Sandeep Ramesh Moudgalya

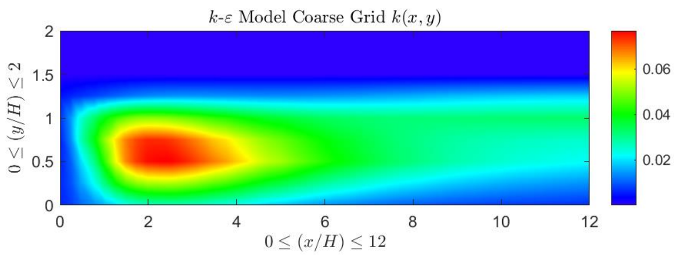
smoudga1@asu.edu

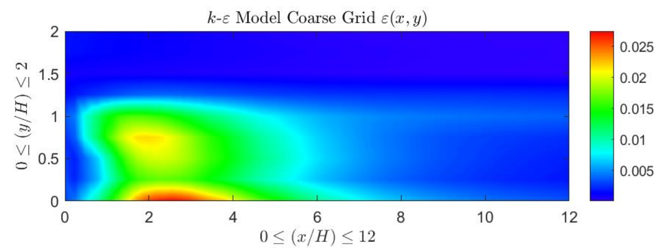
MAE 575

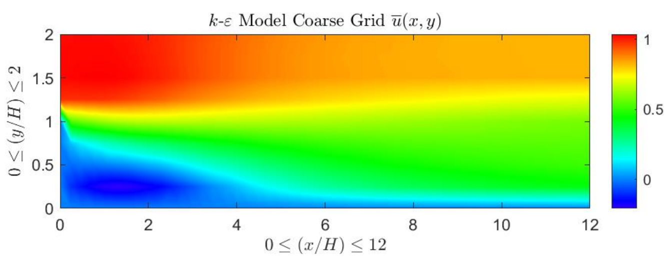
Project Report

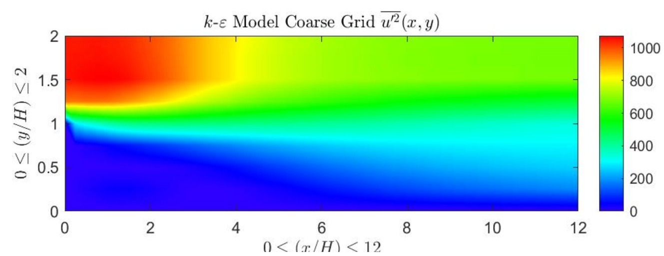
05/01/2019

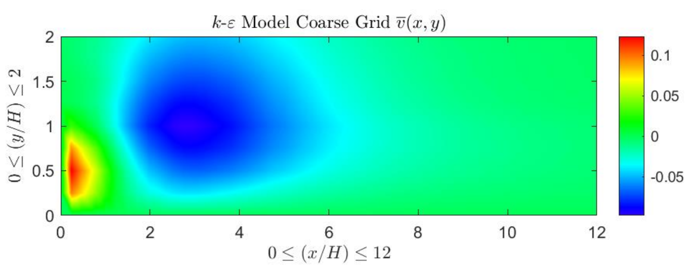
1. Color fields:
   k-e Coarse grid:

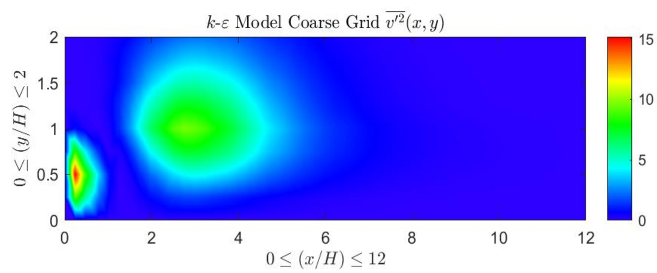


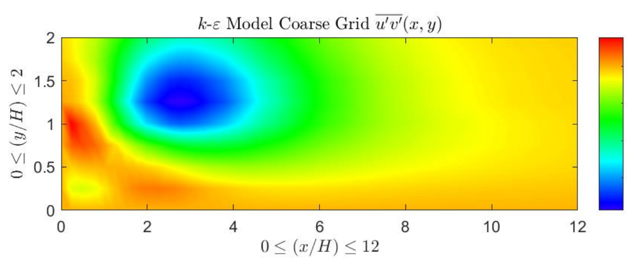












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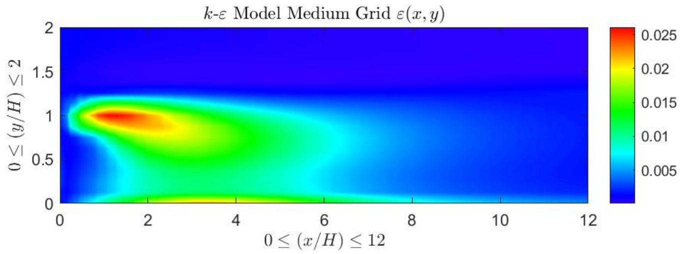

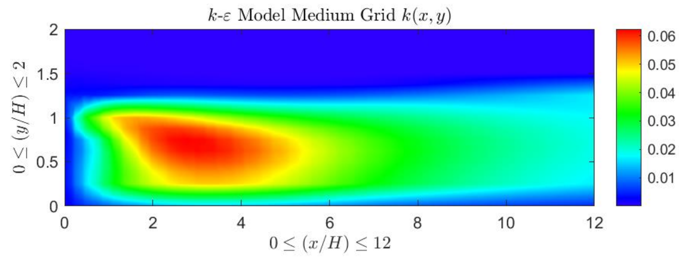

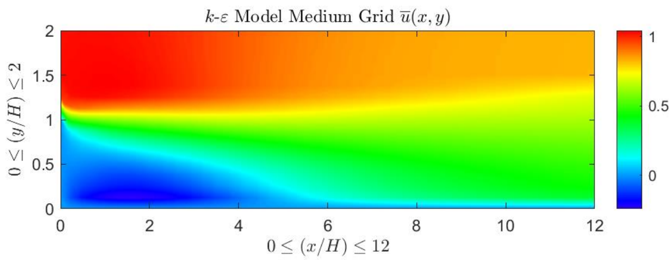

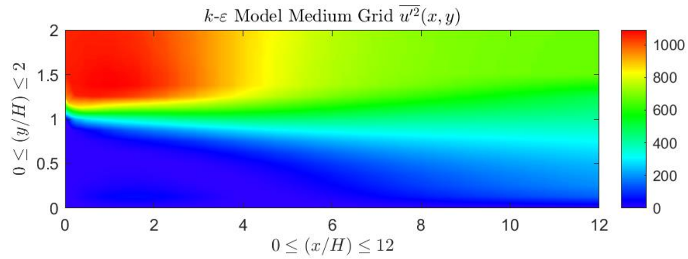

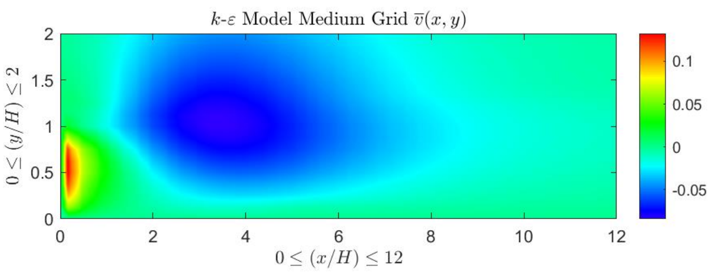

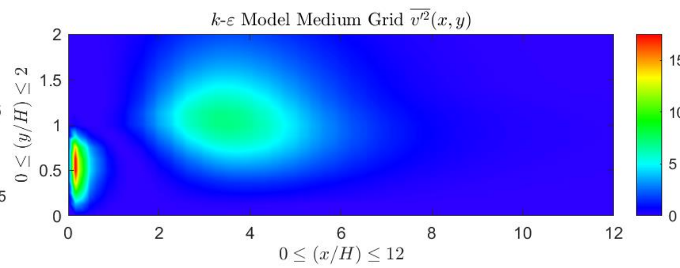

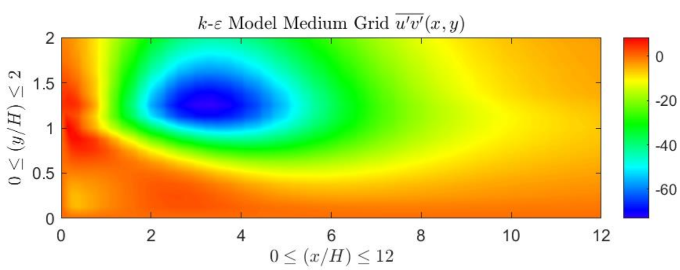

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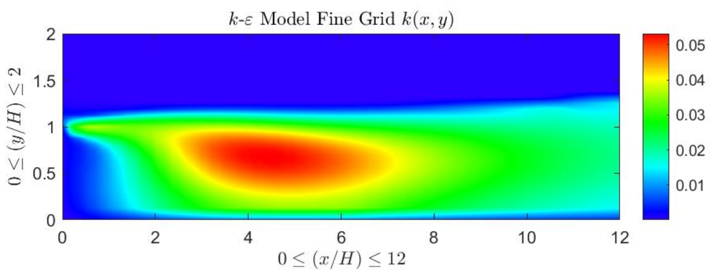
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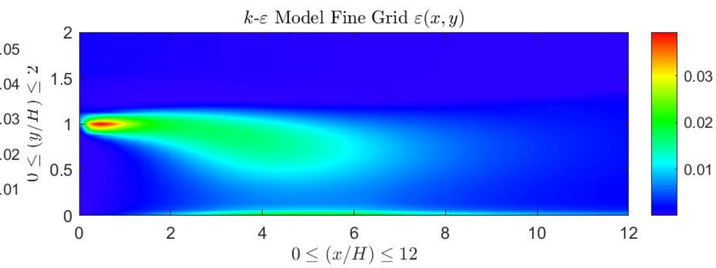
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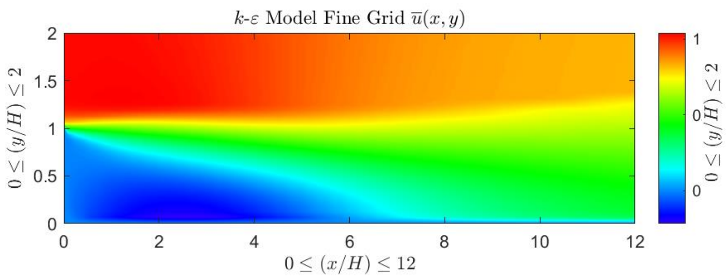
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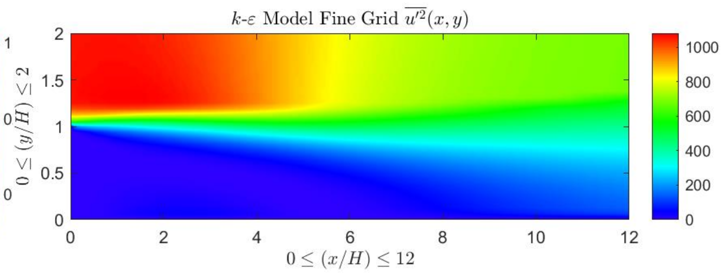
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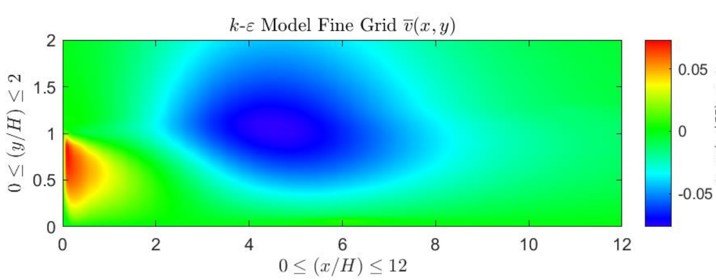
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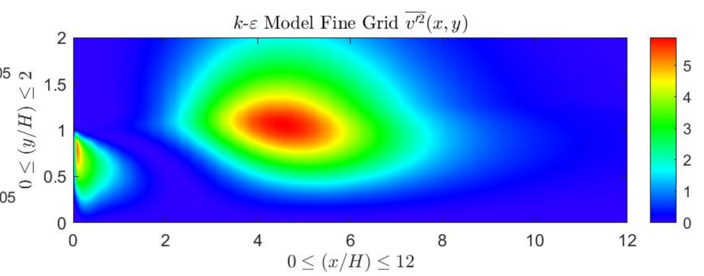
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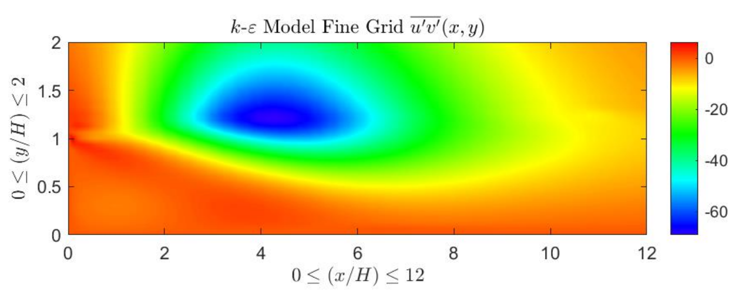
k-ε Model Fine Grid $\overline{u'v'}(x,y)$
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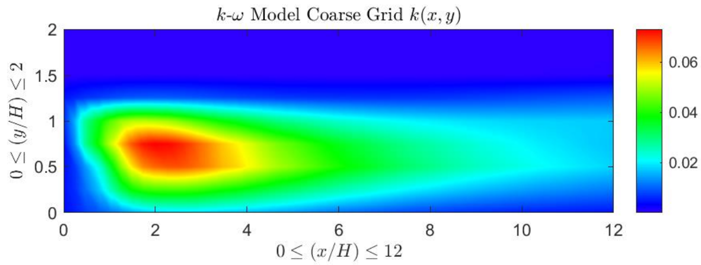
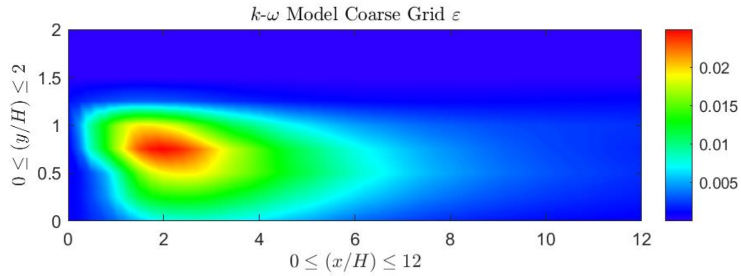
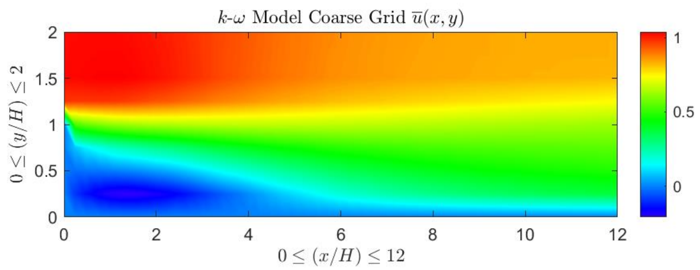
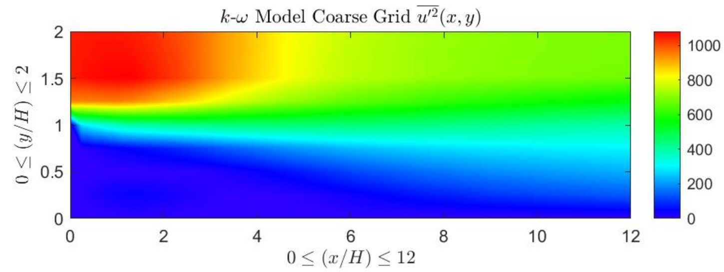
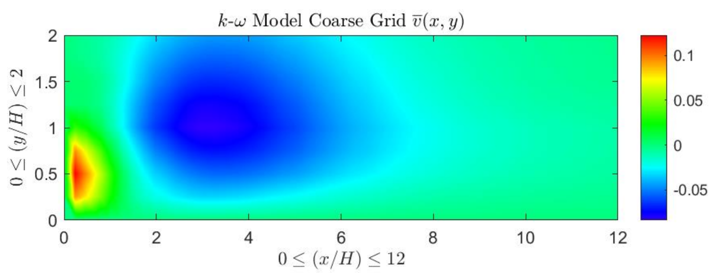
k-w coarse grid:

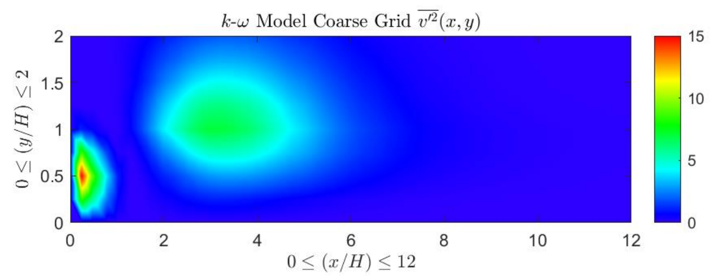


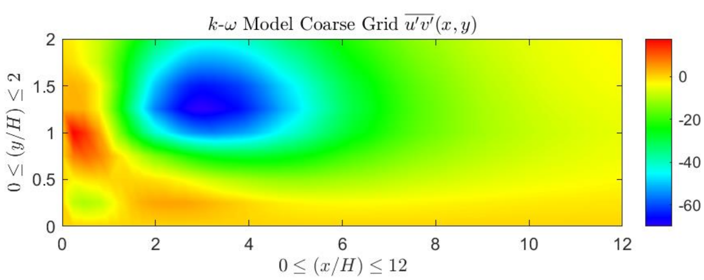




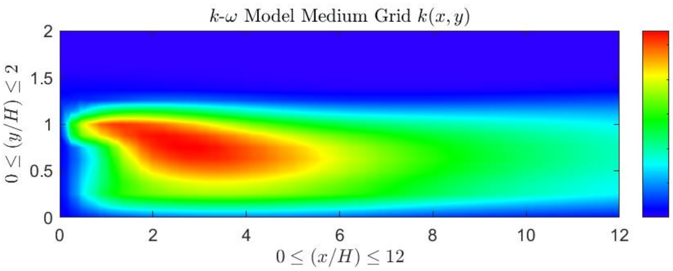


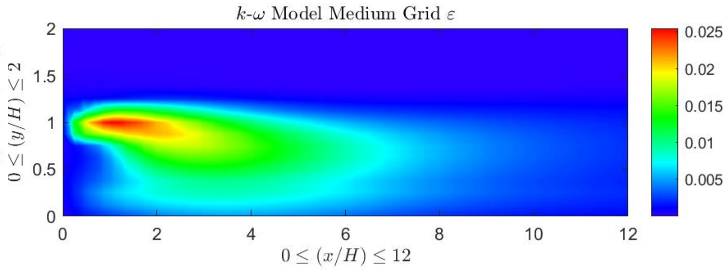


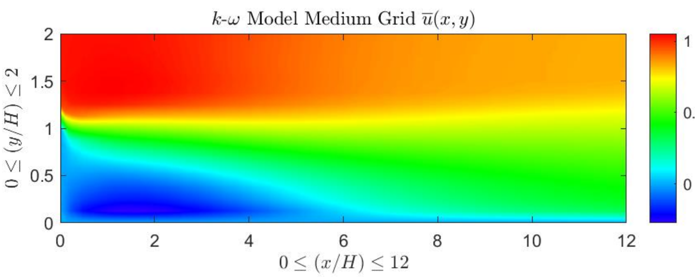


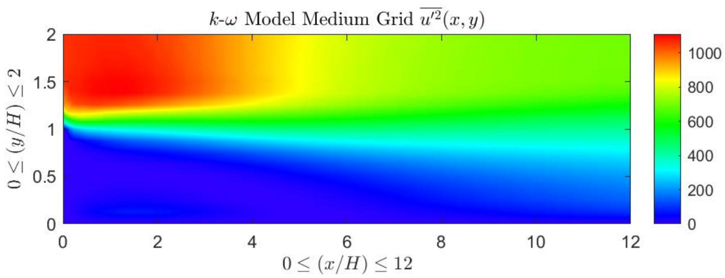


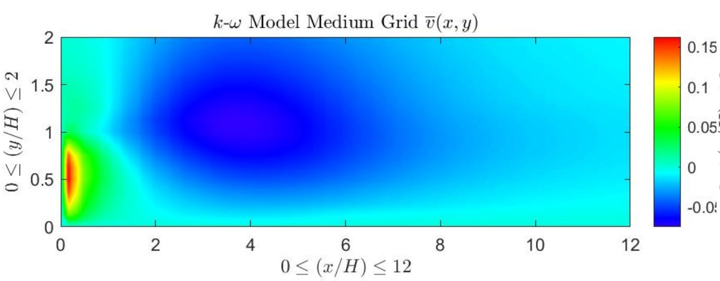
k-w medium grid:

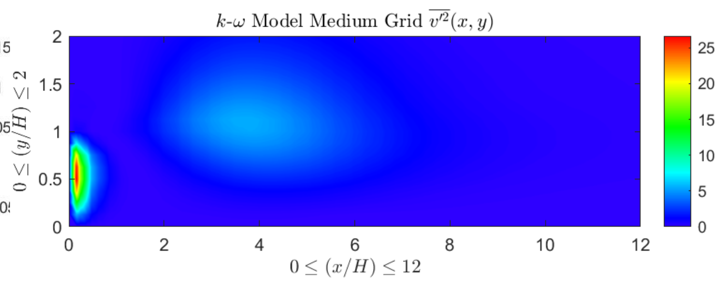


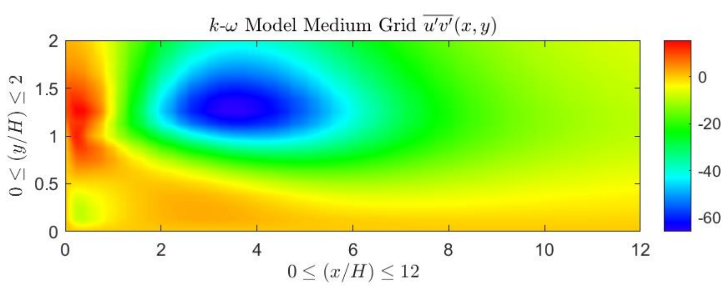












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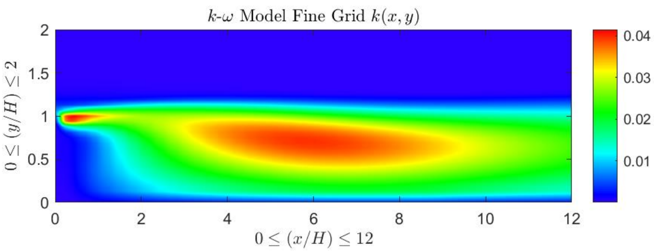
k-ω Model Fine Grid $k(x,y)$
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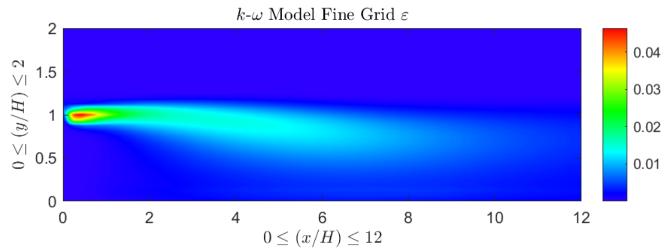
k-ω Model Fine Grid ε
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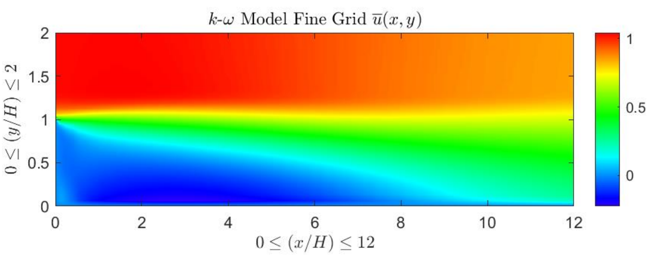
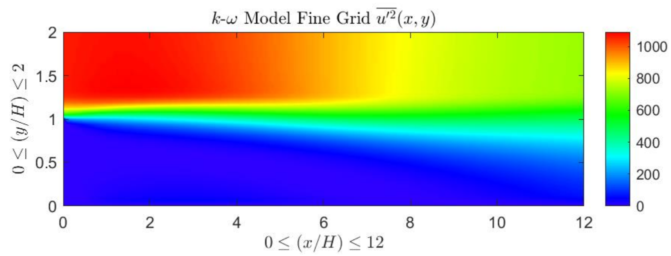

k-ω Model Fine Grid $\overline{u}(x,y)$
$0 \leq (y/H) \leq 2$
$0 \leq (x/H) \leq 12$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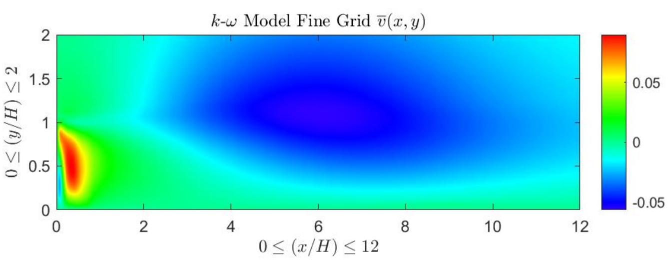
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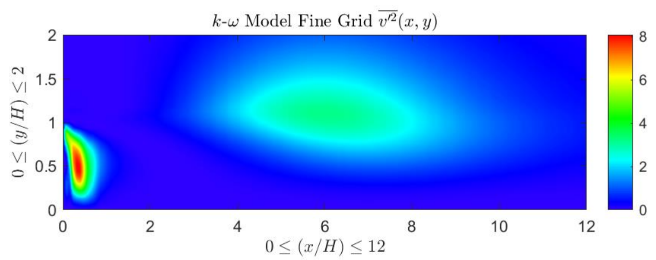
k-ω Model Fine Grid $\overline{v'^2}(x,y)$
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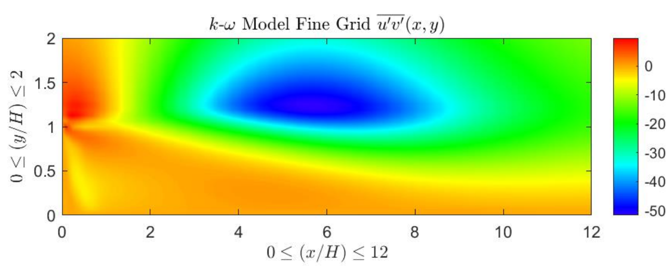
k-ω Model Fine Grid $\overline{u'v'}(x,y)$
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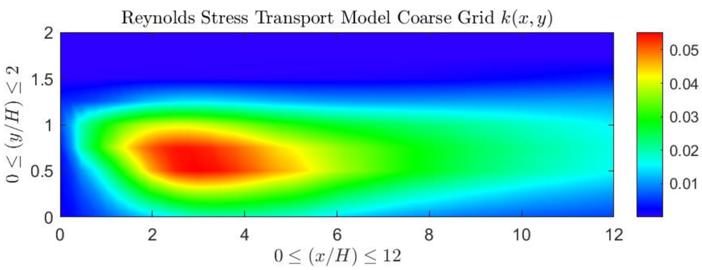
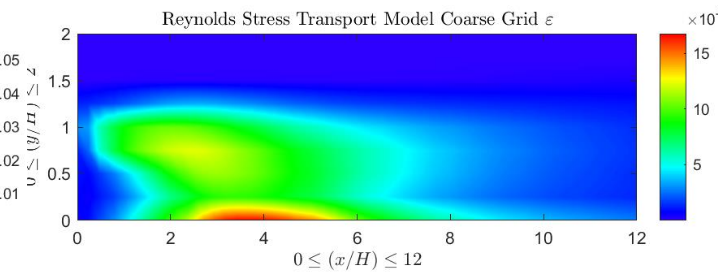
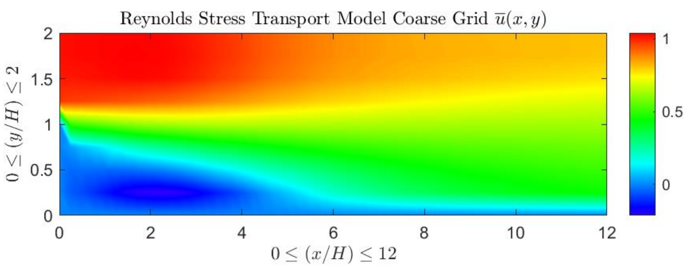
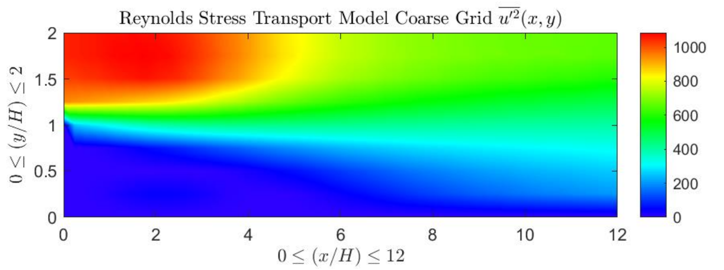
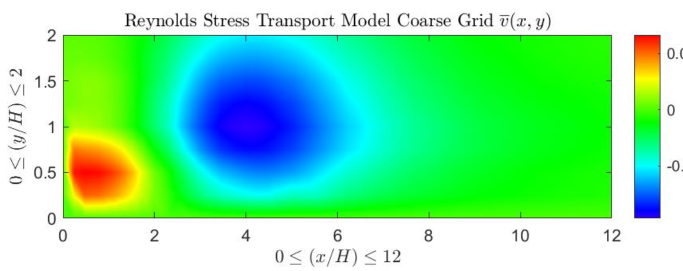
Reynolds Stress Transport model – Coarse grid:

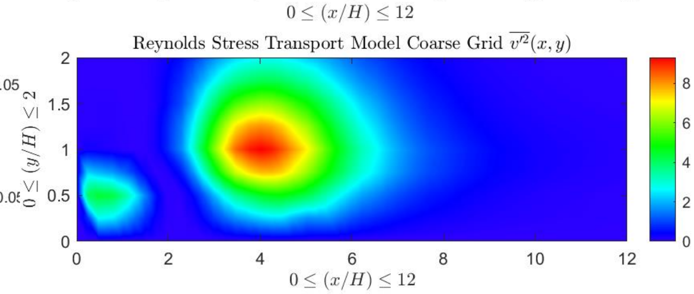


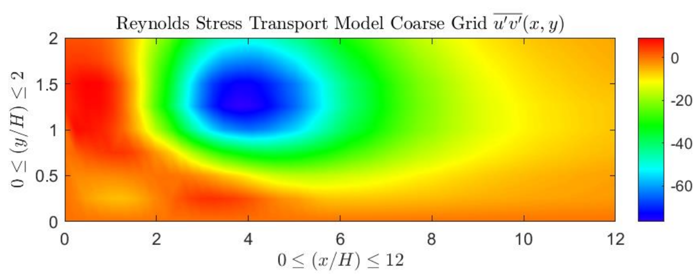




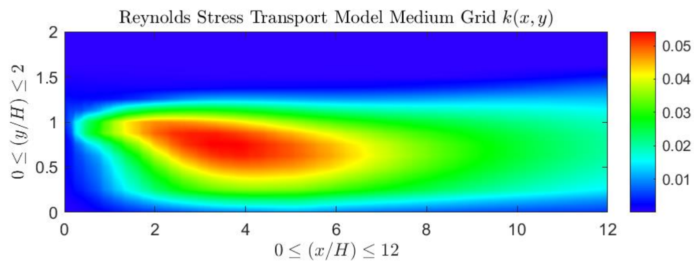


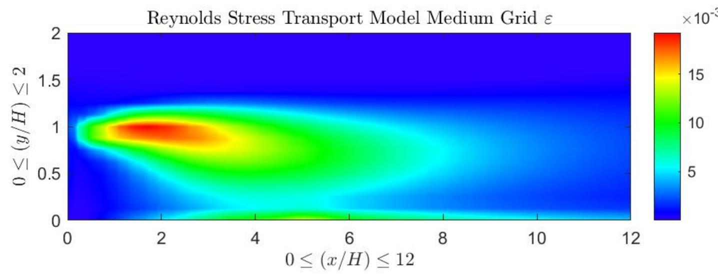


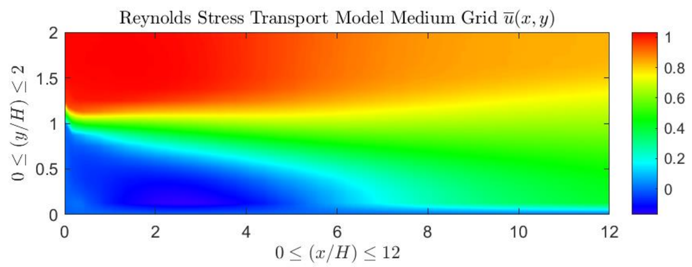


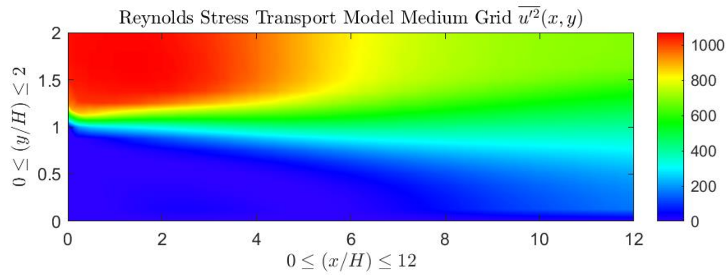


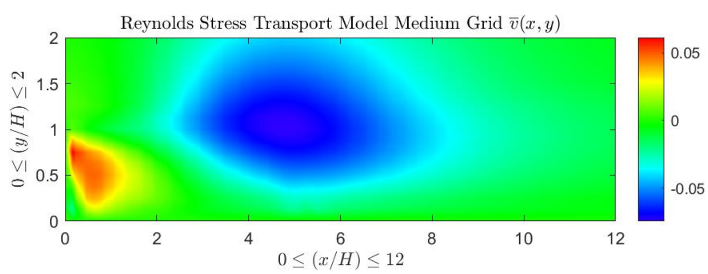
Reynolds Stress Transport model – Medium grid:

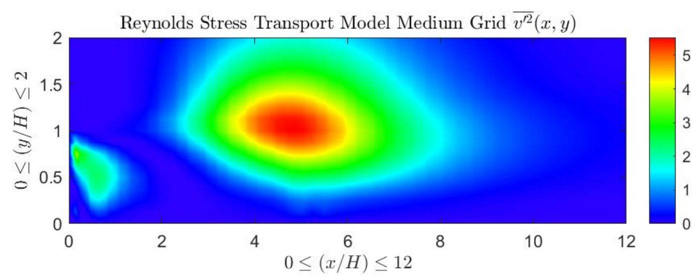


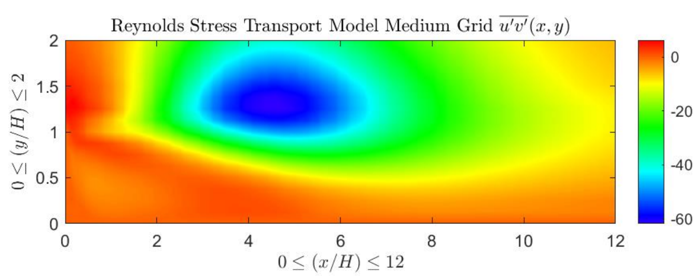




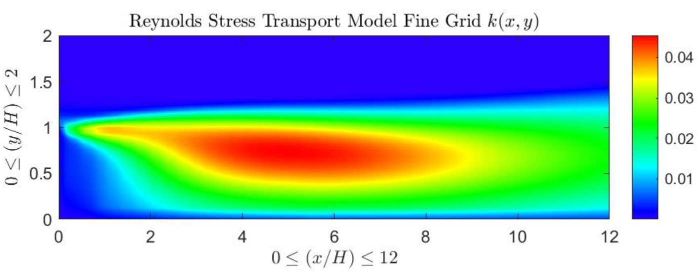


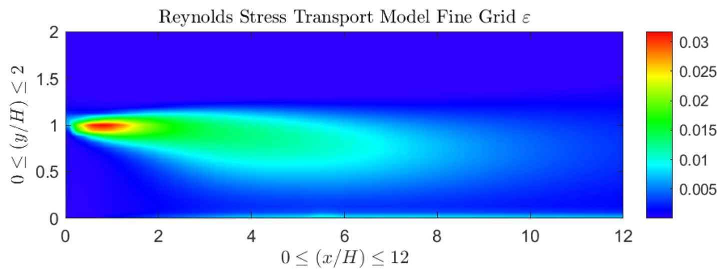


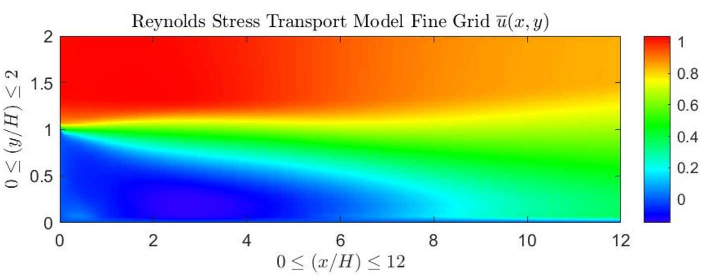


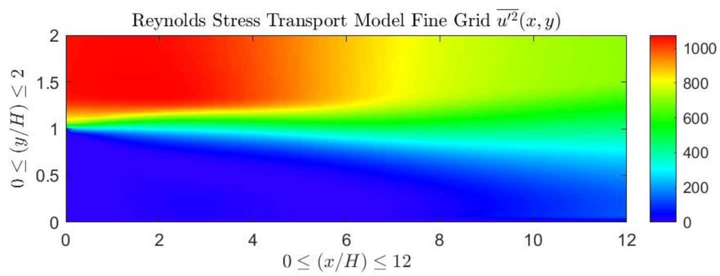


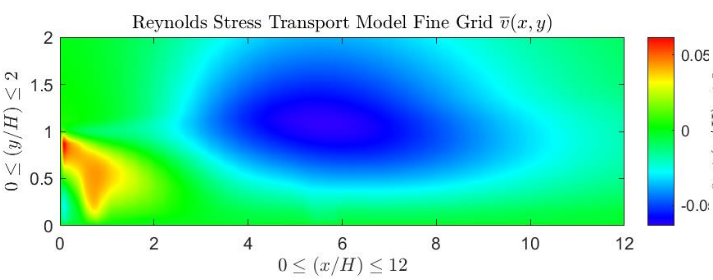
Reynolds Stress Transport model – fine grid:

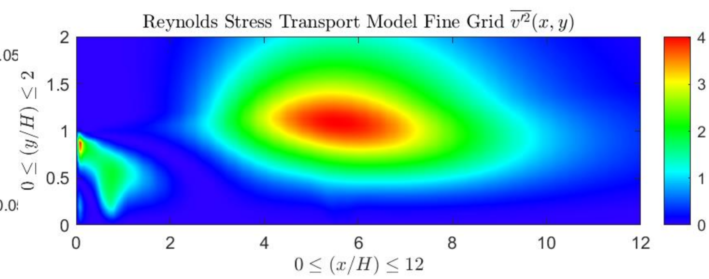


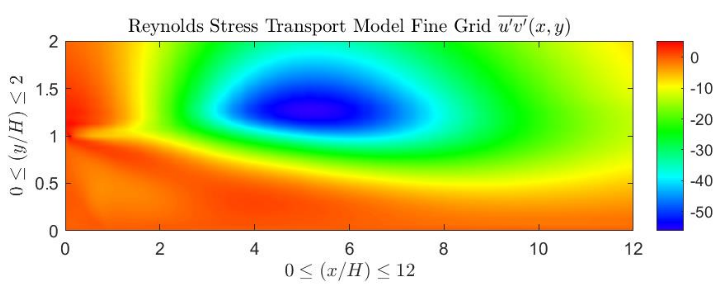












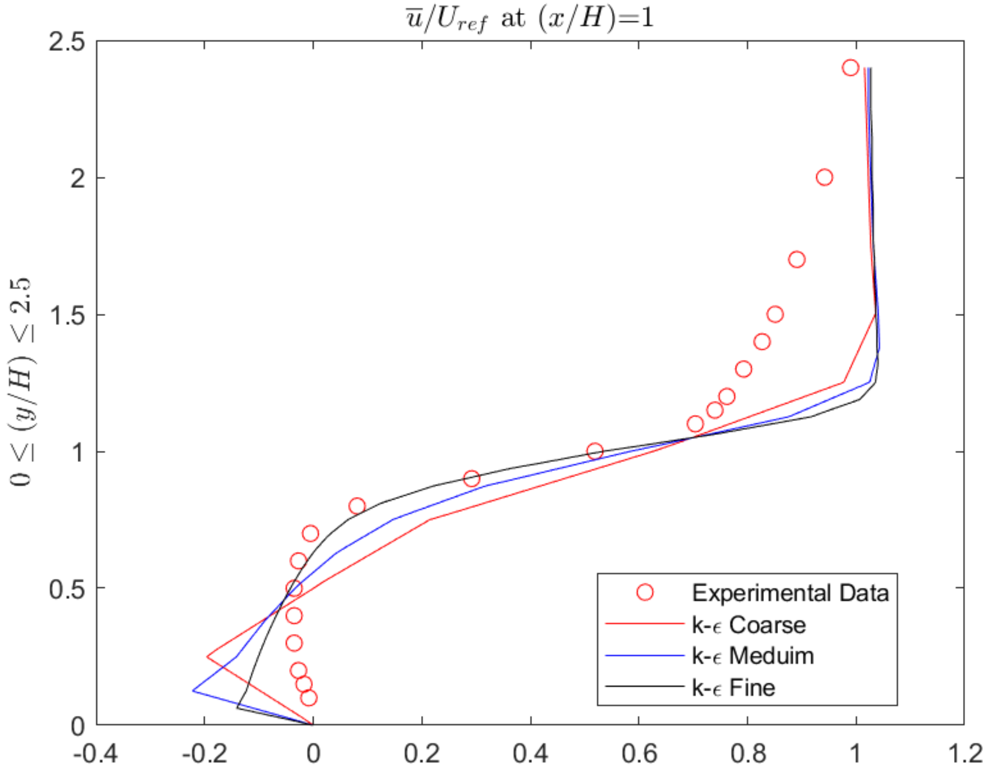
Observations:

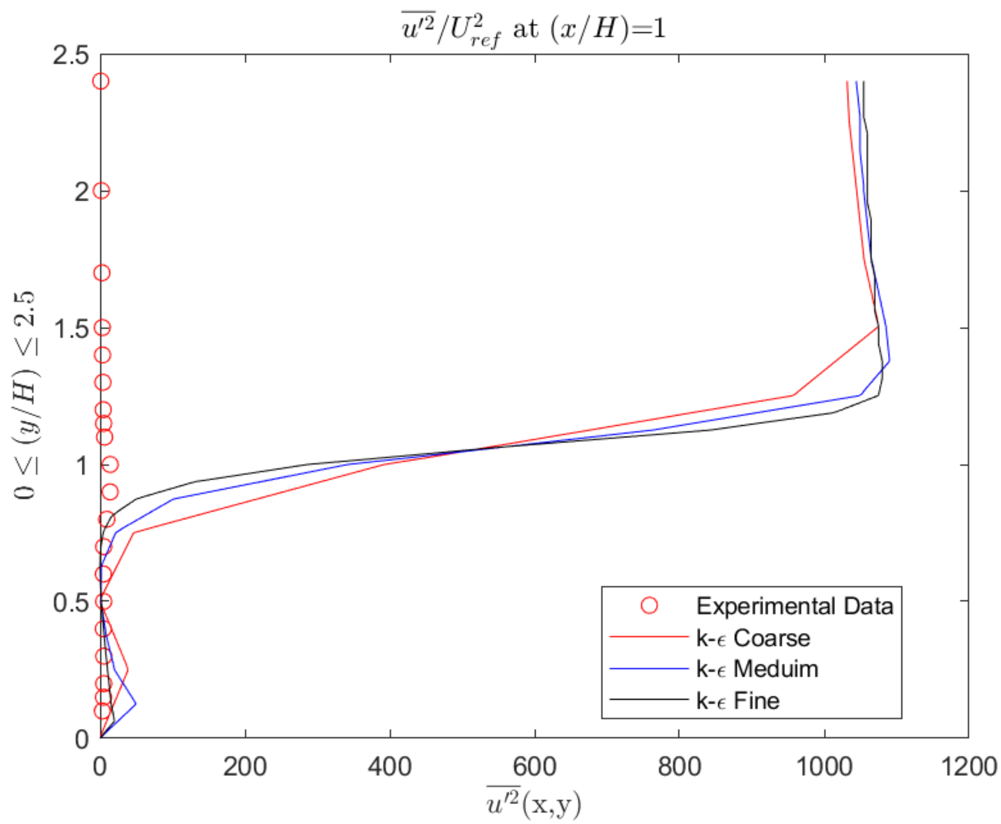
All three methods give similar results as seen.

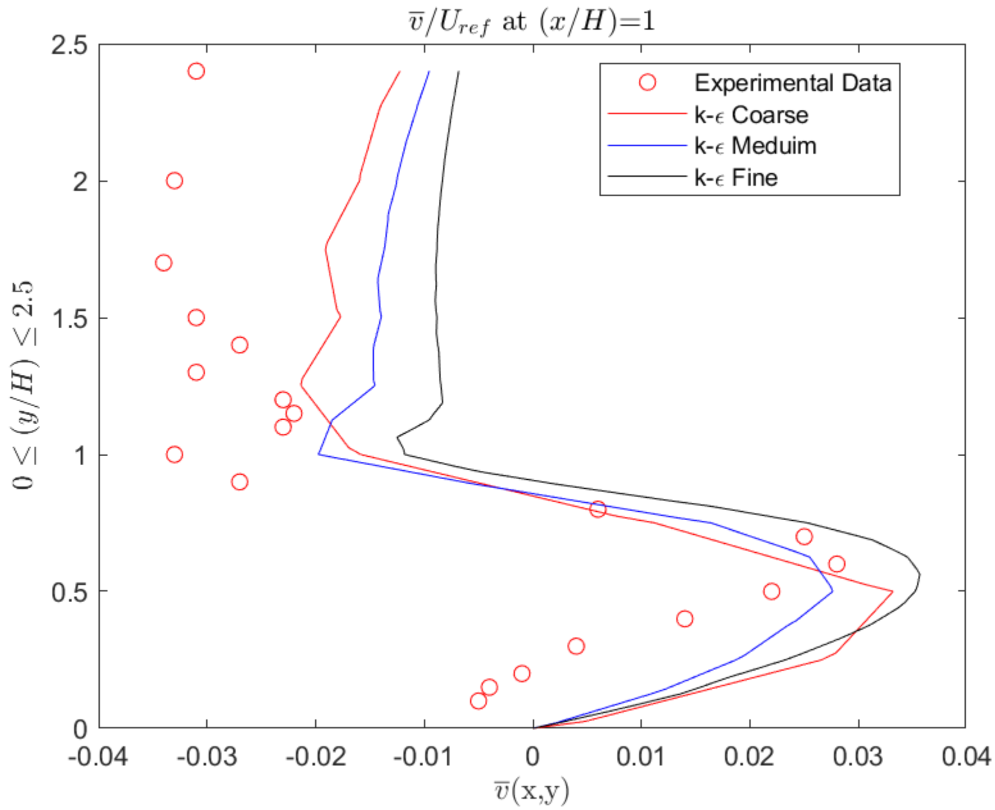
One interesting thing to note is that the K-e and k-w models give sharper changes while the Reynolds model has more gradual changes in properties.
The increased and decreased in turbulence is much more sudden in the first two models as compared to the Reynolds method.

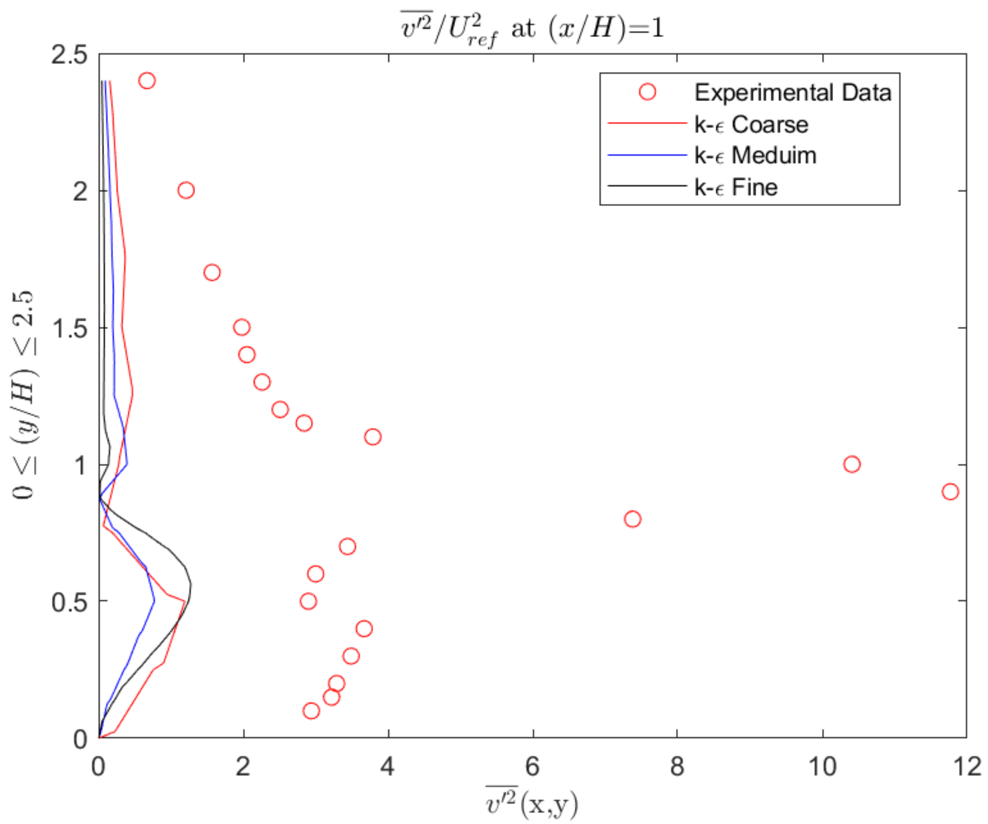
The Reynolds method has higher consistency between the meshes as opposed to the other two.

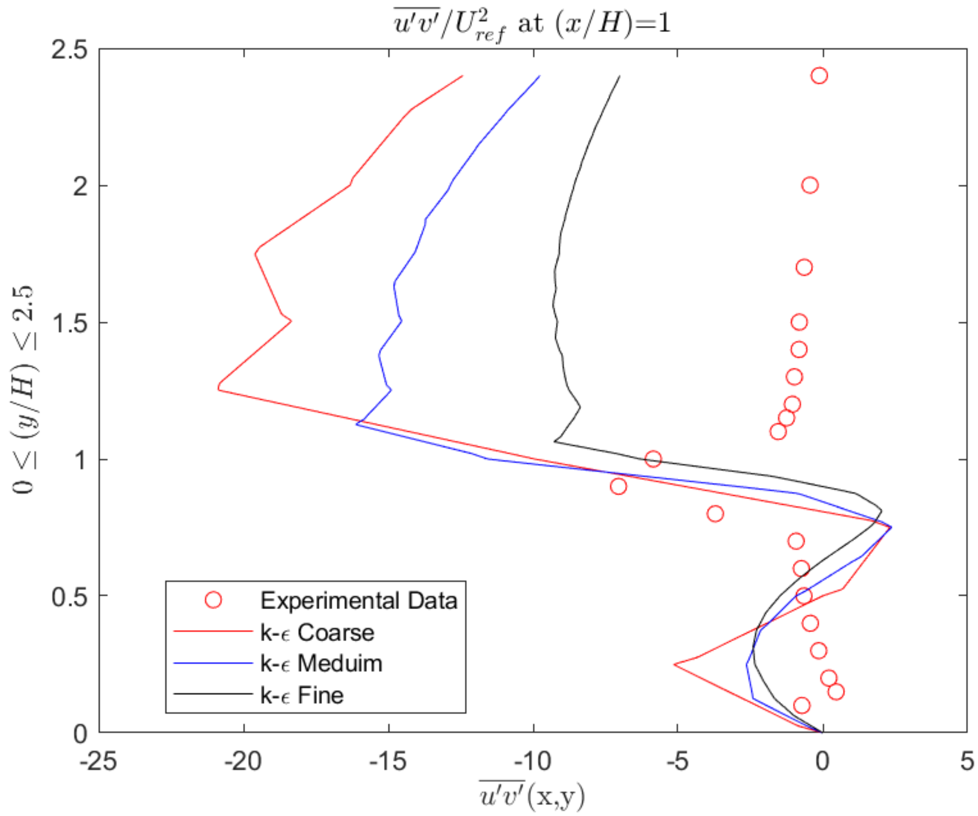
2. Grid convergence study:
   a. x/H = 1

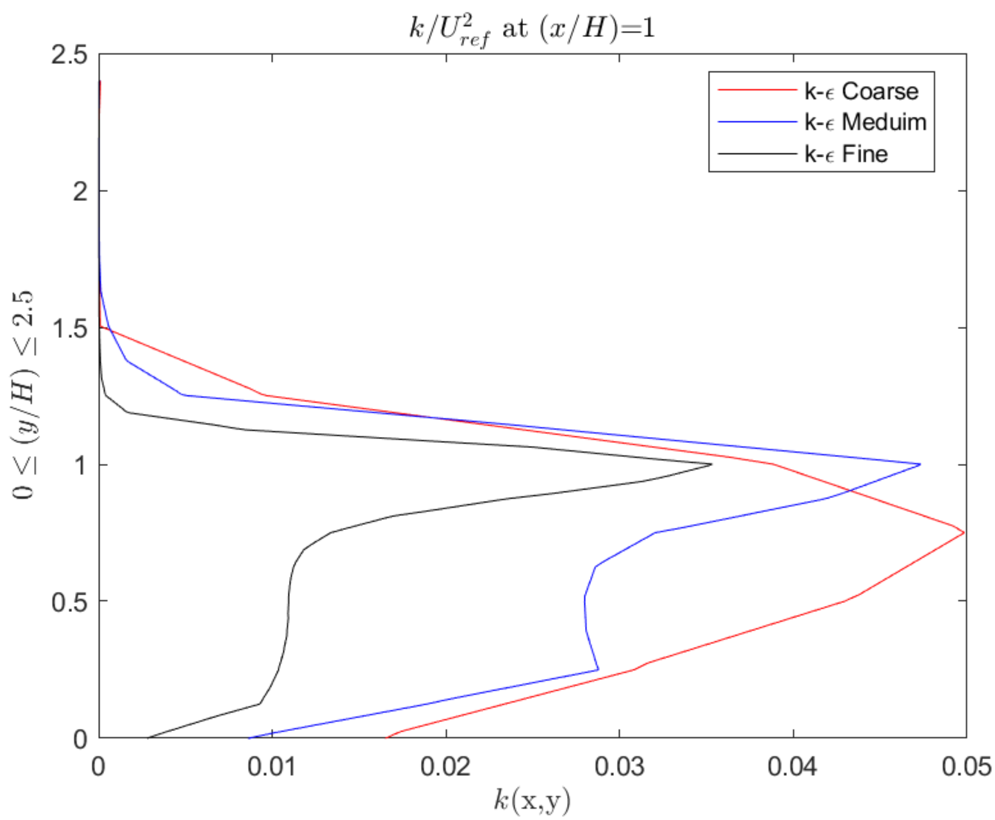


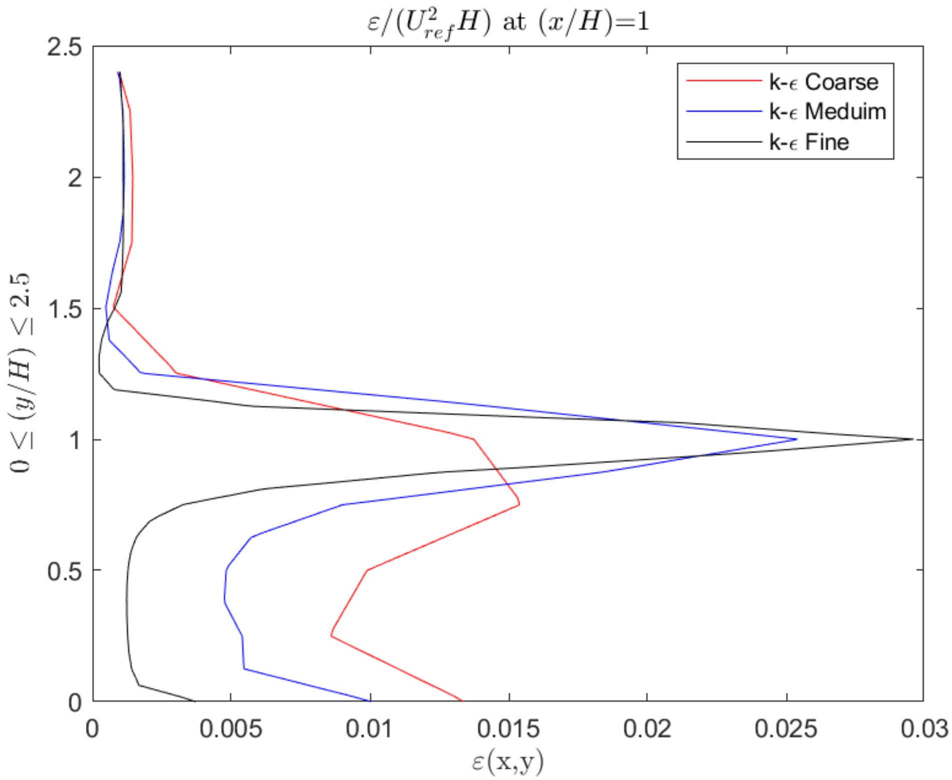



$\overline{v}/U_{ref}$ at (x/H)=1
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)

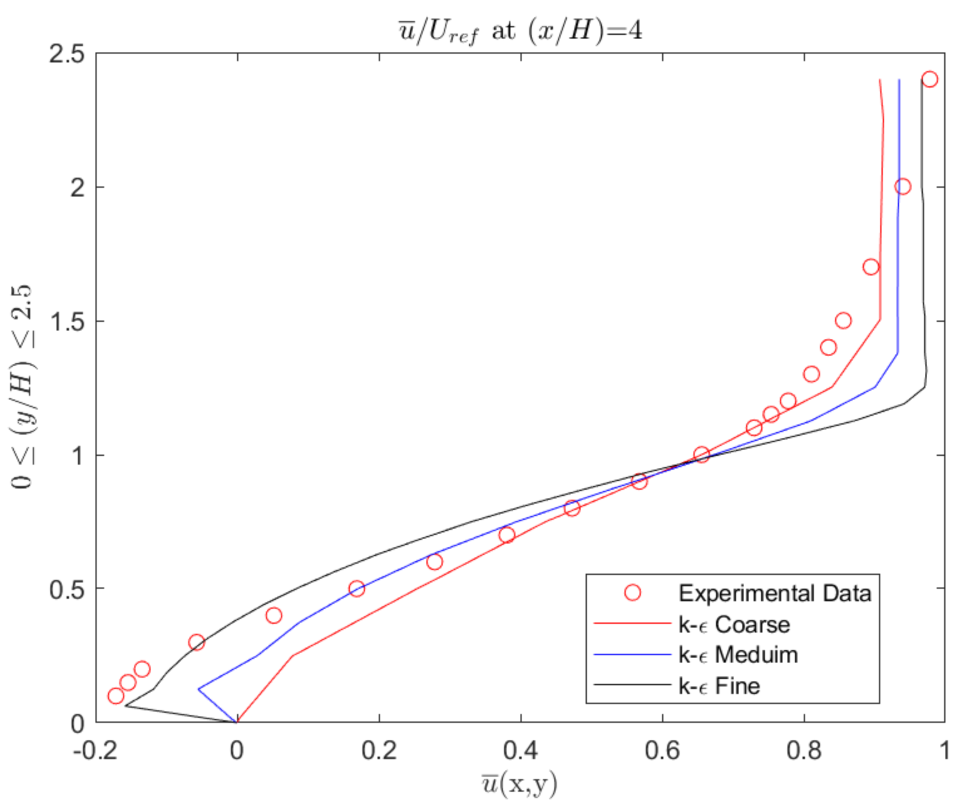

$\overline{v'^2}/U_{ref}^2$ at (x/H)=1
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)

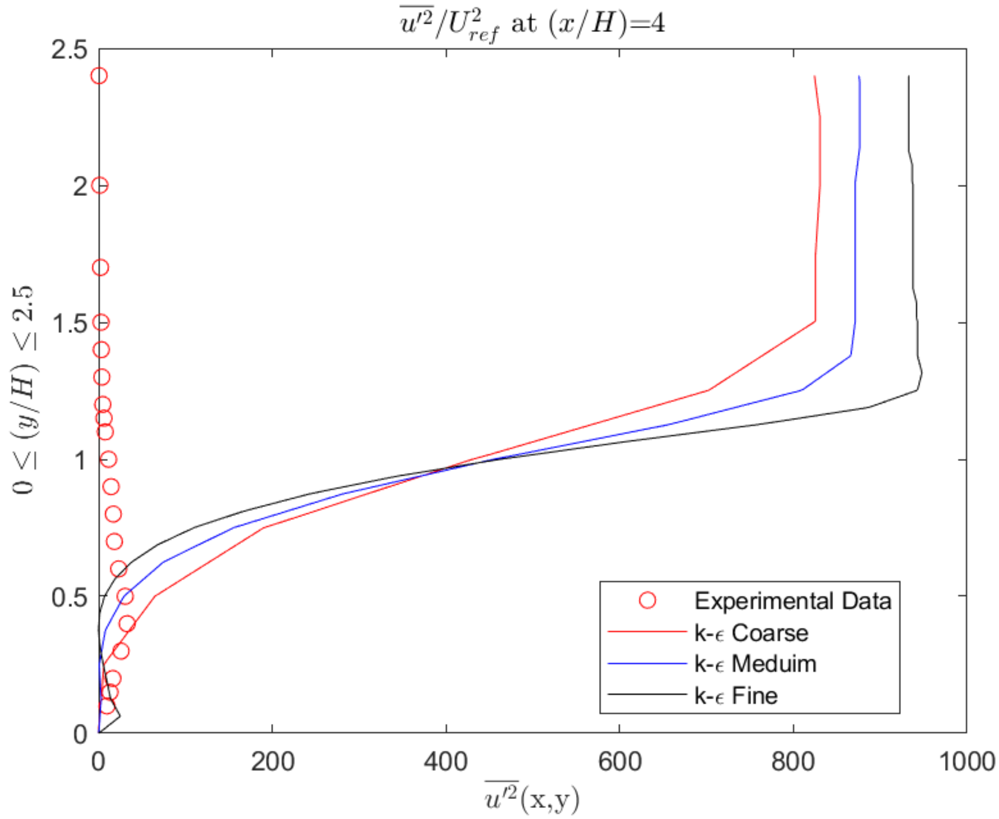

$\overline{u'v'}/U_{ref}^2$ at (x/H)=1
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
-25
-20
-15
-10
-5
0
5
0
0.5
1
1.5
2
2.5

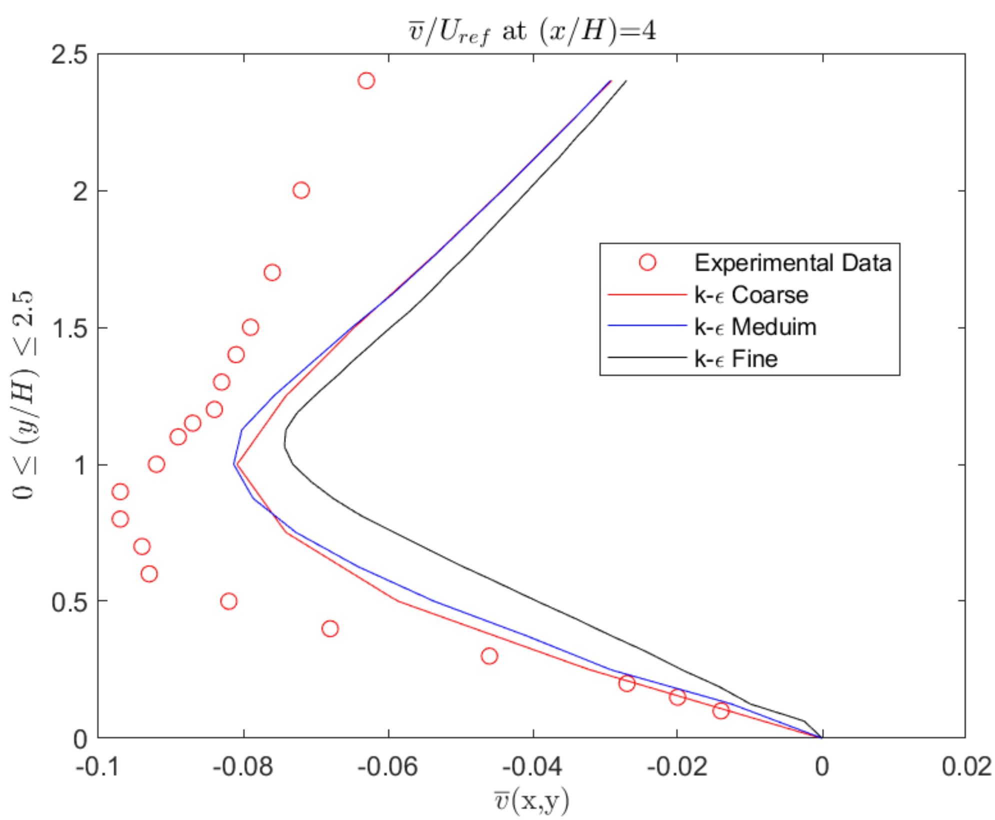

k/U_{ref}^2 at (x/H)=1
$0 \leq (y/H) \leq 2.5$
k(x,y)
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
0
0.01
0.02
0.03
0.04
0.05
0
0.5
1
1.5
2
2.5

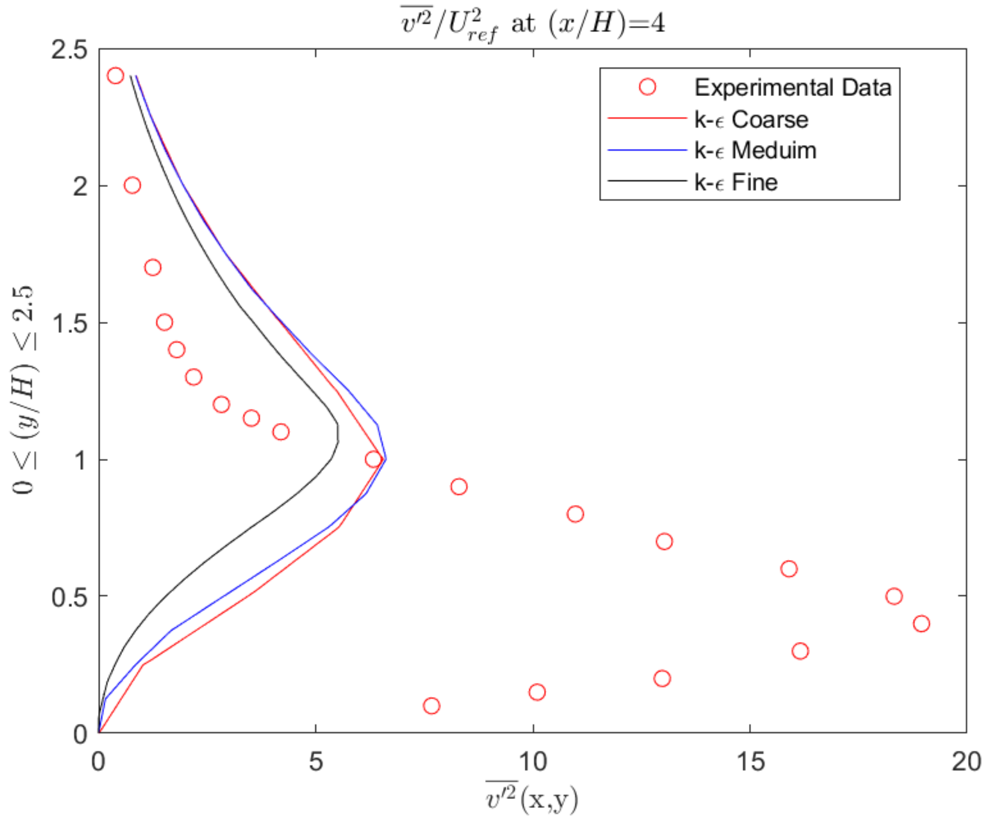

$\varepsilon/(U_{ref}^2 H)$ at (x/H)=1
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \le (y/H) \le 2.5$
ε(x,y)

b. x/H=4

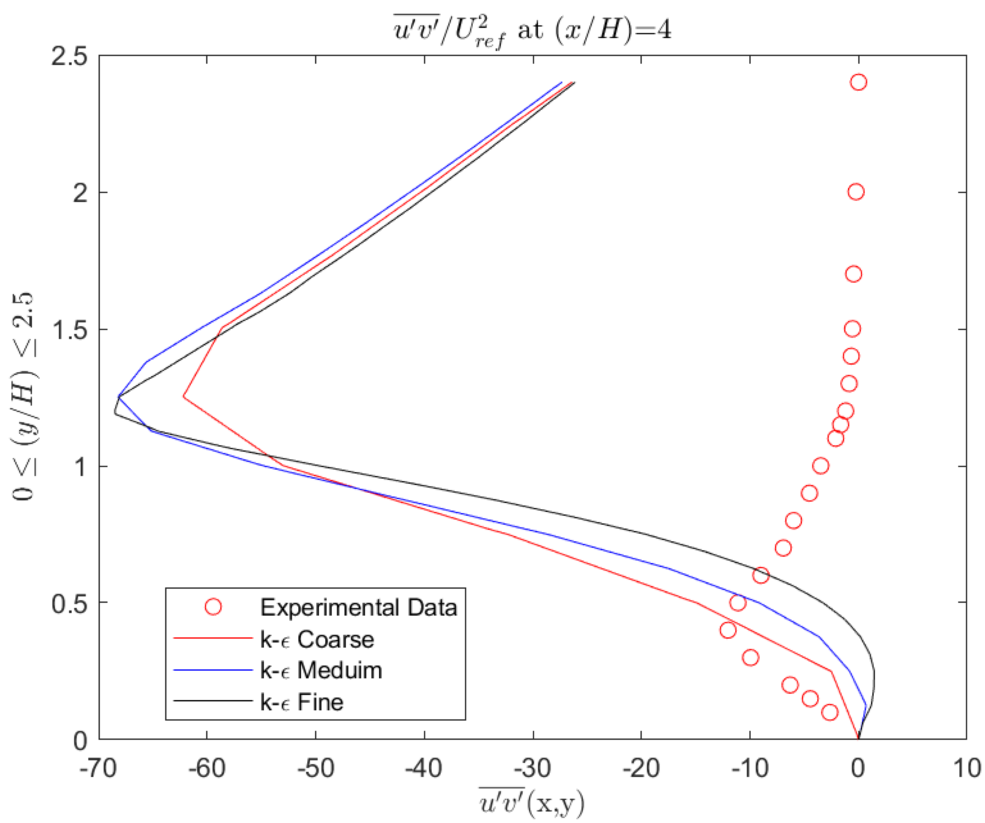

$\overline{u}/U_{ref}$ at (x/H)=4
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \le (y/H) \le 2.5$
$\overline{u}$(x,y)


$\overline{u'^2}/U_{ref}^2$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine

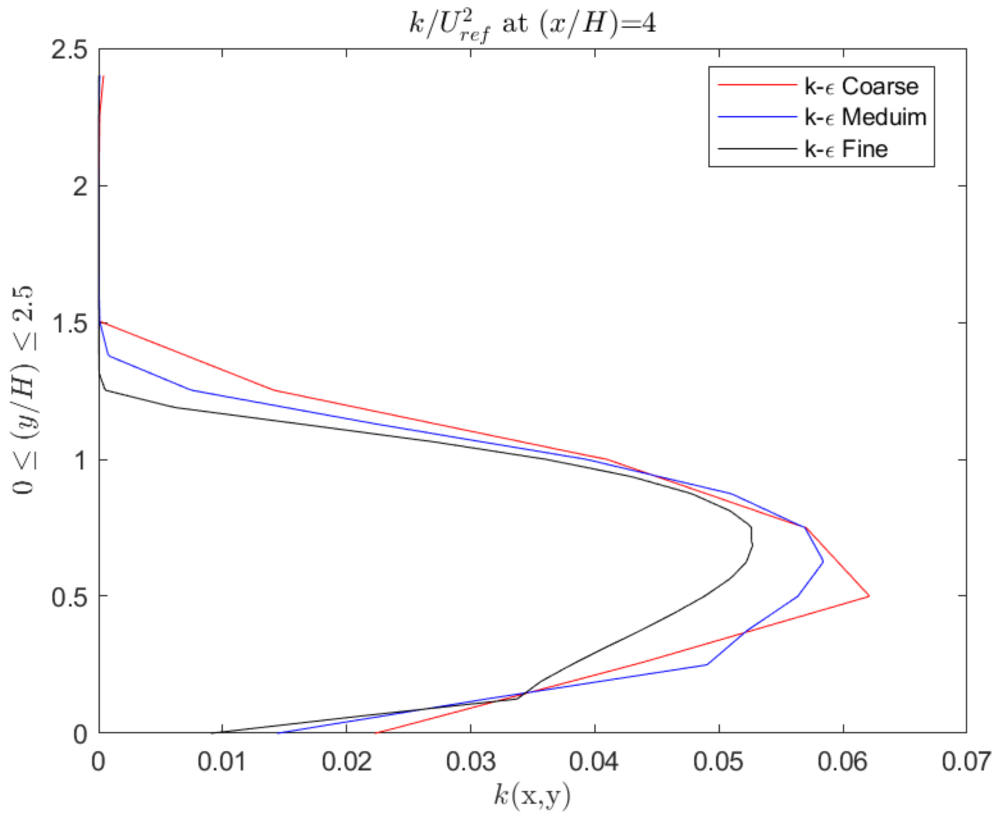

$\overline{v}/U_{ref}$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine

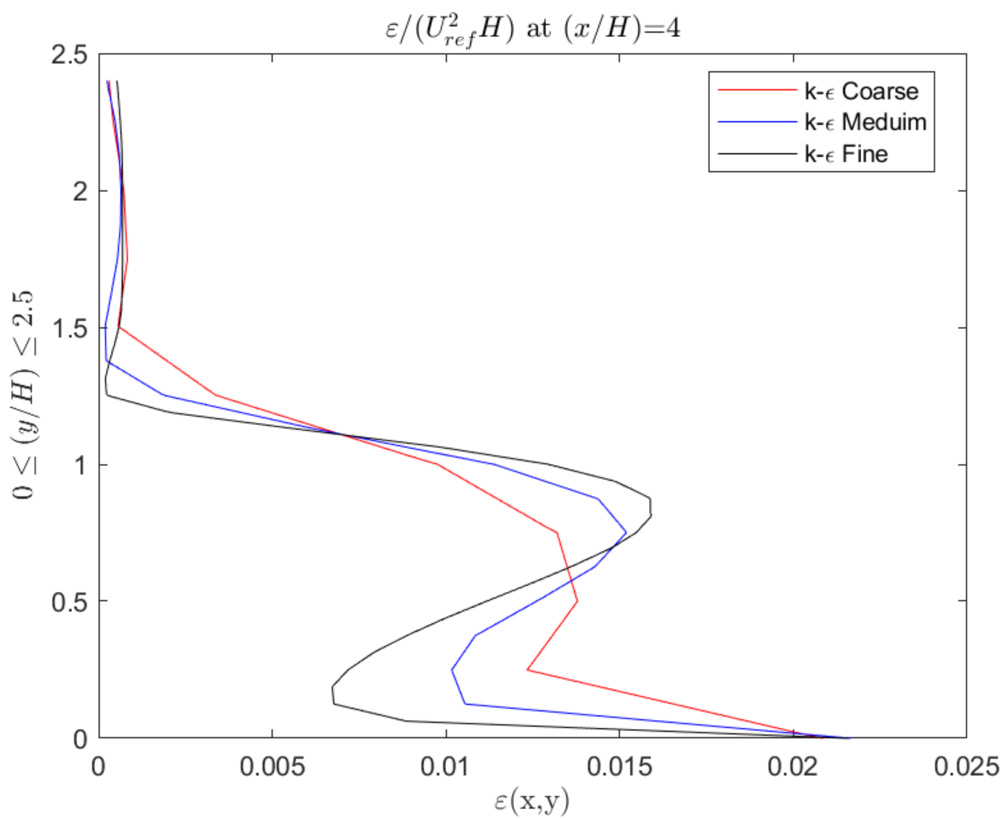


$\overline{v'^2}/U_{ref}^2$ at (x/H)=4
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
5
10
15
20



$\overline{u'v'}/U_{ref}^2$ at (x/H)=4
Experimental Data
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
0
0.5
1
1.5
2
2.5
-70
-60
-50
-40
-30
-20
-10
0
10


k/U_{ref}^2 at (x/H)=4
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
k(x,y)
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.5
1
1.5
2
2.5


$\varepsilon/(U_{ref}^2 H)$ at (x/H)=4
k-ϵ Coarse
k-ϵ Meduim
k-ϵ Fine
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.005
0.01
0.015
0.02
0.025
0.5
1
1.5
2
2.5

Observations:

We can see large variations in behavior depends on mesh size for x/H=1, while the dependence reduces at x/H=4.
This is logical as there is a lot more variations in the flow close to the wall and it reduces further away from the wall.

Having a small mesh size closer to points of interest is key for good accuracy.

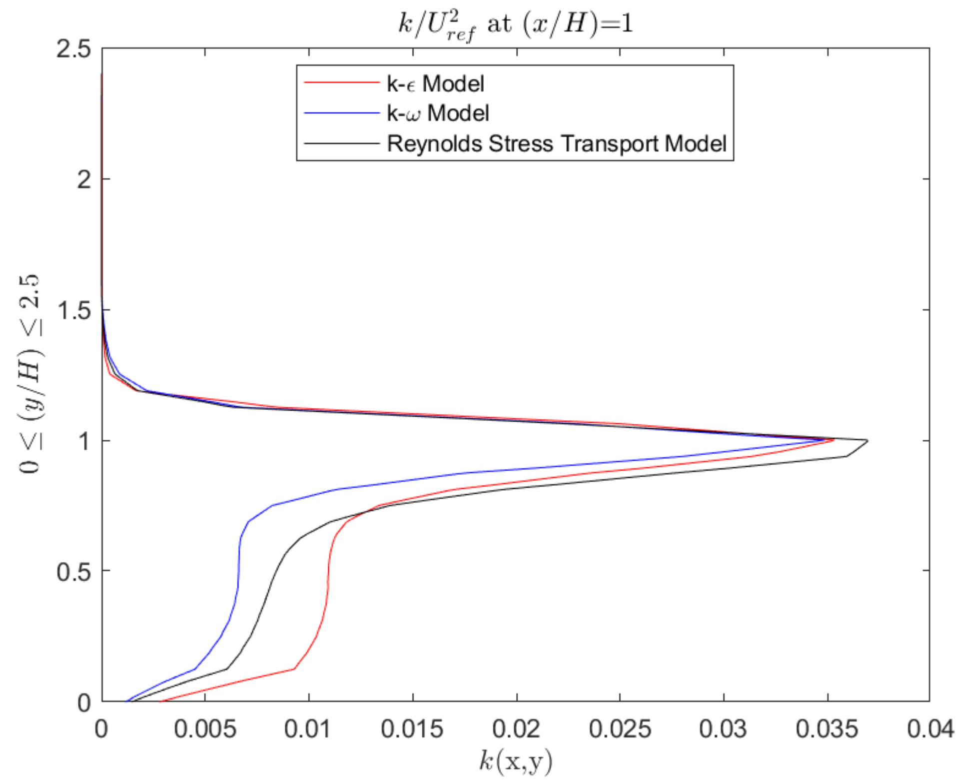
The FLUENT data agrees with experimental data where ever there isn’t an error with the experimental data.

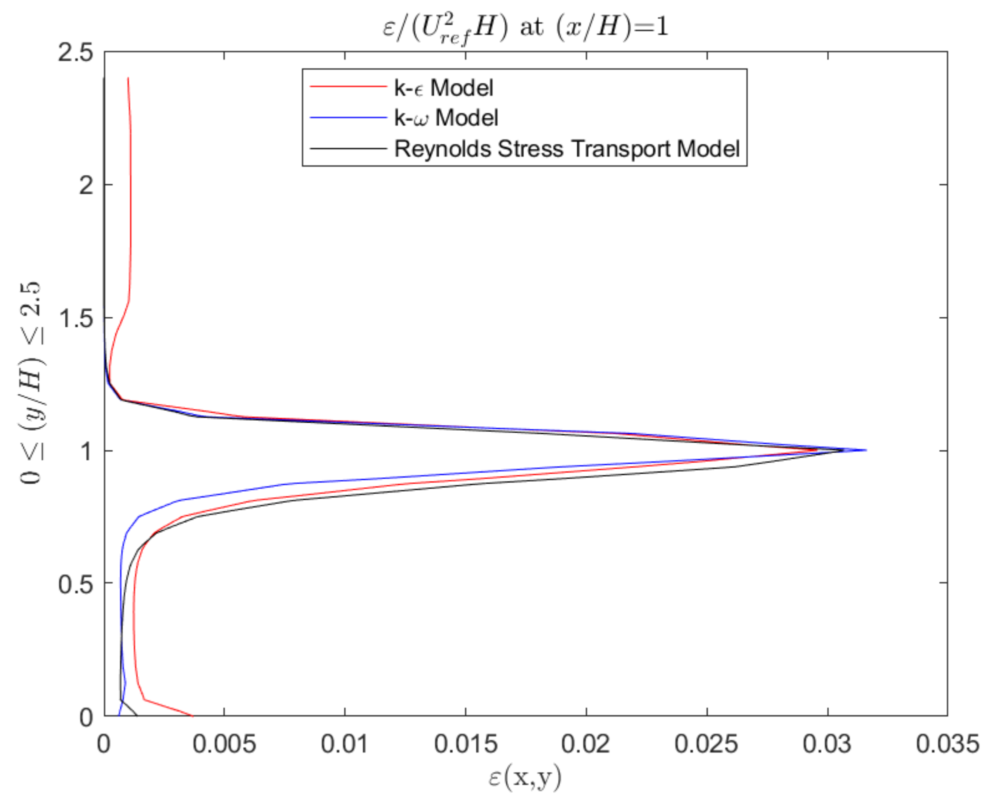
This error is likely due to incorrect storage/reading from the excel file of the experimental data.

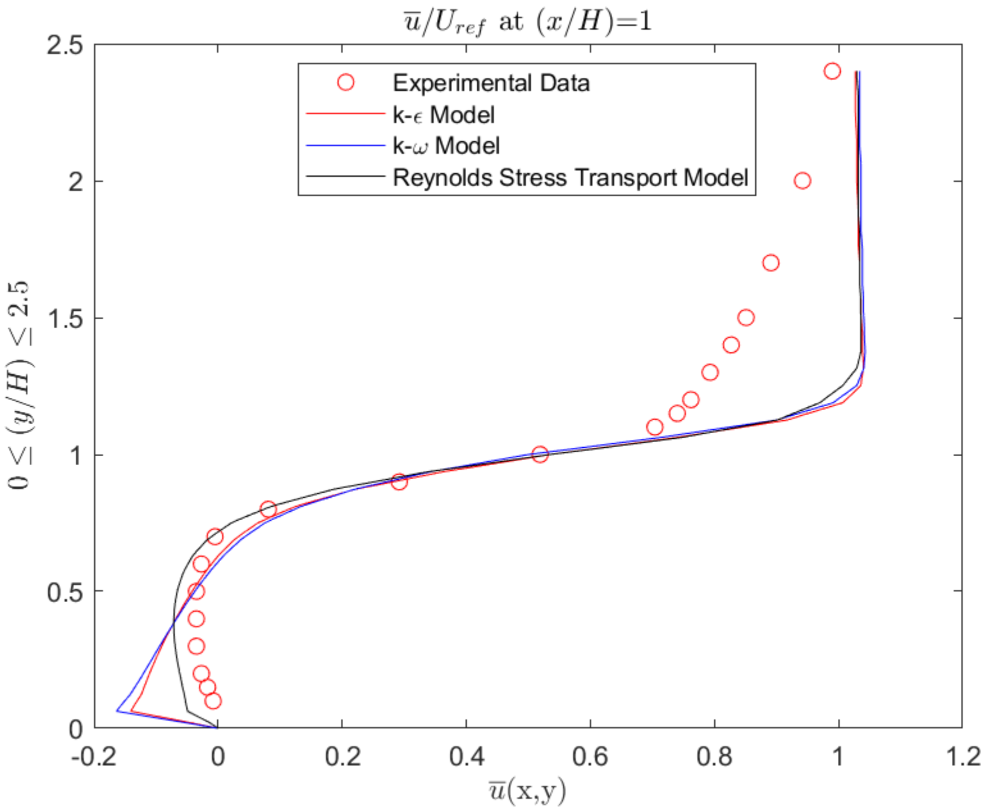
It is also observable that the finer the mesh, the closer the result to the experimental result.

3. Part 3: Effect of Turbulence method in FLUENT:

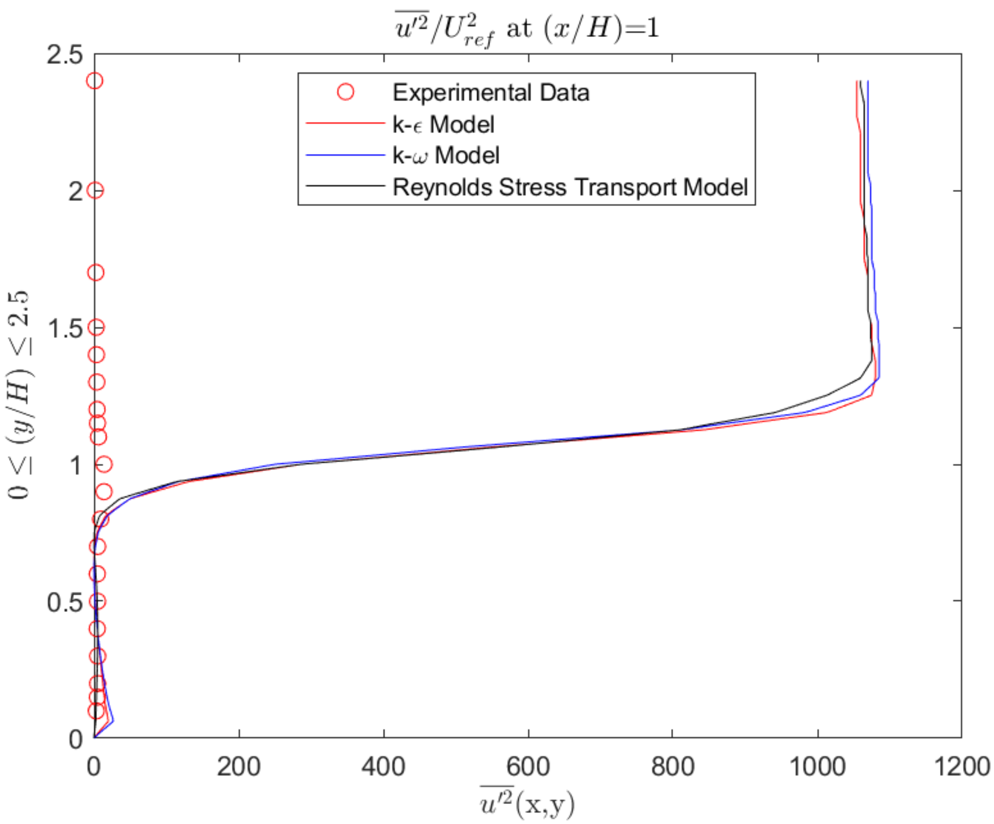
a. x/H=1



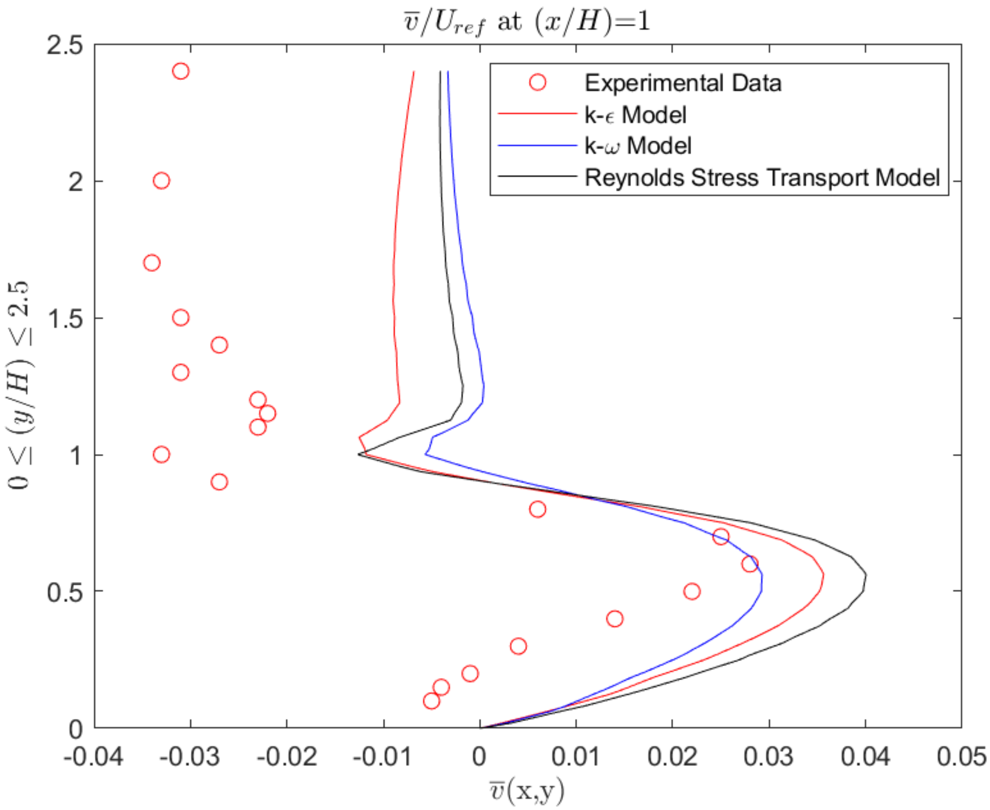




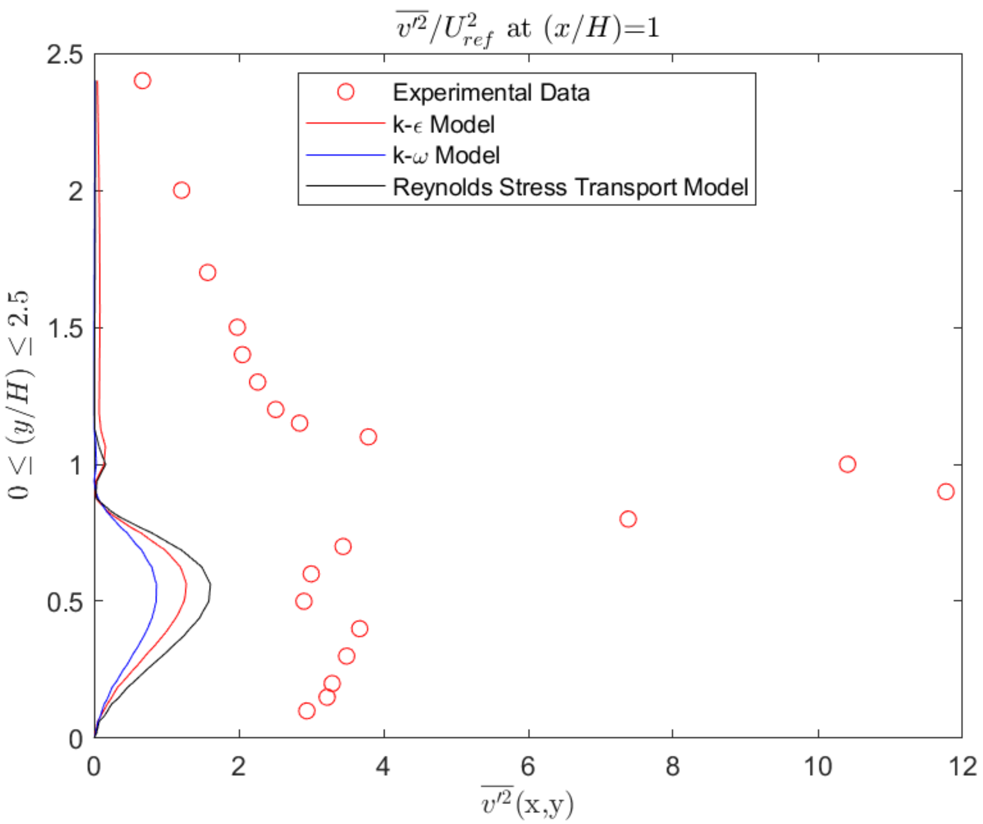
$\overline{u}/U_{ref}$ at (x/H)=1
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)



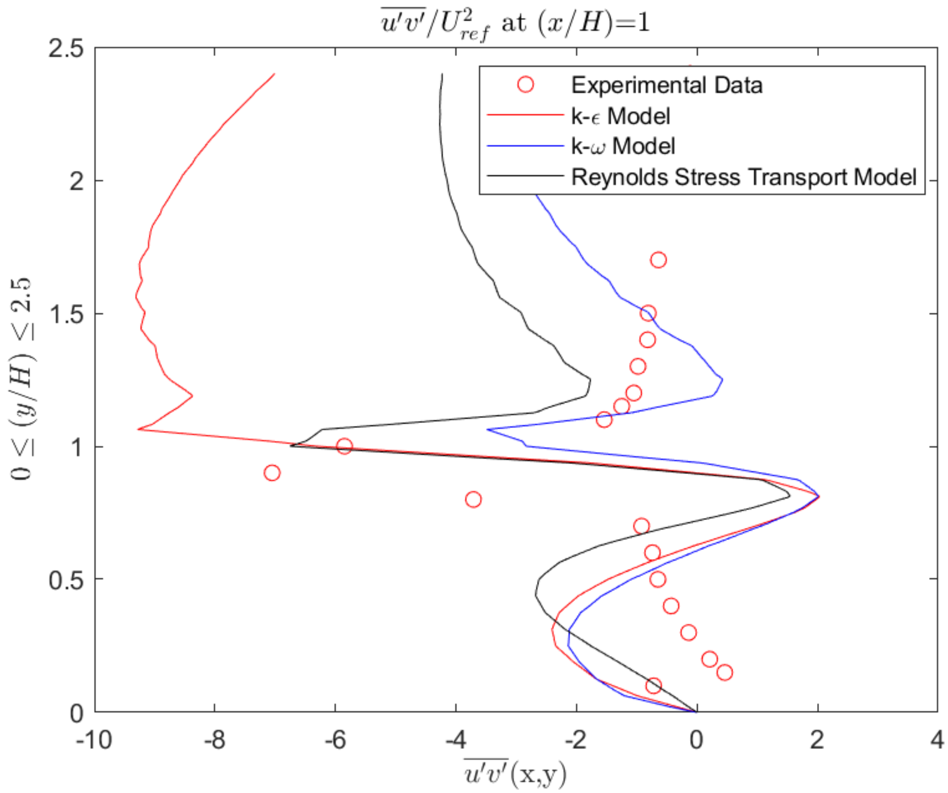
$\overline{u'^2}/U_{ref}^2$ at (x/H)=1
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)



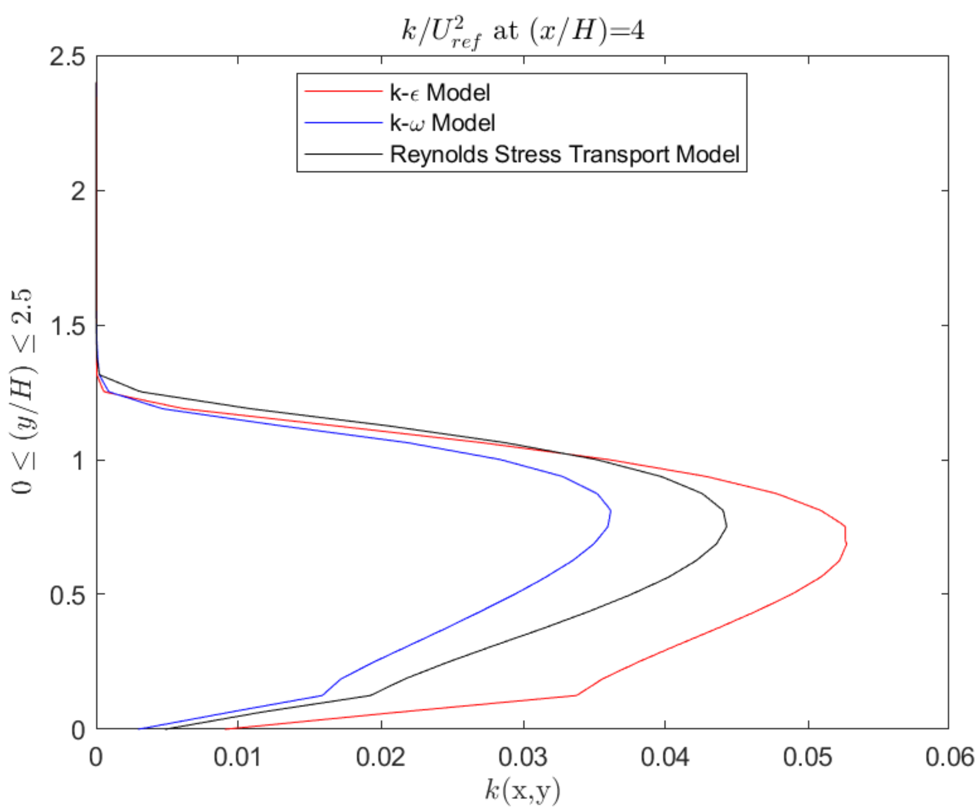
$\overline{v}/U_{ref}$ at (x/H)=1
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)

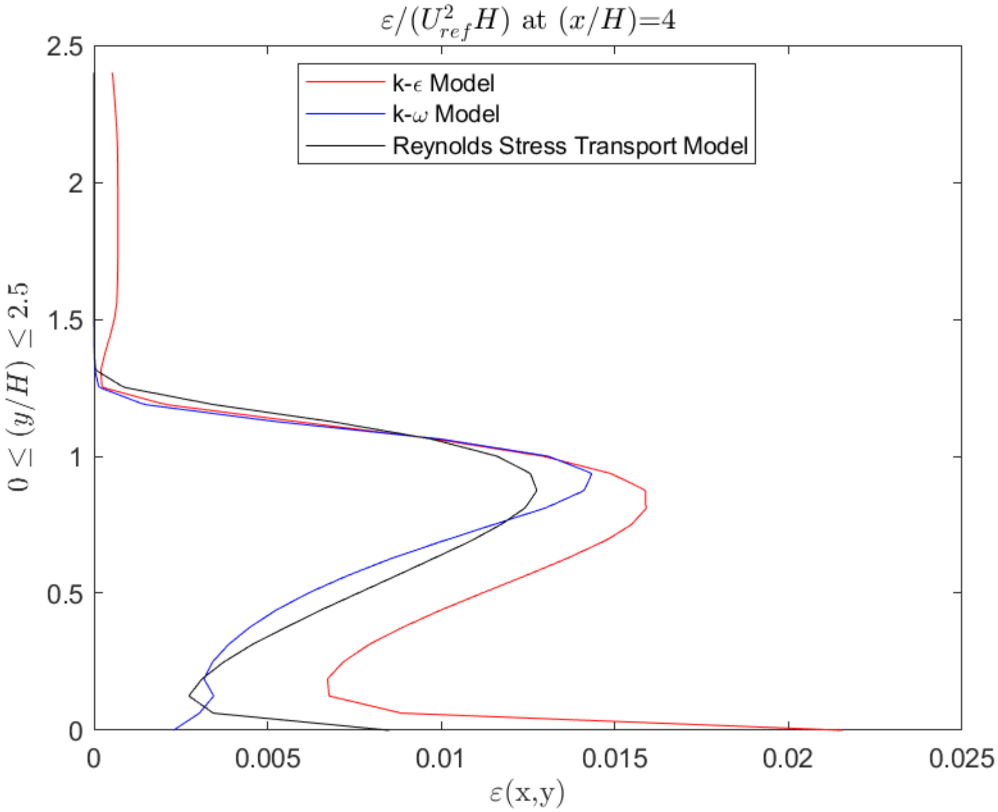


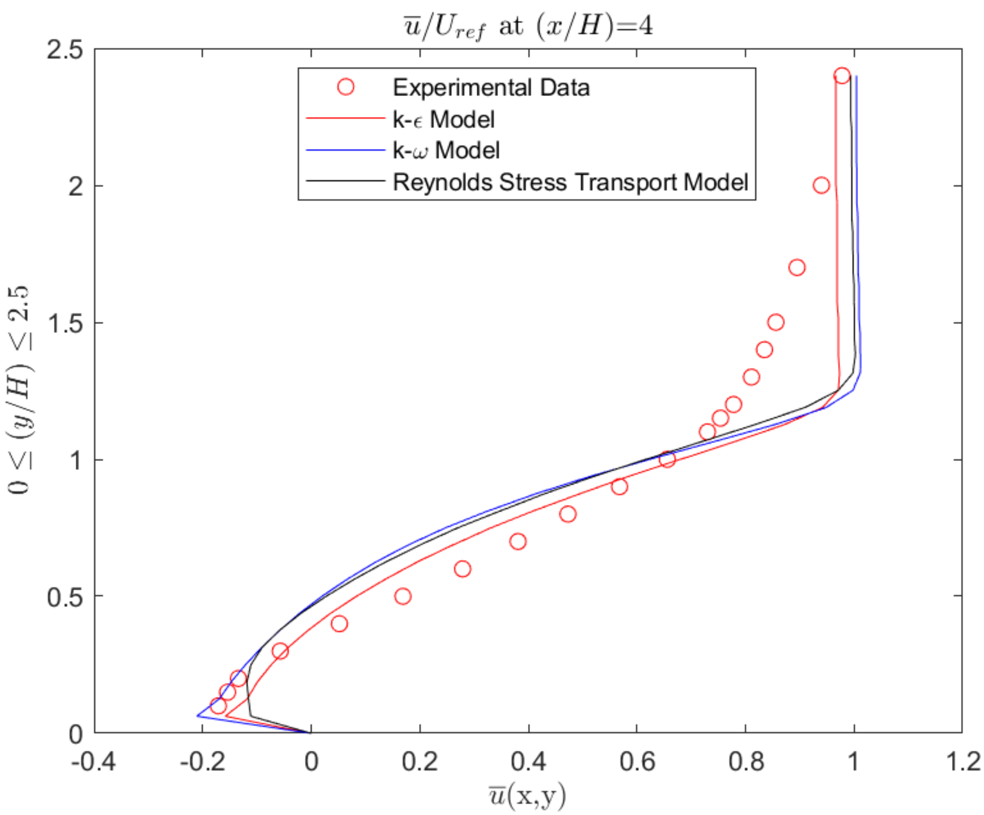
$\overline{v'^2}/U_{ref}^2$ at (x/H)=1
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)

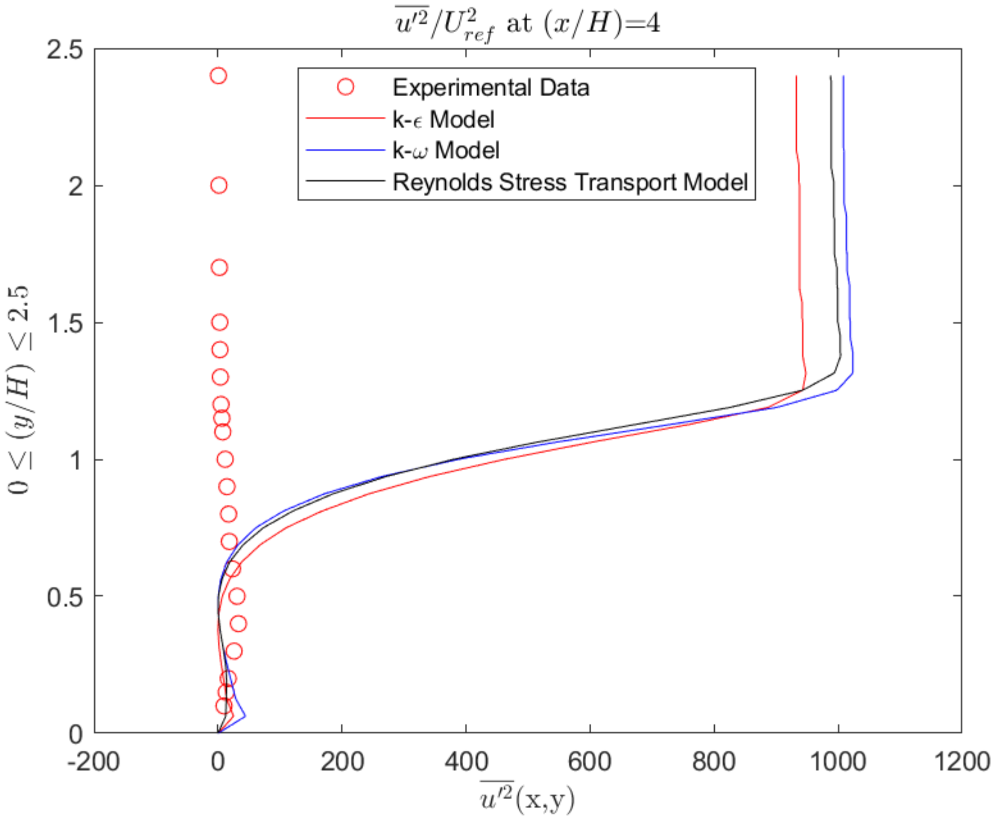

$\overline{u'v'}/U_{ref}^2$ at (x/H)=1
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
2.5
2
1.5
1
0.5
0
-10
-8
-6
-4
-2
0
2
4

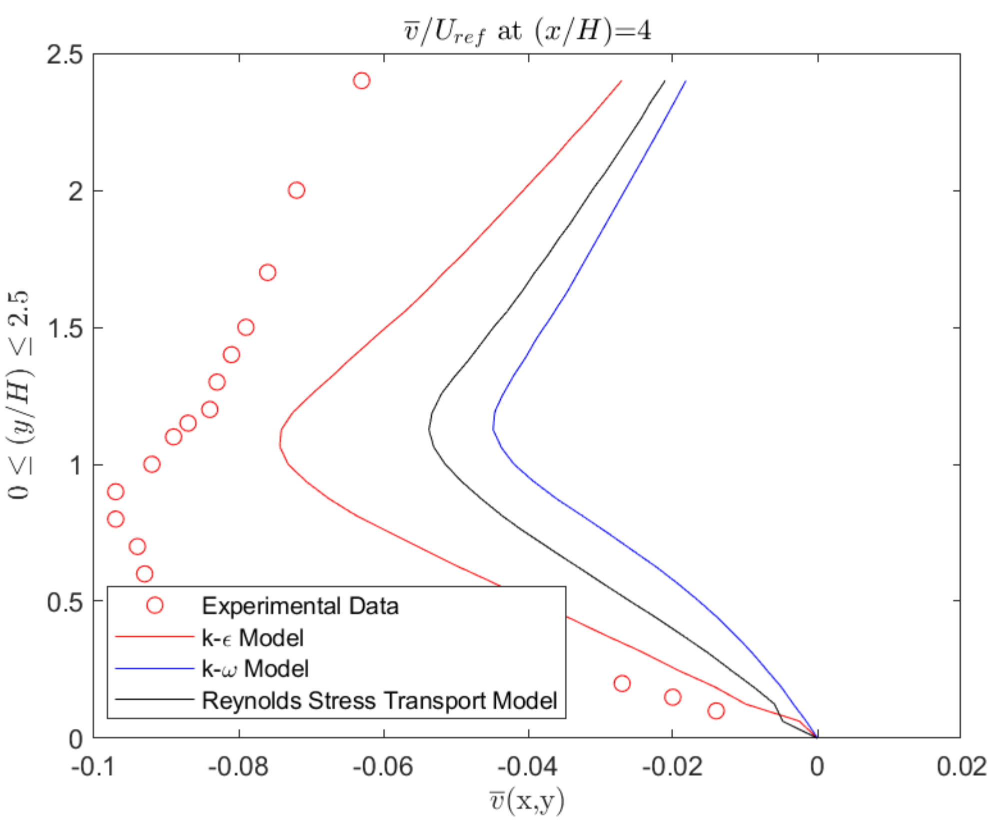
b. x/H=4

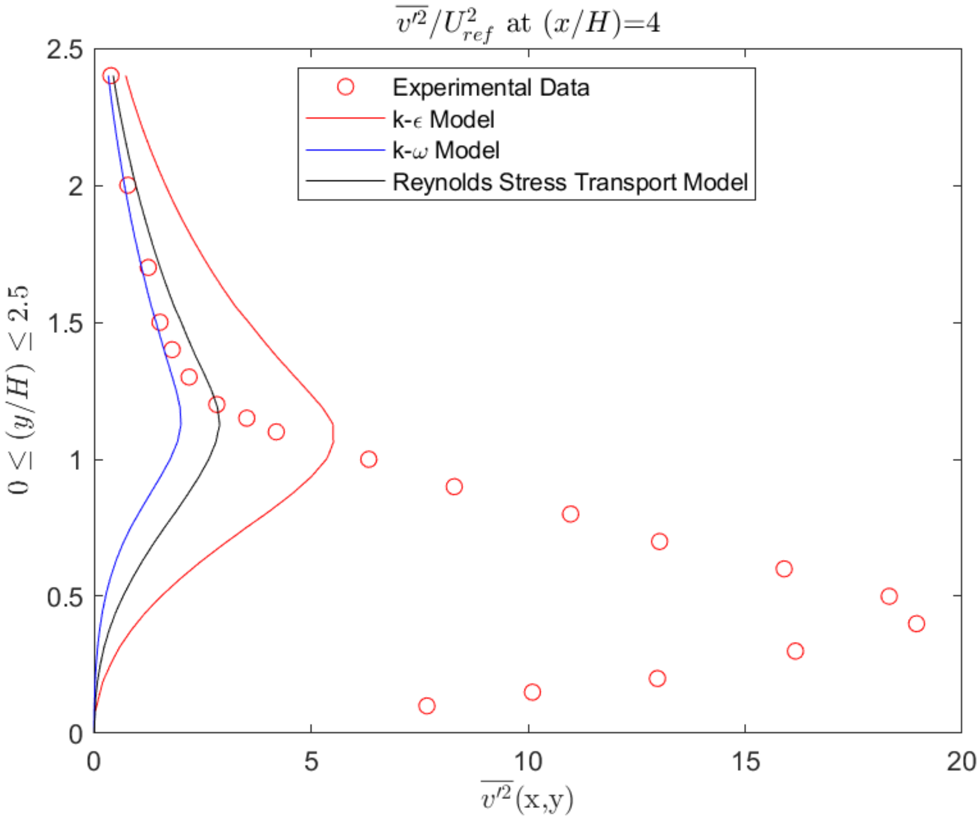

k/U_{ref}^2 at (x/H)=4
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
k(x,y)
2.5
2
1.5
1
0.5
0
0
0.01
0.02
0.03
0.04
0.05
0.06


$\varepsilon/(U_{ref}^2 H)$ at (x/H)=4
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.005
0.01
0.015
0.02
0.025
0.5
1
1.5
2
2.5

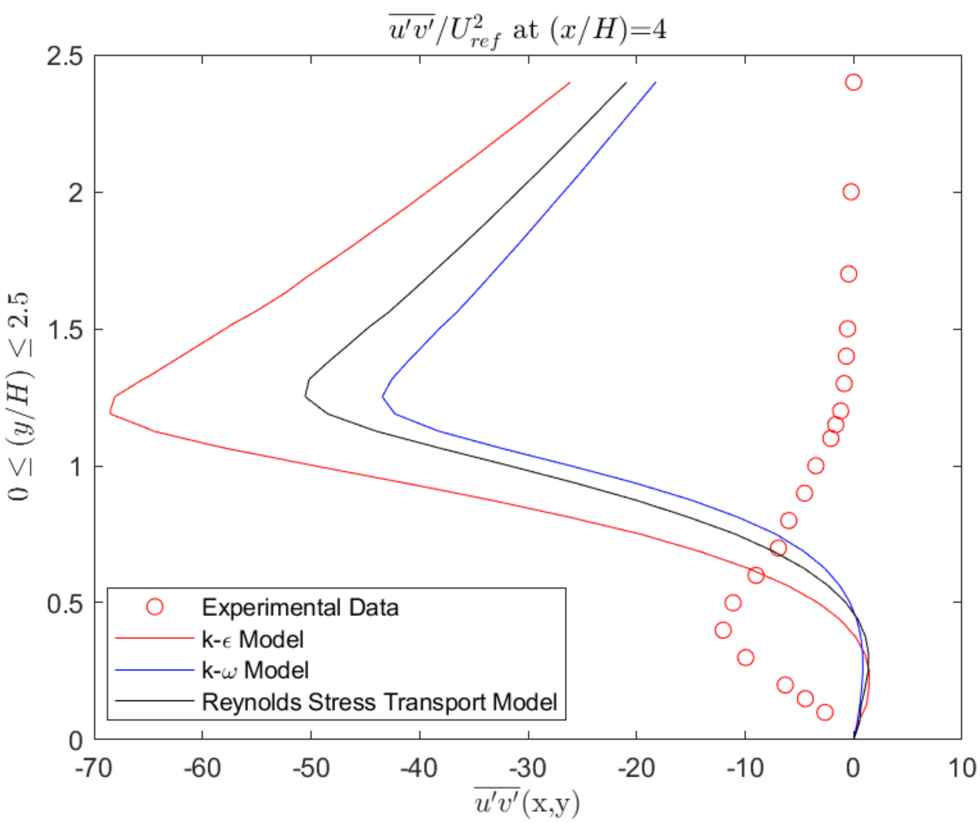

$\overline{u}/U_{ref}$ at (x/H)=4
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
0.5
1
1.5
2
2.5


$\overline{u'^2}/U_{ref}^2$ at (x/H)=4
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
2.5
2
1.5
1
0.5
0
-200
0
200
400
600
800
1000
1200


$\overline{v}/U_{ref}$ at (x/H)=4
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
2.5
2
1.5
1
0.5
0
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02

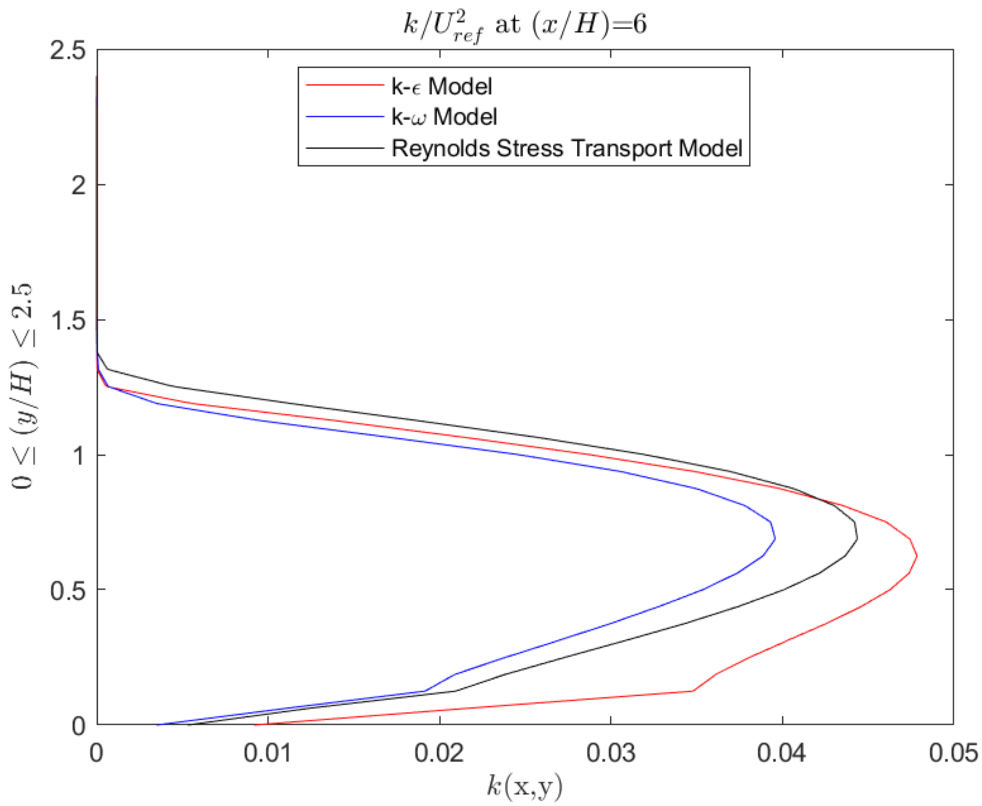


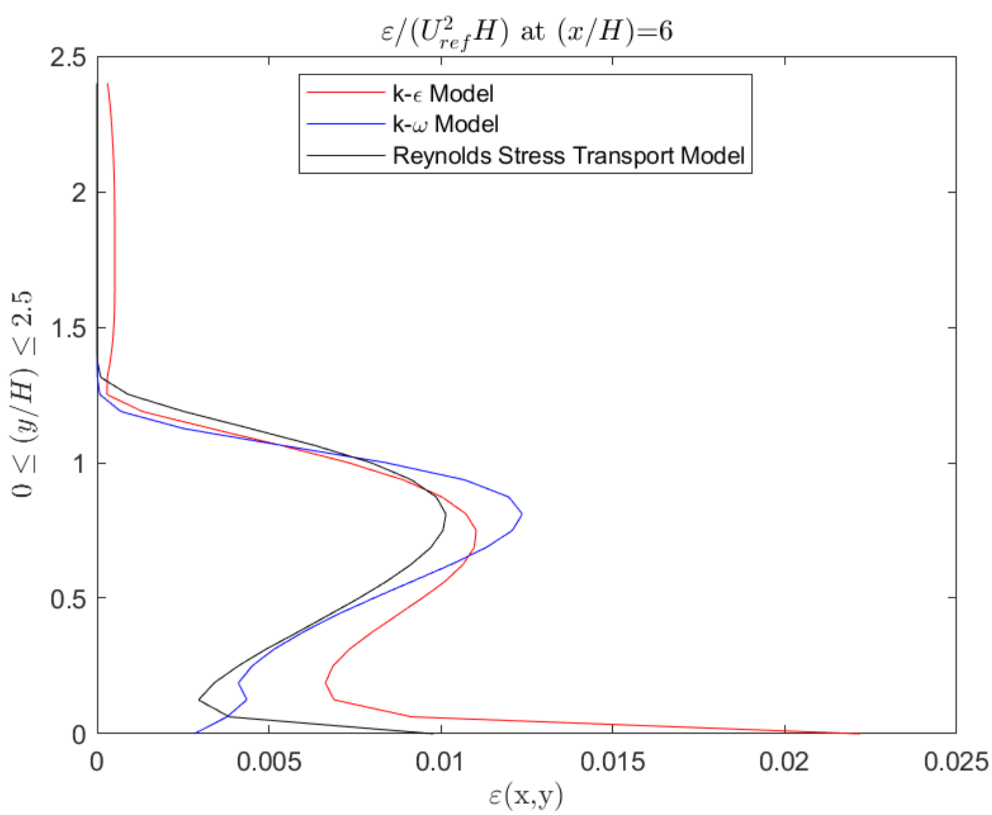
$\overline{v'^2}/U_{ref}^2$ at (x/H)=4
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
5
10
15
20

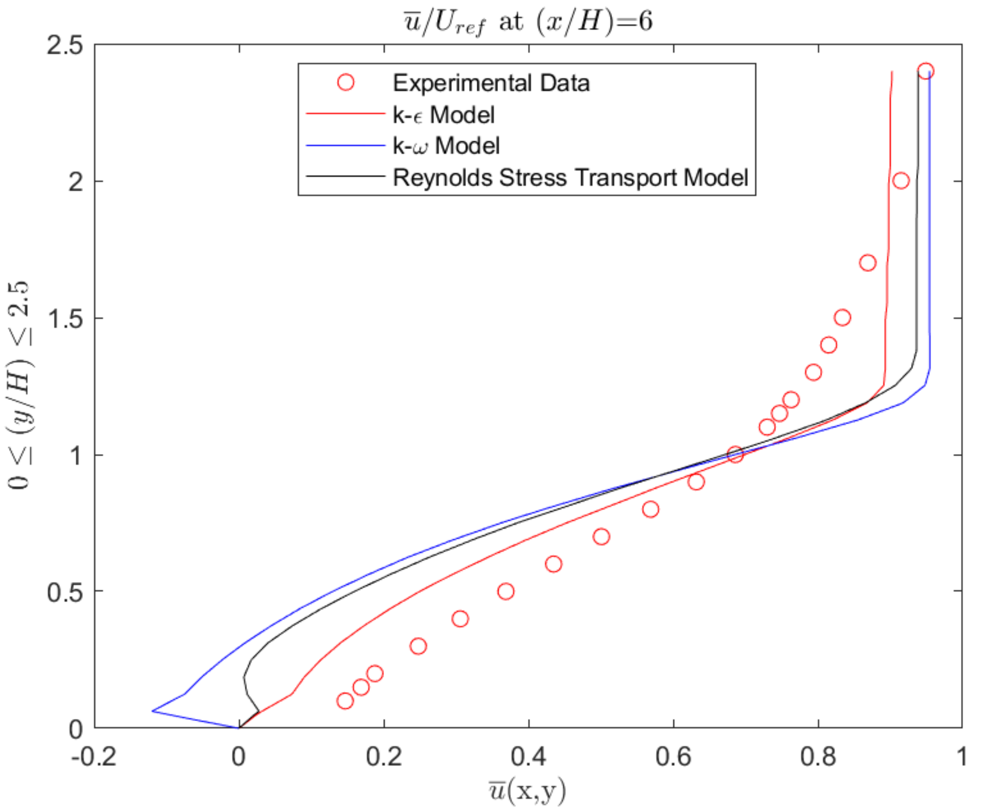


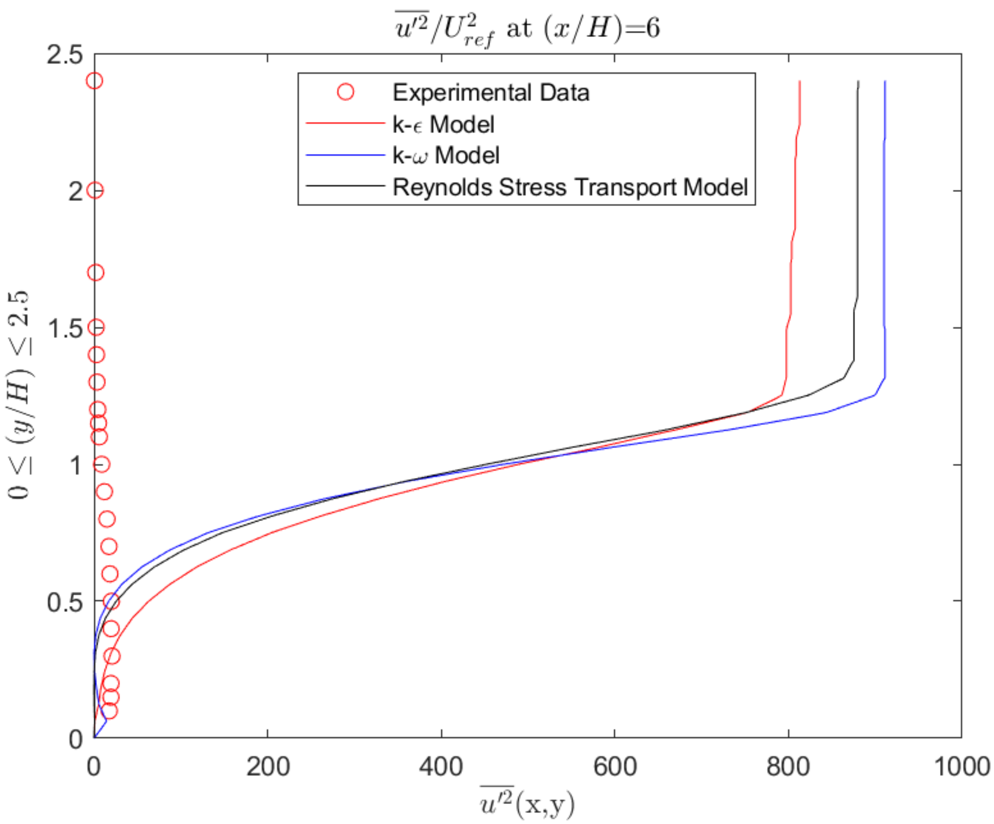
$\overline{u'v'}/U_{ref}^2$ at (x/H)=4
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
0
0.5
1
1.5
2
2.5
-70
-60
-50
-40
-30
-20
-10
0
10

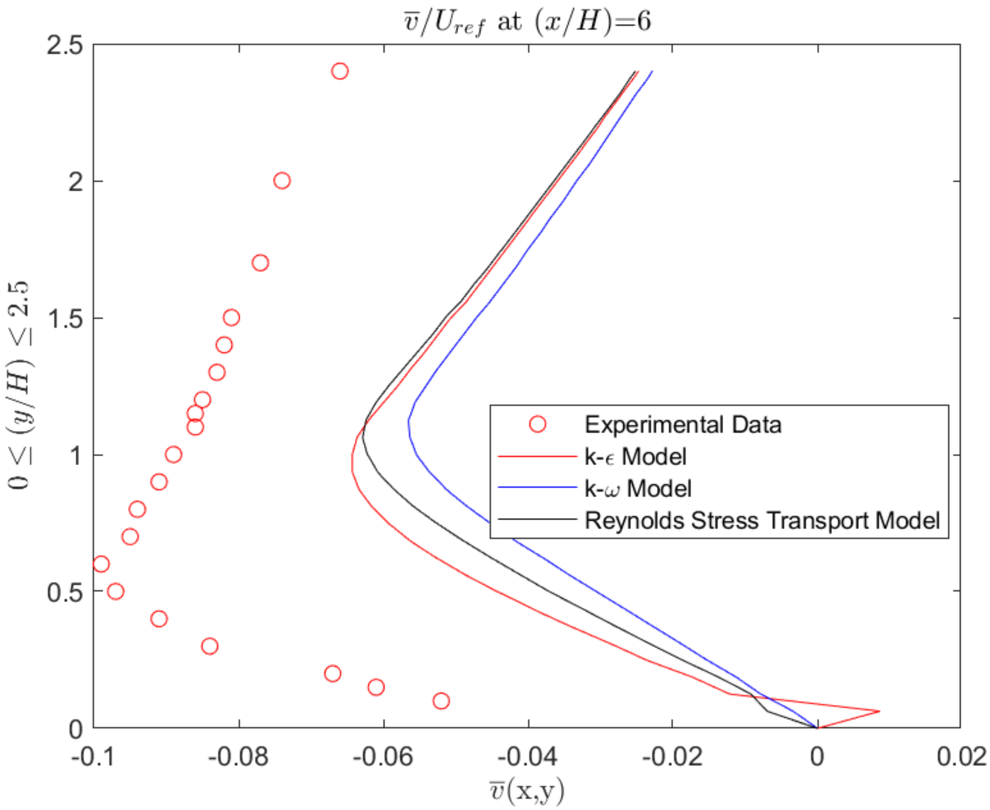
c. x/H=6


k/U_{ref}^2 at (x/H)=6
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
k(x,y)
0
0.5
1
1.5
2
2.5
0.01
0.02
0.03
0.04
0.05

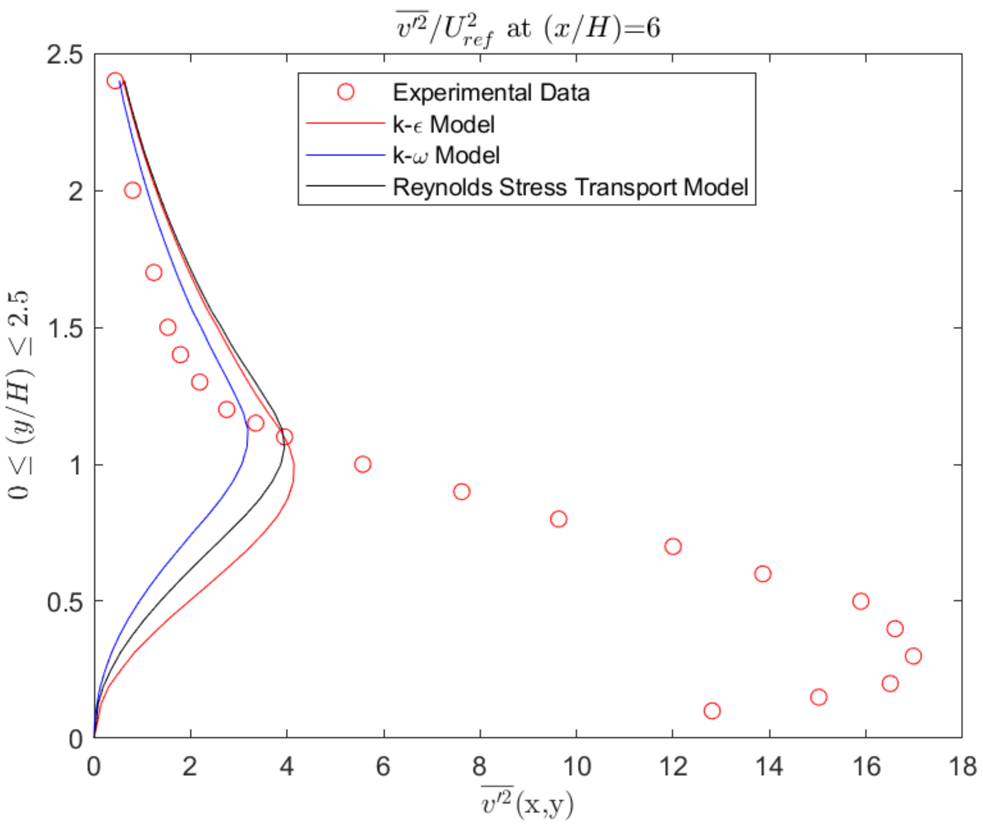

$\varepsilon/(U_{ref}^2 H)$ at (x/H)=6
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.5
1
1.5
2
2.5
0.005
0.01
0.015
0.02
0.025


$\overline{u}/U_{ref}$ at (x/H)=6
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
2.5
2
1.5
1
0.5
0
-0.2
0
0.2
0.4
0.6
0.8
1

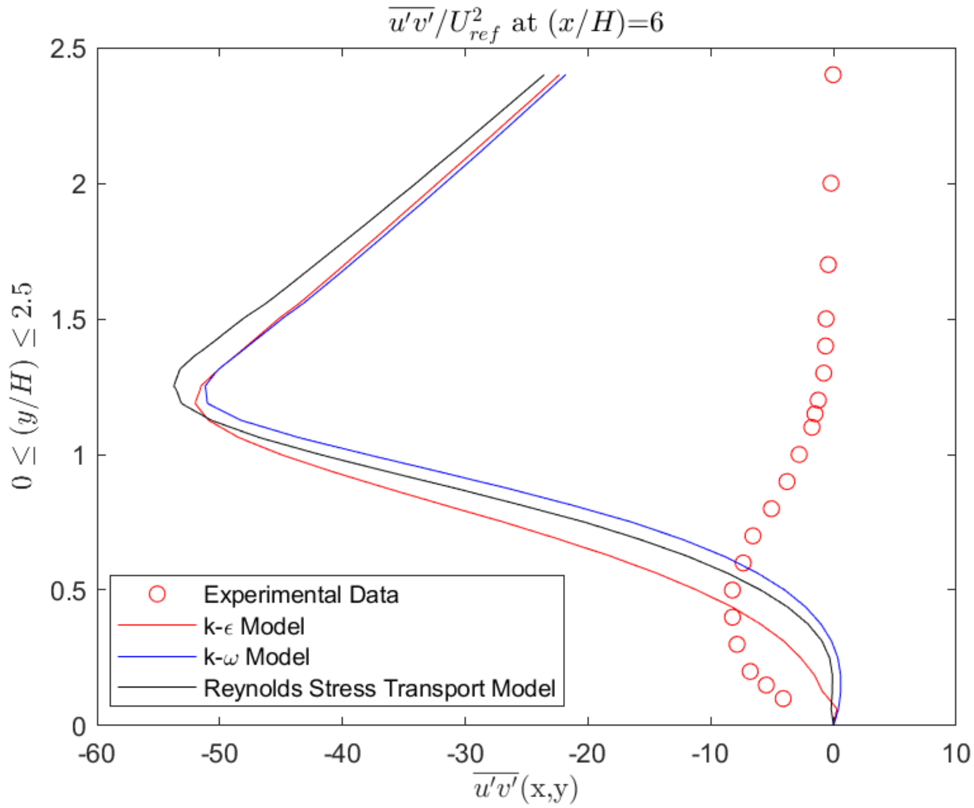

$\overline{u'^2}/U_{ref}^2$ at (x/H)=6
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
2.5
2
1.5
1
0.5
0
0
200
400
600
800
1000



$\overline{v}/U_{ref}$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model

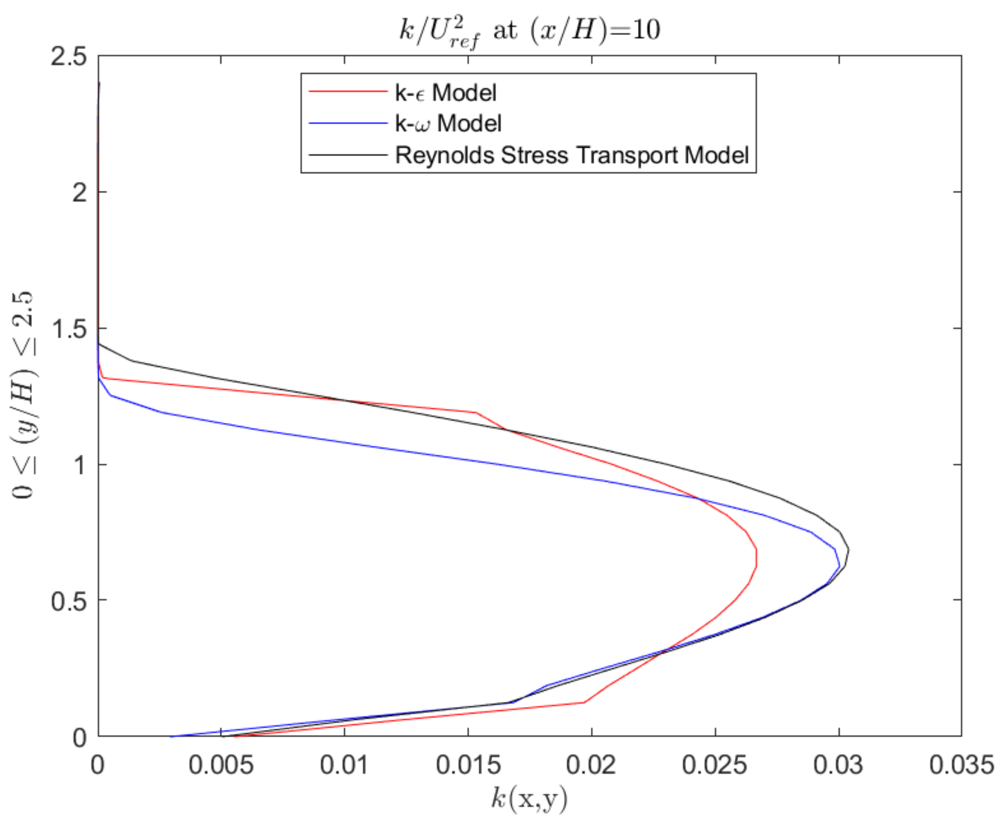


$\overline{v'^2}/U_{ref}^2$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model

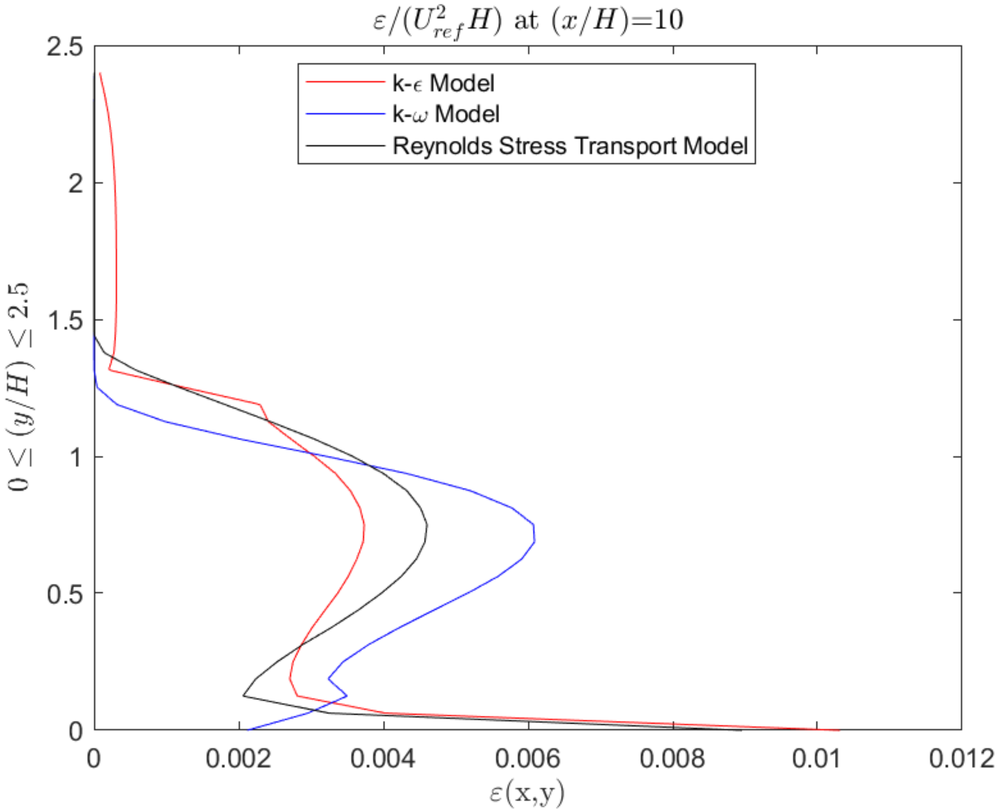


$\overline{u'v'}/U_{ref}^2$ at (x/H)=6
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)

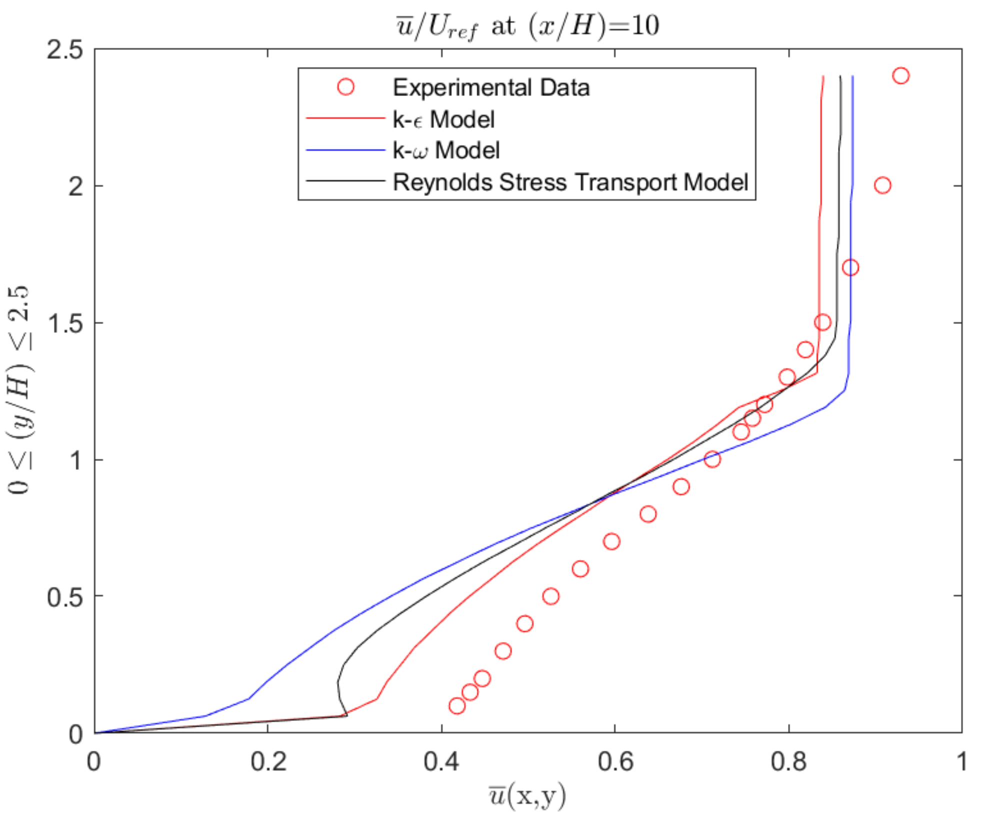
d. x/H=10



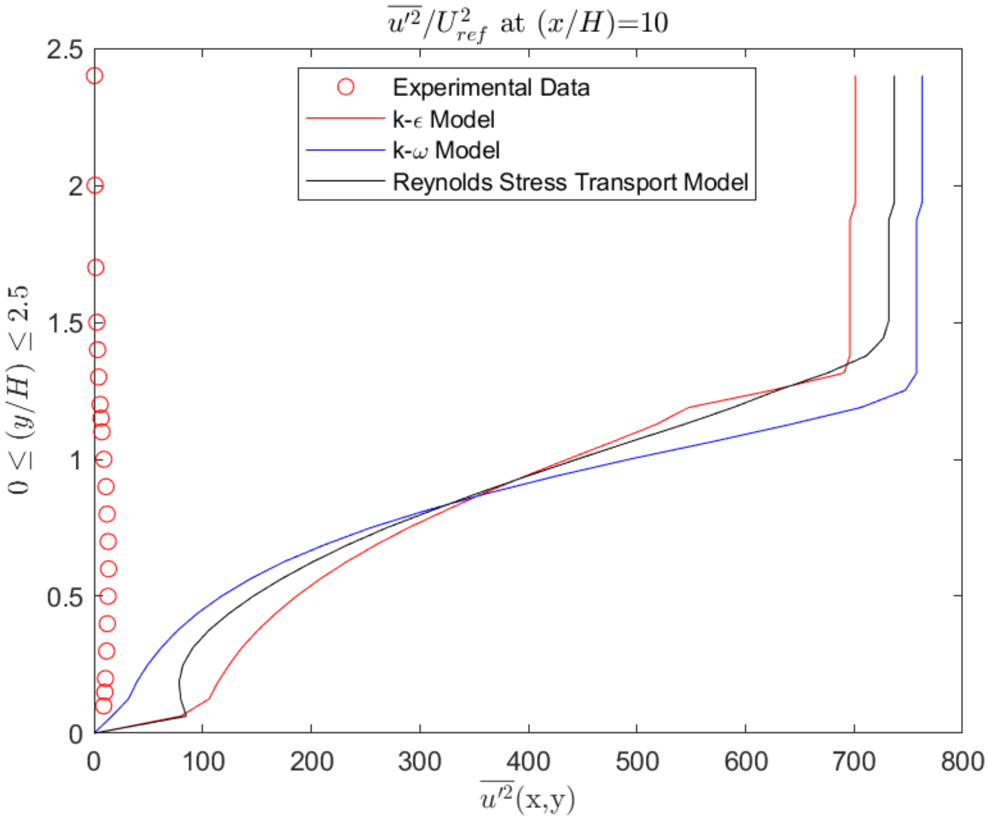
k/U_{ref}^2 at (x/H)=10
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
k(x,y)



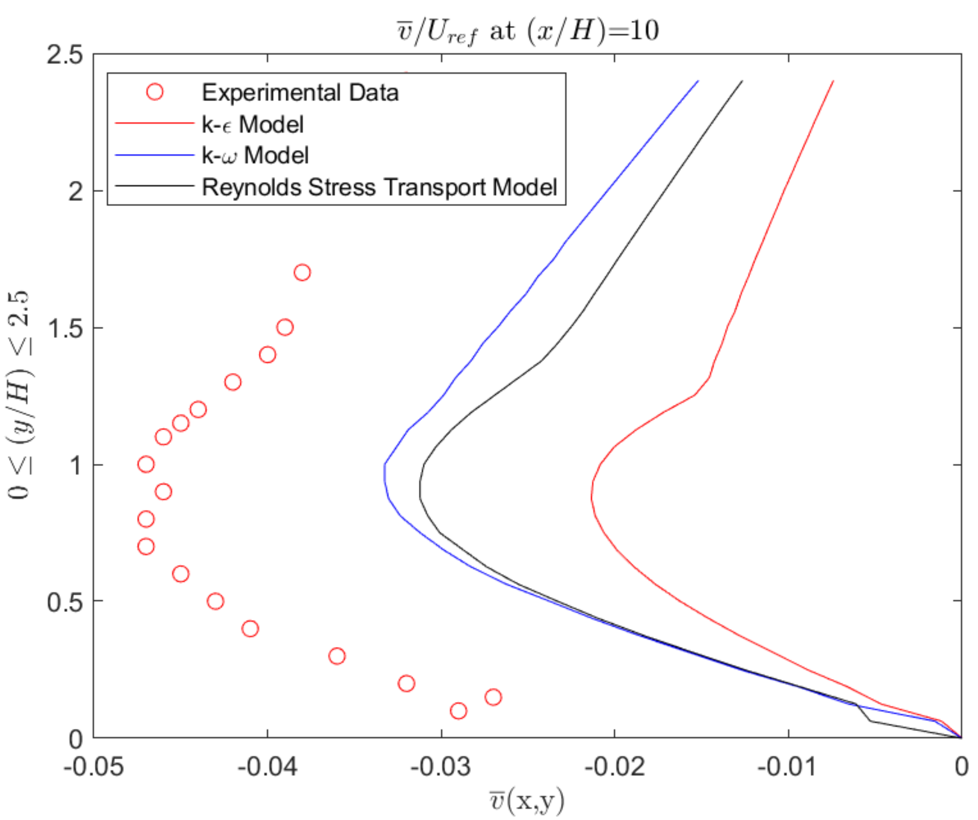
$\varepsilon/(U_{ref}^2 H)$ at (x/H)=10
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.5
1
1.5
2
2.5
0.002
0.004
0.006
0.008
0.01
0.012



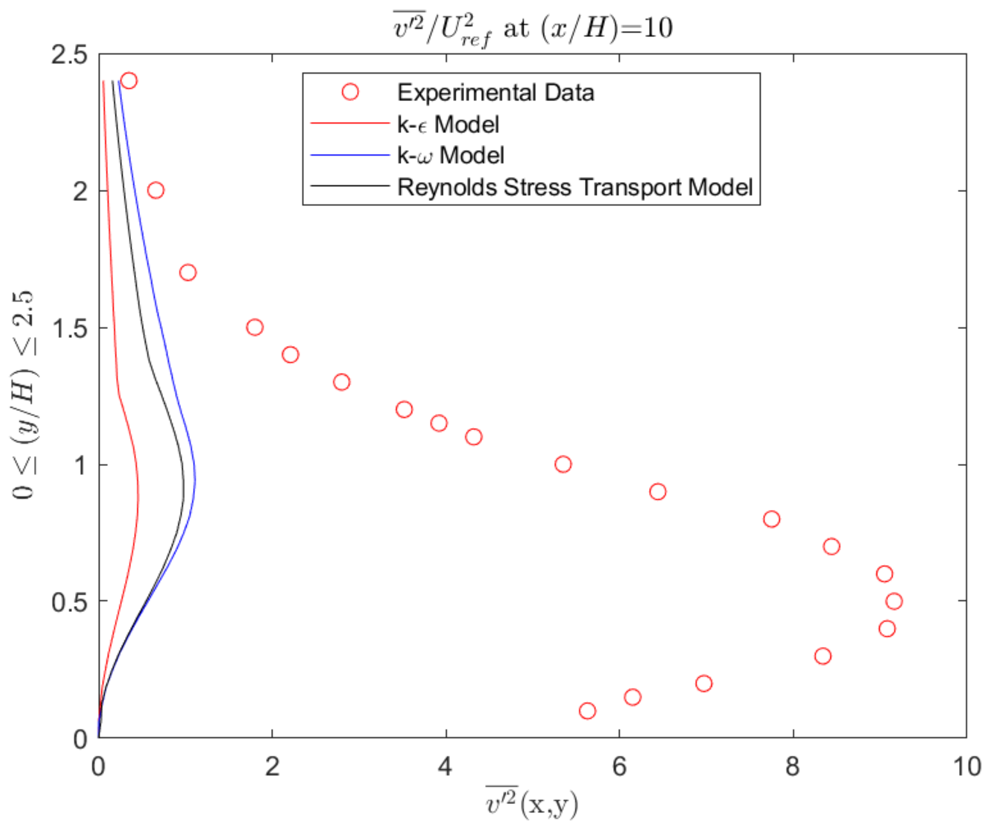
$\overline{u}/U_{ref}$ at (x/H)=10
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
0
0.5
1
1.5
2
2.5
0.2
0.4
0.6
0.8
1

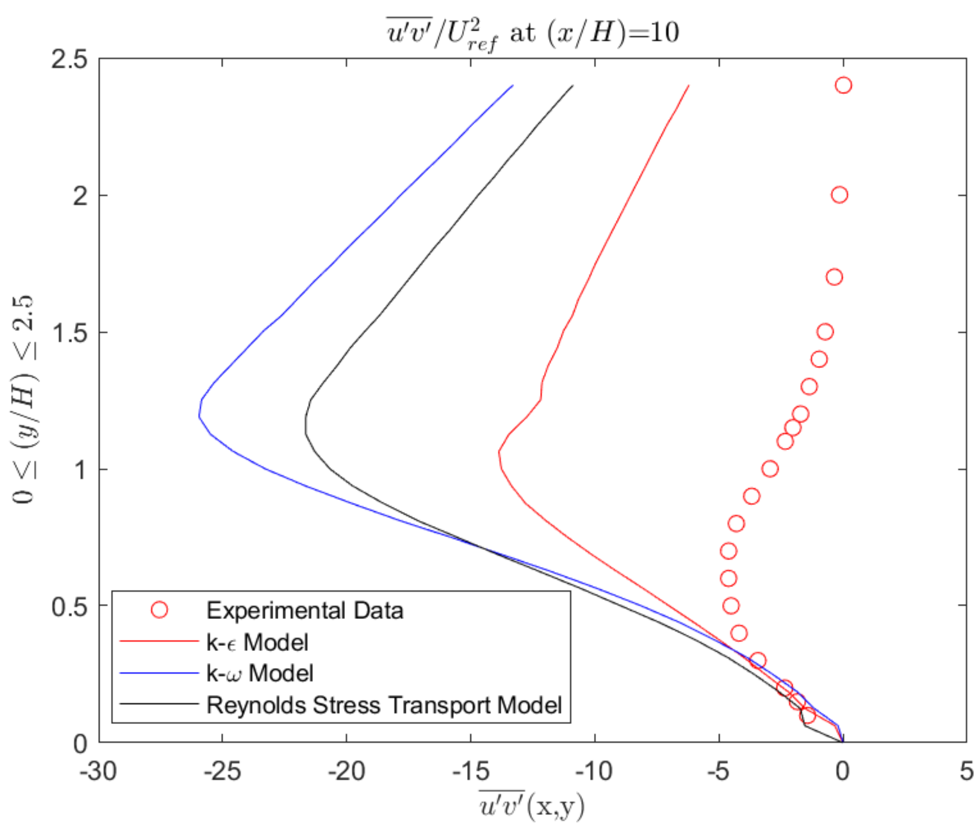


$\overline{u'^2}/U_{ref}^2$ at (x/H)=10
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)



$\overline{v}/U_{ref}$ at (x/H)=10
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)


$\overline{v'^2}/U_{ref}^2$ at (x/H)=10
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10


$\overline{u'v'}/U_{ref}^2$ at (x/H)=10
Experimental Data
k-ϵ Model
k-ω Model
Reynolds Stress Transport Model
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
0
0.5
1
1.5
2
2.5
-30
-25
-20
-15
-10
-5
0
5

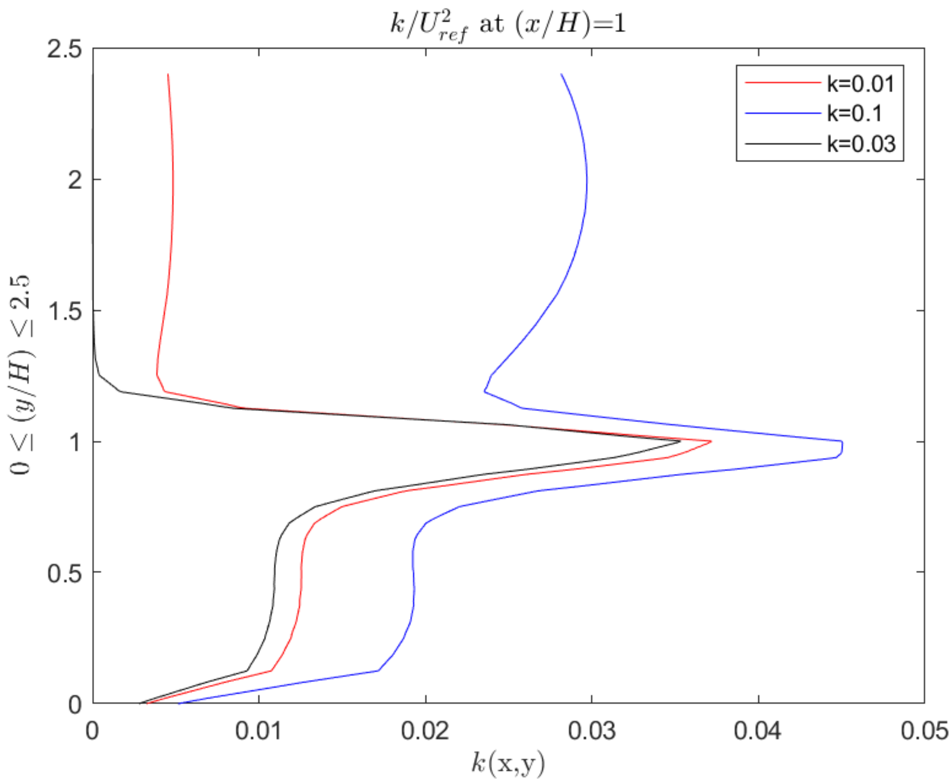
Observations:

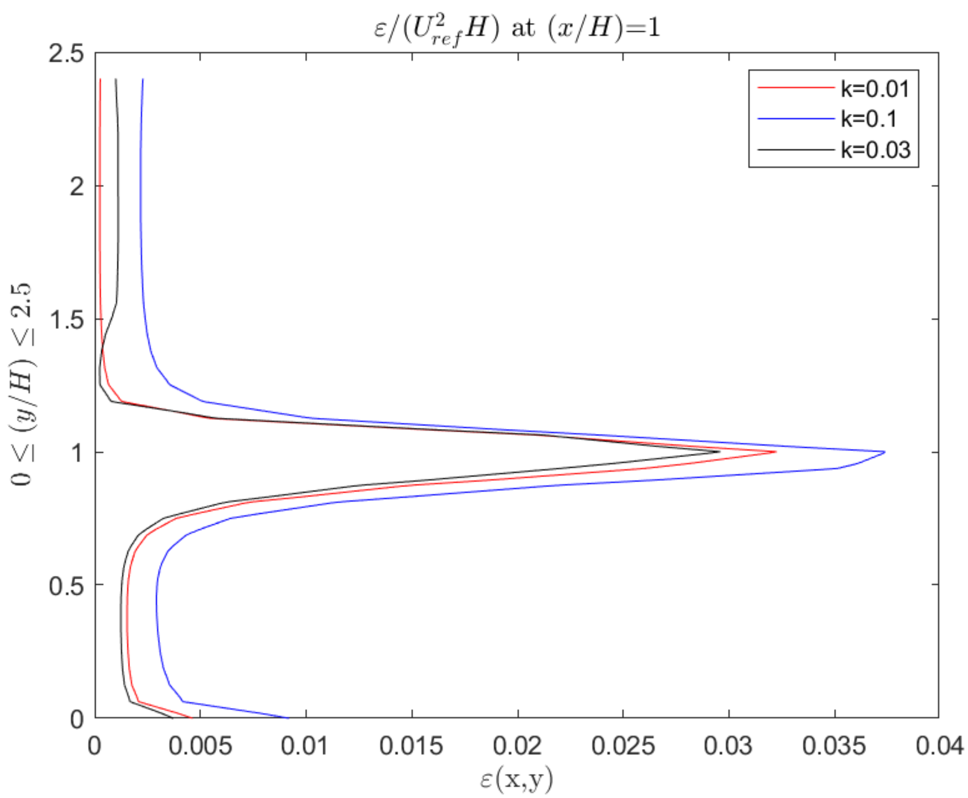
The graphs pertaining to u(x, y) has good agreement with experimental data.

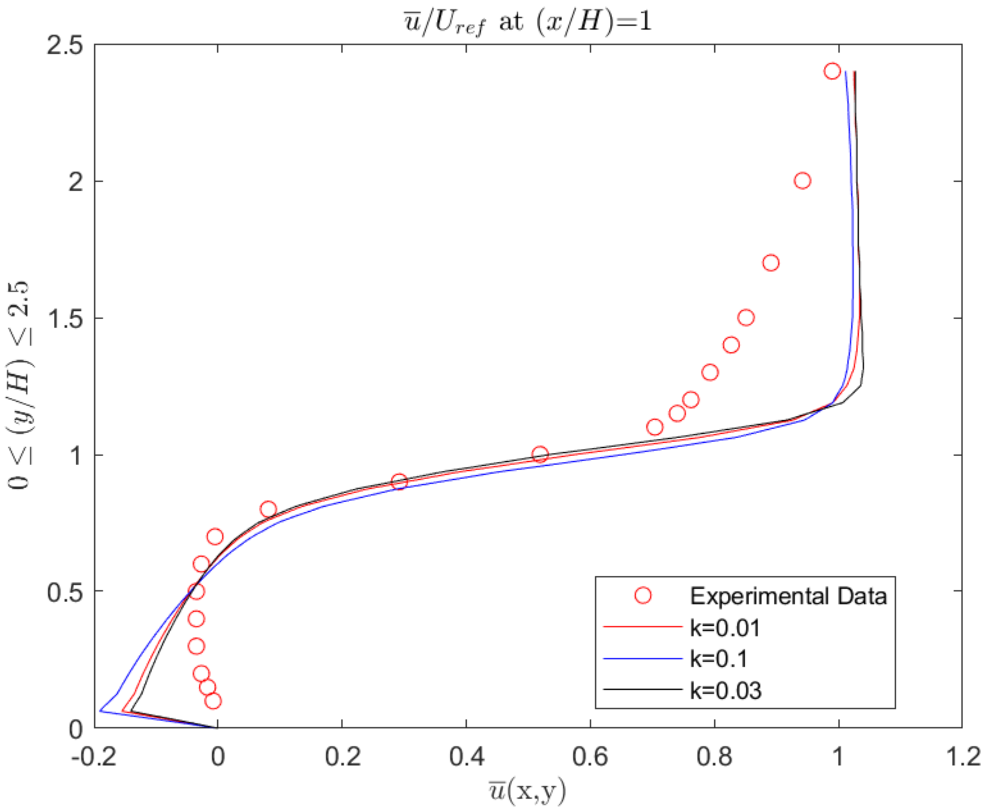
This is not the case with v(x, y), where the experimental data shows much larger swings in values, where the software algorithm doesn't keep up. Similarly, $u_i u_j$ has sudden changes.

These differences in the simulation and experiment are likely due to the linear approximations that the software performs to obtain data where it cannot accurately resolve the equations.

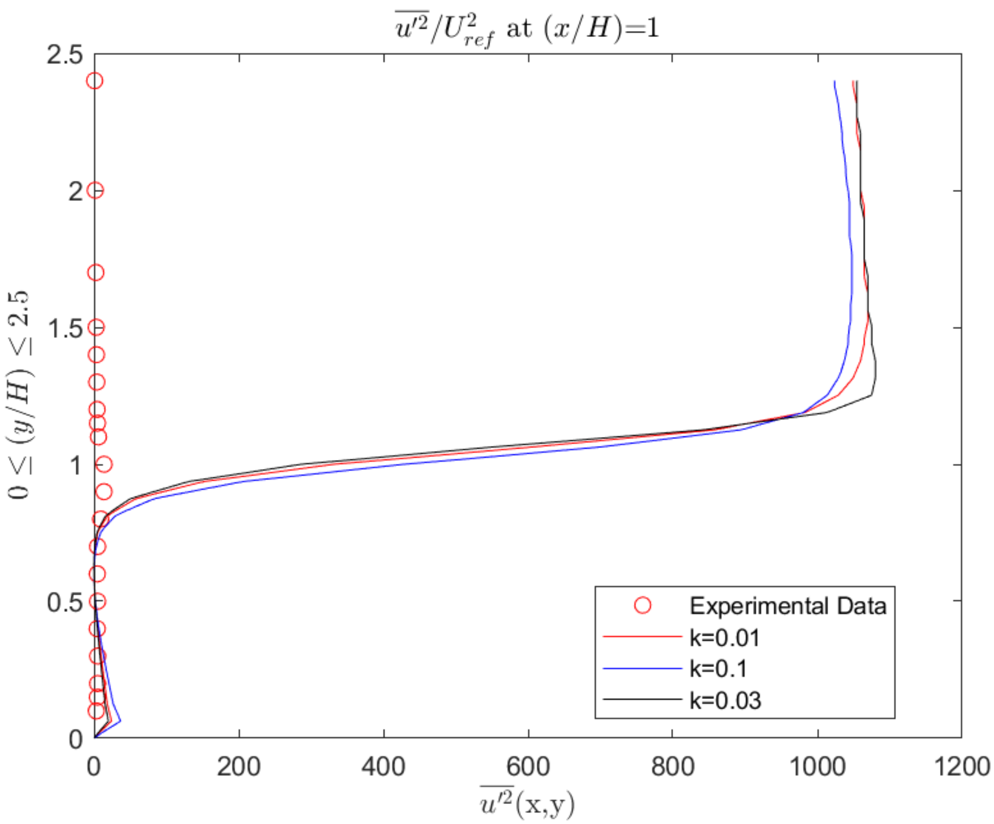
4. Part 4: Variations with inflow turbulence.
   a. x/H=1



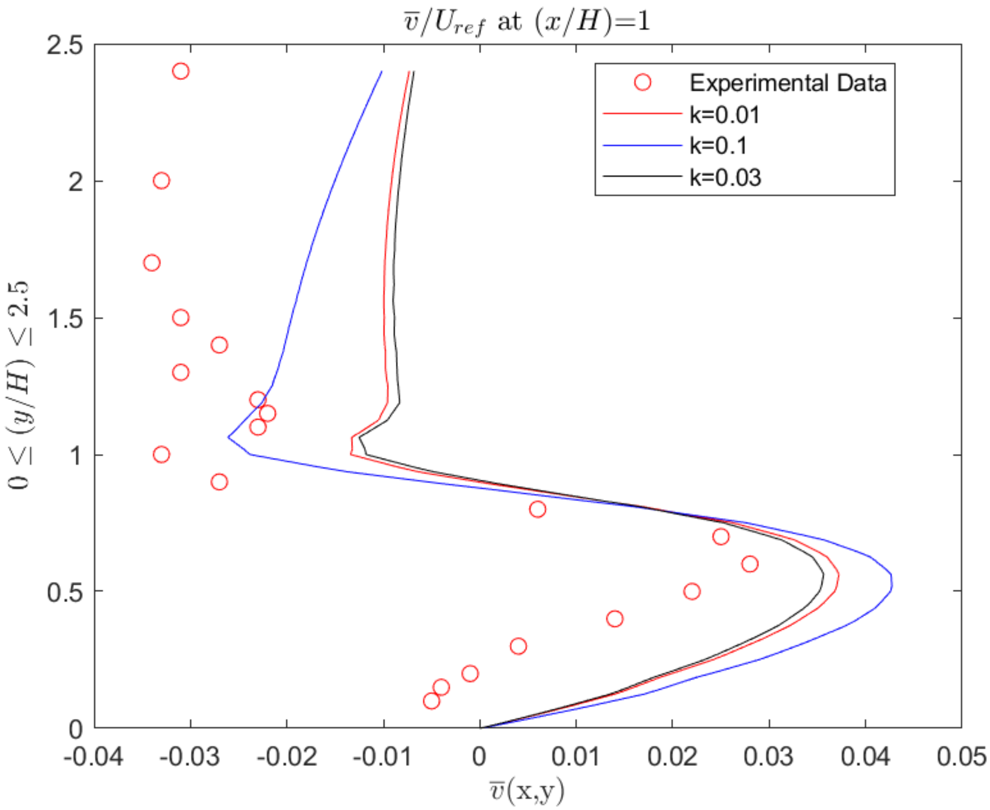




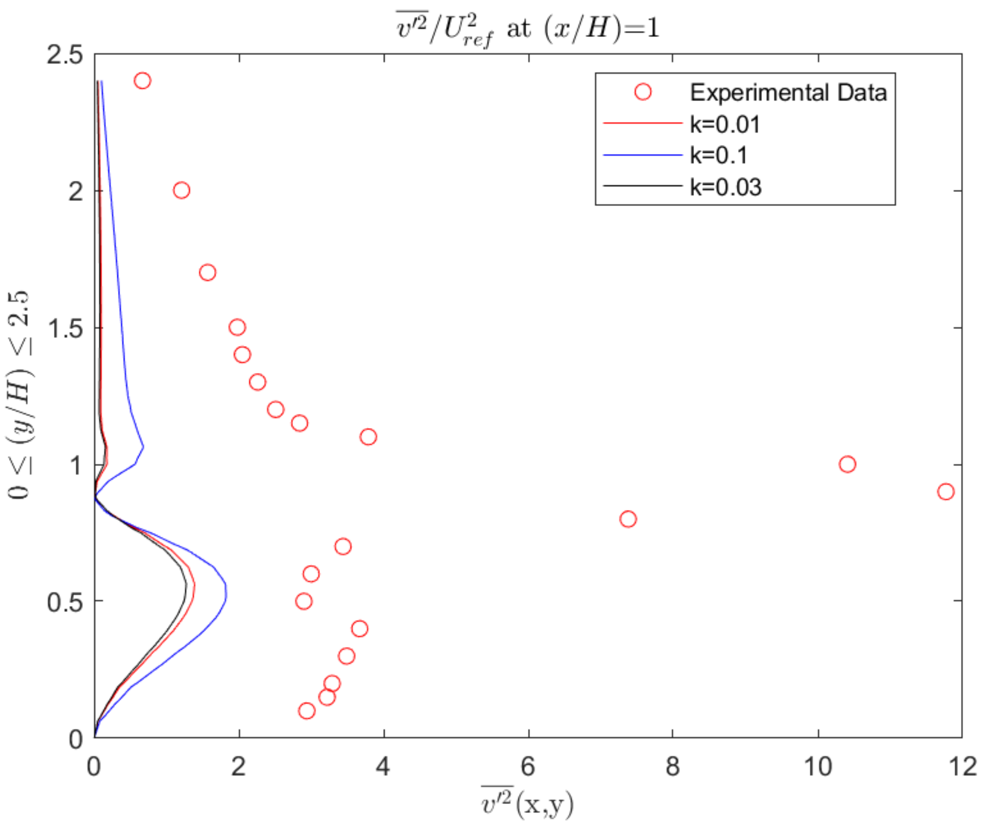
$\overline{u}/U_{ref}$ at (x/H)=1
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
Experimental Data
k=0.01
k=0.1
k=0.03



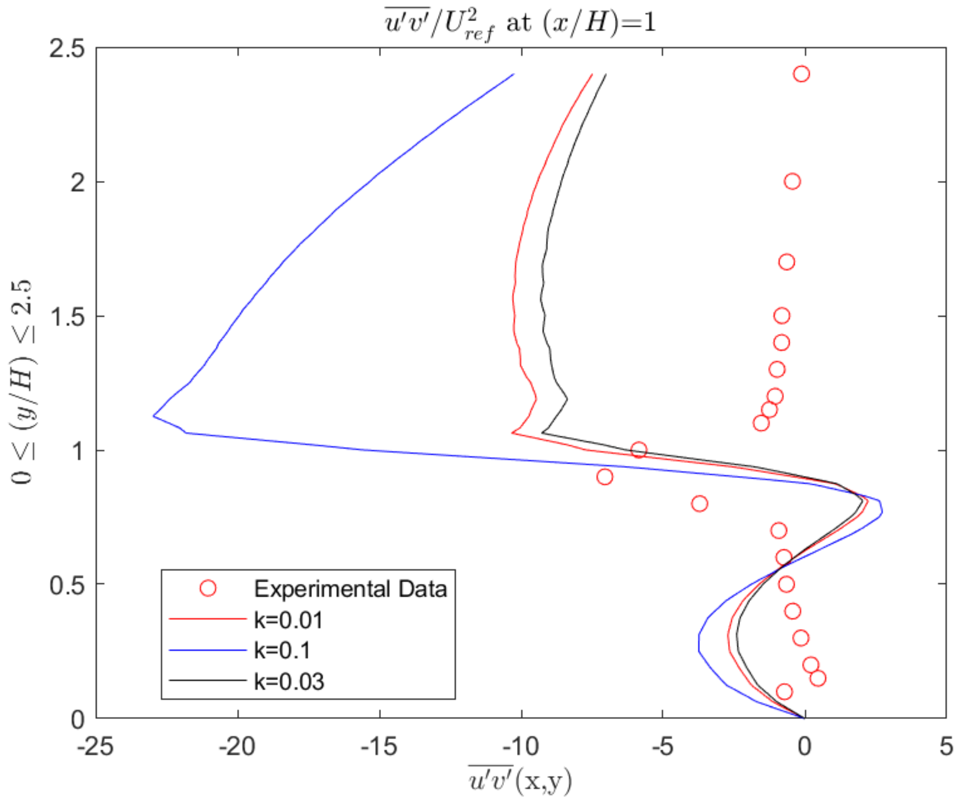
$\overline{u'^2}/U_{ref}^2$ at (x/H)=1
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
k=0.01
k=0.1
k=0.03



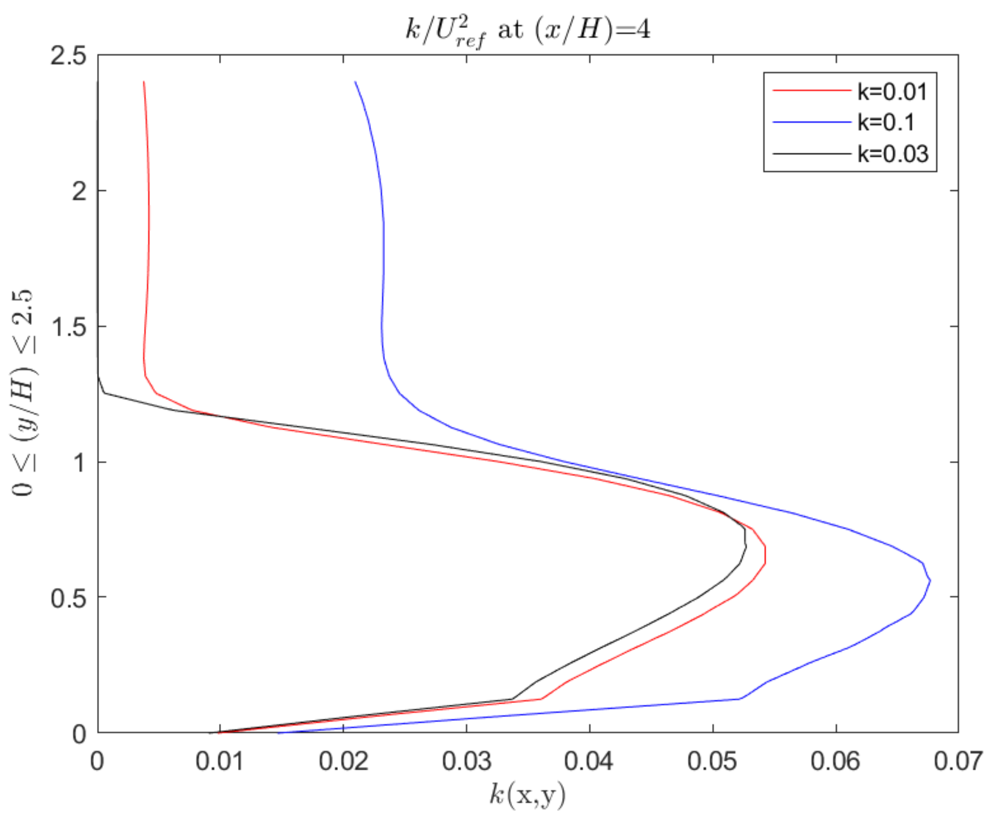
$\overline{v}/U_{ref}$ at (x/H)=1
Experimental Data
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)

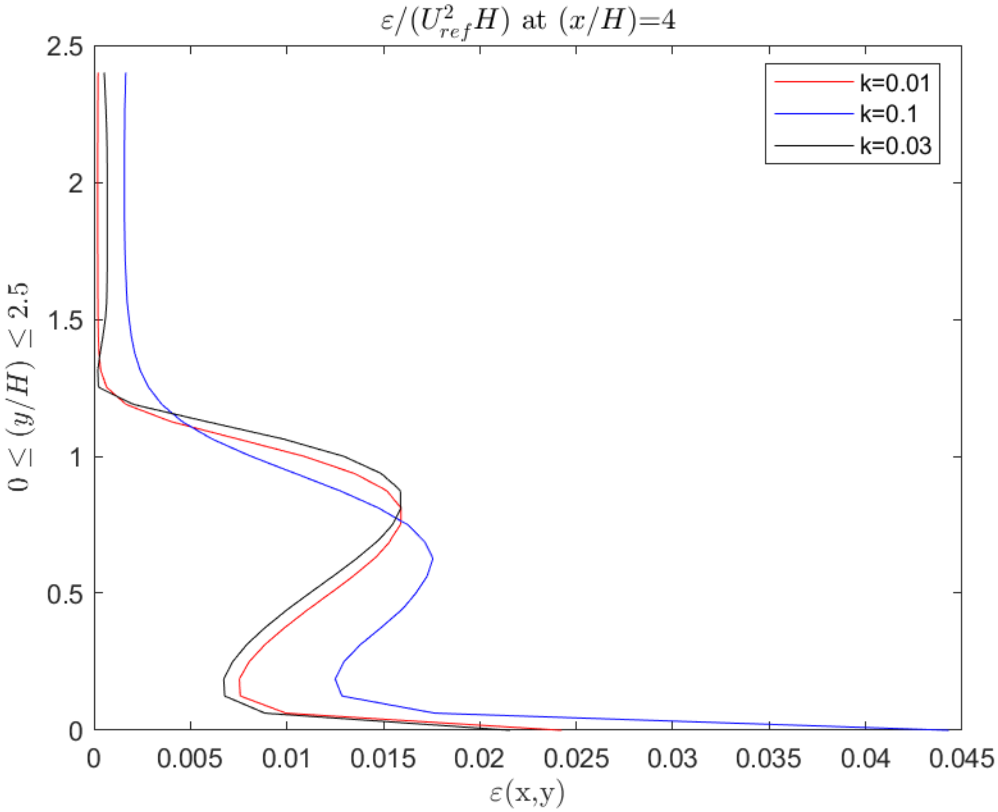


$\overline{v'^2}/U_{ref}^2$ at (x/H)=1
Experimental Data
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)

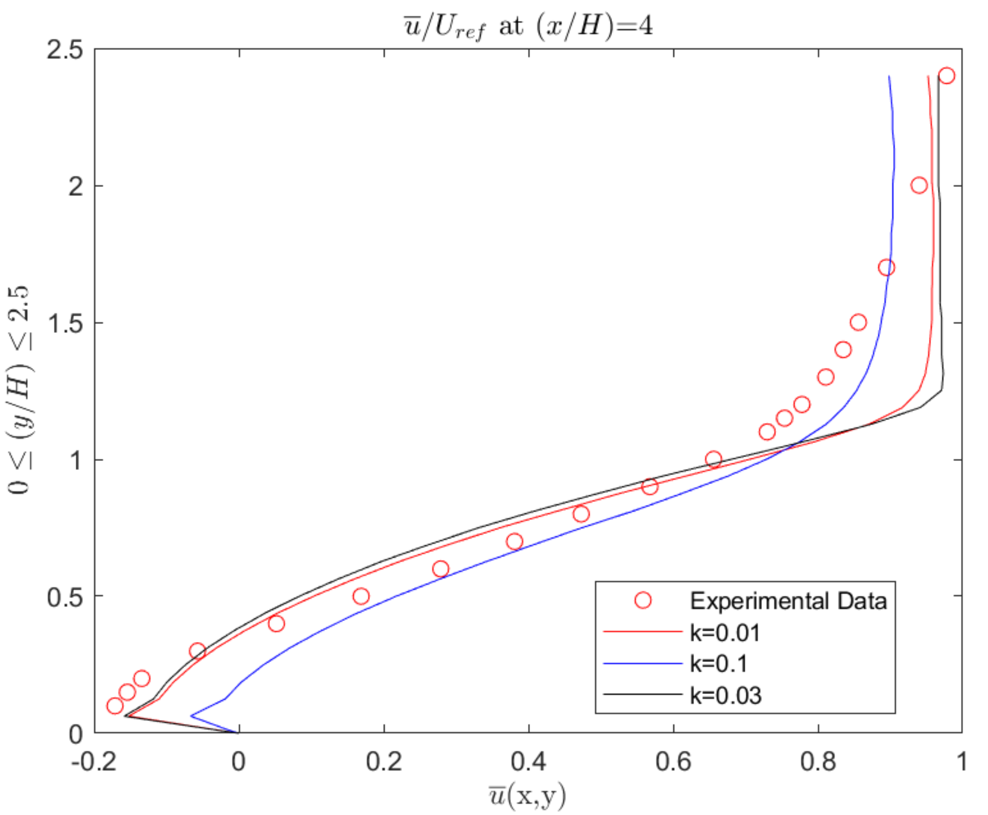

$\overline{u'v'}/U_{ref}^2$ at (x/H)=1
$0 \le (y/H) \le 2.5$
$\overline{u'v'}$(x,y)
Experimental Data
k=0.01
k=0.1
k=0.03

b. x/H=4

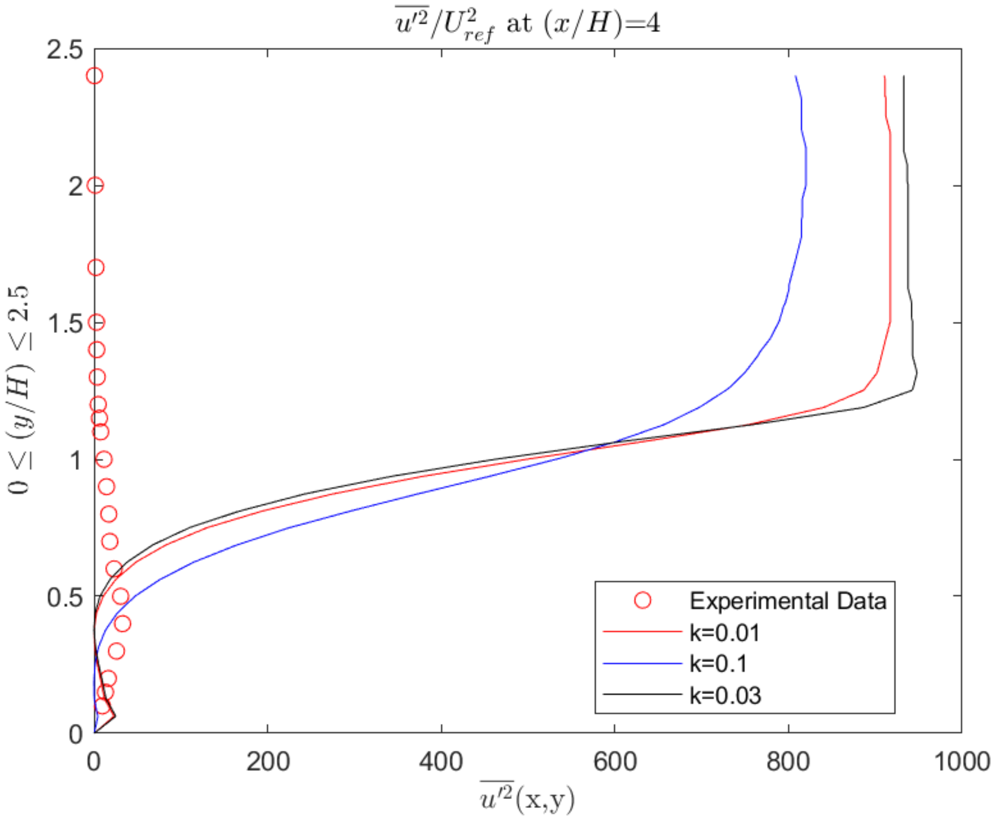

k/U_{ref}^2 at (x/H)=4
$0 \le (y/H) \le 2.5$
k(x,y)
k=0.01
k=0.1
k=0.03



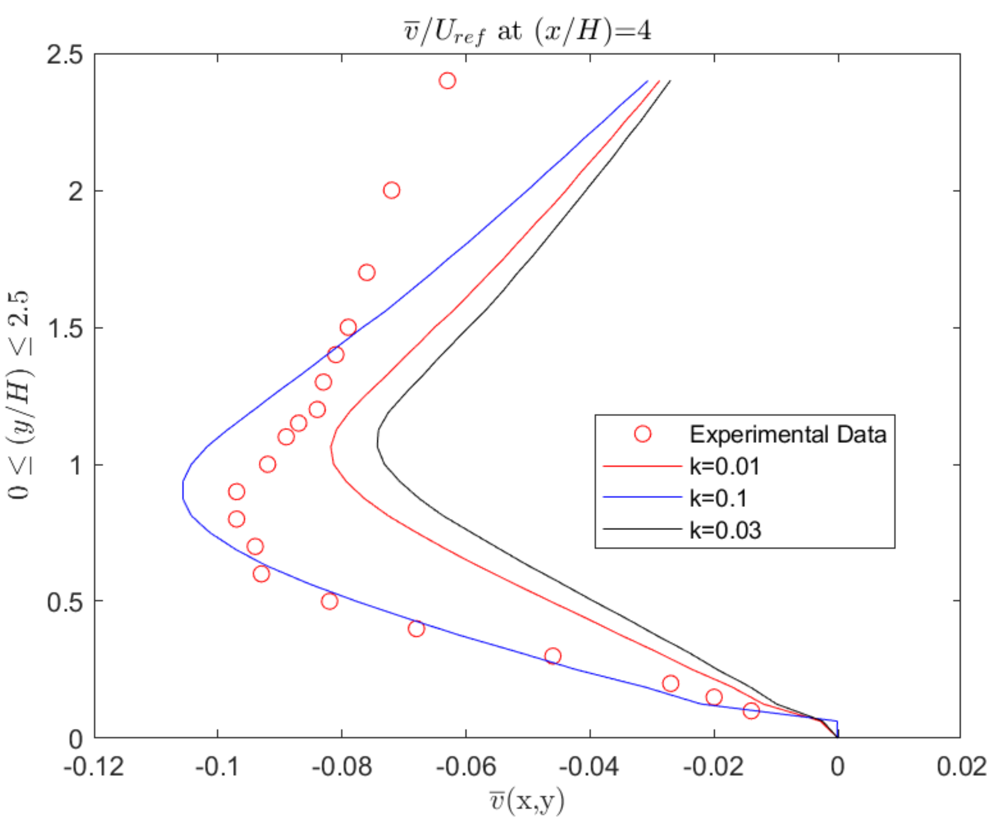
$\varepsilon/(U_{ref}^2 H)$ at (x/H)=4
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
ε(x,y)



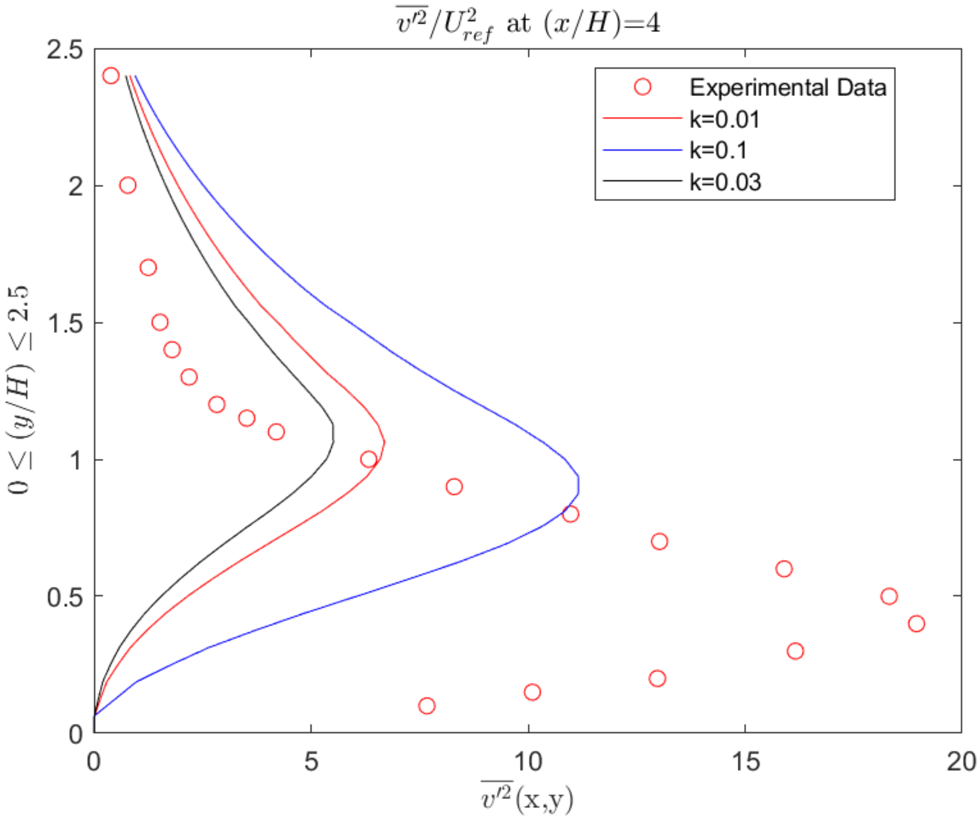
$\overline{u}/U_{ref}$ at (x/H)=4
Experimental Data
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)

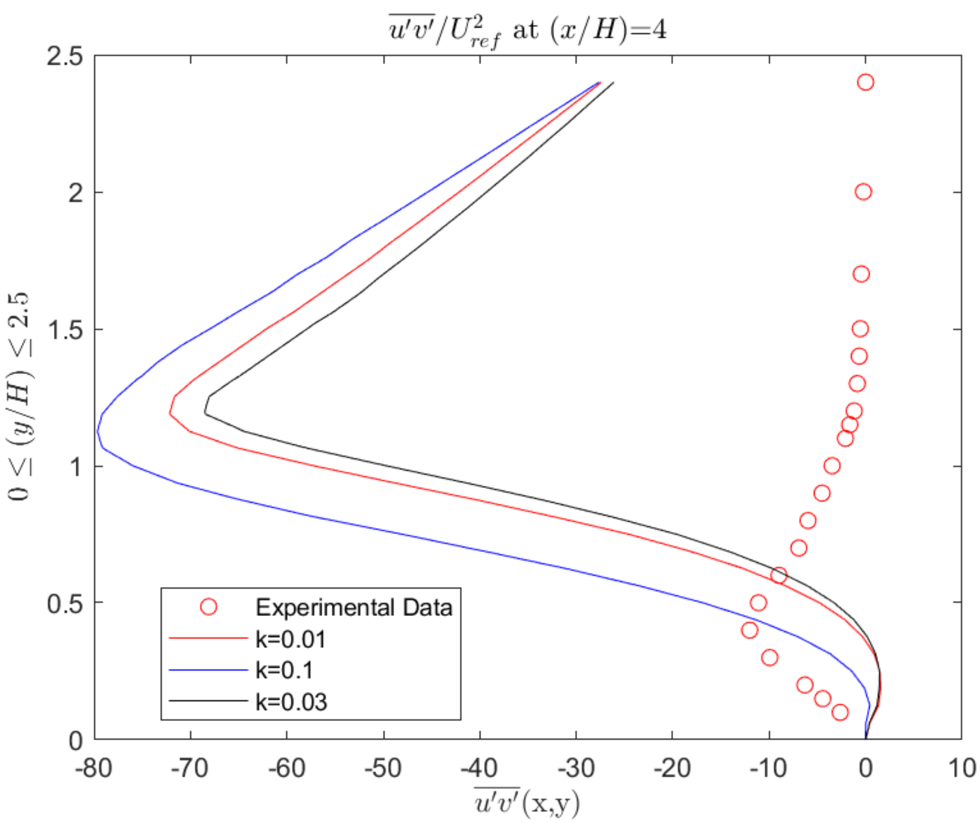


$\overline{u'^2}/U_{ref}^2$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
k=0.01
k=0.1
k=0.03



$\overline{v}/U_{ref}$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
Experimental Data
k=0.01
k=0.1
k=0.03


$\overline{v'^2}/U_{ref}^2$ at (x/H)=4
Experimental Data
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)

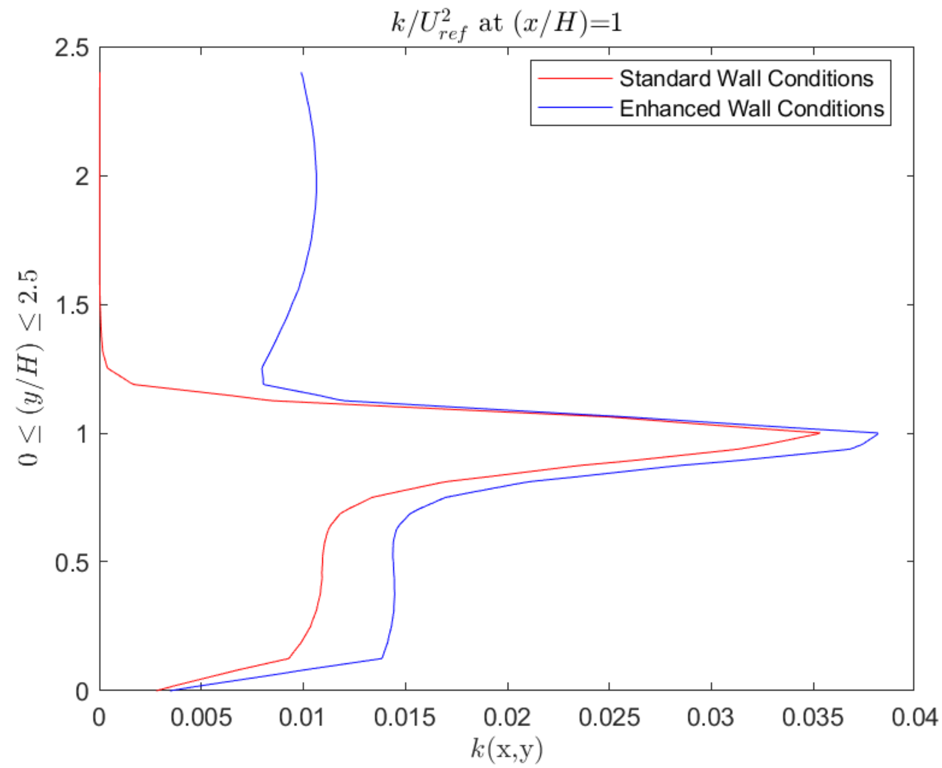

$\overline{u'v'}/U_{ref}^2$ at (x/H)=4
Experimental Data
k=0.01
k=0.1
k=0.03
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)

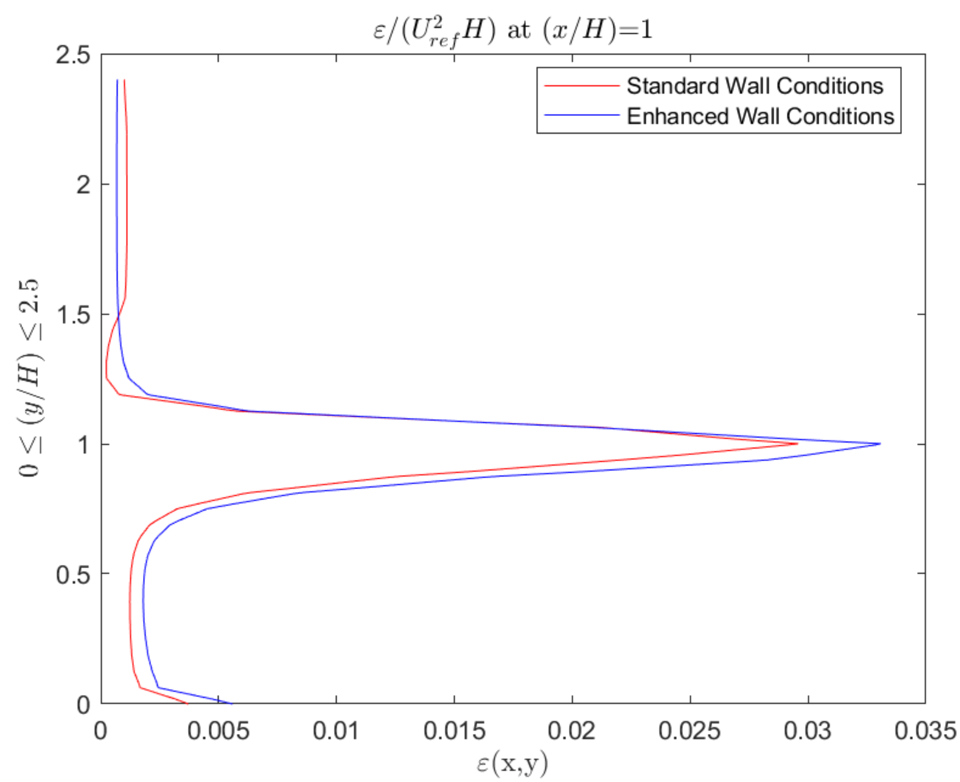
Observations:

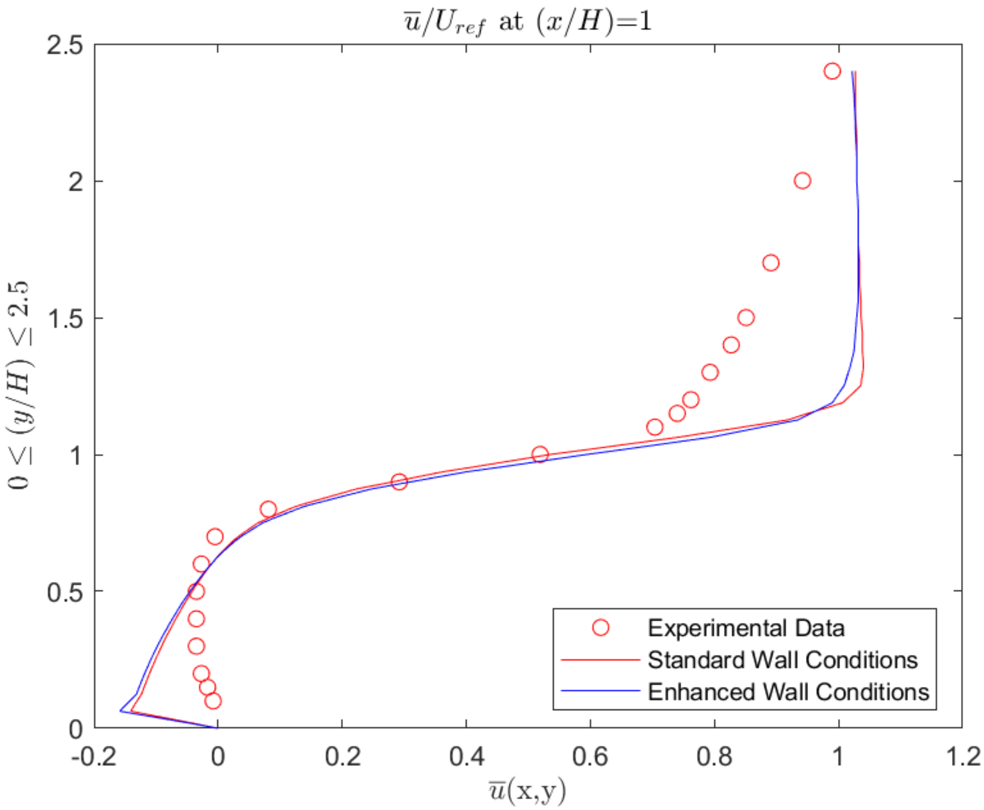
Its evident that FLUENT is very sensitive to inlet turbulence.
The lower the inlet turbulence, the more accurate the results with respect to the experimental results.

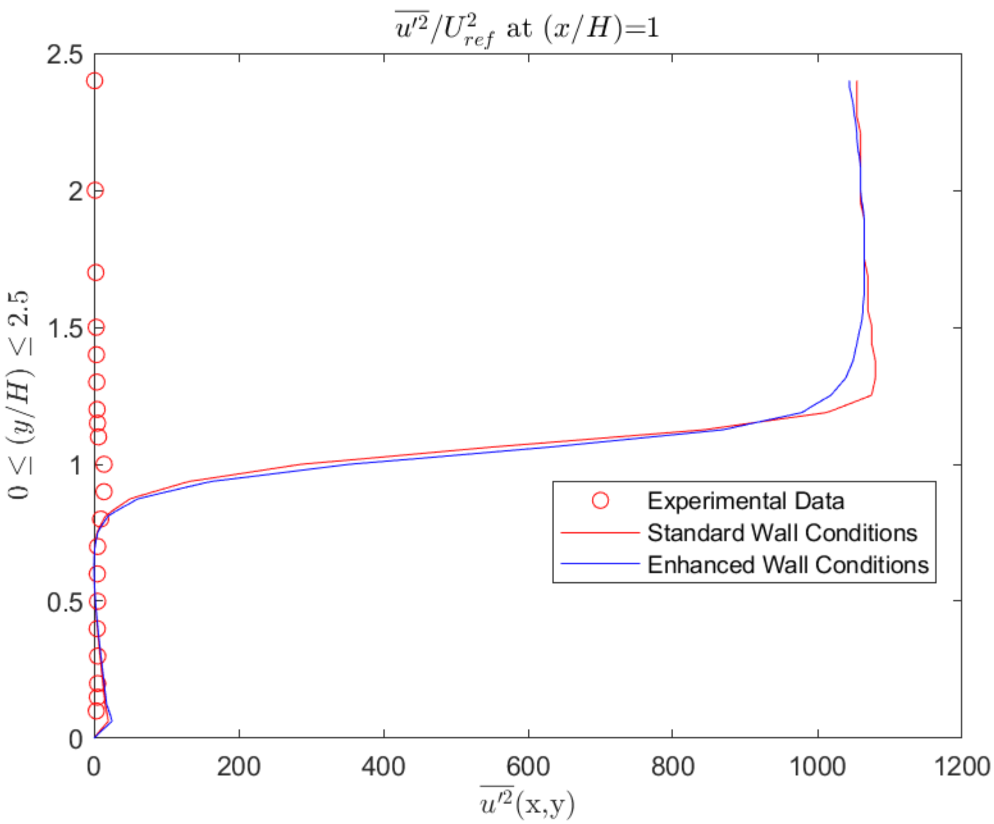
This is likely because any inlet turbulence is multiplied by the turbulence generated by the flow section, amplifying the errors as we increased inlet turbulence.

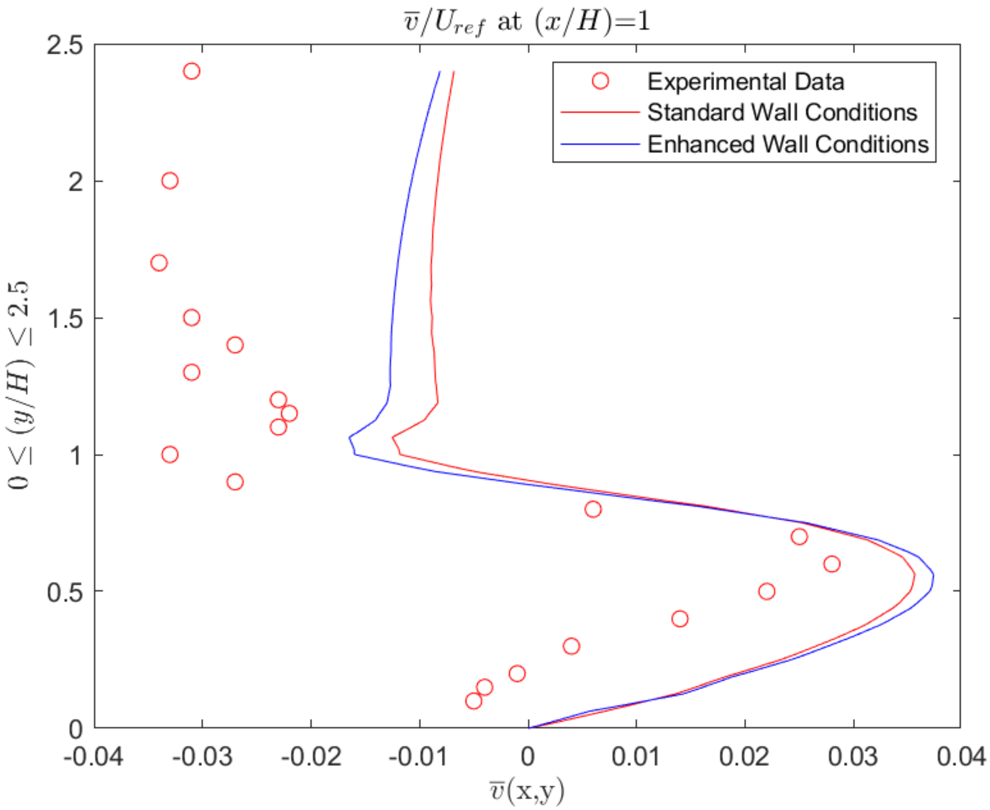
5. Part 5: Effect of wall treatment:
    a. x/H=1

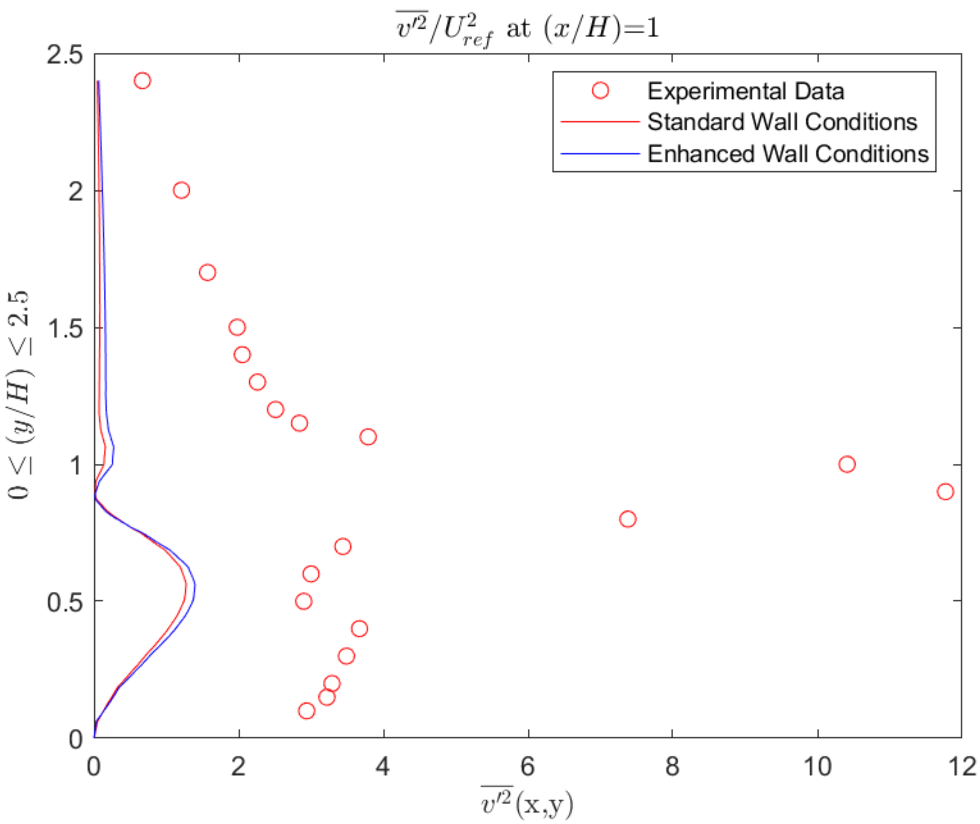


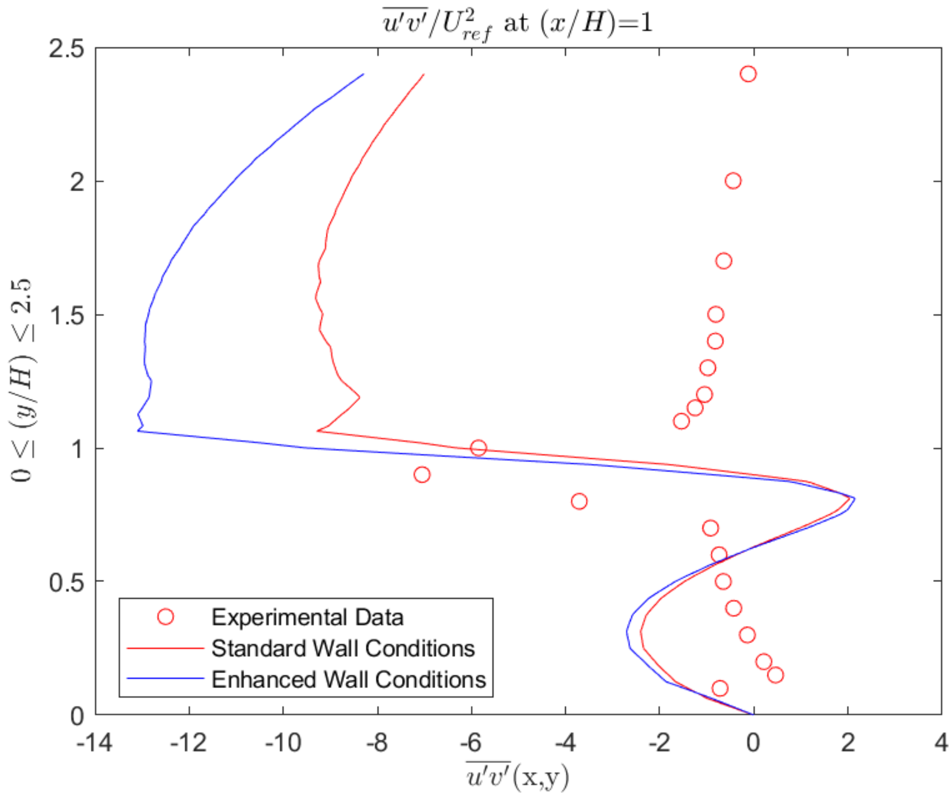



$\overline{u}/U_{ref}$ at (x/H)=1
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions

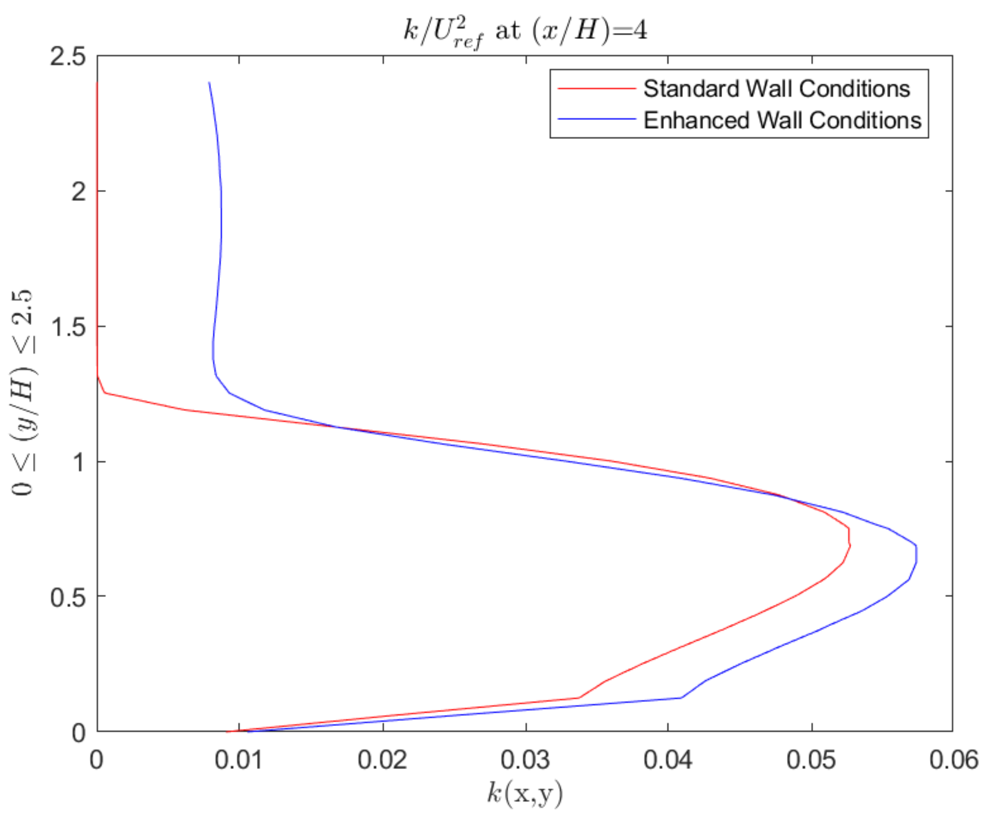

$\overline{u'^2}/U_{ref}^2$ at (x/H)=1
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions

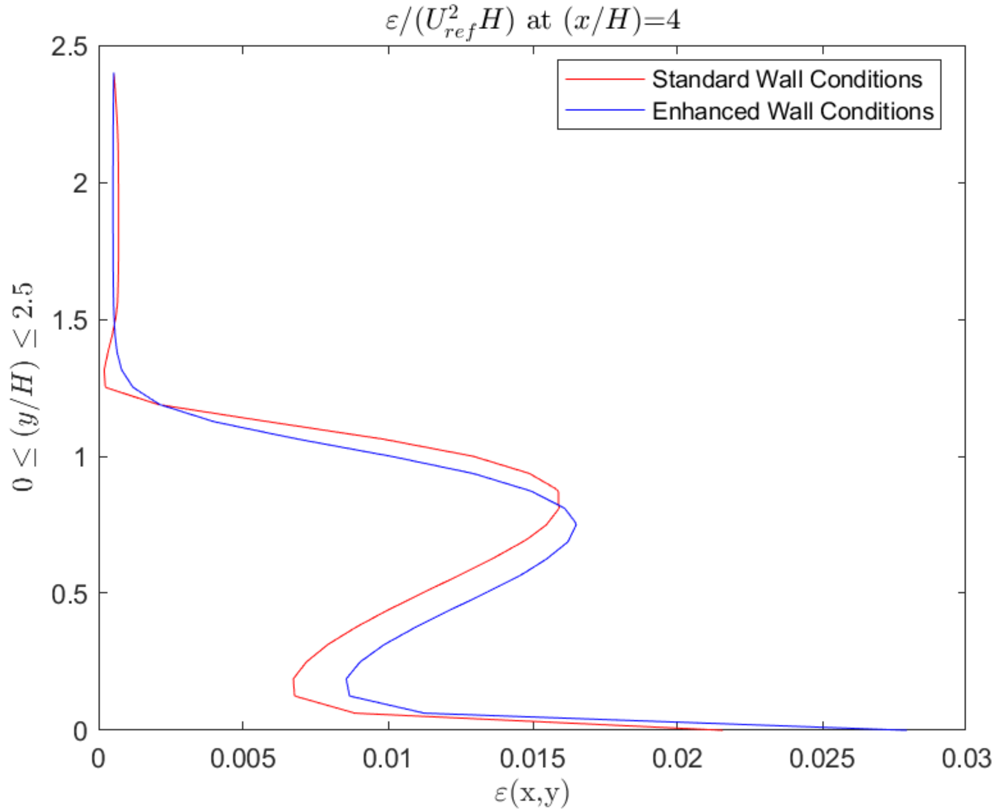

$\overline{v}/U_{ref}$ at (x/H)=1
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)


$\overline{v'^2}/U_{ref}^2$ at (x/H)=1
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)

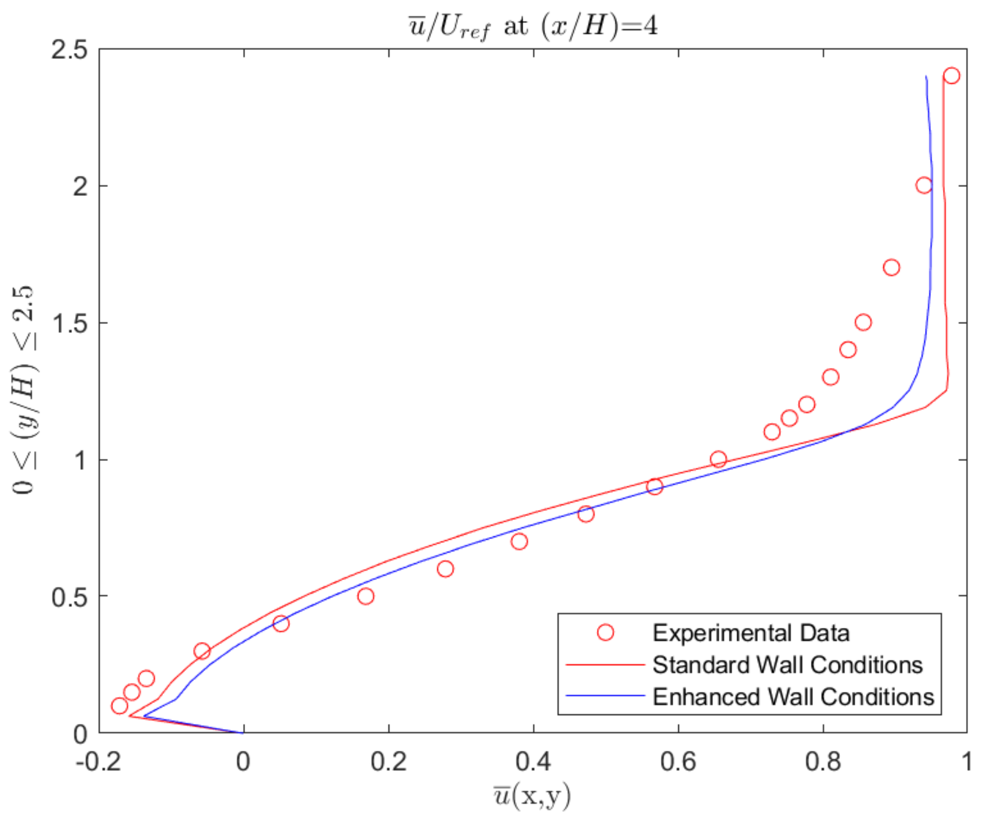

$\overline{u'v'}/U_{ref}^2$ at (x/H)=1
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)

b. x/H=4

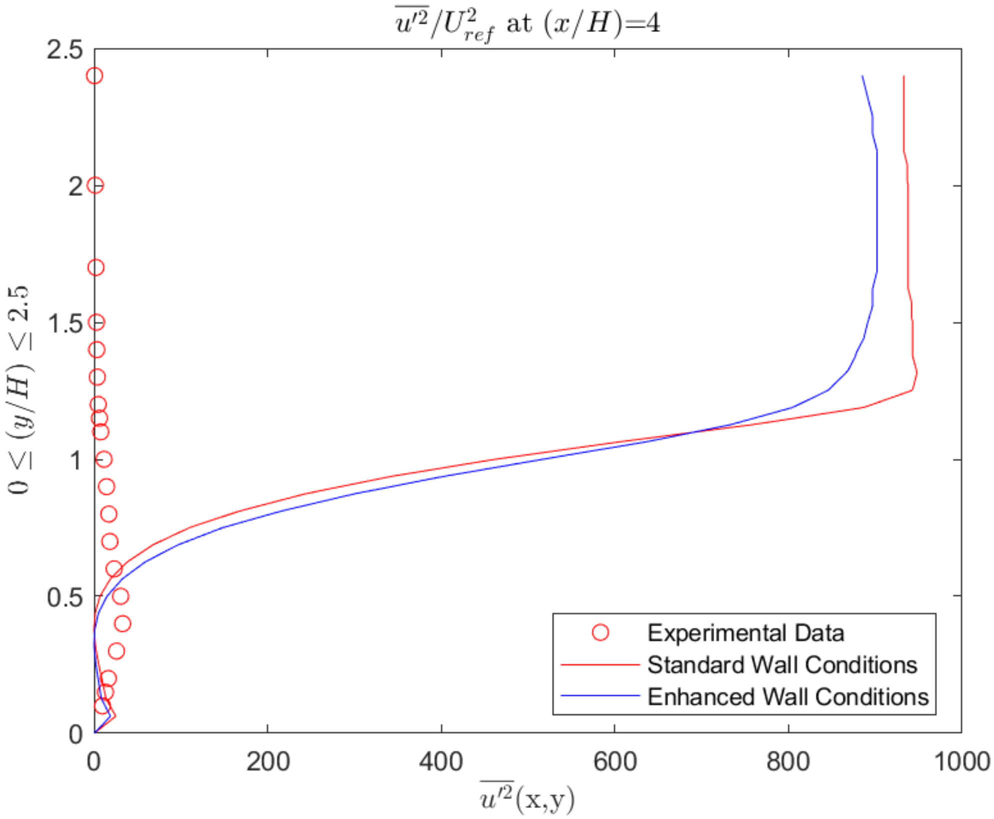

k/U_{ref}^2 at (x/H)=4
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
k(x,y)

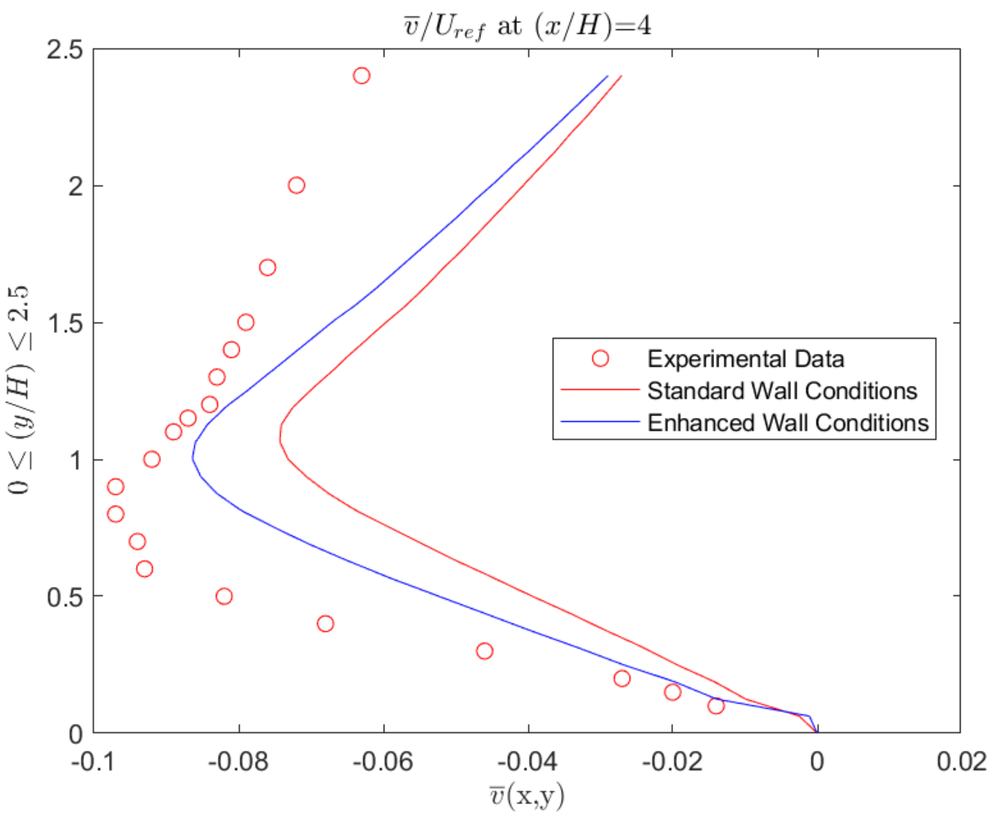


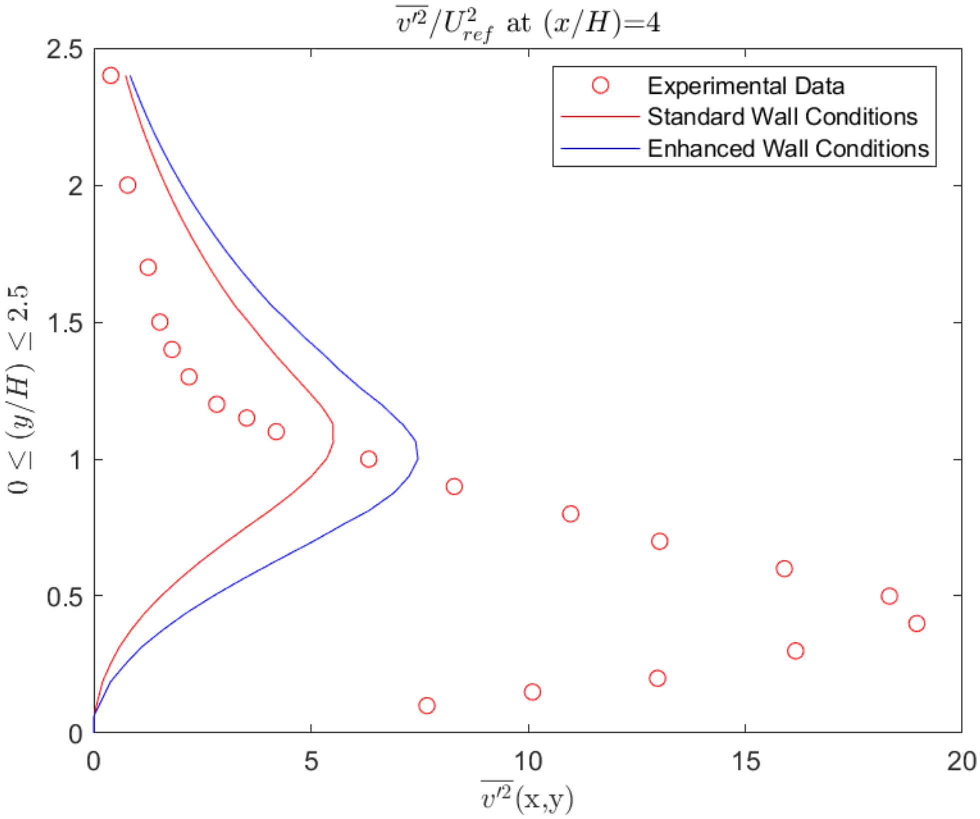
$\varepsilon/(U_{ref}^2 H)$ at (x/H)=4
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.5
1
1.5
2
2.5

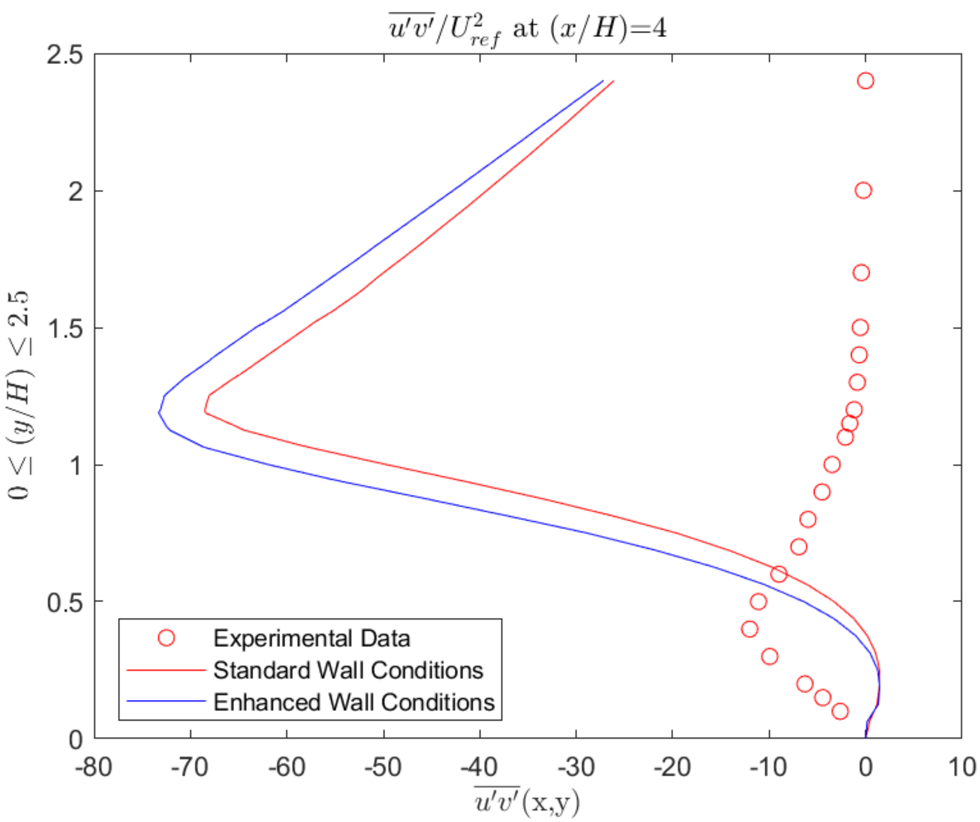


$\overline{u}/U_{ref}$ at (x/H)=4
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
-0.2
0
0.2
0.4
0.6
0.8
1
0.5
1.5
2
2.5

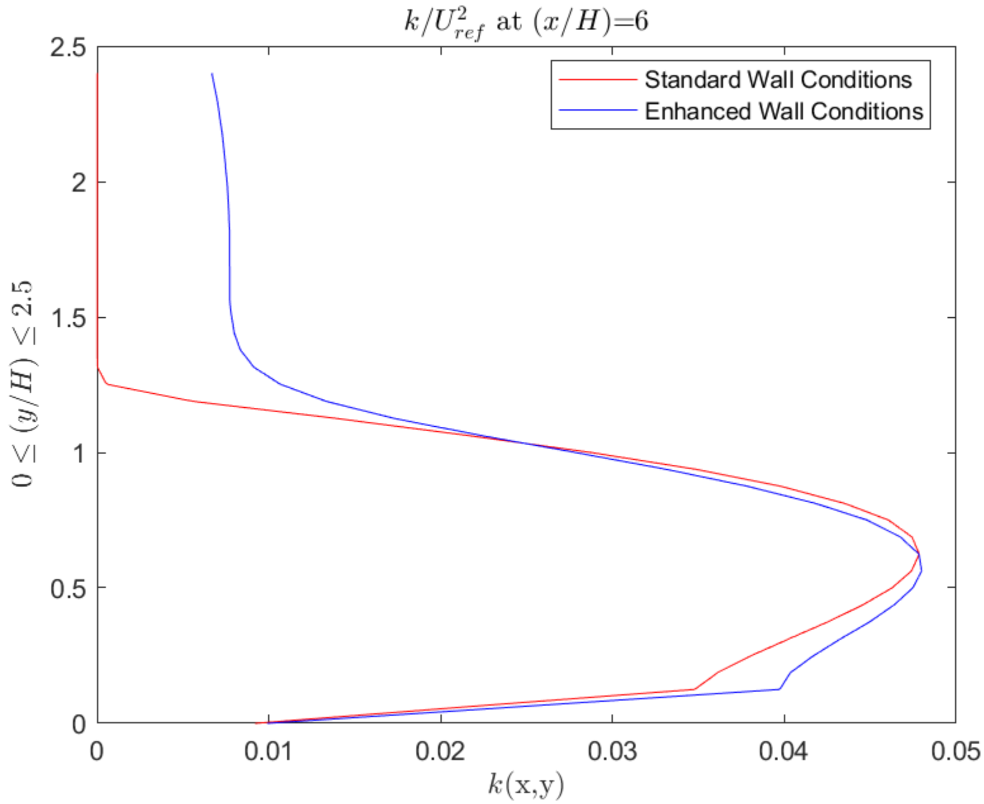

$\overline{u'^2}/U_{ref}^2$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
200
400
600
800
1000
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions


$\overline{v}/U_{ref}$ at (x/H)=4
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
0
0.5
1
1.5
2
2.5
-0.1
-0.08
-0.06
-0.04
-0.02
0
0.02
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions

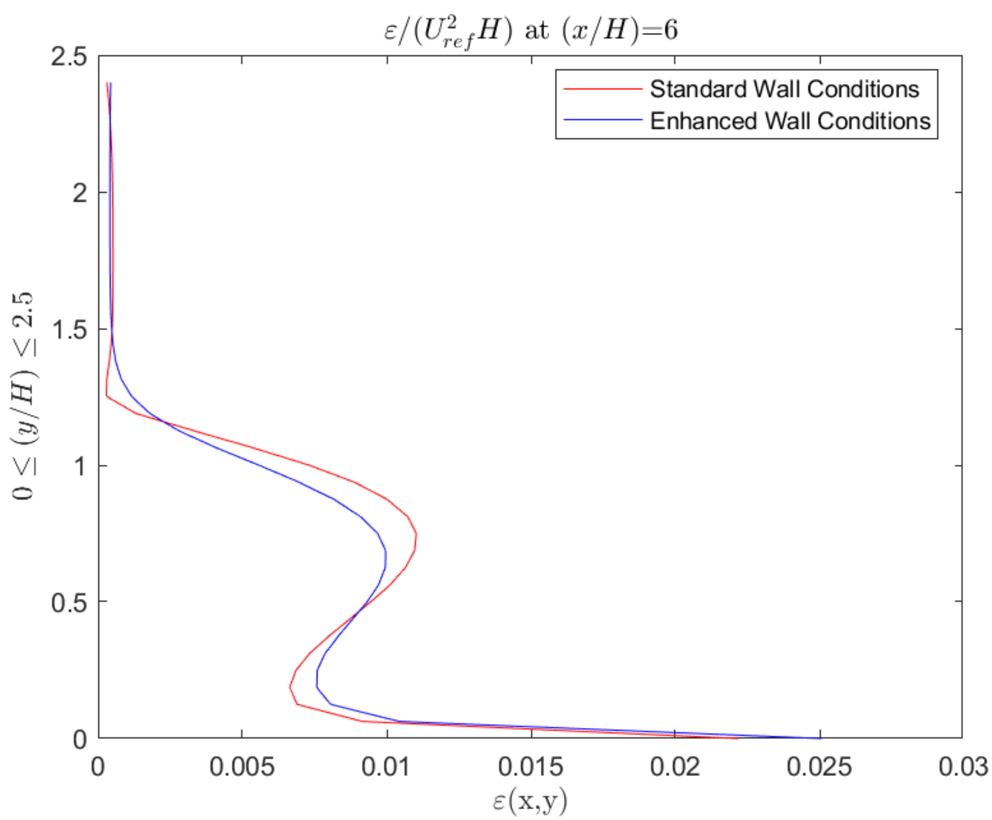

$\overline{v'^2}/U_{ref}^2$ at (x/H)=4
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
5
10
15
20


$\overline{u'v'}/U_{ref}^2$ at (x/H)=4
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)
0
0.5
1
1.5
2
2.5
-80
-70
-60
-50
-40
-30
-20
-10
0
10

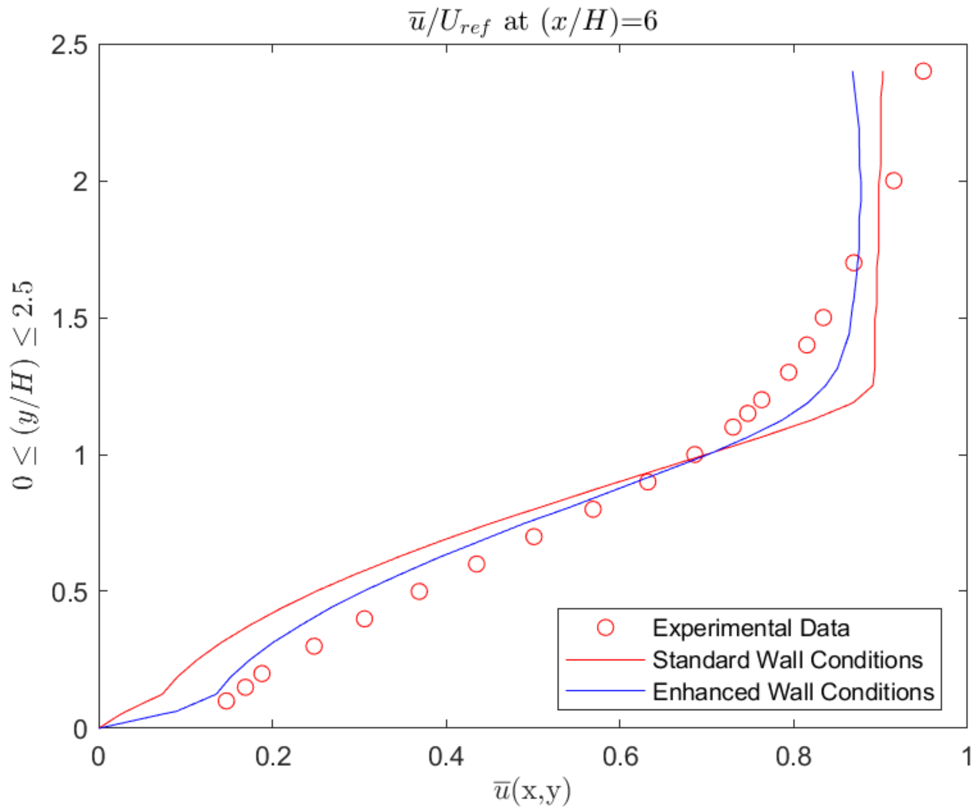
c. x/H=6



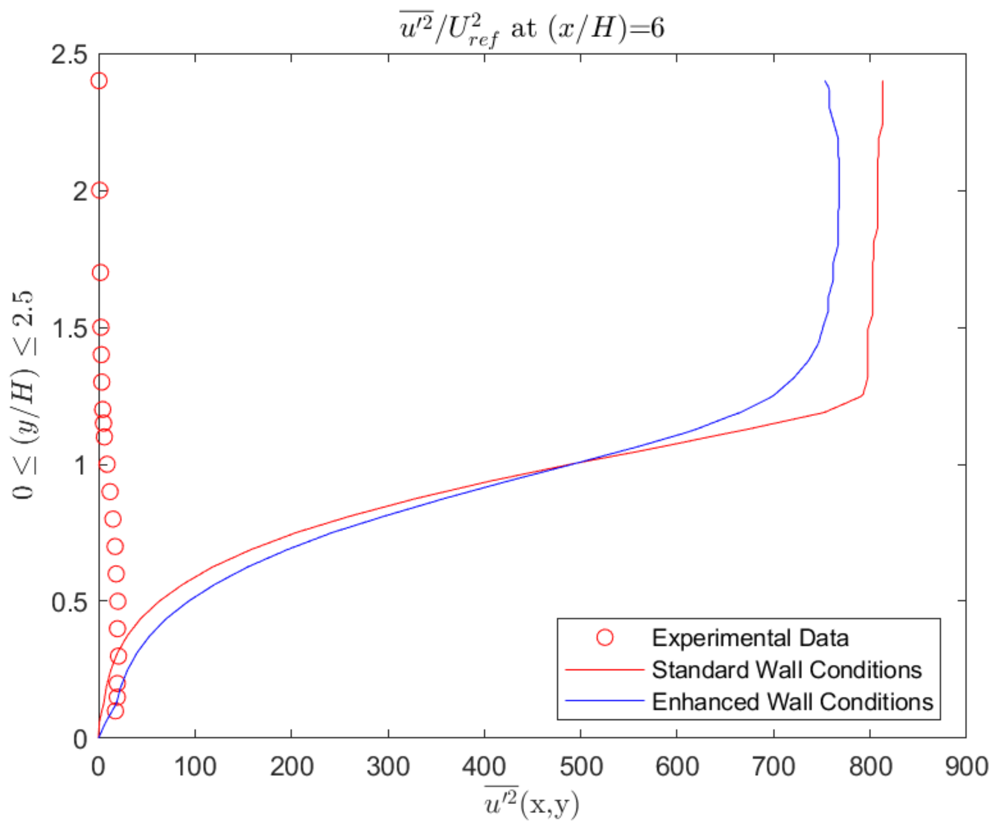
k/U_{ref}^2 at (x/H)=6
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
k(x,y)
0
0.01
0.02
0.03
0.04
0.05
0.5
1
1.5
2
2.5



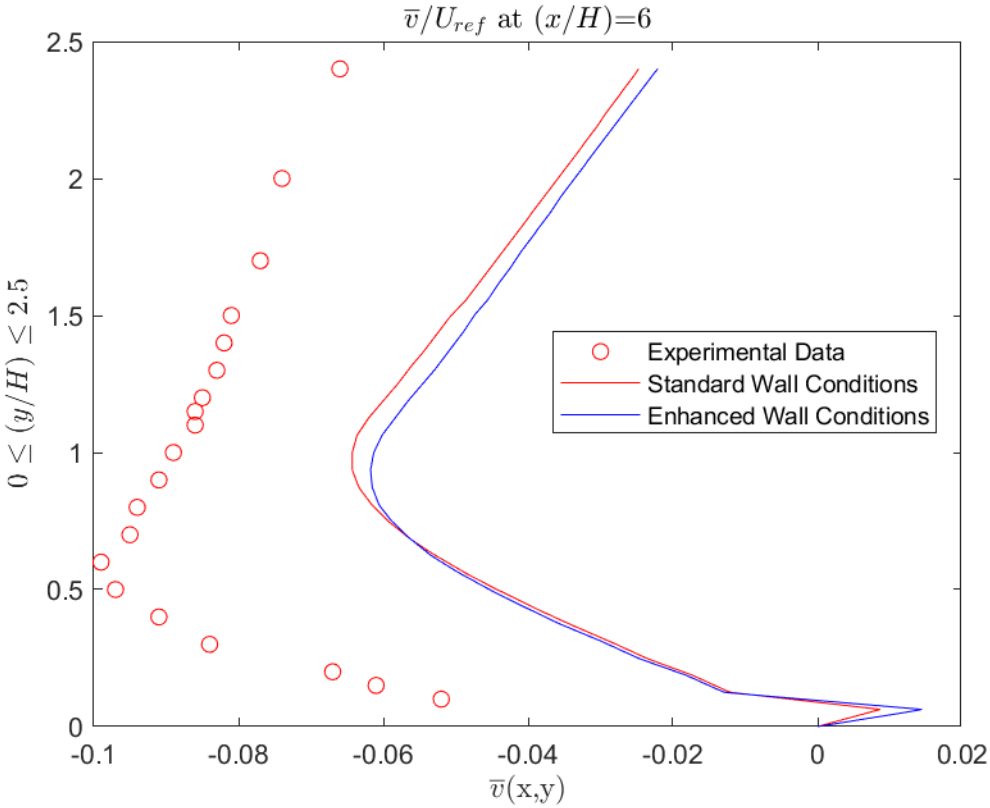
$\varepsilon/(U_{ref}^2 H)$ at (x/H)=6
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.005
0.01
0.015
0.02
0.025
0.03
0.5
1
1.5
2
2.5



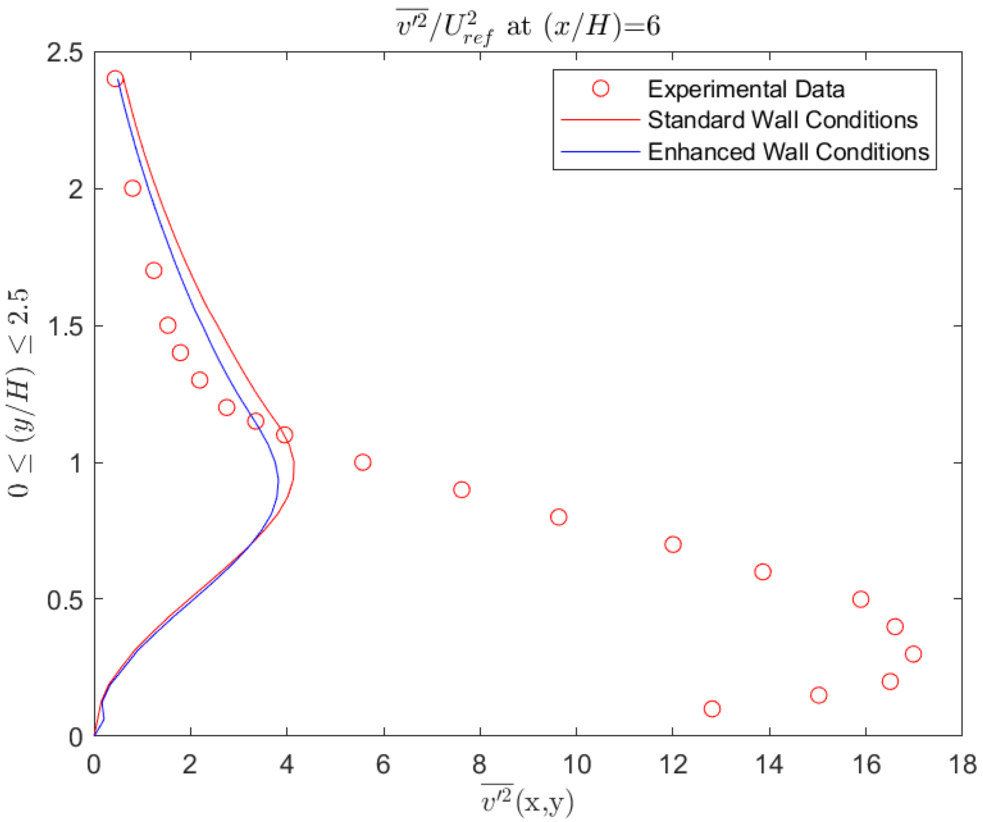
$\overline{u}/U_{ref}$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions



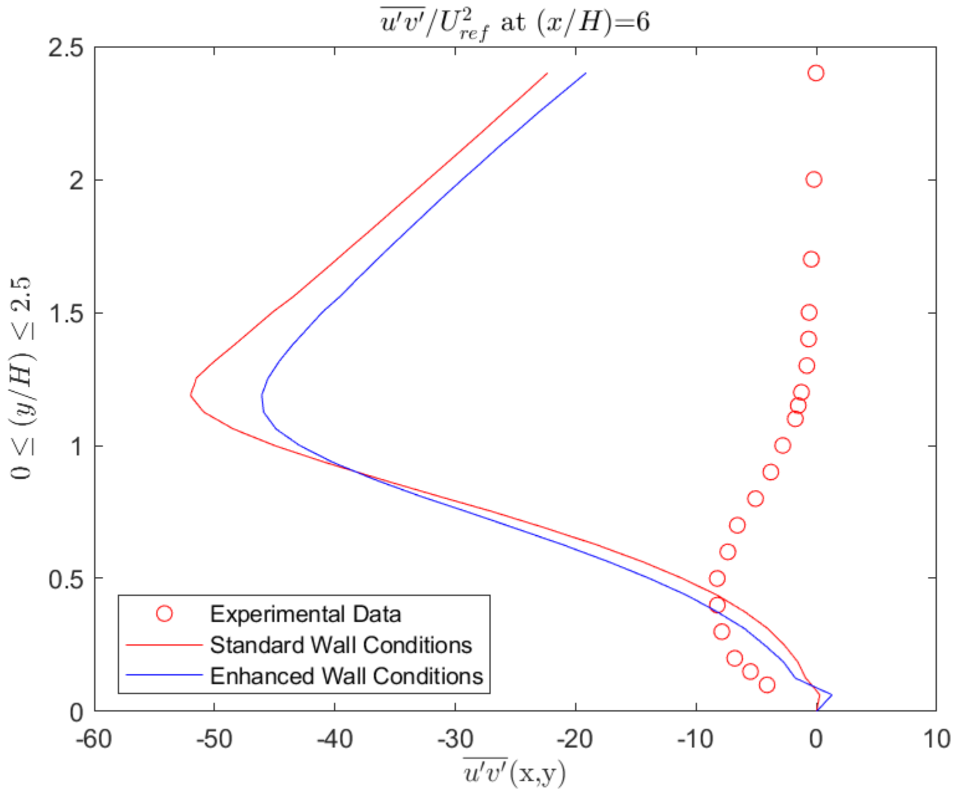
$\overline{u'^2}/U_{ref}^2$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions



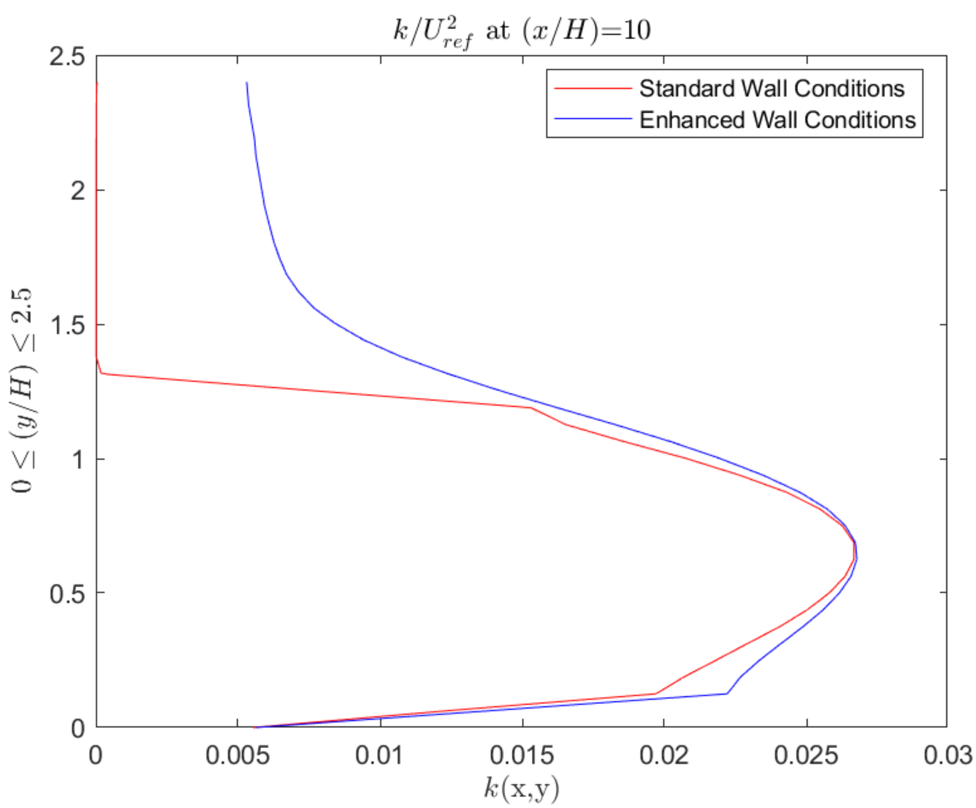
$\overline{v}/U_{ref}$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions

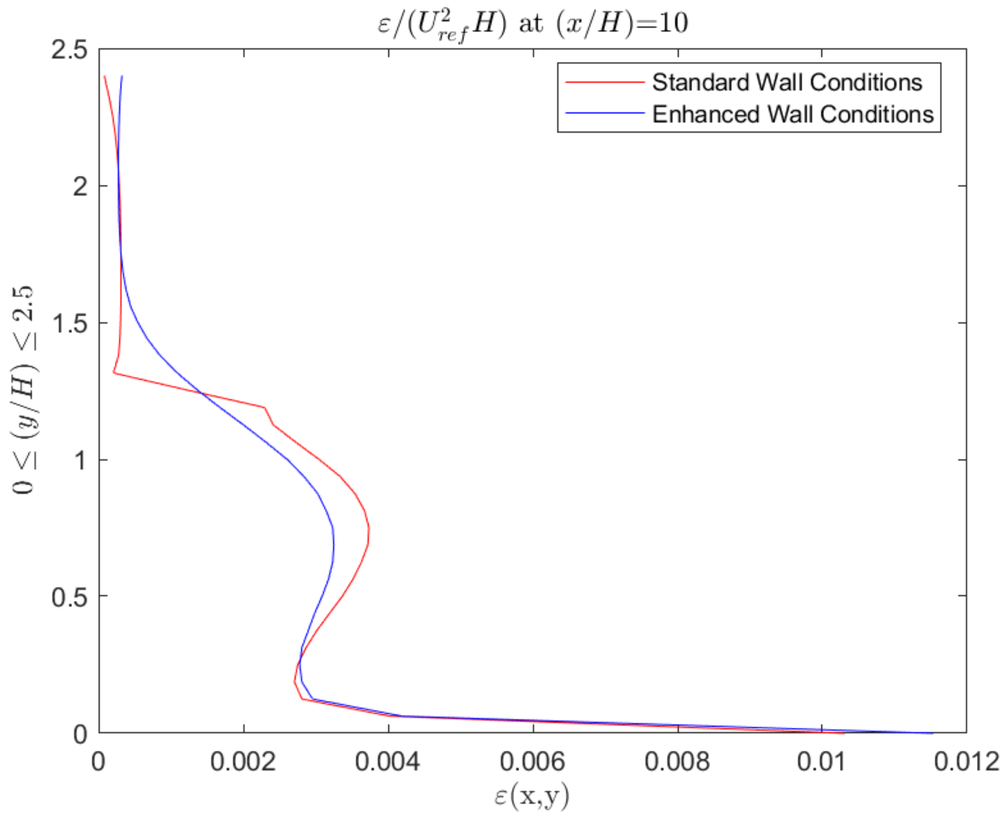


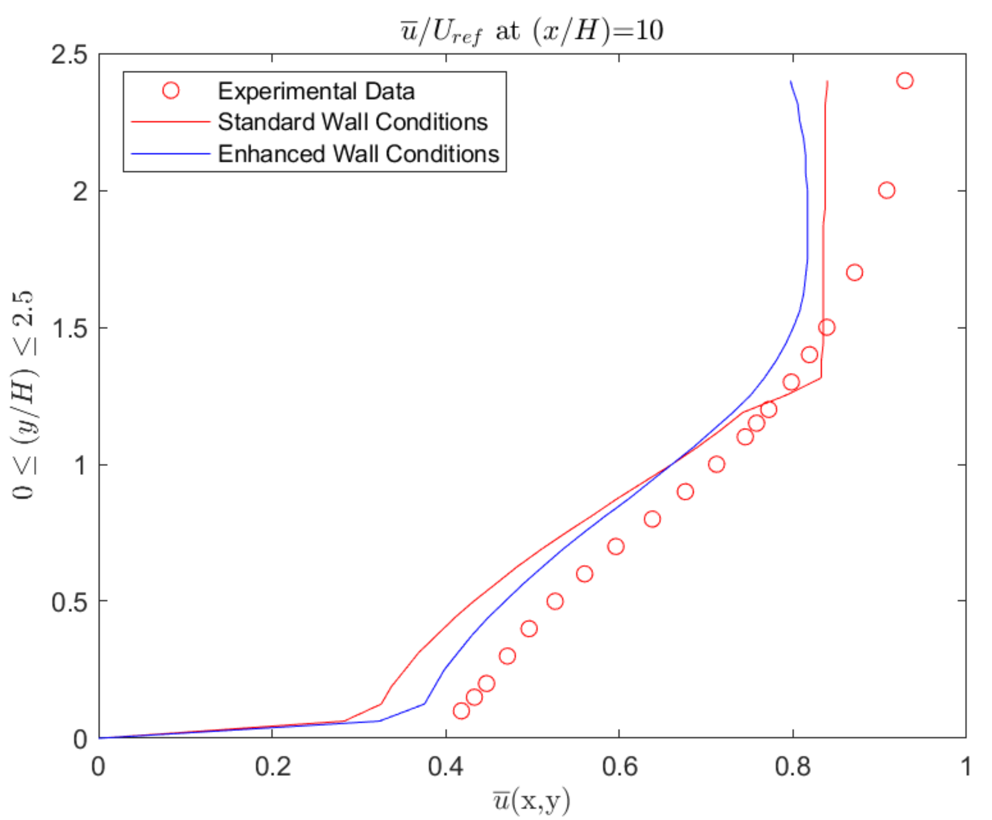
$\overline{v'^2}/U_{ref}^2$ at (x/H)=6
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions

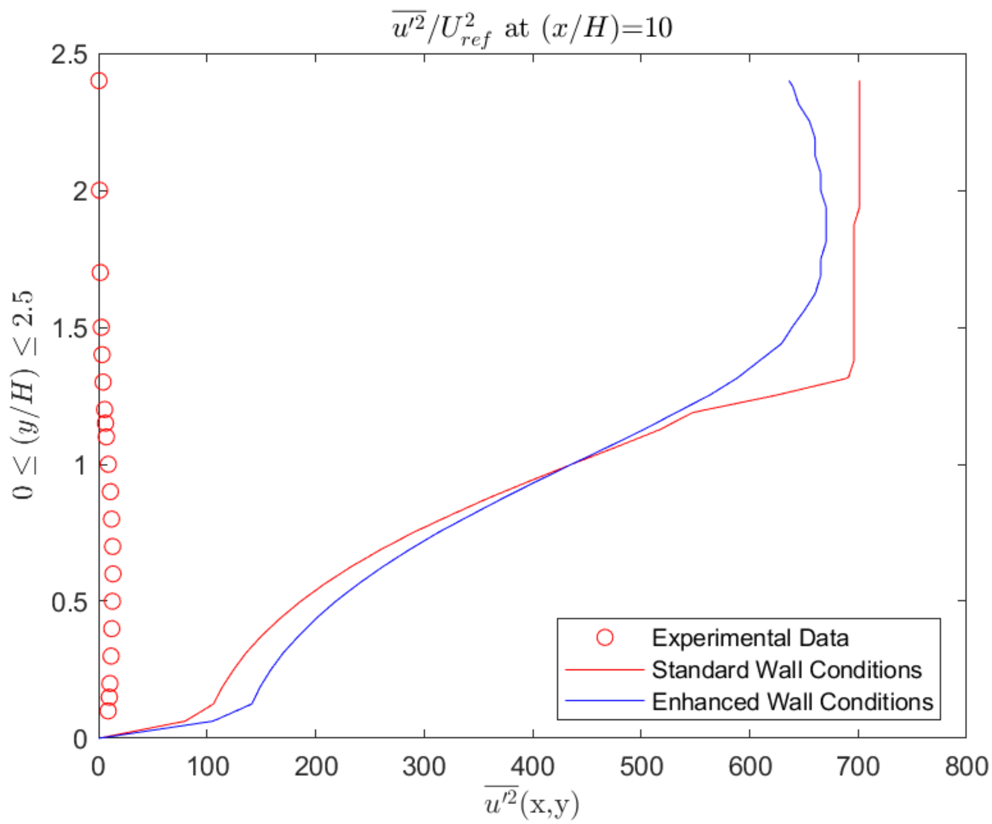

$\overline{u'v'}/U_{ref}^2$ at (x/H)=6
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u'v'}$(x,y)

d. x/H=10

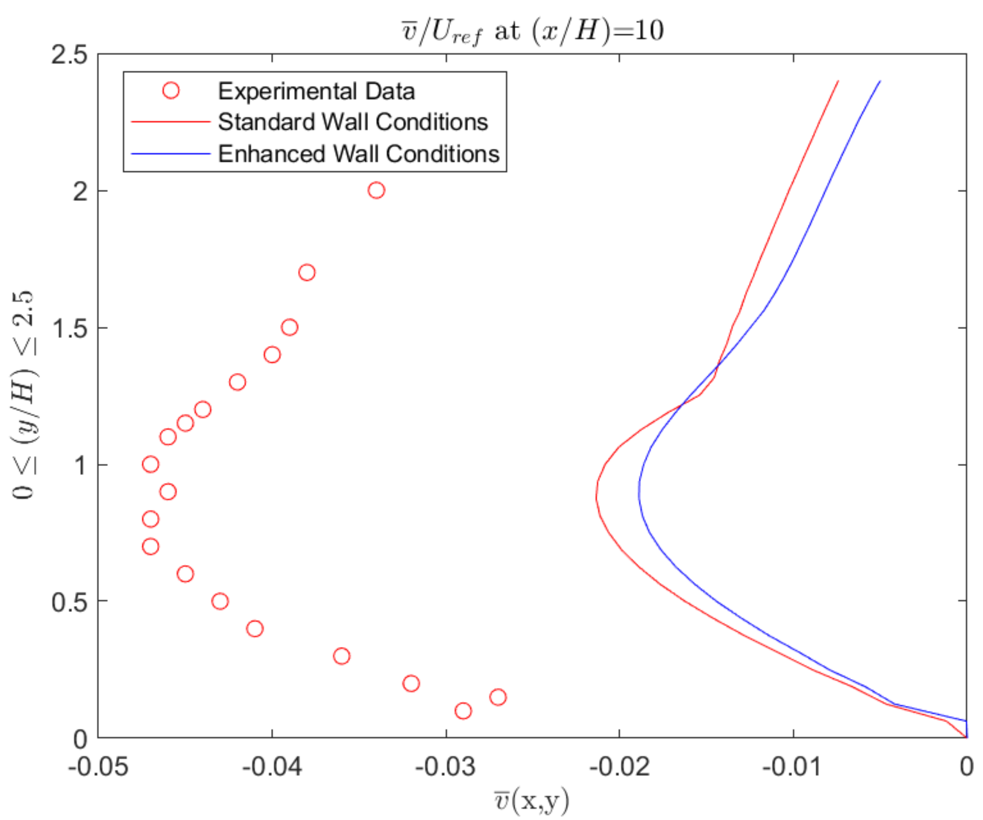

k/U_{ref}^2 at (x/H)=10
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
k(x,y)


$\varepsilon/(U_{ref}^2 H)$ at (x/H)=10
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
ε(x,y)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.5
1
1.5
2
2.5

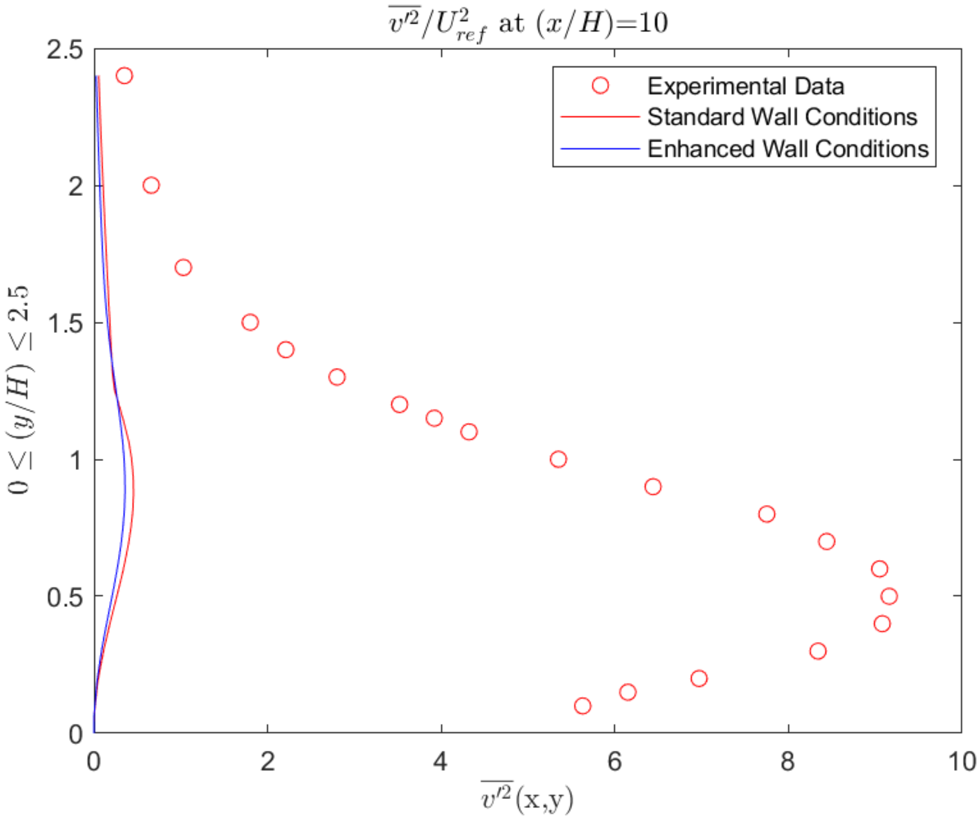

$\overline{u}/U_{ref}$ at (x/H)=10
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u}$(x,y)
0
0.2
0.4
0.6
0.8
1
0.5
1.5
2
2.5

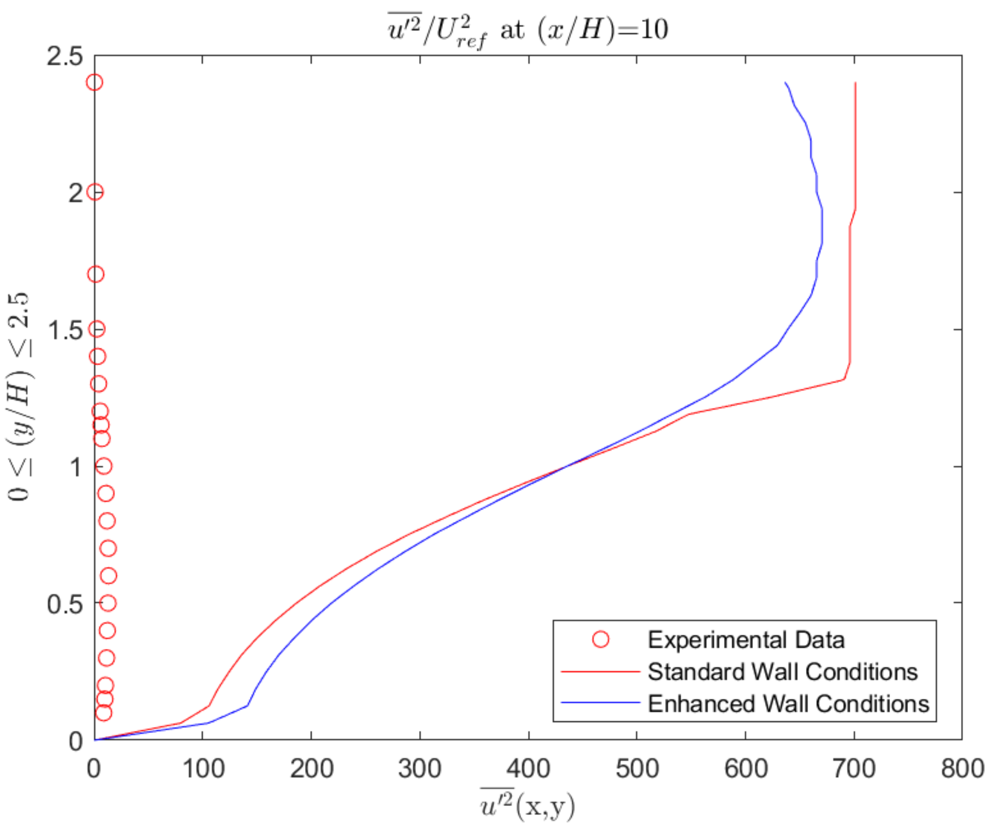


$\overline{u'^2}/U_{ref}^2$ at (x/H)=10
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
600
700
800
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions



$\overline{v}/U_{ref}$ at (x/H)=10
2.5
2
1.5
1
0.5
0
-0.05
-0.04
-0.03
-0.02
-0.01
0
$0 \leq (y/H) \leq 2.5$
$\overline{v}$(x,y)
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions


$\overline{v'^2}/U_{ref}^2$ at (x/H)=10
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{v'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
2
4
6
8
10


$\overline{u'^2}/U_{ref}^2$ at (x/H)=10
Experimental Data
Standard Wall Conditions
Enhanced Wall Conditions
$0 \leq (y/H) \leq 2.5$
$\overline{u'^2}$(x,y)
0
0.5
1
1.5
2
2.5
0
100
200
300
400
500
600
700
800

Observations:

Surprisingly in most cases, the standard wall conditions outperform the enhanced conditions.

From the data, it is evident that using Enhanced conditions do not improve the results obtained from FLUENT.

6. Conclusions:

From the experiments and simulations, and comparing the data obtained it is beneficial to use the RSTM method for the least approximations in the results as the other two models make equilibrium approximations.

The mesh size needs to be small where the maximum turbulence/variations in flow is expected. The parts where laminar or less varying flow is expected can have larger meshes to reduce computation time while not loosing out on much accuracy.

It is also clear the having very low inlet turbulence is essential even if a fairly long section is present to stabilize the flow.

Using Standard wall treatment is sufficient as the Enhanced mode adds computation time while not adding any accuracy to the results.

APPENDIX:

Code for Part 1:

```
%%
close all
clear all
clc
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%K_Epsilon Model Coarse
file='KE_coarse.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_coarse';
T1='$k$-$\varepsilon$ Model Coarse Grid $\overline{u}(x,y)$';
T2='$k$-$\varepsilon$ Model Coarse Grid $\overline{v}(x,y)$';
T3='$k$-$\varepsilon$ Model Coarse Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\varepsilon$ Model Coarse Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\varepsilon$ Model Coarse Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\varepsilon$ Model Coarse Grid $k(x,y)$';
T7='$k$-$\varepsilon$ Model Coarse Grid $\varepsilon(x,y)$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
%%%%%%%%%%%%%%%%%%%%%%K epsilon Medium
file='KE_medium.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_medium';
T1='$k$-$\varepsilon$ Model Medium Grid $\overline{u}(x,y)$';
T2='$k$-$\varepsilon$ Model Medium Grid $\overline{v}(x,y)$';
T3='$k$-$\varepsilon$ Model Medium Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\varepsilon$ Model Medium Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\varepsilon$ Model Medium Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\varepsilon$ Model Medium Grid $k(x,y)$';
T7='$k$-$\varepsilon$ Model Medium Grid $\varepsilon(x,y)$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%
%%%%%%%%%%%%%%%%%%%%%%K epsilon Fine
file='KE_fine.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_fine';
T1='$k$-$\varepsilon$ Model Fine Grid $\overline{u}(x,y)$';
T2='$k$-$\varepsilon$ Model Fine Grid $\overline{v}(x,y)$';
T3='$k$-$\varepsilon$ Model Fine Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\varepsilon$ Model Fine Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\varepsilon$ Model Fine Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\varepsilon$ Model Fine Grid $k(x,y)$';
T7='$k$-$\varepsilon$ Model Fine Grid $\varepsilon(x,y)$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%55
%%
close all
clear all
clc
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%K_Epsilon Omega Coarse
file='Kw_coarse.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Kw_coarse';
T1='$k$-$\omega$ Model Coarse Grid $\overline{u}(x,y)$';
T2='$k$-$\omega$ Model Coarse Grid $\overline{v}(x,y)$';
T3='$k$-$\omega$ Model Coarse Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\omega$ Model Coarse Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\omega$ Model Coarse Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\omega$ Model Coarse Grid $k(x,y)$';
T7='$k$-$\omega$ Model Coarse Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
%%
%%%%%%%%%%%%%%%%%%%%%%K epsilon Medium
file='Kw_medium.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Kw_medium';
T1='$k$-$\omega$ Model Medium Grid $\overline{u}(x,y)$';
T2='$k$-$\omega$ Model Medium Grid $\overline{v}(x,y)$';
T3='$k$-$\omega$ Model Medium Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\omega$ Model Medium Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\omega$ Model Medium Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\omega$ Model Medium Grid $k(x,y)$';
T7='$k$-$\omega$ Model Medium Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%
%%%%%%%%%%%%%%%%%%%%%%K omega Fine
file='Kw_fine.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Kw_fine';
T1='$k$-$\omega$ Model Fine Grid $\overline{u}(x,y)$';
T2='$k$-$\omega$ Model Fine Grid $\overline{v}(x,y)$';
T3='$k$-$\omega$ Model Fine Grid $\overline{u''^2}(x,y)$';
T4='$k$-$\omega$ Model Fine Grid $\overline{v''^2}(x,y)$';
T5='$k$-$\omega$ Model Fine Grid $\overline{u''v''}(x,y)$';
T6='$k$-$\omega$ Model Fine Grid $k(x,y)$';
T7='$k$-$\omega$ Model Fine Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir);
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%% Reynolds Stress Coarse
file='Re_coarse.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Re_coarse';
T1='Reynolds Stress Transport Model Coarse Grid $\overline{u}(x,y)$';
T2='Reynolds Stress Transport Model Coarse Grid $\overline{v}(x,y)$';
T3='Reynolds Stress Transport Model Coarse Grid $\overline{u''^2}(x,y)$';
T4='Reynolds Stress Transport Model Coarse Grid $\overline{v''^2}(x,y)$';
T5='Reynolds Stress Transport Model Coarse Grid $\overline{u''v''}(x,y)$';
T6='Reynolds Stress Transport Model Coarse Grid $k(x,y)$';
T7='Reynolds Stress Transport Model Coarse Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
```

```
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%5
%%
%%%%%%%%%%%%%%%%%%%%%% Reynolds Stress Transport
file='Re_medium.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Re_medium';
T1='Reynolds Stress Transport Model Medium Grid $\overline{u}(x,y)$';
T2='Reynolds Stress Transport Model Medium Grid $\overline{v}(x,y)$';
T3='Reynolds Stress Transport Model Medium Grid $\overline{u''^2}(x,y)$';
T4='Reynolds Stress Transport Model Medium Grid $\overline{v''^2}(x,y)$';
T5='Reynolds Stress Transport Model Medium Grid $\overline{u''v''}(x,y)$';
T6='Reynolds Stress Transport Model Medium Grid $k(x,y)$';
T7='Reynolds Stress Transport Model Medium Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)
%%
%%%%%%%%%%%%%%%%%%%%%% Reynolds Stress Transport
file='Re_fine.csv';
dir='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Re_fine';
T1='Reynolds Stress Transport Model Fine Grid $\overline{u}(x,y)$';
T2='Reynolds Stress Transport Model Fine Grid $\overline{v}(x,y)$';
T3='Reynolds Stress Transport Model Fine Grid $\overline{u''^2}(x,y)$';
T4='Reynolds Stress Transport Model Fine Grid $\overline{v''^2}(x,y)$';
T5='Reynolds Stress Transport Model Fine Grid $\overline{u''v''}(x,y)$';
T6='Reynolds Stress Transport Model Fine Grid $k(x,y)$';
T7='Reynolds Stress Transport Model Fine Grid $\varepsilon$';
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
Ttl={T1 T2 T3 T4 T5 T6 T7};
Turbulence_Proj_Part1(file,Ttl,store,dir)


function [] =Turbulence_Proj_Part1(file,Ttl,store,dir)
%This function was used to make the contour plots
%reading file data
data=csvread(file,1,1);
%velocities
x=data(:,1);
y=data(:,2);
%number of data points
N=500;
NC=500;
%uref
U=44.2;
%length referecne
href=0.0127
xs=10*0.0127;
%area of interest
xq=linspace(xs,xs+12*0.0127,N);
yq=linspace(0,2*0.0127,N);
[X,Y]=meshgrid(xq,yq);
norm=[U U U^2/10^3 U^2/10^3 U^2/10^3 U^2 U^3/href];
xh1=linspace(0,12,N);
yh1=linspace(0,2,N);
[xh,yh]=meshgrid(xh1,yh1);
for i=1:size(data,2)-2
```

```
    F=scatteredInterpolant(x,y,data(:,i+2));
    Val=F(X,Y)/norm(i);
    f=figure('visible','off');
    [C,h]=contourf(xh,yh,Val,NC);
    set(h,'LineColor','none')
    n =300; %// desired number of colors
    t = .7; %// trimming factor
    cm = hsv(ceil(n/t));
    cm = cm(1:n,:);
    cm = flipud(cm); %if needed. Thanks to Dan
    colormap(cm);
    caxis([min(min(Val)),max(max(Val))])
    colorbar
    xlabel('$0\leq (x/H) \leq 12$','interpreter','latex');
    ylabel('$0\leq (y/H) \leq 2$','interpreter','latex');
    title(Ttl(i),'interpreter','latex');
    iptsetpref('ImshowBorder','tight')
    pbaspect([3 1 1])
    set(gca,'LooseInset',get(gca,'TightInset'))
    saveas(f,fullfile(dir,store{i}),'png');
end
end
```

Code for Part 2:

```
close all
clc
%extracting the data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
dir1='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots2\XH1';
dir4='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots2\XH4';
dir={dir1 dir4};
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileD1='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH1.csv';
fileD4='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH4.csv';
dataexp1=csvread(fileD1,1,0);
dataexp4=csvread(fileD4,1,0);
exp_data={dataexp1 dataexp4};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileCoarse='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_coarse.csv';
fileMed='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_medium.csv';
fileFine='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_fine.csv';
dataEps=csvread(fileCoarse,1,1);
dataOmega=csvread(fileMed,1,1);
dataRS=csvread(fileFine,1,1);
data={dataEps dataOmega dataRS};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%number of data points for the contour
N=500;
ND=20;
%reference values
U=44.2;
Href=0.0127;
%location values
H=[1 4];
%normalization
yplot=linspace(0,2.4,N);
norm=[U U U^2/10^3 U^2/10^3 U^2/10^3 U^2 U^3/Href];
%ploting tools
mrk={'r' 'b' 'k'};
xlb={'$\overline{u}$(x,y)','$\overline{v}$(x,y)','$\overline{u''^2}$(x,y)','$
\overline{v''^2}$(x,y)','$\overline{u''v''}$(x,y)','$k$(x,y)','$\varepsilon$(
x,y)'};
Loc1={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc2={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc3={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc4={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Title={'$\overline{u}/U_{ref}$ at $(x/H)$=','$\overline{v}/U_{ref}$ at
$(x/H)$=','$\overline{u''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{v''^2}/U_{ref}^2$ at
```

```
$(x/H)$=','$\overline{u''v''}/U_{ref}^2$ at $(x/H)$=','$k/U_{ref}^2$ at
$(x/H)$=','$\varepsilon/(U_{ref}^2 H)$ at $(x/H)$='};
for n=1:2
 if n==1
 Loc=Loc1;
 elseif n==2
 Loc=Loc2;
 elseif n==3
 Loc=Loc3;
 else
 Loc=Loc4;
 end
%plotting the experimenatl data
for j=1:7
f=figure('visible','on');
if j<6
exp_data2=exp_data{n};
yexp=exp_data2(1:ND,1);
Eval_exp=exp_data2(1:ND,j+1);
plot(Eval_exp,yexp,'ro')
end
for i=1:3
%making eqaution of the data
 meth=data{i};
 x=meth(:,1);
 y=meth(:,2);
 par=meth(:,j+2);
 %plotting the data at the location
 F=scatteredInterpolant(x,y,par);
 xs=0.127+0.0127*H(n)*ones(N,1);
 ys=linspace(0,2.4*0.0127,N)';
 Eval=F(xs,ys)/norm(j);
%plotting
 hold on
 plot(Eval,yplot,mrk{i})
end
%plotting
box on
xlabel(xlb{j},'interpreter','latex');
ylabel('$0\leq (y/H) \leq 2.5$','interpreter','latex')
title([Title{j},int2str(H(n))],'interpreter','latex')
if j<6
 legend('Experimental Data','k-\epsilon Coarse','k-\epsilon Meduim','k-
\epsilon Fine','Location','best');
else
 legend('k-\epsilon Coarse','k-\epsilon Meduim','k-\epsilon
Fine','Location','best');
end
%storing
saveas(f, fullfile(dir{n}, store{j}), 'png');
end
end
```

Code for Part 3:

```
close all
clc
%extracting the data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
dir1='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots3\XH1';
dir4='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots3\XH4';
dir6='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots3\XH6';
dir10='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots3\XH10';
dir={dir1 dir4 dir6 dir10};
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileD1='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH1.csv';
fileD4='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH4.csv';
fileD6='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH6.csv';
fileD10='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH10.csv';
dataexp1=csvread(fileD1,1,0);
dataexp4=csvread(fileD4,1,0);
dataexp6=csvread(fileD6,1,0);
dataexp10=csvread(fileD10,1,0);
exp_data={dataexp1 dataexp4 dataexp6 dataexp10};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileEps='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_fine.csv';
fileOmega='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Kw_fine.csv';
fileRS='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Re_fine.csv';
dataEps=csvread(fileEps,1,1);
dataOmega=csvread(fileOmega,1,1);
dataRS=csvread(fileRS,1,1);
data={dataEps dataOmega dataRS};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%number of data points for the contour
N=500;
ND=20;
%reference values
U=44.2;
Href=0.0127;
%location values
H=[1 4 6 10];
%normalization
yplot=linspace(0,2.4,N);
norm=[U U U^2/10^3 U^2/10^3 U^2/10^3 U^2 U^3/Href];
%ploting tools
mrk={'r' 'b' 'k'};
xlb={'$\overline{u}$(x,y)','$\overline{v}$(x,y)','$\overline{u''^2}$(x,y)','$
\overline{v''^2}$(x,y)','$\overline{u''v''}$(x,y)','$k$(x,y)','$\varepsilon$(
x,y)'};
Loc1={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
```

```
Loc2={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc3={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc4={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Title={'$\overline{u}/U_{ref}$ at $(x/H)$=','$\overline{v}/U_{ref}$ at
$(x/H)$=','$\overline{u''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{v''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{u''v''}/U_{ref}^2$ at $(x/H)$=','$k/U_{ref}^2$ at
$(x/H)$=','$\varepsilon/(U_{ref}^2 H)$ at $(x/H)$='};
for n=1:4
 if n==1
 Loc=Loc1;
 elseif n==2
 Loc=Loc2;
 elseif n==3
 Loc=Loc3;
 else
 Loc=Loc4;
 end
%plotting the experimenatl data
for j=1:7
f=figure('visible','on');
if j<6
exp_data2=exp_data{n};
yexp=exp_data2(1:ND,1);
Eval_exp=exp_data2(1:ND,j+1);
plot(Eval_exp,yexp,'ro')
end
for i=1:3
%making eqaution of the data
 meth=data{i};
 x=meth(:,1);
 y=meth(:,2);
 par=meth(:,j+2);
 %plotting the data at the location
 F=scatteredInterpolant(x,y,par);
 xs=0.127+0.0127*H(n)*ones(N,1);
 ys=linspace(0,2.4*0.0127,N)';
 Eval=F(xs,ys)/norm(j);
%plotting
 hold on
 plot(Eval,yplot,mrk{i})
end
%plotting
box on
xlabel(xlb{j},'interpreter','latex');
ylabel('$0\leq (y/H) \leq 2.5$','interpreter','latex')
title([Title{j},int2str(H(n))],'interpreter','latex')
if j<6
 legend('Experimental Data','k-\epsilon Model','k-\omega Model','Reynolds
Stress Transport Model','Location','best');
else
 legend('k-\epsilon Model','k-\omega Model','Reynolds Stress Transport
Model','Location','best');
end
```

```
%storing
saveas(f, fullfile(dir{n}, store{j}), 'png');
end
end
```

Code for Part 4:

```
close all
clc
%extracting the data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
dir1='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots4\XH1';
dir4='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots4\XH4';
dir={dir1 dir4};
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileD1='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH1.csv';
fileD4='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH4.csv';
dataexp1=csvread(fileD1,1,0);
dataexp4=csvread(fileD4,1,0);
exp_data={dataexp1 dataexp4};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileCoarse='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\4_2.csv';
fileMed='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\4_3.csv';
fileFine='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_fine.csv';
dataEps=csvread(fileCoarse,1,1);
dataOmega=csvread(fileMed,1,1);
dataRS=csvread(fileFine,1,1);
data={dataEps dataOmega dataRS};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%number of data points for the contour
N=500;
ND=20;
%reference values
U=44.2;
Href=0.0127;
%location values
H=[1 4];
%normalization
yplot=linspace(0,2.4,N);
norm=[U U U^2/10^3 U^2/10^3 U^2/10^3 U^2 U^3/Href];
%ploting tools
mrk={'r' 'b' 'k'};
xlb={'$\overline{u}$(x,y)','$\overline{v}$(x,y)','$\overline{u''^2}$(x,y)','$
\overline{v''^2}$(x,y)','$\overline{u''v''}$(x,y)','$k$(x,y)','$\varepsilon$(
x,y)'};
Loc1={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc2={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc3={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc4={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Title={'$\overline{u}/U_{ref}$ at $(x/H)$=','$\overline{v}/U_{ref}$ at
$(x/H)$=','$\overline{u''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{v''^2}/U_{ref}^2$ at
```

```
$(x/H)$=','$\overline{u''v''}/U_{ref}^2$ at $(x/H)$=','$k/U_{ref}^2$ at
$(x/H)$=','$\varepsilon/(U_{ref}^2 H)$ at $(x/H)$='};
for n=1:2
 if n==1
 Loc=Loc1;
 elseif n==2
 Loc=Loc2;
 elseif n==3
 Loc=Loc3;
 else
 Loc=Loc4;
 end
%plotting the experimenatl data
for j=1:7
f=figure('visible','on');
if j<6
exp_data2=exp_data{n};
yexp=exp_data2(1:ND,1);
Eval_exp=exp_data2(1:ND,j+1);
plot(Eval_exp,yexp,'ro')
end
for i=1:3
%making eqaution of the data
 meth=data{i};
 x=meth(:,1);
 y=meth(:,2);
 par=meth(:,j+2);
 %plotting the data at the location
 F=scatteredInterpolant(x,y,par);
 xs=0.127+0.0127*H(n)*ones(N,1);
 ys=linspace(0,2.4*0.0127,N)';
 Eval=F(xs,ys)/norm(j);
%plotting
 hold on
 plot(Eval,yplot,mrk{i})
end
%plotting
box on
xlabel(xlb{j},'interpreter','latex');
ylabel('$0\leq (y/H) \leq 2.5$','interpreter','latex')
title([Title{j},int2str(H(n))],'interpreter','latex')
if j<6
 legend('Experimental Data','k=0.01','k=0.1','k=0.03','Location','best');
else
 legend('k=0.01','k=0.1','k=0.03','Location','best');
end
%storing
saveas(f, fullfile(dir{n}, store{j}), 'png');
end
end
```

Code for Part 5:

```
close all
clc
%extracting the data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
dir1='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots5\XH1';
dir4='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots5\XH4';
dir6='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots5\XH6';
dir10='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\Plots5\XH10';
dir={dir1 dir4 dir6 dir10};
store={'ubar' 'vbar' 'uubar' 'vvbar' 'uvbar' 'k' 'eps'};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileD1='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH1.csv';
fileD4='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH4.csv';
fileD6='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH6.csv';
fileD10='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\ExpXH10.csv';
dataexp1=csvread(fileD1,1,0);
dataexp4=csvread(fileD4,1,0);
dataexp6=csvread(fileD6,1,0);
dataexp10=csvread(fileD10,1,0);
exp_data={dataexp1 dataexp4 dataexp6 dataexp10};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fileEps='C:\Work\SEM
2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\KE_fine.csv';
fileOmega='C:\Work\SEM 2\Turbulence\Project\Sketch_files\dp0\FFF\MECH\5.csv';
dataEps=csvread(fileEps,1,1);
dataOmega=csvread(fileOmega,1,1);
data={dataEps dataOmega};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%number of data points for the contour
N=500;
ND=20;
%reference values
U=44.2;
Href=0.0127;
%location values
H=[1 4 6 10];
%normalization
yplot=linspace(0,2.4,N);
norm=[U U U^2/10^3 U^2/10^3 U^2/10^3 U^2 U^3/Href];
%ploting tools
mrk={'r' 'b' 'k'};
xlb={'$\overline{u}$(x,y)','$\overline{v}$(x,y)','$\overline{u''^2}$(x,y)','$
\overline{v''^2}$(x,y)','$\overline{u''v''}$(x,y)','$k$(x,y)','$\varepsilon$(
x,y)'};
Loc1={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc2={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Loc3={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
```

```
Loc4={'NorthWest','NorthEast','NorthEast','NorthEast','NorthWest','NorthEast'
,'NorthEast'};
Title={'$\overline{u}/U_{ref}$ at $(x/H)$=','$\overline{v}/U_{ref}$ at
$(x/H)$=','$\overline{u''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{v''^2}/U_{ref}^2$ at
$(x/H)$=','$\overline{u''v''}/U_{ref}^2$ at $(x/H)$=','$k/U_{ref}^2$ at
$(x/H)$=','$\varepsilon/(U_{ref}^2 H)$ at $(x/H)$='};
for n=1:4
 if n==1
 Loc=Loc1;
 elseif n==2
 Loc=Loc2;
 elseif n==3
 Loc=Loc3;
 else
 Loc=Loc4;
 end
%plotting the experimenatl data
for j=1:7
f=figure('visible','on');
if j<6
exp_data2=exp_data{n};
yexp=exp_data2(1:ND,1);
Eval_exp=exp_data2(1:ND,j+1);
plot(Eval_exp,yexp,'ro')
end
for i=1:2
%making eqaution of the data
 meth=data{i};
 x=meth(:,1);
 y=meth(:,2);
 par=meth(:,j+2);
 %plotting the data at the location
 F=scatteredInterpolant(x,y,par);
 xs=0.127+0.0127*H(n)*ones(N,1);
 ys=linspace(0,2.4*0.0127,N)';
 Eval=F(xs,ys)/norm(j);
%plotting
 hold on
 plot(Eval,yplot,mrk{i})
end
%plotting
box on
xlabel(xlb{j},'interpreter','latex');
ylabel('$0\leq (y/H) \leq 2.5$','interpreter','latex')
title([Title{j},int2str(H(n))],'interpreter','latex')
if j<6
 legend('Experimental Data','Standard Wall Conditions','Enhanced Wall
Conditions','Location','best');
else
 legend('Standard Wall Conditions','Enhanced Wall
Conditions','Location','best');
end
%storing
saveas(f, fullfile(dir{n}, store{j}), 'png');
end
end
```