To use ANSYS Fluent in your house, please use VDI (See below Link) https://etc.engineering.uiowa.edu/help-desk/how-use/vdi-how-use-virtual-windows-desktop

Simulation of Turbulent Flow over the Ahmed Body

ME:5160 Intermediate Mechanics of Fluids CFD LAB 4 (ANSYS 2022 R1; Last Updated: July 19, 2022)

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1. Purpose

The Purpose of CFD Lab 4 is to simulate **unsteady turbulent** flows over the Ahmed body following the "CFD process" by an interactive step-by-step approach and conduct verifications using CFD Educational Interface ANSYS. Students will have "hands-on" experiences using ANSYS to **predict drag coefficients and axial velocity for slant angle 25 degrees and compare them with EFD data.** Students will use post-processing tools (streamlines, velocity vectors, contours, animations) to **visualize the mean and instantaneous flow fields and compute the non-dimensional shedding frequency (Strouhal number)**. Students will analyze the differences between CFD and EFD and present results in a CFD Lab report.



Flow Chart for "CFD Process" for ahmed body

2. Simulation Design

The problem to be solved is unsteady turbulent flows over the Ahmed body (2D). Reynolds number is around 768,000 based on inlet velocity and vehicle height (h). The following figure shows the sketch window you will see in ANSYS with definitions for all geometry parameters. The origin of the simulation is located at the rear of the body. θ is the slant angle. L is the length of the body and h is the height of the body. Uniform velocity specified at inlet and constant pressure specified at outlet. The top boundary of the simulation domain is regarded as "Symmetry" and there is a distance between the car body and road, GL.



For CFD Lab4, all EFD data can be found under the "CFD Lab4: Ahmed Car" section on the class website: <u>http://www.engineering.uiowa.edu/~me_160/</u>.

3. Opening ANSYS Workbench Software

3.1. Start > All Programs > ANSYS 2021 R2 > Workbench 2021 R2

3.2. Drag and drop three component into the **Project Schematic**, name the components and create connections between components as per below.



4. Geometry Creation

4.1. From the **Project Schematic** right click **Geometry** and select **New DesignModeler Geometry...**



4.2. Make sure that Unit is set to Meter and Degree (default settings).



4.3. Select the XYPlane then click the New Sketch button.



4.4. Enable the auto constraints option to pick the exact point as below

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4.5. Use the **Rectangle** tool under **Draw** to make a rectangle starting from the origin and ending inside the first quadrant. Dimension it using **General** dimension as per below. (Click the z arrow of the 3D orientation located at the bottom right to make the view perpendicular to xy-plane. Make sure to click the origin when the mouse cursor is changed to "P")



4.6. Use the **Rectangle** tool again to draw an another rectangle as per below.



4.7. Use the **Fillet** tool in **Modify** to put a radius on the front corners of the Ahmed Car as per below. Use the **Radius** size of 0.1m. After changing the value, click the front corners.



4.8. Use the **Chamfer** tool to put a chamfer on the back of the Ahmed Car as per below. Use the **Length** of 0.25m. (Shape of the body could be different depending on the rectangle you made)



4.9. Put a constraint on the two radii using the **Equal Radius** tool in **Constraints**. (Note: in the bottom left corner next to the checkmark in a green circle is the note on how to use a tool)



4.10. Dimension the body inside the rectangle as per below using **Horizontal**, **Vertical**, **Radius**, and **Angle** under **Dimensions**. (The name of each dimension will be followed by the order you make it, so it may be different from the manual)



4.11. Concept > Surface From Sketches. Select the sketch you just created under the tree outline and click Apply. Click Generate.



4.12. Select **XYPlane** and click the **New Sketch** button. In this new sketch, use the **Line** tool under **Draw** to make the lines as per below. Three lines will extend over the entire domain, horizontally or vertically. Make sure that the **C** appears when you are on the line and the **V/H** appears next to the line being created, ensuring that you are pointing on the edge and the line is vertical/horizontal.



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4.13. Use the Horizontal and Vertical dimension tool to dimension the lines as per below.

4.14. Go back to **Modeling** tab and then **Tools** > **Face Split**.



4.15. Select the gray surface for **Target Face** and click **Apply.** For **Tool Geometry** select two endpoints of the one line you just created while holding **Ctrl** then click **Apply**. Select **Tool Geometry** again and select two more endpoints of another line and click **Apply**. Repeat this process for the last line and click **Apply**. Click **Generate**. This splits the surface into six pieces.



(The picture above was taken right before clicking 'Generate')

4.16. Tools > Merge.



4.17. Change the **Merge Type** to **Faces** and select the top three faces. Click **Apply** then **Generate**.



(The picture above was taken right before clicking 'Apply')

4.18. File > Save Project. Close the Design Modeler window.

5. Mesh



5.1. Right click Mesh and from the dropdown menu then select Edit...

5.2. Right click on Mesh > Insert > Inflation.



5.3. For Geometry option, select the surface of the domain which borders the Ahmed Car and click Apply (Change the cursor to 'Surface Selector' at upper region to select the surface). For the Boundary, select the edges of the Ahmed Car by holding Ctrl and selecting the edges and then click Apply. There should be seven edges selected for the Boundary. Change the parameters in Details of "Inflation" – Inflation as per below.



5.4. Right click **Mesh** > **Insert** > **Method**. Select the whole domain (surfaces) for Geometry and click **Apply**. Change the **Method** to **Triangles**.



5.5. Right click Mesh > Insert > Sizing. Select the line as per below and click Apply. Change the parameters of sizing as per below. Repeat this for the following figures below. There should be 22 edge sizings in total. Change the cursor to "Edge Selector" to select the edges.















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5.6. Click on Mesh under the Outline and change the Physics Preference to CFD.



5.7. Click Generate Mesh.



5.8. Select 'Edge Selector'. Select the top edges of the domain by holding **Ctrl** while selecting, right click, select **Create Named Selection** from the dropdown menu. Name the top edge 'symmetry'.



5.9. Repeat step 5.8 for the bottom edges and name them 'road'.





5.10. Repeat step 5.8 for the left edges and name them *'inlet'*.

5.11. Repeat step 5.8 for the right edges and name them 'outlet'.



5.12. Repeat step 5.8 for the filleted corners and the straight segment that connects them and name them '*nose*'.



5.13. Repeat step 5.8 for the sloped edge of the Ahmed Car and name it 'slope'.





5.14. Repeat step 5.8 for the top edge of the Ahmed Car and name it 'ahmed top'.

5.15. Repeat step 5.8 for the bottom edge of the Ahmed Car and name it 'ahmed bottom'.





5.16. Repeat step 5.8 for the right vertical edge of the Ahmed Car and name it *back*.

- 5.17. File > Save Project. Close Meshing window.
- 5.18. Update the mesh by right clicking Mesh and from the dropdown menu select Update.



6. Setup

6.1. Right click Setup and select Edit...

| ✓ A 1 Geometry 2 Geometry ✓ A | ✓ B 1 Wesh 2 Wesh ✓ | ✓ C 1 | |
|---------------------------------------------------------------------|-----------------------------------------------------------|-----------------------------------|-----------------------------------------------------------------------------------------|
| ahmed body | unstructured | 3 🕼 Solution | Edit Register Startup Scheme File |
| | | ĸ-e | Import Fluent Case And Data > Import Fluent Case > Import ROM > |
| | | a | Duplicate Transfer Data From New Transfer Data To New |
| | | 7 | Update |

6.2. Select Double Precision and click START.

| Setting Edit Only) - | | × |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------|------------------------|
| Fluent Launcher | <mark>/\</mark> ns | sys |
| Simulate a wide range of steady and transient industrial application general-purpose setup, solve, and post-processing capabilities of A including advanced physics models for multiphase, combustion, ele and more. | ns using NSYS Fl ectrocher | the uent nistry, |
| Dimension | | |
| () 2D | | |
| 0 20 | | |
| ⊖ 3D | | |
| Options | | |
| | | |
| | | |
| 🗹 Display Mesh After Read | ling | |
| Do not show this panel a | again | |
| | 2 | |
| | | |
| Parallel (Local Machine) | | |
| Solver Processes | 1 | ¢ |
| Solver GPGPUs per Machine | 0 | \$ |
| ✓ Show More Options ✓ Show Learning Resources Start Cancel Help | | |



6.3. Setup > General. Change Solver to Transient as per below.

6.4. Setup > **Models** > **Viscous** > **Edit...** Change the turbulent model and near-wall treatment as per below.



6.5. Setup > Materials > Fluid > air > Create/Edit... Change the air Density and Viscosity as per below and click Change/Edit then close the window.

| C General | rista | | - + | | | |
|------------------------------|-------------------|------------------------------|-----------------------------|------|----------|----------------|
| Ø Models | Fluid | | | | | |
| A Materials | di | | -Q+ | | | |
| 🕞 🚑 Fluid | Create/Edit Mater | ials | | | | × |
| 🔐 air | Name | | Material Type | | Order Ma | terials by |
| 💿 🗳 Solid | air | | fload | | | |
| 🔹 🖽 Cell Zone Conditions | un | | India | | • Name | 6 |
| 📀 🖽 Boundary Conditions | Chemical Formula | | Fluent Fluid Materials | | ⊖ Chem | ical Formula |
| 🗱 Mesh Interfaces | | | air | * | | |
| Ø Dynamic Mesh | | | Mixture | | Fluer | nt Database |
| Reference Values | | | 0000 | | GRANTA | MDS Database |
| 💿 🔀 Reference Frames | | | none | | <u> </u> | |
| f> Named Expressions | | | | | User-De | fined Database |
| Solution | | Deservation | | | | |
| % Methods | | Properues | | | | |
| 🔀 Controls | | Density [kg/m ³] | constant | * | Edit | |
| Report Definitions | | | | | _ | |
| A Monitors | | 1 | .225 | | | |
| Cell Registers | | Viecosity [ka/(m.e)] | constant | | Edit | |
| Automatic Mesh Adaption | | viacoardy Exgr (in a)1 | constant | | East | |
| Initialization | | 1 | .787e-05 | | | |
| Calculation Activities | | - | | | | |
| Run Calculation | | | | | | |
| Results | | | | | | |
| Surfaces | | | | | | |
| 📀 🔮 Graphics | | | | | | |
| • Plots | | | | | | |
| Animations | | | | | | |
| 📀 🔜 Reports | | Ch | nange/Create Delete Close I | Help | | |
| Parameters & Customization | | | | | | |

6.6. Setup > **Boundary Conditions** > **inlet** > **Edit...** Change the inlet boundary conditions as per below and click **OK(Apply)**.

| Outline View | Task Page | P Velocity Inlet | \times |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| Filter Text | Boundary Conditions | Zone Name | |
| Filter Text | Boundary Conditions Zone Filter Text ahmed_bottom ahmed_top back interior-surface_body nose outlet road slope surface_body symmetry | inlet Momentum Thermal Radiation Species DPM Multiphase Potential UD Velocity Specification Method Components Reference Frame Absolute Supersonic/Initial Gauge Pressure (pascal) 0 X-Velocity (m/s) 40 Y-Velocity (m/s) 0 Turbulence Specification Method Intensity and Viscosity Ratio Turbulent Intensity (%) 2.93047 Turbulent Viscosity Ratio 10 K Cancel Help | |

6.7. Setup > Boundary Conditions > Zone > outlet > Edit... Change the outlet boundary condition as per below and click OK(Apply).

| Setup | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|---------------------------------------------------------------------------|
| C General | Zone Filter Text | xt See Pressure Outlet X |
| O Models O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O O | ahmed bottom | m Zone Name |
| Attended | ahmed top | outlet |
| 😑 🚑 Fluid | back | |
| A air | inlet | Momentum Thermal Radiation Species DPM Multiphase Potential Structure UDS |
| 📀 🐺 Solid | interior-surface_ | ce_k |
| (*) I Cell Zone Conditions | nose | Backflow Reference Frame Absolute |
| | outlet | Cause Processes [Pa] e |
| (+) = inlet | road | Guuge rressure [ru] 0 |
| († E Internal | slope | Pressure Profile Multiplier 1 |
| | surface_body | |
| a outlet (pressure-outlet id=9) | symmetry | Backflow Direction Specification Method Normal to Boundary |
| (*) E Symmetry | | Backflow Pressure Specification Total Pressure |
| () | | |
| Mach Interfaces | | Prevent Reverse Flow |
| Dunamic Moch | | Average Pressure Specification |
| Beference Values | | Torret Mars Flow Pate |
| Reference Values | | Target Mass Flow Rate |
| Kelerence Frames | | Turbulence |
| Solution | | Specification Method Intensity and Viscosity Ratio |
| 9 Methods | | |
| S Controls | | Backflow Turbulent Intensity [%] 2.93047 |
| Report Definitions | | Backflow Turbulent Viscosity Ratio 10 |
| | | |
| Coll Registers | | |
| Automatic Mach Adaption | | Apply Close Help |
| Automatic Mesh Adaption | | |

| Outline View | < | Task Page | < |
|------------------------------------------------------------------------------------------------------------------------------|---|--------------------------------|---|
| Filter Text | | Reference Values | ? |
| Setup ☑ General ☑ Models ☑ Materials | | Compute from Reference Values | • |
| 📀 🛄 Cell Zone Conditions | | Area [m ²] 0.288 | |
| Boundary Conditions | | Density [kg/m³] [1.225 | |
| Mesh Interfaces | | Depth [m] 1 | |
| B Reference Values | | Enthalpy [J/kg] 0 | |
| Keference Frames | | Length [m] 1 | |
| for Named Expressions | | Pressure [Pa] 0 | |
| Solution | | Temperature [K] 288.16 | |
| Methods Controls | | Velocity [m/s] 40 | |
| Report Definitions | | Viscosity [kg/(m s)] 1.787e-05 | |
| Q Monitors | | Ratio of Specific Heats 1.4 | = |
| 🗃 Cell Registers | | Value for Heat Tran. Coof 200 | = |
| Automatic Mesh Adaption Initialization Calculation Activities Bun Calculation | | Reference Zone | |

6.8. Setup > **Reference Values**. Change the reference values as per below.

In case of 'Yplus for Heat Tran. Coef' leave it as a default value (300)

```
6.9. Solution > Methods. Change solutions methods as per below.
```

| Outline View < | Task Page < |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Filter Text | Solution Methods |
| Setup General Models Materials Cell Zone Conditions Boundary Conditions Mesh Interfaces Dynamic Mesh Reference Values A Reference Frames Named Expressions Solution Methods Controls Seport Definitions Methods Methods Methods Methods Methods | Pressure-Velocity Coupling Scheme PISO Skewness Correction 1 * Neighbor Correction 1 * Skewness-Neighbor Coupling Flux Type Rhie-Chow: distance based * Auto Select Spatial Discretization Gradient Graen-Gauss Cell Based * |
| Cell Registers Automatic Mesh Adaption Initialization Calculation Activities Run Calculation Results Surfaces Graphics Plots Piots Reports Parameters & Customization | Pressure PRESTO! Momentum QUICK Turbulent Kinetic Energy QUICK Turbulent Dissipation Rate QUICK Transient Formulation |
| € Simulation Reports | First Order Implicit Non-Iterative Time Advancement Frozen Flux Formulation Warped-Face Gradient Correction High Order Term Relaxation Default |



6.10. Solution > Monitors > Residuals. Change the parameters as per below and click ok.

*Step 6.11~6.14 is for saving the time history file of the total drag coefficient.

| Outline View | Task Page 🛞 🚺 |
|---------------------------------------------------------------------------|----------------------------------------------------------------------------|
| Filter Text | Monitors Report Definition quantities can be monitored |
| ⊂ Setup | during solution when they are included in Report Files or Report Plots. |
| | Report File Definitions |
| (*) ⊞ Boundary Conditions ⊘ Dynamic Mesh 🔁 Reference Values | Report Files [0/0] |
| | |
| Methods Controls Report Definitions | |
| A Monitors Residual | New Edit Delete Activate Deactivate Report File Properties |
| E Report Files Report Plots X Convergence Conditi | |
| Cell Registers Initialization Consultion | |
| Calculation Activities E Run Calculation Results | Close Help |
| Parameters & Customization | |

6.11. Solution > Monitors > Report Files > New...

6.12. New > Force Report > Drag....

| New Report File | | | × |
|--------------------------------------------------------------------------------------------------------------|----------------------------------------------|-----------------|----------|
| Name report-file-0 | | | |
| Available Report Definitions [0/2] | Selected Report Definition | ons [0/1] | - |
| delta-time iters-per-timestep Add>> < <remove< th=""><th>flow-time</th><th></th><th></th></remove<> | flow-time | | |
| File Name report-file-0.out Browse Full File Name report-file-0.out | New → Edit Expression Surface Report → | | |
| Get Data Every 1 🗘 time-step 💌 | Force Report | Drag Lift | |
| OK Cancel Help | DPM Report ► User Defined | Moment Force | |

6.13. Change name, select wall zones as below and click OK(Apply) to exit.

| Drag Report Definition | | × |
|--------------------------|---------------------------------|----------|
| Name | | |
| drag-coefficient | | |
| Options | Report Output Type | |
| | Drag Coefficient Drag Force | |
| Per Zone | Wall Zones Filter Text | ₹, ₹, ₹, |
| Average Over(Time Steps) | ahmed_bottom ahmed_top | |
| Force Vector | back | |
| | road | |
| | slope | |
| | | |
| Report Plots [0/0] | | |
| Create | | |
| Report File | | |
| Report Plot | | |
| Frequency 1 | | |
| Print to Console | | |
| Create Output Parameter | | |
| | OK Compute Cancel Help | |

6.14. Change name and click **Browse** to locate the file. Click **OK(Apply)** to exit. Exit the Report File Definition dialog as well.

| New Report File | × |
|-----------------------------------------------------------------------------|-------------------------------------------------------------------------|
| Name drag-coefficient I Active Available Report Definitions [0/2] | Selected Report Definitions [2/2] = = = = = = = = = = = = = = = = = = = |
| | < <remove< td=""></remove<> |
| File Name H:/9. TA/report-file-0.out Full File Name report-file-0.out | New , Edit |
| Print to Console | ancel Help |

*Step 6.15~6.16 is for the plotting of the time history of the total drag coefficient during the computation.

| Outline View | Task Page | • |
|----------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|------------------------|
| Filter Text | Monitors Report Definition quantities can be monitored | |
| 🕞 Setup 🗟 General | during solution when they are included in Report Files or Report Plots. | |
| Ø Models Ø Materials El Cell Zone Conditions | Report Plot Definitions | × |
| Boundary Conditions Dynamic Mesh Reference Values | Report Plots [0/0] | Report Definitions |
| Keterence Frames Named Expressions Solution Methods | | |
| Controls | | |
| | New Edit Delete Activate Deactivate | Report Plot Properties |
| Convergence Conditi | | |
| Initialization Calculation Activities Run Calculation | | |
| ● Results ● Parameters & Customization | Close Help | |

6.15. Solution > Monitors > Report Plots > New...

6.16. Select drag-coefficient generated from step 6.12~6.13 and **add** to right. Name the plot and change the x-axis condition by clicking **Axes...** as below. Exit from all dialogs.

| New Report Plot | | × | | |
|------------------------------------|------------------------|-----------------|-----------------|---|
| Name drag-coefficient 🗸 Active | | | | |
| Available Report Definitions [0/2] | Selected Report Defini | tions [0/1] 🗾 🔫 | | |
| iters-per-timestep | drag-coefficient | | | |
| Add> | > | | | |
| << Rem | love | | | |
| | love - | | ****** | |
| | | | ****** - | |
| | | | | |
| Options | New 🖵 Edit | | | |
| Get Data Every 1 🖕 time-step | | | | |
| Plot Title drag-coefficient | Axes - Report Plots | | | × |
| X-Axis Label flow-time | Axis | Number Format | Maior Rules | |
| Y-Axis Label Drag | • x | Туре | Color | |
| Plot Instantaneous Values | > O Y | float | light gray | * |
| Print to Console | Labol | Precision | Weight | |
| | | 3 🌲 | 1 | |
| OK Plot Axes Curves | in Ontions | Pange | Minor Pulos | |
| | | Minimum | Color | |
| | Auto Range | 0.01 | light gray | - |
| | Major Rules | Maximum | Weight | |
| | Minor Rules | 0.225 | 1 | |
| | | | | |
| ` | | Apply Close Hel | D | |
| | | | <u>.</u> | |

Solution > Initialization. Change X-Velocity and turbulent parameters as per below. Click Initialize.

| Outline View | < | Task Page |
|-------------------------------------------------|---|--------------------------------------------------------------|
| Filter Test | | |
| Filter Text | | Solution Initialization |
| Setup | | Initialization Methods |
| C General | | Hybrid Initialization |
| Ø Models | | Standard Initialization |
| Arr Materials Arr Coll Zong Conditions | | Compute from |
| Cell Zone Conditions El Boundary Conditions | | |
| Mesh Interfaces | | |
| Dynamic Mesh | | Reference Frame |
| Reference Values | | Relative to Cell Zone |
| 📀 🔼 Reference Frames | | O Absolute |
| for Named Expressions | | Initial Values |
| Solution Mathada | | Gauge Pressure [Pa] |
| Controls | | 0 |
| Report Definitions | | X Velocity [m/s] |
| 😑 🔍 Monitors | | 40 |
| 🖄 Residual | | Y Velocity [m/s] |
| 😑 🖻 Report Files | | |
| drag-coefficient2 | | Turkulant Kinatia Energy [m ² /a ²] |
| Conversion Conditions | | Turbulent Kinetic Energy [m-/s ⁻] |
| Convergence Conditions | | 2.061034 |
| Automatic Mesh Adaption | | Turbulent Dissipation Rate [m ² /s ³] |
| Initialization | | 2620.743 |
| 📀 🏶 Calculation Activities | | |
| Run Calculation | | |
| Results | | Initialize Reset Patch |
| Surfaces A Cranhier | | |
| Graphics Graphics Dists | | Reset DPM Sources Reset LWF Reset Statistics |
| Animations | | |
| 💿 🔜 Reports | | VOF Check |
| Parameters & Customization | | |
| Simulation Reports | | |

6.17. Solution > Calculation Activities > Solution Animations (right click) > New... Change the parameters as per below.

| Animation Definition | × | Contours | | | × |
|------------------------------------------------------|------------|-------------------|----------------------|--------------------------------------------|------|
| Name: streamline-ani | | Contour Name | | | |
| Porord after eveny 50 | | contour-1 | | | |
| Storago Tupo | | Options | Contours of | | |
| PPM Image + | | Filled | Velocity | | Ŧ |
| Storage Directory | | ✓ Node Values | Stream Function | | Ŧ |
| Animation View | | Contour Lines | Min | Max | |
| The selected object | USC ACUTC | Auto Range | 0 | 10 | |
| Animation Object | F | ✓ Clip to Range | Surfaces Filter Text | | E, |
| residuals | | 🔲 Draw Profiles | ahmed bottom | | - |
| drag-coefficient2 | | Draw Mesh | ahmed_top | | - 8 |
| | | | back | | |
| | | Coloring | interior-surface bo | dv. | |
| | | Banded | nose | * | . 8 |
| | | O Smooth | outlet | | - |
| | | Calanna Oationa | Display State | | |
| | | colorniap options | None | Use Active New Surface | ce 🖵 |
| New Object 🚽 Edit Object | | | | | _ |
| Mesh | | | ave/Display | oute Close Help | |
| Contours OK Cancel Help | | | |)()(| |
| Vectors. | | Coloimap | | | ^ |
| Pathlines | | Show Colormap | | | |
| Particle Tracks | | Associated Object | | | |
| Scene | | contour-1 | | | |
| XY Plot | = | Labels | | Colormap | |
| Report Plot | | Automatic Skip | | Log Scale | |
| | | Skip | | Colormap Size | |
| | | 8 w | | 99 👻 | |
| | - <u>u</u> | Type | | Colormap Alignment | - |
| Create/Edit | | exponential | | Currently Defined | |
| Automatically Initialize and Modify Case | | Precision | | hor | * |
| | ` | 2 | a - | | |
| Initialization: Initialize with Values from the Case | * | Font | | Edit Delete | |
| Original settings, Duration = 1 | | Font Name | | Colormap Dimensions | |
| | 5 | Helvetica | - | Length | |
| | | Font Behavior | | Width Patio | |
| | | Automatic | | 6 | |
| | | Font Size | | | |
| | | 0.032 | | | |
| | | | | | |
| | | | Apply | Belp | |
| | Console | | | | |

6.18. After 6.18, make sure to highlight streamline as an object and then close by clicking OK.

| Animation Defined | nition | | × |
|-------------------|----------------------|-----------|------------|
| Name: streamline- | ani | | |
| Record after even | y 50 | time-step | - |
| Storage Type | PPM Image | | |
| Storage Directory | | | |
| Animation View | From Selected Object | • Preview | Use Active |
| Animation Object | | | F |
| residuals | | | |
| streamlines | | | |
| drag-coefficient | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |
| New Object 🔪 | Edit Object | | |
| | OK Cancel | Help | |

6.19. Solution > Calculation Activities > Solution Animations (right click) > New... Change the parameters as per below.



6.20. After 6.20, make sure to highlight viscosity-ratio as an object and then click OK.

| Animation Definition | × |
|---------------------------------------------------------|--------|
| Name: viscosityratio-ani | |
| Record after every 50 iteration Storage Type PPM Image | • |
| Animation View From Selected Object Preview Use A | Active |
| Animation Object | = |
| viscosity-ratio streamlines drag-coefficient | |
| New Object 🔪 Edit Object | |
| OK Cancel Help | |

6.21. Solution > Run Calculation. Change parameters as per below and click Calculate. If you have the correct setup you should see four tabs on the upper sides of the display. You can change what the window shows by changing the tab. Tab 1-4 shows the residuals, streamlines, turbulent viscosity ratio and time-history of drag coefficient. After running for about 0.05 flow time you should see vortices at the back of the ahmed car on tab 2 and 3. NOTE: This simulation could take up to an hour depending on the computer performance. Please make sure your setup is correct before running the simulation! If you close Fluent window after running the simulation, the data for the post-process is not lost, but harder to access. If at all possible, finish post-processing after solving. Accessing the time-history of drag coefficient and post processing videos after the Fluent window is closed will be explained in later sections.





After the computation, you should see the images below:

7. Results

7.1. Creating lines to plot modified TKE and modified U.

Setting Up Domain > Surface > Create > Line/Rake. Create 10 lines at the locations given at the table below.

| <u>F</u> ile Domain | Physics User-D | efined Solution | Results | Vie | w Pa | arallel Design | ^ | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|------------------------------------------------------------------------------------|------------------------|------------------------------------------------------------------------------------------|
| Mesh | Scale ∴ Transform ↓ ity ↓ Amake Polyhedra | Combine → Delete. Separate → Combine → Adjacency Adjacency | es [the App rate 📸 Rep e 📑 Rep | end 🖕 Iace Mesh Iace Zone | Interfaces Mesh Werset | Mesh Models Dynamic Mesh Mixing Planes Turbo Topology | Adapt Refine / Coarsen | Surface + Create Zone Partition |
| Outline View | Task Page | X | | 🚺 Line/Rake | Surface | > | drag-coefficient | Imprint Co |
| Filter Text Setup General O Models Cell Zone Conditions Cell Zone Cell Zone Conditions Cell Zone | Run Calculation Check Case Time Stepping Method Fixed * Settings Options Extrapolate Variables Data Sampling for Tir Sampling Interval 1 \$ Time Sample | Preview Mesh Motion Time Step Size (s) 0.0001 Vmmber of Time Steps 2000 Re Statistics Sampling Options d (s) 0.2 | streamline Stream Flutts 9.60 - 9.09 - 8.59 - 8.08 - 7.58 - 7.58 - 7.60 - 5.55 - 5.55 | New Surface position-1 Options Line Reset End Points x0 (m) 1.78 y0 (m) 0.05 z0 (m) 0 | Type Line 192 x Select Points | Number of Poin 10 1(m) 1.78192 1(m) 5 1(m) 6 with Mouse se] Help | | Point Line/Rake Plane Line/Rake Quadric Iso-Surface Iso-Clip Transform |

| Surface Name | x0 | y0 | x1 | y1 |
|--------------|---------|------|---------|----|
| position-1 | 1.78192 | 0.05 | 1.78192 | 3 |
| position-2 | 1.932 | 0.05 | 1.932 | 3 |
| position-3 | 1.98208 | 0.05 | 1.98208 | 3 |
| position-4 | 2.03191 | 0.05 | 2.03191 | 3 |
| position-5 | 2.08201 | 0 | 2.08201 | 3 |
| position-6 | 2.13212 | 0 | 2.13212 | 3 |
| position-7 | 2.23206 | 0 | 2.23206 | 3 |
| position-8 | 2.332 | 0 | 2.332 | 3 |
| position-9 | 2.482 | 0 | 2.482 | 3 |
| position-10 | 2.6819 | 0 | 2.6819 | 3 |

7.2. Creating custom function

User-Defined > **Field Functions** > **Custom**. Create custom field functions and click **Define**. You will need to create three custom field functions shown in the table below.

| <u>F</u> ile [| Domain | Phys | cs | Use | er-Defir | ned | Solu | ition | Result | ts View | Parallel | De |
|------------------------------------------------|-------------------------|--------------|----------|---------|-----------|---------|-------------|----------|------------------------|--------------------------|----------|----|
| Field Functions | | | User | Define | d | | | Mod | lel Specific | | | |
| Custom | ∫ | ∱∞ Fu | nction H | ooks | 2 | nem 🎸 🗸 | iory ars | 1 🔁 1 | D Coupling an Model | | | |
| Parameters | | Ex Ex | ecute or | Demar | nd [| 🔒 Read | l Table | | | | | |
| Outline View | | Cust | om Field | Functio | n Calcula | ator | | | | | | × |
| Filter Text | | Definition | 1 3 | | | | | | | | | |
| Setup General | | + | - | x | | v^x | ABS | | Selec | t Operand Field Function | ons from | |
| General Models | | | cin | 606 | tan | | log10 | | Field | Functions | | |
| 💿 🖉 Materia | ls | | | | | | | | Mes | h | - | |
| 🕂 🖽 Cell Zon | e Conditions | | | 2 | 3 | 4 | SQRT | | Y-O | oordinate | - | |
| 🐨 🗖 Boundar | ry Conditions • Mesh | 5 | 6 | 7 | 8 | 9 | CE/C | | Sole | xt | | |
| 🖹 Referen | ce Values | | | PI | e | | DEL | | UCK | | | |
| 🕀 🔀 Referen | ce Frames | | | | | | | | | | | |
| ∫∞ Named | Expressions | New Fun | ction Na | me y-b | y-n | | | | | | | |
| Solution % Method | s | | | | | | De | fine | | lose Help | | |
| 🕺 Controls | 5 | | | | | | De | | | lose (nep) | | |

| Function Name | Definition |
|---------------|-------------------------------------------|
| y-by-h | y / 0.288 |
| Modified-U | (mean-x-velocity / 120) + (x / 0.288) |
| Modified-TKE | (turb-kinetic-energy / 500) + (x / 0.288) |

Operand field function including x and y position, mean-x-velocity and turb-kinetic-energy can be found in the following table:

| Operand field function | From field functions |
|------------------------|----------------------|
| х, у | Mesh |
| Mean-x-velocity | Unsteady statistics |
| Turb-kinetic-energy | Turbulence |

7.3. Plotting values along the lines created

Results > **Plots** > **XY Plot** > **Set Up**. Click **Load File...** and load the experimental data. Select the lines you created (position-1 through position-10) and experimental data then click **Plot**. (Note: You can download the 'Modified_u_slant25.xy' file from the class website for plotting the '*Modified-u vs. y-by-h'* figure. For '*Modified-TKE vs. y-by-h'* figure, please plot CFD values only)

| Solution XY Plot | | × |
|--------------------|---------------------|----------------------------|
| XY Plot Name | | |
| xy-plot-1 | | |
| Options | Plot Direction | Y Axis Function |
| ✓ Node Values | X 1 | Custom Field Functions |
| Position on X Axis | Y 0 | y-by-h |
| Position on Y Axis | ZO | X Axis Function |
| Write to File | | Custom Field Functions |
| Order Points | | |
| | | modified-u |
| File Data [1/1] | | Surfaces Filter Text 💦 🔁 🛒 |
| Modified Velocity | Load The | |
| | Free Data | Fluid Inlet |
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| | | position-1 |
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| | | position-6 |
| | | position-7 |
| | | position-8 |
| | | position-9 |
| | | (Outlet |
| | | Symmetry |
| | | Wall |
| | | |
| | | New Surface 🚽 |
| | | |
| | Save/Plot Axes Curv | es Close Help |

Note: You can change the style and color of the data by clicking **Curves** button and changing the parameters below then clicking **Apply**. Click **Axes...** and adjust the Y axis maximum to 2.5 and minimum to -0.5.

| E Curves | - Solution XY Plot | × | Axes - Solution XY Plot | | × |
|----------|--------------------|--------------|-------------------------|-----------------------|----------------------|
| Curve # | Line Style | Marker Style | Axis O X | Number Format Type | Major Rules Color |
| 0 | Pattern | Symbol | • Y Label | float Precision | foreground Weight |
| | Color | Color | Options | 2 v Range | 1 Minor Rules |
| | Weight | Size | Log Auto Range | Minimum -0.5 | Color dark gray |
| | | 0.3 | Minor Rules | Aaximum 2.5 | Weight 1 |
| | Apply Close | Help | | Apply Close Help | |

Result:



7.4. Printing drag coefficient components

| Results > Reports > Forces. Select the region where you want to calculate the drag coeffic | cient |
|--------------------------------------------------------------------------------------------|-------|
| under wall zone then click print. | |

| Force Reports | | × |
|-----------------------------------------------------------------------------------|------------------|-------------------------------------------------------------------|
| Options Forces Moments Center of Pressure Save Output Parameter | Direction Vector | Wall Zones Filter Text To Text Text Text Text Text Text Text Text |
| | Print | te) Close Help |

7.5. Plotting time-history of total drag coefficient in Tecplot

Note: If you closed Fluent without first plotting and saving drag coefficient time history, navigate to "\Lab 4 Project File_files\dp0\FLU\Fluent" and find an ascii file named as "cd-1-history". **You can choose either Excel or Tecplot for plotting with this file:**

Plotting with Tecplot: Right click on file *cd-1-history* and select **Open** again click **Open** when window asking if you would like to open this file comes up. Click **Browse (or Look for another app in this PC)**, and navigate to C:\Program Files\Tecplot\Tecplot 360 EX 2016 R2\bin and select **tec360** and click **Open**, and in *Open With* window click **Ok** and in *Open File* window click **Open**. Change vertical Range by clicking Plot > Axis..., select Y1 from top axis icons and change range to 0 for min and 1 for max. Further refine that range to properly capture curve. Change axis names by clicking Plot > Axis..., select **Use text** and enter axis title as **Cd** for vertical axis and **Flow Time** for horizontal axis. Save picture by **File > Export... >** change *Export format* to **JPEG** and save as **Cd-history.jpg**. If you have questions, please see TA in office hours.



7.6. Plotting Pressure Contours

| Contours | | × | Selormap | |
|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|------------------------------------------------------------------------------------|---------------------|
| Contour Name | | | ✓ Show Colormap | |
| contour-2 | | | Associated Object | |
| Options | Contours of | | contour-2 | |
| ✓ Filled | Pressure | • | Labels | Colormap |
| Node Values Boundary Values Contour Lines Auto Range Clip to Range Draw Profiles Draw Mesh Coloring | Static Pressure Min [Pa] Max [Pa] -3758.465 1308.698 Surfaces Filter Text ahmed_bottom ahmed_top back inlet interior-surface_body nose | | Automatic Skip Skip Number Format Type exponential Precision 2 Font Font Ent Name | Colormap Dimensions |
| Colormap Options | Display State None Ve/Display Compute Close | v Ise Active New Surface v | Helvetica Font Behavior Automatic Font Size 0.032 | Vidth Ratio |
| | L. C. | -3.25e+03 | A | pply Close Help |

Results > **Graphics** > **Contours**. Change parameters as per below and click **Display**.

| contour-1 State PreSSare03 1.12e+03 8.48e+02 5.79e+02 4.07e+01 -2.28e+02 -7.66e+02 -7.66e+02 -1.03e+03 -1.84e+03 -1.30e+03 -1.84e+03 -2.28e+03 -2.28e+03 -2.28e+03 -2.28e+03 -3.19e+03 -3.99e+03 pascal] | | | |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|--|--|

7.7. Plotting Velocity Vectors

Results > **Graphics** > **Vectors** > **Set Up...** Change parameters as per below and click **Display**.

| Sectors | | × | Colormap Colormap | × |
|------------------|-----------------------|----------------------------|-------------------|---------------------|
| Vector Name | | | Show Colormap | |
| vector-1 | | | Associated Object | |
| Options | Vectors of | | vector-1 | |
| ✓ Global Range | Velocity | * | Labels | Colormap |
| Auto Range | Color by | | ✓ Automatic Skip | Log Scale |
| Clip to Range | Velocity | · | Skip | Colormap Size |
| ✓ Auto Scale | Velocity Magnitude | • | 8 | 99 🌲 |
| Draw Mesh | Min [m/s] N | lax [m/s] | Number Format | Colormap Alignment |
| Style | 0.488667 | 38.44909 | Туре | Left 💌 |
| 3d arrow 🔻 | | | exponential 💌 | Currently Defined |
| Scale Skip | Surfaces Filter Text | To (T, T) 🔽 | Precision | bgr 💌 |
| 1 0 | ahmed_bottom | A | 2 | Edit Delete |
| Vector Options | anmed_top back | | Font | Colormap Dimensions |
| Custom Mastern | inlet | | Font Name | Length |
| Custom vectors | interior-surface_body | | Helvetica | 0.54 |
| Colormap Options | outlet | | Font Behavior | Width Ratio |
| | road | | Automatic | 6 |
| | slope | × | Font Size | |
| | Display State | | 0.032 | |
| | None | ▼ Use Active New Surface ↓ | | |
| Sa | ve/Display | te Close Help | Appły | Close Help |



7.8. Creating videos

Results > **Animations** > **Playback**. Change the window to streams or viscous ratio then click play button to see the animation. Select the "Picture Files" and click the "Write" button. The picture files will be saved below directory, and it would used to make the Video clip.

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Once the figure files are saved correctly, return to the first time-step, change the **Write/Record Format** to **Picture Files** and click **Write**. Please go through the same procedure for viscosity-ratios.

.80e+00 .60e+00



Pictures of streamline for ahmed car: (a) frame=100; (b) frame=200; (c) frame=300



Pictures of turbulent viscosity ratio for ahmed car: (a) frame=100; (b) frame=200; (c) frame=300

If you have closed the Fluent after the calculation, there could be no 'streamline' or 'viscosityratio' under the Animation Sequence in Animation Playback when you reopen it (select **solution** instead **setup** in the workbench when you reopen). You need to read the set-up file to bring back those options. If this is the case, click **Read** and read the '*.cxa' file saved in the location you assigned at the animation part. Select both streamline and viscosity-ratio files (one at each time). Once the options appear under the Animation Sequence, save video files like the beginning of this section (section 7.8). Please note that the setup files (*.cxa) can be modified by opening it with notepad or any ascii readers. Please change the options according to your needs.



| AnimationSequence1.0 | AnimationSequence1.0 |
|------------------------------|---------------------------------------|
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| STORAGE: 4 | STORAGE: 4 |
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8. Data Analysis and Discussion

You need to complete the following assignments and present results in your lab reports following the lab report instructions.

8.1. Simulation of turbulent flows over Ahmed body (slant angle=25 deg) (+24):

Fill in the table for the four drag coefficients and compute the relative error between CFD and EFD (Ahmed data), EFD data for C_k , C_B , and C_s can be found from the figure below. Where $C_k = C_k^*$, $C_B = C_B^*$, and $C_s = C_s^*$. The definitions of the drag coefficients are: C_k is the forebody pressure drag coefficient, C_B is the vertical based pressure drag coefficient, C_R is the friction drag coefficient, C_s is the slant surface pressure drag coefficient, and $C_w = C_D$ is the total drag coefficient. So, $C_w = C_D = C_S + C_B + C_k + C_R$



| | C_k | CB | Cs | CD |
|-------------|-------|----|----|-------|
| Ahmed (EFD) | | | | 0.289 |
| k-e | | | | |
| Error (%) | | | | |

Questions (+21):

- Do you observe separations in the wake region (use streamlines)? If yes, where is the location of separation point?
- What is the Strouhal number based on the shedding frequency (C_D vs. time), the height of the Ahmed body and the inlet velocity? Note: the shedding frequency f=1/T where T is the typical period of the oscillation of C_D that can be evaluated using the peaks between 0.1<time<0.14.
- **Figures need to be reported:** (1) XY plots for residual history, (2) modified U vs. y-by-h (with EFD), (3) Modified-TKE vs. y-by-h, (4) time history of drag coefficient, (5) Contour of pressure, (6) contour of velocity magnitude, (7) velocity vectors, (8) 3 or 4 snapshots of animations for turbulent-viscosity-ratio and streamlines (hints: you can use <<**Alt+print Screen**>> during the play of the animations).
- **Data need to be reported:** the above table with values.

9. Grading scheme for CFD Lab Report

(Applied to all CFD Lab reports)

Section

| Section | | Points |
|---------------------------------------------------------------------|-------|--------|
| 1 Title Page | | 5 |
| 1.1 Course Name | | |
| 1.2 Title of report | | |
| 1.3 Submitted to "Instructor's name" | | |
| 1.4 Your name (with email address) | | |
| 1.5 Your affiliation (group, section, department) | | |
| 1.6 Date and time lab conducted | | |
| 2 Test and Simulation Design | | 10 |
| Purpose of CFD simulation | | |
| 3 CFD Process | | 20 |
| Describe in your own words how you implemented CFD process | | |
| (Hint: CFD process block diagram) | | |
| 4 Data Analysis and Discussion - Section 8 (Page# 54) for CFD Lab 4 | | 45 |
| Answer questions given in Exercises of the CFD lab handouts | | |
| 5 Conclusions | | 20 |
| Conclusions regarding achieving purpose of simulation | | |
| Describe what you learned from CFD | | |
| Describe the "hands-on" part | | |
| Describe future work and any improvements | | |
| 5 1 | Total | 100 |

Additional Instructions:

- 1. Each student is required to hand in individual lab report.
- 2. Conventions for graphical presentation (CFD):
 - * Color print of figures recommended but not required
- 3. Reports will not be graded unless section 1 is included and complete