Analysis Of NACA 6412 Airfoil (Purpose: Propeller For Flying Bike)

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Abstract: The propeller for the aircraft is always an pull or pushed propeller. For the pull propeller it is always driven with the help of an engine being coupled with crank shaft and for the push propeller it has been always driven with the help of chain drive or by the pulley arrangement which means an propeller is connected to the wheels of the vehicle through a chain or belt drive. So, that when the wheels rotate it will rotate or spin the propeller in order to produce thrust for the forward movement. With reference to the paper "Analysis of Down-Wind propeller Vehicle" the selected Airfoil is NACA 6412 which does very well with the performance and a wind driven vehicle travels faster than the wind along its direction. The analysis i carried out in the Java Prop software to study the behaviour of NACA 6412 airfoil selected as push propeller to fly the bike in air to have the less induced drag and also with minimum drag for the same amount of lift and wing area. Even for the Wind Turbine it has been chosen best according to the paper" Design and Blade Optimisation of Contra rotation double Rotor Wind turbine" for its optimum results for the 3 blades with 600 mm diameter in the front and rear. **Keywords:** NACA 6412, Propeller, Wind Turbine

I. Introduction

To drive fly the vehicle in air one always needs a requirement of thrust. The thrust is based on the Newton's second law of motion. The main purpose of the propeller is to cut the air and to provide the movement (pull or push) of a vehicle in a road or in air. The best cutting angle provides the best performance of a propeller. While the wings helps in gliding much more than propeller. Also the performance of a propeller based on its diameter and the blade chosen for an angle of attack. The best propeller always results the minimum fuel consumption due to the minimum drag.

Objective:

II. Research And Analysis

With reference to the paper: Dhakad, Amit Singh, and Arun Singh. "Power Requirement for Flying Bike."International Journal of Innovative Research and Development 3.5 (2014), the required thrust is 88.75N for speed (axial vel.) = 16.6 m/s=60 km/hr and 487.00 for speed (axial vel.) = 38.88 m/s=140 km/hr, the objective is to find the suitable propeller among 2 and 3 blades.

The input values for design and analysis in Java Prop are:

Propeller Chosen	NACA 6412
Blade	2 and 3 (for analysis)
Propeller diameter	580mm=0.58mm
Propeller spinner	19 mm
Max revolution per minute	8000 rpm
Max Thrust (T)	487.00 N
Max Velocity (V)	140 km/hr
Fort Wing	Rear Wing Direct Driven Properties

Fig 1 Side view of an Air propeller bike/vehicle (Ref): Amit Singh Dhakad, Pramod Singh. "Flying Bike Concept." international research journal of mechanical engineering 1.1 (2014): 001-011.

Design card:

For analysis on Java Prop we have the design output data (for two and three blade propeller) as:

	Enter Design Parameters	and pr	ess the Desig	n It' button.		
	Propeller Name:	apporte a	6412	-		
	Number of Blades B		2			
			8000	-		
	Revolutions per minute in	om:	0000	(1 xmin)		
	Diameter D:		0.58	(m)		
	Spinner Dia, Dsp:		0.19	[m]		
	Velocity v:		38.88	[m/s]		
	Power P.	¥	9460	EV4		
	shrouded rotor			🗖 square tip		
	Propeller					
	v/(nD)	0.5	503	v/(ΩR)	0.16	
	Efficiency n	64.0	49 %	loading	medium	
	Thrust T	155	84 N	α	0.0634	
	Power P	9.46	S K/V	Ср	0.0498	
	Torque Q	11.2	9 Nm	Cs	0.916	
	β at 75%R	14	.6*	Pitch H	357 mm	

Fig 2 (Design parameter of 2 blade propeller)

So, by putting the input values we have output with certain properties of propeller where the propeller design is simple but without shrouded and squared tip condition.

ign card (shrouded	d)									
🚟 JavaProp										_ 2
	Design	Airfoils	Geometry	Modify	Multi Analy:	sis Single	Analysis	Flow Field	Options	
		Enter D	Design Paramet	ers and pre	ss the 'Design	t!' button.				
		Propell	ler Name:		6412	_				
		Numbe	r of Blades B:		2	[-]				
		Revolu	itions per minut	e rpm:	8000	[1/min]				
		Diamet	er D:		0.58	[m]				
		Spinne	er Dia. Dsp:		0.19	[m]				
		Veloci	ty v:		38.88	[m/s]				
		Powe	r P:	~	9460	[VV]				
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		_								
			Propeller	0.5	02			16		
		Ef	ficiency n	73.73	4%	loading	me	dium		
			Thrust T	179.3	39 N	Ct	0	073		
			Power P	9.46	kw l	Cn	0.0	1498		
		T	orque Q	11.29	l Nm	Cs	0.	916		
		β	at 75%R	18.	4°	Pitch H	455	5 mm		
		Remar	k: The RPM sett	ting is also	used for Analy:	sis page.				
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🛃 start	@ 🧿 🖄) » Jaw Proj	JavaProp		🧿 www.ijsrp	.org/res	📜 Windo	ows XP Snippi	634	9, 💽 1:54 F
Fig 3	(Desig	n pars	ameter	of 2 b	lade pro	peller 1	ınder	shroude	d condif	tion)

Shrouded:

The characteristic of propeller says that along the length of the propeller airfoil the thrust decreases and at tip it becomes zero. So, to avoid and to cover such thrust loss at the tip the propeller used to be shrouded and the thrust can be maximised.

Enter Design Parameters and press the 'Design II' button. Propeller Name: 6412 Number of Blades B: 2 [-] Revolutions per minute rpm: 8000 [1/min] Diameter D: 0.58 [m] Spinner Dia. Dsp: 0.19 [m] Velocity v: 38.88 [m/s] Power P: ▼ 3460 [V/] ♥ shrouded rotor ♥ square tip: Propeller V(nD) 0.503 v/(nR) 0.16 Ffficiency D, 73.720 % Ion/Rp 0.16	Enter Design Parameters and press the 'Design th' button. Propeller Name: 6412 Number of Blades B: 2 Revolutions per minute rpm: 6000 Diameter D: 0.58 Spinner Dia. Dsp: 0.19 Velocity v: 38.88 Power P: ✓ 9460 (M) ✓ shrouded rotor ✓ Propeller √((OR)) 0.16 Efficiency n 73.729 % loading Power P 9.46 kW Cp 0.073 Power P 9.46 kW Cp 0.0498 Torque Q 11.29 Nm Cs 0.916 9 at 75%R 18.4* Pitch H 456 mm	Design	Airfoils	Geometry	Modify	Multi Analys	is Single Ar	nalysis	Flow Field	Options	
Propeller Name: 6412 Number of Blades B: 2 Revolutions per minuter prime 8000 Diameter D: 0.58 Spinner Dia. Dsp: 0.19 Velocity v: 38.88 Power P: 9460 Frouded rotor V(NF)	Propeller Name: 6412 Number of Blades B: 2 Revolutions per minute rpm: 9000 Diameter D: 0.58 Spinner Dia. Dsp: 0.19 Velocity v: 38.88 Power P: 9460 V(n/n) 0.16 Efficiency n; 73.729 % Ioading medium Thrust T 179.41 N Ct 0.073 Power P 9.46 kW Cp 0.0498 Torque Q 11.28 Nm Cs Ø at 75%R 18.4* Pitch H H d56 mm Association of the setting is also used for Analysis page.		Enter I	Design Paramet	ers and pr	ess the 'Design I	t!' button.				
Number of Blades B: 2 [-] Revolutions per minute rpm: 8000 [1/min] Diameter D: 0.58 [m] Spinner Dia. Dsp: 0.19 [m] Velocity v: 38.88 [m/s] Power P: ▼ 9460 [V/] F shrouded rotor ✓ square tip: Propeller	Number of Blades B: 2 [-] Revolutions per minute rpm: 9000 [1/min] Diameter D: 0.58 [m] Spinner Dia. Dsp: 0.19 [m] Velocity v: 38.88 [m/s] Power P: 9460 [M] ✓ shrouded rotor ✓ square tip: Propeller √((∩R)) 0.16 ✓ fifciency n 73.729 % loading medium Thrust T 179.41 N Ct 0.073 Power P 9.46 kW Cp 0.0498 Torque Q 11.28 Nm Cs 0.916 Ø at 75%R 18.4* Pitch H 456 mm		Propel	ller Name:		6412	-				
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Diameter D: 0.58 [m] Spinner Dia. Dsp: 0.19 [m] Velocity v: 38.88 [m/s] Power P: 9460 [W] If shrouded rotor If square tip:	Diameter D: 0.58 [m] Spinner Dia. Dsp: 0.19 [m] Velocity v: 38.88 [m/s] Power P: ♥ 9460 [M] I shrouded rotor I structure tip Propeller I structure tip V(nD) 0.503 v/(OR) O.16 Efficiency n 73.729 % I fright T 179.41 N Ct O.073 Power P 9.46 kW Cp 0.0488 Torque Q 11.29 Nm Cs 0.916 β at 75%R 18.4* Ptch H 456 mm		Revoil	utions per minuti	e rpm:	0000	[17min]				
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Velocity v: 38.88 [m/s] Power P: 9460 [M] If shrouded rotor If square tip Propeller If square tip V(nD) 0.503 v/(nR) Efficiency p 73.79 % loading	Velocity v: 38.83 [m/s] Power P: 9460 [M] Image: shrouded rotor Image: superstate state s		Spinne	er Dia. Dsp:		0.19	[m]				
Power P: y 9460 µ/j ✓ shrouded rotor ✓ square tip Propeller ✓ √x(nD) 0.503 √y(nR) Efficiency p 73.729 % loading	Power P: 9460 [M] ✓ shrouded rotor ✓ square tip: Propeller ✓ ✓ √(nD) 0.503 √((nR)) 0.16 Efficiency n 73.729 % loading medium Thrust T 179.41 N Ct 0.073 Power P 9.46 kW Cp 0.0498 Torque Q 11.29 Nm Cs 0.916 β at 75% R 18.4* Pitch H 456 mm		Veloci	ity v:		38.88	[m/s]				
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v/(nD) 0.503 v/(ΩR) 0.16 Efficiency p 73.729 % leading medium	v(nD) 0.503 v((ΩR) 0.16 Efficiency η 73.729 % loading medium Thrust T 179.41 N Ct 0.073 Power P 9.46 kW Cp 0.0498 Torque Q 11.29 Nm Cs 0.916 β at 75%R 18.4* Ptch H 456 mm			Propeller							
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Power P 9.46 kW Cp 0.0498	Torque Q 11.29 Nm Cs 0.916 β at 75%R 18.4* Pitch H 456 mm Remark: The RPM setting is also used for Analysis page. 10.000 mm 10.000 mm			Power P	9.46	i KVV	Ср	0.04	98		
Torque Q 11.29 Nm Cs 0.916	ß at 75% R 18.4* Pitch H 456 mm Remark: The RPM setting is also used for Analysis page.			Torque Q	11.2	9 Nm	Cs	0.9	16		
βat 75%R 18.4* Pitch H 456 mm	Remark: The RPM setting is also used for Analysis page.		L F	3 at 75% R	18	.4°	Pitch H	456	mm		
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Design card (shrouded and squared tipped)

Fig 4 (Design parameter of 2 blade propeller with shrouded and square tip)

Square tip:

The square tip is the concept for creating the blades with rounded tips which produces a tip with final chord length by the simple extrapolation of the last section and the optimum design results good for the light and medium loaded propellers. And this is classified in terms of the coefficient of thrust. i.e.,

- 1. $T_C > 1$, (highly loaded)
- 2. $T_{\rm C} > 0.25$, (medium loaded)
- 3. $T_C \leq 0.25$, (lightly loaded)

Note: So, under both shrouded and square tip condition the thrust can be maximise additionaly.

Prop	eller Name:		6412			
Numl	ber of Blades B:		3	[-]		
Revo	olutions per minute	rpm:	8000	[1/min]		
Diam	neter D:		0.58	[m]		
Spin	ner Dia. Dsp:		0.19	[m]		
Velo	icity v:		38.88	[m/s]		
Pow	ver D:	~	9460	0.00		
- Ow	voi r.			[v v]		
l ⊻ st	hrouded rotor			🖌 square tip		
	Propeller					
	V(nD)	0.5	03	V/OR)	0.16	
	Efficiency n	73.74	48 %	loading	medium	
	Thrust T	179.	44 N	ct	0.073	
	Power P	9.46	KVV	Ср	0.0498	
	Torque Q	11.2	9 Nm	Cs	0.916	
	βat75% R	18	.4°	Pitch H	455 mm	
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Fig 5 (Design parameter of 3 blade propeller)

Note: From fig 4 and fig 5, on design analysis we come to know that as we go for the increase of number of blades the propeller efficiency will increase with thrust for the same power and torque than two blade propellers with a different angle of attack along the length of the propeller but the weight consideration is the major issue for flight.



Analysis of two blade propeller in order to have minimum drag and weight: Airfoils:

Note: The best performance of an airfoil depends on the blade angle. And by default the angle of attack is set as 3 degree always for best performance. And here we can see the red dot for coefficient of drag = 0.0200 and coefficient of lift = 0.549



Fig 7 (Geometry of the Two blade propeller)



Analysis of NACA 6412 Airfoil (purpose: propeller for flying bike)

Fig 8 (Two blade propeller result along the length of propeller)



Fig 9 (Two blade propeller results with pitch along the diameter)

Therefore form the geometry card (Fig 6, 7 and 8) we have:

- 1. The 3D view of the propeller in red color and also the front and side view (fig 6)
- 2. The different properties like
- (a) 'r' is the radius station or origin i absolute dimensions
- (b) 'c'is the chord length in absolute dimensions
- (c) 'R' is the radius of the propeller in m

- (d) $\frac{r}{R}$ is the relative radius of propeller and can be read along the length of it. (e) $\frac{c}{R}$ is the relative chord along the length of the propeller radius.
- (f) [']H' is the pitch in mm
- (g) 't' is the thickness of an propeller along the diameter of an propeller.

Note: Since the spinner is only to mount and spin the propeller their thickness, pitch and angle of radius is left blank as it nothing to do with it.

iy card:						
Prop Jav	aProp					
	Design	Airfoils Geometry Mo	dify Multi Analysis	Single Analys	is Flow Field	Options
		Modify Propeller Geomet	rv.			
		Change Blade Angle by:	0.00	0 [1]		
		Scale Blade Angle by:	1.00	о н		
		Increase Chord by:	0.00	0 (m	n]	
		Scale Chord by:	1.00	0 [-]		
		Taper Chord by:	1.00	0 [-]	tip/root	
		v/V at r/R = 0 (1.0 = undi	sturbed inflow): 1.00	0 [-]		
		r/R where v/V = 1:	0.50	0 [-]		
		Threading line at % chor	d: 33.0	00 [%]	
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Fig 10 (The default desired data of an propeller)

The modify card is to modify in creation as per our requirement. **Multi Analysis card:**_____

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0.050	0.016	0.207988	0.072093	0.084604	9.999999	9.999999	14.43	12.48	27.00
0.100	0.032	0.175819	0.087401	0.162816	9.999999	9.999999	20.12	25.17	0.00 !
0.150	0.048	0.166033	0.085803	0.245127	9.999999	9.999999	29.03	35.92	0.00 !
0.200	0.064	0.155020	0.083355	0.328733	9.868903	9.999999	37.20	45.62	0.00 !
0.250	0.080	0.143280	0.080299	0.413998	5.837762	9.999999	44.61	54.30	0.00 !
0.300	0.095	0.130738	0.076537	0.501587	3.699124	7.218546	51.24	62.07	0.00
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Fig 11 (The multi analysis result)

Analysis of NACA 6412 Airfoil (purpose: propeller for flying bike)

Design Airfoils Geometry Modify / Multi Analysis Single Analysis Flow Field Options
Design Airfolls Geometry Modify / Multi Analysis Single Analysis Flow Field Options
Propeller Off-Design Analysis for full v/bD range
Te Pe n n n* stalled u rom Power Thrust
[-] [-] [%] [%] [%] [m/s] [1/min] [kW] [kN]
051 9.999999 9.999999 0.01 0.01 3.00! 0.00 8000 16.183 0.512
604 9.999999 9.999999 14.43 12.48 27.00 ! 3.87 8000 13.695 0.511
816 9.999999 9.999999 20.12 25.17 0.00! 7.73 8000 16.603 0.432
127 9.999999 9.999999 29.03 35.92 0.00! 11.60 8000 16.300 0.408
733 9.868903 9.999999 37.20 45.62 0.00! 15.47 8000 15.834 0.381
<u>998</u> 5.837762 9.999999 44.61 54.30 0.00! 19.33 8000 15.254 0.352
587 3.699124 7.218546 51.24 62.07 0.00 23.20 8000 14.539 0.321
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Fig 12 (The multi analysis result with various properties like power and thrust)

Therefore according to the multi analysis we have the different values based on the constant rpm=8000. i.e., (a) Different velocity (v) in m/s deliver by propeller rotating with constant speed.

(b) Power also varies from initial point to the final point with the thrust.



Fig 13 (The flow around propeller)

Here from the flow field we see that the (V_a) : axial flow speed increment increases immediately after the propeller and also the (V_t) : the tangential velocity increases immediately after the propeller.

Since, the ratio (V_x/V) for red colour start with 1.1537 and it is around 1.1973 and 0.136. And for the yellow colour the ratio (V_x/V) starts with 1.3074 and it is around 1.3945 and 0.1478 around the propeller with the delivering velocity.

HOD SHARE	Prop							
	Design	Airfoils	Geometry	Modify	Multi Analysis	Single Analysis	Flow Field	Options
	А	djust the desired	d Option(s).					
					JavaProp			
				Versio	n 1.64 - February	1,2014.		
				Copyright	© 2001-2014 Mart	in Hepperle		
		Translations Translation to Er Translation to G Translation to Fr Translation to Ita	nglish by Ma erman by Ma rench by Gio alian by Gior	rtin Hepperle artin Hepperle orgio Toso, 20 gio Toso, 200	, 2001. a, 2001. 002. 12.			
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The option card is to set the data as per the standardization to get the appropriate result. **Validation:**

According tom the reference paper:

- 1. Amit Singh Dhakad, Pramod Singh. "Flying Bike Concept." international research journal of mechanical engineering 1.1 (2014): 001-011 &
- 2. Dhakad, Amit Singh, and Arun Singh. "Power Requirement for Flying Bike." International Journal of Innovative Research and Development 3.5 (2014).

The force required for to overcome the drag (D) = F=ma, is $280 \text{kg} \times 0.648 \text{m/s}^2 = 181.44$ N through mathematical modelling and the thrust obtained on analysis for three conditions are T= 155.84N in fig 2 (for unshrouded and unsquared tip propeller), T = 179.39 N in fig 3 (for shrouded propeller) and

T = 179.41 N in (fig 4) for both shrouded and squared tip propeller). Hence the analysis validates the mathematical modelling meeting the nearby target with a difference 0.02%.

III. Conclusion

On analysis it is very clear that two blade propeller has (efficiency) $\eta = 73.729$ % and the three blade propeller has $\eta = 73.748$ producing the same thrust with constant power. Therefore keeping the weight into consideration it is better to have the two blade propeller for flying bike. And as the coefficient of thrust $T_c = 0.073$ the propeller is lightly loaded.

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