Aerodynamics Homework 03

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I. Part 1

The airfoil pressure data used in homework assignment 1 (and problem 2 below) was generated using ideal-flow assumptions. The air was assumed to be incompressible and inviscid. For this homework assignment, the data is generated using a standard NASA computational fluid dynamics code that solves the "Reynolds-Averaged Navier-Stokes" equations, or RANS. The data in the files for part 1 of this assignment were created for a Mach number of 0.1 (low speed) and a Reynolds number of 1,000,000. The files are named with the angle of attack. Note that the data in these files is tabulated starting at the trailing edge going counterclockwise. Note that both x and z values for the airfoil surface have been made dimensionless with respect to the airfoil chord length.

A. Question 1.1 Problem Statements:

1. *Using MATLAB, estimate the lift and drag coefficients per unit span on this airfoil for all data sets. In a table, show Cl and Cd for each angle of attack.*
2. *Using MATLAB, estimate the lift and drag coefficients per unit span on this airfoil for all data sets. In a table, show Cl and Cd for each angle of attack.*

Assume: Dimensionless data

Given: Provided data files**,** compressibility and viscosity,

Solution: The folder containing the data files for each airfoil was looped on for each file, and the same code from HW01 and HW02 was executed to calculate the lift and drag coefficients. Tabulated results can be seen in Tab. [1] and Tab. [2] for NACA 0012 and NACA 4412, respectively. Files were read in using the dir() command, the names of which were then appended to the path to the folder. Note the standard '.' and '..' listings were removed. The file name was parsed to find the angle of attack (AoA), which was then converted to radians, keeping in mind the convention for a negative AoA. The data was collected in a way which conflicts with the standard, and as such the flipud() command was used to correct the data before manipulation. The same trapz() method used in HW02 and HW02 was used to find the force coefficients in the x and z directions, and using trigonometric functions, were then used to find the lift and drag coefficients. These coefficients are stored in a matrix for later calculations.

Results: The coefficient data is tabulated below. Tab. [1] shows C_l and C_d for NACA 0012, while Tab. [2] shows C_l and C_d for NACA 4412:

Table 1: NACA 0012		
AoA (deg)	C_l	C_d
-6	-0.6258	0.0024
-3	-0.3192	0.0029
0	-0.0016	0.0029
3	0.3155	0.0048
6	0.5151	0.0048
9	0.6227	0.0099
12	0.9319	0.0191
15	1.1979	0.1502

Table 2: NACA 4412		
AoA (deg)	C_l	C_d
-6	-0.2352	0.0032
-3	0.0672	0.0037
0	0.3801	0.0044
3	0.7010	0.0066
6	1.0109	0.0076
9	1.3011	0.0133
12	1.5381	0.0233
15	1.5959	0.0349

Table 1 & Table 2: C_l and C_d for NACA 0012 and NACA 4412, respectively, at AoAs ranging between -6 degrees and 15 degrees.

Discussion: It can be seen here that the data for the lift coefficient increases as a function of angle of attack. The drag coefficient is similar, however the increase follows a much less linear trend. It can also be seen that both the lift and drag coefficient values at an AoA of 15 degrees is consistently an outlier value for both airfoils. At this AoA, the C_l of NACA 0012 lies close to its first order regression line, Fig. [], however the C_d increases disproportionately by almost eight times. Interestingly, the opposite seems to happen for NACA 4412. At this AoA, the C_l disproportionately increases by just 3.75%, however the C_d lies close to its third-order regression line, Fig. []. Based on these findings, it can be assumed that both airfoils reach some 'critical point' somewhere between 12 and 15 degrees. At this point, the airfoil experiences either a loss of lift or a severe increase in drag, i.e. a stall, and determining which will happen must be some function of airfoil shape.

B. Question 1.2 Problem Statements:

3. *On one graph, plot cl vs. α for the NACA 0012 and the NACA 4412. What is the lift-curve slope for each? (Slope of the cl vs. α curve.) What is the zero-lift angle of attack for each?*
4. *On one graph, plot cd vs. α for the NACA 0012 and the NACA 4412. Comment on the result.*
5. *Discuss the effect of camber on the lift-curve slope and the zero-lift angle of attack*

Assume: Dimensionless data, problem statement expects separate graphs for each airfoil

Given: Provided data files**,** compressibility and viscosity

Solution: The C_l and C_d values calculated in the last question were plotted for analysis. At first, all data points were plotted, but it is very quickly seen that the values for both C_l and C_d at an AoA of 15° is an outlier. This will be discussed more later, but to obtain an accurate linear regression slope for C_l vs. AoA, this data point was excluded for both NACA 0012 and NACA 4412. This was done using a modified version of the code from the last question that builds the data matrix using a secondary iterator that checks for an AoA of 15° and does not increment nor record the C_l and C_d values for this AoA. The zero-lift AoA was computed by using roots() in MATLAB, obtaining the x-intercept for each linear regression. The lift-curve slope and the zero-lift AoA for NACA 0012 and NACA 4412 excluding an AoA of 15 degrees can be seen in Tab. [3]. The graph of C_d vs. AoA for both NACA 0012 and NACA 4412 can be modeled best with a third-degree LSQ regression, unlike the linear LSQ regression plotted for C_l vs. AoA.

Results: The graphs below, Fig[1,2] show C_l vs. AoA for NACA 0012 and NACA 4412:

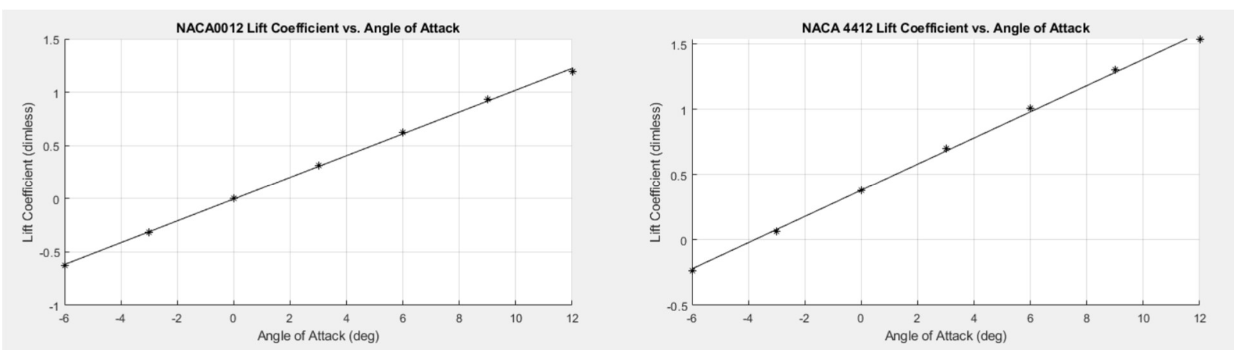

Figure 1,2: C_l vs α for NACA 0012 & 4412

The graphs below, Fig.[3,4] show C_d vs. AoA for NACA 0012 and NACA 4412:

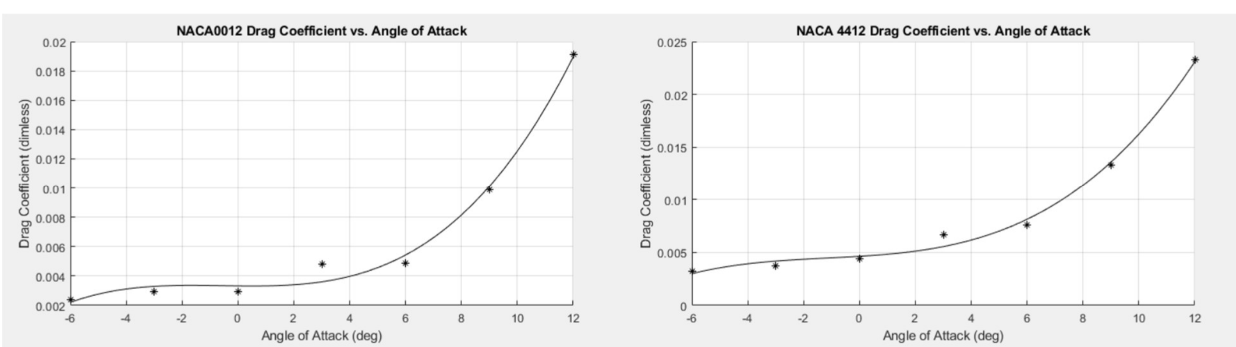

Figure 3,4: C_d vs α for NACA 0012 & 4412

The table below, Tab.[3] shows the computed values for the lift-curve slope for both NACA 0012 and NACA 4412:

Table 3: Lift-Curve Slope & Zero-Lift AoA for NACA 0012 and NACA 4412		
Airfoil	**NACA 0012**	**NACA 4412**
Lift-Curve Slope (C_l/deg)	0.1024	0.1002
Zero-Lift AoA (deg)	0.0389	-3.7894

Table 3: Lift-curve slope of a 1st order LSQ regression and zero-lift angle of attack for NACA 0012 and NACA 4412.

Discussion: The first thing to notice is the similarity between the lift-curve slopes of the two airfoils. This shows that there is little difference in lift as a function of angle of attack between the two airfoils, as both see an increase by about 0.1 per angle of attack. Also note the big difference in zero-lift angles of attack – the C_l for NACA 0012 is zero at an AoA of roughly zero degrees while the C_l for NACA 4412 is zero at an AoA of roughly negative three point eight degrees. The graphs of C_d vs. AoA show a much less linear relationship than seen with airfoil lift. There is clearly an exponential relationship between angle of attack and the drag generated by the surface. From these observations, it is shown that an airfoil with *more* camber should allow for a *larger* negative AoA margin, however producing *more* drag. In contrast, a *symmetric* airfoil will produce *no lift* at an AoA of zero degrees. This is expected, as there is no difference in flow over the upper and lower surfaces, and thus no pressure differential is generated. This design, of course, generates less drag as it has less bluff surface exposed to the freestream flow.

C. Question 2:

1. *Plot the airfoil and notice its shape. For example, is it cambered or symmetric? Is it relatively thin or thick?*
2. *Plot the pressure distribution as a function of the x-coordinate.*
3. *Find the lift coefficient and drag coefficients. The angle of attack is -2.15°. Explain why you would suspect this data set derives from an ideal-flow calculation.*
4. *Explain how you could predict this lift coefficient by observing the plot in part 7.*

Assume: Dimensionless data

Given: Provided data file

Solution: The same code used to plot the cross section and the pressure distribution in HW01 and HW02 was used here to plot the cross section and pressure distribution for the xx15 airfoil at an angle of attack α = -2.15°.

Results: Tab. [4] shows C_l and C_d for the xx15 airfoil:

Table 4: xx15		
AoA (deg)	$\boldsymbol{C_l}$	$\boldsymbol{C_d}$
-2.15	0.000393	-0.000290

Table 4: C_l and C_d for xx15 at an AoA α = -2.15°

The graphs below, Fig. [5,6], show the xx15 airfoil x-z cross-section and the pressure distribution as a function of the x-coordinate:

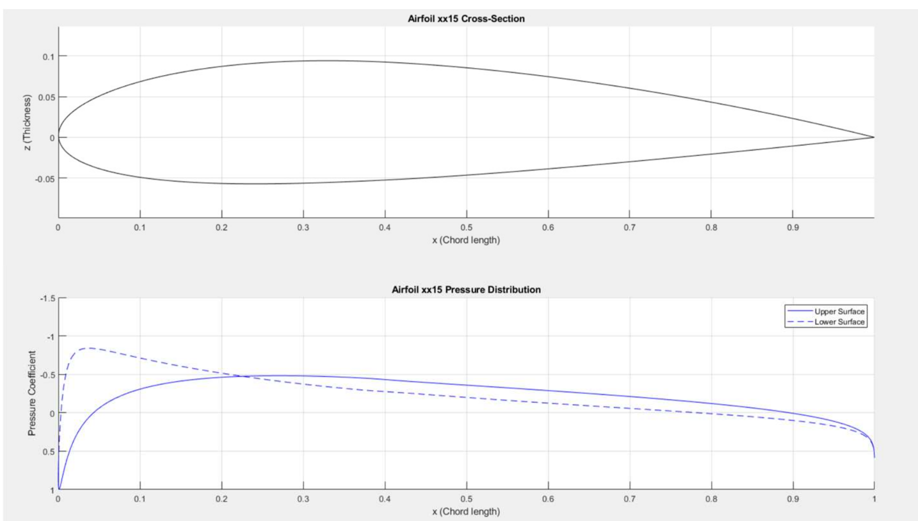

Figure 5,6: x-z cross-section and pressure distribution across the xx15 surfaces

Discussion: The airfoil here is positively cambered – the upper camber is almost double that of the lower camber. It is also worth noting that the airfoil is relatively thick in a general sense, especially in comparison to that of the NACA 0012 and NACA 4412. The pressure distribution here is unique – there is some strong negative lift produced at the front of the airfoil, but traditional positive lift is recovered at roughly 0.22 along the x dimension. This must be partially due to the negative angle of attack. Notice that the leading edge's top and bottom cambers are nearly symmetric until roughly |0.05| in the z dimension; the negative AoA produces lift in accordance with Fig. [1], an example of a symmetric airfoil. As the wing camber prevails across the x dimension, traditional lift restores as would be expected according to Fig. [2], an example of a cambered airfoil. The lift and drag coefficient for xx15 at this AoA are both very small. This is likely a function of the negative angle of attack and airfoil shape producing some negative lift, and as such the integral of C_p to find C_x and C_z return small values. This indicates a much smaller amount of differential pressure, and less potential to generate aerodynamic force. This can be predicted from Fig. [6] because of the idea of a pressure differential. Looking at the total area under the curves, there is some positive area *and* negative area, and as such the total area will have to be smaller.

II. Part 2

D. Consider the stream function $\psi = \frac{K}{2}(z^2 - x^2)$

1. *Does this flow satisfy the conservation of mass?*
2. *Plot streamlines in the right half-plane, 0<x<5. Let K = 2, and use values of* ψ *between -25 and 0. Indicate flow direction*
3. *Is this flow irrotational? If so, find the velocity potential. If not, show a velocity potential does not exist.*
4. *Describe the flow represented by this stream function. Note* $\psi = 0$ *represents a solid surface.*

Assume: Steady, planar x-z flow

Given: $K = 2; -25 < \psi < 0; 0 < x < 5$

Solution: The definition of a stream function must be considered, seen in Eq. [1.1] below:

$$\psi = (x, z), \text{where } w = -\frac{\partial \psi}{\partial x} \text{ and } u = \frac{\partial \psi}{\partial z} \tag{1.1}$$

To first prove that the given stream function satisfies the conservation of mass, the definition of continuity must be used, seen in Eq. [1.2]:

$$\nabla \cdot \vec{v} = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = \frac{\partial^2 \psi}{\partial x \partial z} - \frac{\partial^2 \psi}{\partial x \partial z} = 0 \tag{1.2}$$

To define our stream function according to Eq. [1.1], the partial derivative of ψ was taken w.r.t. x and z to determine w and u, as seen below in Eqs. [1.3,1.4]:

$$w = -\frac{\partial \psi}{\partial x} = -\frac{K}{2}\left[\frac{\partial}{\partial x} z^2 - \frac{\partial}{\partial x} x^2\right] = K \cdot x \tag{1.3}$$

$$u = \frac{\partial \psi}{\partial \mathrm{z}} = \frac{K}{2}\left[\frac{\partial}{\partial \mathrm{z}} z^2 - \frac{\partial}{\partial \mathrm{z}} x^2\right] = K \cdot z \tag{1.4}$$

Using these w and u and plugging them into Eq. [1.2] demonstrates that the stream function does satisfy the conservation of mass:

$$\frac{\partial}{\partial x} u = K \frac{\partial}{\partial x} z = 0 \textit{ and } \frac{\partial}{\partial \mathrm{z}} w = K \frac{\partial}{\partial \mathrm{z}} x = 0$$

$$\therefore \nabla \cdot \vec{v} = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 + 0 = 0$$

To next check if the given stream function is irrotational, consider the definition of irrotational flow in 2 dimensions, Eq. [1.5], where flow vorticity is zero:

$$\vec{\xi} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \nabla \times \vec{v} = 0 \tag{1.5}$$

Considering the definitions of u and w from Eq. [1.1] yields Eq. [1.6]:

$$\vec{\xi} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \frac{\partial^2 \psi}{\partial z^2} + \frac{\partial^2 \psi}{\partial x^2} = \nabla^2 \psi = 0 \tag{1.6}$$

Already knowing u and w from Eqs. [1.3,1.4], the next partial derivatives are computed:

$$\frac{\partial}{\partial x} w = \frac{\partial}{\partial x} Kx = K \textit{ and } \frac{\partial}{\partial z} u = \frac{\partial}{\partial z} Kz = K$$

Plugging into Eq. [1.6] shows the vorticity of the flow to be zero and thus irrotational:

$$\vec{\xi} = \nabla^2\psi = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = K - K = 0$$

To determine a velocity potential, first extending the continuity definition, Eq. [1.2], yields the Laplace equation, Eq. [1.7]:

$$\nabla \cdot \vec{v} = \nabla \cdot \nabla\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial z^2} = \nabla^2\phi = 0 \tag{1.7}$$

Recognizing the similarity to Eq. [1.6], and knowing that a fundamental solution to ϕ is the same as the fundamental solution to ψ, these can be set equal, seen in Eq. [1.8]:

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial z^2} = 0 = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial z^2} = \nabla^2\phi \tag{1.8}$$

Expanding the second partials according to the definitions of w and u yields the following:

$$\frac{\partial^2\psi}{\partial \mathrm{x}^2} = \frac{\partial}{\partial x}\frac{\partial\psi}{\partial x} = \frac{\partial}{\partial x}(-w) = \frac{\partial}{\partial x}\left(-\frac{\partial\phi}{\partial z}\right)$$

$$\frac{\partial^2\psi}{\partial z^2} = \frac{\partial}{\partial z}\frac{\partial\psi}{\partial z} = \frac{\partial}{\partial z}(u) = \frac{\partial}{\partial z}\left(\frac{\partial\phi}{\partial x}\right)$$

These equations can be manipulated to form a system that solves for ϕ as a function of x and z, seen in Eq. [1.9]:

$$\phi(x,\mathrm{z}) = \begin{cases} \int u\,\mathrm{d}x = \int \mathrm{K}z\,\mathrm{d}x = Kzx + c_x \\ \int w\,\mathrm{dz} = \int \mathrm{K}x\,dz = Kxz + c_z \end{cases} \tag{1.9}$$

Since both equations are independently valid forms of ϕ, it is expected that equating the two particular solutions will produce simply $0 = 0$. Thus, the equation for ϕ is found to be $\phi(x,\mathrm{z}) = Kzx = 2 \cdot zx$.

To make a plot of the streamlines in the right-half plane, the equations derived above were computed along 0<x<5 and then plotted as contours on a meshgrid in MATLAB.

Results: The streamline plot for ψ in the right half-plane is shown in Fig. [7] below:

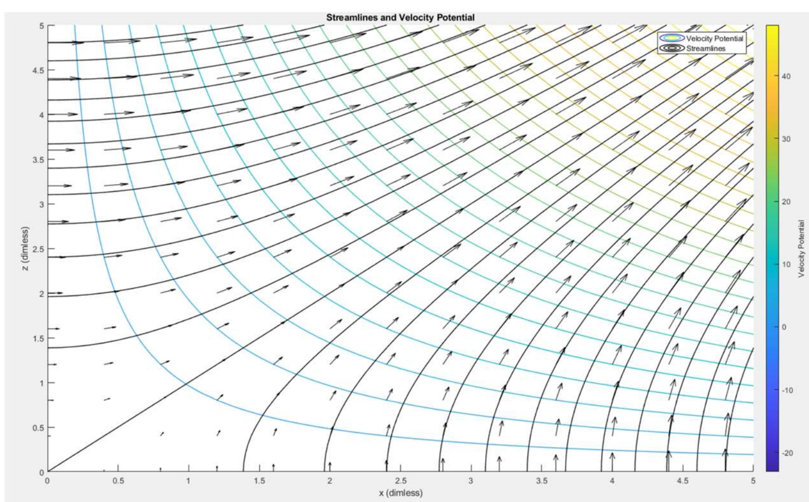

Figure 7: Streamlines and constant velocity potential for the given ψ. Note that the streamlines are always perpendicular to the lines of constant potential.

Discussion: The plot in Fig. [7] shows the streamlines from $-25 \leq \psi \leq 0$ and the associated lines of constant ϕ, colored as a gradient, where warm tones represent greater values. It is clear that \psi and \phi intersect at 90° angles everywhere. The stream lines look as if they're being drawn toward the upper right corner, toward the greater lines of constant \phi. The stream lines also bunch up closer together – since the conservation of mass can be shown, this means the flow velocity along each streamline must increase as it approaches the upper left corner, which makes sense as the velocity potential is greater. This stream function could represent the cross section of flow into an inlet pipe, or some similar movement of fluid from high to low pressure.

E. Consider the stream function $\psi = \frac{K}{2}(z^2 + x^2)$

1. *Does this flow satisfy the conservation of mass?*
2. *Plot streamlines. Let K = 2, and use values of* ψ *between -25 and 0. Indicate flow direction*
3. *Is this flow irrotational? If so, find the velocity potential. If not, show a velocity potential does not exist.*
4. *Describe the flow represented by this stream function. Note* $\psi = 0$ *represents a solid surface.*

Assume: Steady, planar x-z flow

Given: $K = 2; -25 < \psi < 0$

Solution: The definition of a stream function must be considered, seen in Eq. [2.1] below:

$$\psi = (x, z), \text{where } w = -\frac{\partial \psi}{\partial x} \text{ and } u = \frac{\partial \psi}{\partial z} \tag{2.1}$$

To first prove that the given stream function satisfies the conservation of mass, the definition of continuity must be used, seen in Eq. [2.2]:

$$\nabla \cdot \vec{v} = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = \frac{\partial^2 \psi}{\partial x \partial z} - \frac{\partial^2 \psi}{\partial x \partial z} = 0 \tag{2.2}$$

To define our stream function according to Eq. [2.1], the partial derivative of ψ was taken w.r.t. x and z to determine w and u, as seen below in Eqs. [2.3,2.4]:

$$w = -\frac{\partial \psi}{\partial x} = -\frac{K}{2}\left[\frac{\partial}{\partial x} z^2 + \frac{\partial}{\partial x} x^2\right] = -K \cdot x \tag{2.3}$$

$$u = \frac{\partial \psi}{\partial z} = \frac{K}{2}\left[\frac{\partial}{\partial z} z^2 + \frac{\partial}{\partial z} x^2\right] = K \cdot z \tag{2.4}$$

Using these w and u and plugging them into Eq. [2.2] demonstrates that the stream function does satisfy the conservation of mass:

$$\frac{\partial}{\partial x} u = K \frac{\partial}{\partial x} z = 0 \; and \; \frac{\partial}{\partial z} w = -K \frac{\partial}{\partial z} x = 0$$

$$\therefore \; \nabla \cdot \vec{v} = \frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0 + 0 = 0$$

To next check if the given stream function is irrotational, consider the definition of irrotational flow in 2 dimensions, Eq. [2.5], where flow vorticity is zero:

$$\vec{\xi} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \nabla \times \vec{v} = 0 \tag{2.5}$$

Considering the definitions of u and w from Eq. [2.1] yields Eq. [2.6]:

$$\vec{\xi} = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = \frac{\partial^2 \psi}{\partial z^2} + \frac{\partial^2 \psi}{\partial x^2} = \nabla^2 \psi = 0 \tag{2.6}$$

Already knowing u and w from Eqs. [2.3,2.4], the next partial derivatives are computed:

$$\frac{\partial}{\partial x} w = \frac{\partial}{\partial x} - Kx = -K \; and \frac{\partial}{\partial z} u = \frac{\partial}{\partial z} Kz = K$$

Plugging into Eq. [2.6] shows the vorticity of the flow is **not** equal zero and thus **not** irrotational:

$$\vec{\xi} = \nabla^2 \psi = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} = K - (-K) = 2K \neq 0$$

To show that a velocity potential does not exist, first extending the continuity definition, Eq. [2.2], yields the Laplace equation, Eq. [2.7]:

$$\nabla \cdot \vec{v} = \nabla \cdot \nabla\phi = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial z^2} = \nabla^2\phi = 0 \tag{2.7}$$

Recognizing the similarity to Eq. [2.6], and knowing that a fundamental solution to ϕ is the same as the fundamental solution to ψ, these can be set equal, seen in Eq. [2.8]:

$$\nabla^2\psi = \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial z^2} = 0 = \frac{\partial^2\phi}{\partial x^2} + \frac{\partial^2\phi}{\partial z^2} = \nabla^2\phi \tag{2.8}$$

Expanding the second partials according to the definitions of w and u yields the following:

$$\frac{\partial^2\psi}{\partial x^2} = \frac{\partial}{\partial x}\frac{\partial\psi}{\partial x} = \frac{\partial}{\partial x}(-w) = \frac{\partial}{\partial x}\left(-\frac{\partial\phi}{\partial z}\right)$$

$$\frac{\partial^2\psi}{\partial z^2} = \frac{\partial}{\partial z}\frac{\partial\psi}{\partial z} = \frac{\partial}{\partial z}(u) = \frac{\partial}{\partial z}\left(\frac{\partial\phi}{\partial x}\right)$$

These equations can be manipulated to form a system that solves for ϕ as a function of x and z, seen in Eq. [2.9]:

$$\phi(x, z) = \begin{cases} \int u\, dx = \int Kz\, dx = Kzx + c_x \\ \int w\, dz = \int -Kx\, dz = -Kxz + c_z \end{cases} \tag{2.9}$$

Both equations are still independently valid forms of ϕ, however, solving both reveals that they do not result in the same answer. Computing $\phi \neq \phi$ proves that a function $\phi(x, z)$ does not exist for this stream function.

Results: The streamline plot for ψ is shown in Fig. [8] below:

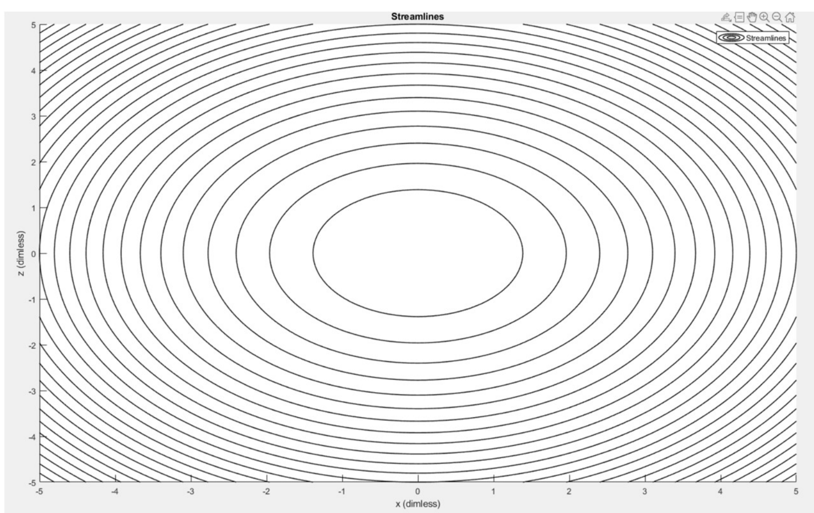

Figure 8: Streamlines for the given ψ. Note the lack of constant potential lines since they do not exist.

Discussion: The flow shown in Fig. [8] shows streamlines for this ϕ. Note they are all closed curves, and as such have no velocity potential, and thus no definite flow direction. This flow has vorticity and does not satisfy Laplace's equation criteria to have a defined ϕ. In retrospect, this is hinted at by the $(z^2 + x^2)$ term in the streamline equation, as in polar coordinates, it nearly assumes the form of $\psi_{vortex} = \frac{\Gamma}{2\cdot\pi} \cdot ln(r)$, the form followed by ψ for a point vortex.

III. Appendix

```
%% Header
% Author: Zakary Steenhoek
% Date: 26 September 2024
% AEE 360 HW03_1_1

clc; clear; clf; %close all;

%% Find data files for NACA 0012 & 4412

% Load data from the text files for both airfoils
dataPath_0012 = 'C:\Users\zaste\OneDrive\Documents\Software\MATLAB\AEE360\HW03\0012_data';
dataPath_4412 = 'C:\Users\zaste\OneDrive\Documents\Software\MATLAB\AEE360\HW03\4412_data';
dataFiles_0012 = dir(fullfile(dataPath_0012));
dataFiles_4412 = dir(fullfile(dataPath_4412));

% Get rid of standard listed dirs
dataFiles_0012(1:2)=[]; dataFiles_4412(1:2)=[];

% To record the data for each airfoil
allC_0012 = zeros(length(dataFiles_0012), 3);
allC_4412 = zeros(length(dataFiles_4412), 3);

%% Generate Cl & Cd for NACA 0012

% For the number of 0012 data files
for itr = 1:length(dataFiles_0012)
  % Build path to the file and import the data
  filePath = fullfile(dataPath_0012, dataFiles_0012(itr).name);
  dataFile = importdata(filePath);

  % Parse the filename to get the angle of attack
  subs = split(dataFiles_0012(itr).name, '_'); lastSub = subs{end};
  alphadeg = erase(lastSub, '.txt');

  % Determine if alpha is negative and convert to int
  if contains(lastSub, 'm')
    alphadeg = erase(alphadeg, 'm');
    alphadeg = -1*str2double(alphadeg);
  else
    alphadeg = str2double(alphadeg);
  end

  % Convert to rad
  alpha = alphadeg*pi/180;

  % Extract x and z columns and ipc column
   dimlessX = flipud(dataFile.data(:, 1));
   dimlessZ = flipud(dataFile.data(:, 3));
   ipc = flipud(dataFile.data(:, 4));

  % Find force coefficients for x and z
   cfx = trapz(dimlessZ, ipc); cfz = trapz(dimlessX, -ipc);

   % Lift and drag coefficient calculations
```

```
    cl = cfz*cos(alpha)-cfx*sin(alpha);
   cd = cfz*sin(alpha)+cfx*cos(alpha);

   allC_0012(itr,1) = alphadeg;
   allC_0012(itr,2) = cl; allC_0012(itr,3) = cd;
end

% Sort the data
allC_0012 = sort(allC_0012);

%% Generate Cl & Cd for NACA 4412

% For the number data files
for itr = 1:length(dataFiles_4412)
   % Build path to the file
   filePath = fullfile(dataPath_4412, dataFiles_4412(itr).name);
   dataFile = importdata(filePath);

   % Parse the filename to get the angle of attack
   subs = split(dataFiles_4412(itr).name, '_'); lastSub = subs{end};
   alphadeg = erase(lastSub, '.txt');

   % Determine if alpha is negative and convert to int
   if contains(lastSub, 'm')
      alphadeg = erase(alphadeg, 'm');
      alphadeg = -1*str2double(alphadeg);
   else
      alphadeg = str2double(alphadeg);
   end

   % Convert to rad
   alpha = alphadeg*pi/180;

   % Extract x and z columns and ipc column
    dimlessX = flipud(dataFile.data(:, 1));
    dimlessZ = flipud(dataFile.data(:, 3));
    ipc = flipud(dataFile.data(:, 4));

   % Find force coefficients for x and z
    cfx = trapz(dimlessZ, ipc); cfz = trapz(dimlessX, -ipc);

    % Lift and drag coefficient calculations
    cl = cfz*cos(alpha)-cfx*sin(alpha);
    cd = cfz*sin(alpha)+cfx*cos(alpha);

   allC_4412(itr,1) = alphadeg;
   allC_4412(itr,2) = cl; allC_4412(itr,3) = cd;
end

% Sort the data
allC_4412 = sort(allC_4412);

%% Cl-Alpha Plot

  % Plot Cl data for airfoil 0012
figure(1); tiledlayout(2,2);
```

```
Cl0012 = nexttile(); hold on;
scatter(allC_0012(:,1), allC_0012(:,2), 'k*');
ClCv_0012 = polyfit(allC_0012(:,1), allC_0012(:,2), 1);
fplot(poly2sym(ClCv_0012), 'k-');
xlabel('Angle of Attack (deg)'); ylabel('Lift Coefficient (dimless)');
 title('NACA0012 Lift Coefficient vs. Angle of Attack');
 grid on; hold off; zeroLiftAoA_0012 = roots(ClCv_0012);

% Plot Cl data for airfoil 4412
Cl4412 = nexttile(); hold on;
scatter(allC_4412(:,1), allC_4412(:,2), 'k*');
ClCv_4412 = polyfit(allC_4412(:,1), allC_4412(:,2), 1);
fplot(poly2sym(ClCv_4412), 'k-');
xlabel('Angle of Attack (deg)'); ylabel('Lift Coefficient (dimless)');
 title('NACA 4412 Lift Coefficient vs. Angle of Attack');
 grid on; hold off; zeroLiftAoA_4412 = roots(ClCv_4412);

 %% Cd-Alpha Plot

 % Plot Cd data for airfoil 0012
Cd0012 = nexttile(); hold on;
scatter(allC_0012(:,1), allC_0012(:,3), 'k*');
CdCv_0012 = polyfit(allC_0012(:,1), allC_0012(:,3), 3);
fplot(poly2sym(CdCv_0012), 'k-');
xlabel('Angle of Attack (deg)'); ylabel('Drag Coefficient (dimless)');
 title('NACA0012 Drag Coefficient vs. Angle of Attack');
 grid on; hold off;

% Plot Cd data for airfoil 4412
Cd4412 = nexttile(); hold on;
scatter(allC_4412(:,1), allC_4412(:,3), 'k*');
CdCv_4412 = polyfit(allC_4412(:,1), allC_4412(:,3), 3);
fplot(poly2sym(CdCv_4412), 'k-');
xlabel('Angle of Attack (deg)'); ylabel('Drag Coefficient (dimless)');
 title('NACA 4412 Drag Coefficient vs. Angle of Attack');
 grid on; hold off;


 %% Header
 % Author: Zakary Steenhoek
 % Date: 26 September 2024
 % AEE 360 HW03_1_2

 clc; clear; clf; %close all;

%% Find data files for NACA 0012 & 4412

 % Load data from the text file
dataFile = importdata("xx15data.txt");
alphadeg = -2.15;

% Convert to rad
alpha = alphadeg*pi/180;

% Extract x and z columns and ipc column
dimlessX = dataFile.data(:, 1);
```

```
dimlessZ = dataFile.data(:, 2);
ipc = dataFile.data(:, 3);
% dimlessX = flipud(dataFile.data(:, 1));
% dimlessZ = flipud(dataFile.data(:, 2));
% ipc = flipud(dataFile.data(:, 3));
n = length(dimlessX);

% Find force coefficients for x and z
cfx = trapz(dimlessZ, ipc); cfz = trapz(dimlessX, -ipc);

% Lift and drag coefficient calculations
cl = cfz*cos(alpha)-cfx*sin(alpha);
cd = cfz*sin(alpha)+cfx*cos(alpha);

 %% Cl-Alpha Plot

 % Plot the x-z cross section and pressure distribution data for airfoil 0012
 figure(1); tiledlayout(2,1); x_section = nexttile; hold on;
 plot(dimlessX, dimlessZ, 'black-');
 xlabel('x (Chord length)'); ylabel('z (Thickness)');
 title('Airfoil xx15 Cross-Section');
 grid on; axis equal;
hold off;

 press_dist = nexttile; hold on;
 plot(dimlessX(n/2:n), ipc(n/2:n), 'b', dimlessX(1:n/2+1), ipc(1:n/2+1), 'b--');
 xlabel('x (Chord length)'); ylabel('Pressure Coefficient');
 title('Airfoil xx15 Pressure Distribution');
 legend('Upper Surface', 'Lower Surface');
 axis ij; grid on; axis([0 1 -1.5 1]); hold off;

 %% Header
 % Author: Zakary Steenhoek
 % Date: 26 September 2024
 % AEE 360 HW03_2_1

 clc; clear; clf; %close all;

%% Contour Plot

% Define known values
syms X Z;
K = 2;
psi = @(X,Z) (K/2).*(Z.^2-X.^2);
phi = @(X,Z) K.*Z.*X;
U = diff(psi, Z);
W = diff(psi, X);

% Create a meshgrid
xDim = 0:0.1:5;
zDim = 0:0.1:5;
[x,z] = meshgrid(xDim, zDim);

% Compute streamlines and velocity potentials
stmLn = psi(x,z);
velPot = phi(x,z);
```

```
%% Configure the plot
figure(1); clf; hold on;
contour(x, z, velPot, 25, 'LineWidth', 1); colorbar;
[C,h] = contour(x, z, stmLn, 25, 'k->', 'LineWidth', 1);


%% Use velocity gradient to create directional quiver arrows

% Downsize the grid so quiver not so busy
[qx,qz] = meshgrid(0:0.4:5,0:0.4:5); qvelPot = phi(qx,qz);
[qu,qv] = gradient(qvelPot);

% Configure the plot
quiver(qx,qz,qu,qv, 0.70, "filled", 'k');
xlim([0,5]); ylim([0,5]); hold off;
title('Streamlines and Velocity Potential');
legend('Velocity Potential','Streamlines');
xlabel('x (dimless)'); ylabel('z (dimless)');
ylabel(colorbar, 'Velocity Potential');


 %% Header
 % Author: Zakary Steenhoek
 % Date: 26 September 2024
 % AEE 360 HW03_2_2

 clc; clear; clf; %close all;

%% Contour Plot

% Define known values
syms X Z;
K = 2;
psi = @(X,Z) (K/2).*(Z.^2+X.^2);
U = diff(psi, Z);
W = diff(psi, X);

% Create a meshgrid
xDim = -5:0.1:5;
zDim = -5:0.1:5;
[x,z] = meshgrid(xDim, zDim);

% Compute streamlines
stmLn = psi(x,z);

% Configure the plot
figure(1); hold on;
contour(x, z, stmLn, 25, 'k->', 'LineWidth', 1);
title('Streamlines');
legend('Streamlines');
xlabel('x (dimless)'); ylabel('z (dimless)');
```