Dynamic Soaring: Assignment 3

Izza (AE18B006) &

RV Ramkumar (AE20D025)

Characteristics of the Albatross Species

The different Albatross species and their parameters are tabulated in below mentioned table 1. These data has been pulled out from the reference [1]. From these parameters and along with the drag polar of the birds it is possible to find the various glide characteristics. Further, the maximum lift coefficient $C_{L_{\max}}$ is assumed as 1.3 for all the bird species.

Table 1: Parameters of Albatross Species

Species	Mass (kg)	Span (m)	Wing Area (S)	W/S (N/m^2)	AR
Wandering Albatross (WAN)	8.73	3.03	0.611	140	15
Black Blowed Albatross (BBA)	3.79	2.16	0.356	104	13.1
Grey Headed Albatross (GHA)	3.79	2.18	0.352	106	13.5
Light Mantled Sooty Albatross (STY)	2.84	2.18	0.338	82.4	14.1
Giant Petrel (MAC)	5.19	1.99	0.331	154	12
White Chinned Petrel (WCP)	1.37	1.4	0.169	79.5	11.6
Cape Pigeon (CAP)	0.433	0.875	0.0773	55	9.9
Dove Prion (PRN)	0.168	0.626	0.046	35.8	8.52
Wilson's Petrel (WIL)	0.038	0.393	0.0192	19.4	8.04

Stall Characteristics

The stall speed is the minimum speed at which the the bird can sustain the weight by generating aerodynamic lift without flapping. This implies flying at the Maximum lift coefficient $C_{L_{\max}}$ such that the lift generated by wings balances the weight. The equation for estimation of the stall speed is given by equation (1):

$$L = W \implies C_{L_{\max}} \frac{1}{2}\rho V_{\text{stall}}^2 S = W \implies V_{\text{stall}} = \sqrt{\frac{2(W/S)}{\rho C_{L_{\max}}}} \tag{1}$$

where (W/S) is the Wing Loading of the bird (N/m^2), ρ is the density and assumed to be constant at sea level $(1.225 kg/m^3)$. From the relationship, it is evident that the stall speed is a function of wing loading for a given altitude. The calculated V_{stall} for each of the species is indicated in the table 2.

Table 2: Species and their V_{stall}

Species	W/S (N/m^2)	$V_{\text{stall}}(m/s)$
WAN	140	13.2599
BBA	104	11.4286
GHA	106	11.5379
STY	82.4	10.1728
MAC	154	13.9071
WCP	79.5	9.9921
CAP	55	8.3111
PRN	35.8	6.7053
WIL	19.4	4.9360

Drag Polar

The parasitic drag coefficient is assumed to be C_{D_0}=0.024 from the reference [2] for the case of vulture considering the low Reynolds number of the flight. The lift induced drag coefficient factor is assumed to be corresponding to the elliptic wing (efficiency = 1.0) and hence $K = 1.0/(\pi AR)$. For all the birds according to their aspect ratio, the drag polar is found:

$$C_D = 0.024 + \frac{1}{\pi AR} C_L^2 \tag{2}$$

Glide Polar

The Glide polar of any bird / airplane is the plot between the air speed (x-axis) and the sink speed/Vertical speed (y-axis) considering a steady gliding flight (where the force balance is established). From this plot, it is possible to figure out the minimum sink speed as well as best glide angle and gliding speed. The various equations are as follows:

$$\dot{z} = \frac{dh}{dt} = V \sin\gamma$$
$$m\frac{dV}{dt} = -D - mg\sin\gamma$$

Considering a steady flight,

$$-V\sin\gamma = \frac{DV}{W}$$

In view of the rate of sink $V_s = -V\sin\gamma$, the above equation can be written as

$$V_s = \frac{DV}{W} = \frac{C_D \frac{1}{2}\rho V^3}{(W/S)}$$

C_D is a function of C_L and the relationship is called the drag polar which is explained in the previous section including the one assumed for all the albatross species enlisted in the table (1). The minimum sink speed can be directly obtained. However, the best gliding speed is the tangent from the origin to the curve or where the maximum aerodynamic efficiency $(L/D)_{\text{max}}$ is achieved.

The glide polar for the wandering albatross (WAN) is given in figure (1). The blue circle in the glide polar indicates the best glide speed and the flattest glide i.e. minimum glide angle. This also indicates the speed where the range can be maximized. For the Wandering albatross the speed for the flattest glide is 14.59 m/s and the glide angle (γ) is 2.59 deg. The sink speed corresponding to this point is found to be 0.6628 m/s.

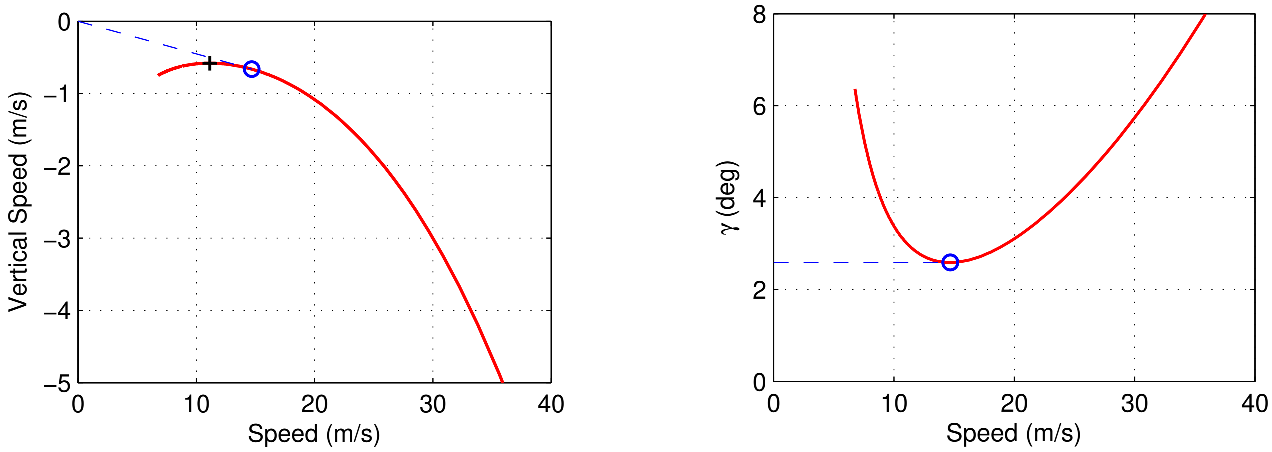

Figure 1: Glide Polar of Wandering Albatross

If there is an updraft speed of at least 0.6628 m/s to compensate for the sink speed, then the bird will be flying without losing altitude and the range of the bird will be infinite. At this point the force balance is completely achieved.

Similar calculations are performed for all the bird species and the table below indicate the best glide angle, best gliding speed and the minimum updraft required for the bird to fly without loosing altitude.

Table 3: Albatross Species and their Glide Parameters

Species	W/S (N/m^2)	V_{stall} (m/s)	γ_{max_R} (deg)	V_{best} (m/s)	Min V_w for R_∞ (m/s)
WAN	140	13.26	2.59	14.59	0.663
BBA	104	11.43	2.77	13.03	0.629
GHA	106	11.54	2.73	13.16	0.626
STY	82.4	10.17	2.67	11.37	0.530
MAC	154	13.91	2.89	16.18	0.817
WCP	79.5	9.99	2.94	11.75	0.603
CAP	55	8.31	3.19	10.22	0.568
PRN	35.8	6.71	3.43	8.55	0.512
WIL	19.4	4.94	3.53	6.37	0.393

The figures 2 and 3 indicate the glide polar of the different species and the speed where the flight path angle is minimum (flattest glide / best glide speed) respectively.

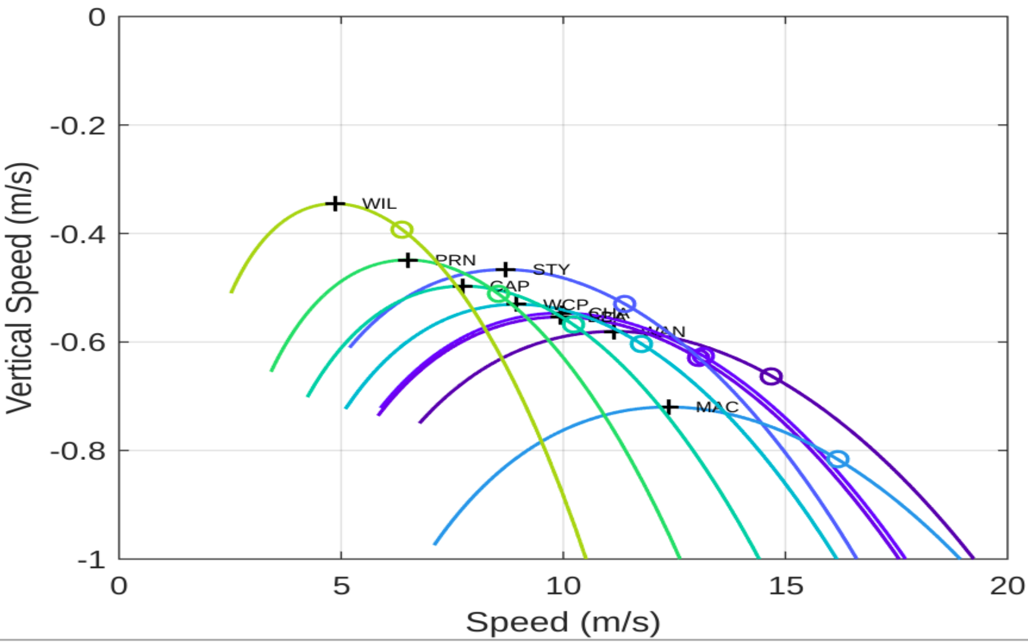

Figure 2: Glide Polars of Different Species

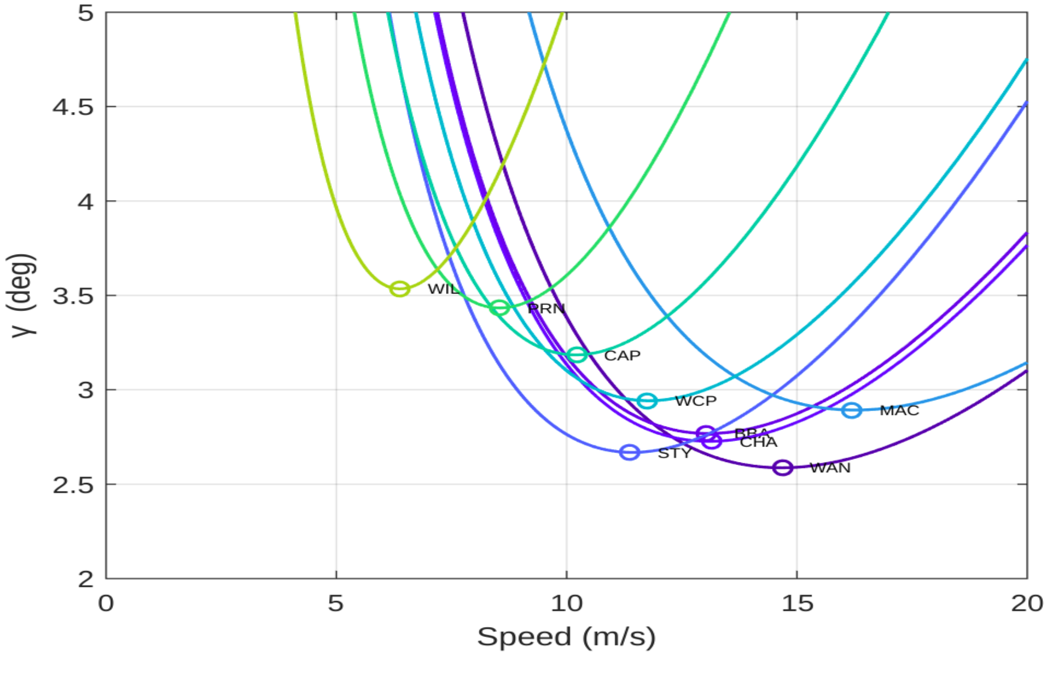

Figure 3: Speed Vs Flight Path Angle of Different Species

References

[1] Colin James Pennycuick. The flight of Petrels and Albatrosses (Procellariiformes), Observed in South Georgia and its Vicinity. *Philosophical Transactions of the Royal Society of Londa. B, Biological Sciences,* 300 (1098): 75-106, 1982.

[2] Philip C. Withers. An Aerodynamic analysis of bird wings as fixed aerofoils. *Journal of Experimental Biology,* 90(1): 143-162, 1981

Matlab Program

```
clear all; close all; clc;

%% Mass Span Wing_Area Wing_Loading Disc_Loading AR Sh_spacing

bird =[8.73    3.03    0.611   140     11.9    15     130;
    3.79    2.16    0.356   104     10.1    13.1    100;
    3.79    2.18    0.352   106     9.96    13.5    100;
    2.84    2.18    0.338   82.4    7.46    14.1    100;
    5.19    1.99    0.331   154     16.4    12.0    100;
    1.37    1.40    0.169   79.5    8.73    11.6    60;
    0.433   0.875   0.0773  55      7.06    9.9     36;
    0.168   0.626   0.046   35.8    5.35    8.52    24;
    0.038   0.393   0.0192  19.4    3.07    8.04    15];

mass= bird(:,1);    b = bird(:,2);      S = bird(:,3);
WbyS = bird(:,4);   AR = bird(:,6);
jmax=size(bird);
rho = 1.225; CLmax=1.3;
for j=1:jmax
    vstall(j) = sqrt(2*WbyS(j)/(rho*CLmax));
end
%% for minimum glide angle one must have to find the max CL/CD;
CD0 = 0.024;
% CD0 = 0.01;
cl=0.1:0.02:5.0;
imax = size(cl,2);
for j=1:jmax
    for i=1:imax
        vel(i,j) = sqrt(2*WbyS(j)/(rho*cl(i)));
        cd1(i) = CD0 + 1/(pi*AR(j))*cl(i)^2;
        DVbyW(i,j) = (cd1(i)*0.5*rho*vel(i,j)^3)/(WbyS(j)); %sink speed;
        lbyd(i,j) = vel(i,j)/DVbyW(i,j);
        clcd(i,j) = cl(i)/cd1(i);
        gama(i,j) = asin(1.0/lbyd(i,j));
    end
end

%id1 = find((DVbyW(:,1))<=min(DVbyW(:,1)));
%id2 = find(clcd(:,1)==max(clcd(:,1)));
```

```
%data1 = [gama(id2,1)*180/pi vel(id2,1) DVbyW(id2,1)]

c_map = parula(12)
for i=1:jmax
    id1 = find((DVbyW(:,i))<=min(DVbyW(:,i)));
    id2 = find(clcd(:,i)==max(clcd(:,i)));
    data1 = [gama(id2,i)*180/pi vel(id2,i) DVbyW(id2,i)];
    figure(3)
    plot (vel(:,i),-DVbyW(:,i),'-','LineWidth',1.2 ,'Color',c_map(i,:)); grid on; hold on;
    xlabel ('Speed (m/s)');
    ylabel ('Vertical Speed (m/s)');
    plot (vel(id1,i),-DVbyW(id1,i),'k+','LineWidth',1.2);
    plot (vel(id2,i),-DVbyW(id2,i),'o','LineWidth',1.2, 'Color',c_map(i,:));hold on;
    %plot (vel(id2,i),gama(id2,1)*180/pi,'o','LineWidth',1.2, 'Color',c_map(i,:));hold on;
    %xlim([0 20]); ylim([-1 -0.3]);
    labels = {'WAN', 'BBA','CHA','STY','MAC','WCP','CAP','PRN','WIL'};
    labelpoints2(vel(id1,i),-DVbyW(id1,i), labels(i) , 'E', 0.3, 1, 'FontSize' , 6);
    %labelpoints2(vel(id1,i),gama(id2,i)*180/pi, labels(i) , 'E', 0.3, 1, 'FontSize' , 6);
end
figure(1);subplot(2,2,1)
plot (vel(:,1),-DVbyW(:,1),'r-','LineWidth',1.3); grid on;
xlabel ('Speed (m/s)');
ylabel ('Vertical Speed (m/s)'); hold on;
plot (vel(id1,1),-DVbyW(id1,1),'k+','LineWidth',1.2);
plot (vel(id2,1),-DVbyW(id2,1),'bo','LineWidth',1.2);
x1=[0; vel(id2,1)]; y1 = [0;-DVbyW(id2,1)];
plot(x1,y1,'b--'); ylim([-5 0]); xlim([0 40]);
print -depsc 'glide_polar.eps'

figure(2); subplot (2,2,1);
plot (vel(:,1),gama(:,1)*180/pi,'r-','LineWidth',1.2); grid on; hold on;
xlabel ('Speed (m/s)');
ylabel ('\gamma (deg)');
plot (vel(id2,1),gama(id2,1)*180/pi,'bo','LineWidth',1.2);
xlim([0 40]); ylim([0 8]);
x2=[0;vel(id2,1)]; y2=[gama(id2,1)*180/pi;gama(id2,1)*180/pi];
plot (x2,y2,'b--');
print -depsc 'gama_speed.eps'
```