Wing Aerodynamics

ES100

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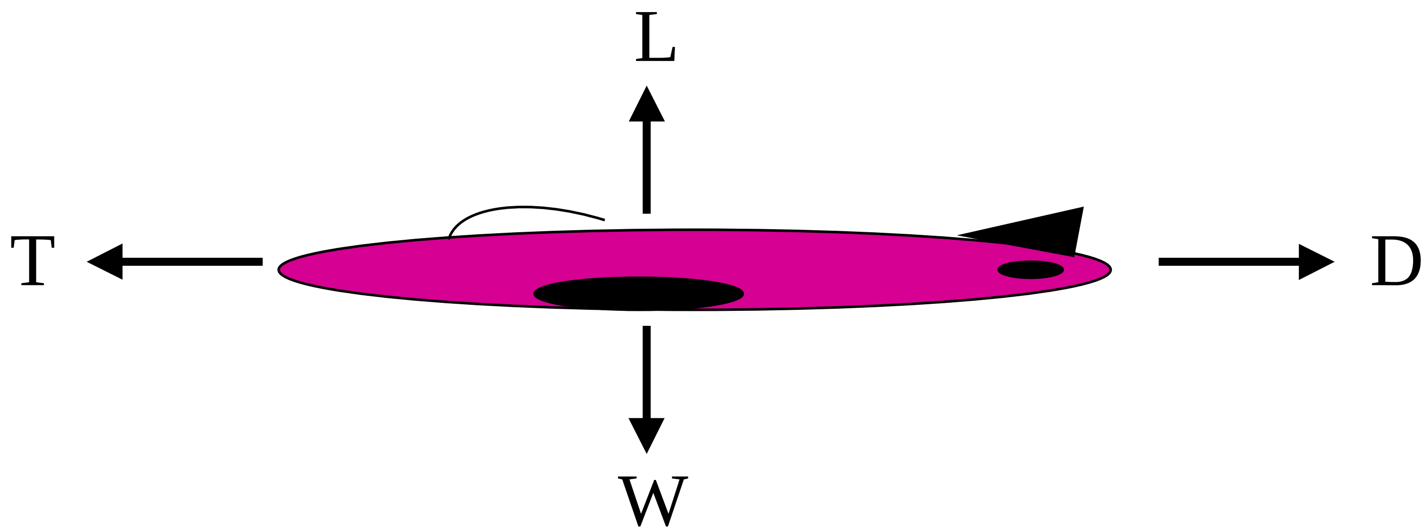
Topics

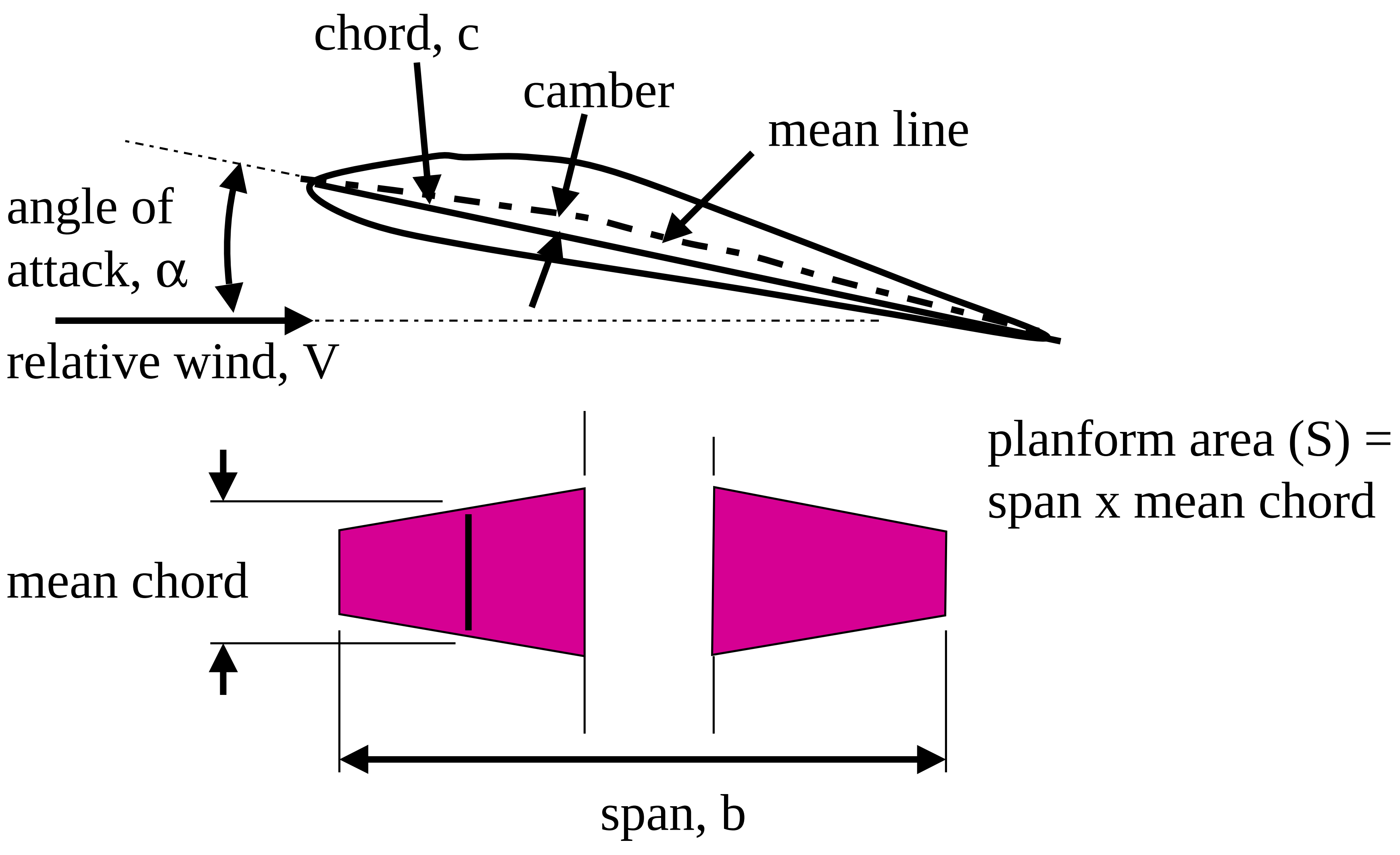
- Wind tunnel experiment arrangements
- Airplane in steady, level flight
- Some wing geometry
- Lift and drag
- Measuring lift and drag in a wind tunnel
- Utility of model tests
- Data reduction program LIFTDRAG.M

Airplane in Steady, Level Flight

- Equilibrium requires T = D and L = W



Wing Geometry



Lift Coefficient of Wing

lift coefficient

$$c_L = \frac{L}{S\,\frac{1}{2}\rho V^2}$$

lift force

planform area

air density

relative air speed

$$\frac{N}{(m^2)\left(\frac{N}{m^2}\right)} \Rightarrow$$ c_L is dimensionless

Drag Coefficient of Wing

drag coefficient

drag force

$$c_D = \frac{D}{S\,\frac{1}{2}\rho V^2}$$

planform area

air density

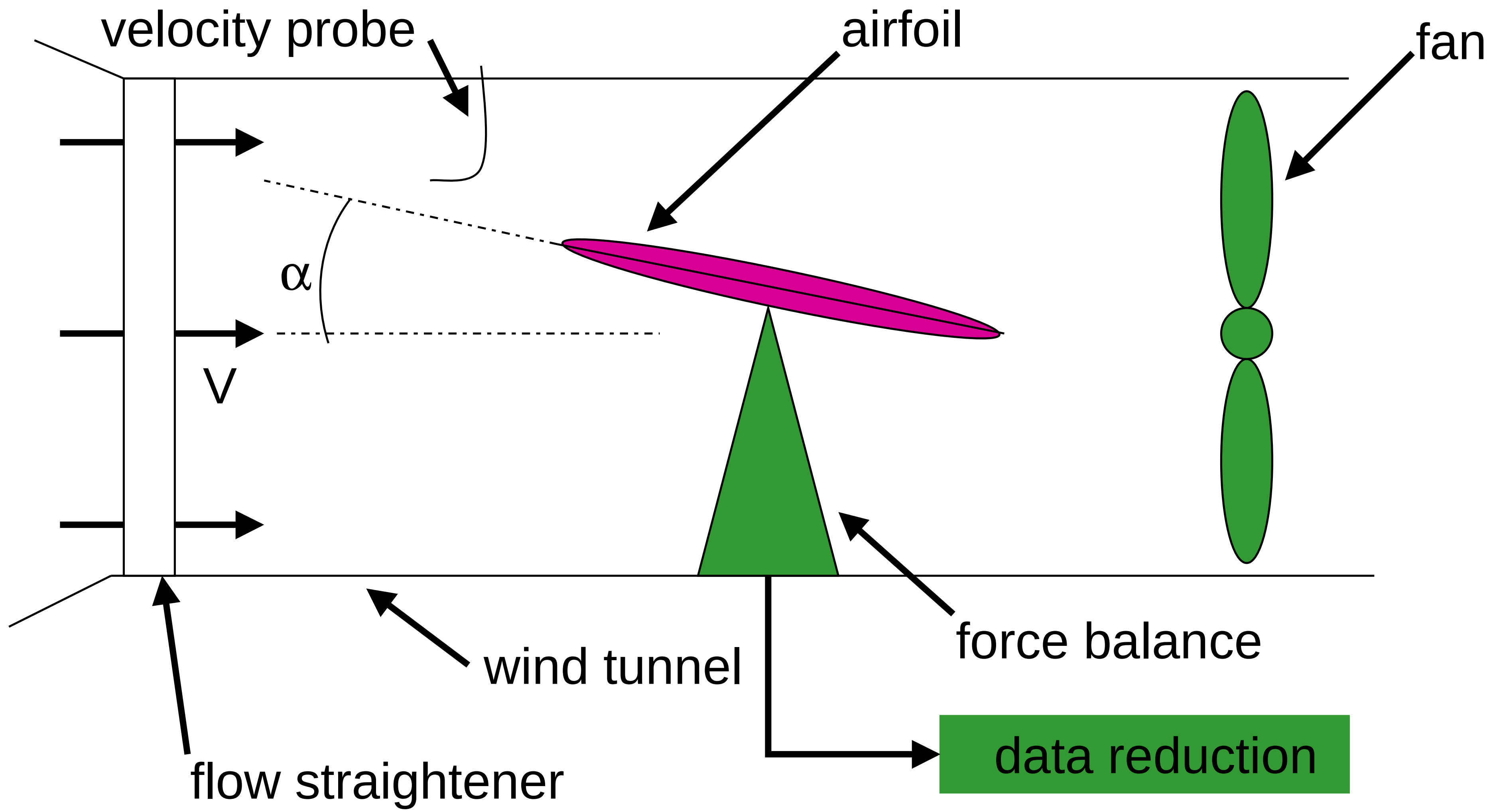
relative air speed

$$\frac{N}{(m^2)\left(\frac{N}{m^2}\right)} \Rightarrow$$ c_D is dimensionless

Lift and Drag

- Lift and drag depend on
  - The relative airspeed
  - The viscosity and density of the air
  - The shape of the airfoil
  - The angle of attack of the airfoil
- For given airflow conditions and shape
  - Lift and drag depend on the angle of attack

Measuring c_L and c_D



Lift and Drag Data (LD1.TXT)

α(deg)	L(N)	D(N)	V(m/s)
0	0.11	0.27	38.177
3	0.389	0.093	38.087
5	1.869	0.069	38.05
7	2.849	0.064	37.973
9	3.571	0	37.894
11	4.514	0.147	37.918
13	5.347	0.221	37.871
15	6.845	0.246	37.953
17	7.456	0.26	37.821
19	8.455	0.226	37.75
21	9.361	0.339	37.743
23	10.342	0.255	37.605
25	10.915	0.52	37.523
27	11.193	0.633	37.673
29	8.656	1.198	37.708
31	8.769	1.016	37.711

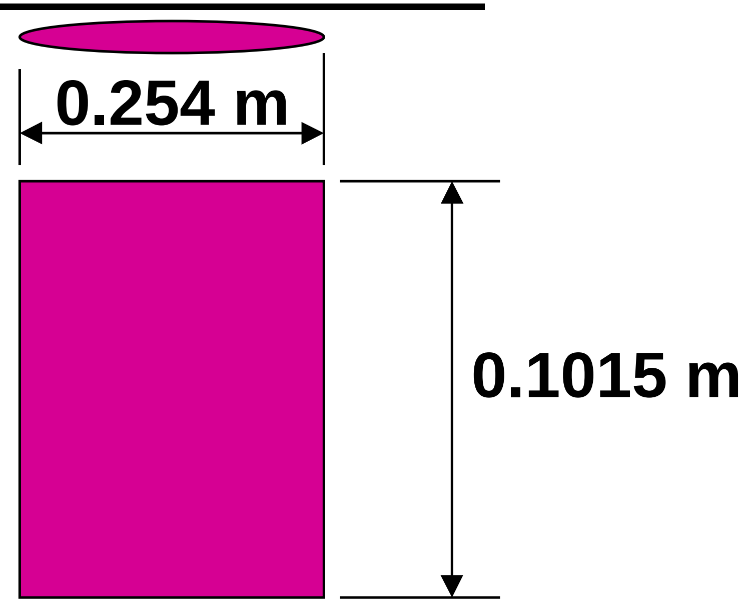
Ambient temperature & pressure and viscosity:

T = 21.94 °C

P = 755.1 mm Hg

μ = **182.147 (10^{-7}) N-s/m^2**

Airfoil dimensions:



Utility of Model Tests

- Use c_L and c_D *for full scale airfoil* **if**
  - Geometrically similar wing
  - Same Reynolds number

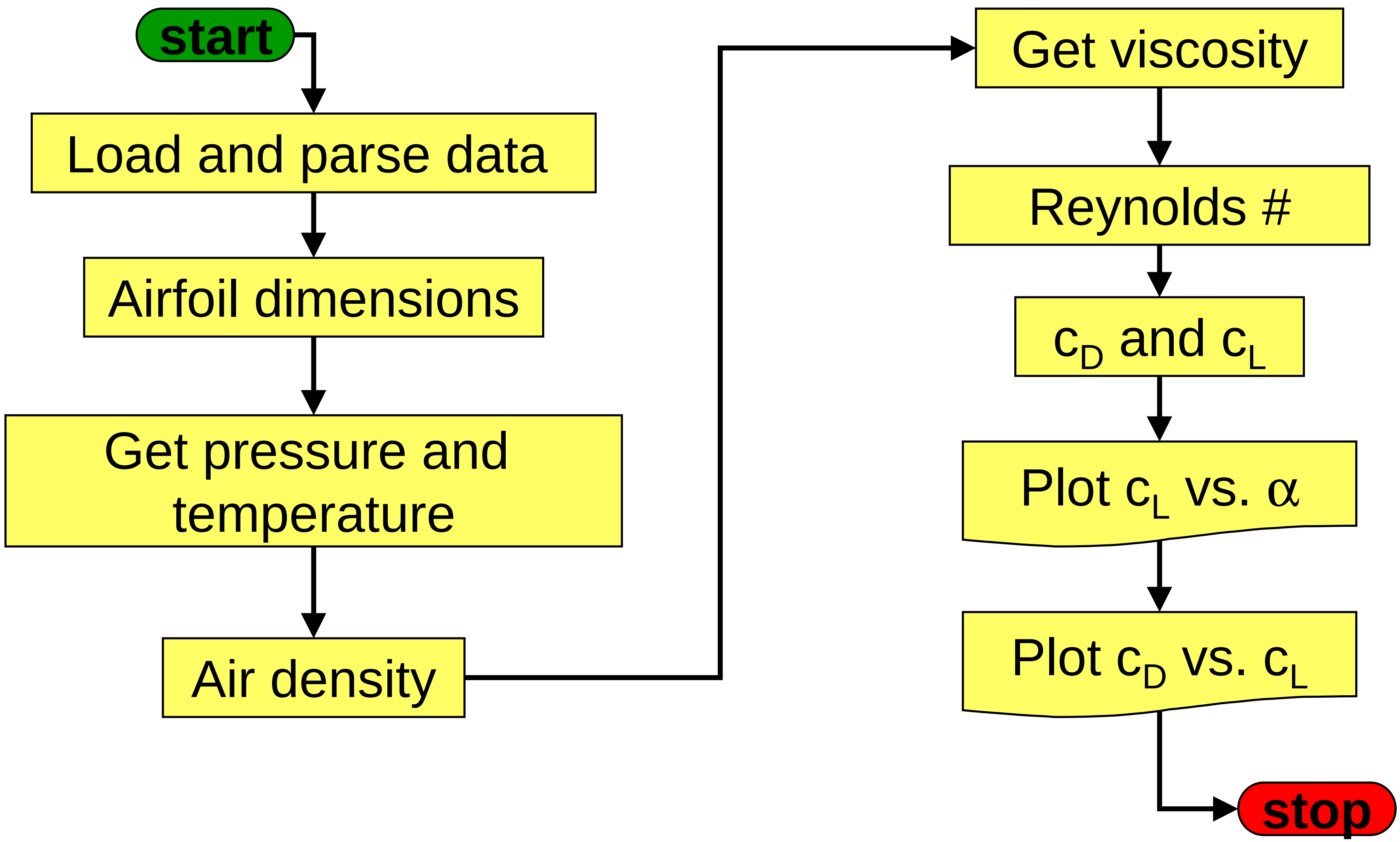
Reynolds Number

Proportional to the
ratio of dynamic to viscous forces
acting on a fluid element

Re = ρVc/μ

$$\frac{\left(\frac{kg}{m^3}\right)\left(\frac{m}{\sec}\right)(m)}{\frac{N\sec}{m^2}} = \frac{\frac{N}{m^2}}{\frac{N}{m^2}} \Rightarrow n.d.$$

LIFTDRAG.M Flow Chart



LIFTDRAG.M I

```
% Load and parse the data file
load a:\ld1.txt
V = ld1(:,4);            % vector of air speeds (m/s)
L = ld1(:,2);            % vector of lifts (N)
D = ld1(:,3);            % vector of drags (N)
angle = ld1(:,1);        % vector of angles (degree)

% Airfoil dimensions
c = 0.10152;             % m
b = 0.254;               % m
S = b*c;                 % planform area (m^2)
```

LIFTDRAG.M II

```
% Get the ambient pressure and temperature
HmmHg = input( 'Enter air pressure (mm Hg): ' );
p = mmhg2pa( HmmHg );   % air pressure (N/m^2)

Tc = input( 'Enter temperature (C): ' );
T = tk( tc );           % convert to absolute (K)

% Calculate air density
rho = airden ( p, T );
```

LIFTDRAG.M III

```
% Calculate the wing chord Reynolds number
mu = input( ’Enter the viscosity (N-s/m^2): ’ );
Vave = sum(V)/length(V); % average airspeed (m/s)
Re = reynolds ( c, mu, rho, Vave );
fprintf (’\nThe Reynolds number is: %7.5e\n', …
          Re )

% Calculate the lift and drag coefficients
q = .5*rho*V.^2;
pq = S*q;
cL = L./pq;
cD = D./pq;
```

LIFTDRAG.M IV

```
% Plot cL and cD vs. angle of attack
subplot (1,2,1)
plot ( angle, cL, ’square’, angle, cD, ’+’ );
legend (’lift coefficient’, ’drag coefficient’);
xlabel (’angle of attack (degrees)’);
ylabel (’lift, drag coefficient’);
title…
('Lift and Drag Coefficients vs. Angle of Attack'
% Plot cD vs. cL
subplot (1, 2, 2)
plot ( cL, cD, 'o')
xlabel ('lift coefficient')
ylabel ('drag coefficient')
title ('Drag Coefficient vs. Lift Coefficient')
```

Functions in LIFTDRAG.M I

```
function p = mmhg2pa ( HmmHG )
% MMHG2PA.M converts absolute air pressure in
% mm of Hg to absolute pressure in Pa assuming
% the density of Hg is independent of
% temperature
rhoHg = 13571.938;  % mercury density (kg/m^3)
p = (HmmHg/1000)*rhoHg*9.807; % pressure (N/m^2)

function T = tk ( Tc )
% TK.M calcultes the absolute temperature in
% Kelvin given the temperature in Celcius
T = Tc + 273.15;
```

Functions in LIFTDRAG.M II

```
function rho = airden ( p, T )
% AIRDEN.M calculates the air density (kg/m^3)
% given the absolute temperature (K) and
% pressure (Pa)
rho = 287*T/p;

function Re = reynolds( c, mu, rho, V )
% REYNOLDS.M finds the Reynolds number
% corresponding to the arguments passed.
Re = rho*V*c./mu;
```