Conceptual Engine Sizing for a Tactical Unmanned Aerial Vehicle using Statistical Methods

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Abstract— Every aircraft requires a primary source of power to takeoff and fly safely in the air. This power comes from an onboard power plant which could be in the form of an electric motor, a gasoline engine, or a solar system among others. Basically, the type and size of the engine is determined by the size and type of the aircraft. Aircraft engines are characterized by high inertia and heavy gyroscopic effect which affect aircraft control and the overall flight performance. This phenomenon constitutes a design challenge that must be resolved through a dedicated research effort. Thus, it becomes imperative to accurately size and select aircraft engines from an informed position which is possible through a proper drag estimation process or parametric analysis using data obtained from reliable existing competitors in the same configuration and weight class. While a proper drag polar derivation may require some computational fluid dynamics and simulation inputs, parametric analysis can give a timely and cost-effective result for engine power estimation especially for engine sizing at conceptual level. Consequently, this work developed an aircraft engine sizing model that can be applied on a wide range of tactical unmanned aerial vehicles at conceptual level.

Index Terms— Engine sizing for UAVs, propulsion system design, piston engine.

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1 INTRODUCTION

Every aircraft requires a primary source of power which comes from an onboard power plant. Hence, propulsion system design becomes an essential part of aircraft design. The objective is to ensure large power output per unit of engine size and weight as well as a balanced distribution of aerodynamic and gyroscopic forces during flight.

There are two basic methods of engine power estimation namely: drag polar method and parametric method which is often based on statistical data. The parametric method is most suitable for initial and conceptual design levels. To do this however, adequate data must be obtained on the weight, size and power budget of a number of reliable existing aircraft. The benefit is speedy and cost-effective result that meets operational exigencies in tactical and other time constraint missions. A tactical UAV is considered as payload bearing drone that is involved in military and policing missions such as Intelligence, Surveillance and Reconnaissance (ISR), strike and other security missions [1]. The conceptual UAV considered in this work is code-named NAF OLE. NAF OLE UAV is a tactical ISR drone that is intended for strategic surveillance, policing and monitoring of other national assets.

In aircraft design, the Maximum Takeoff Weight (MTOW) represents the weight class whereas the wingspan gives a measure of the aircraft size. [2] The data is then analyze using statistical methods and a trend is generated for a particular aircraft class and configuration. In this study therefore, data obtained from 219 frontline UAVs in the same weight class as the Concept UAV was applied in generating the aircraft engine sizing model. The solution can be obtained from this paper and used appropriately without restriction. Also, the method can be followed to produce similar solutions for other UAV classes.

2 POWER GENRATION METHODS

2.1. Incidence of the Different Power Generation Methods

UAVs can be powered by a piston or turbine engine, electric, glow or solar [3]. An analysis of data obtained on 219 current UAVs, suggests that use of piston internal combustion engine is currently the most predominant power generation method among UAVs [3]. About 60% of the UAVs studied utilize piston engine for thrust generation as shown in Table 1.

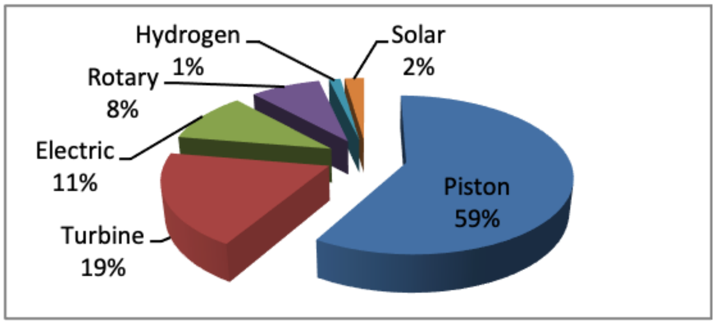

Fig.1 Distribution of Power Generation Methods for 219 UAVs

The piston engines used on UAVs fall under four main categories. These are the 2-stroke, 4-stroke, stepped and rotary engines. The basic difference between 2 and 4-stroke engines is that a 2-stroke engine has a power-stroke on each revolution of the crank-shaft whereas the 4-stroke has a power-stroke every other revolution. Most of the UAVs using Piston engines use either 2-stroke or 4-stroke type. Two-stroke engines are widely used in UAVs and small and very light aircraft. [5][6] The advantages of 2 stroke engines are that they have excellent power to weight ratio, simple structure and are relatively inexpensive.

However, they are not fuel efficient and exhibit high levels of vibration and noise than 4 stroke engines. One of the advantages of the 4-stroke engine is that it has higher torque than a 2 stroke engine. It also has the advantage of low noise and low vibration. Its downside is that it is complicated [7].

It is therefore necessary to understand the advantages and disadvantages of the different types of engines for good integration with the airframe and other aircraft systems. [8] Considering the merits and demerits of the different types of propulsion system and the confidence built on working with Piston engine in previous projects, Piston power generation method was adopted for NAF OLE UAV.

3 ENGINE SIZING

The very top requirements of any UAV engine are high power output per unit weight, high power in all speeds and very low idle in operation [7]. To achieve this feat, a correct engine sizing is necessary at all stages of UAV design process. The particular requirement which determines the engine size will be dictated by both engine and airframe characteristics. Two basic methods are involved in engine sizing namely: the drag polar (empirical) and the statistical method. This paper deals with the statistical method.

3.1 Conceptual Framework

The 3D rendered image of the NAF OLE UAV is shown in Fig 3.

Fig.2. A 3D CAD Model of NAF OLE UAV.

The UAV was designed to use a piston engine with pusher configuration. To estimate an appropriate engine with respect to power-to-weight ratio and be efficient at the same time, critical flight phases must be use for benchmarking. In practice, engine size is determined by either the take-off performance or the climb performance to the initial cruise altitude. This necessitated the need for a detailed aircraft performance analysis to ensure that the initially sized engine can meet the tactical requirements of the UAV. [4] To achieve this, the following conceptual specifications were used in power prediction and performance data analysis:

TABLE 1
CONCEPTUAL SPECIFICATIONS

Wingspan	4m
MTOW	38 – 42kg
OEM	24kg
Cruise speed	70 - 100kts
Range	80 - 120km
Endurance	8 -10 hrs
Altitude	10,000ft
Payload weight	8 – 10kg
Navigation/Control	Autonomous/GCS
Airframe	Composite
Launch/recovery	Landing gear
Mission	ISR

3.2 Statistical Power Estimation

For reasons advanced in section 2.1, data of 23 top class UAVs using piston engines that are currently flying in the world was obtained for the analysis. However, a good conceptual design requires a set criterion for the analysis. Therefore, the first criterion for this analysis is that the case is limited to 5kg<MTOW<100kg. This boundary is chosen because it adequately covers the class of UAVs OLE UAV belongs to. The second criterion is that the solution must not be less than 80% accurate for all aircraft models within the above category. A list of these UAVs is contained in Table 3.

TABLE 2
Data of 23 UAVs in the Class of NAF OLE UAV [9]

UAV	Power (hp)	MTOW (kg)	Wing span (m)
Backpack	1.6	5.44	1.22
Javelin	2	9	2.44
X-Sight	3.5	16	2.6
Half-Scale	4.5	18.1	2.5
ALO	6.5	20	3.03
Heli 25	7.5	25	2.4
K-100	6	28	2.6
Luna	8	30	4.17
Mercury	6	30	2.5
Yarará	8	30	3.98
Pelican Observer	17	36.3	7.05
Aerolight	10	40	4
Canard	10	40	2.4
Sheddon MK3	10	40	4.2
Mini-Vanguard	17	45	2.16
Lipan M3	17.8	60	4.38
Apid MK IV A	16	62	3
Aerosky	18	70	4.5
Chacal 2	24	75	2.6
Raven	21	84	3.6
Apid MKIV B	28	90	3
RPG Midget MK III	24	90	2.6
Aerohawk	40	100	3

4 RESULTS AND DISCUSSION

4.1. Power as a Function of MTOW

In a traditional conceptual design case, power is estimated as a function of a single variable which is the MTOW. This variable is used as standard because of its direct relationship with aircraft lift [10].

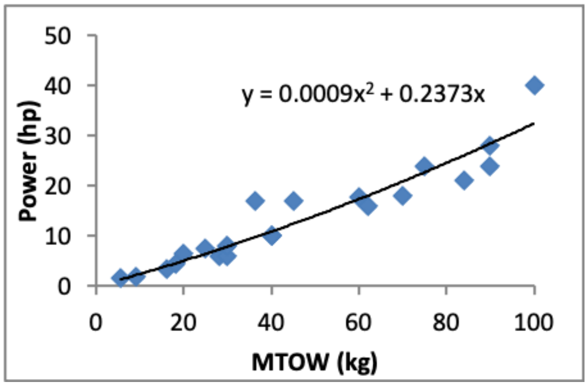

Fig.3. Power as a Function of MTOW for 23 Model UAVs

The above solution is constraint by a single variable as indicated in eqn (1).

$$Pw = f(W) \qquad (1)$$

This gives a single variable and second order polynomial solution as contained in eqn (2).

$$y = 0.0009x^2 + 0.2373x \qquad (2)$$

However, the scatter of deviation of the solution from the published data shows that the result of 26% of the models fall outside the 20% deviation as shown in Fig 2. This result is not good enough for a tactical UAV that would require, low speed, low altitude and long endurance capabilities for surveillance and law enforcement. [4][11]

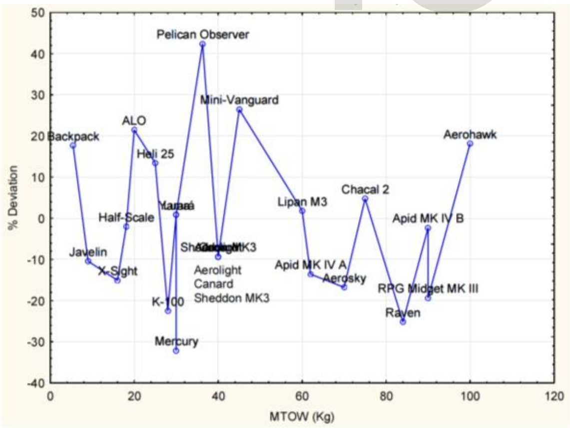

Fig.4. Scatter of % Deviation of the Solution [Pw=f(W)] from the Published Data

In order to optimize the above solution, the scope of the traditional statistical method was extended to include a second variable which is the wingspan. Wingspan directly affects the form factor which is directly linked to the induced drag which is an important component of the total drag/thrust [11],[12].

4.2. Power as a Function of MTOW and Wingspan

Introducing wingspan in the computation has increase the fidelity of the solution obtained under a single variable.

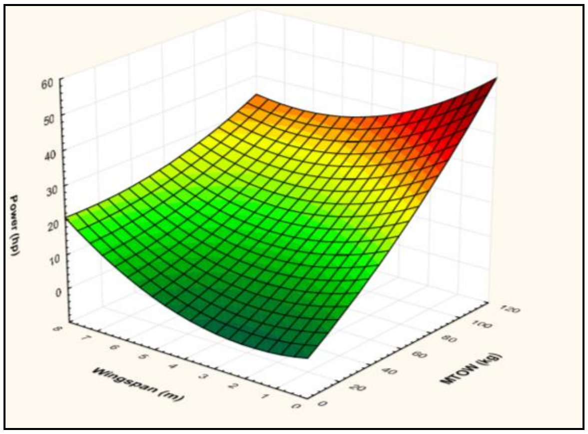

Fig.5. Solution of Power=f(MTOW, Wingspan)

Fig 4 is a 3D plot of power against the MTOW and wingspan. A second order quadratic formulation was used to describe the relationship between the three variables as shown in eqn (3).

$$Pw = 1.4975 + 0.3236x - 2.0641y + 0.0011x^2 - 0.0426xy + 0.05607y^2 \qquad (3)$$

Where;

$x = MTOW \ and \ y = Wingspan$

Eqn (3) solution is an improvement on the existing method of estimating power based on a single variable such as the MTOW. This is proven by Fig 4 which clearly shows the that the two variable solution produces closer results to the published data than a single variable solution.

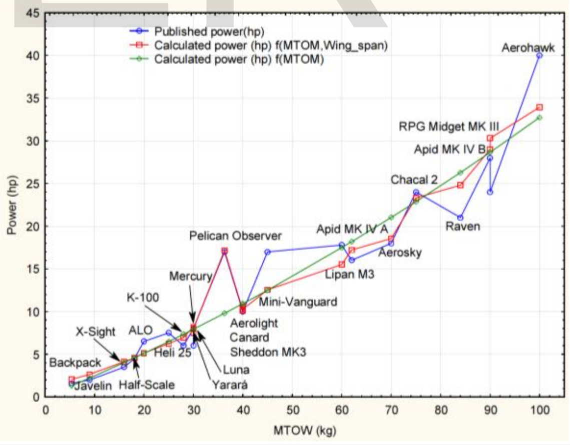

Fig.6. Comparison of calculated values to the published data

A comparison of the published data with the calculated values shows a close match-up in all the 23 cases involving existing UAVs. To interrogate the match up, a scatter plot was generated using STATISTICA II software to quantify the variations. Accordingly, the scatter plot of the two variable solution shows in Fig 6 that 74% of the model UAVs fall under the 20 % deviation with the peak being 32%. This is quite better than one variable solution which produced a peak deviation of 42%.

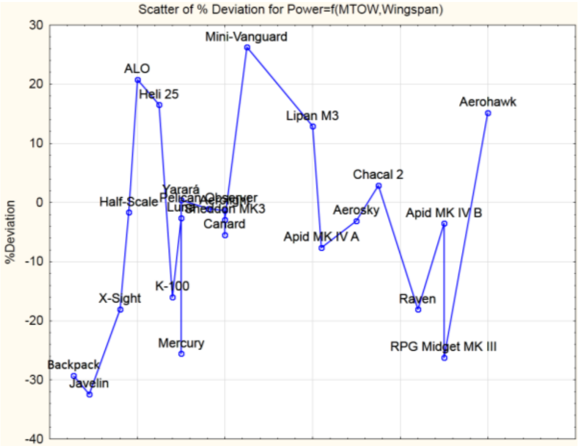

Fig.7. Scatter of % Deviation of the 2 Variable Solution

4.3 VALIDATION OF RESULT

The solution was validated against published data of three UAVs with exact 40kg MTOW as OLE [9][13]. The solution matched the data by over 90% as shown in Fig 7.

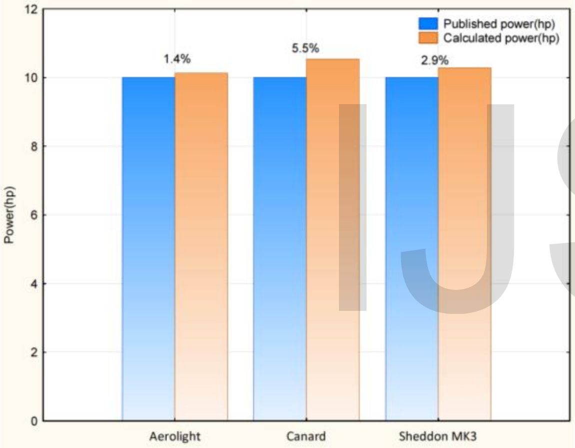

Fig..8. Comparison of 40kg UAVs Power with the Solution

The calculated values were close to the published data by over 90% as shown in Fig 7. Because of the small deviation (<5%), this methodology is acceptable for sizing at conceptual level. [14]

5 CONCLUSION

Applying a statistical solution to the case study gives the estimated engine power for the Concept UAV as 10hp. Considering that Aerolight, Canard and Sheddon MK3 UAVs, all of which are in the same weight category as the Concept UAV, the study concludes as follows:

1. Statistical solutions can be comfortably used for UAV engine sizing at conceptual level even prior to solving drag laws.
2. There is direct relationship among UAV weight, geometry and power requirements. Hence, the model developed in this study can be used for conceptual engine sizing for a mini-UAV.
3. Any solution derived using the model developed in this study is considered true for $5kg < MTOW < 100kg$ categories only.

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