Designing Small Propellers for Optimum Efficiency

Juan Munguia[2] and Kenneth W. Van Treuren[1]

Baylor University, Waco, TX, 76798

Unmanned aircraft systems (UAS) extend human potential and allow us to execute dangerous or difficult tasks safely and efficiently, saving time, saving money and, most importantly, saving lives. Recently, legislation was signed into law that will help safely and responsibly unlock the tremendous potential of UAS to keep the public safe, create lasting jobs, boost local economies, and further develop in technology and innovation.

In the UAS community, one of the pillars is the design and performance of open propellers used in hand launched, small UASs. The performance of these small propellers directly influences the operational capabilities of the UAS. As such, the design and testing of these propellers is necessary to accurately predict UAS performance. This experimental investigation examined the relationship between diameter and pitch to aerodynamic efficiency. Thrust, torque, power, and propeller rotational speed (RPM) were tested for 8 different propeller configurations, 5 commercial propellers and 3 designed and printed locally. The commercial propellers had diameters ranging from 9 to 7 inches and pitches from 8 to 4. Each configuration was tested statically, so the advance ratio was not considered for our study. The larger diameter propeller performed the best and the 6 was the pitch that also had a better performance. Of the three built propellers, NACA 4415, ClarkY and ClarkYM15. ClarkY worked the best.

[1] Professor, Department of Mechanical Engineering, Baylor University #97356, and Senior Member.
[2] Undergraduate student, Department of Mechanical Engineering

Nomenclature

A	=	throughflow area (perpendicular to the station local velocity), *in*^{2}
c_d	=	blade section drag coefficient
c_l	=	blade section lift coefficient
C_D	=	blade total drag coefficient
C_L	=	blade total lift coefficient
C_P	=	power coefficient
C_T	=	thrust coefficient
D	=	propeller blade drag, lb_f
D	=	propeller outer diameter, *in*
L	=	propeller blade lift, lb_f
n	=	number of propeller blades
N	=	propeller rotational speed, *RPM*
p	=	static pressure, lb_f/ft^2
P	=	power, *W*
P_b	=	pitch of blade, *in*
r	=	arbitrary radius, *in*
r_h	=	hub radius, *in*
RPM	=	rotational speed, *revolutions per minute*
r_m	=	mean radius, *in*
r_t	=	tip radius, *in*
R	=	propeller outer radius, *in*
S_b	=	planform area of blade, *in*^{2}
T	=	propeller thrust, lb_f
UAS	=	unmanned aerial system
V	=	velocity, *ft/s*
W_t	=	tangential velocity
W_a	=	the axial velocity
W	=	resultant velocity vector
c	=	chord length, ft
r	=	radial coordinate r

Greek

α	=	angle of attack or blade incidence angle of flow, *deg*
β	=	angle of blade relative to circumferential or tangential, *deg*
γ	=	local flow angle relative to circumferential or tangential, *deg*
η_o	=	overall system efficiency
ρ	=	density of air, lb_m/ft^3
τ_p	=	torque on propeller, $ft\text{-}lb_f$
ω	=	propeller rotational speed, *rad/s*
Ω	=	angular velocity

I. Introduction

Within the past decade major corporations are seeing who can improve and implement unmanned aircraft in several different industries. Unmanned aircraft have developed and are now being used for military operations, but the US government still has bans and regulations on unmanned aircraft use for civilians.

Figure 1. Unmanned Aerial Vehicle[1]

Currently, the race is on between aircraft design and manufacturing companies to see who can improve and design the newest and greatest version of the unmanned aircraft. Money plays a key role in determining the success of an aircraft, but prices vary so drastically because of factors such as implementation cost, maintenance cost, the cost of paying pilots (both remote and physical pilots), etc., therefore UAS are expensive. It is a very unreasonable to make any comparisons until a few more years in the future.

Since most of these vehicles are used for intelligence, surveillance, and reconnaissance (ISR), sensors are an important part of the system. Regardless of the mission and propulsion system (Smaller UASs will utilize an internal combustion engine (ICE) or electric motor), the customer always desires additional sensor capability and/or to remain on station for the longest possible period of time. This results in a tradeoff as the UAS has a limited amount of internal power from which to draw for its mission. If the propulsion system is more efficient, less power would be required for flight allowing for a longer endurance time. Thus, the guiding principle for this research effort is to examine an existing propulsion system for a current UAS and to seek ways to improve the propulsive efficiency, decreasing the power needed. It would also be desired to reduce the noise of the propellers, but it will not be considered for this study. Therefore, in this paper we will show the procedures to design, develop and test propellers for a small UAS. We will only test the propeller efficiency, in terms of torque, thrust and power. First, we will describe propeller design theories that will lead to an overview of open-source software available for propeller design. Second, we will design, and

Figure 2. UAS operating together.[2]

print propellers, using a software tool called BEARCONTROL, an integrated software program developed by the authors, using LabVIEW, Excel and Solidworks. After all this, the operation of our propellers will be compared with commercial propellers operating under the same static conditions.

Figure 3. Two different type of UAS.[3]

Propeller theory:

Propellers consist of multiple rotating subsonic airfoil sections that behave similarly to a spinning wing. The propeller's rotary motion through the air creates a pressure differential that, like an aircraft wing, produces lift that is directed forward as thrust. One of the primary contributors to the performance and efficiency of a wing is the behavior of the air at the wingtips. Wings have a high-pressure lower surface and a low-pressure upper surface. The wingtip is a region of the wing where these two conditions meet. The high-pressure air under the wing spills over the wingtip to the low-pressure region above the wing, creating a circular pattern of rotating air that continues to propagate in the flow field downstream of the wing. This phenomenon, called a tip vortex, is also seen with propeller blades. Tip vortices are one of the primary sources of propeller aerodynamic noise, so reducing the strength and coherence of the vortices coming off the propeller blade should correspond to a decrease in overall noise signature, but we are not examining noise in this paper.

First, we will define the expression of overall efficiency:

$$\eta_O = \frac{Uninstalled\ Propulsive\ Power}{Propeller\ Power\ Required}$$

Since in the tests were static and will not introduce any initial flight speed (speed equals zero), there is no reason to include the advance ratio "J" in these studies, therefore we will neglect it for any calculations.

A. Isolated Blade Theory

The chord length, airfoil shape of the blade, relative angle of attack, and Reynolds number all describe and characterize the propeller and dictate its performance. In simple terms a propeller works as an airfoil spinning about the hub generating lift that provides thrust for the aircraft. A propeller has a relative angle of attack based on its radius, pitch, local axial velocity, and rotational speed (*RPM*). Figure 4 shows the cross-section of a propeller that is rotating into the page. The relative wind velocity (V_1) at any given propeller cross-section is the vector sum of the incoming axial velocity (V_2) and the tangential velocity (ωr) for that cross-section which form the inflow angle, γ. The angle of attack or incidence angle of flow that the propeller blade experiences at a given cross-section is then the difference between the circumferential inflow angle (γ) and the local blade circumferential angle of the propeller (β)

$$\alpha = \beta - \gamma$$

where all three angles are evaluated at the same radial location. It is standard practice to maintain a constant angle of attack (α) across the span of the propeller blade in an attempt to have the propeller blade operate near large values of C_L and minimum values of C_D. This translates to desiring large values of c_l and low c_d for the airfoil which means operating close to the maximum c_l/c_d. The radial dependence of ωr causes the inflow angle γ to vary in the radial direction requiring the β angle to vary in the radial direction in order to keep the angle of attack, α, the same for specified rotational and freestream velocities. This results in the familiar twist of a propeller blade with large β angles near the hub and smaller β angles near the tip. Each cross-section of the propeller blade generates lift and drag based on the aerodynamic characteristics of the airfoil section. The lift and drag forces can be resolved into forces in the thrust and torque directions which dictate the performance of the propeller at the specified operating conditions. There can also be a dependence on Reynolds number for the optimum C_L/C_D ratio.

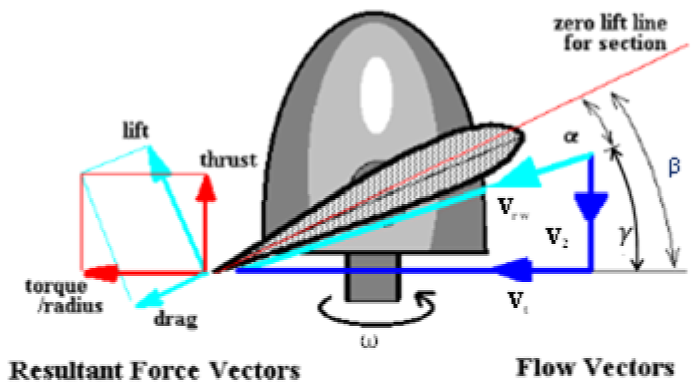

Figure 4. Force and velocity vectors on a rotating propeller blade.[4]

B. Blade Element Theory

Because linear momentum theory does not account for blade geometry, Blade Element Theory (BET) was developed. BET divides the blades of the propeller into individual airfoil cross-section elements which are analyzed based on the local, two-dimensional velocities seen at each location. After analyzing the flow over each element, the resulting forces can be determined. A final integration over the entire blade will give the performance characteristics. This theory allows for the analysis of specific propellers with radially varying geometric shapes. While BET is more detailed than the one-dimensional theory, it does not account for induced velocities at the blades, swirl in the slipstream, non-uniform flow, or propeller blockage. This analysis requires the knowledge of the aerodynamic properties of the airfoil cross-section(s) in use when designing the blade. It is worth noting that because this theory does not account for induced velocities at the blade, it is assumed that the c_l and c_d data for each element's resultant velocity based on freestream conditions is enough for acceptable results. For small UASs, propeller performance depends on having accurate airfoil data, however, limited airfoil data at low Reynolds numbers are available. For small-scale propellers with low chord-based Reynolds numbers, airfoil performance can change significantly with radial location.[5]

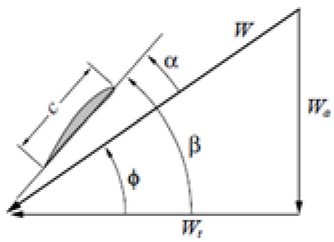

Figure 5. Airfoil Cross-section geometric properties.[5]

Figure 5 shows an airfoil cross-section with a chord length of c, at a radial coordinate r, along a propeller blade with a tip radius of R. The cross-section experiences a resultant velocity, W, that is composed of W_a, the axial velocity, and W_t, the tangential velocity. In this theory, the axial velocity represents the forward speed of the propeller, or the flight speed. The tangential velocity represents the velocity seen by the propeller due to rotation. The velocity near the hub is much less than that of the velocity at the tip of the propeller. This can be seen by the relation shown in Eq. (1)

$$W_t = \Omega r = 2\pi n r$$

where Ω is the angular velocity of the propeller in radians per second and n is the rotational velocity in cycles per second. The remaining parameters are β, the geometric pitch of the cross-section with respect to the plane of rotation, Φ, the resultant flow angle with respect to the plane of rotation, and α, the airfoil cross-section angle of attack, which is measured from the resultant velocity vector, W.

C. Analysis

Our main analysis is focused on the efficiency of our propellers, and the effect that the diameter and the pitch have on the propeller efficiency. Therefore, these two parameters are defined as:

Propeller Diameter

Diameter is the distance across the circle made by the blade tips. In general, "Diameter is determined primarily by the RPM at which the propeller will be turning and the amount of power that will be delivered to the propeller,". Theoretically, power will increase as diameter increases and will decrease as propeller RPM decreases

Propeller Pitch

Blade pitch, often shortened to pitch, as we showed in Figure 4, refers to the angle between the propeller blade chord line and the plane of rotation of the propeller. Blade pitch is most often described in terms of units of distance that the propeller would move forward in one rotation assuming that there was no slippage.

A propeller blade's "lift", or its thrust, depends on the angle of attack combined with its speed. Because the velocity of a propeller blade varies from the hub to the tip, it is of twisted form for the thrust to remain approximately constant along the length of the blade; this is called washout. This is typical of all but the crudest propellers.

It is quite common in aircraft for the propeller to be designed to vary pitch in flight, to give optimum thrust over the maximum amount of the aircraft's speed range, from takeoff and climb to cruise. This is not possible with small UASs.

Conversely, a higher pitch will deliver greater top speeds, but slower acceleration. However low-powered engines can bog down if fitted with a propeller with too high a pitch and diameter, and that can wear heavily on internal engine parts.

In the results we will check if all the theoretical predictions match the actual performance of the propeller.

II Propeller experimental testing

In the second part of the paper, we will explain the procedures followed to design and test our propellers.

Designing:

For the design of our propellers, we built three propellers. Therefore, we are going to talk about the three propellers that were designed for the same thrust condition. For those three propellers we used three different airfoils: **ClarkY**, **NACA 4415** and **ClarkYm15**. The steps taken to build the three blades were the following:

Step 1: C_L/C_D

To start with, looking at the multiple airfoils we can choose for our propeller, we should know what is our designing point. This means, which C_L is the most appropriate depending on our airfoil. Taking a look at the Cl/Cd and Cl v Alpha curves, which we can download easily from **airfoil tools** website [7], we can find the necessary values.

For the Cl v Alpha curves, it is know that almost for every airfoil the linear slope is 0.1/deg. We want this curve to be as high as possible in order to give a high Cl value. [7]

If we look to the Cl/Cd v Alpha curves, the most interesting point for us is the peak. As it is proportional to L/D, the pick is L/Dmax, this means the least amount of drag for the most amount of lift, which basically translates to thrust for our case. Therefore, for our design, we are trying to find a curve that has the flattest peak possible, that is to say the wider range of angles of attack maintaining L/Dmax for our operating point. Once we know the angle of attack we need, we move to the Cl v Alpha curve and find the value of our CL, which will be used to determine the propeller pitch from the hub to the tip of the blade.

Thus, we put it in practice with the curves of our three airfoils and chose our CL's for our designing point.

ClarkY

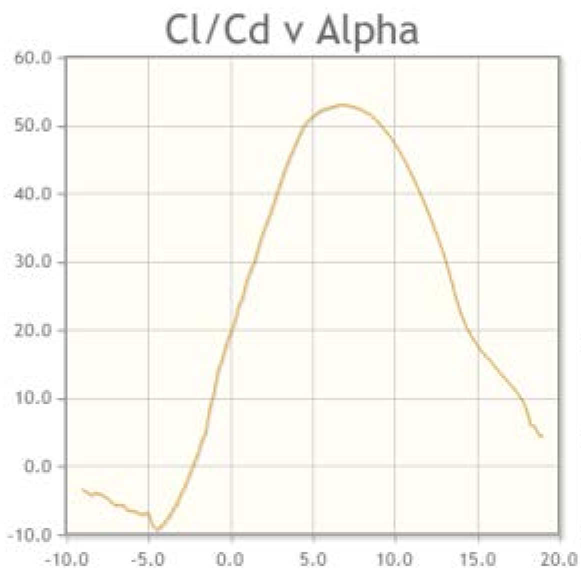

Figure 6. ClarkY curves.[7]

Figure 7. ClarkY curves.[7]

For the ClarkY, it's clear that the L/Dmax happens for around a 7 AOA. Therefore, if we go to the Cl v Alpha curve, we find our CL to be around 1.08

NACA 4415

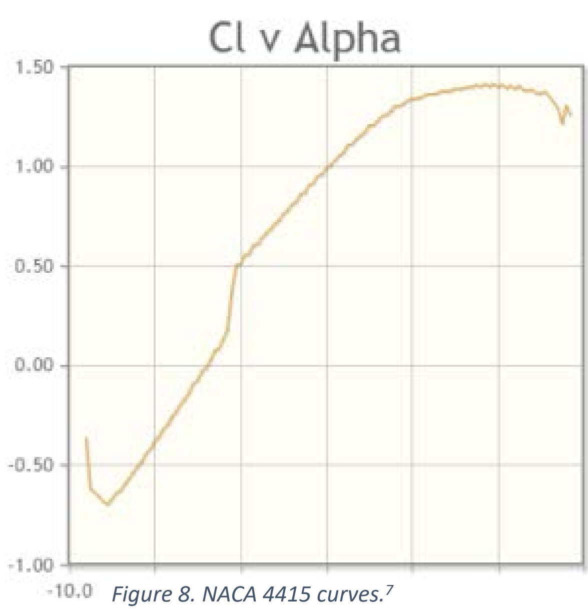

Figure 8. NACA 4415 curves.[7]

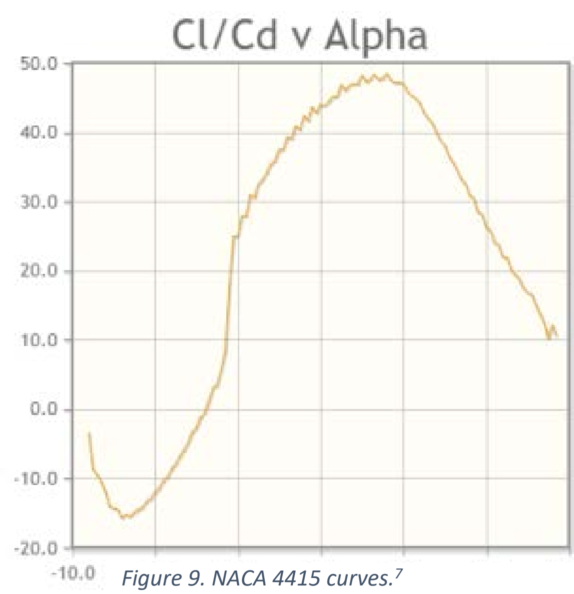

Figure 9. NACA 4415 curves.[7]

For

the NACA 4415 we can see that the CL/Cdmax is at 8-8.5 AOA, and thus, our Cl is also around 1.1.

Clark Ym15

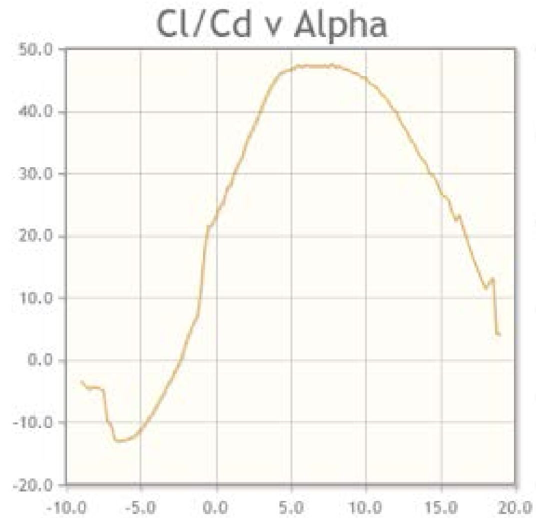

Figure 10. Clark Ym15 curves.[7]

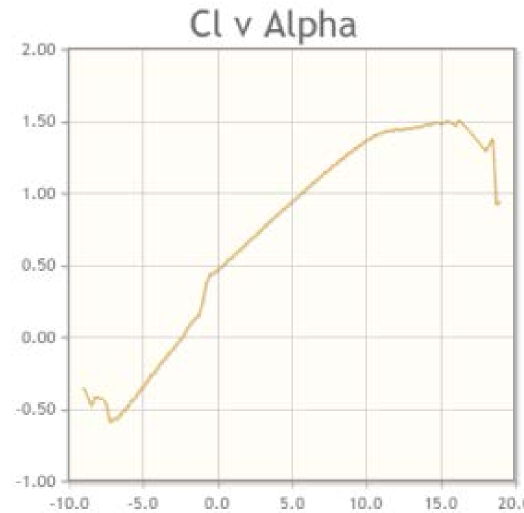

Figure 11. ClarkYm15 curves.[7]

In this case, we have a good Cl/Cd curve, due to the fact that its peak is very flat, which gives us a solid range of AOA to work with, between 5 and 9. Furthermore, we do not want to approach to the limit which could gave us a sudden drop, so we picked the mean which is around 7.5 AOA, and hence we have a CL of 1.25.

Step 2: Bearcontrol

Once we know our CL it is time to use the software designed by one of Baylor's graduate student, Trae Liller. The software is Bearcontrol [9], which is a program written in MATLAB that gives a user the ability to quickly design a propeller, predict its performance, and then model it in SolidWorks. The overarching MATLAB code allows the user to control the design, analysis, and modeling programs through a user-friendly GUI. This ultimately results in a mostly automated process that allows an individual who is unfamiliar with command prompt programs and SolidWorks modeling to design, analyze and model a propeller in a time efficient manner.

Basically you pick the airfoil you want to work with and, in addition, you introduce the design parameters you want for your design, like the number of blades, hub radius, the desired flight speed(zero for us),propeller RPM's, thrust, power and the **CL** we chose in **step 1**.

The following picture shows the parameters I entered for the design of the clarkY airfoil:

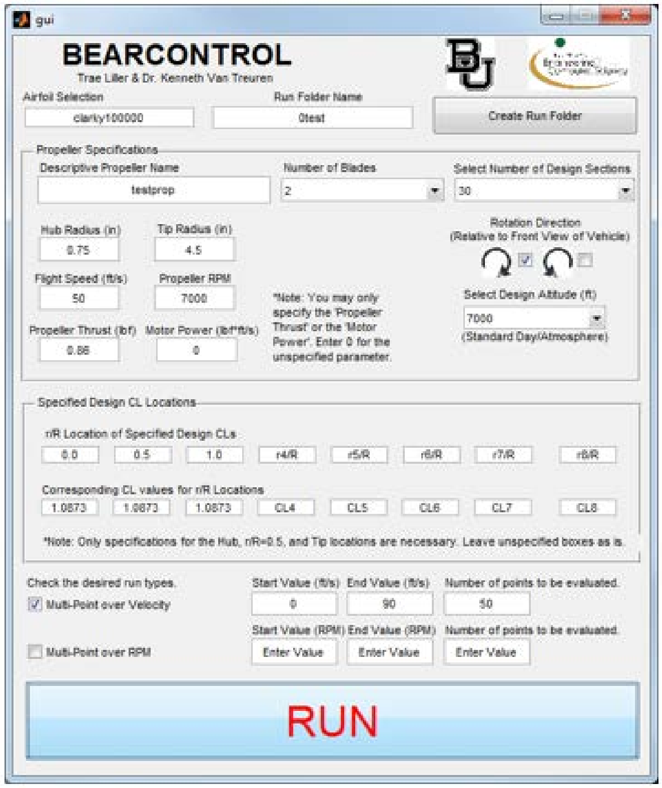

Figure 12. Bearcontrol GUI.[9]

After filling in the boxes, we click on the RUN button and the program creates 8 files for us in the folder we chose. Those files will lead on a 3D model of our propeller in solidworks.

Step 3: Solidworks

To continue with, the following software tool is solidworks. I will include a basic guide for all the users to loft the whole propeller:

1. We basically create 2 macros with the data contained in the files “planemacro.txt” and “splinemacro.txt”, and we run them. Furthermore, we also add the “baylor hub” to the solidworks file. As a result, we will obtain something like this.

Figure 13. Sketches and Baylor hub.[10]

2. Now we have all the sketches created, we click on “lofted boss/base”. Then we right click on the profile’s blue box and click on selection manager. After that we select our first surface where we are starting the loft, that is situated on the hub. Notice that we must click on the bigger blue square, not the small one. Click accept.

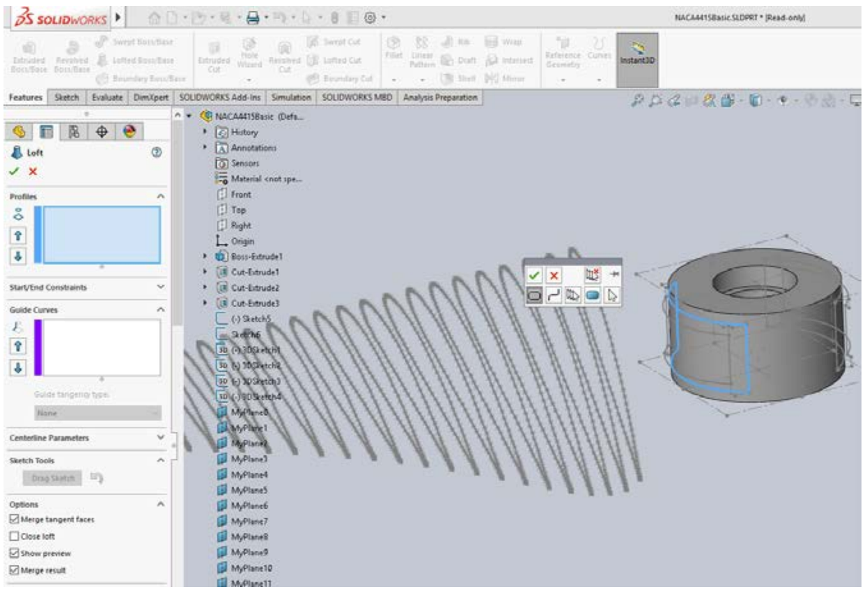

Figure 14. Lofting feature, selection manager.[10]

3. The following step is to open the list where all our sketches appear, and we have to select them one by one until we reach the very tip sketch. If you don’t have any errors doing this, jump to **step 7**.

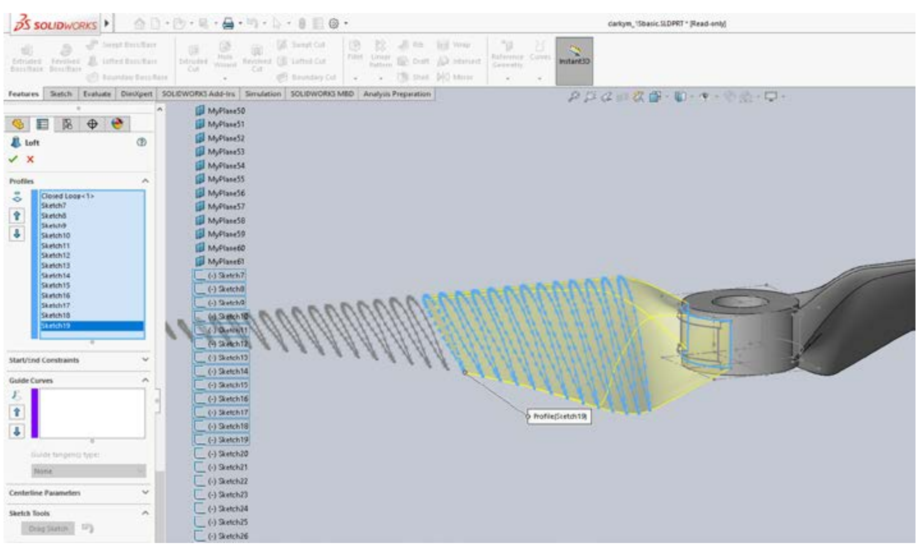

Figure 15. Selecting the sketches.[10]

4. This should be all the steps you might follow to do the loft if everything works normally. However, sometimes the airfoil is not thick enough and it gives some self-intersecting errors. Basically, this leads on the impossibility to loft all the sketches in one single loft from the hub to the tip. If this happens, the solution is to figure out and do the loft to the highest number of sketches as possible, that the program let you do.
   Once we have this first loft done, we click on reference geometry → planes. We click on the surface and in coincident with 0 offset.

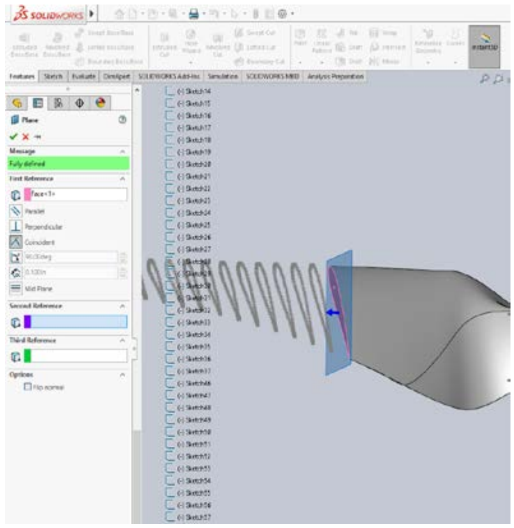

Figure 16. Creating a plane.[10]

5. After that, we find in the list the plane that we just created, right click on it and click on sketch. Next, we open the sketch window right next to features. We click on convert entities, click on the surface we want and accept. A new sketch is created so now we can do the second part of the loft.

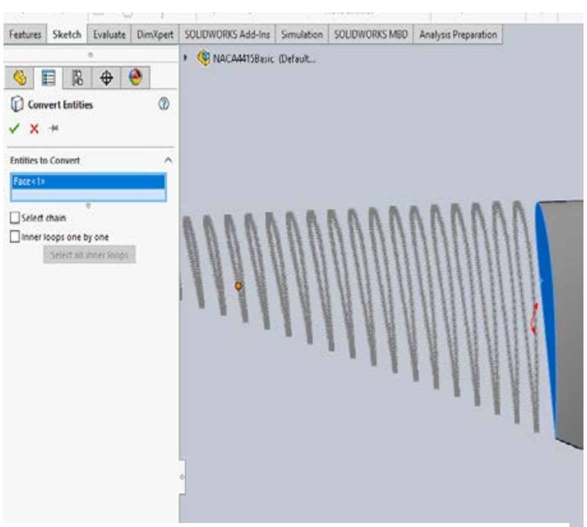

Figure 17. Creating a sketch on the plane.[10]

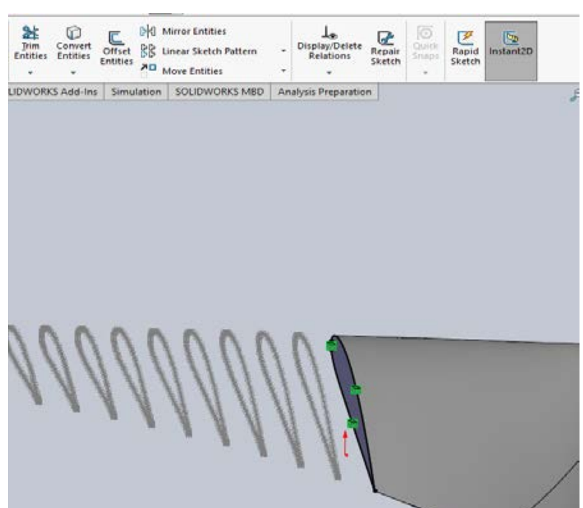

Figure 18. Using "convert entities".[10]

6. Again, we go to loft and follow the same procedure in step 3, to create the second part loft, by selecting one by one all the sketches, from the one we just we just created, to the tip.

7. The loft is done. It is time to make the transition between the airfoil and the hub smoother. We will use fillets tool for this. We just have to click on fillets and select the edges we want to fill, and the radius we want. A 0.05 in radius fillet was used for our propellers.

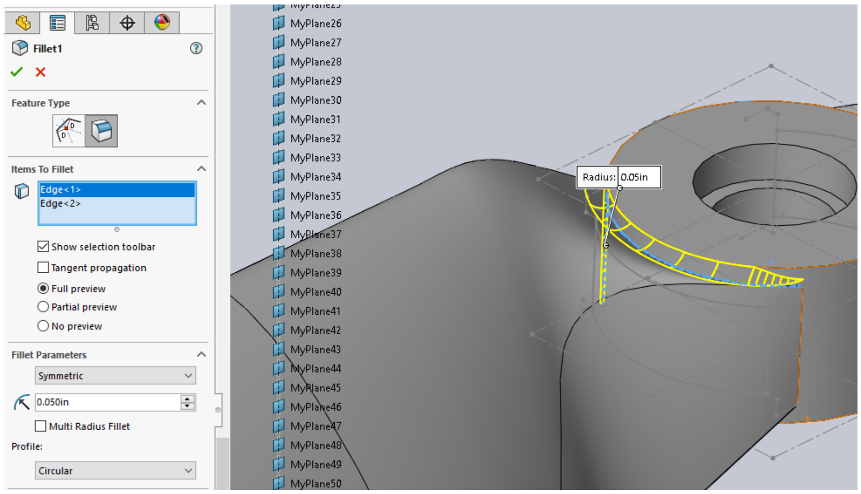

Figure 19. Designing the fillets. [10]

8. The last step is to adjust the diameter of the hub hole to the dimensions we want. We need it to fit in the torque cell which diameter is 5/16 in, so this should be our measurement. Baylor's hub default "Cut-extrude1" meet the requirements. We only have to delete the cut extrusions 3 and 2.

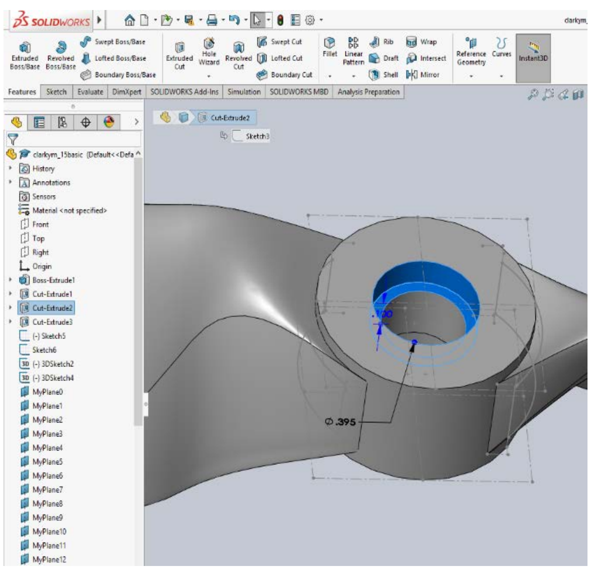

Figure 20. Deleting cut-extrude2. [10]

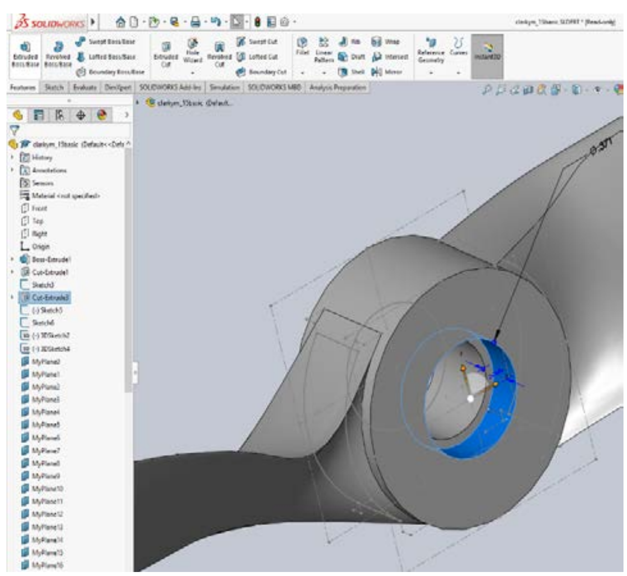

Figure 21. Deleting cut-extrude3. [10]

Our propeller is completed.

3D Printing:

The final part for the design of the propeller is build it. Once we have the solidworks files completed, we can use any 3D printer to build it as long as the material is stiff enough. In this case a stereolithographic machine was used due to the fact that the material is stiffer, and the shape is also smoother with a superior surface finish.

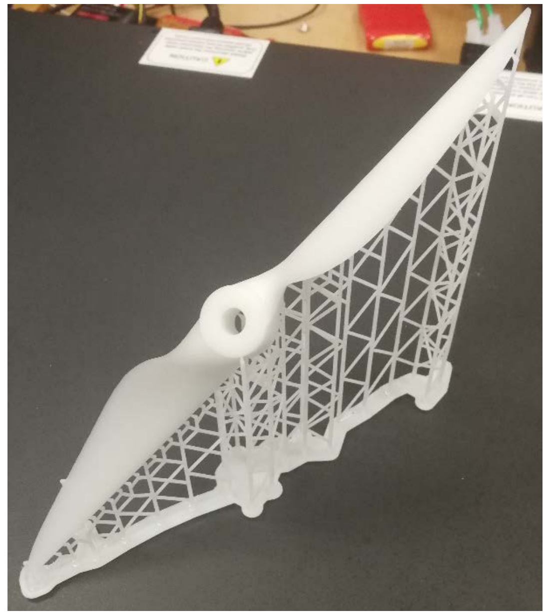

Figure 22. Propeller just printed with the stereolithographic machine.

Testing part:

Once the propeller is built, the next step is setting everything up for the testing. As we mentioned in the introduction, the test stand measures the efficiency of our propellers, and thus, the parameters tested are going to be the propeller RPM, propeller thrust, propeller torque and power supplied to the propeller motor. In order to do that, our devices also measured the room test conditions such as temperature, pressure and relative humidity.

Instruments used:

Propeller test stand:

It is one of the most important devices for the testing. It is divided in three elements: the torque cell, the load cell and the Omega remote optical sensor.

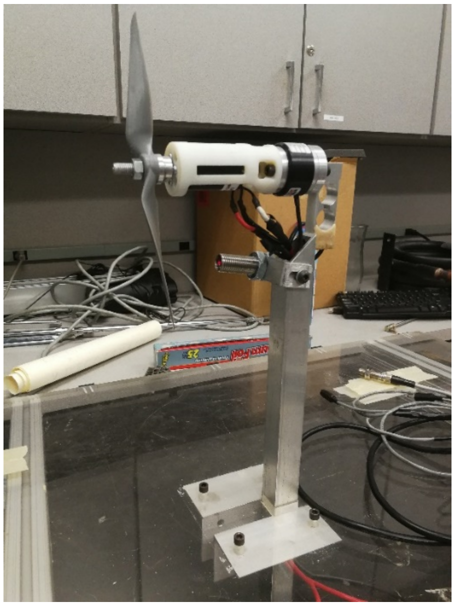

Figure 23. Propeller test stand.

The interface MRT-0.2 Nm torque transducer is basically a transducer used to directly measure the torque of the propeller. It must be wired in the appropriate DAQ card and calibrated with LabVIEW.

The Transducer Techniques LSP-1 load cell is composed by the motor housing, motor and propeller to be attached. The custom-3D motor housing has some open spaces in it in order to help to cool the motor so It can work at higher RPM without any problem. It needs to be appropriately wired to the DAQ system before starting its calibration.

The job of the HHT20-ROS Omega Remote optical sensor is to read the RPM of the propeller and show the result at the panel tachometer. Both of them need to be wired to each other.

Calibration tool:

This device allows us to do the proper calibration of the load cell. It basically helps to orient the load of a hanging mass in the thrust direction of the propeller.

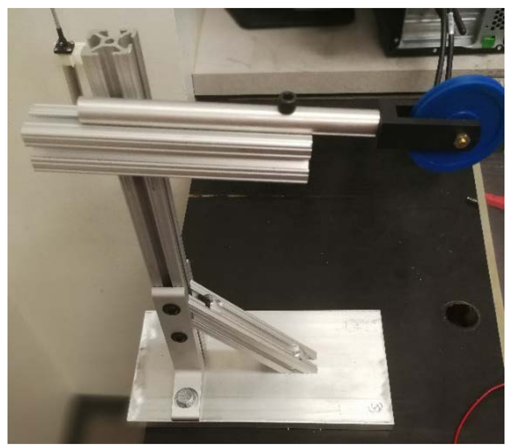

Figure 24. Calibration tool.

Panel Tachometer

The ACT-3X panel tachometer is the instrument used for the reading of RPM. It reeds the pulses from the optical sensor and shows the propeller speed in RPM. It also needs to be calibrated to ensure that it fits with the actual voltage output that it reads from the sensor. Furthermore, it must be plugged into a power strip.

Figure 25. ACT-3X panel tachometer.

Stroboscope

To properly calibrate the tachometer, we used the stroboscope to check that the readings for different RPMs matched with what the tachometer read.

Figure 26. Stroboscope.

Power supply

For the testing, we will use a XLN3640 BK precision as a power supply. We will work at a constant voltage of 14.0 V, and we set up a maximum current of 10 amps. The device could send up to 30 A, but in terms of safety, working with 10 A is more appropriate because of the power limit of 140W for the motor.

Figure 27. XLN3640 BK PRECISION power supply.

Propeller balance stand

This device is used in order to adjust the weight distribution in both blades, so the propeller is perfectly balanced. This was especially important with the propellers we made in order to do safe testing.

Figure 28. Propeller balance stand.

Remote control

For a better control of the RPM of the propeller during the testing, under the contitions for a UAS we used a Futaba T4EXA remote control paired with a FP-R127DF receiver that is wired to the UAS motor controller.

Figure 29. Futaba T4EXA.

Figure 30. FP- R127DF receiver.

Propeller testing

Once the calibration of all the instrumentation is done, the output data will be read with a custom LabView GUI through a series of National Instruments Data Acquisition hardware.[11]

Our testing consisted in doing RPM sweeps for every 500 rpm, starting at 1000 rpm, and going through around 8000 rpm, depending on the propeller. Therefore, we measured the RPM, thrust, torque, voltage and current, so with those last two we easily calculated the power supplied.

Therefore, the propellers we first tested were 5 commercial propellers, **9x6,8x6 ,7x6,8x8 and 8x4** and after that, our designed propellers, the **ClarkY, ClarkYM15** and **NACA 4412.** We exported all the data to an Excel file.

III. Results and discussion

For the evaluation of the results, this section is divided in 3 parts. The first two parts contain the comparison of the commercial propellers. Thus, the first part compares how the propellers efficiency (power consumption) vary while we change its diameter. The second part examines the change in pitch from one propeller to another.

Therefore, it is easy to distinguish the dimensions of the propeller we want to test, because they always follow the same designation. Propellers are categorized by two numbers: Diameter and Pitch. Thus, a 9x6 propeller is 9” in diameter and has 6” of pitch. Pitch is the distance a propeller will move forward in one revolution in a perfect fluid (which air is not). Therefore, a 6” pitch will move forward 6” with each 360° revolution of the propeller.

Figure 31. Propellers by pitch 8x4, 8x6 ,8x8

Figure 32. Propellers by diameter 9x6, 8x6, 7x6

The last part shows the differences between our designed and built propellers.

The following plots display the graphs Thrust Vs ROM, Power Vs RPM, Torque vs RPM and Power Vs Thrust. Furthermore, for clearer results, we established a **design point** in terms of a constant thrust value, and we interpolated to calculate the values of Rpms, Torque and Power for that design point. For the commercial propellers our design point is **Thrust=0.8 lbf**, whereas for the designed propellers it is **Thrust=0.6 lbf** in order to obtain a better representation on the graphs.

Figure 33. From left to right, NACA 4415, ClarkY and ClarkYM15.

Figure 34. From top to bottom, NACA 4415, ClarkY and ClarkYM15.

Commercial Propellers

1.Diameters:

Design point:

Propeller	Thrust(lbf)	RPM	Power(W)	Torque(in*lbf)
9x6	0.8	5384.11	47.022	0.4554
8x6	0.8	6597.9	53.637	0.4616
7x6	0.8	8383.84	66.768	0.469

Table 1. Tested propeller configurations for different diameters. [12]

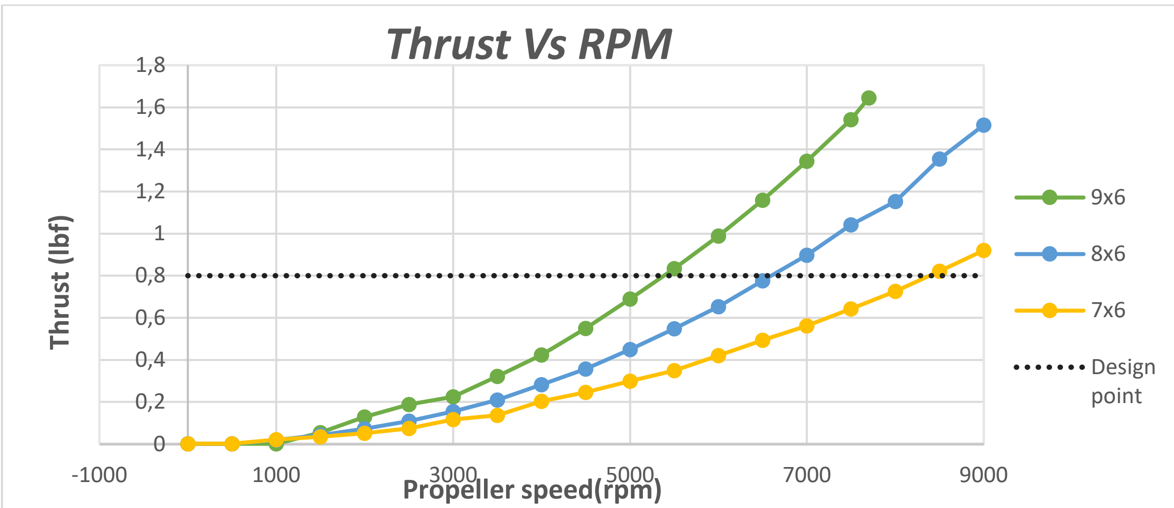

Figure 35. Thrust Vs propeller RPM. [12]

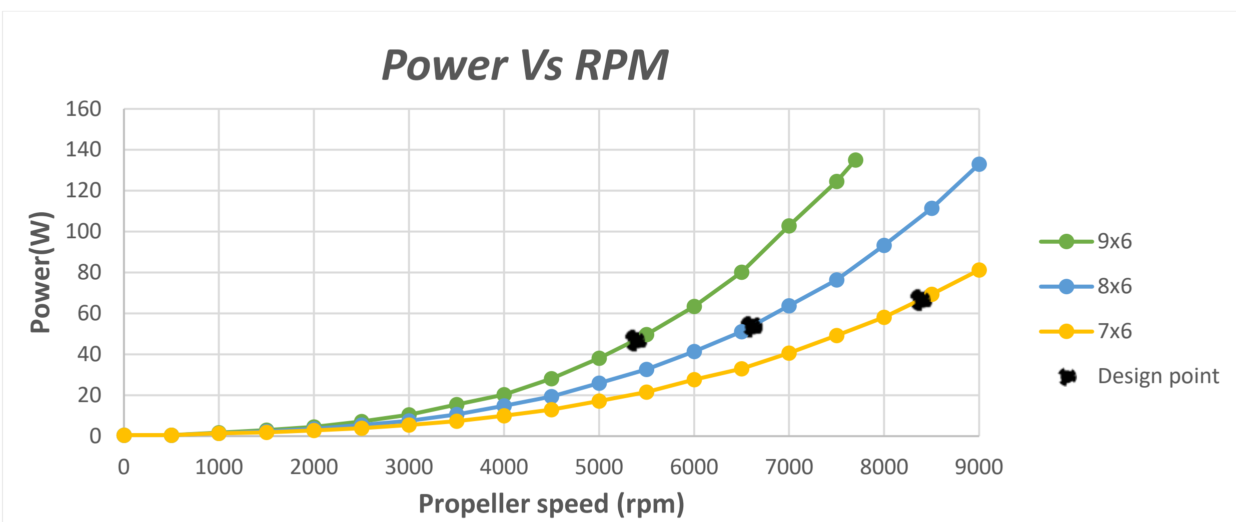

Figure 36. Power Vs propeller RPM. [12]

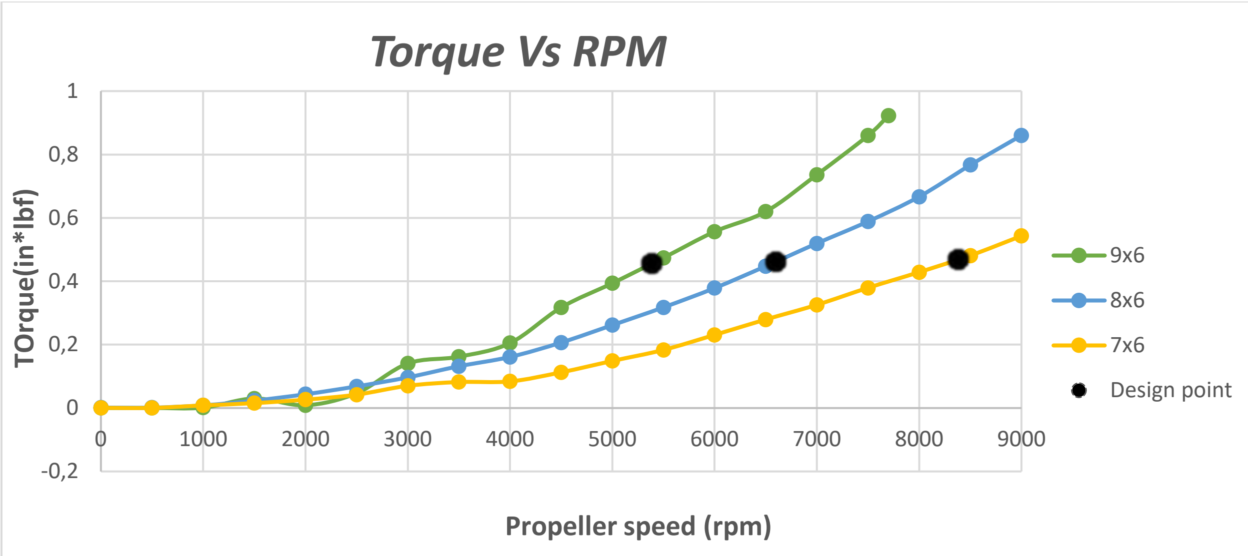

Figure 37. Torque Vs propeller RPM. [12]

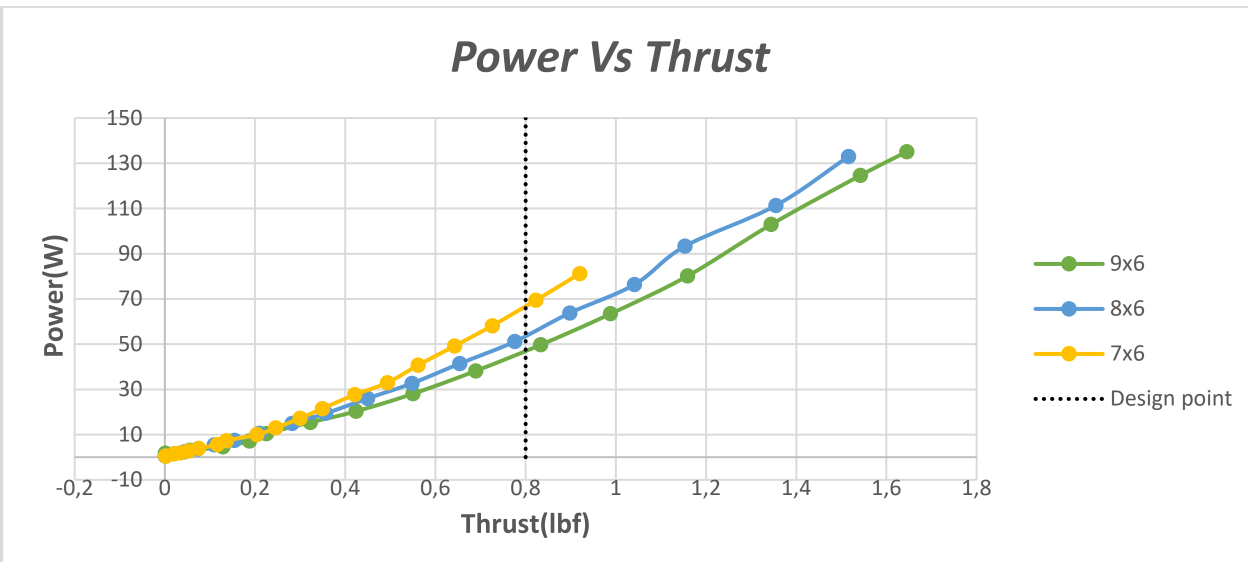

Figure 38. Power Vs thrust. [12]

So, if we compare the effects of the diameter its obvious that the 9x6 is the best propeller in terms of efficiency. For the same amount of thrust, the 9x6 needs a lower number of RPM (fig 35). Moreover, it needs less power than the others to produce that RPM (fig 36), and, without any doubt it needs less power to produce the same thrust as the other propellers (fig 38).

2.Pitch

Design point:

Propeller	Thrust(lbf)	RPM	Power(W)	Torque (in*lbf
8x8	0.8	6445.53	79.017	0.67643
8x6	0.8	6597.9	53.637	0.46167
8x4	0.8	7672.58	50.642	0.36146

Table 2. Tested propeller configurations for different pitches. [12]

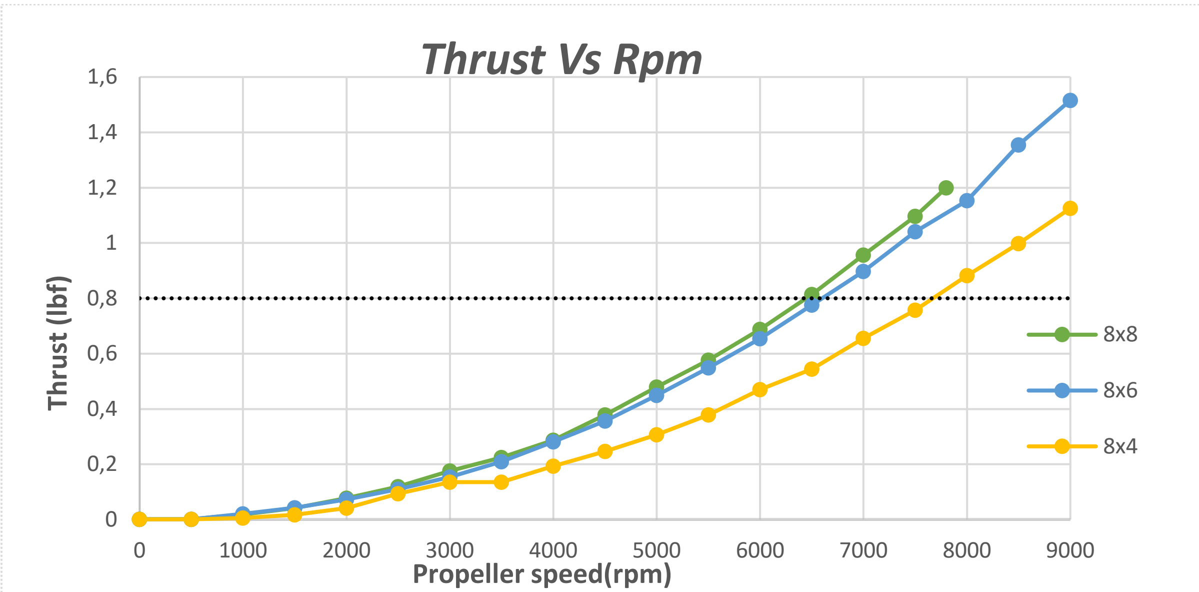

Figure 39. Thrust Vs propeller RPM. [12]

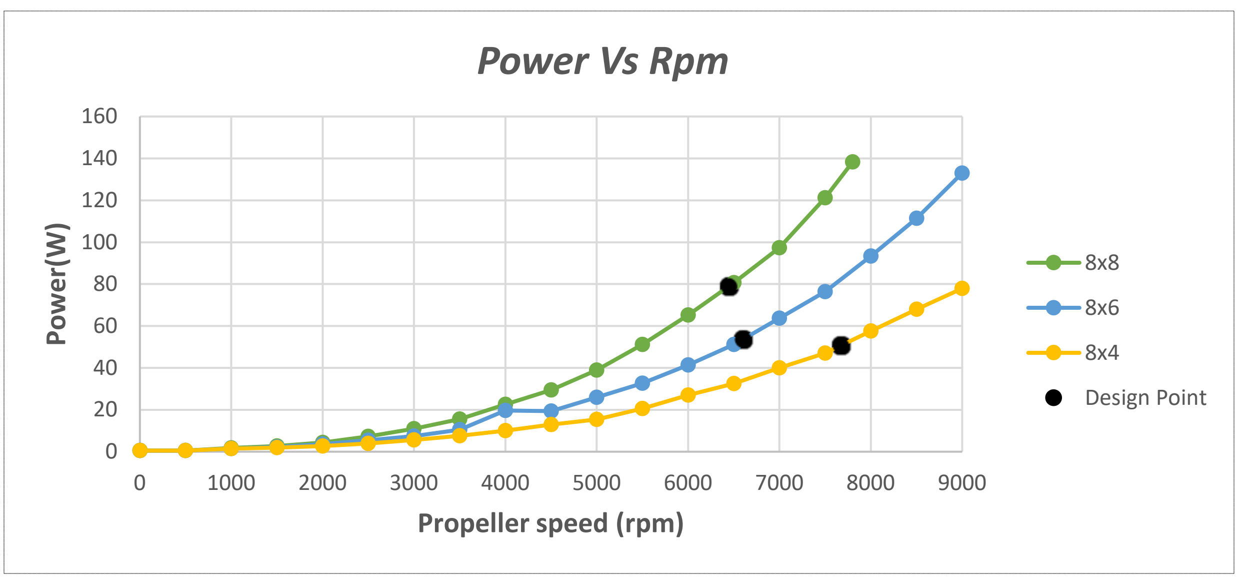

Figure 40. Power Vs propeller RPM. [12]

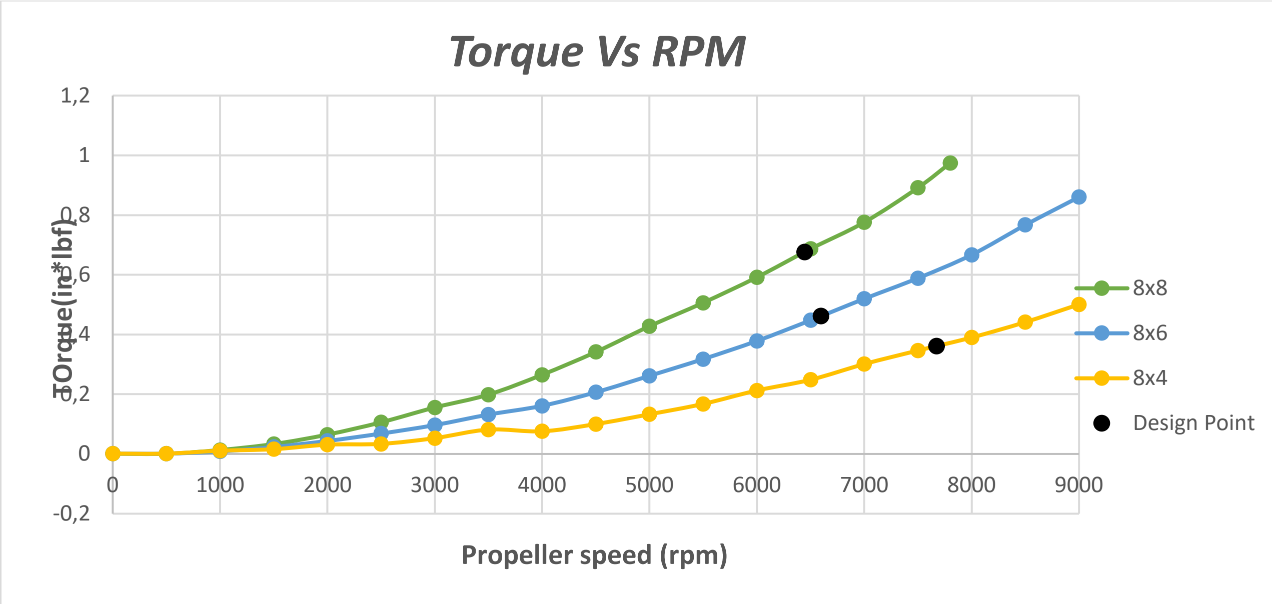

Figure 41. Torque Vs propeller RPM. [12]

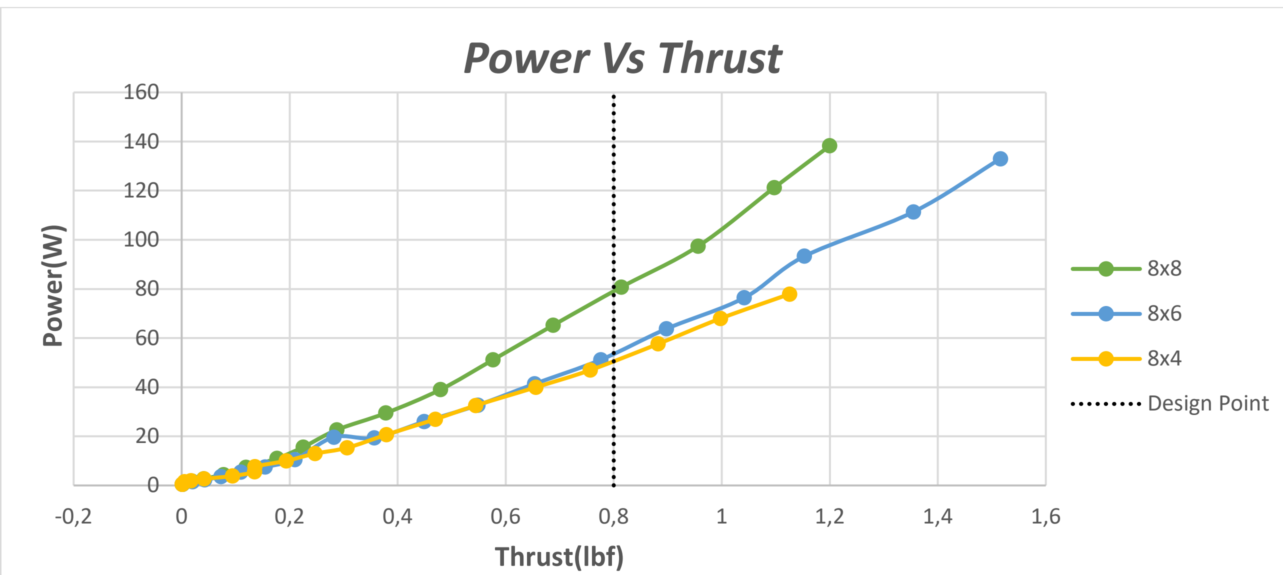

Figure 42. Power Vs Thrust. [12]

In this case, comparing the effects of the pitch in the propellers we had surprising results. If we look at the thrust vs RPM graph, we can see that both 8x8 and 8x6 propellers produce the same amount of thrust for almost the same RPM (fig 39). However, there is much more power required in the 8x8 to reach the same amount of thrust than in the 8x6 (fig 42). That means that our 8x6 propeller produces the required thrust by using less power than the 8x8, therefore, it is more efficient. The 8x4 propeller actually produces the required thrust at a slightly lower power setting, however, the higher RPM would definitely produce more noise so was not considered.

Designed and built Propellers

Design point:

Propeller	Thrust(lbf)	RPM	Power(W)	Torque(in*lbf)
ClarkY	0.6	5516.41	67.21	0.64327
ClarkYM15	0.6	5951.47	101.16	0.85492
NACA 4415	0.6	5248.31	78.4	0.76543

Table 3. Tested propeller configurations for designed propellers. [12]

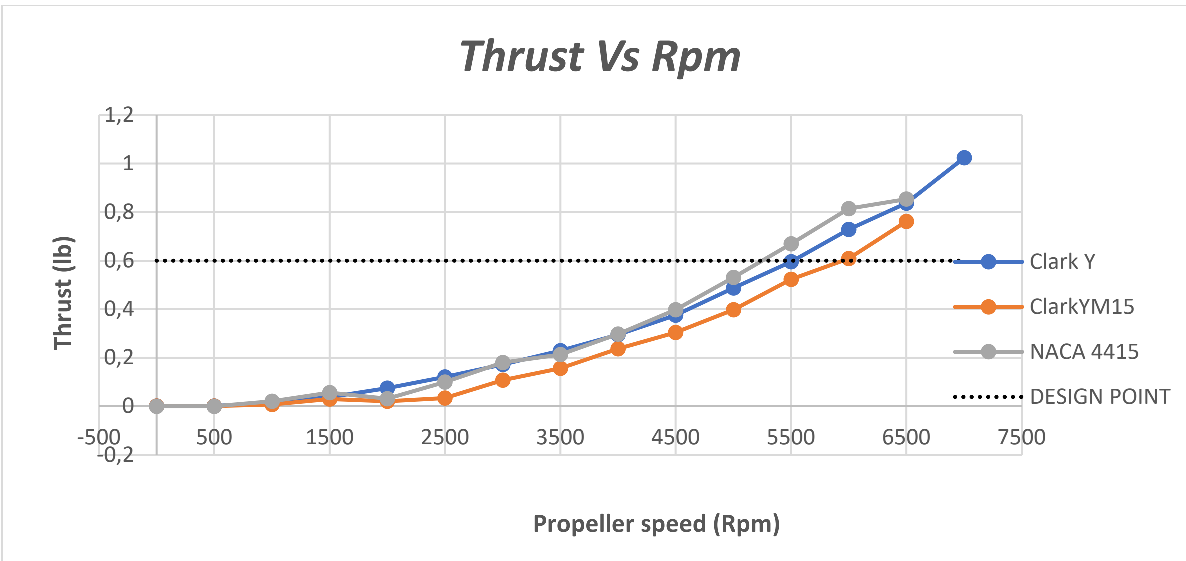

Figure 43. Thrust Vs propeller RPM. [12]

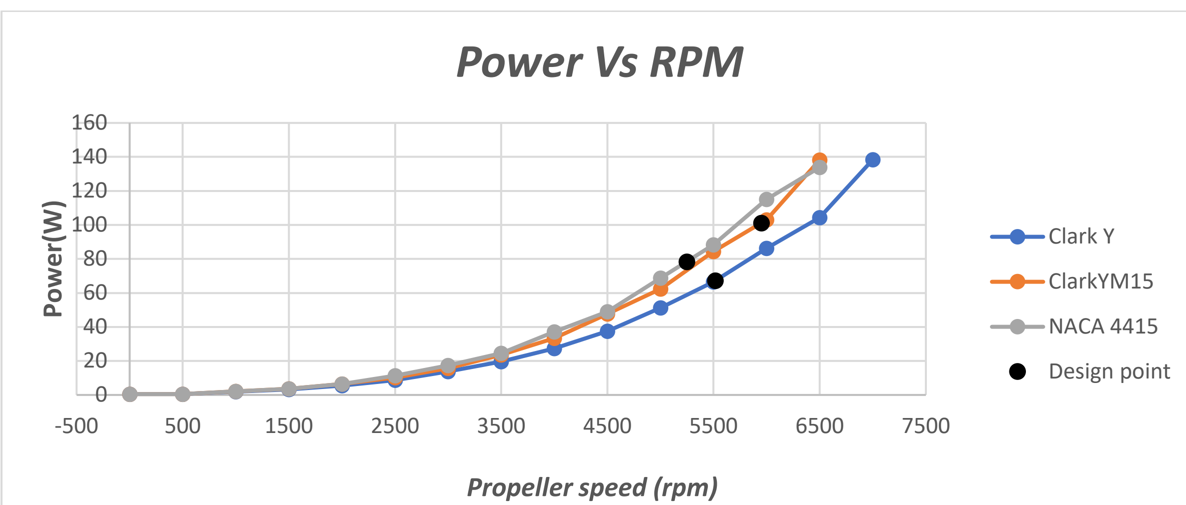

Figure 44. Power Vs propeller RPM. [12]

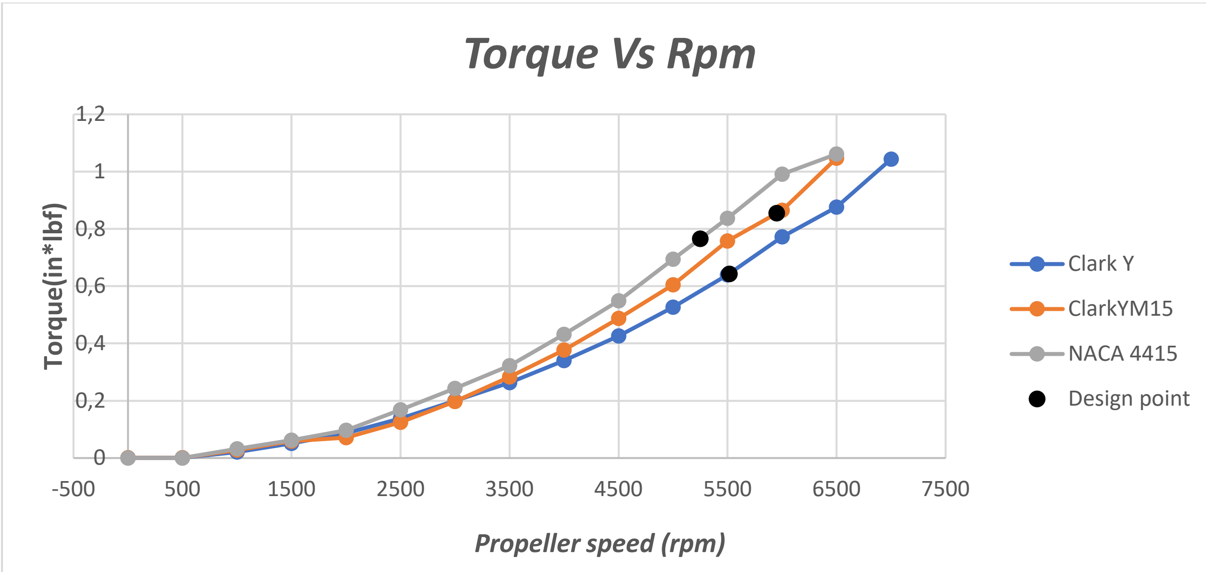

Figure 45. Torque Vs propeller RPM. [12]

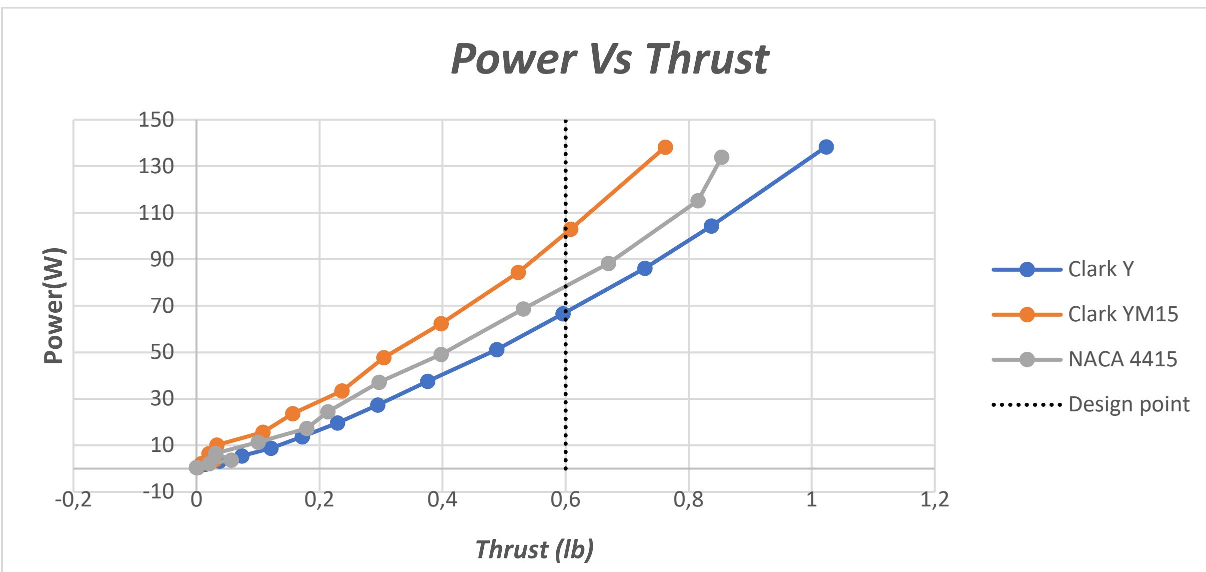

Figure 46. Power Vs Thrust. [8]

For our propellers, the one that did the best was the ClarkY. It is obvious that needs less power to meet our thrust design point (fig 46). However, the NACA 4415 generates more torque than the ClarkY for the designing point (fig 45), but anyways the ClarkY is a better option. The ClarkYM15 and the NACA 4415 consume more power than the ClarkY (fig46). The ClarkYM15 needs power to generate thrust, since it is a thicker airfoil and weights more, so it needs more power to generate thrust. Therefore, the most efficient is ClarkY.

IV. Conclusions

With the importance of UASs today, a study was done to examine the influence of airfoil shape, in terms of diameter and pitch. Furthermore, a procedure has been to design and manufacture propellers for testing. BEARCONTROL is a MATLAB GUI that allows the user to input propeller design parameters into the interface screen. With these inputs, the appropriate files are generated to use QMIL and QPROP as well as output geometry files formatted specifically for the SolidWorks macros. With this procedure a propeller can be designed, printed in a matter of hours. After that, the testing equipment was properly calibrated and ready to display the operating characteristics of our airfoils. A comparison was made in order to determine which of our three propellers (**ClarkY**, **ClarkYM15** and **NACA 4415**) was the most efficient. The **ClarkY** was the one that produced thrust with the less amount of input power required, mainly because it was the thinner airfoil. The **CLarkYM15**, was the second propeller in terms of performance, and the **NACA 4415** was the propeller that needed more power

Moreover, the same comparison was done with commercial propellers. Dividing them in two sections, diameter and pitch. In the diameter section, the bigger diameter (propeller **9x6**) performed the best, being able to reach a good amount of thrust at high RPM. In the pitch section, the **8x8** and **8x6** were very similar in thrust produced for the same amount of RPM, however, the **8x6** needed less power to produce that thrust and thus, it performed better.

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