-b},$
$k_{lT}, k_{hT}, T_{\max}, G_e, G_{f_0}, V_k, K_V, G_b^{opt}, V_b^{50}[\cdot]$
$x_G^b, x_G^e, x_G^f, x_G^T, x_G^L, \overline{x}_G^{T-L}, G_f^{opt}, G_{f-b}^{opt}, V_f^{50}[\cdot]$
$T_{total}^{opt}, T_{level}^{opt}, T_{hover}^{opt}\ V_k^{opt}, T_{total}^{50}[\cdot], T_{level}^{50}[\cdot], T_{hover}^{50}[\cdot]$
$G_b^{50}[\cdot], G_f^{50}[\cdot], G_{f\text{-}b}^{50}[\cdot],\ \overline{T}_{total}^{50}[\cdot], V_k^{20}[\cdot]$
$T_{total}^{20}[\cdot], T_{level}^{20}[\cdot], T_{hover}^{20}[\cdot], V_b^{20}[\cdot], V_f^{20}[\cdot]$
$G_b^{20}[\cdot], G_f^{20}[\cdot], G_{f\text{-}b}^{20}[\cdot],\ \overline{T}_{total}^{20}[\cdot]$
$\Delta G_b = \left(G_{\max}^b - G_{\min}^b\right) / M$

L1: *for* $m = 1$ *to* M *do*
$G_b = G_{\min}^b + m \cdot \Delta G_b,\ V_b = K_{VG}^b \cdot G_b$

$G_f = G_0 - G_b, V_f = K_{VG}^f \cdot G_f$

if $(V_b + V_f) > V_0$ *then*

goto L1

end if

$\Delta G_{f-b} = \left(k_{f-b}^{up} \cdot G_f - k_{f-b}^{down} \cdot G_f\right) / N$

for $n = 1$ *to* N *do*

$G_{f-b} = k_{f-b}^{down} \cdot G_{f-b} + n \cdot \Delta G_{f-b}$

$T_{level} = K_T^f \cdot \left(G_f - G_{f_0} - G_{f-b}\right)$

$T_{hover} = K_T^b \cdot \left(G_b - G_{\min}^b\right) + K_T^{f-b} \cdot G_{f-b}$

$T_{total} = T_{level} + T_{hover}$

$\bar{T}_{total} = \left(k_{lT} \cdot T_{level} + k_{hT} \cdot T_{hover}\right) / T_{\max}$

for $k_1 = 1$ *to 50 do*

if $\bar{T}_{total} > \bar{T}_{total}[\mathrm{k}_1]$ *then*

$\bar{T}_{total}[\mathrm{k}_1] = \bar{T}_{total}, G_b[\mathrm{k}_1] = G_b$

$G_f[\mathrm{k}_1] = G_f, G_{f-b}[\mathrm{k}_1] = G_{f-b}$

$T_{level}[\mathrm{k}_1] = T_{level}, T_{hover}[\mathrm{k}_1] = T_{hover}$

$V_b[\mathrm{k}_1] = V_b, V_f[\mathrm{k}_1] = V_f$

$T_{total}[\mathrm{k}_1] = T_{total}$

end if

end for

end for

end for

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for $k_1 = 1$ *to 50 do*

$G_b = G_b[\mathrm{k}_1], G_f = G_f[\mathrm{k}_1]$

$G_{f-b} = G_{f-b}[\mathrm{k}_1]$

$T_{level} = T_{level}[\mathrm{k}_2], T_{hover} = T_{hover}[\mathrm{k}_2]$

$V_b = V_b[\mathrm{k}_2], V_f = V_f[\mathrm{k}_2]$

$x_G^T = \left(G_b \cdot x_G^b + G_f \cdot x_G^f + G_e \cdot x_G^e\right) / \left(G_b + G_f + G_e\right)$

$x_G^L = \left(G_b \cdot x_G^b + G_{f_0} \cdot x_G^f + G_e \cdot x_G^e\right) / \left(G_b + G_{f_0} + G_e\right)$

$\bar{x}_G^{T-L} = \left(k_{tx} \cdot x_G^T + k_{lx} \cdot x_G^L\right) / L$

for $k_2 = 1$ *to 20 do*

if $\bar{x}_G^{T-L} > \bar{x}_G^{T-L}[\mathrm{k}_2]$ *then*

$\bar{x}_G^{T-L}[\mathrm{k}_2] = \bar{x}_G^{T-L}, G_b[\mathrm{k}_2] = G_b$

$G_f[\mathrm{k}_2] = G_f, G_{f-b}[\mathrm{k}_2] = G_{f-b}$

$T_{level}[\mathrm{k}_2] = T_{level}, T_{hover}[\mathrm{k}_2] = T_{hover}$

$V_b[\mathrm{k}_2] = V_b, V_f[\mathrm{k}_2] = V_f$

end if

end for

end for

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for $k_2 = 1$ *to 20 do*

$V_b = V_b[\mathrm{k}_2], V_f = V_f[\mathrm{k}_2]$

$V_k = V_b + V_f$

$K_V = V_k / V_0$

if $K_V > K_V^{\max}$ *then*

$G_b^{opt} = G_b[\mathrm{k}_2], G_f^{opt} = G_f[\mathrm{k}_2]$

$G_{f\text{-}b}^{opt} = G_{f-b}[\mathrm{k}_2], T_{total}^{opt} = T_{total}[\mathrm{k}_2]$

$T_{level}^{opt} = T_{level}[\mathrm{k}_2], T_{hover}^{opt} = T_{hover}[\mathrm{k}_2]$

$V_k^{opt} = V_k, V_f[\mathrm{k}_2] = V_f$

end if

end for

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4 Optimizing Design Experiments

In this paper, the VTOTL UAV is 30 ft. long, has a wingspan of 45ft., weights 2000 pounds. The optimized weight allocations of the UAV's energy resources have been achieved based on above MDO module.

The optimization is assumed following limits:

$$G_0 = 400kg \qquad V_0 = 3.5m^3$$

Table 1 Comparing Result of optimization

G_b	G_f	G_{f-b}	$\bar{T}_{total}$
33.5000	366.5000	109.9500	0.5961
33.5000	366.5000	146.6000	0.4764
37.0000	363.0000	145.2000	0.4704
40.5000	359.5000	143.8000	0.4645
	• • •	• • •	
44.0000	356.0000	78.3200	0.6679
44.0000	356.0000	85.4400	0.6446
44.0000	356.0000	92.5600	0.6213
44.0000	356.0000	99.6800	0.5981
44.0000	356.0000	106.8000	0.5748
44.0000	356.0000	113.9200	0.5516
44.0000	356.0000	121.0400	0.5283
44.0000	356.0000	128.1600	0.5051
44.0000	356.0000	135.2800	0.4818
44.0000	356.0000	142.4000	0.4585
	• • •	• • •	
47.5000	352.5000	141.0000	0.4526
51.0000	349.0000	139.6000	0.4466
54.5000	345.5000	138.2000	0.4407
58.0000	342.0000	136.8000	0.4347
61.5000	338.5000	135.4000	0.4288
65.0000	335.0000	134.0000	0.4228
68.5000	331.5000	132.6000	0.4169

72.0000	328.0000	131.2000	0.4109
75.5000	324.5000	129.8000	0.4050
79.0000	321.0000	128.4000	0.3990
82.5000	317.5000	127.0000	0.3931
86.0000	314.0000	125.6000	0.3871
89.5000	310.5000	124.2000	0.3812
93.0000	307.0000	122.8000	0.3752
96.5000	303.5000	121.4000	0.3693
	• • •	• • •	
100.0000	300.0000	66.0000	0.5397
100.0000	300.0000	72.0000	0.5201
100.0000	300.0000	78.0000	0.5005
100.0000	300.0000	84.0000	0.4809
100.0000	300.0000	90.0000	0.4613
100.0000	300.0000	96.0000	0.4417
100.0000	300.0000	102.0000	0.4221
100.0000	300.0000	108.0000	0.4025
100.0000	300.0000	114.0000	0.3829
100.0000	300.0000	120.0000	0.3633

It is worth mentioning that $\left[G_b, G_f, G_{f-b}\right]_{50}^{T}$ means the top 50 sets of the weight allocations for maximizing $\bar{T}_{total}$ and G_{f-b} means the weight of extra fuel consumed by turbine engine for charge up the battery.

The outcomes of optimization are listed below:

$$G_b^{opt} = 44kg \qquad G_f^{opt} = 356kg \qquad G_{f-b}^{opt} = 78kg$$
$$T_{total}^{opt} = 8.80h \qquad T_{level}^{opt} = 7.25h \qquad T_{hover}^{opt} = 1.55h$$
$$V_k = 1.8m^3$$

5 Conclusions

The above outcomes accord with the results obtained by utilizing human experience and statistics data. The MDO algorithm used for optimization in this paper is rather simple and will be replaced with the Genetic Algorithm in future.

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