# Drag Calculator

MAE 158 Prof. Huynh
Shashwat Sparsh
21697442

12 March 2022

Constants

$t/c_w = 0.18$

$\Lambda_{c/4} = 28°$

$L_f = 105$

$D_f = 11$

# Drag Calculation Process & Hand Calculations

Calculating the total drag on an aircraft in steady level flight requires solving for the Coefficient of Drag, $C_D$, which in turn is calculated by summing the Coefficients of Induced and Parasitic Drag, $C_{DI}$ and $C_{DP}$ respectively. These are summarized in equations 1 and 2. As a result, it is convenient to compute the two coefficients separately which can then be plugged to derive the Parasitic Drag and the Induced Drag individually. These are summarized in equations 3 and 4.

| | |
|---|---|
| (1) | $D_{Total} = 0.5\rho V^2 * S * C_{DTotal}$ |
| (2) | $C_{DTotal} = C_{DI} + C_{DP}$ |
| (3) | $D_P = 0.5\rho V^2 * S * C_{DP}$ |
| (4) | $C_{DP} = 1.1\frac{\sum_{i=1}^{n = number\ of\ components} f}{Sref} = \frac{f_{wing} + f_{horizontal\ tail} + f_{vertical\ tail} + f_{pylon} + f_{fuselage} + f_{nacelle}}{Sref}$ |
| (5) | $D_I = 0.5\rho V^2 * S * C_{DI}$ |
| (6) | $C_{DI} = \frac{C_L^2}{\pi * AR_W * e}$ |

# Parasitic Drag

The Coefficient of Parasitic Drag can be calculated by summing the individual <f> components for each part of the aircraft and then dividing by the reference area. The general form for f is given in equation 6 where K is the form factor, $C_f$ is the skin friction coefficient, and Swet is the wetted surface area of the component.

| | |
|---|---|
| (7) | $f = K * C_f * Swet$ |
| (8) | $Swet = 2 * 1.02 * Sexp$ |
| (9) | $Sexp = (1 - \%WingCovered) * Sref$<br>This equation is only used for getting Sexp for the wing |
| (10) | $C_f = \frac{0.455}{(log_{10}(RN))^{2.58}}$ |
| (11) | $RN = \frac{\rho * V * L_c}{\mu}$ |

| | |
|---|---|
| (12) | $MACexp = (2/3) * (c_{Rexp} + c_T - \frac{(c_{Rexp} * c_T)}{(c_{Rexp} + c_T)})$ |
| (13) | $c_{Rexp} = c_R - ((c_R - c_T) * (2 * \frac{y}{b}))$<br>This equation is only used for the wing |
| (14) | $K_{wing, tail, pylon} = 1 + (Z * t/c) + (100 * t/c^4)$ |
| (15) | $Z = \frac{(2 - M_o^2) * cos(\Lambda)}{\sqrt{1 - (M_o^2 cos(\Lambda))}}$ |
| (16) | $K_{fuse, nacelles} = (1.991 * (\frac{L}{D})^{-1.024}) + 0.9084$<br>This equation is created via digitizing Figure 11.14 |

## Atmospheric Conditions and Results

| Given | |
|---|---|
| Variable | Value |
| R | 1716 |
| T | 400°R |
| γ | 1.4 |

| Getting Mach Number |
|---|
| $M = \frac{v}{\sqrt{\gamma RT}} = \frac{765}{\sqrt{1.4*1716*400}} = 0.780$ |

## Wing

| Given | |
|---|---|
| Variable | Value |
| b | 93.2 |
| tc | 0.18 |
| Λ | 28° |

| | |
|---|---|
| σ | 0.2 |
| $c_R$ | 17.8 |
| $R_{fuse}$ | 11/2 |
| Wing coverage | .17 |
| Sref | 1000 |

| Getting the Wetted Surface Area |
|---|
| $Swet = 2 * 1.02 * ((1 - 0.17) * Sref) = 1693.2$ |

| Getting Characteristic Length |
|---|
| $c_T = \sigma * c_R = 0.2 * 17.8 = 3.56$ |
| $c_{Rexp} = 17.8 - ((17.8 - 3.56) * (2 * \frac{11/2}{93.2})) = 16.1193$ |
| $MACexp = (2/3) * (16.1193 + 3.56 - \frac{(16.1193*3.56)}{(16.1193+3.56)}) = 11.1755$ |

| Calculating the Reynolds Number |
|---|
| $RN = \frac{.0008754*765*11.1755}{3.025E^{-7}} = 2.474E^{7}$ |

| Coefficient of Skin Friction |
|---|
| $C_f = \frac{0.455}{(log_{10}(2.47E^{7}))^{2.58}} =.0026$ |

| Getting Form Factor |
|---|
| $K_{wing} = 1 + (\frac{(2-.7804^{2})*cos(28)}{\sqrt{1-(.7804^{2}cos(28))}} * 0.18) + (100 * .18^{4}) = 1.43$ |

| Getting f |
|---|

| $f_{wing} = 1.43 * .0026 * 1693.2 = 6.3165$ |
|---|

## Horizontal Tail

| Given | |
|---|---|
| Variable | Value |
| Sexp | 261 |
| tc | 0.09 |
| Λ | 31.6° |
| σ | 0.35 |
| $c_R$ | 11.1 |

| Getting the Wetted Surface Area |
|---|
| $Swet = 2 * 1.02 * 261 = 532.44$ |

| Getting Characteristic Length |
|---|
| $c_T = \sigma * c_R = 0.35 * 11.1 = 3.885$ |
| $MACexp = (2/3) * (11.1 + 3.885 - \frac{(11.1*3.885)}{(11.1+3.885)}) = 8.0715$ |

| Calculating the Reynolds Number |
|---|
| $RN = \frac{.0008754*765*8.0175}{3.025E^{-7}} = 1.7869E^{7}$ |

| Coefficient of Skin Friction |
|---|
| $C_f = \frac{0.455}{(log_{10}(1.7869E^{7}))^{2.58}} =.0027417$ |

| Getting Form Factor |
|---|

| |
|---|
| $K_{horiz.\ tail} = 1 + (\frac{(2-.7804^2)*cos(31.6)}{\sqrt{1-(.7804^2cos(31.6))}} * 0.09) + (100 * .09^4) = 1.1603$ |

| Getting f |
|---|
| $f_{horiz.\ tail} = 1.1603 *.0027417 * 532.44 = 1.6937$ |

## Vertical Tail

| Given | |
|---|---|
| Variable | Value |
| Sexp | 161 |
| tc | 0.09 |
| Λ | 43.5° |
| σ | 0.8 |
| $c_R$ | 15.5 |

| Getting the Wetted Surface Area |
|---|
| $Swet = 2 * 1.02 * 161 = 328.44$ |

| Getting Characteristic Length |
|---|
| $c_T = \sigma * c_R = 0.8 * 15.5 = 12.4$ |
| $MACexp = (2/3) * (15.5 + 12.4 - \frac{(15.5*12.4)}{(15.5+12.4)}) = 14.007$ |

| Calculating the Reynolds Number |
|---|
| $RN = \frac{.0008754*765*14.007}{3.025E^{-7}} = 3.101E^7$ |

| Coefficient of Skin Friction |
|---|

| |
|---|
| $C_f = \frac{0.455}{(log_{10}(3.101E^7))^{2.58}} =.0025213$ |

| Getting Form Factor |
|---|
| $K_{vert.tail} = 1 + (\frac{(2-.7804^2)*cos(43.5)}{\sqrt{1-(.7804^2 cos(43.5))}} * 0.09) + (100 * .09^4) = 1.1281$ |

| Getting f |
|---|
| $f_{vert.tail} = 1.1281 *.0025213 * 328.44 =.9347$ |

## Pylon

| Given | |
|---|---|
| Variable | Value |
| Swet | 117 |
| tc | 0.06 |
| Λ | 0° |
| Lpylon | 16.2 |

| Calculating the Reynolds Number |
|---|
| $RN = \frac{.0008754*765*16.2}{3.025E^{-7}} = 3.5864E^7$ |

| Coefficient of Skin Friction |
|---|
| $C_f = \frac{0.455}{(log_{10}(3.5864E^7))^{2.58}} =.0024673$ |

| Getting Form Factor |
|---|
| $K_{pylon} = 1 + (\frac{(2-.7804^2)*cos(0)}{\sqrt{1-(.7804^2 cos(0))}} * 0.06) + (100 * .06^4) = 1.1348$ |

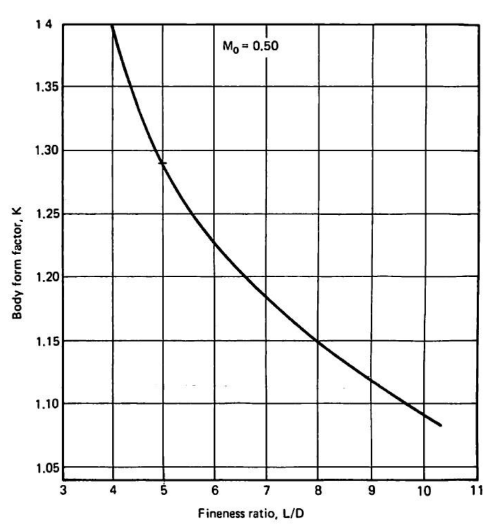
| Getting f |
| --- |
| $f_{pylon} = 1.1348 * .00254673 * 117 = 0.32757$ |

## Nacelles

| Given | |
| --- | --- |
| Variable | Value |
| Swet | 455 |
| $L_{nacelle}$ | 16.8 |
| $R_{fineness}$ | 5 |

| Calculating the Reynolds Number |
| --- |
| $RN = \frac{.0008754*765*16.8}{3.025E^{-7}} = 3.7192E^{7}$ |

| Coefficient of Skin Friction |
| --- |
| $C_f = \frac{0.455}{(log_{10}(3.7192E^{7}))^{2.58}} =.002454$ |

| Getting Form Factor |
| --- |
|  |

| $K_{nacelles} = 1.2915$ |
|---|

| Getting f |
|---|
| $f_{nacelles} = 1.2915 *.002454 * 455 = 1.4421$ |

## Fuselage

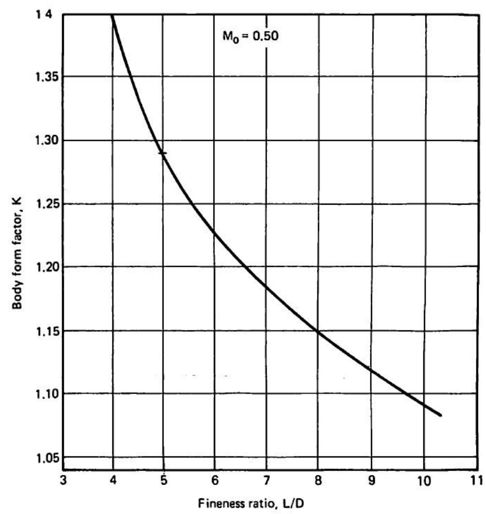
| Given | |
|---|---|
| Variable | Value |
| Lf | 105 |
| Df | 11 |

| Getting the Wetted Surface Area |
|---|
| $Swet = 0.8 * \pi * 105 * 11 = 2902.83$ |

| Calculating the Reynolds Number |
|---|
| $RN = \frac{.0008754*765*105}{3.025E^{-7}} = 2.3245E^{8}$ |

| Coefficient of Skin Friction |
|---|
| $C_f = \frac{0.455}{(log_{10}(2.3245E^{8}))^{2.58}} =.0018961$ |

| Getting Form Factor |
|---|




$$K_{fuselage} = 1.11$$

| Getting f |
|---|
| $f_{fuselage} = 1.11 * .00189 * 2902.832 = 6.0876$ |

Total Parasitic Drag

| Getting CDP Total |
|---|
| $C_{DP} = 1.1 * \frac{f_{wing} + f_{horizontal\ tail} + f_{vertical\ tail} + f_{pylon} + f_{fuselage} + f_{nacelle}}{Sref} = .0185$ |

| Getting Total Parasitic Drag |
|---|
| $D_P = 0.5 * .0008754 * 765^2 * 1000 * .0185 = 4.73E^3$ |

# Induced Drag

The Coefficient of Induced Drag can be calculated using the Lifting Theory as can be seen in equation 6. The Lift can be equated to the Weight due to the cruise flight conditions. The aspect ratio can be derived from the given wing specifications. Finally the Oswald Efficiency factor can be derived using chart 11.8; for the purposes of the software, the chart was digitized to create 4 distinct curves corresponding to the varying $C_{DP}$'s. The appropriate equation was chosen by rounding a given $C_{DP}$ to the closest 2 decimal points and filtered through an if statement to then utilize the appropriate curve.

| Given | |
|---|---|
| Variable | Value |
| W | 98000 |
| $b_{Wing}$ | 93.2 |
| Sref | 1000 |

| Getting $C_L$ | |
|---|---|
| | $L = W = 98000$ |
| | $Q = 0.5\rho V^2 = 0.5 * .0008754 * 765^2 = 256.1530$ |
| (17) | $C_L = \frac{W}{Q*Sref} = \frac{98000}{256.1530*1000} = 0.3826$ |

| Getting $AR_W$ |
|---|
| $AR_w = \frac{b^2}{Sref} = \frac{93.2^2}{1000} = 8.682$ |

Getting Oswald Efficiency Factor

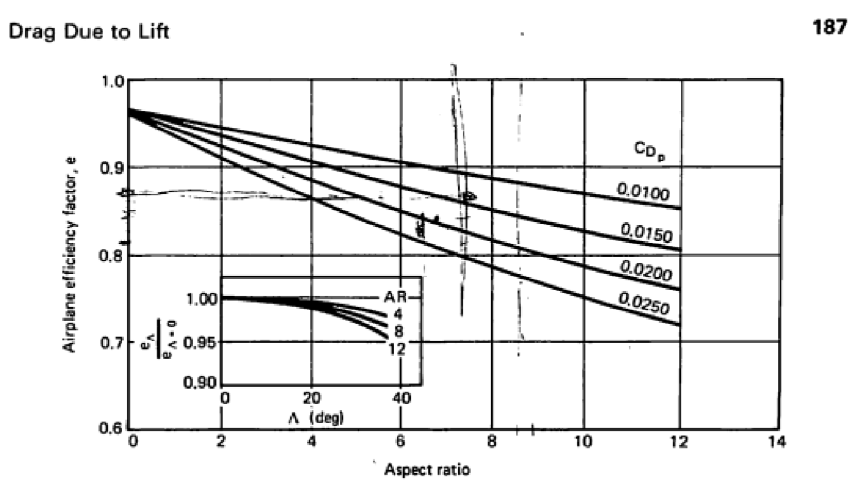



Figure 11.8 Airplane efficiency factor, e.

| $C_{DP} = .0185 \Rightarrow e = 0.8049$ |
|---|

| Calculating $C_{DI}$ |
|---|
| $C_{DI} = \frac{0.3826^2}{\pi * 8.682 * 0.8049} = .0067$ |

## Total Drag and Lift to Drag Ratio

The Total Drag can be calculated by using equation 1 and the total Drag Coefficient defined by equation 2. Based on the flight conditions as mentioned earlier, weight and lift are equal and the Lift to Drag ratio can be calculated.

| Getting Total Drag |
|---|
| $C_{DTotal} = .0067 + .0185 = .0251$ |
| $D_{Total} = 0.5 * .000854 * 765^2 * 1000 * .0251 = 6.441E^3 pounds$ |

| Lift to Drag Ratio |
|---|
| $\frac{L}{D} = \frac{W}{D} = \frac{98000}{6441} = 15.2147$ |

## Tabularized Data for V = 765ft/s

| Component | Leff | Re | Cf | K | Swet | CDP |
|---|---|---|---|---|---|---|
| **Wing** | 11.1755 | 2.474E7 | 0.0026085 | 1.4301 | 1693.2 | 6.3165/1000 |
| **Fuselage** | 105 | 2.325E8 | 0.0018961 | 1.106 | 2902.8316 | 6.0876/1000 |
| **H. Tail** | 8.0715 | 1.787E7 | 0.0027417 | 1.1603 | 532.44 | 1.6937/1000 |
| **V. Tail** | 14.0074 | 3.101E7 | 0.0025213 | 1.1281 | 328.44 | 0.93417/1000 |
| **Pylon** | 16.2 | 3.586E7 | 0.0024673 | 1.1348 | 117 | 0.32757/1000 |
| **Nacelles** | 16.8 | 3.719E7 | 0.002454 | 1.2915 | 455 | 1.4421/1000 |

Matlab Plots:

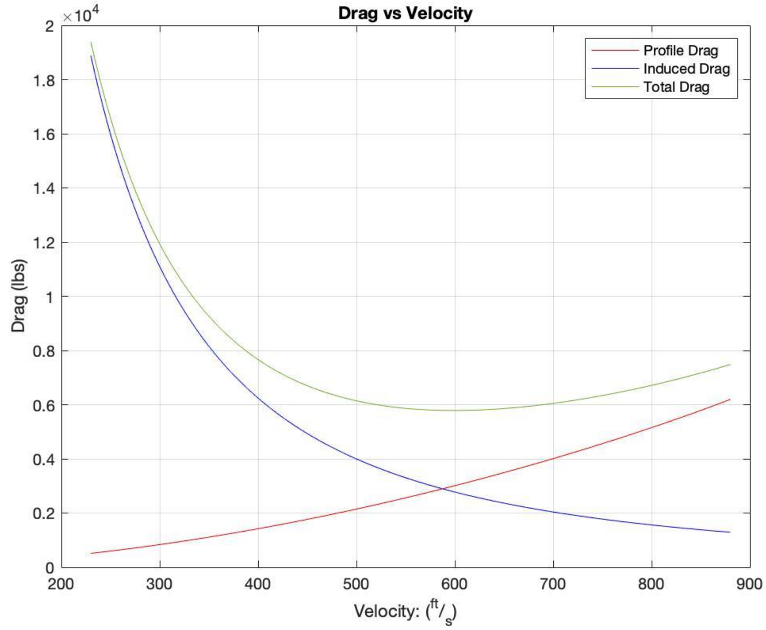



Figure 1: Drag vs Velocity

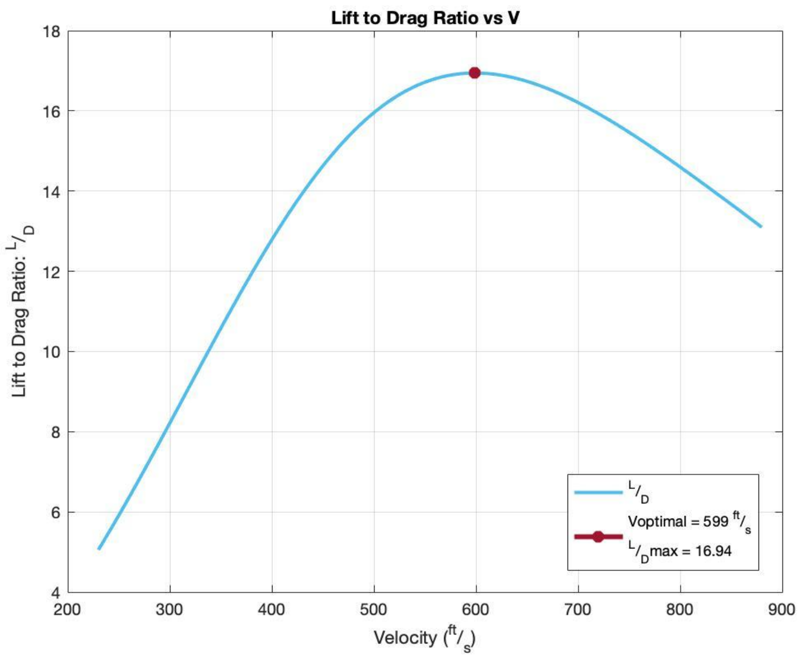



Figure 2: Lift to Drag Ratio vs Velocity

Based on the generated plots, the optimal Velocity to fly at occurs where the Lift to Drag ratio is maxed in Figure 2. Therefore the optimal Velocity is 599 ft/s which occurs at the max Lift to Drag Ratio of 16.94.

## Conclusion

The Parasitic Drag and Induced Drag are inversely proportional. Parasitic Drag increases with the airspeed while Induced Drag decreases. Parasitic Drag is due to the fluid interactions along the various components of the aircraft, e.g. fuselage, wings, tails, etc. It is proportional to the dynamic pressure as can be seen in equation 3. This is graphically showcased in figure 1 with the profile drag curve in red. The Induced Drag is inversely proportional to the dynamic pressure because it is proportional to $C_L$ which is inversely proportional to dynamic pressure as can be seen in equation 17. This expression is squared in the calculation of $C_{DI}$ which is showcased in equation 6. This relationship is graphically showcased in figure 1 with the induced drag curve in blue creating a dip. Summing the two curves to create the total Drag curve in green creates a bowl shaped space.

In order to maximize the optimal velocity, the Parasitic Drag needs to be reduced. A lower Parasitic Drag Curve would intersect with the Induced Velocity Curve at a higher velocity at which the total Drag would be minimal as can be seen in figure 1. This is also where the L/D maximizes as the Lift remains constant while Drag would decrease which would then correspond to a more optimal velocity in figure 2.

## Appendix: MATLAB Code

This code was written as a live script. For convenience, it has been generated as a .m and .pdf file in addition to the live script .mlx format. The code can also be found on my Github along with all the relevant files used to generate the digitized curves, plots, and tables.

MAE 158 Drag Calculator
Shashwat Sparsh
ID: 21697442

**Profile Drag Coeff**

*Setup*

```
hp_aircraft = 1;
T = 400;
%P = 1;  % via Table  A.2
R = 1716;
rho = 0.0008754;
speedSound = sqrt(1.4*R*T);
V = [230:1:880];        %765;
M = V/speedSound;    % Mach Number
Sref = 1000;
```

```
%% Characteristic Lengths
MACexpW = 0;
MACexpH = 0;
MACexpV = 0;
%Lc = [MACexpW, MACexph, MACexpv, 16.2, 16.8];
Lc = []; %Charactersitic Lengths

%% Ratios
Lf = 119;
Df = 11;
ratios = [0.12, 0.09, 0.09, 0.06, Lf/Df, 5]  % Thickness and Fineness
sigma = [0.2, 0.35, 0.8, 1]; % Taper
%% Sexp
Sexpw = 0;  % Defined Later on
Sexp = [Sexpw, 261, 161];
%% Swet
Swet = [0, 0, 0, 117, 0, 455];
```

*Calculations*

**Component 1 Wing**

```
bW = 93.2;                  % Span
tcW = 0.18;
sweepangleW = 28;           % Sweep Angle
sigmaW = 0.2;               % Taper Ratio: cT/cR
CRW = 17.8;                 % Root Chord
Coverage_wing = .17;        % Percent Covered
Rfuse = 11/2;

% Getting Swet %
SexpW = (1-Coverage_wing)*Sref;
SwetW = SWET(SexpW);

% Getting Skin Friction Coefficient %
CTW = sigmaW * CRW;
CRexp_wing = CREXP(CRW, CTW, Rfuse, bW);
MACexpW = MAC(CRexp_wing,CTW);
Lc = [Lc, MACexpW];

RNw = ReynoldsNumber(V, MACexpW);
Cf_w = CF(RNw);
```

```
% Getting Form Factor %
Kwing = Kairfoil(tcW, M, sweepangleW);

% Calculating f and adding to array %
fwing = F(Kwing, Cf_w, SwetW);
```

**Horizontal Tail**

```
SexpH = 261;
tcH = 0.09;
sweepangleH = 31.6;         % Sweep Angle
sigmaH = 0.35;              % Wing Taper Ratio
CRH = 11.1;                 % Root Chord

% Getting Swet %
SwetH = SWET(SexpH);

% Getting Skin Friction Coefficient %
CTH = sigmaH * CRH;
MACexpH = MAC(CRH,CTH);
Lc = [Lc, MACexpH];

RNh = ReynoldsNumber(V, MACexpH);
Cf_h = CF(RNh);

% Getting Form Factor %
Khoriztail = Kairfoil(tcH, M, sweepangleH);

% Calculating f and adding to array %
fhoriztail = F(Khoriztail, Cf_h, SwetH);
```

**Vertical Tail**

```
SexpV = 161;
tcV = 0.09;
sweepangleV = 43.5;         % Sweep Angle
sigmaV = 0.8;               % Wing Taper Ratio
CRV = 15.5;                 % Root Chord

% Getting Swet %
SwetV = SWET(SexpV);
```

```
% Getting Skin Friction Coefficient %
CTV = sigmaV * CRV;
MACexpV = MAC(CRV,CTV);
Lc = [Lc, MACexpV];

RNv = ReynoldsNumber(V, MACexpV);
Cf_v = CF(RNv);

% Getting Form Factor %
Kverttail = Kairfoil(tcV, M, sweepangleV);

% Calculating f and adding to array %
fverttail = F(Kverttail, Cf_v, SwetV);
```

**Pylons**

```
SwetP = 117;                  % Wetted Area
tcP = 0.06;
sweepangleP = 0;              % Sweep Angle
sigmaP = 1;                   % Taper Ratio: cT/cR
chordP = 16.2;                % Chord

% Getting Skin Friction Coefficient %
Lc = [Lc, chordP];
RNp = ReynoldsNumber(V, chordP);
Cf_p = CF(RNp);

% Getting Form Factor %
Kpylon = Kairfoil(tcP, M, sweepangleP);

% Calculating f and adding to array %
fpylon = F(Kpylon, Cf_p, SwetP);
```

**Component 2: Fuselage**

```
Lf = 105;
Df = 11;

% Calculating Swet %
SwetF = 0.8 * pi * Df * Lf;

% Getting Skin Friction Coefficient %
```

```
RNf = ReynoldsNumber(V, Lf);
Lc = [Lc, Lf];
Cf_f = CF(RNf);

% Getting Form Factor %
ratioF = Lf/Df;
Kfuse = KFR(ratioF);          % Via Digitized Figure 11.4

% Calculating f and adding to array %
ffuselage = F(Kfuse, Cf_f, SwetF);
```

**Nacelles**

```
% Swet %
SwetN = 455;

% Getting Skin Friction Coefficient %
Ln = 16.8;
Lc = [Lc, Ln];
RNn = ReynoldsNumber(V, 16.8);
Cf_n = CF(RNn);

% Getting Form Factor %
ratioN = 5;
Knacelle = KFR(ratioN);       % Via Digitized Figure 11.4

% Calculating f and adding to array %
fnacelle = F(Knacelle, Cf_n, SwetN);
```

**Profile Drag Coeff Calculation**

```
ftotal = fwing + fhoriztail + fverttail + fpylon + ffuselage + fnacelle;
CDP_total = 1.10 * ftotal./Sref;
```

**Induced Drag Coeff**

```
% Getting CL %
W = 98000;                 % Aircraft Weight
q = 0.5 * rho * (V.^2);  % Dynamic Pressure
CL = W ./ (q * Sref);   % Coeff of Lift
% Getting Aspect Ratio %
ARw = (bW^2)/Sref;
% Getting CDi %
```

```
efactor = oswaldEff(ARw, CDP_total);         % Oswald Efficiency Factor
e = 1;                                        % Ignore
CDi = (CL.^2) ./ ((pi * ARw) .* efactor);    % Coeff of Induced Drag
```

**Total Drag & Lift/Drag Ratio**

```
ProfileDrag = CDP_total .* q .* Sref;
InducedDrag = CDi .* q .* Sref;
CDtotal = CDP_total + CDi;
TotalDrag = CDtotal .* q .* Sref;
L = W;
LiftToDrag = L ./ TotalDrag;
[LiftToDragMax, index] = max(LiftToDrag)
max(LiftToDrag)
Voptimum = V(index)
```

V = 765 ft/s Information

This section is used to verify the software to the hand calculations

```
indexV765 = find(V==765);
%{
M765 = M(indexV765);
%   Profile Calculation__
%   Wing Data
ChordVals = [CRW, CTW, CRexp_wing, MACexpW];
RNw(indexV765);
Cf_w(indexV765);
%   Horizontal Tail Data
ChordVals = [CRH, CTH, MACexpH];
RNh(indexV765);
%   Vertical Tail Data
ChordVals = [CRV, CTV, MACexpV];
RNv(indexV765);
%   Pylons
RNp(indexV765);
%   Nacelles
RNn(indexV765);
%   Fuselage
RNf(indexV765);
SwetF;
%   Profile Total
CDP_total(indexV765);
```

```
ProfileDrag(indexV765);
%   Induced Calculation__
%   CL
q(indexV765);
CL(indexV765);
ARw;
efactor(indexV765);
CDi(indexV765);
%   Total Calculations__
CDtotal(indexV765);
TotalDrag(indexV765);
LiftToDrag(indexV765);
%}
%   Table Info
ComponentName = ["#", "Component", "Leff", "Re", "Cf", "K", "Swet", "CDP"];
WingValues = ["Wing", MACexpW, RNw(indexV765), Cf_w(indexV765), Kwing(indexV765),
SwetW, fwing(indexV765) + "/1000"];
FuselageValues = ["Fuselage", Lf, RNf(indexV765), Cf_f(indexV765), Kfuse, SwetF,
ffuselage(indexV765) + "/1000"];
HTailValues = ["H. Tail", MACexpH, RNh(indexV765), Cf_h(indexV765),
Khoriztail(indexV765), SwetH, fhoriztail(indexV765) + "/1000"];
VTailValues = ["V. Tail", MACexpV, RNv(indexV765), Cf_v(indexV765),
Kverttail(indexV765), SwetV, fverttail(indexV765) + "/1000"];
PylonValues = ["Pylon", chordP, RNp(indexV765), Cf_p(indexV765), Kpylon(indexV765),
SwetP, fpylon(indexV765) + "/1000"];
NacelleValues = ["Nacelles", Ln, RNn(indexV765), Cf_n(indexV765), Knacelle, SwetN,
fnacelle(indexV765) + "/1000"];
testTable = [WingValues; FuselageValues; HTailValues; VTailValues; PylonValues;
NacelleValues];
FinalTable = array2table(testTable);
FinalTable.Properties.VariableNames(1:7) = {'Component','Leff','Re','Cf','K','Swet','CDP'};
writetable(FinalTable, 'FinalTable.csv');        %   Generate CSV Table

Plots
plot(V, ProfileDrag, 'r', V, InducedDrag, 'b')
hold on;
plot(V, TotalDrag, Color=[0.4660 0.6740 0.1880])
grid on
title("Drag vs Velocity")
ylabel("Drag (lbs)")
```

```
xlabel("Velocity: (^{ft}/_{s})")
legend("Profile Drag", "Induced Drag", "Total Drag")
hold off
plot(V,LiftToDrag, Color=[0.3010 0.7450 0.9330], LineWidth=2)
hold on
%plot(Voptimum, LiftToDragMax, 'Color', 'r', 'Marker','o', 'LineWidth',1)
plot(Voptimum, LiftToDragMax, Color=[0.6350 0.0780 0.1840], Marker="*", LineWidth=3);
grid on
title("Lift to Drag Ratio vs V")
ylabel("Lift to Drag Ratio: ^{L}/_{D}")
xlabel("Velocity (^{ft}/_{s})")
legend("^{L}/_{D}","Voptimal = 599 ^{ft}/_{s}" + newline + "^{L}/_{D}max =
16.94",Location="best")
hold off;
```

Functions

**Reynolds Number Function**

```
function RN = ReynoldsNumber(Velocity, characteristicLength)
    mu = 3.025E-7;
    rho = 0.0008754;
    V = Velocity;
    Lc = characteristicLength;
    RN = (rho * V * Lc)/mu;
end
```

**Swet Function**

```
function Swet = SWET(Sexp)
    Swet = 2 * 1.02 * Sexp;
end
```

**MAC Function**

```
function cbar = MAC(cR, cT)
    cbar= (2/3) * (cR + cT - ((cR*cT)/(cR+cT)));
end
```

**CR Exposed Function**

```
function crexp = CREXP(cR, cT, y, b)
    crexp = cR - ((cR- cT)*(2*(y/b)));
end
```

**Skin Friction Coefficient**

```
function Cf = CF(RN)
    Cf = 0.455 ./ ((log10(RN)).^2.58);
end
```

**Form Factor for Airfoils**

```
function K = Kairfoil(tc, Mo, sweepAngle)
    numTerm = (2-Mo.^2) * cosd(sweepAngle);
    denTerm = sqrt(1-((Mo.^2)*cosd(sweepAngle)));
    Z = numTerm./denTerm;
    K = 1 + (Z .* tc) + (100*tc^4);
end
```

**Form Factor via Fineness Ratio**

```
function K = KFR(LbyD)
    K = 1.991*LbyD^-1.024+0.9084;
    % General model Power2:
    % Coefficients (with 95% confidence bounds):
    %       a =     1.991  (1.882, 2.101)
    %       b =     -1.024  (-1.091, -0.9582)
    %       c =     0.9084  (0.8888, 0.9279)
end
```

**F Function**

```
function f = F(K, Cf, Swet)
    f = K .* Cf * Swet;
end
```

**Oswald Efficiency Function**

```
function e = oswaldEff(ARW, CDP)
    e = [];
    for N = 1:length(CDP)
    CDProunded = round(CDP(N),2);   % Skips Interpolation
    switch CDProunded
    case .01
        e = [e, .000114*ARW^2 - .01085*ARW + .9659];          % e vs ARw, CDP =
.01
    case .015
```

```
            e = [e, (2.5e-05)*ARW^3 - .0002244*ARW^2 - .01422*ARW + .9649];     % e vs
ARw, CDP = .015
        case  .02
            e = [e, .000364*ARW^2 - .02149*ARW + .9641];    % e vs ARw, CDP = .02
        case .025
            e = [e, (-6.849e-06)*ARW^3 + .0006443*ARW^2 - .0269*ARW + .9614];   % e
vs ARw, CDP = .025
        end
        end
end

%% Digitized Curved Results for Oswald Efficiency Factor %%
%{
        CDP = .01
        f(x) = p1*x^2 + p2*x + p3
        Coefficients (with 95% confidence bounds):
        p1 =     0.000114  (0.000103, 0.0001251)
        p2 =     -0.01085  (-0.01099, -0.01071)
        p3 =     0.9659  (0.9655, 0.9663)
%}
%{
        CDP = .015
        f(x) = p1*x^3 + p2*x^2 + p3*x + p4
        Coefficients (with 95% confidence bounds):
        p1 =     2.5e-05  (1.971e-05, 3.03e-05)
        p2 =  -0.0002244  (-0.0003207, -0.0001281)
        p3 =     -0.01422  (-0.01471, -0.01373)
        p4 =     0.9649  (0.9642, 0.9655)
%}
%{
        CDP = .02
        f(x) = p1*x^2 + p2*x + p3
        Coefficients (with 95% confidence bounds):
        p1 =     0.000364  (0.0003456, 0.0003824)
        p2 =     -0.02149  (-0.02171, -0.02126)
        p3 =     0.9641  (0.9635, 0.9647)
%}
%{
        CDP = .025
        f(x) = p1*x^3 + p2*x^2 + p3*x + p4
```

```
      Coefficients (with 95% confidence bounds):
      p1 =  -6.849e-06  (-1.049e-05, -3.207e-06)
      p2 =   0.0006443  (0.0005786, 0.0007101)
      p3 =     -0.0269  (-0.02723, -0.02656)
      p4 =      0.9614  (0.961, 0.9619)
%}
```