SAINT MARTIN'S UNIVERSITY

MME 523 Project

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1 Project Proposal:

An Unmanned Aerial Vehicle (UAV) to be owned by small businesses and used for delivering small packages to consumers. The UAV must be priced to be attractive to potential owners while offering a desirable delivery speed. In the long term, an auto-gyro design will be utilized to minimize takeoff and landing distances, however, Auto-gyros are not well understood compared to fixed-wing aircraft. A flying wing will be used as a preliminary design to test the flight avionics and algorithms necessary for autonomous delivery; the flying wing might be adapted into a longer-range delivery system for rural communities.

1.1 Assumptions

The items below highlight idealizations and implicit assumptions built into the proposal and will constrain the design. They may also double as design variables where appropriate.

- Weight to power ratio of motor: 0.0022N/W[1]
- Energy density of batteries: 4.86kJ/kg [1] with a voltage of 48V
- Cruising altitude greater than 300m per FAA mandate[2]
- Battery capacity is a multiple of 100mAh [1]
- Net propeller efficiency of 80% (μ_p)[3]
- Motor efficiency of 95%(μ_m), based on existing high-performance synchronous motors[4]
- Taper ratio of 0.7 (λ) [1]
- Root chord > 25cm (c_{root})for storage [1]
- Wing sweep at the quarter chord is 0.4 ($\psi_{c/4}$)[1]
- Aspect ratio (AR) between 4 and 12 [1]

1.2 Primary Objectives

To meet product objectives, the following parameters are considered essential. As such, they will constrain the system design and, where applicable, will be heavily weighted in the objective function:

- A payload capacity of 5kg, in addition to any avionics (LIDAR or ultrasonic radar, etc.)
- Delivery range of 15km within 10 minutes, takeoff/landing inclusive, cruise velocity: v_c = 112.5km/h
- A total range of 40km with two takeoffs and landings Minimize (stall) velocity to facilitate steeper climbs, design may fly/climb at near stall velocity for 1 min, 9 m/s will be considered good, 12 m/s will be considered adequate [1]
- Minimize takeoff and landing distance
- An all-electric system

The payload selected was deemed sufficient for most consumer expectations (coffees, beer, take-out dinners, and everyday items). Some packages might be awkwardly sized (pizzas) and may complicate design or may require a dedicated design. The range and speed were selected to support a competitive small business in a midsize urban area. Takeoff and landing will define the feasibility of the system in an urban and suburban environment; in those use cases, consumers may not have the luxury of a long stretch of road or field to land on. An all-electric system is considered essential; electric systems require less maintenance and do not require exotic fuels.

1.3 Secondary Objectives

The following objectives are not considered mission-critical and will not constrain the design. These variables will feature in the objective function:

- Minimize battery size/capacity (C)
- Minimize upfront cost

Batteries may be the most expensive component of most electric systems: minimizing the battery size will reduce initial and replacement costs, improve the system reliability, reduce battery monitoring requirements, and improve the system in nearly every other objective. Cost is considered a secondary objective in that the delivery system is sufficiently innovative and appropriate for its market to justify a high asking price: especially when the savings on a delivery vehicle and driver is factored in along with expansion to previously inaccessible customers (island deliveries).

1.4 Design Variables

The following variables will define the design and will direct the optimization process:

- Battery capacity (C)
- Aspect ratio (AR)
- Wing span (b)
- Motor power (W)

All these design variables,save wing span, have been touched on previously and will be constrained or minimized. Wing span will not be directly constrained; however, it is closely entangled with aspect ratio, root chord, and taper ratio resulting in an implicit constraint. To simplify the analysis, the precise aspects of the motor design will be left for another day. Those interested in the specifics of non-superconductive high-performance aerospace motors can read I. Bouzidi and K. Petermaier [4]–[6].

2 Project Conclusion

There were several aspects to the project as originally proposed that had to be modified or were found to be infeasible.

To start with, some minor revisions had to be made to fill in gaps in the original proposal:

- The density of air ρ_{air} was set at $1.217\frac{kg}{m^3}$ [7]
- Dynamic viscosity of air set at 1.82e-5 pascal seconds

- Aspect ratio removed from design variables
- V_{max} and V_{min} and Payload added to design vars

Takeoff and landing components had to be abandoned for reasons of complexity. It became apparent that the flying wing is not an ideal frame for payload delivery and speed. That does not exclude the possibility of (a) mistake(s) within the analysis algorithm.

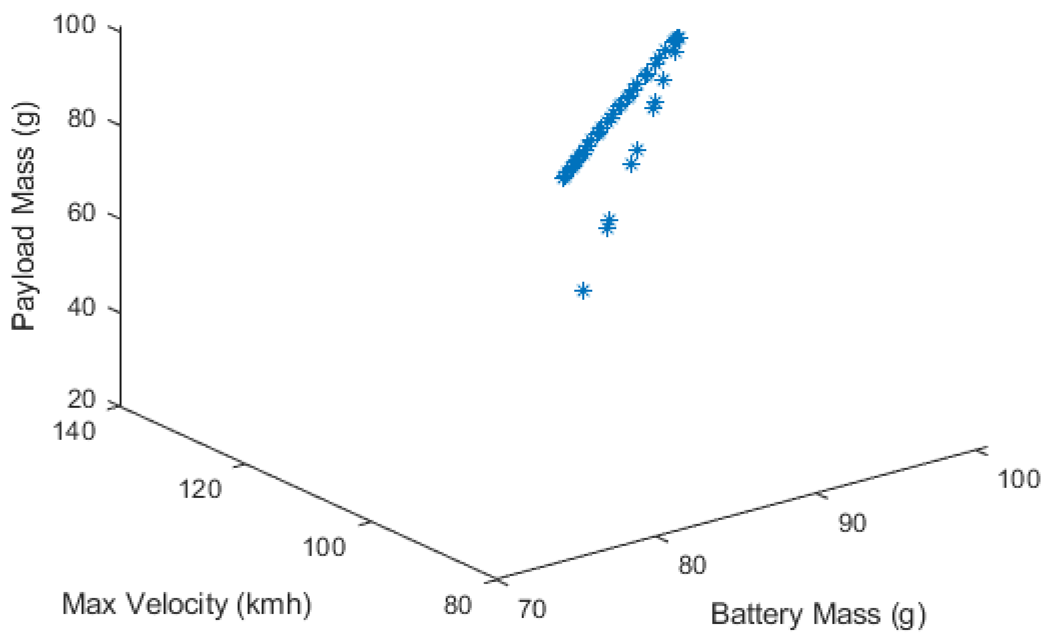

Table 1 demonstrates that the flying wing analyzed will not be capable of meeting the 5kg payload requirement specified in the proposal. In fact, the payload barely came within 20% of that target. The V_{min}, aka the stall speed, had to be expanded to generate a broader Pareto front. To compensate for the more generous upper limit, the stall speed had a new constraint of less than or equal to half the max speed imposed.

Analysis into the limiting factors suggests that it may be possible to support a higher payload with a higher aspect ratio. Other airframe paradigms (most notably the autogyro suggested in the proposal) might be capable of meeting project needs provided a certain minimal threshold of knowledge could be met.

The proposal and analysis highlight how little I know about airframe design outside of basic heuristics. A stronger grasp of the essential mathematics would help answer basic questions including but not limited to whether a motor power of 10W is anywhere close to appropriate. It seems unlikely that 10W is sufficient to maintain a speed of over 100kmh, however I lack any frame of reference.

C_{batt} (mAh)	m_{batt} (g)	Wingspan (m)	Motor Power (W)	V_{stall} (kmh)	V_{max} (kmh)	Range (km)	Payload (g)
200	74.4	0.41	10	40	81	118	101.2
200	79.7	0.36	10	45	90	127	97.1
200	84.8	0.33	10	50	100	135	93
200	89.8	0.3	11	54	109	143	88.6
200	74.4	0.41	10	40	81	118	101.2
200	79.2	0.37	10	45	89	126	97.6
200	83.8	0.34	10	49	98	133	93.8
200	88.3	0.31	11	53	106	141	89.9
200	74.4	0.41	10	40	81	118	101.2
200	78.7	0.37	10	44	88	125	98
200	82.8	0.34	10	48	96	132	94.7
200	86.8	0.32	10	52	103	138	91.2
200	90.8	0.3	11	55	110	144	87.7
200	74.4	0.41	10	40	81	118	101.2
200	78.1	0.38	10	44	87	124	98.4
200	81.8	0.35	10	47	94	130	95.5
200	85.3	0.33	10	50	100	136	92.5
200	88.8	0.31	11	53	107	141	89.5
200	92.3	0.29	11	57	113	147	86.4
200	74.4	0.41	10	40	81	118	101.2
200	77.6	0.38	10	43	86	123	98.8
200	80.7	0.36	10	46	92	128	96.3
200	83.8	0.34	10	49	98	133	93.8
200	86.8	0.32	10	52	103	138	91.2
200	89.8	0.3	11	54	109	143	88.6
200	74.4	0.41	10	40	81	118	101.2
200	77.1	0.38	10	43	86	123	99.2
200	79.7	0.36	10	45	90	127	97.1
200	82.3	0.35	10	47	95	131	95.1
200	84.8	0.33	10	50	100	135	93
200	87.3	0.32	11	52	104	139	90.8
200	89.8	0.3	11	54	109	143	88.6
200	92.3	0.29	11	57	113	147	86.4
200	74.4	0.41	10	40	81	118	101.2
200	76.6	0.39	10	42	85	122	99.6
200	78.7	0.37	10	44	88	125	98
200	80.7	0.36	10	46	92	128	96.3
200	82.8	0.34	10	48	96	132	94.7
200	84.8	0.33	10	50	100	135	93
200	86.8	0.32	10	52	103	138	91.2
200	88.8	0.31	11	53	107	141	89.5
200	90.8	0.3	11	55	110	144	87.7
200	74.4	0.41	10	40	81	118	101.2
200	76	0.39	10	42	84	121	100

200	77.6	0.38	10	43	86	123	98.8
200	79.2	0.37	10	45	89	126	97.6
200	80.7	0.36	10	46	92	128	96.3
200	82.3	0.35	10	47	95	131	95.1
200	83.8	0.34	10	49	98	133	93.8
200	85.3	0.33	10	50	100	136	92.5
200	86.8	0.32	10	52	103	138	91.2
200	88.3	0.31	11	53	106	141	89.9
200	74.4	0.41	10	40	81	118	101.2
200	75.5	0.4	10	41	83	120	100.4
200	76.6	0.39	10	42	85	122	99.6
200	77.6	0.38	10	43	86	123	98.8
200	78.7	0.37	10	44	88	125	98
200	79.7	0.36	10	45	90	127	97.1
200	80.7	0.36	10	46	92	128	96.3
200	81.8	0.35	10	47	94	130	95.5
200	82.8	0.34	10	48	96	132	94.7
200	83.8	0.34	10	49	98	133	93.8
200	74.4	0.41	10	40	81	118	101.2
200	75	0.4	10	41	82	119	100.8
200	75.5	0.4	10	41	83	120	100.4
200	76	0.39	10	42	84	121	100
200	76.6	0.39	10	42	85	122	99.6
200	77.1	0.38	10	43	86	123	99.2
200	77.6	0.38	10	43	86	123	98.8
200	78.1	0.38	10	44	87	124	98.4
200	78.7	0.37	10	44	88	125	98
200	79.2	0.37	10	45	89	126	97.6
300	94.7	0.28	12	59	118	151	84.1
300	99.6	0.26	13	63	127	158	79.6
300	99.8	0.25	18	65	129	164	68.7
300	98.1	0.25	128	65	129	156	55.2
300	96.4	0.25	193	65	129	154	41.8
300	94.7	0.26	264	65	129	151	28.3
300	92.8	0.29	12	57	114	148	85.9
300	97.2	0.27	12	61	122	155	81.9
300	100.8	0.25	13	64	129	160	76.7
300	99.3	0.24	28	64	129	165	64.6
300	97.7	0.25	142	65	129	156	52.5
300	96.2	0.25	203	65	129	153	40.4
300	94.7	0.28	12	59	118	151	84.1
300	98.7	0.26	13	62	125	157	80.2
300	100.4	0.25	13	65	129	163	74
300	99.1	0.25	89	65	129	158	63.3
300	97.7	0.25	142	65	129	156	52.5
300	95.7	0.28	12	60	119	152	83.2
300	99.1	0.26	13	63	126	158	80.1
300	100.4	0.25	13	65	129	163	74

300	99.3	0.24	28	64	129	165	64.6
300	92.8	0.29	12	57	114	148	85.9
300	95.7	0.28	12	60	119	152	83.2
300	98.7	0.26	13	62	125	157	80.2
300	100.8	0.26	13	64	129	160	76.7
300	94.7	0.28	12	59	118	151	84.1
300	97.2	0.27	12	61	122	155	81.9
300	92.8	0.29	12	57	114	148	85.9

3 Bibliography

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[2] “Aeronautical Information Manual - AIM - Airport Operations.” .https://www.faa.gov/air_traffic/publications/atpubs/aim_html/chap4_section_3.html (accessed Jun. 14, 2020).

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[4] K. Petermaier, “2015 Transformational Vertical Flight Workshop.” NASA.gov, SIEMENS, Aug. 2015, Accessed: Jun. 07, 2020. [Online]. Available: https://nari.arc.nasa.gov/sites/default/files/attachments/Korbinian-TVFW-Aug2015.pdf.

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[6] I. Bouzidi, A. Masmoudi, and N. Bianchi, “Electromagnetic/Thermal Design Procedure of an Aerospace Electric Propeller,” IEEE Trans. Ind. Appl., vol. 51, no. 6, pp. 4364–4371, doi: 10.1109/TIA.2015.2442524.

[7] “Earth Fact Sheet.” https://nssdc.gsfc.nasa.gov/planetary/factsheet/earthfact.html (accessed Oct. 18, 2020).

4 Code

4.1 Main

[ ]:
```
clear; clc;

%% Initialization
% Constants

% chi=y(1);         %motor weight to power ratio N/W
% zeta=y(2);        %Converting density from kg to N
% Vbatt=y(3);       %V
% mu_p=y(4);        %Net propellor efficiency
```

```
% mu_m=y(5);      %motor efficiency
% lamda=y(6);     %Taper ratio
% quarterChord=y(7);%Wing sweep at the quarter chord
% Wel=y(8);       %N
% ro=y(9) & %Density of Air
% C_Lmax = y(10); %Max Coef. of Lift
% Vmotor = y(11); %Voltage of motor
% w1 = y(12);
% w2 = y(13);
% w3 = y(14);

chi =  0.0022;  %motor weight to power ratio N/W
zeta = 47700;   %Battery Dens. J/N
Vbatt = 48;     %V
mu_p = 0.85;    %Net propellor efficiency
mu_m = 0.95;    %motor efficiency
lambda = 0.7;   %Taper ratio
quarterChord = 0.4;%Wing sweep at the quarter chord
Wel = 1;        %N
ro = 1.217;     %kg/m3
C_Lmax = 0.55;  %Max coef. of lift
Vmotor = 11.1;  %Motor Voltage

w1=0;w2=0;w3=0;
y = [chi, zeta, Vbatt, mu_p, mu_m,...
    lambda, quarterChord, Wel,ro, C_Lmax,...
    Vmotor, w1,w2,w3];

%% Design Vars

%Cbatt = x(1);      %(Ah)
%wingspan = x(2);   %(m)
%Pm = x(3); & %(W)
%Vmin = x(4);       %(m/s)
%Vmax = x(5);       %(m/s)
%payload = x(6);    %(kg)

x0 = [5,1,300, 1, 40,2];

LB = [0.2,0.05,10,6,80,0];
UB = [100, 5, 3000,40,inf,inf];

%Completing Fmincon Reqs
a = []; b = []; aeq = []; beq = [];

%% Optimization, no takeoff
Wbatt = zeros(3,1);
```

```
Vmax = zeros(3,1);
payload = zeros(3,1);


for i = [1:3]

    w1 = 0;
    w2 = 0;
    w3 = 0;

    switch i
        case 1
 &  w1 = 1;
        case 2
 &  w2 = 1;
        case 3
 &  w3 = 1;
    end

    y = [chi, zeta, Vbatt, mu_p, mu_m,...
    lambda, quarterChord, Wel,ro, C_Lmax,...
    Vmotor, w1,w2,w3];

    options = optimset('Display', 'off','largescale','off','MaxFunEvals',1e3,...
 &  'MaxIter',1e3,'Algorithm','sqp');
    [xopt] = fmincon(@objfun, x0, a, b, aeq, beq, LB, UB, @nonlincon, options,␣
 ↪y);

    z = analysis(xopt, y);

    Vmax(i) = xopt(5);
    payload(i) = xopt(6);
    Wbatt(i)= z(5);

    xoptRange(i,:) = xopt;
    optRange(i,:) = analysis(xopt,y);

end


utopiaPt = [min(Wbatt);max(Vmax);max(payload)];
nVec = utopiaPt/norm(utopiaPt);

payoffMat = [0,optRange(2,5)-optRange(1,5),optRange(3,5)-optRange(1,5);...
    xoptRange(1,5)-xoptRange(2,5),0,xoptRange(3,5)-xoptRange(2,5);...
    xoptRange(1,6)-xoptRange(2,6),xoptRange(2,6)-xoptRange(3,6),0];
```

```
%% Reseting for Pareto Optimization
%t = x(7);
mult0 = [5,1,300, 1, 40,2,0.5];
multLB = [0.2,0.05,10,6,20,0,0];
multUB = [100, 5, 3000,inf,150,inf,inf];

Cbatt = zeros(100,1);       %(Ah)
wingspan = zeros(100,1);    %(m)
Pm = zeros(100,1); & %(W)
Vmin = zeros(100,1);        %(m/s)
Vmax = zeros(100,1);        %(m/s)
payload = zeros(100,1);     %(kg)
range = zeros(100,1);       % in km

instance = 1;
for i = linspace(0,0.9,10)

    for j  = linspace(0,1-i, 10)
        w1 = i;
        w2 = j;
        w3 = 1-i-j;
        beta = [w1;w2;w3];

        q = [chi, zeta, Vbatt, mu_p, mu_m,...
        lambda, quarterChord, Wel,ro, C_Lmax,...
        Vmotor, {payoffMat},{beta},{nVec}];

        options = optimset('Display',␣
 ↪'off','largescale','off','MaxFunEvals',1e3,...
 &    'MaxIter',1e3,'Algorithm','sqp');
        [xopt] = fmincon(@objfunMult, mult0, a, b, aeq, beq,...
 &  multLB, multUB,@nonlinconMult, options, q);

        Cbatt(instance) = xopt(1);      %(Ah)
        wingspan(instance) = xopt(2);   %(m)
        Pm(instance) = xopt(3); & %(W)
        Vmin(instance) = xopt(4);       %(m/s)
        Vmax(instance) = xopt(5);       %(m/s)
        payload(instance) = xopt(6);    %(kg)

        %powerReq = z(1);%in W
        %powerAvail = z(2);% W
        %range = z(3);% in km
        %AR = z(4);
        %Wbatt = z(5)
        %reynolds = z(6)
        %c_root = z(7)
```

```
        z = analysis(xopt, y);

        range(instance) = z(3);% in km
        Wbatt(instance)= z(5); % in kg


        instance = instance+1;
    end
end
round(Cbatt,3);round(wingspan,2);round(Pm,0);round(Vmin,0);
round(Vmax,0);round(payload*1000,1);round(Wbatt*1000,1);round(range,0)

tableNames = {'Battery Cap.(Ah)','Battery Mass (g)','Wingspan (m)','Motor Power␣
 ↪(W)',...
    'Stall Speed (m/s)', 'Max Speed (m/s)','Range (km)','Payload (g)'};
results = sortrows(table(Cbatt, Wbatt*1000, wingspan, Pm, Vmin, Vmax,␣
 ↪range,payload,...
    'VariableNames', tableNames),1,'ascend')


plot3(Wbatt*1000, Vmax, payload*1000,'*')
xlabel('Battery Mass (g)')
ylabel('Max Velocity (m/s)')
zlabel('Payload Mass (g)')
```

4.2 Objective Function, Initial

[ ]:
```
function [out] = objfun(x,y)
%Objective Function for Flying Wing

% Cbatt = x(1);
% wingspan = x(2);
% Pm = x(3);
Vmin = x(4);
Vmax = x(5);
payload = x(6);

w1 = y(12);
w2 = y(13);
w3 = y(14);

z = analysis(x,y);
%powerReq = z(1);%in kW
%powerAvail = z(2);% kW
%range = z(3);% in km
```

```
%AR = z(4);
Wbatt = z(5);
%reynolds = z(6);
%takeoffDistance = z(7);

out = w1*((Wbatt-0)/(0-5000))^4 +w2*((Vmax-150)/(150-100))^4 + w3*((payload-5)/
↪(5-0))^4;
end
```

4.3 Objective Function, Multi-Objective Pareto Front

[ ]:
```
function [out] = objfunMult(x,y)
%Objective Function for Flying Wing

t = x(7);

out = -t;
end
```

4.4 Constraint Function, Initial

[ ]:
```
function [C, Ceq] = nonlincon(x,y)
%Nonlinear constraints for the flying wing
% Cbatt = x(1);
% wingspan = x(2);
% Pm = x(3);
Vmin = x(4);
Vmax = x(5);
% payload = x(6);

z = analysis(x,y);
powerReq = z(1);%in W
powerAvail = z(2);% W
range = z(3);% in km
AR = z(4);
% Wbatt = z(5);
reynoldsScaled = z(6);
c_root = z(7)*10;

Ceq = [];
%Ceq = mod(Cbatt,100);

C(1) = AR-12;
C(2) = 4-AR;
C(3) = powerReq-powerAvail;
C(4) = 40-range;
```

```
C(5) = reynoldsScaled - 1;
C(6) = 0.15-c_root;
C(7) = 2*Vmin-Vmax;
%C(6) = -takeoffDistance;

end
```

4.5 Constraint Function, Multi-Objective Pareto Front

[ ]:
```
function [C, Ceq] = nonlinconMult(x,y)
%Nonlinear constraints for the flying wing
Cbatt = x(1);
% wingspan = x(2);
Pm = x(3);
Vmin = x(4);
Vmax = x(5);
payload = x(6);
t = x(7);

psiOpt = y{12};
beta = y{13};
nVec = y{14};

z = analysisMult(x,y);
powerReq = z(1);%in W
powerAvail = z(2);% W
range = z(3);% in km
AR = z(4);
Wbatt = z(5);
reynoldsScaled = z(6);
c_root = z(7)*10;

Ceq = psiOpt*beta+t*nVec-[Wbatt;Vmax;payload];

C(1) = AR-12;
C(2) = 4-AR;
C(3) = powerReq-powerAvail;
C(4) = 40-range;
C(5) = reynoldsScaled - 1;
C(6) = 0.25-c_root;
C(7) = 2*Vmin-Vmax;
end
```

4.6 Analysis Function, Initial

[ ]:
```
function z = analysis(x,y)
Cbatt = x(1); & %Battery Cap in Ah
b = x(2); &     %wingspan (m)
Pm = x(3); &    %Motor Power (W)
Vmin = x(4)*1000/3600;  %Stall speed (kmh to m/s)
Vmax = x(5)*1000/3600;  %#ok<*NASGU> %Max Speed (kmh to m/s)
payload = x(6);

Wpl = payload*9.81;

chi=y(1);         %motor weight to power ratio N/W
zeta=y(2);        %Converting density from kg to N
Vbatt=y(3);       %V
mu_p=y(4);        %Net propellor efficiency
mu_m=y(5);        %motor efficiency
lambda=y(6);       %Taper ratio
quarterChord=y(7);%Wing sweep at the quarter chord
Wel=y(8);         %N
ro = y(9)*9.81; %Density of air, converted to N/m3
C_Lmax = y(10); %Max Coef. of Lift
Vmotor = y(11); %Motor Voltage

%% Internal Constants
mu  =1.82e-5;% pascal seconds, dynamic vis of air

%% Analysis Begins
energy = (3600)*Vbatt*Cbatt;
Wbatt = energy/zeta;
Wmotor = Pm*chi;


%% Weights
X = 0.5 + 0.05*b;
W0 =(Wbatt + Wel + Wpl + Wmotor)/(1-X);

%% Wing Geometry
S = (2*W0)/(ro*Vmin^2*C_Lmax);
AR =(b^2)/S;
c_bar = S/b;
c_root = (2*c_bar)/(lambda+1);
c_tip = c_root*lambda;
leadingEdgeSweep = atan(b*tan(quarterChord)+(c_root-c_tip)/4)/b;
reynolds = (ro*Vmax*c_bar)/mu;

%% Dynamics
```

```
parasiticDrag = 4.98/sqrt(reynolds);

e = 4.61*(1-0.045*(AR^0.68));
K = 1/(pi*e*AR);

%% Performance
powerReq = 0.5*parasiticDrag*ro*Vmax^3*S+(2*K*W0)/(ro*Vmax*S);
powerAvail = mu_m*mu_p*Pm;

%% Takeoff performance

% Range and Capacity
endurance = energy/powerReq;
range = Vmax*endurance;

Wbatt = Wbatt/9.81; %N to kg
%% Outputs
%powerReq = z(1);%in W
%powerAvail = z(2);% W
%range = z(3);% in km
%AR = z(4);
%Wbatt = z(5)
%reynolds = z(6)
%c_root = z(7)
z = [powerReq, powerAvail, range/1000, AR,Wbatt, reynolds/500e3, c_root];

end
```

4.7 Analysis Function, Multi-Objective Pareto Front

[ ]:
```
function z = analysis(x,y)
Cbatt = x(1); & %Battery Cap in Ah
b = x(2); &     %wingspan (m)
Pm = x(3); &    %Motor Power (W)
Vmin = x(4)*1000/3600;  %Stall speed (kmh to m/s)
Vmax = x(5)*1000/3600;  %#ok<*NASGU> %Max Speed (kmh to m/s)
payload = x(6);

Wpl = payload*9.81;

chi=y{1};       %motor weight to power ratio N/W
zeta=y{2};      %Converting density from kg to N
Vbatt=y{3};     %V
mu_p=y{4};      %Net propellor efficiency
mu_m=y{5};      %motor efficiency
lambda=y{6};     %Taper ratio
```

```
quarterChord=y{7};%Wing sweep at the quarter chord
Wel=y{8};       %N
ro = y{9}*9.81; %Density of air, converted to N/m3
C_Lmax = y{10}; %Max Coef. of Lift
Vmotor = y{11}; %Motor Voltage

%% Internal Constants
mu  =1.82e-5;% pascal seconds, dynamic vis of air

%% Analysis Begins
energy = (3600)*Vbatt*Cbatt;
Wbatt = energy/zeta;
Wmotor = Pm*chi;


%% Weights
X = 0.5 + 0.05*b;
W0 =(Wbatt + Wel + Wpl + Wmotor)/(1-X);

%% Wing Geometry
S = (2*W0)/(ro*Vmin^2*C_Lmax);
AR =(b^2)/S;
c_bar = S/b;
c_root = (2*c_bar)/(lambda+1);
c_tip = c_root*lambda;
leadingEdgeSweep = atan(b*tan(quarterChord)+(c_root-c_tip)/4)/b;
reynolds = (ro*Vmax*c_bar)/mu;

%% Dynamics
parasiticDrag = 4.98/sqrt(reynolds);

e = 4.61*(1-0.045*(AR^0.68));
K = 1/(pi*e*AR);

%% Performance
powerReq = 0.5*parasiticDrag*ro*Vmax^3*S+(2*K*W0)/(ro*Vmax*S);
powerAvail = mu_m*mu_p*Pm;

%% Takeoff performance

% Range and Capacity
endurance = energy/powerReq;
range = Vmax*endurance;

Wbatt = Wbatt/9.81; %N to kg
%% Outputs
%powerReq = z(1);%in W
```

```
%powerAvail = z(2);% W
%range = z(3);% in km
%AR = z(4);
%Wbatt = z(5)
%reynolds = z(6)
%c_root = z(7)
z = [powerReq, powerAvail, range/1000, AR,Wbatt, reynolds/500e3, c_root];

end
```