



# CFD PROJECT NO. 2

EGME 436-01

## Abstract

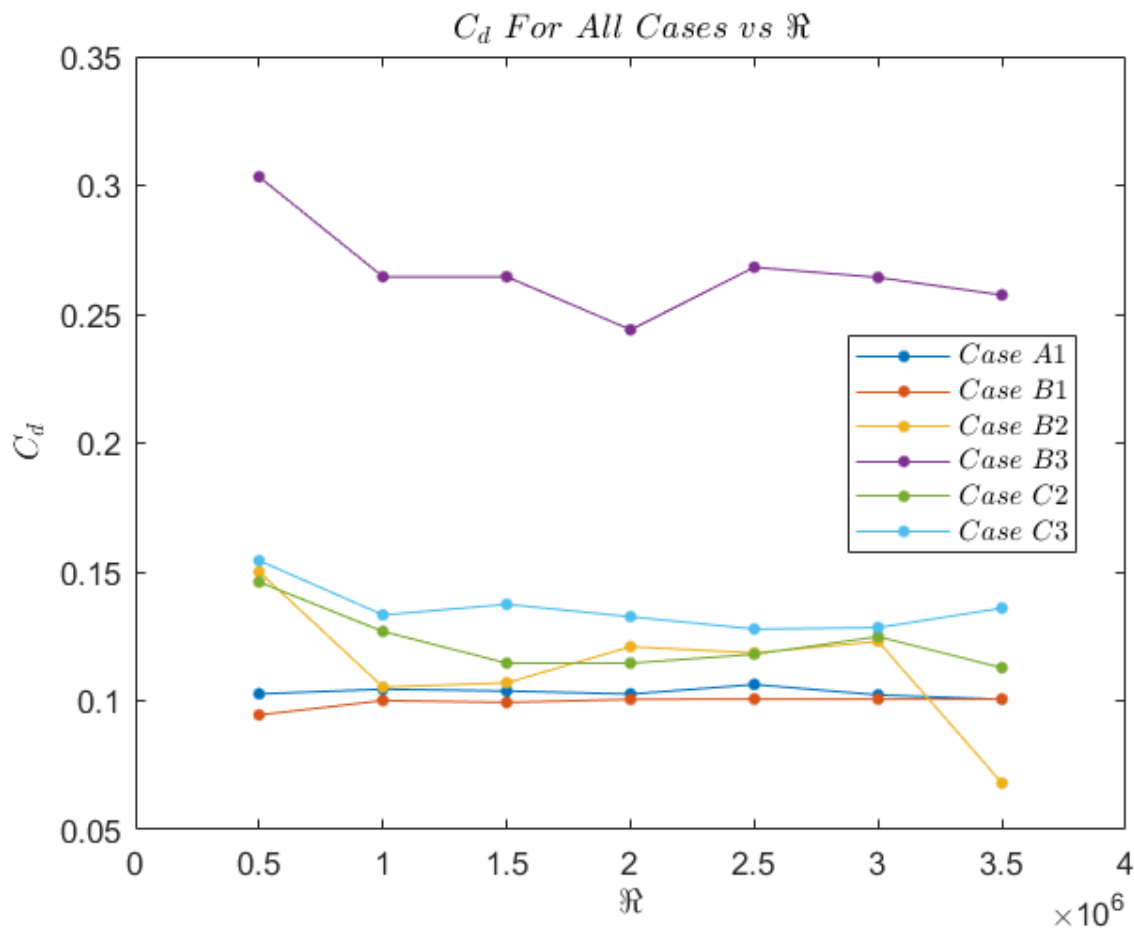
OpenFoam simulations of Drivaer models at various Reynolds numbers to determine coefficient of drag for each variation

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### 1/3. Varying Drivaer models at different Reynolds numbers

Different cases of Drivaer car models were simulated using OpenFoam to determine the effects of Reynolds number on the coefficient of drag for each vehicle. The general trend found was that as Reynolds number increased, the coefficient of drag decreased. These changes were very slight for some of models, and it was thought that the mesh might not be fine enough to resolve details of turbulence as Reynolds number increased.

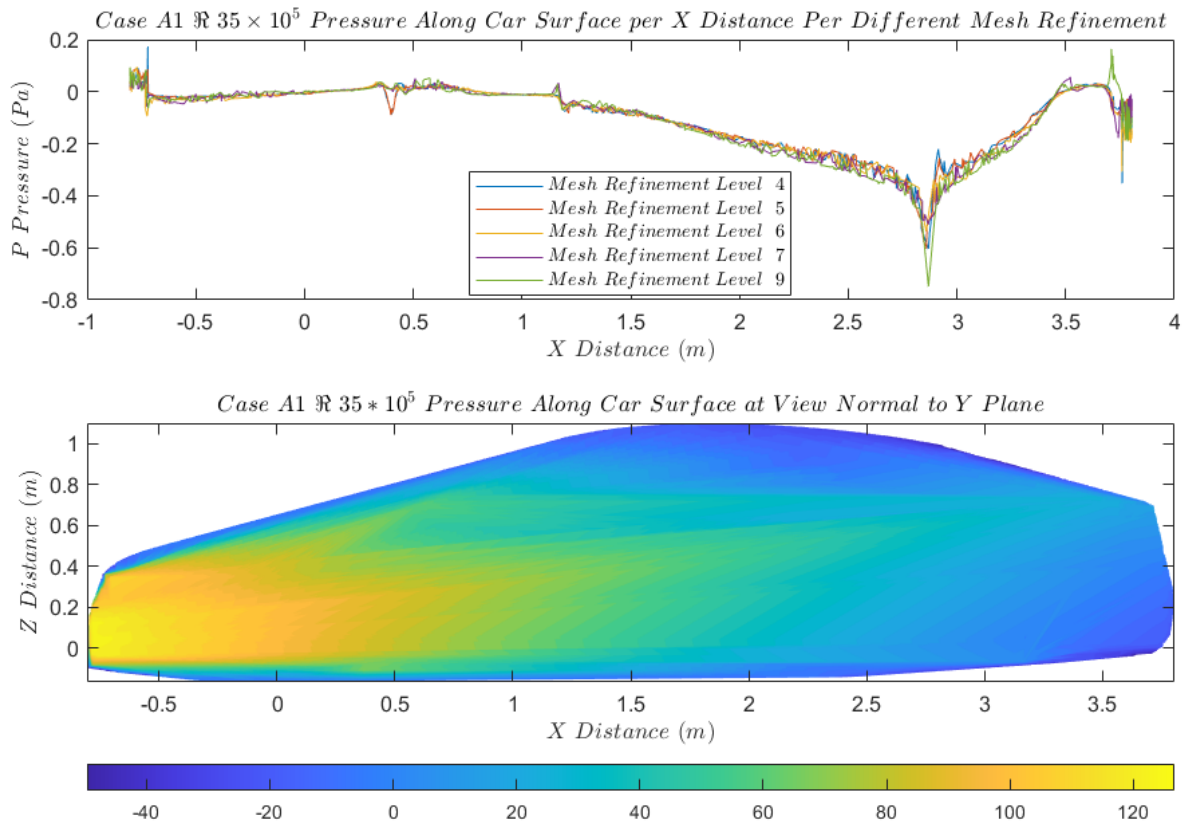
**Figure 1.  $C_d$  for every Drivaer model at Reynolds numbers from  $5e5$  to  $35e5$ .**



## 2. Grid Independent Study

Grid independence was determined by increasing the refinement regions of the different stl files provided, while keeping the block mesh uniform throughout, and changing the mesh refinement levels. It can be seen that the solution never really becomes grid independent, and there are variations in the “dip” between 2.5 and 3 seconds. So we decided to go with the highest mesh possible, level 9. Shown below is the pressure distribution along the surface of the car versus the axial position. Shown also, is a contour plot of pressure distribution when viewed normal to the y axis. The general shape of the car can be seen, and as expected, the most pressure occurs at the tip of the car, where the wind hits it.

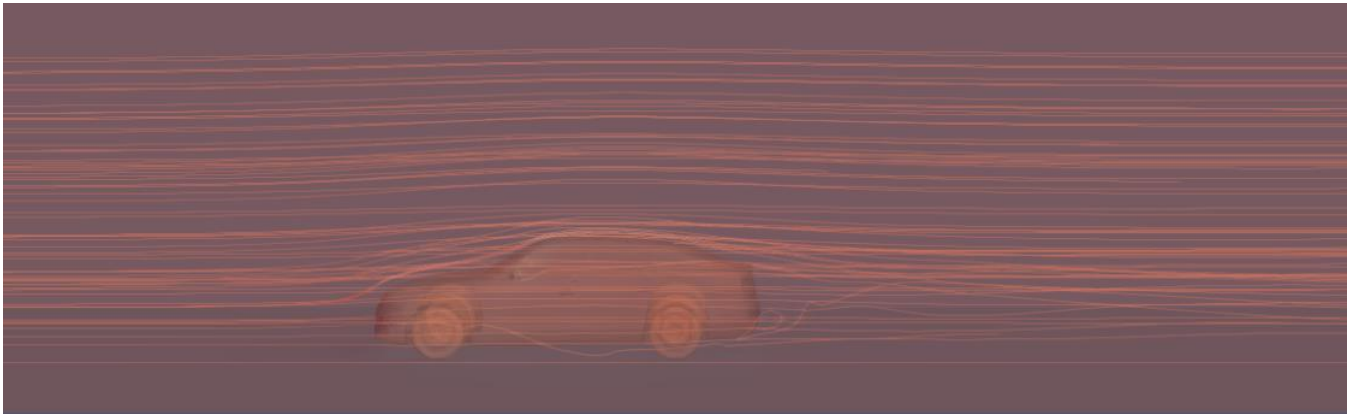
**Figure 2.** Pressure along car surface to determine grid independence.



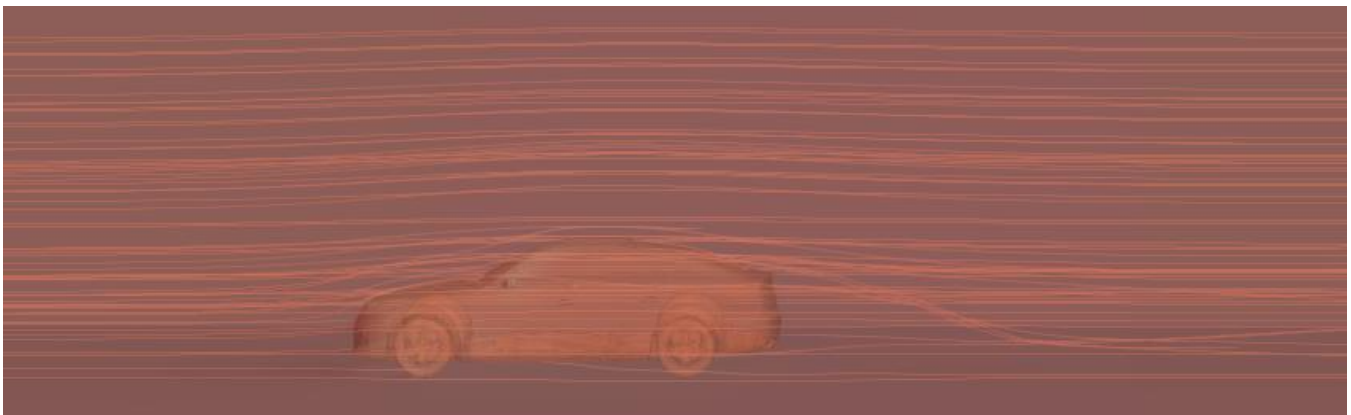
#### 4. B Cases and their $c_d$ values

Case B focused on simulating the effects of detail of the car body on drag produced. For some reason the base case, B.1, gave more drag than B.2 which had more detail on it. This may have been from inconsistency in meshing within the team for the various cases. However, case B.2 and B.3 follow the trend of increasing coefficient of drag as more detail is put on the model in **Table 1**.

**Figure 3.** Streamlines of case B.2 in Paraview.



**Figure 4.** Streamlines of case B.3 in Paraview.



**Table 1.** Coefficients of drag for case B Drivaer models at  $Re = 35e5$ .

	$C_d$
B.1	0.2013
B.2	0.1361
B.3	0.2574

## 5. C Cases and their $c_d$ values

The C cases focused on the effects of the back style of the car with respect to drag. These cases behaved closer to what we expected, having the more streamlined rear bodies experiencing less drag and the sharper cut off of the hatchback experiencing the highest coefficient of drag as seen in **Table 2**. You can also observe the vortices in **Figure 6** as the streamlines come back at the car producing more pressure drag.

**Figure 5.** Streamlines of case C.2 in Paraview.



**Figure 6.** Streamlines of case C.3 in Paraview.



**Table 2.** Coefficients of drag for case C Drivaer models at  $Re = 35e5$ .

	$c_d$
C.1	0.2013
C.2	0.2256
C.3	0.2719

## Appendix

```
clc;
clear;
close all;

fileName =
'C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re05_xe05_CaseA1/postProcessing/residuals/0/residuals.dat';
A_resid = readtable(fileName,'filetype','text');

%plotting residuals for y vs u_x along centerline x = 0.5
y = table2array( A_resid(:,1) );
for ii = 2:width(A_resid) -1
    %plot(y, table2array( A_resid(:,ii) ) )
    %hold on;
end

%%Problem 1
Re = 5:5:35;
indecies_forOneDigit_Re = find(Re<10);
Re_string = string(Re);
Re_string(indecies_forOneDigit_Re) = "0" + Re_string(indecies_forOneDigit_Re);
cases = [ "A1", "B1", "B2", "B3", "C2", "C3"];%, "B2", "B3", "C2", "C3"];
Re = Re*10^5;
figure;
for i = 1:length(cases)
    Cd_Cases = zeros(1,length(Re));
    for ii = 1:length(Re)
        fileName = strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re',
Re_string(ii) ,...

'_xe05_Case',cases(i), '/postProcessing/forceCoeffsIncompressible/0/forceCoeffs.dat');
        forceCoeffsTable = readtable(fileName,'filetype','text');
        forceCoeffsTable = forceCoeffsTable(3:end,1:end-1); %Gets rid of the titles,
which are NaN
        if cases(i) ~= "B3"
            forceCoeffsTable = 0.5 .* forceCoeffsTable; %Need to double, since did half
area only
        end
        %forceCoeffsTable = importdata(fileName).data;
        Cd_Cases(1,ii) = forceCoeffsTable{end,3};

    end

    plot(Re,Cd_Cases, '-.','MarkerSize',12)
    hold on;
end
title("$ C_d \ For \ All \ Cases \ vs \ \Re $",'Interpreter','latex')
xlabel("$ \Re $",'Interpreter','latex')
ylabel("$ C_d $",'Interpreter','latex')
xlim([0,Re(end)+5*10^5]);
lgnd= legend("$Case \ " + cases + " $",'Location','best');
set(lgnd, 'Interpreter','latex')
hold off;
```

```

%%Problem 2
%{
fileName =
'C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_CaseA1/postProcessing/residuals/0/residuals.dat';
lastIteration = readtable(fileName,'filetype', 'text');
lastIteration = table2array( lastIteration(end,1) ); %returns a number. Just gets the
last iteration the sim stopped on
fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_CaseA1/postProcessing/cuttingPlane/' ...
, num2str(lastIteration) ,'/yNormal.xy');
cutPlane = table2array( readtable(fileName,'filetype', 'text') );
n = 6; %every nth row of matrix, remove nn rows just to save space on mesh when plotting
nn = 4;
indeciesToRemove = [];
for i = n:n:height(cutPlane)
    indeciesToRemove = [indeciesToRemove,i:i+nn];
end
indeciesToRemove = indeciesToRemove(indeciesToRemove < height(cutPlane) ); %incase it is
above the length of cutplane
cutPlane(indeciesToRemove,:) = [];
x = cutPlane(:,1);
z = cutPlane(:,3);
p = cutPlane(:,4);
[X,Z] = meshgrid(x,z);
pField = griddata(x,z,p,X,Z);
clearvars indeciesToRemove x z;
pFieldMin = -1 * max( abs( rmoutliers( pField( find(pField < 0) ) ) ) );
pFieldMax = max(pField,[],"all");
%pFieldMin = min(pField,[],"all");
pFieldContourLevels = linspace(pFieldMin,pFieldMax,50);
figure;
%contourf(X,Z,pField , 'LevelList', pFieldContourLevels,'LineColor','none');
%plot3(x,z,p,".")
%hold on
%surf(X,Z,pField,'EdgeColor','none','LineStyle','none')
%shading interp
title("$ Case \ A1 \ Pressure \ Field \ at \ Center \ Y \ Plane $",'Interpreter','latex')
xlabel("$X \ Distance \ (m) $",'Interpreter','latex')
ylabel("$Z \ Distance \ (m) $",'Interpreter','latex')
col_bar = colorbar('southoutside','Orientation','Horizontal');
hold off;
%}

figure;
tiledlayout(2,1);
nexttile;
meshLevels = [4,5,6,7,9];
for m = 1:length(meshLevels)
    if meshLevels(m) ~= 9
        fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/Case_A1_Re05_LOWER_MESHES/drivaer_Re35_
xe05_CaseA1_Mesh'...

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        ,num2str(meshLevels(m)), '/postProcessing/residuals/0/residuals.dat');
    lastIteration = readtable(fileName, 'filetype', 'text');
    lastIteration = table2array( lastIteration(end,1) ); %returns a number. Just
gets the last iteration the sim stopped on
    fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/Case_A1_Re05_LOWER_MESHES/drivaer_Re35_
xe05_CaseA1_Mesh'...
        ,num2str(meshLevels(m)), '/postProcessing/wallSampling/',
num2str(lastIteration) , '/xWall.xy');
    else
        fileName =
'C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_CaseA1/postProcessing/residu
als/0/residuals.dat';
        lastIteration = readtable(fileName, 'filetype', 'text');
        lastIteration = table2array( lastIteration(end,1) ); %returns a number. Just
gets the last iteration the sim stopped on
        fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_CaseA1/postProcessing
/wallSampling/' ...
        , num2str(lastIteration) , '/xWall.xy');
    end
    cutPlane = table2array( readtable(fileName, 'filetype', 'text') );

    sortedCut = sort(cutPlane,1);
    %plot(sortedCut(:,1),sortedCut(:,4))
    clearvars sortedCut
    %sort data by type
    U = 16;
    xa = cutPlane(:,1);
    ya = cutPlane(:,2);
    za = cutPlane(:,3);
    pa = cutPlane(:,4)/(0.5*U*U);

    % firter data so that it is within the center (x-z) plane +/- 0.01
    dy = 0.01;
    index = ya<dy;
    xb = xa(index);
    yb = ya(index);
    zb = za(index);
    pb = pa(index);

    index = yb>(-1*dy);

    xa = xb(index);
    ya = yb(index);
    za = zb(index);
    pa = pb(index);

    % firter data so that it is on the upper surface within the center plance
    index = za>0;
    xb = xa(index);
    yb = ya(index);
    zb = za(index);
    pb = pa(index);

    % sort data by x-axis
    [~,index] = sort(xb);

```



```

        x = xb(index);
        y = yb(index);
        z = zb(index);
        p = pb(index);
        plot(x,p)
        hold on;
        length(p)
    end
clearvars pa pb xa xb ya yb za zb
title("$ Case \ A1 \ \Re \ 35*10^5 \ Pressure \ Along \ Car \ Surface \ per \ X \ Distance \ Per \ Different \ Mesh \ Refinement$", 'Interpreter', 'latex')
xlabel("$X \ Distance \ (m) $", 'Interpreter', 'latex')
ylabel("$P \ Pressure \ (Pa) $", 'Interpreter', 'latex')
lgnd= legend("$Mesh \ Refinement \ Level \ \ " + meshLevels + " $", 'Location', 'best');
set(lgnd, 'Interpreter', 'latex')
hold off;

nexttile;
height(cutPlane)
n = 40; %every nth row of matrix, remove nn rows just to save space on mesh when plotting
nn = 38;
indiciesToRemove = [];
for i = n:n:height(cutPlane)
    indiciesToRemove = [indiciesToRemove,i:i+nn];
end
indiciesToRemove = indiciesToRemove(indiciesToRemove < height(cutPlane) ); %incase it is above the length of cutplane
cutPlane(indiciesToRemove,:) = [];
height(cutPlane)
x = cutPlane(:,1);
z = cutPlane(:,3);
p = cutPlane(:,4);
[X,Z] = meshgrid(x,z);
pField = griddata(x,z,p,X,Z);
clearvars indiciesToRemove x z;
pFieldMin = -1 * max( abs( rmoutliers( pField( find(pField < 0) ) ) ) );
pFieldMax = max(pField,[],"all");
%pFieldMin = min(pField,[],"all");
pFieldContourLevels = linspace(pFieldMin,pFieldMax,50);

%contourf(X,Z,pField , 'LevelList', pFieldContourLevels,'LineColor','none');
%plot3(x,z,p,".")
%hold on
%surf(X,Z,pField,'EdgeColor','none','LineStyle','none')
%shading interp
title("$ Case \ A1 \ \Re \ 35*10^5 \ Pressure \ Along \ Car \ Surface \ at \ View \ Normal \ to \ Y \ Plane $", 'Interpreter', 'latex')
xlabel("$X \ Distance \ (m) $", 'Interpreter', 'latex')
ylabel("$Z \ Distance \ (m) $", 'Interpreter', 'latex')
col_bar = colorbar('southoutside','Orientation','Horizontal');
hold off;

%%Problem 3
Re = 5:5:25;
indicies_forOneDigit_Re = find(Re<10);
Re_string = string(Re);

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Re_string(indicies_forOneDigit_Re) = "0" + Re_string(indicies_forOneDigit_Re);
Cd_A_Cases = zeros(1,length(Re));
Re = Re*10^5;

for i = 1:length(Re)
    fileName = strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re',
Re_string(i),...
'_xe05_CaseA1/postProcessing/forceCoeffsIncompressible/0/forceCoeffs.dat');
    forceCoeffsTable = readtable(fileName,'filetype','text'); %Need to double, since did
half area only
    forceCoeffsTable = forceCoeffsTable(3:end,1:end-1); %Gets rid of the titles, which
are NaN
    forceCoeffsTable = 2 .* forceCoeffsTable; %Need to double, since did half area only
    %forceCoeffsTable = importdata(fileName).data;
    Cd_A_Cases(1,i) = forceCoeffsTable(end,3);

end

figure;
plot(Re,Cd_A_Cases, '-.','MarkerSize',12)
title(strcat("$ C_d \ For \ Case \ A1 \ vs \ \Re $"),'Interpreter','latex')
xlabel("$ \Re $",'Interpreter','latex')
ylabel("$ C_d $",'Interpreter','latex')
xlim([0,Re(end)]);
hold off;

%%Problem 4
cases = ["B1","B2","B3"];
Cd_B_Cases = array2table(zeros(1,3),'RowNames',["C_d"]);
Cd_B_Cases.Properties.VariableNames = "Case " + cases + " Re_35xe05";
for i = 1:length(cases)
    fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_Case',cases(i),...
'/postProcessing/forceCoeffsIncompressible/0/forceCoeffs.dat');
    forceCoeffsTable = readtable(fileName,'filetype','text');
    forceCoeffsTable = forceCoeffsTable(3:end,:); %Gets rid of the titles, which are NaN
    %forceCoeffsTable = importdata(fileName).data;
    Cd_B_Cases(1,i) = forceCoeffsTable(end,3);
end

%%Problem 5
cases = ["B1","C2","C3"];
Cd_C_Cases = array2table(zeros(1,3),'RowNames',["C_d"]);
Cd_C_Cases.Properties.VariableNames = "Case " + cases + " Re_35xe05";
for i = 1:length(cases)
    fileName =
strcat('C:/Users/n8dsa/Documents/OpenFOAM/drivaer/drivaer_Re35_xe05_Case',cases(i),...
'/postProcessing/forceCoeffsIncompressible/0/forceCoeffs.dat');
    forceCoeffsTable = readtable(fileName,'filetype','text');
    forceCoeffsTable = forceCoeffsTable(3:end,:); %Gets rid of the titles, which are NaN
    %forceCoeffsTable = importdata(fileName).data;
    Cd_C_Cases(1,i) = forceCoeffsTable(end,3);
end

```

