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Propulsion Selection and Analysis for Unmanned Aerial Vehicles for SAE Aero Design Series

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ABSTRACT

Society of Automotive Engineers (SAE) conducts 'Aero Design Series' competition annually in the United States of America (USA). This paper explains and details about Propellers and the significance of selecting the optimum one for the respective unmanned aerial vehicle. The propellers were selected on the techniques of methods based on the efficiency of thrust produced. In order to produce the maximum amount of thrust, the study of individual and interactional results of the propellers based on engine and muffler attachments. The major criteria for selection of the propellers were based on noise, downwash, torque and revolution per minute characteristics. The system defined in this paper, is cost effective and rugged. This system can be implemented for various types of UAVs and provides the perfect fit in terms of effective lift, least downwash and ideal stability.

KEYWORDS: *Aero, Propellers, Thrust, SAE, Engine, Muffler*

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I. INTRODUCTION

SAE International is an international association of more than 150,000 engineers and related to automotive, aerospace and commercial vehicles. Technical experts are present in the aerospace, automotive and commercial-vehicle industries. SAE International's core competencies are practical and voluntary consensus standards development. To build and encourage talent in the field of aviation, SAE International conducts 'Aero Design Series' competition annually in the USA. The competition involves student teams from all over the world designing and fabricating UAVs. Depending on the design and event objectives, there are three classes in this competition: Micro, Regular and Advanced Class. The objective of the Advanced Class, of the 2014 edition of SAE Aero Design Series, was to design the most efficient aircraft capable of accurately dropping a three pound (3 lb) humanitarian aid package from a minimum of 100ft off the ground. To fulfil the objective of designing the most efficient aircraft, one must have an efficient engine and propeller. But just as a car engine is useless until its power is transmitted to the ground, a model engine is useless until its power is transmitted to the air i.e. thrust. Model aircraft use propellers for this job. A model's engine is only as good as its propeller. The propeller's size and composition determine how much of the engine's power is transmitted to the air and the manner in which the aircraft can best use that power. Selecting the right propeller also depends on the engine one is using. The engine we selected wasO.S.46AX engine with a standard issue muffler. Accordingly, afixed pitch, two bladed Carbon Fibre propeller of dimension 11"x 6" was selected, where "11" being the diameter of the propeller which indicates the area swept by the propeller and "6" being the pitch which has an effect on the speed of the propeller. The rules proposed by the association were to :

- No use of metallic or propellers were allowed
- Multiple engines, multiple propellers, propeller shrouds, and
- ducted fans are allowed in Advanced Class.
- Use only a 2 stroke 0.46 cc engine

Following the given rules we are able to select and design the engine, muffler and propeller on good amount of analysis.

BLOCK DIAGRAM

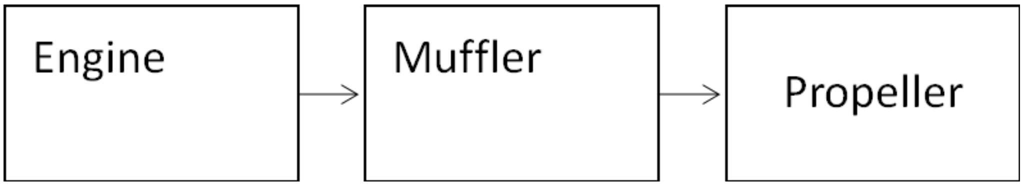

Figure 1: Block Diagram

ENGINE : The engine requirement was to produce 2.5 kilograms of thrust in order to attain sufficient take off acceleration and velocity to lift the aircraft. Different type of engines were studied in terms of their weights and the amount of thrust produced. Their performance was tested by experience pilots and testing mechanisms such as the static thrust machine. The average altitude the aircraft had to fly was about 120-150 feet and the air density was 1.1013 gram per cubic centimetre. The engine finally selected was the OS .46AX engine due its flight characteristics and performed better than other engines studied on basis of thrust and revolution per minutes produced. The engine being the heart of the aircraft has to function smoothly and develop enough power to gain momentum in order for it to travel.

Figure 2: OS .46 AX EnginE

- Power Box muffler features a squared-off shape for easier fits in more cowls.
- 40K carburettor has high- and low-speed needles, plus a mixture adjustment screw. Tighter tolerances between the piston and ABL create a tighter compression seal and improved power.
- Dual ball bearing-supported crankshaft lowers friction and wear.
- Head automatically centres and levels itself — and snugs down with just 4 screws.
- Subtly tapered low-end needle eliminates surging at transition, ensuring smooth, controllable power across the rpm range.
- Updated liner ports and a ball-milled inlet port minimize turbulence and promote better fuel/air mixing.
- Minimizes "creep" • and resets with seals on both needles and a ratchet spring on the high-speed needle. A rotor guide screw eliminates spring-related movement, too.
- Includes a lock nut and a longer crankshaft with more thread length to ensure better prop nut engagement and greater pilot safety.
- Includes glow plug, muffler, cable extension and warranty.
- The ABL (Advanced Bi-Metallic Liner) includes one layer for better bonding, and another to reduce wear and extend life.

MUFFLER : Themuffler in simple terms is the exhaust part of the aircraft. It works on the principle of a venture meter. In order to select the right muffler for our propulsion system we studied the various weights, cost and effect on thrust on the OS 0.46AX engine. The muffler’s main role to reduce the noise of the internal combustion engine and if modified to certain specifications can produce excess amount of thrust. The specifications involve increasing weight of the system and thus care must take as weight is the major criteria in an aerial vehicle.

II. PROPELLER

Classification By Pitch of the Blade

Fixed Pitch Propeller : The blades in fixed pitch propeller are permanently attached to the hub. The fixed pitch type propellers are casted and the position of the blades and hence the position of the pitch is permanently fixed and cannot be changed during the operation. Fixed pitch propellers are robust and reliable as the system doesn't incorporate any mechanical and hydraulic connection as in Controlled Pitch Propeller (CPP). The manufacturing, installation and operational costs are lower than controlled pitch propeller (CPP) type.

Controllable Pitch Propeller : In Controlled Pitch type propeller, it is possible to alter the pitch by rotating the blade about its vertical axis by means of mechanical and hydraulic arrangement in flight or while operating the engine. This helps in driving the propulsion machinery at constant load with no reversing mechanism required as the pitch can be altered to match the required operating condition. Thus the manoeuvrability improves and the engine efficiency also increases.

Ground Adjustable Pitch Propeller : The pitch setting can be adjusted only with tools on the ground before the engine is running. This type of propellers usually has a split hub. The blade angle is specified by the aircraft specifications.

Constant speed Propeller : The constant speed propeller utilizes a hydraulically or electrically operated pitch changing mechanism which is controlled by governor. The setting of the governor is adjusted by the pilot with the rpm lever in the cockpit. During operation, the constant speed propeller will automatically changes its blade angle to maintain a constant engine speed.

Classification by Number of Blades Attached

Two Blade Propeller : A standard 2 blade propeller is more efficient than 3 and 4 bladed propellers for small engines with relatively small horsepower (i.e. small airplanes with engine power less than 500 horsepower). A blade creates lift just like the wings of an airplane. Each blade follows nearly the same path as the prop spins. The more blades there are, the less space there is between each blade.Basically, the blades on a 2 blade prop get a much cleaner bite on the air making it more efficient.

Three And Four Bladed Propeller : For larger engines with more horsepower, there must be more blades to maintain a reasonable power distribution to each blade (i.e. the powerful engines with 1000+ horsepower). An alternative to adding more blades would be to give each propeller blade a larger radius, but there is a practical limitation on radius because of the necessity for the blade to clear the ground. Hence the need to have more blades rather than to increase the radius as engine power increases. From the above types of propellers, Fixed Pitch two bladed Propeller was selected. Fixed pitch propeller was used because of its simplicity, effectiveness and cost friendly comparing to others. Similarly, two bladed Propeller was selected for its efficiency and the lift it provides. For the SAE AERO DESIGN SERIES, selecting other types of propellers would be redundant. It would only result in complexity, inefficiency and increase in the cost margin.

III. MATERIAL

SAE AERO DESIGN SERIES allows us to use from the following materials for the propellers:

1. Wooden Propellers
2. Fibreglass Reinforced
3. Carbon Fibre

Fiberglass-reinforced propellers are stiffer and sometimes feature under cambered (concave-bottom) air foils. Fiberglass-reinforced propellers have wingtip designs that most closely resemble the elliptical wing shape. The reduced tip drag allows the propeller to accelerate quickly and to reach a higher top speed. That combined with the more rigid blade make fiberglass propellers famous for excellent climb performance.However, these stiffer fiberglass-reinforced blades still flex a bit under load and are easy to break during hard landings. Paved runways are rough on them since the tip area is small and may be destroyed with one contact, even if the propeller is not rotating. Wood propellers are more rigid than fiberglass-filled and fiberglass-reinforced nylon types. Some wood propellers have special tip designs to produce increased thrust and rpm. Most have roughly the same blade area as fiberglass-filled propellers that are the same size. However, wood propellers must be carved—not moulded—and therefore do not usually feature the more exotic blade designs that are so common in some moulded model propellers. Depending on their design, wood propellers produce excellent top speeds and quick acceleration because they are light and stiff. Wood propellers break easily with any ground contact, and prolonged use on grass runways results in excessive blade wear. They also require the most balancing effort because density and water content may vary in a single propeller. Carbon Fibre (CF) propellers are the ultimate in rigidity; they have almost no detectable flex. They can assume any air foil shape and blade area as they are moulded. Some are solid and others are hollow. CF propellers are light, allowing for the fastest engine acceleration possible, and hollow ones accelerate even more quickly. The solid and hollow kind feature excellent performance across the entire aerobatic spectrum. You can even purchase them prebalanced.

On comparing, Carbon Fibre is the most rigid, light and can be easily moulded according to required air foil shape. They are a tad expensive but the pros of it makes it worth using. If you want to go a little light on pockets, then Fibreglass Reinforced will be the one to go with. Some air foils have mixture of materials, varying them along the tip, leading and trailing edge according to the needs of the pilot.

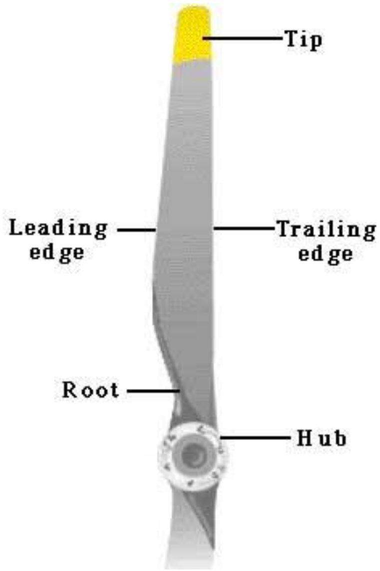

Figure 3: Blade elements

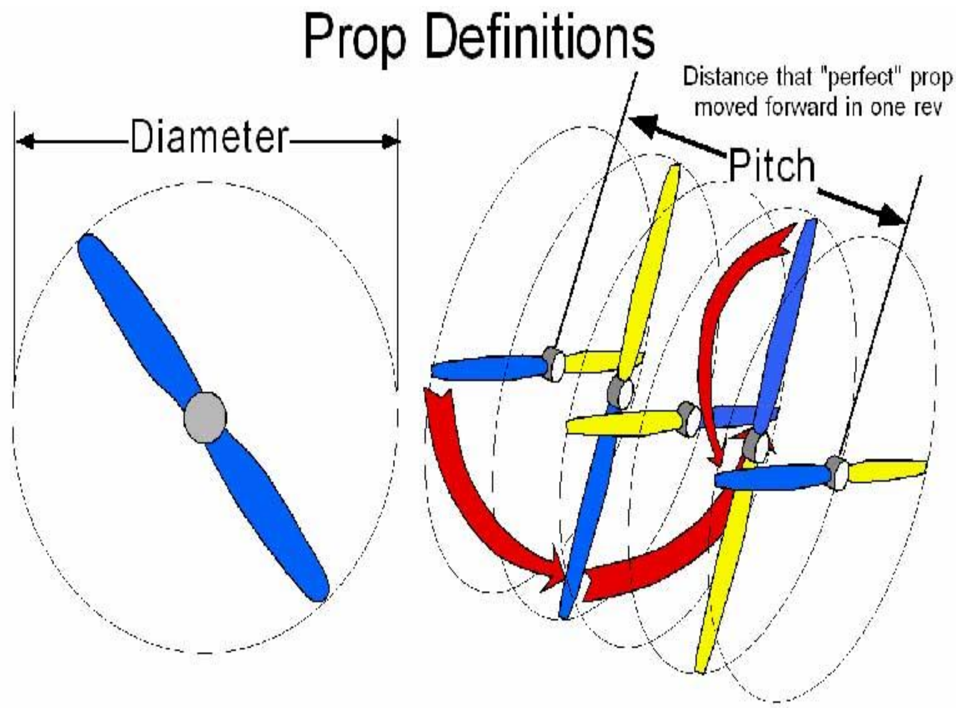

Figure 4: Propeller Sizing

SIZING : A Propeller is designated by two dimensions in the following manner- A" x B". "A" denotes the diameter of the propeller and "B" denotes the pitch of the propeller. Understanding both numbers' performance implications is critical. They interact in a complicated dance of airflow, engine performance, thrust, and geometry. The propeller's efficiency for a given task is determined by the amount of air it moves per revolution and its speed. On a *sport airplane*, if a propeller can move a huge amount of air, but only at a slower speed, that is better than moving small amounts of air at high speeds.The diameter of the disc that the rotating propeller produces has more effect on the power transmitted than a speed increase does because the disc area increases by the square of the radius. Therefore, an increase in diameter (radius) moves additional amounts of air by the square of the radius. This is a large force multiplied. The incremental pitching moment about the airplanecentre of gravity due to the propulsions system is:

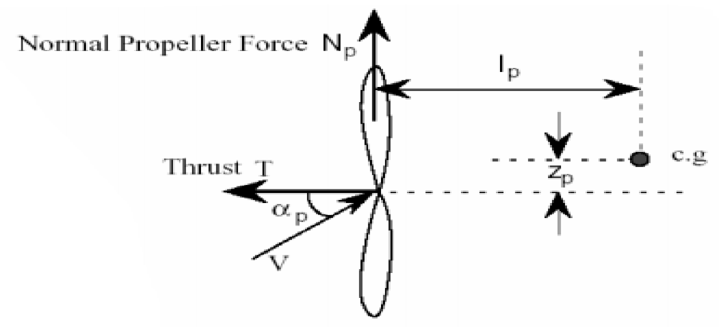

Figure 5:Blade element subdivision

Where T is the thrust and Np is the propeller or inlet normal force due to turning of the air. Another influence comes from the increase in flow velocity induced by the propeller or the jet slipstream upon the tail, wing and aft fuselage.
In terms of moment coefficient,

$$\Delta C_{M_{cg}} = \frac{T}{qS}\frac{z_p}{c} + \frac{N_p}{qS}\frac{l_p}{c}$$

Since the thrust is directed along the Propeller axis and rotates with the airplane, its contribution to the moment about th centre of gravity is independent of α_w. Then we have:

Where the propeller normal coefficient $dC_{np}/d\alpha$ and the downwash (or upwassh) ε_a are usually determined empirically.
*Downwash- In aeronautics **downwash** is the change in direction of air deflected by the aerodynamic action of an airfoil, wing or propeller in motion, as part of the process of producing lift.

Propeller Thrust and Torque Coefficients and Efficiency.

The overall propeller thrust and torque will be obtained by summing the results of all the radial blade element values.

$T = \Sigma\, \Delta T$ (for all elements), and $Q = \Sigma\, \Delta Q$ (for all elements)

The non-dimensional thrust and torque coefficients can then be calculated along with the advance ratio at which they have been calculated.

$C_T = T/(\rho n^2 D^4)$ and $C_Q = Q/(\rho n^2 D^5)$ for $J = V_{inf}/(nD)$

where n is the rotation speed of propeller in revs per second and D is the propeller diameter.

The efficiency of the propeller under these flight conditions will then be

$$\eta(\text{propeller}) = J/(2\pi).(C_T/C_Q).$$

IV. PRACTICAL ANALYSIS DATA

Sr.No	Propeller	Thrust = Observed - Least Count	Muffler
1	11*6	1.8 - 1.9	AFC
2	12*6	2.2 - 2.3	AFC
3	11*6	1.9 - 2	OS
4	12*6	1.8 - 1.8	OS

Figure 6: Practical study

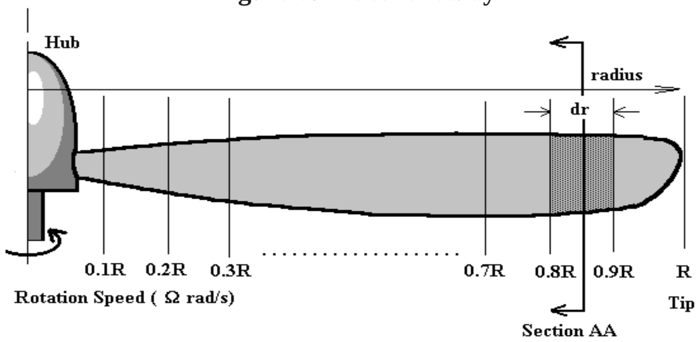

Figure 7:Blade element subdivision

V. CONCLUSION AND FUTURE SCOPE

The complete Propulsion System for a UAV have been designed andimplemented. Apart from conforming to the design requirements of 'SAE Aero Design Series', it is a fully functional unit which can be placed on any UAV. It proves to be an invaluable tool necessary for assisting the flight and mission requirements of the UAV. The future scope from here is to explore suitable material and sizing options with different twist angles in terms of propellers and change the sizing of the mufflers to increase efficiency. Additionally, measurement of critical parameters such as remaining fuel and airspeed can also be undertaken.

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