Intro to UAV Design - Assignment 2
Fixed Wing UAV used for Crop Monitoring

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Given User Specifications:

- Endurance = **60 min.**
- Area of operation = **3 Km radius.**
- Max speed = **20 m/s.** --> max cruise speed (as endurance is 60 min the UAV can fly at 15 m/s itself, but for a conservative design we can also consider cruise speed as 20 m/s. But we need to take care of other factors like battery, energy consumption, camera's images, etc)
- Flying altitude = **100 m** from ground.
- Climb and descent rates = **5 m/s**.

Conceptual Design Phase:

Involves choosing a configuration, size, weight, cost, performance parameters, etc. We need to make sure with the chosen parameters, the UAV works, and also consider some trade off issues. This will be based on the provided requirements.

Following the Design Wheel,

- Step 1 - To get all the requirements/specifications
- Step 2 - Design concept and Analysis
- Step 3 - Sizing and Trading (reiterating the entire design by making necessary changes)

Market Survey for Fixed Wing UAVs for Crop Health Monitoring:

To look at Fixed wing UAVs preferably with similar applications and deduce the necessary requirements specification list. Also to get any necessary parameters and make appropriate assumptions.

Because of the huge terrain or area of operation to be covered, and having larger endurance, it makes sense that we use a fixed wing uav for this application.

Fixed Wing UAV Market Survey - 1 - Gatewing X100 - Required Specifications
Link for product specifications pdf:

http://www.kmcgeo.com/Products/Gatewing/x100_productleaflet.pdf

This product has a very good camera, used generally for terrain mapping, and also for crop monitoring. Catapult launch takeoff.

- Endurance = 45 min.
- Cruise speed = 75 kmph.
- (Default) Flying altitude = 150 m from ground.
- Weight (mass), M = 2.0 kg
- Wing span, b = 100 cm or 0.1 m
- Wing area, S = 23 dm^3
- Dimensions = 100 * 60 * 10 cm

Other specs are in the following image

DATA SHEET X100

CATEGORY	ITEM	VALUE
Wing	Type	Lifting body, fixed wing
	Weight	2.0 kg
	Wingspan	100 cm
	Wing area	23 dm^2
	Dimensions	100 x 60 x 10 cm
	Material	Carbon reinforced EPP structure
Configuration	Propulsion	Electric brushless 250 W Pusher prop
	Battery	Lithium-polymer 11.1 V, 8000 mAh
	Payload	Calibrated 10 MP digital camera
	Autopilot	Automatic take-off & landing Waypoint navigation Autonomous camera triggering Fail-safe routines
Operation	System setup time	15 minutes
	Take off type	Catapult launch
	Climb angle	15 degrees
	Endurance	45 minutes
	Flight altitude (AGL)	100-750 m
	Cruise speed	75 km/h
	Landing type	Belly landing
	Advised landing strip	100 x 30 m
	Weather	up to 50 km/h wind & light rain
Communication	Communication & control link	2.4 GHz
	Communication & control range	Up to 5 km

Fixed Wing UAV Market Survey - 2 - Tuffwing Mapper Fixed Wing UAV - Required Specifications

Link:

http://www.tuffwing.com/products/drone_mapper.html

Required Specifications are in the following image:

Specifications

Wingspan:	48" (1219 cm)
Wing Area:	595 in.2 (15113 mm2)
Weight - with standard camera and battery:	1.9 kg with Nex-5. Below the 4.4 pound (2 kg) FAA proposed requirements for a Micro UAS.
Weight - Maximum:	4.4 pounds (2kg)
Material:	EPP foam, carbon fiber tubes, Coroplast, plywood
Camera:	Mounts for Sony Nex5 / a6000, Sequoia, RedEdge
Camera trigger:	GPS triggered
Battery:	5000 - 6000 mAh, 4 cell, lithium polymer
Flight controller:	Pixhawk
Manual flight control:	Taranis X7
Flight planning software:	Mission Planner
Endurance:	40 minutes
Max safe survey area per flight:	275 acres (1 km^2) while flying 100 meters altitude
Minimum air speed:	17 meters per second
Minimum automatic landing area:	100 ft. x 600 ft.
Launch method:	Hand or bungee
Image geotag method:	Pixhawk flight log file synced with photos, Emlid Reach (PPK) position file synched to photos, or on board camera GPS (Sequoia, RedEdge)

Fixed Wing UAV Market Survey - 3 - eBee SQ/Plus 'An Advanced Agriculture Drone' - eBee X - Required Specifications

Link:

https://www.sensefly.com/drone/ebee-x-fixed-wing-drone/

Cruise speed 40-110 km/h (11-30 m/s or 25-68 mph)

Wind resistance Up to 46 km/h (12.8 m/s or 28.6 mph)

Maximum flight time up to 90 minutes depending on camera and battery

Endurance >60 min

Max. flight range Standard: 37 km (~23 mi) Endurance: 55 km (~34 mi)

Wingspan 116 cm (45.7 in)

Weight (incl. camera & battery) 1.3 kg - 1.6 kg (2.2 - 3.6 lb) depending on camera and battery

Requirement Specs from Market survey and user listed together:

- (Max Take off) **weight** = 2.174 kg (consider 1.5 kg initially and carry on analysis)
- Wing span, b = 1.4 m
- Chord, c = 0.6 m
- Cruise speed = 15 m/s
- Payload weight = 0.4 kg (HD camera) (assumed within components weight initially - ie in first iteration while evaluation)

- Endurance = 60 min.
- Area of operation = 3 Km radius.
- Max speed = 20 m/s.
- Flying altitude = 100 m from ground.
- Climb and descent rates = 5 m/s.

We can proceed with these parameters, any more necessary assumptions are mentioned

UAV Component Identification and weight estimation (considering as per lecture slides)

Component	**Weight** (grams)
GPS	12
Airspeed sensor	60
Autopilot	38
RC receiver	9
Data Telemetry	67
Propeller	1x40=40
Motor	1x181=181
ESC	1x15=15
Battery	528
Servo motor	4x15=60
Camera	64
Gimbal	400
Structure	700
Total	**2174**

Remaining aspects are all handwritten and merged with this pdf
(PTO)

Question 3 - XFLR5 (Ubuntu)

Given Reynolds Num = 5 Lakh (500,000)
For performance computation we need to see how the values of the Coefficients or Parameters C_L, C_L/C_D, C_M are varying with varying alpha (angle of attack).

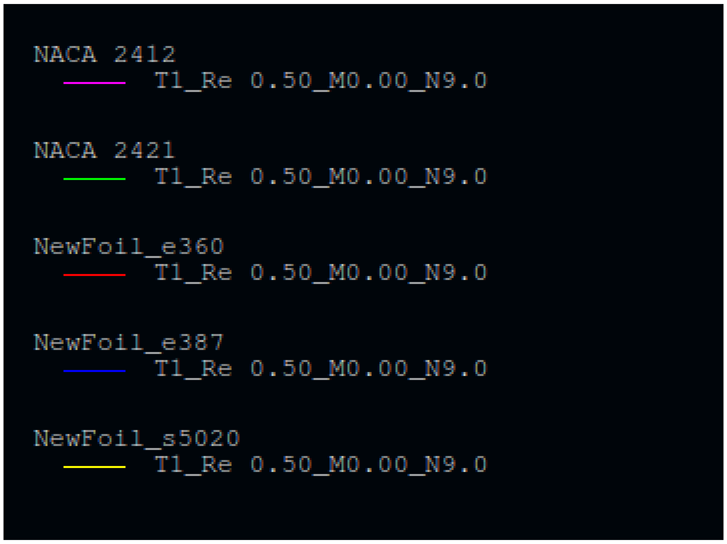
Given airfoils:
E360
S5020
E387
NACA 2412
-> NACA 2421 is also considered - can be seen in plots (just as an experiment with NACA foils)

These data files are obtained from the internet.
Please find all the relevant files attached in the zip

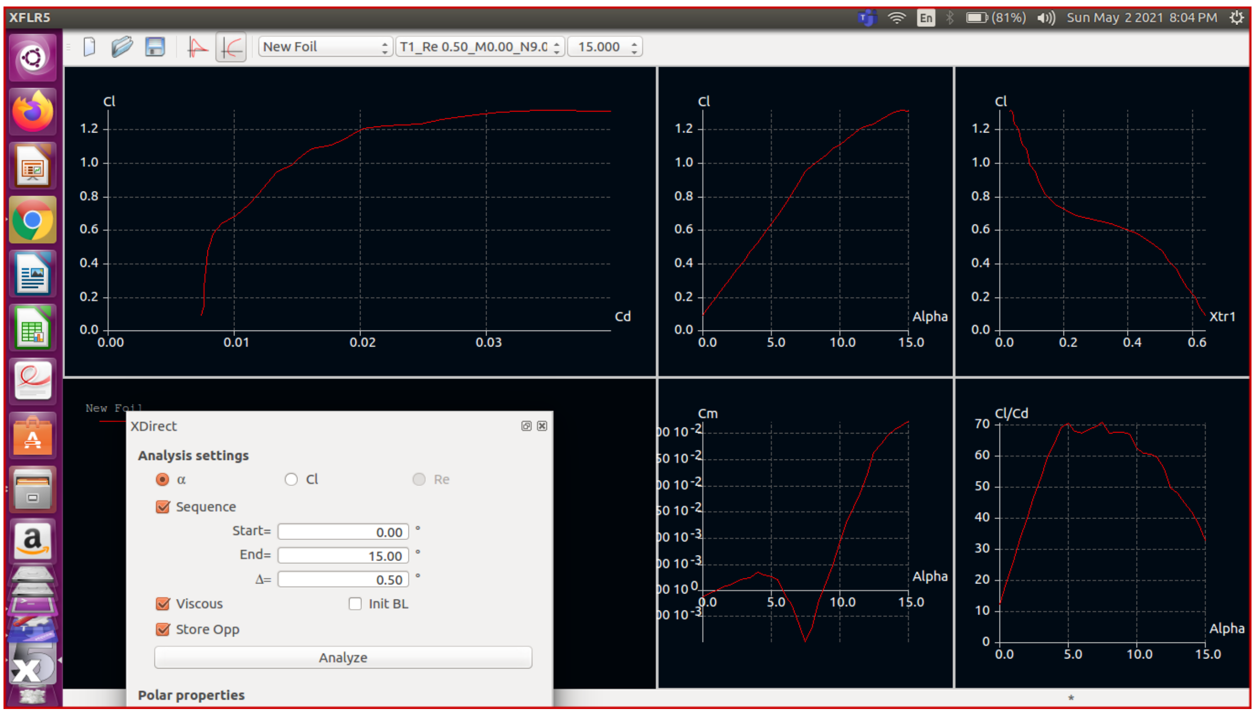
<u>Final Plots:</u>

The following are the final plots obtained while changing the parameter **alpha from 0 degree to 15 degrees** (I chose 15 degrees because alpha, as seen in our course lectures need not be higher than say 20 degrees), alpha step size is 0.5 degrees (default)

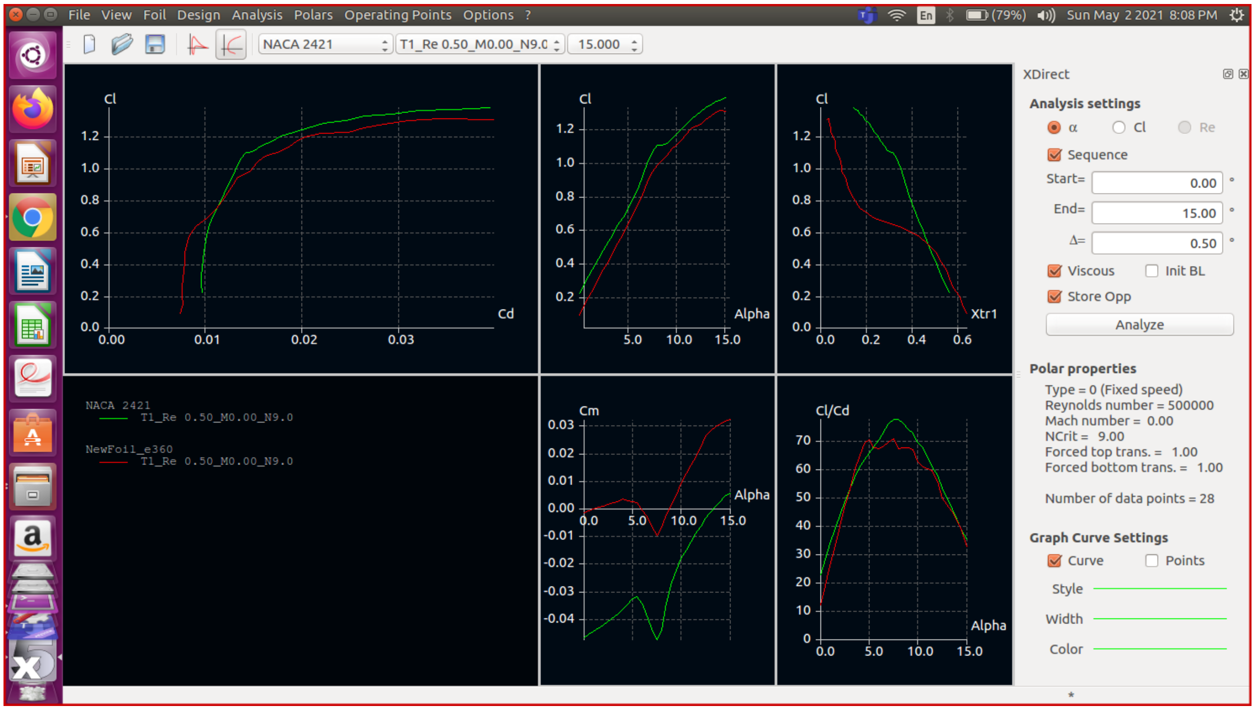
All the air foils are run in single analysis
These colors in the plots represent the following foils



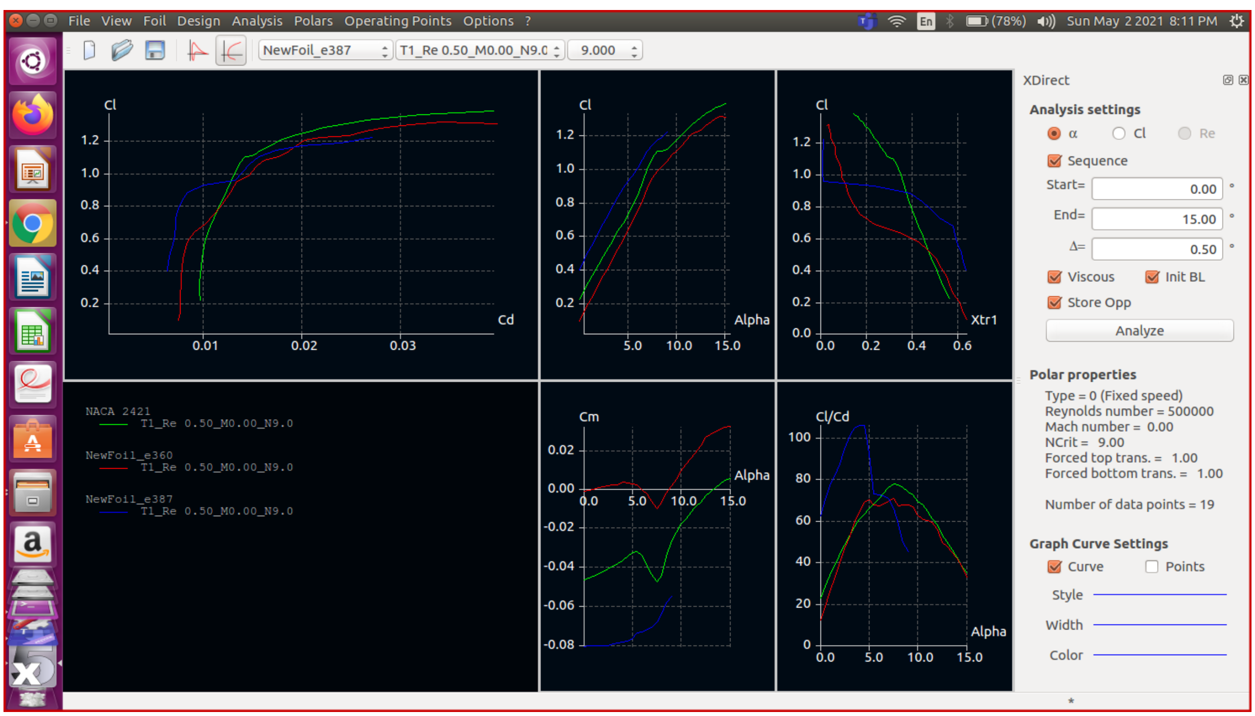
1. **E360 air foil - alpha from 0 to 15**



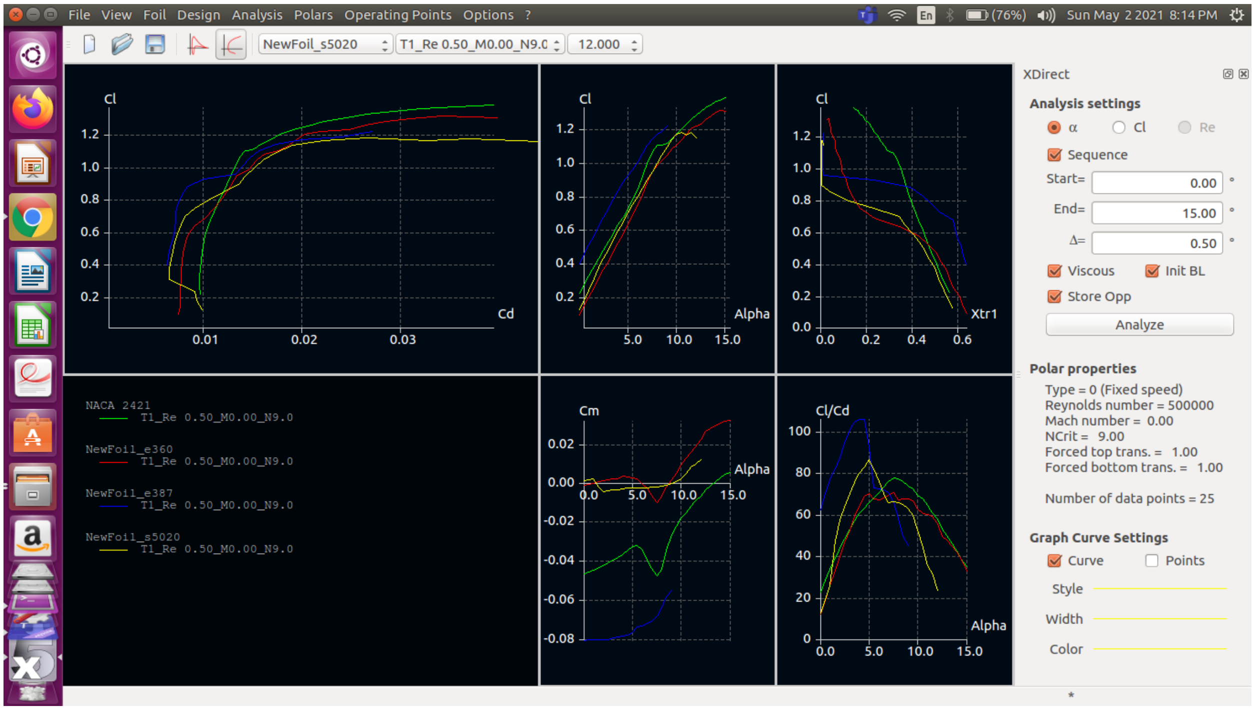
2. **NACA 2421 airfoil and E360 airfoil - alpha from 0 to 15**



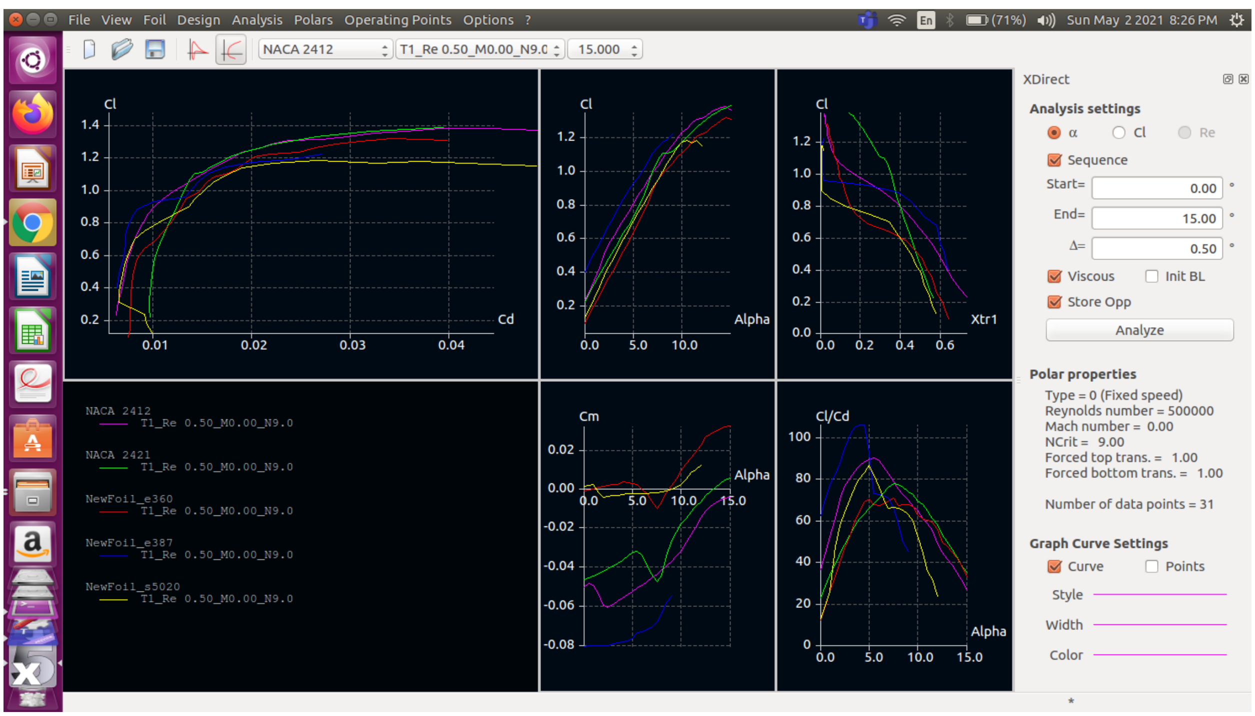
3. NACA 2421, E360 and E387 airfoils - alpha from 0 to 15



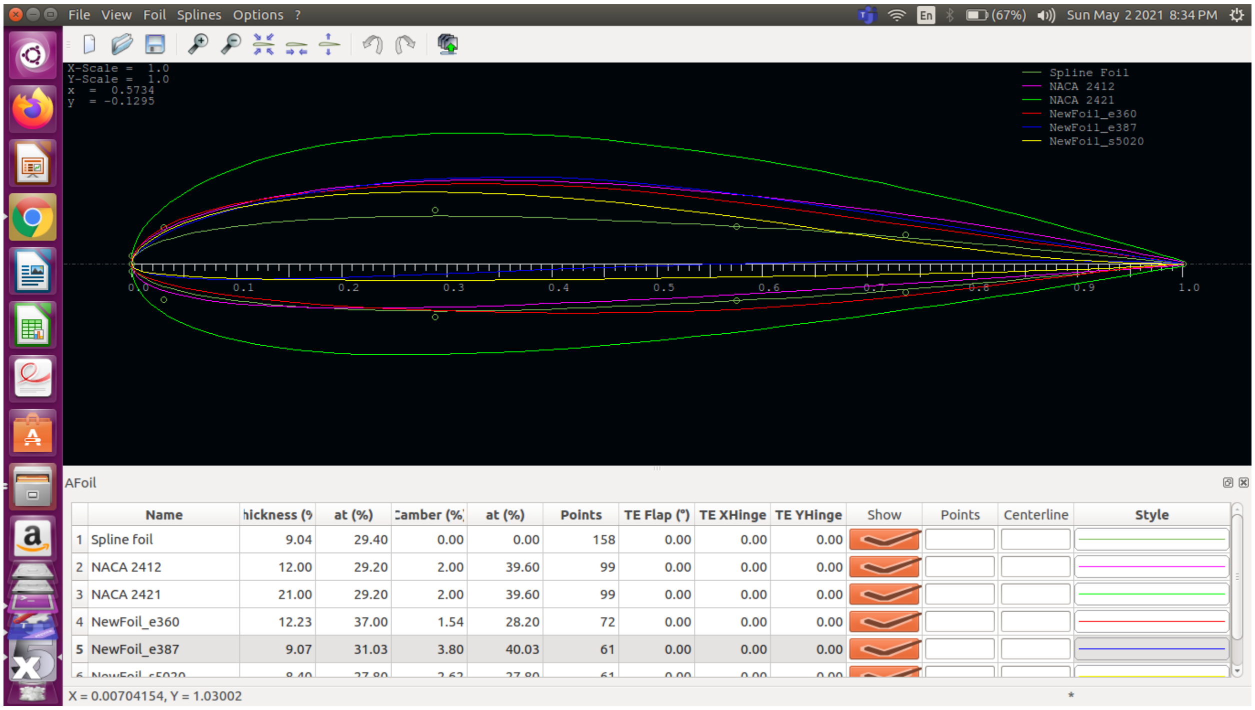
4. NACA 2421, E360, E387 and s5020 airfoils - alpha from 0 to 15



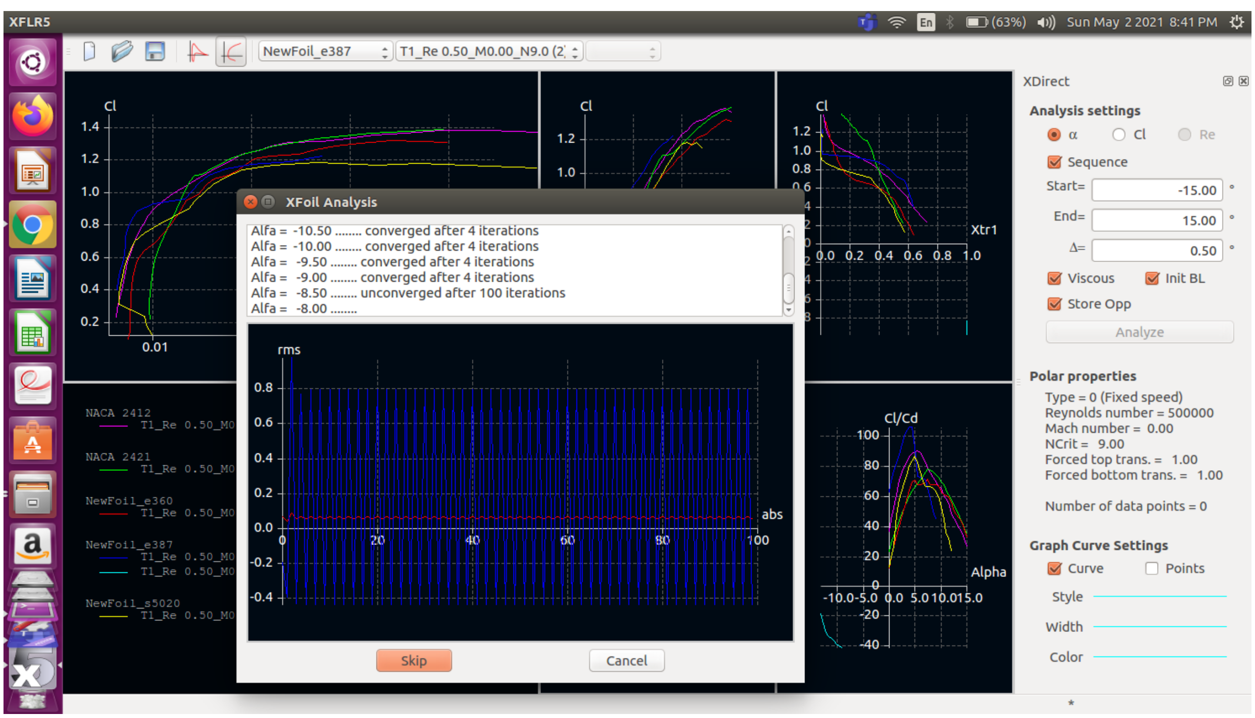
5. NACA 2421, E360, E387, s5020, NACA 2412 airfoils - alpha from 0 to 15



Direct Foil Analysis of all the airfoils considered



Screenshot while running an analysis - during some experimentation



Interpretations and Observations of the plots:
Within the specified alpha range, there is **no stall** occurring, as we can see from the C_L (lift coefficient) plot.

(PTO for handwritten pdf - Q1 and Q2)
(scroll to next page)

Intro to UAV Design
Assignment - 2

Please find another pdf also submitted with

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(2) Given

Airspeed (V_a) is varying from 10 m/s to 50 m/s. To compute the range of the pressure sensor (which can measure these air speeds).

W.K.T, $\Delta p = P_t - P_s = 0.5 \rho V_a^2$ → dyn. pressure

P_t → Dynamic + Static pressure

P_s → static pressure.

(ie Dynamic pressure is due to the movement of the air foil (or) UAV)

$\rho_{air} = 1.225 \text{ kg/m}^3$.

for $V_a = 10$ m/s,

$$\Delta p_1 = 0.5 \times 1.225 \times (10)^2 \text{ Pascal}$$
$$= 61.25 \text{ Pa}$$

for $V_a = 50$ m/s,

$$\Delta p_2 = 0.5 \times 1.225 \times (50)^2 \text{ Pascal}$$
$$= \Delta p_1 \times 25$$
$$= 1531.25 \text{ Pa}$$

$$\boxed{\text{Range: (Pa)} \quad 61.25 \rightarrow 1531.25}$$

∴ Range is $\Delta p_2 \rightarrow \Delta p_1$ (substraction) ⇒ $1531.25 - 61.25$
$= 1470$ Pa

(1) Given, Application: Crop health monitoring fixed wing UAV.

→ User Specs:

ⓐ Endurance = 60 min

ⓑ Area of operation = 3 Km radius

ⓒ Max speed = 20 m/s.

ⓓ Flying altitude = 100 m from ground.

ⓔ climb rate = 5 m/s

descent rate = 5 m/s.

(Market Survey & component Identification in the end of Pdf)

CONOPS:

UAV Mission from the requirements given are as follows (A typical CONOPS (or) one round of operation of the UAV)

→ Take off

→ Climb

→ After achieving the required altitude start Crop monitoring (given application) (Take Snapshots or videos of plants (or) trees)

⇓

→ This stage is Cruise (A predefined path or trajectory might be available)

→ After cruise, descent

→ Then landing. Landing can be at the home location (same runway) itself (or) another location based on mission requirements

→→ aircraft
▷ home

▷ → Take off → climb ⋯ 100 m ⋯ →→ cruise $V_a = 15\,m/s$

$\underbrace{\text{runway}}$ $\underbrace{\text{distance covered during climb}}$

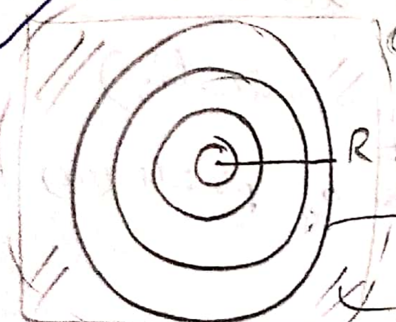
crop monitoring is camera snapshots & videos.

cruise →→ descent ⋯ →→ ⋯ → ▷ landing → home (or) other location.

CONOPS

→ All these operations shown in CONOPS are required to meet the specifications (from user & market survey).

→ CONOPS
→ Crop Monitor Task — Trajectories possible



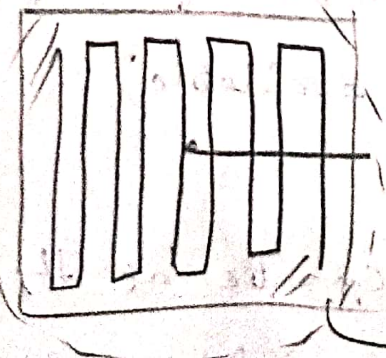
concentric circles (For 90°) → 15 circles.

→ UAV Trajectory (Loiter is involved)

→ field

→ Area of operation

(or)



(Terrain mapping can also be done)

→ Area of operation.

We need to design for the following purposes
→ Take off, Climb, Cruise, Descent, Land.

Design of UAV (fixed wing)

final Requirements - user & market survey :

→ weight or Mass, M = 2.174 kg (Consider 1.5 kg initially).
→ Wingspan, b = 1.4 m
→ Chord, c = 0.6 m.

~~Dimensions~~
→ Cruise speed say = 15 m/s.
→ Endurance = 60 min (1 hr)
→ Area of operation = 3 km radius
→ Max speed = 20 m/s
→ Flying Altitude = 100 ~~m/s~~ m from gnd.
→ Climb rate = 5 m/s
→ Descent rate = 5 m/s.

→ Camera HD = payload → 0.4 kg.

Analysis: — Airfoil selection

→ Surface Area of the wing = S_W = $b \cdot c$
= 1.4×0.6
= 0.84 m^2.

→ Reynolds Number

$$R_e = \frac{\bar{C}\, V_a \cdot \rho}{\mu}$$

flowspeed (V_a)
density of air.
linear dimension (chord mean)

'μ' is the dynamic viscosity.

Consider $\rho = 1.225\ kg/m^3$.

$\mu = 1.801 \times 10^{-5}\ kg/m.s$.

$$Re_{min} = \left(\frac{1.225}{1.801 \times 10^{-5}}\right) \bar{c} . V_a$$

(Re is a dimensionless number)

→ Say min. V_a is 10 m/s $\quad \bar{c} = 0.6\ m$

max is given as 20 m/s.

$$\therefore Re_{min} = \frac{1.225 \times 0.6}{1.801} \times 10 \times 10^5$$

$$= 0.4081 \times 10^6$$

$$Re_{max} = \frac{1.225 \times 0.6}{1.801} \times 20 \times 10^5$$

$$= 2 . Re_{min}$$

$$= 0.8162 \times 10^6$$

$V_{cruise} = 15\ m/s$.

Then $$Re_{cruise} = \frac{1.225 \times 0.6}{1.801} \times 15 \times 10^5$$

$$= 12.2432 \times 10^5$$

→ As per the lecture slides we can take MH45 airfoil & do 2D analysis to get cd, cL, cl/cd & Cm in X-flr.

With the Corresponding Re no's we get

C_L Vs α, cd Vs α, cl/cd Vs α, Cm Vs α

where α is the Angle of Attack.

→ A curve is fitted on the obtained data to get the relations b/w α & the correspon-ding coefficients.

For MH45, we have,

$C_L = 5.7\alpha + 0.18$, $C_d = 0.008$,

$C_L/C_d = 82$, $C_m = -0.07$.

To compute all coefficients Vs α, for a wing

wing $$C_{L\alpha} \simeq \frac{C_{l\alpha}}{1 + \frac{C_{l\alpha}}{\pi AR}}$$

↳ Aspect ratio

is $\frac{b^2}{cb} = \frac{b}{c}$

$= \frac{1.4}{0.6}$

$\Rightarrow AR = 2.33$.

Now,

we get

$C_{LW} = 2.58\alpha + 0.05$, $C_{DW} = 0.86\alpha^2 + 0.0756\alpha + 0.0024$, $C_{MW} = -0.556\alpha - 0.017$.

Calculating lift to drag ratio,

~~[illegible]~~ We have to go for high $\frac{C_L}{C_D}$ ratio, so that max lift & min drag is obtained. Also, we need low pitching moment ie C_m.

To calculate $\frac{\text{Lift}}{\text{drag}}$ for $V_a = 10, 15, 20$ m/s at some 'α'.

$V_a = 10$ m/s, $\alpha = 6°$, Drag $= 0.91$ & $\frac{\text{lift}}{\text{drag}} = 16.17$.

$V_a = 15$ m/s, $\alpha = 2°$, Drag $= 0.63$ & $\frac{\text{lift}}{\text{drag}} = 23.36$

$V_a = 20$ m/s, $\alpha = 0.7°$, Drag $= 0.64$ & $\frac{\text{lift}}{\text{drag}} = 23.00$.

(Max $\frac{\text{lift}}{\text{drag}}$ ratio)

→ Horizontal Tail Parameters

$$Y_{HT} = \frac{S_t \cdot l_t}{S_w c}$$

l_t → Distance b/w tail & wing.

S_t → Horizontal tail area

S_w → Area of the wing

c → mean chord length

$S_w = 1.4 \times 0.6 = 0.84\ m^2$ (calculated before)

$\bar{c} = 0.600$ ft

Say $l_t = 1m$.

let $S_t = 0.2\ m^2$ (ie 0.5×0.4)

$$\therefore V_{HT} = \frac{0.2 \times 1}{0.84 \times 0.6}$$

$= 0.396 \simeq 0.4$

let $S_t = 0.3\ m^2$ (ie 0.75×0.4)

Then $V_{HT} \simeq 0.6$ (after calculating)

Then $C_M = -0.874\alpha + 0.0268$ with $\alpha_t = 1.8$.

for this case with $V_{HT} = 0.4$,

$C_M = -0.7505\alpha + 0.0064$, $\alpha_t = 0.5$;

Tail volume ratio :

horizontal $C_{HT} = 0.50$

vertical $C_{VT} = 0.04$.

(PTO)

Vertical Tail Design

$$V_{VT} = \frac{l_{vt} \cdot S_V}{b \cdot S_W}$$

S_V → vertical tail area

S_W → wing area

b → wing span.

l_{vt} → Dist. b/w tail & wing

Vertical Tail is a Trapezoid with.

$h_V = 0.370m$, $a_V = 0.400m$, $b_V = 0.20m$.

We get $V_{VT} = 0.10$.

Control Surface Sizing (& Drag Estimate)

Let (HT) Elevator be 25% to 50% of Horizontal tail chord length

Rudder (VT) also the same percentage of vertical tail chord length.

i.e (0.1m, 0.75m) = (c, b) → 0.1 (∵ 0.25 × 0.4)

(0.4, 0.37)

aileron chord is (0.12, 0.32)

→ Drag Estimation : Total (or) Most of the drag is due to fuselage & wings.

To find

$$D_{fuselage} = C_{D_f} \cdot 0.5 \cdot \rho V_a^2 S_w,$$

where $C_{D_f} = C_{fe} \cdot \frac{S_{wa}}{S_w}$ &

$$C_{fe} = 0.0003$$

$$S_{wa} = \pi d_f l_f \left(1 - \frac{2}{\lambda_f}\right)^{2/3} \cdot \left(1 + \frac{1}{\lambda_f^2}\right)$$

where $\lambda_f = \frac{l_f}{d_f}$ → 1.5m

it is the length of the fuselage.

$\therefore S_{wa} = 1.05 m^2$

$S_w = 0.84 m^2$ (previously calculated wing area is $S_w = bc$).

$\therefore$ we get $C_{D_f} = 0.0038$

& $\therefore$ we get $D_{fuselage} = 0.0038 \cdot 0.5 \cdot$

$1.225 (V_a)^2 \cdot 0.84$

with $V_a = 15 m/s$,

we have $D_{fuselage} = 0.39$ N

added with the initial drag will give us total drag.
(from analysis)

Propeller Sizing :

we have, $V_a = 15\, m/s$

$K = 2$, $D = 1.02\,N$, $\frac{Lift}{Drag} = 14.4$

T_a for $n = 100$ rps is 2.75.

we need Thrust = Drag.

$T_a = C_t \cdot \rho\, n^2 D^4$

& $C_t = 0.135 - 0.175 J = 0.10926 J$.

$J = \frac{V_a}{nD}$,

$\therefore$ we can use a 11 x 6 inch propeller

(40 g)

For $\eta_p = 0.7$

$P_m = \frac{T_a V_a}{\eta_p} \Rightarrow \frac{2.75 \times 15}{0.7} = 58.92 W$.

& for AX12826 motor, Power = 30 A x

1.68 V = 504 W.

we need Endurance = 60 Min.

$4 \cdot S = 4 \times 4.2 = 16.8 V$

$I_{max} = \frac{84.28}{0.78 \times 16.8} (V_a) = 20 m/s$

$= 6.431 A$

η_m

With all the Considered components,

our Drag will ↑se (as mass is ↑sed of the aircraft).

we get Drag = 1.430 for ~~[illegible]~~ $M = 2.174$ Kg.

we need loiter

→ Note :

Range originally required is

Consider FoV of the HD camera (payload) is 90°

& radius is 3 KM.

we need 15 circles to cover the area

⇒ Distance need to be travelled

= 47.1 KM.

Climb Phase : (say including payload).

$m g \dot{h} = (T_a - D) V_a$

$\dot{h} = 5 M/s$ (Climb rate.)

⇒ $2.174 \times 9.8 \times 5 = (T_a - 1.43) \times 15$

⇒ $T_a = 8.529$
$\simeq 8.53\ N$

with n = 100 rps we got 2.75 N only

∴ we may need to ↑se rps.

Loiter phase :

$$\tan\phi = \frac{V_a^2}{Rg}$$

$$\Rightarrow (C_{L\alpha} \cdot \alpha + C_{L0})(0.5\,\rho V_a^2 S_w) = \frac{mg}{\cos\phi}$$

Loiter energy E_L (given as)

$$= \sum_{i=1}^{15} (T_i \times V_a) \frac{2\pi R_i}{V_a}$$

$= 22663 + 10800 + 17,875$

$= 51338\ J$

Cruise & Climb energies

$E_c = 8.5 \times 15 \times 100/5 = 2,550\ J$

$E_r = 1.43 \times 15 \times 2900/15 = 4147\ J$

Total energy E_T =

$$\frac{E_c + E_r + E_L}{0.7 \times 0.78}$$

$= 106291\ J$

Available Energy $\Rightarrow$ $E_a = 16.8 \times 5 \times 3600$

is $= 298800.$

$t = 20 + 194 + 3140 + 5196$

(Endurance)
for climb, Cruise & Loiter resp.

$= 142.5$ min .

& Range $= 15 \times 142.5$ min

$= 127$ KM .

But communication might not support this long range. We will not operate to that great distance though. It might be just the distance travelled by the UAV. It wont be the displacement from the Centre (of all the Concentric circles in the field).

→ So updated specs are of Endurance & Range.

∴ Specs are met .