

# FLUENT - Flow over an Airfoil- Step 7

Problem Specification

1. Create Geometry in GAMBIT
2. Mesh Geometry in GAMBIT
3. Specify Boundary Types in GAMBIT
4. Set Up Problem in FLUENT
5. Solve!
6. Analyze Results

**7. Validate the Results**

Problem 1

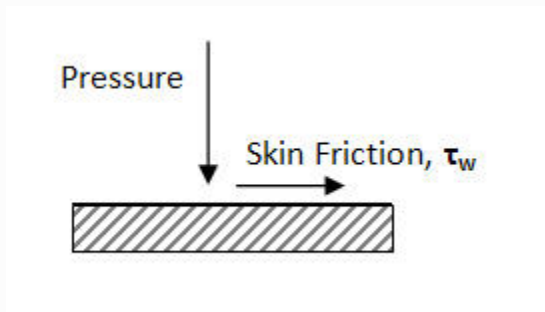
Problem 2

## Step 7: Validate the Results

### **i Force Conventions**

FLUENT report forces in term of pressure force and viscous force. For instance, we are interested in the drag on the airfoil,

$$(\text{Drag})_{\text{total}} = (\text{Drag})_{\text{pressure}} + (\text{Drag})_{\text{viscous}}$$



Drag due to pressure:

$$(\text{Drag})_{\text{pressure}} = \oint P \hat{n} \cdot \hat{e}_d dS$$

Drag due to viscous effect:

$$(\text{Drag})_{\text{viscous}} = \oint \tau_w \hat{t} \cdot \hat{e}_d dS$$

where

$\hat{e}_d$  is the unit vector parallel to the flow direction.

$\hat{n}$  is unit vector perpendicular to the surface of airfoil.

$\hat{t}$  is unit vector parallel to the surface of airfoil.

Similarly, if we are interested in the lift on the airfoil,

$$(\text{Lift}) = (\text{Lift})_{\text{pressure}} + (\text{Lift})_{\text{viscous}}$$

Lift due to pressure:

$$(\text{Lift})_{\text{pressure}} = \oint P \hat{n} \cdot \hat{e}_l dS$$

Lift due to viscous effect:

$$(\text{Lift})_{\text{viscous}} = \oint \tau_w \hat{t} \cdot \hat{e}_l dS$$

where

$\hat{e}_l$  is the unit vector perpendicular to the flow direction.

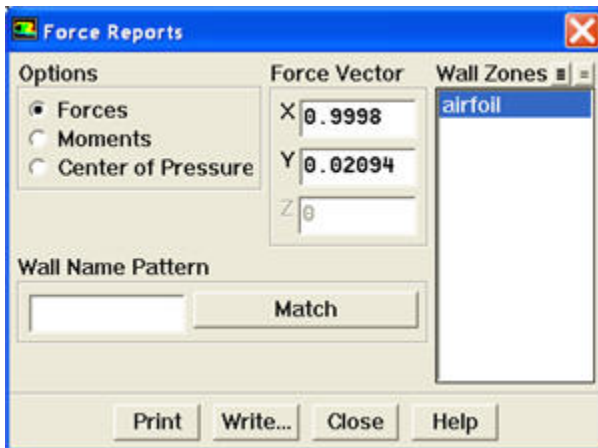
$\hat{n}$  is unit vector perpendicular to the surface of airfoil.

$\hat{t}$  is unit vector parallel to the surface of airfoil.

### **Report Force**

We will first investigate the Drag on the airfoil.

**Main Menu > Report > Forces...**



Select **Forces**. Under **Force Vector**, enter 0.9998 next to **X**. Enter 0.02094 next to **Y**. Select **airfoil** under **Wall Zones**. Click **Print**.

Here's is what we see in the main menu:

|                                      |           |         |           |              |             |             |           |
|--------------------------------------|-----------|---------|-----------|--------------|-------------|-------------|-----------|
| Force vector: (0.99980003 0.02094 0) |           |         |           |              |             |             |           |
|                                      | pressure  | viscous | total     | pressure     | viscous     | to          |           |
| tal                                  |           |         |           |              |             |             |           |
| zone                                 |           |         |           |              |             |             |           |
| name                                 | force     | force   | force     | coefficient  | coefficient | coefficient |           |
|                                      | n         | n       | n         |              |             |             |           |
| -----                                |           |         |           |              |             |             |           |
| airfoil                              | 3.8125084 | 0       | 3.8125084 | 0.0024897052 |             | 0           | 0.0024897 |
| 052                                  |           |         |           |              |             |             |           |
| -----                                |           |         |           |              |             |             |           |
| net                                  | 3.8125084 | 0       | 3.8125084 | 0.0024897052 |             | 0           | 0.0024897 |
| 052                                  |           |         |           |              |             |             |           |

$$C_d = (C_d)_{\text{pressure}} + (C_d)_{\text{skin friction}}$$

where

$(C_d)_{\text{pressure}}$  is due to pressure force.

$(C_d)_{\text{skin friction}}$  is due to viscous force.

Indeed, we see that the  $(C_d)_{\text{skin friction}}$  is zero because of the inviscid model.



In reality,  $(C_d)_{\text{skin friction}}$  has biggest contribution to drag but ignored because of the inviscid model that we specify.  $(C_d)_{\text{pressure}}$  should be zero, but it is not zero because of inaccuracies and numerical dissipation during the computation.

Now, let's look at the lift coefficient.

**Main Menu > Report > Forces...**

Select **Forces**. Under **Force Vector**, enter -0.02094 next to **X**. Enter 0.9998 next to **Y**. Select **airfoil** under **Wall Zones**. Click **Print**.

Here's is what we see in the main menu:

```

Force vector: (-0.02094 0.99980003 0)
total      pressure      viscous      total      pressure      viscous
zone name  force         force         force         coefficient    coefficient
coefficient
              n              n              n
-----
airfoil    1008.3759         0         1008.3759         0.6585058         0
0.6585058
-----
net        1008.3759         0         1008.3759         0.6585058         0
0.6585058

```

Similarly, lift force is due to the contribution of pressure force and viscous force.

$$C_l = (C_l)_{\text{pressure}} + (C_l)_{\text{skin friction}}$$

where

$(C_l)_{\text{pressure}}$  is due to pressure force.

$(C_l)_{\text{skin friction}}$  is due to viscous force.

Since our model is inviscid,  $(C_l)_{\text{skin friction}}$  is zero. We see that the lift coefficient compare well with the experimental value of 0.6.



Do note that the lift coefficient for inviscid model is higher than the experimental value. In reality, if we take into account the effect of viscosity, we will have  $(C_l)_{\text{skin friction}}$  of negative value. The viscous effect will lower the overall lift coefficient. Since our inviscid model neglect the effect of viscosity, we have a slightly higher lift coefficient compared to the experimental data.

## Grid Convergence

A finer mesh with four times the original mesh density was created. The lift coefficient was found to be 0.649.

|       | Original Mesh | Fine Mesh | % Dif |
|-------|---------------|-----------|-------|
| $C_l$ | 0.647         | 0.649     | 0.3%  |
| $C_d$ | 0.00249       | 0.00137   | 45%   |

We see that the difference in drag coefficient is very large. We used inviscid case for our model, so we are expecting a  $C_d$  of zero. However, since the parameter of interest is the lift coefficient, and the value lift coefficient does not deviate much from original mesh to fine mesh, we concluded that the fine mesh is good enough.



The modeling result obtained is still off from the literature result. Further validation steps are needed before we can conclude about the accuracy of our model. Other parameter that will affect the validity of our result is the choice of viscous model. We used inviscid model which basically assumed that the flow inviscid and totally ignore the effect of boundary layer near the airfoil surface. We might want to try out turbulence model for this high Reynolds number flow.

## Summary

Following table shows comparison of modeling result with experimental data.

|                  | $C_l$ | $C_d$   |
|------------------|-------|---------|
| FLUENT Fine Mesh | 0.649 | 0.00137 |
| Experiment       | 0.6   | 0.007   |
| Theory           | -     | 0       |

Though further validation steps are still needed before we can come up with a model that will accurately represent the physical flow, this simple tutorial demonstrates the use of reasonable assumption and approximation in obtaining understanding of physical flow properties around an airfoil.

## Reference

The experimental data is taken from **Theory of Wing Sections** By Ira Herbert Abbott, Albert Edward Von Doenhoff pg. 488

[Google scholar link](#)

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