5. Solution/Calculation Verification
Backward Facing Step

a) Calculations performed

	Code	T. Model	Observations
A	FLUENT	SA	1st-order and 2nd-order convection
B	ISIS	SA	Cartesian, Multiblock and Unstructured grids
C	OpenFOAM	SA	Cartesian and Multiblock grids
D	CFL3D	SA	1st-order convection for $\tilde{\nu}$
E	FUN3D	SA	1st-order convection for $\tilde{\nu}$
F	PARNASSOS	SA	1st-order and 2nd-order convection for $\tilde{\nu}$
G	FLUENT	SKE	1st-order and 2nd-order convection, Wall Functions
H	CADYF	SKE	Wall functions
I	CHAPMAN	BSL	Grid sets A, B and C of 1st Workshop
J	PARNASSOS	BSL	1st-order and 2nd-order convection for k and ω
K	PARNASSOS	STT	2nd-order convection for k and ω
L	All Workshops	SA	All finest grids results since 2004

SA – Spalart & Allmaras one-equation model
BSL – Baseline k-ω two-equation model
SKE – Standard k-ε two-equation model
SST – Shear-Stress transport k-ω two-equation model

b) Meaning of h_i/h_1

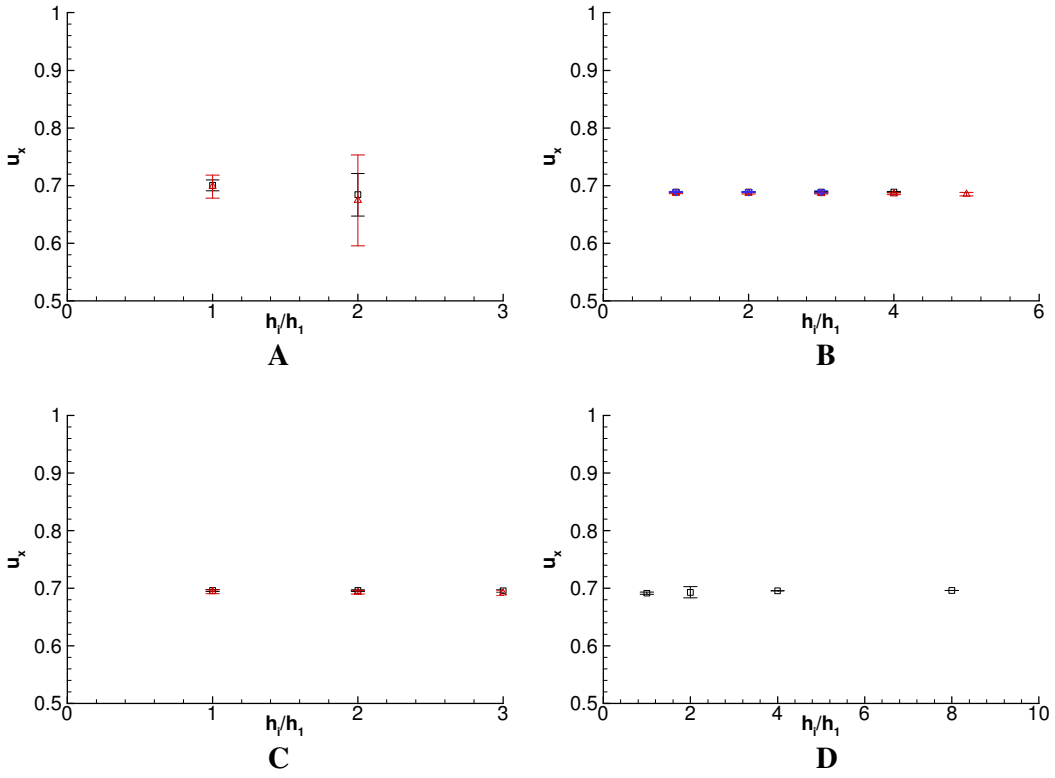
	Code	h_i/h_1
A	FLUENT	1-(143×150), (72×74),(36×38); 2-(72×74) ,(36×38) ,(18×20)
B	ISIS	Sqrt(Cells finest grid/cells of grid$_i$)
C	OpenFOAM	Sqrt(Cells finest grid/cells of grid$_i$)
D	CFL3D	Sqrt(Cells finest grid/cells of grid$_i$)
E	FUN3D	Sqrt(Cells finest grid/cells of grid$_i$)
F	PARNASSOS	Sqrt(Cells finest grid/cells of grid$_i$)
G	FLUENT	1-(143×150), (72×74),(36×38); 2-(72×74) ,(36×38) ,(18×20)
H	CADYF	Reduce error estimate by constant factor (2 or 3, often 2) using convergence rate of the method in proper norm (p=2 generally for error in H1-norm of U and L2 for pressure in the asymptotic range→reducing error estimate by 2 doubles grid points
I	CHAPMAN	Sqrt(Cells finest grid/cells of grid$_i$)
J	PARNASSOS	Sqrt(Cells finest grid/cells of grid$_i$)
K	PARNASSOS	Sqrt(Cells finest grid/cells of grid$_i$)
L	All Workshops	---

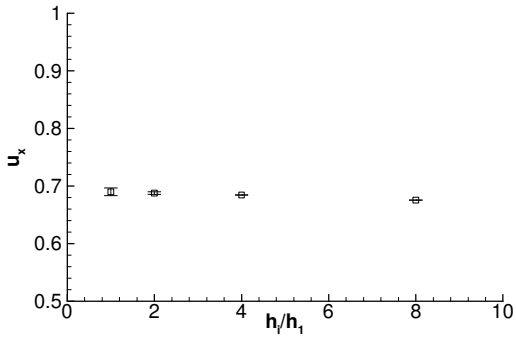
c) Code of plots

	Code	Meaning of colours
A	FLUENT	Black- 2nd order ; Red- 1st order
B	ISIS	Black Cartesian; Red-Multibloc; Blue-Unstructured
C	OpenFOAM	Black Cartesian; Red-Multibloc
F	PARNASSOS	Black – Set A(FD) 1st; Red - Set A(FD) 2nd; Blue - Set B(FD) 1st; Green - Set B(FD) 2nd; Purple- FV
G	FLUENT	Black- 2nd order ; Red- 1st order
I	CHAPMAN	Black- A; Red- B; Blue-C
J	PARNASSOS	Black – Set A(FD) 1st; Red - Set A(FD) 2nd; Blue - Set B(FD) 1st; Green - Set B(FD) 2nd;
K	PARNASSOS	Black – Set A(FD) 2nd; Red - Set B(FD) 2nd;

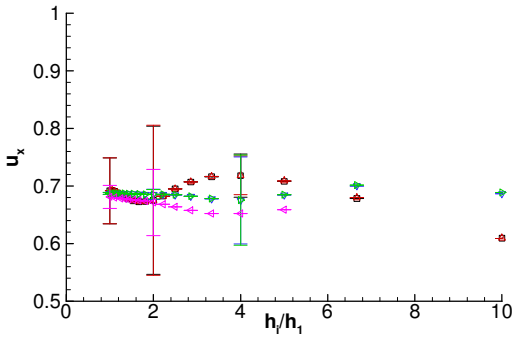
d)Local flow quantities

u_x velocity component at ***x=0, y=1.1h***

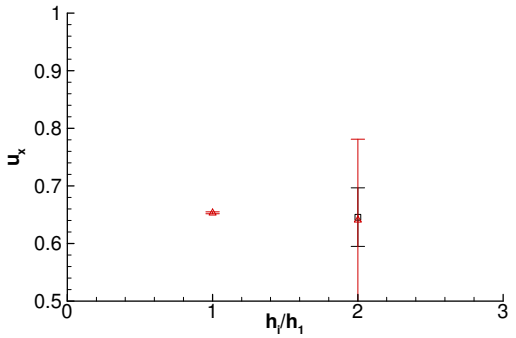



u_x
h_i/h_1

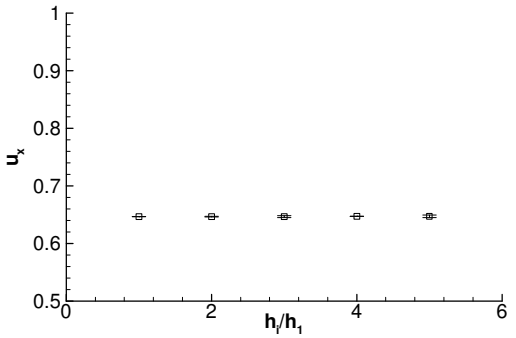
E


u_x
h_i/h_1

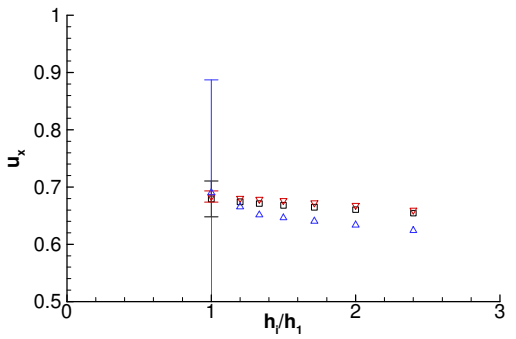
F


u_x
h_i/h_1

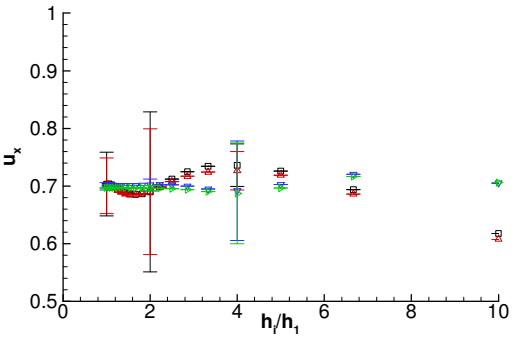
G


u_x
h_i/h_1

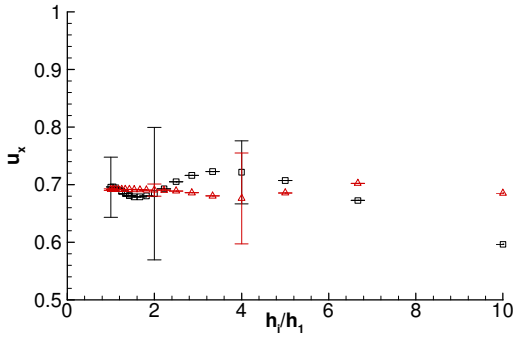
H


u_x
h_i/h_1

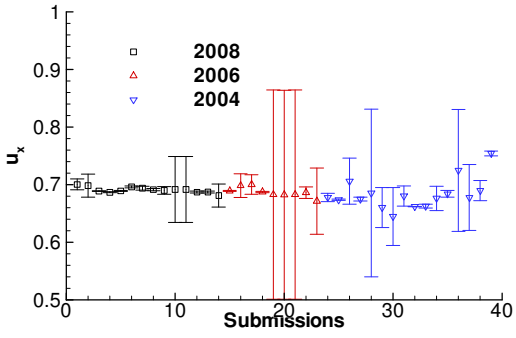
I


u_x
h_i/h_1

J

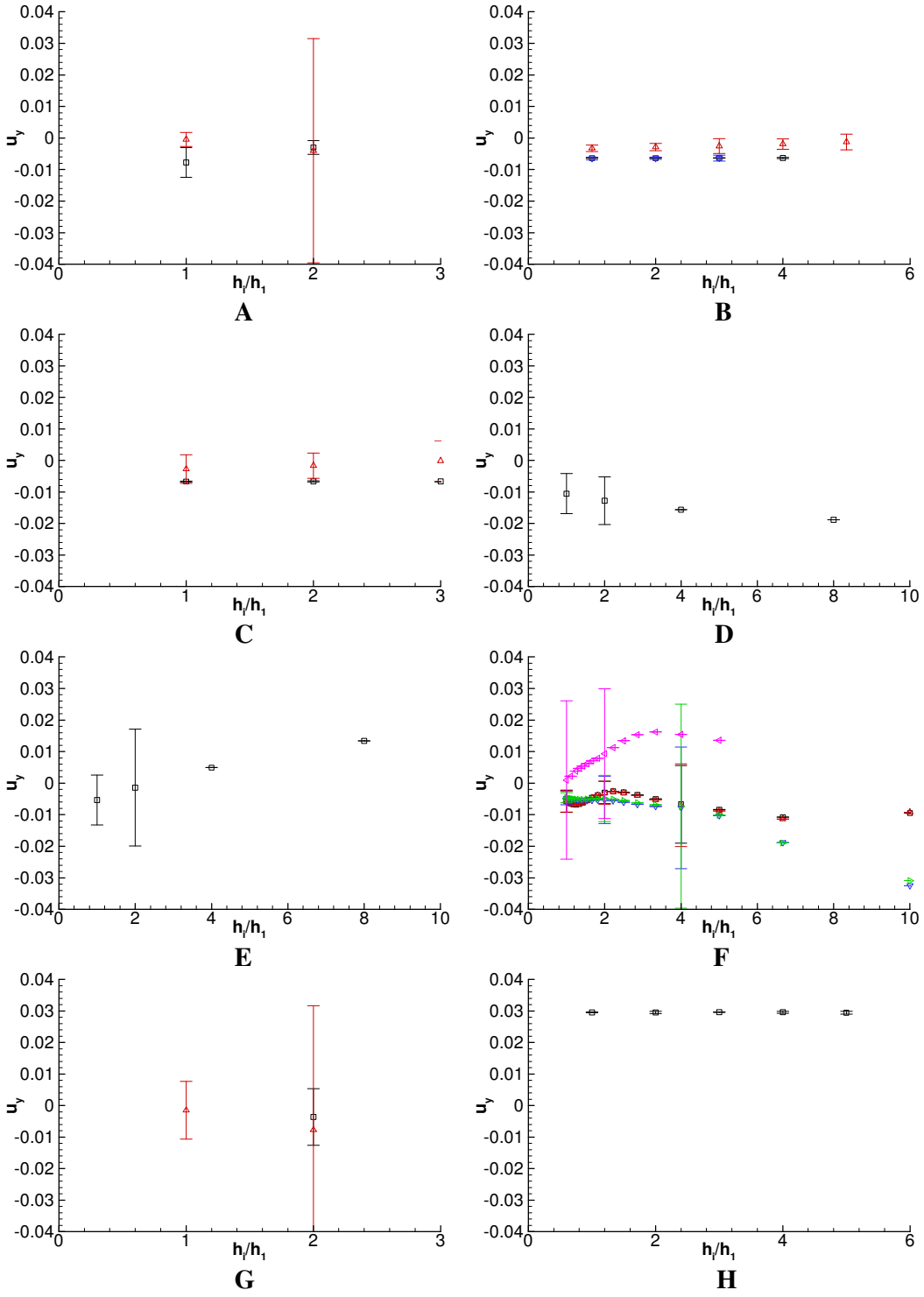

u_x
h_i/h_1

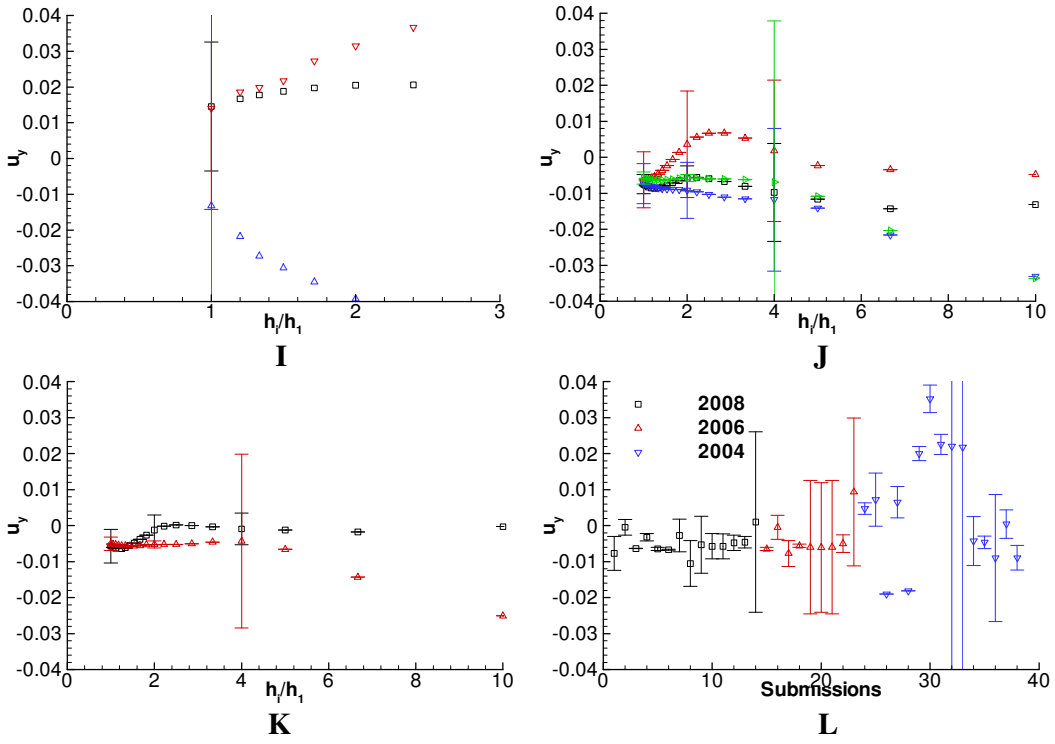
K


2008
2006
2004
u_x
Submissions

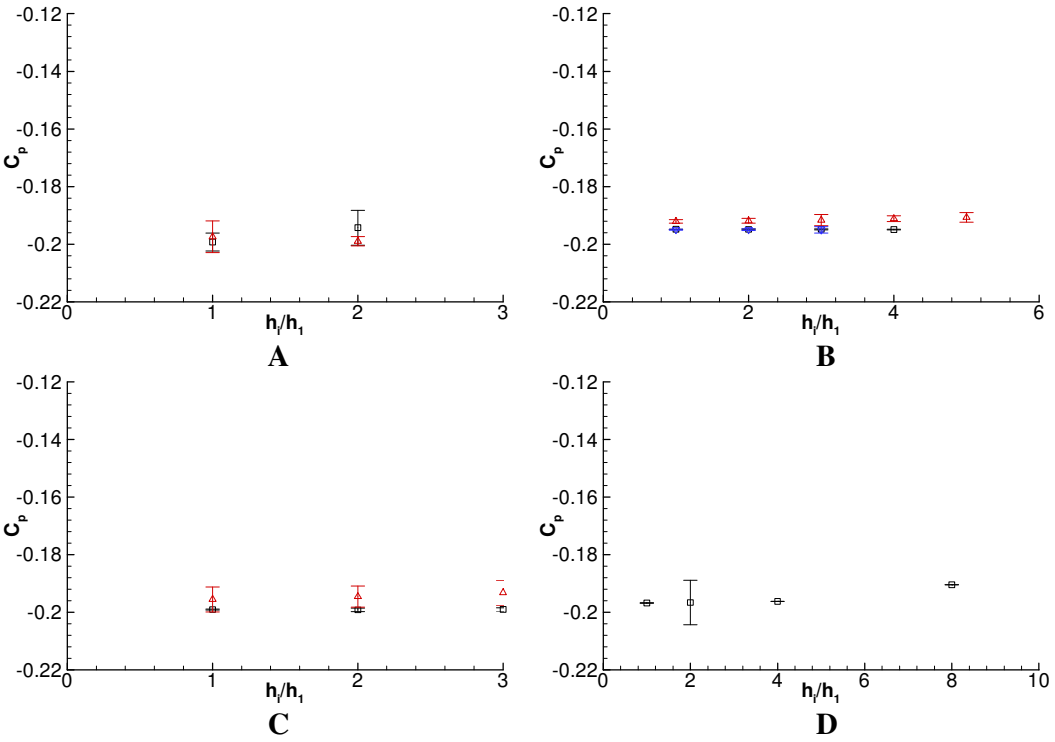
L

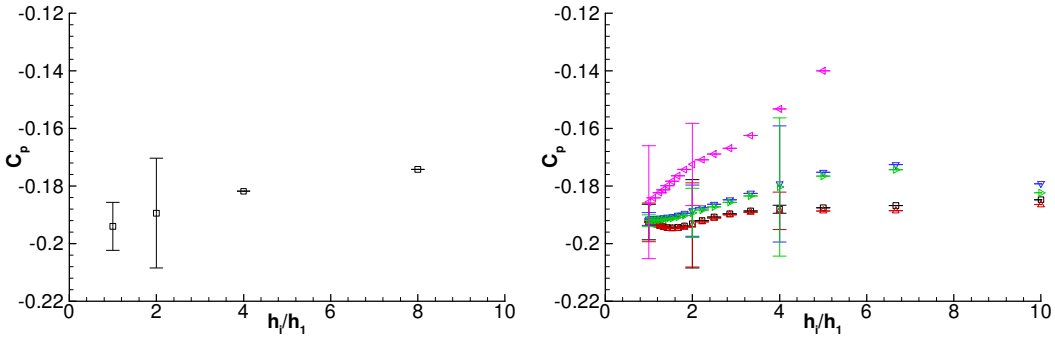
u_y velocity component at ***x=0, y=1.1h***





Cp pressure coefficient at ***x=0, y=1.1h***

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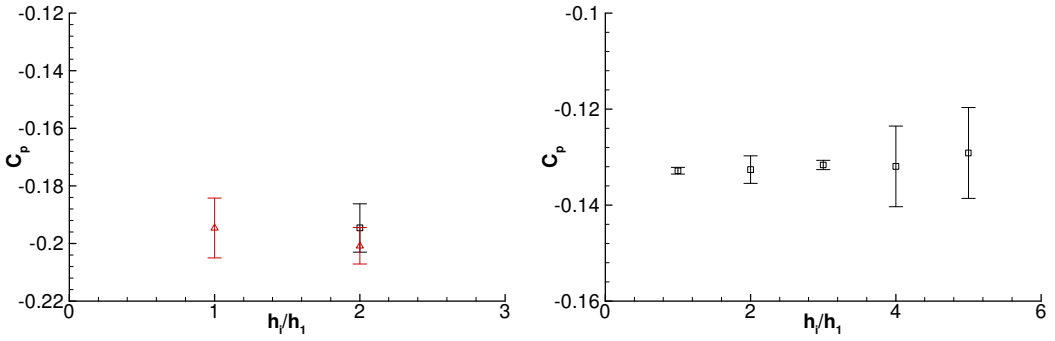
-0.16
-0.18
-0.2
-0.22
C_p
0
2
4
6
8
10
h_i/h_1

E F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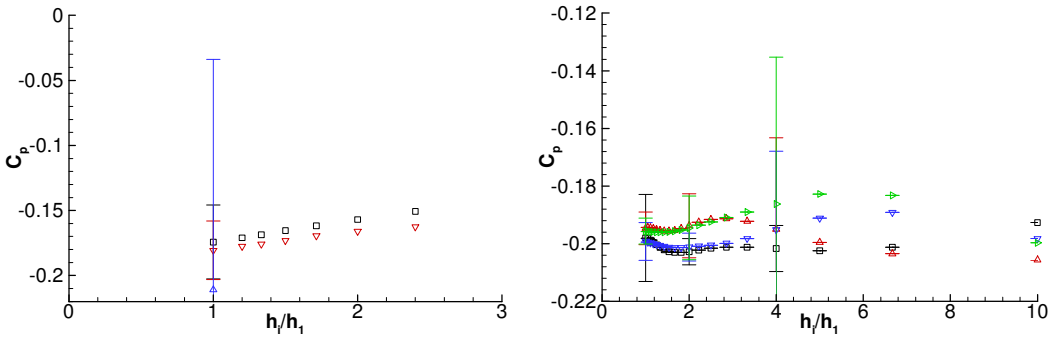
-0.14
-0.16
-0.18
-0.2
-0.22
-0.1
-0.12
-0.14
-0.16
C_p
0
1
2
3
4
6
h_i/h_1

G H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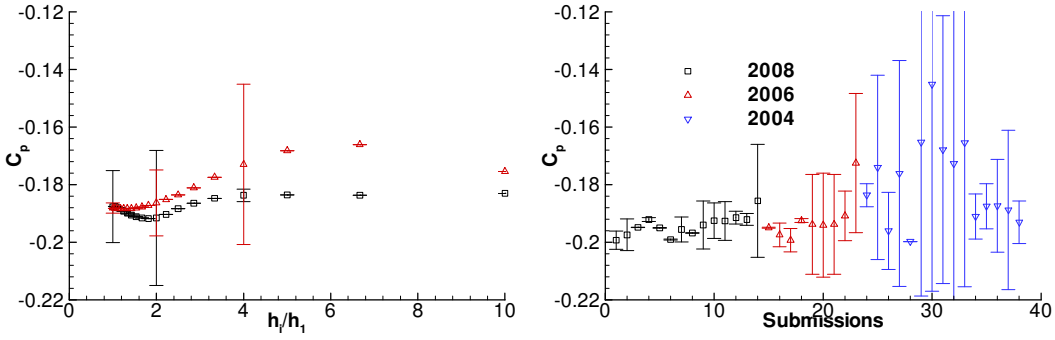
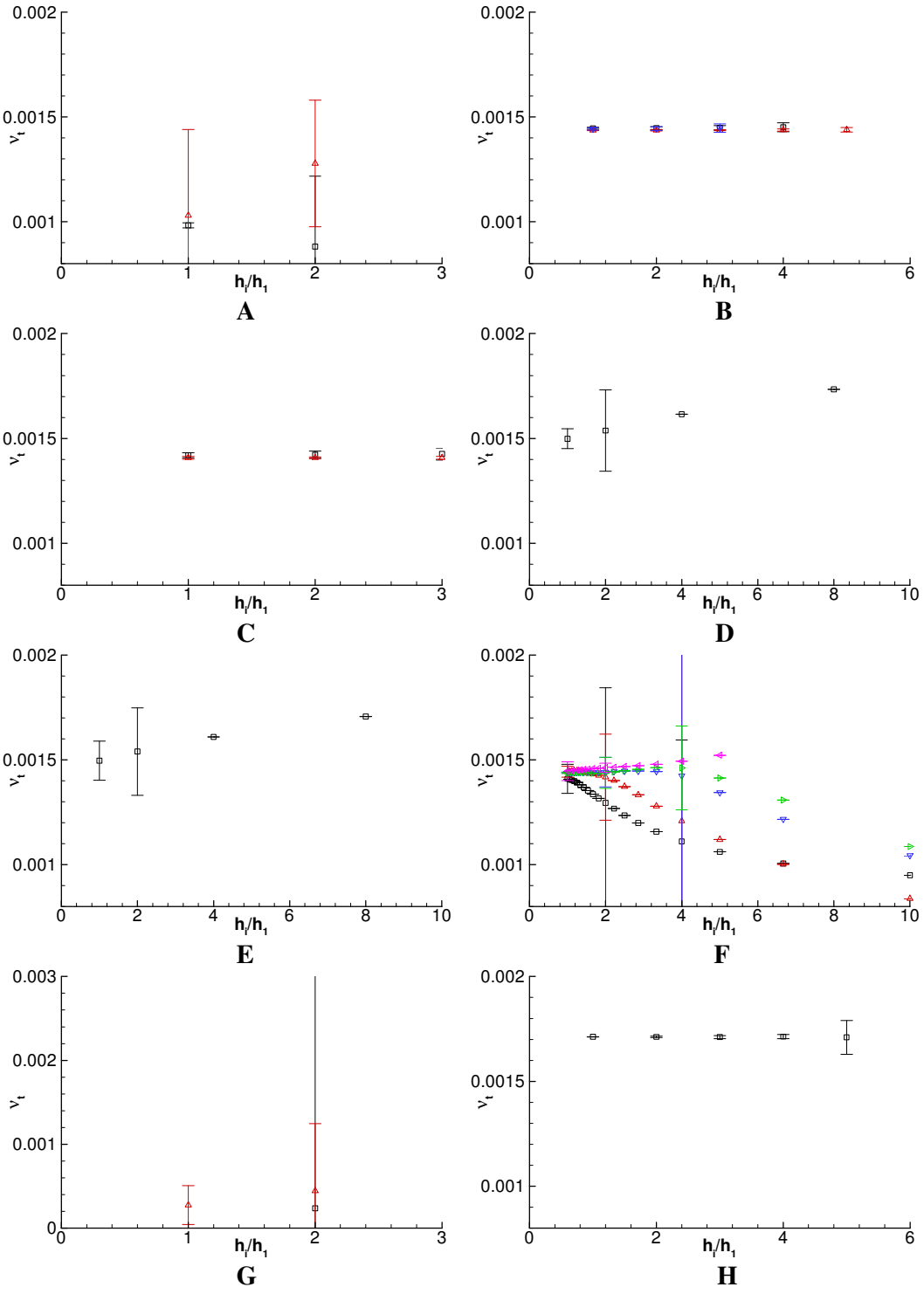
-0.12
-0.14
-0.16
-0.18
-0.22
C_p
0
1
2
3
4
6
8
10
h_i/h_1

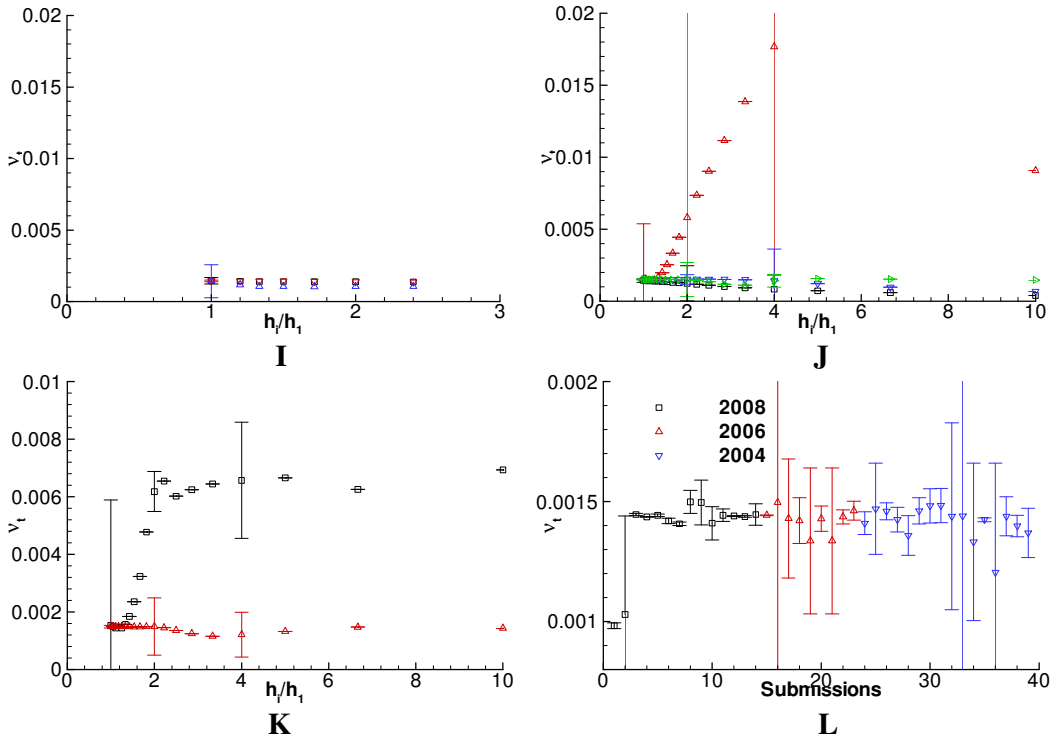
I J


-0.12
-0.14
-0.16
-0.18
-0.2
-0.22
C_p
0
2
4
6
8
10
h_i/h_1
2008
2006
2004
10
20
30
40
Submissions

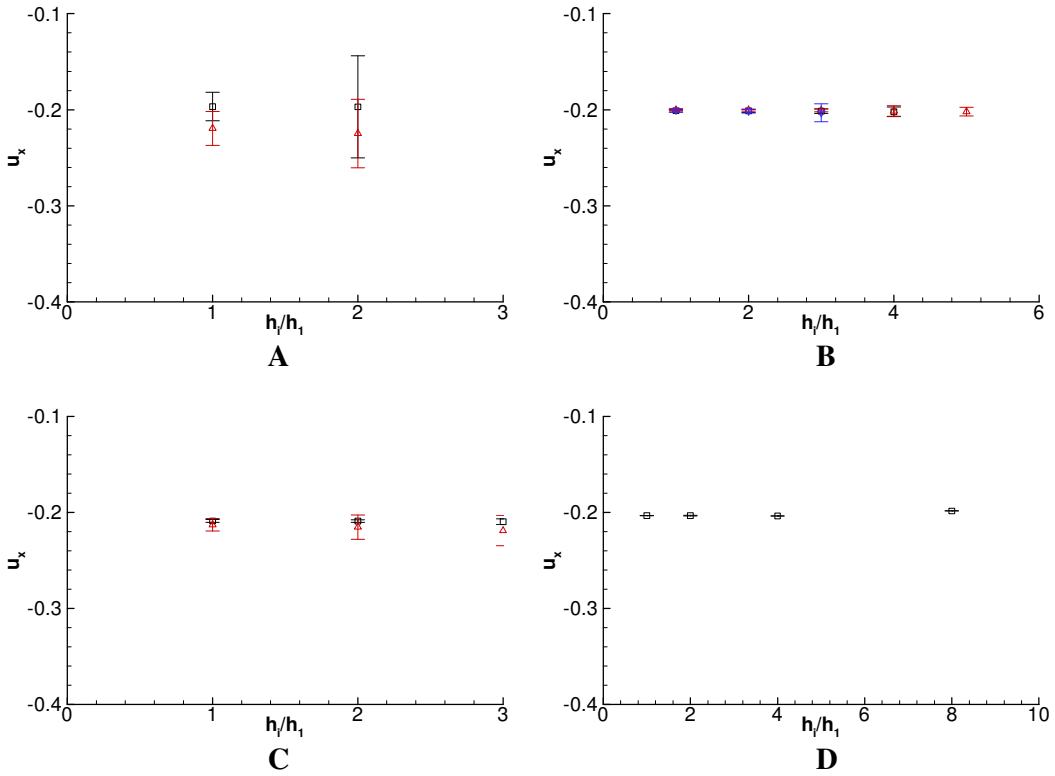
K L

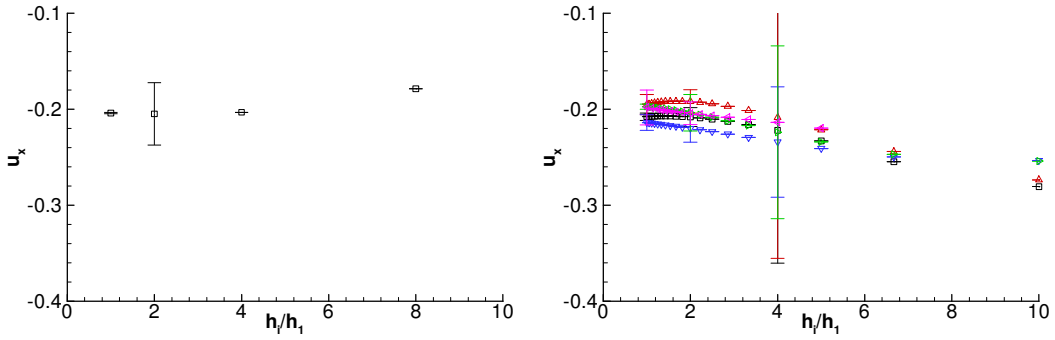
ν_t eddy-viscosity at ***x=0, y=1.1h***





u_x velocity component at ***x=h, y=0.1h***

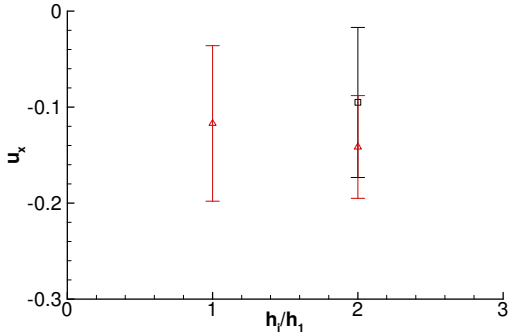



-0.1
-0.2
-0.3
-0.4
u_x
0
2
4
6
8
10
h_i/h_1

E

-0.1
-0.2
-0.3
-0.4
u_x
0
2
4
6
8
10
h_i/h_1

F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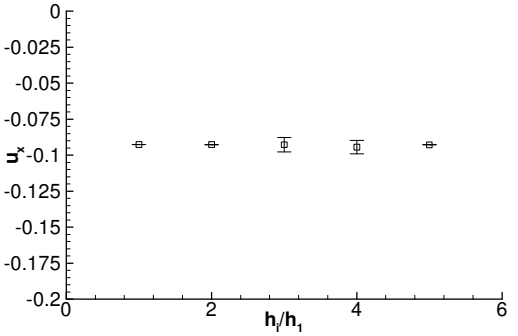
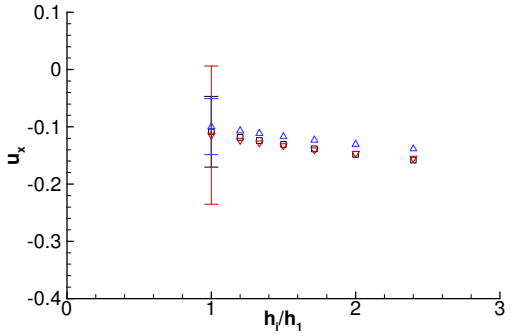
-0.1
-0.2
-0.3
u_x
0
1
2
3
h_i/h_1

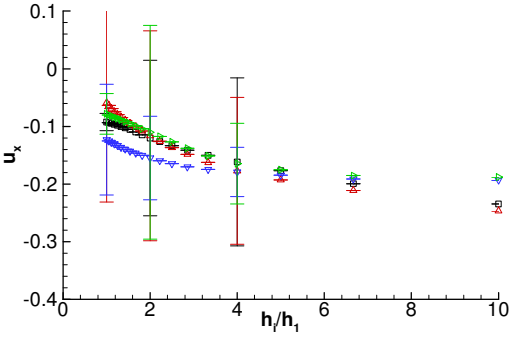
G


0
-0.025
-0.05
-0.075
-0.1
-0.125
-0.15
-0.175
-0.2
u_x
0
2
4
6
h_i/h_1

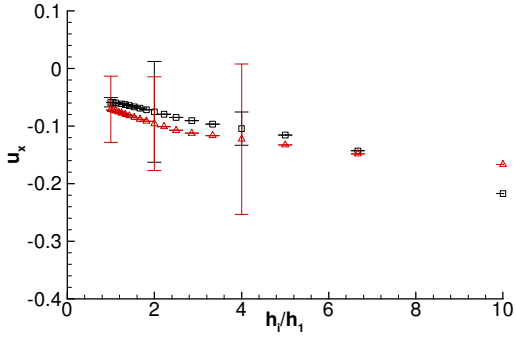
H


0.1
0
-0.1
-0.2
-0.3
-0.4
u_x
0
1
2
3
h_i/h_1

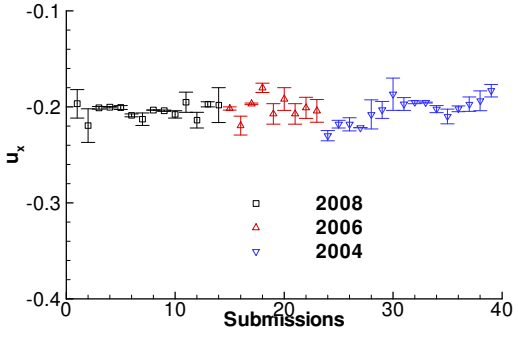
I


0.1
0
-0.1
-0.2
-0.3
-0.4
u_x
0
2
4
6
8
10
h_i/h_1

J

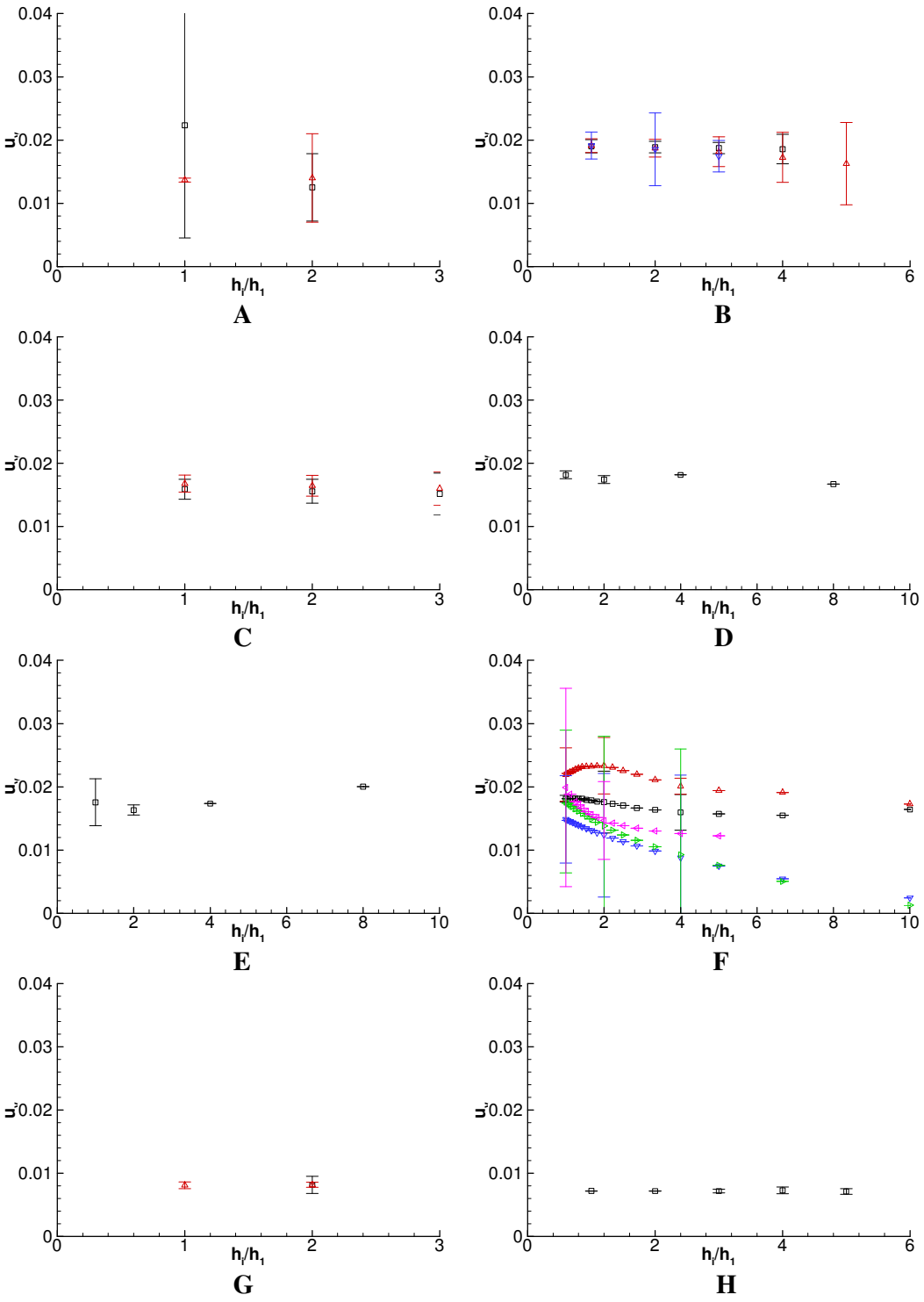

0.1
0
-0.1
-0.2
-0.3
-0.4
u_x
0
2
4
6
8
10
h_i/h_1

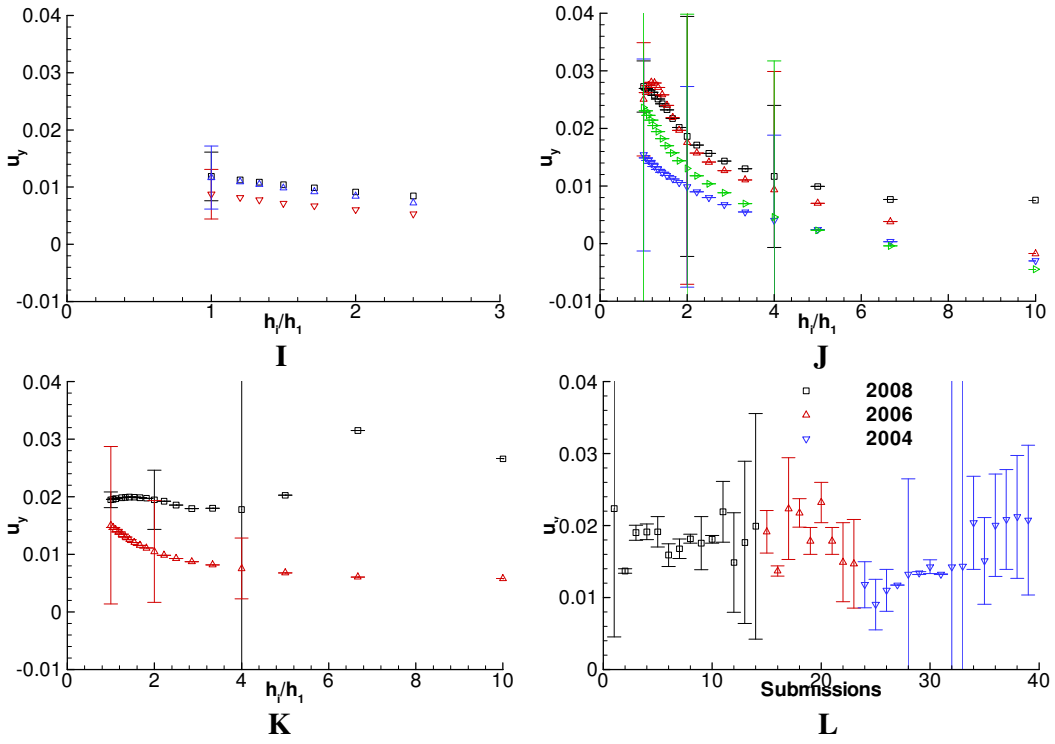
K


-0.1
-0.2
-0.3
-0.4
u_x
2008
2006
2004
0
10
20
30
40
Submissions

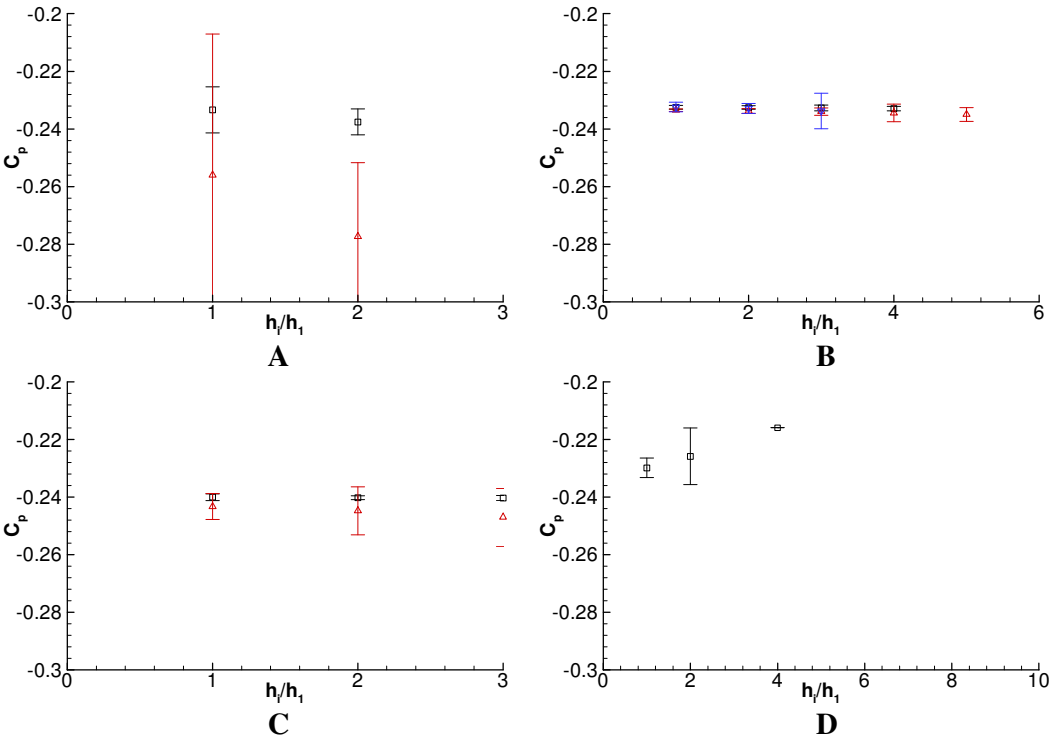
L

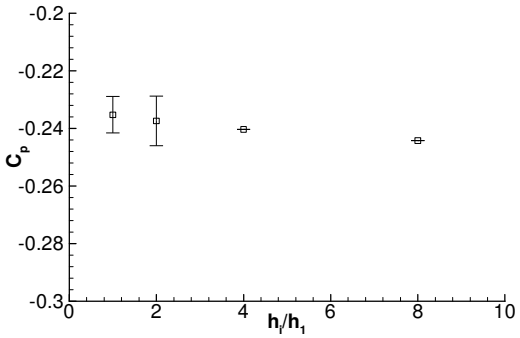
u_y velocity component at ***x=h, y=0.1h***



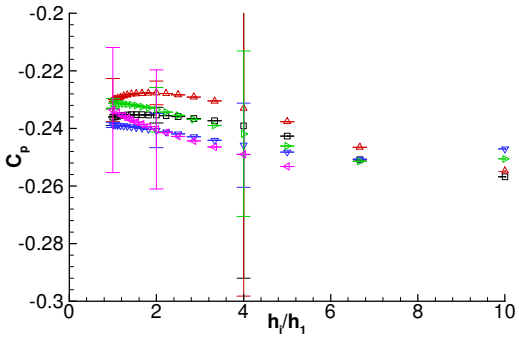


Cp pressure coefficient at ***x=h, y=0.1h***

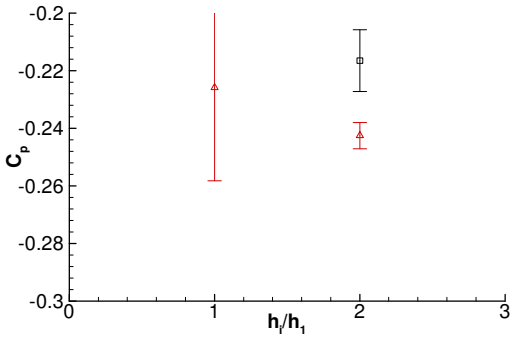



-0.2
-0.22
-0.24
-0.26
-0.28
-0.3
C_p
0
2
4
6
8
10
h_i/h_1

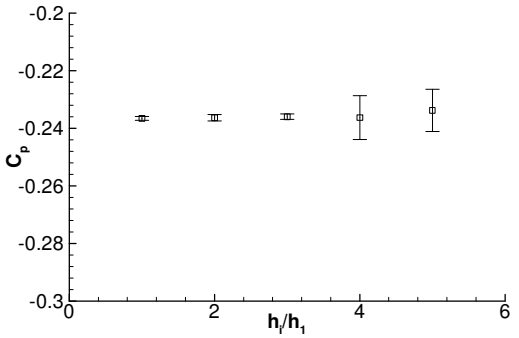
E


-0.2
-0.22
-0.24
-0.26
-0.28
-0.3
C_p
0
2
4
6
8
10
h_i/h_1

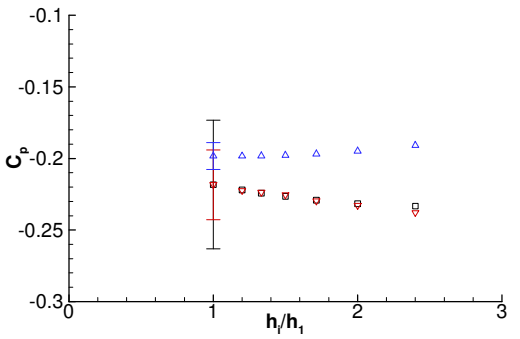
F


-0.2
-0.22
-0.24
-0.26
-0.28
-0.3
C_p
0
1
2
3
h_i/h_1

G


-0.2
-0.22
-0.24
-0.26
-0.28
-0.3
C_p
0
2
4
6
h_i/h_1

H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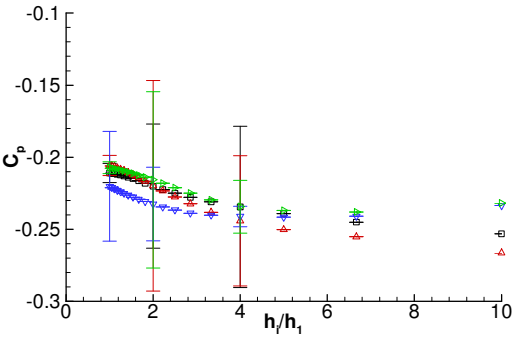
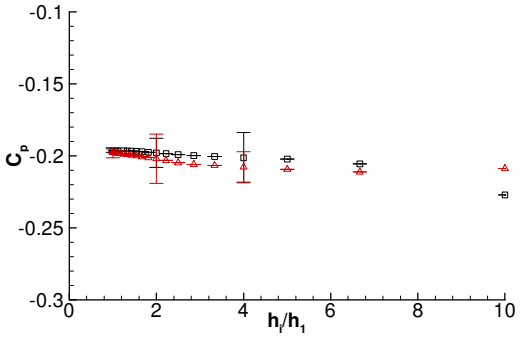
-0.15
-0.2
-0.25
-0.3
C_p
0
1
2
3
h_i/h_1

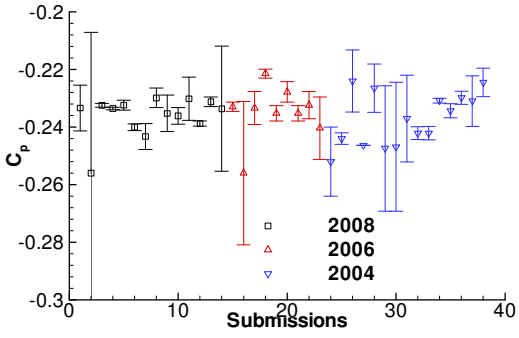
I


-0.1
-0.15
-0.2
-0.25
-0.3
C_p
0
2
4
6
8
10
h_i/h_1

J

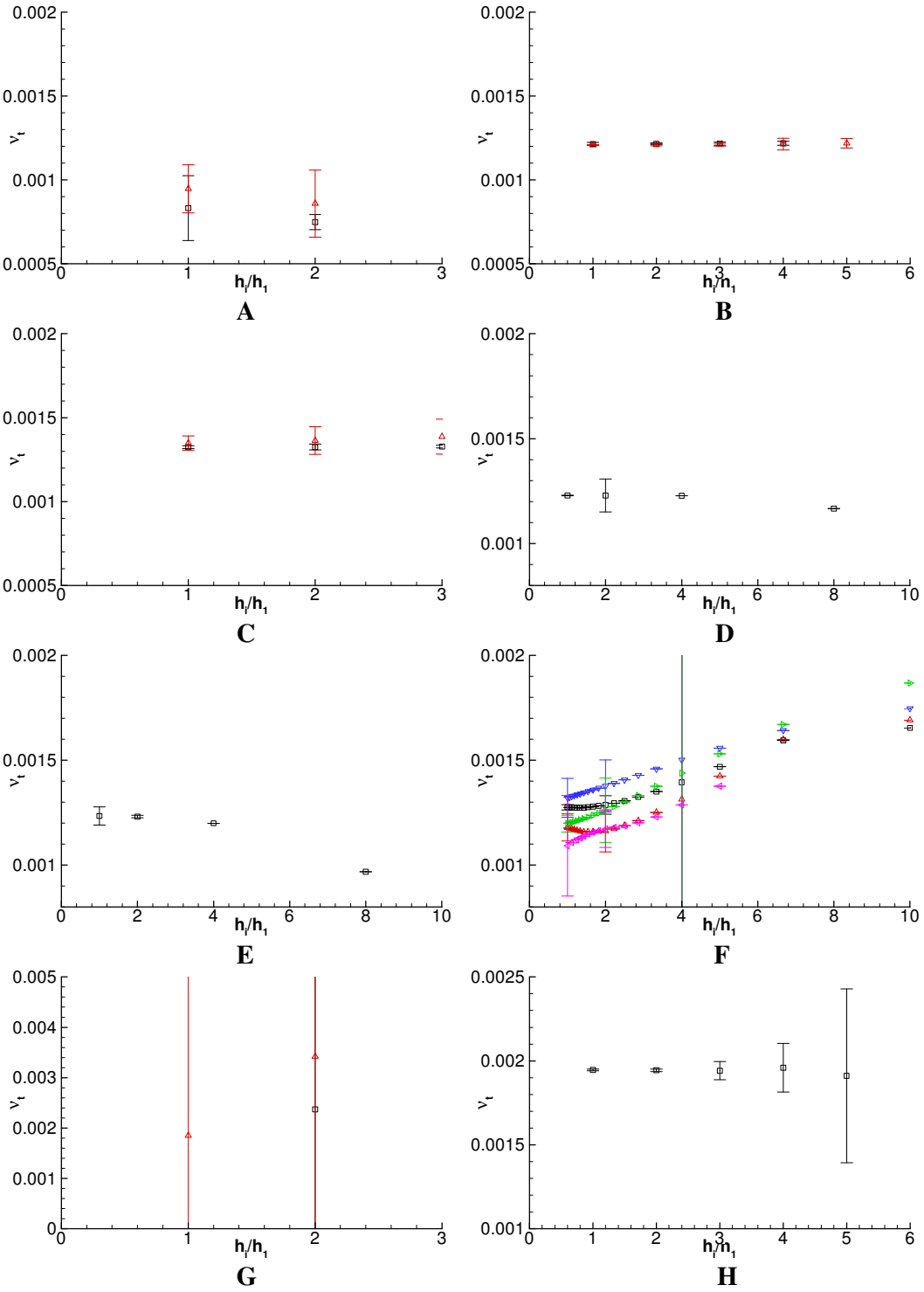

-0.1
-0.15
-0.2
-0.25
-0.3
C_p
0
2
4
6
8
10
h_i/h_1

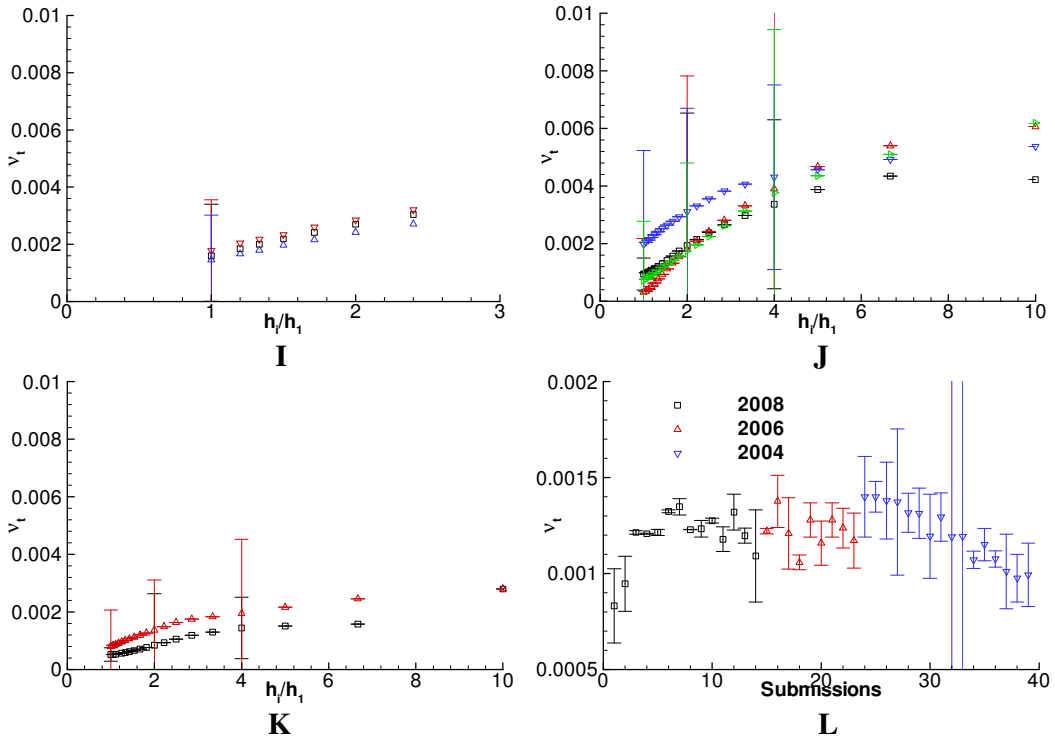
K


-0.2
-0.22
-0.24
-0.26
-0.28
-0.3
C_p
0
10
20
30
40
Submissions
2008
2006
2004

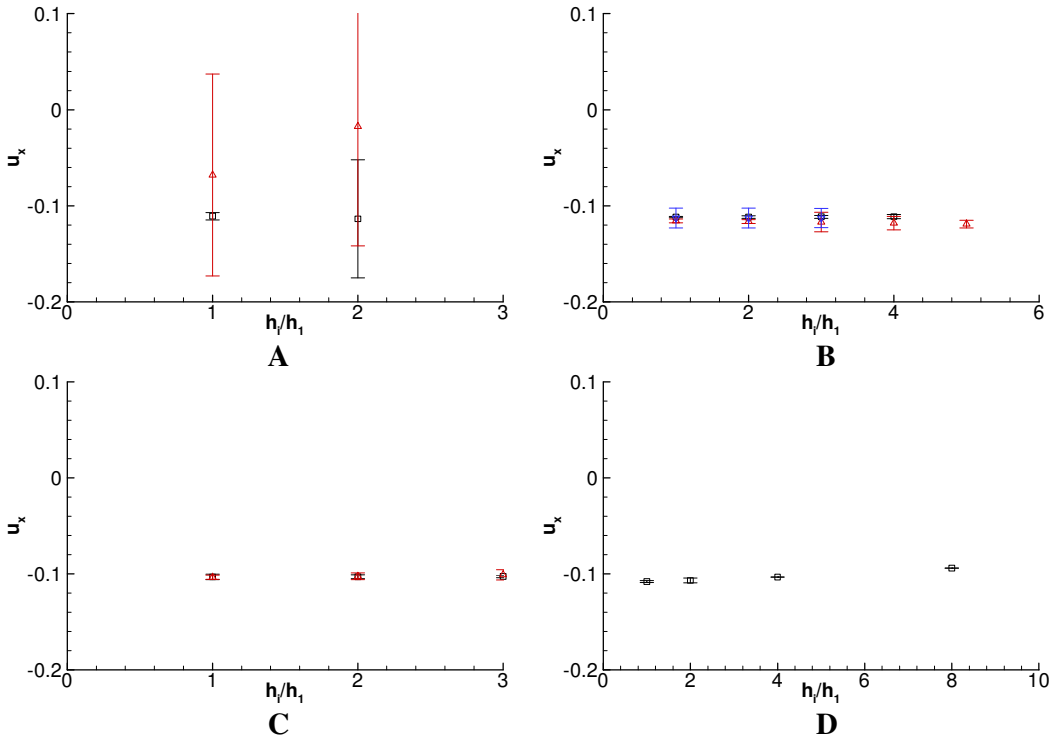
L

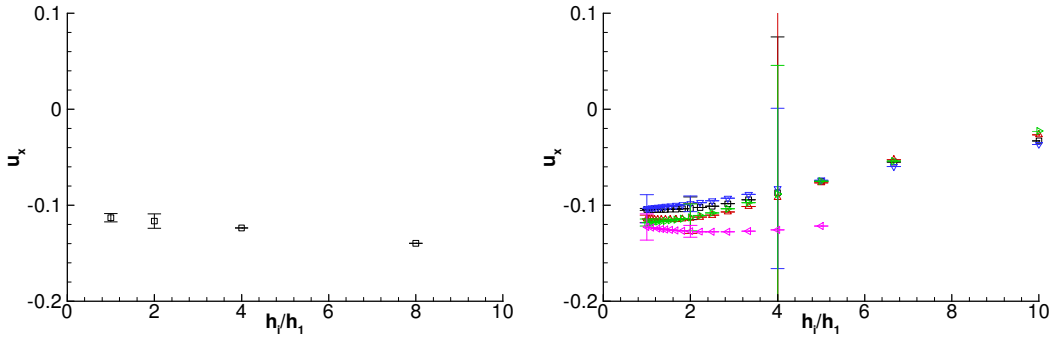
ν_t eddy viscosity at ***x=h, y=0.1h***





u_x velocity component at ***x=4h, y=0.1h***

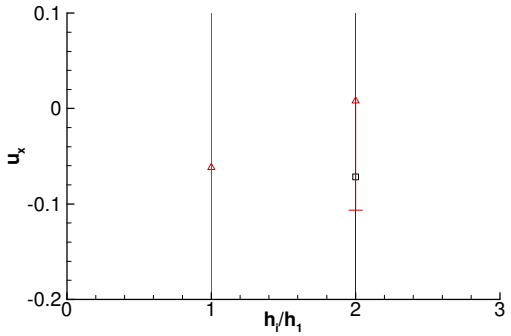



0.1
0
-0.1
-0.2
u_x
0
2
4
6
8
10
h_i/h_1

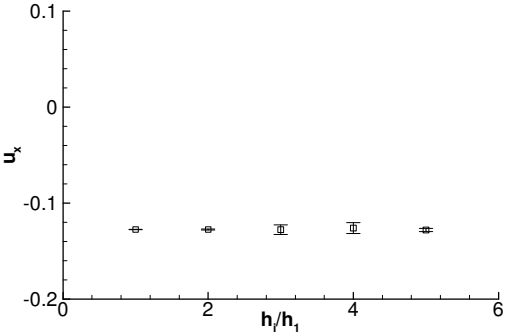
E

0.1
0
-0.1
-0.2
u_x
0
2
4
6
8
10
h_i/h_1

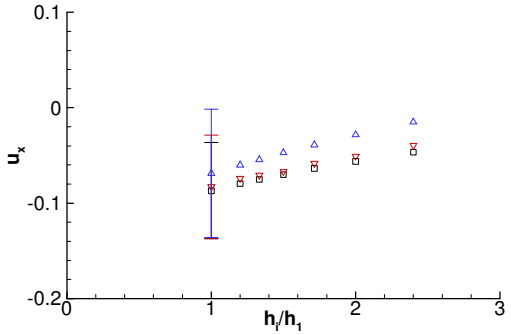
F


0.1
0
-0.1
-0.2
u_x
0
1
2
3
h_i/h_1

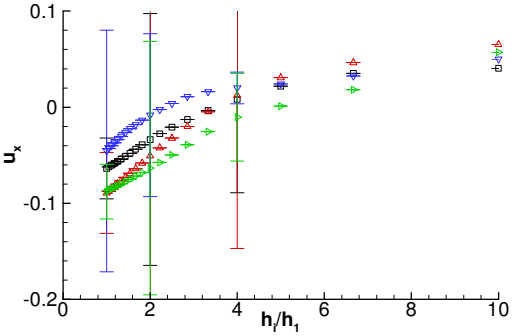
G


0.1
0
-0.1
-0.2
u_x
0
2
4
6
h_i/h_1

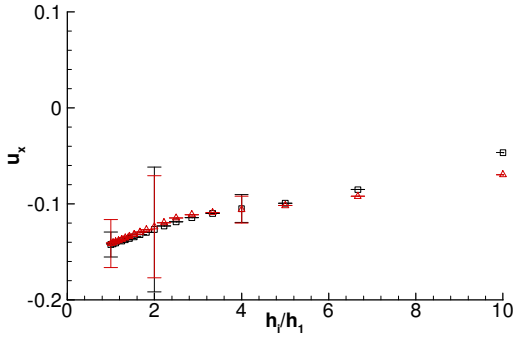
H


0.1
0
-0.1
-0.2
u_x
0
1
2
3
h_i/h_1

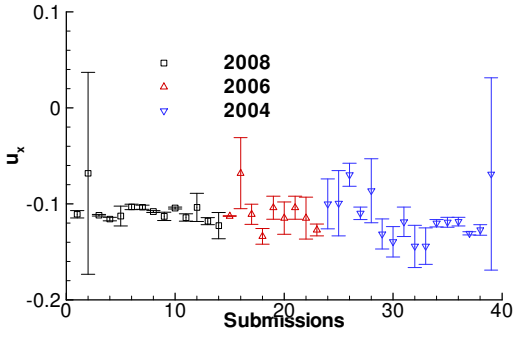
I


0.1
0
-0.1
-0.2
u_x
0
2
4
6
8
10
h_i/h_1

J

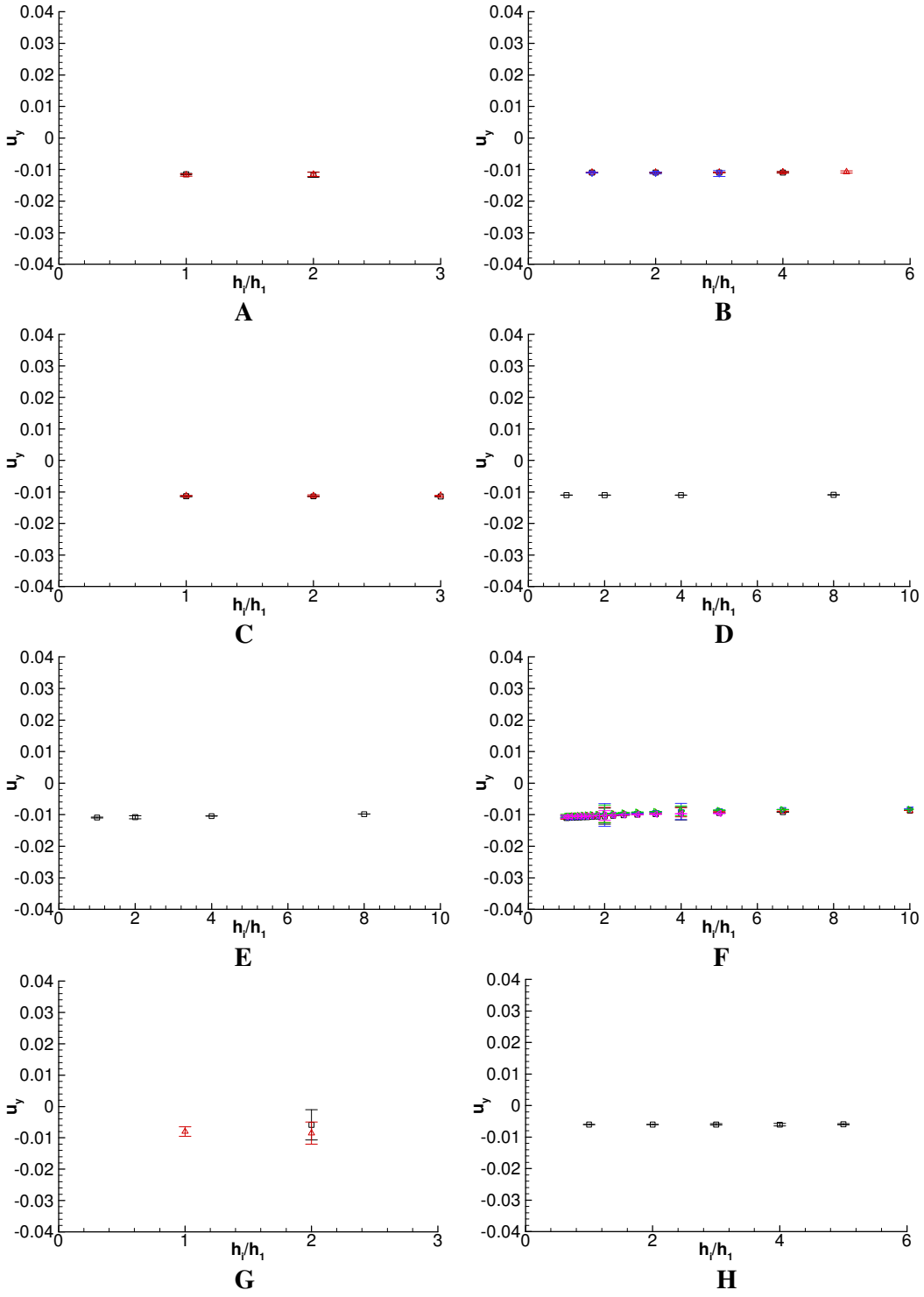

0.1
0
-0.1
-0.2
u_x
0
2
4
6
8
10
h_i/h_1

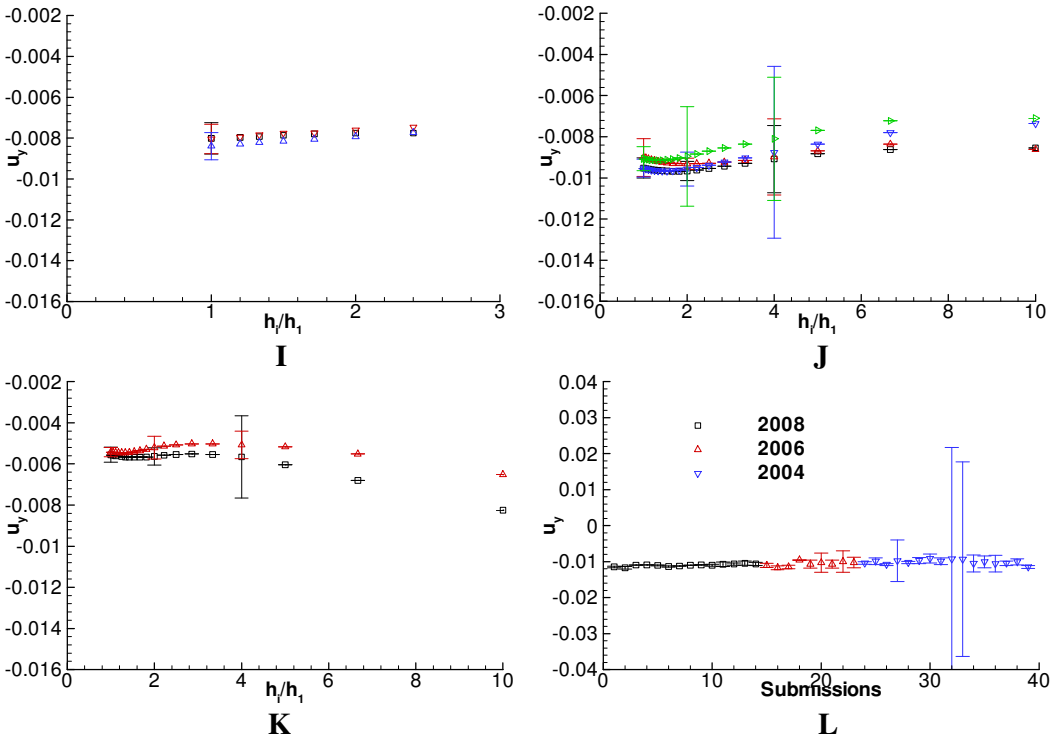
K


0.1
0
-0.1
-0.2
u_x
2008
2006
2004
0
10
20
30
40
Submissions

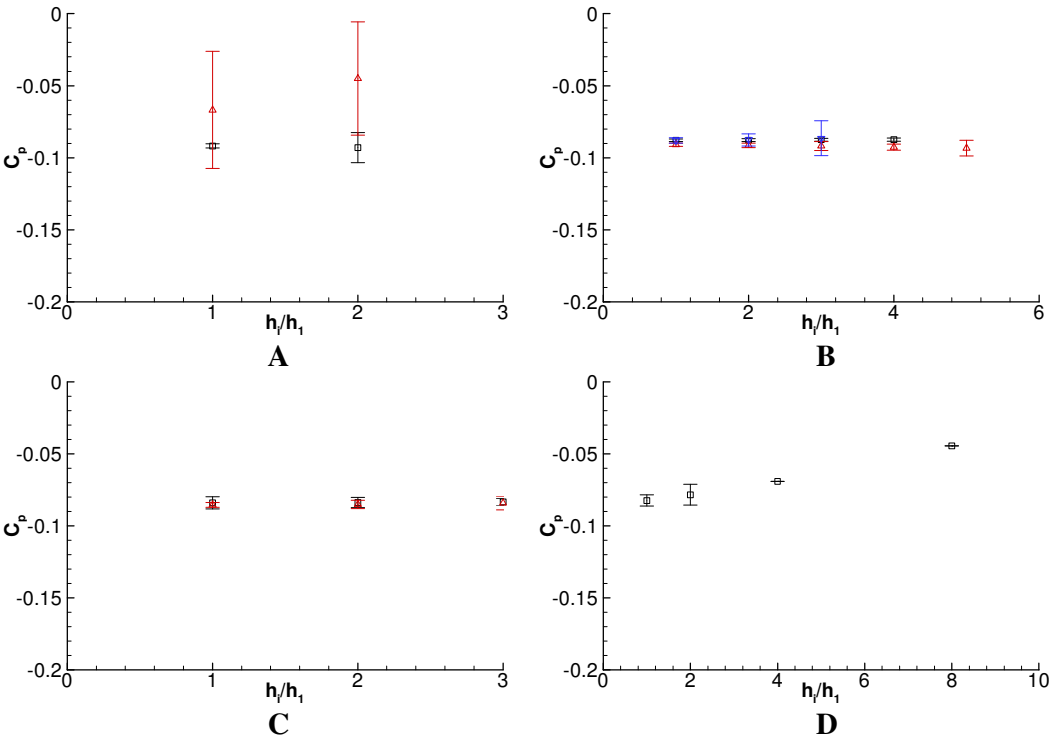
L

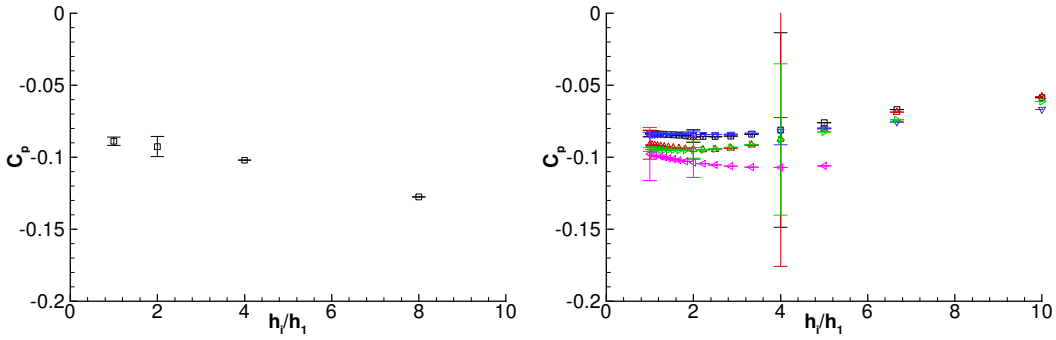
u_y velocity component at ***x=4h, y=0.1h***





Cp pressure coefficient at ***x=4h, y=0.1h***

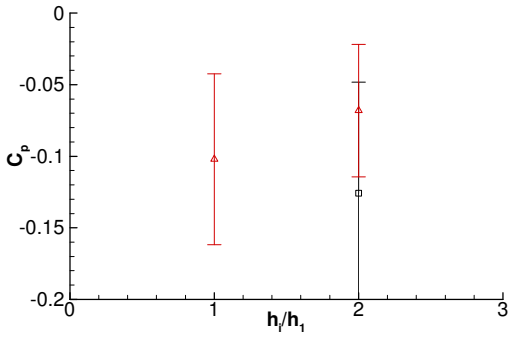



0
-0.05
-0.1
-0.15
-0.2
C_p
0
2
4
6
8
10
h_i/h_1

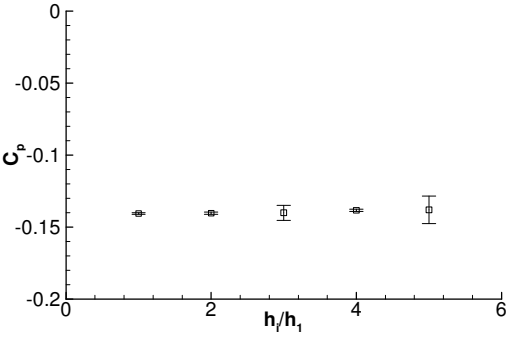
E

0
-0.05
-0.1
-0.15
-0.2
C_p
0
2
4
6
8
10
h_i/h_1

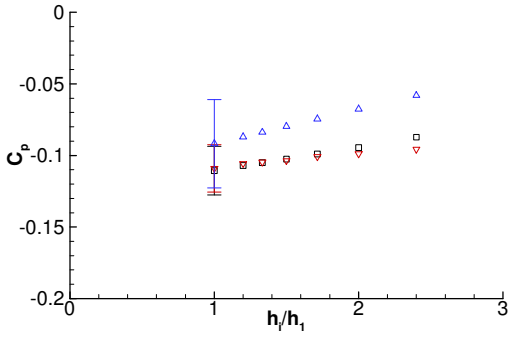
F


0
-0.05
-0.1
-0.15
-0.2
C_p
0
1
2
3
h_i/h_1

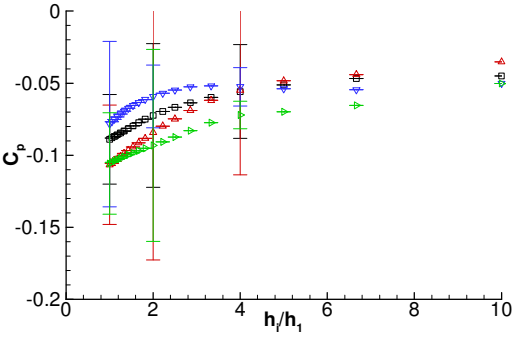
G


0
-0.05
-0.1
-0.15
-0.2
C_p
0
2
4
6
h_i/h_1

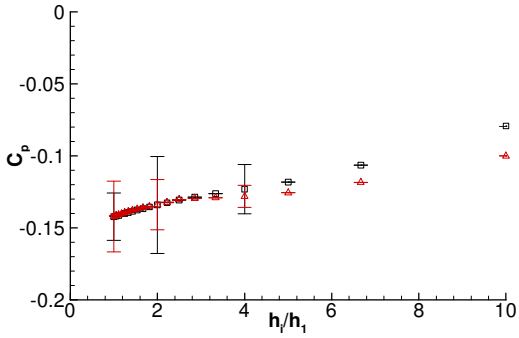
H


0
-0.05
-0.1
-0.15
-0.2
C_p
0
1
2
3
h_i/h_1

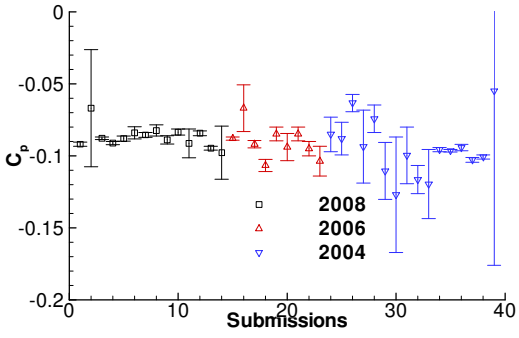
I


0
-0.05
-0.1
-0.15
-0.2
C_p
0
2
4
6
8
10
h_i/h_1

J

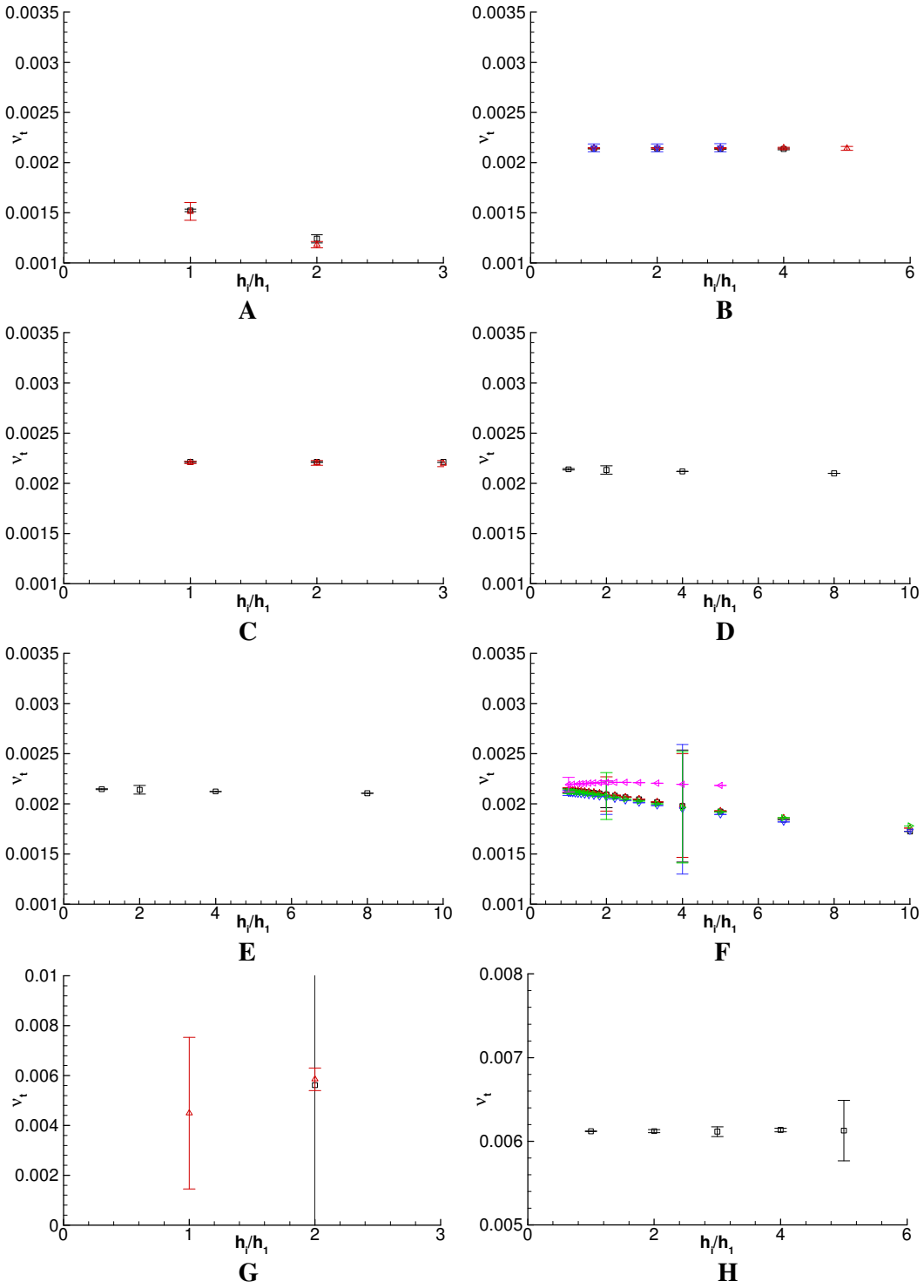

0
-0.05
-0.1
-0.15
-0.2
C_p
0
2
4
6
8
10
h_i/h_1

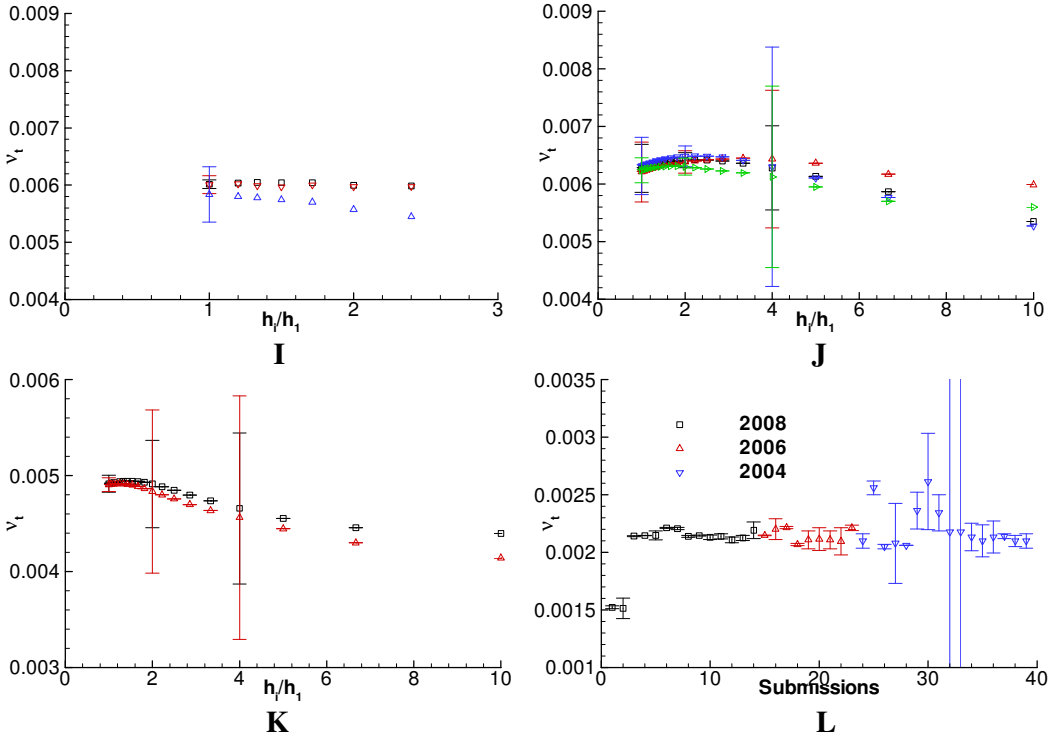
K


0
-0.05
-0.1
-0.15
-0.2
C_p
2008
2006
2004
0
10
20
30
40
Submissions

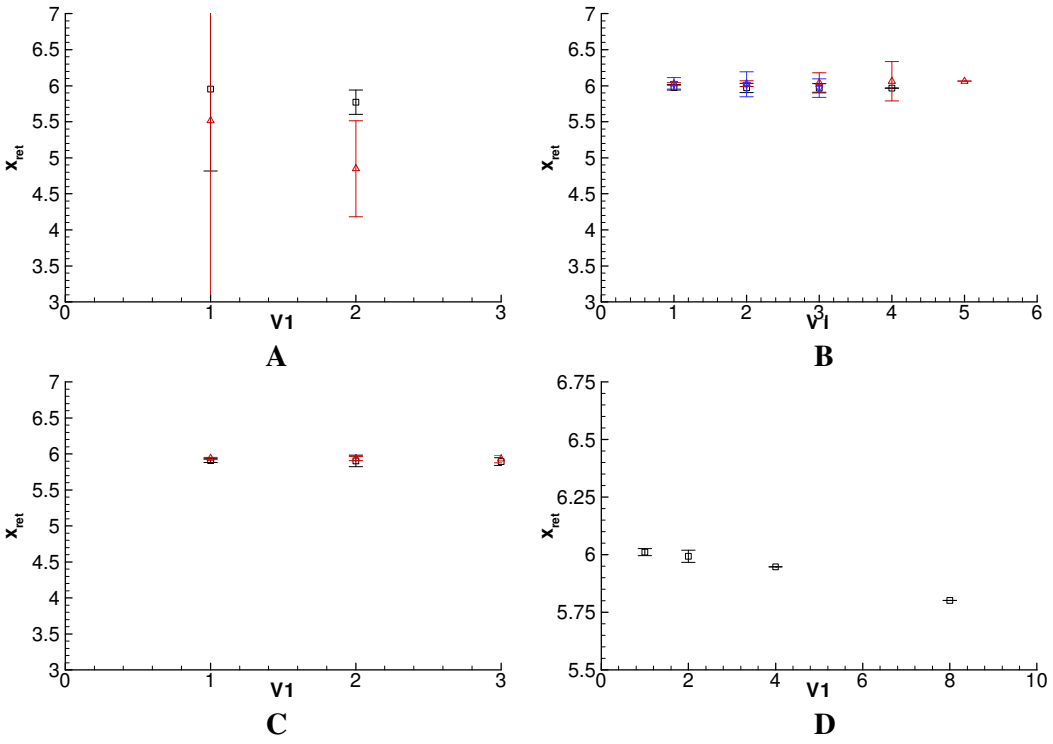
L

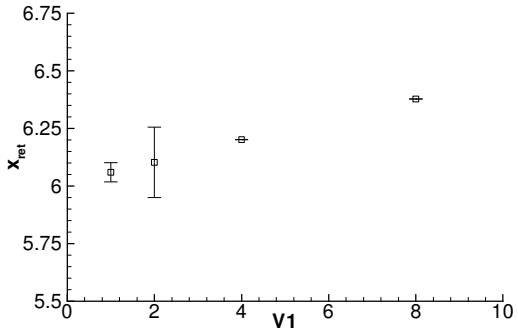
ν_t eddy viscosity at ***x=4h, y=0.1h***



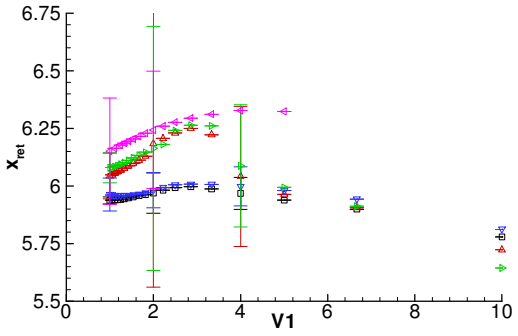


Re-attachment point

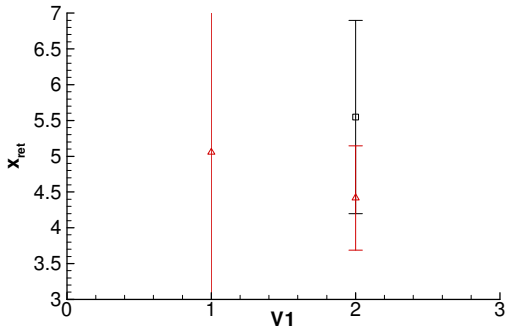



6.75
6.5
6.25
6
5.75
5.5
x_{ret}
0
2
4
6
8
10
V1

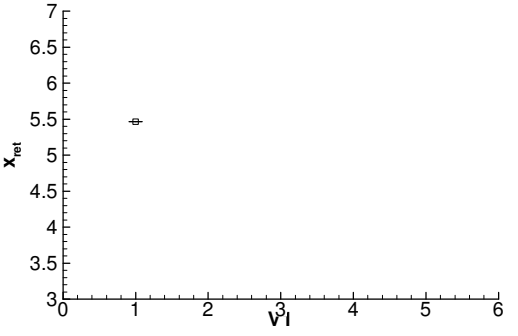
E


6.75
6.5
6.25
6
5.75
5.5
x_{ret}
0
2
4
6
8
10
V1

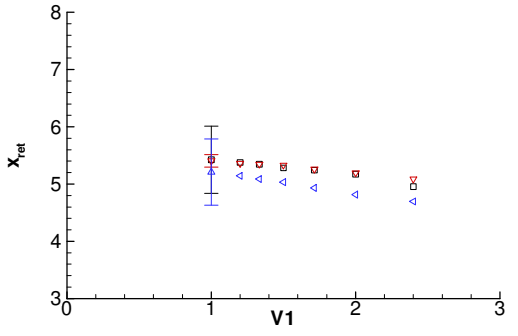
F


7
6.5
6
5.5
5
4.5
4
3.5
3
x_{ret}
0
1
2
3
V1

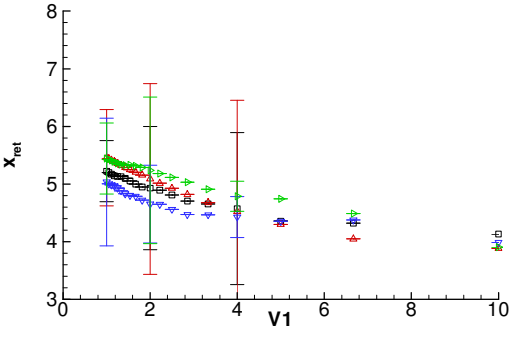
G


7
6.5
6
5.5
5
4.5
4
3.5
3
x_{ret}
0
1
2
3
4
5
6
V1

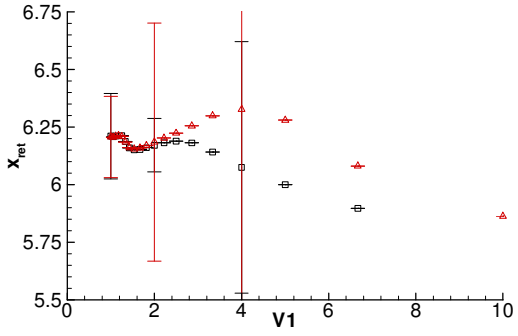
H


8
7
6
5
4
3
x_{ret}
0
1
2
3
V1

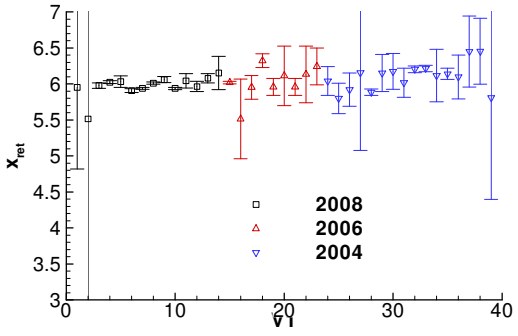
I


8
7
6
5
4
3
x_{ret}
0
2
4
6
8
10
V1

J


6.75
6.5
6.25
6
5.75
5.5
x_{ret}
0
2
4
6
8
10
V1

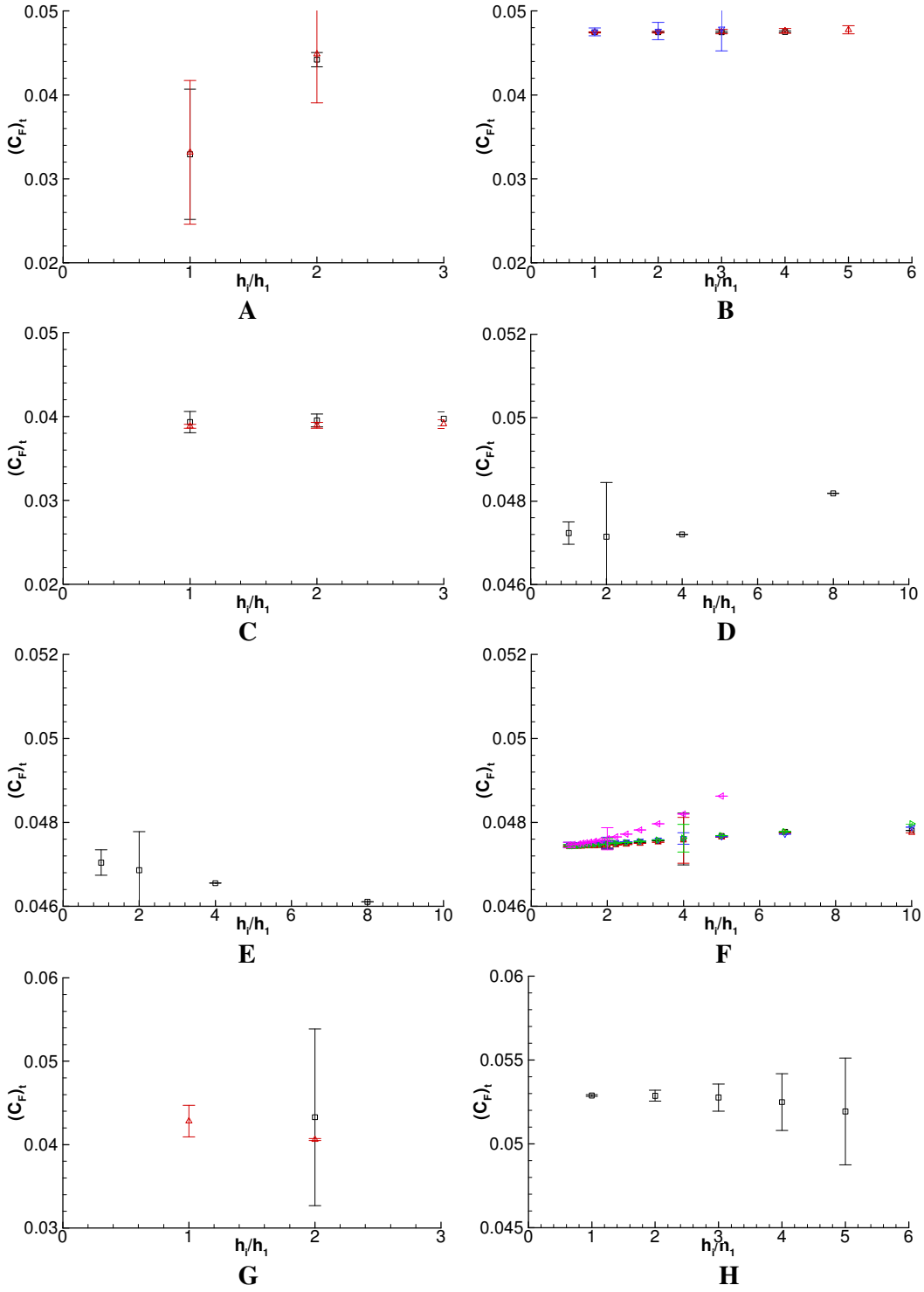
K

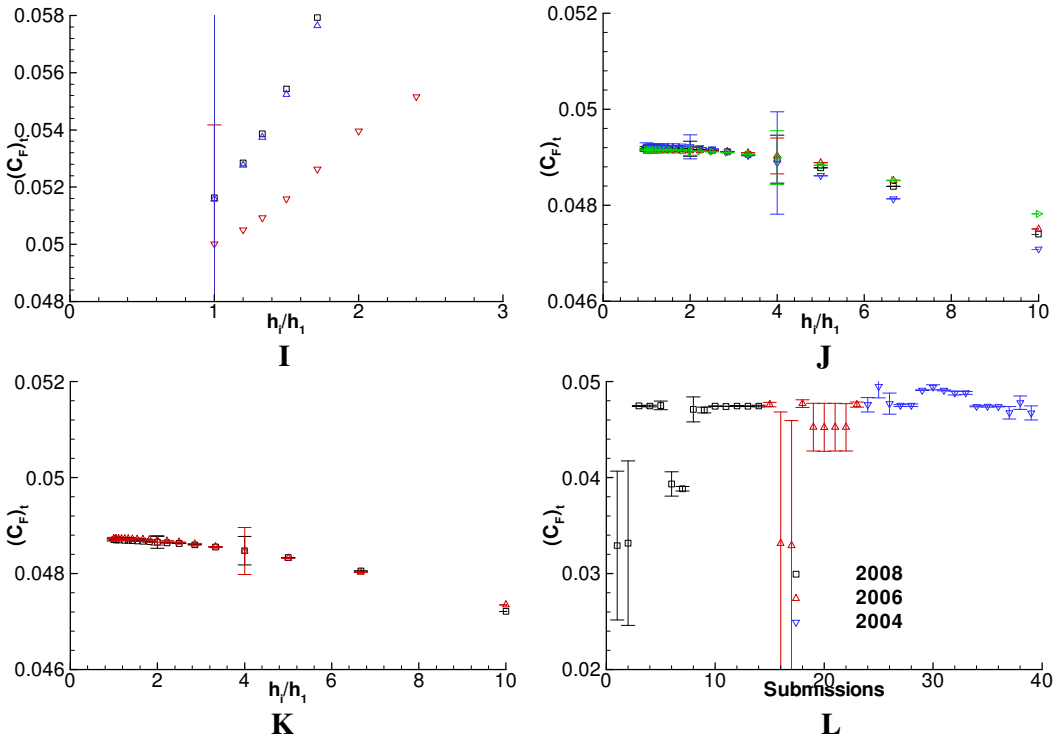

7
6.5
6
5.5
5
4.5
4
3.5
3
x_{ret}
0
10
20
30
40
V1
2008
2006
2004

L

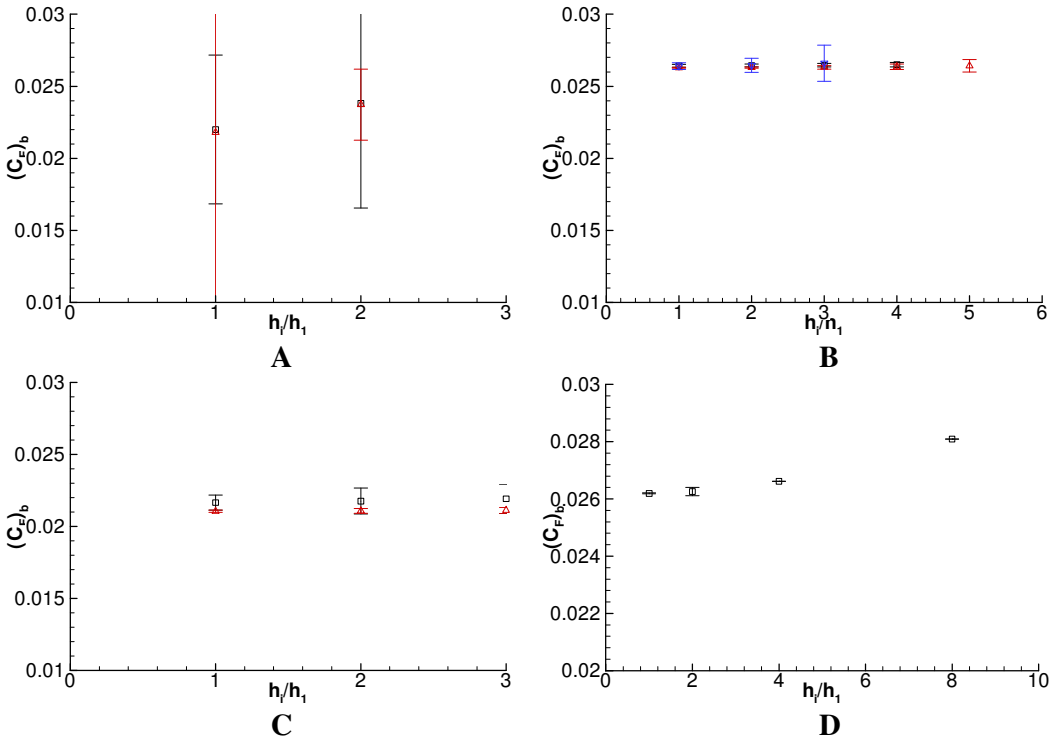
e) Integral flow quantities

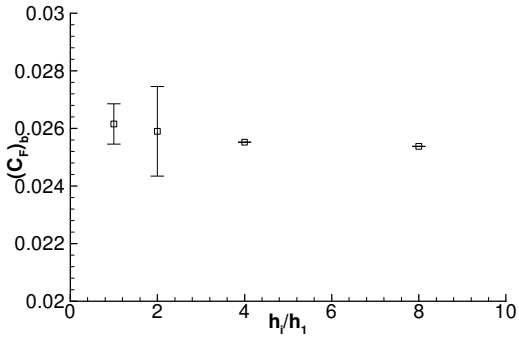
Friction resistance of the top wall



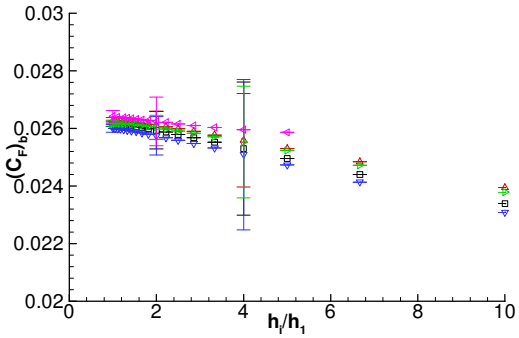


Friction resistance of the bottom wall

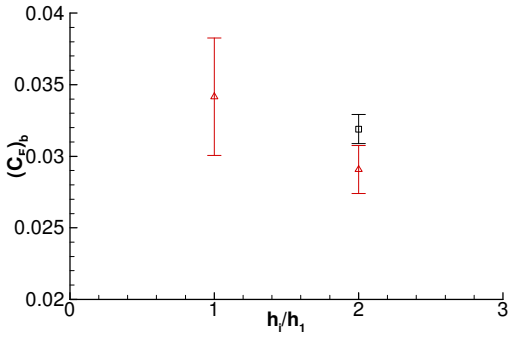



0.03
0.028
0.026
0.024
0.022
0.02
$(C_F)_b$
0
2
4
6
8
10
h_i/h_1

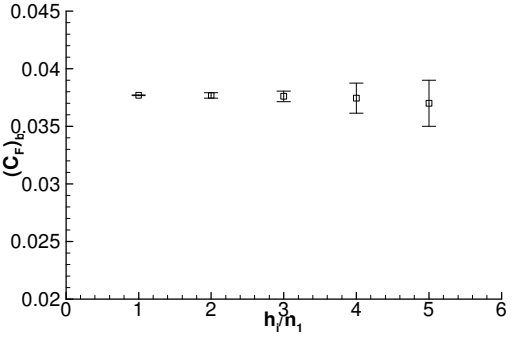
E


0.03
0.028
0.026
0.024
0.022
0.02
$(C_F)_b$
0
2
4
6
8
10
h_i/h_1

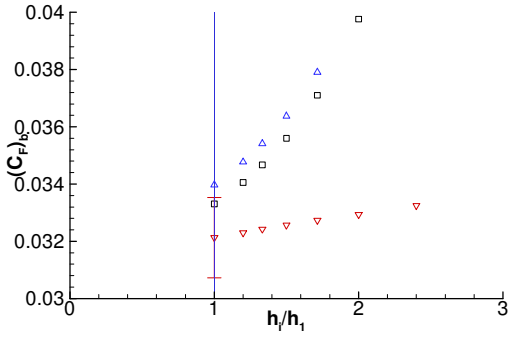
F


0.04
0.035
0.03
0.025
0.02
$(C_F)_b$
0
1
2
3
h_i/h_1

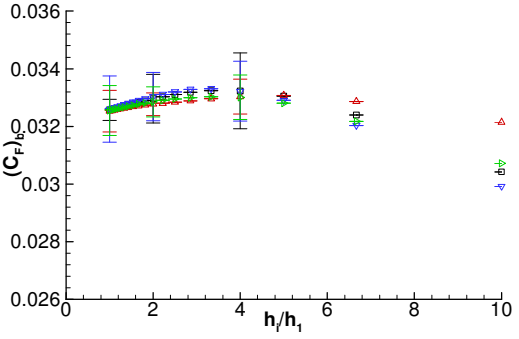
G


0.045
0.04
0.035
0.03
0.025
0.02
$(C_F)_b$
0
1
2
3
4
5
6
h_i/h_1

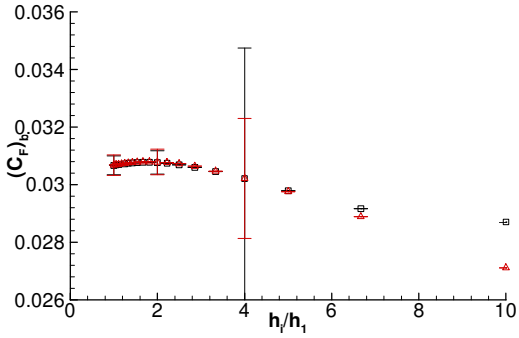
H


0.04
0.038
0.036
0.034
0.032
0.03
$(C_F)_b$
0
1
2
3
h_i/h_1

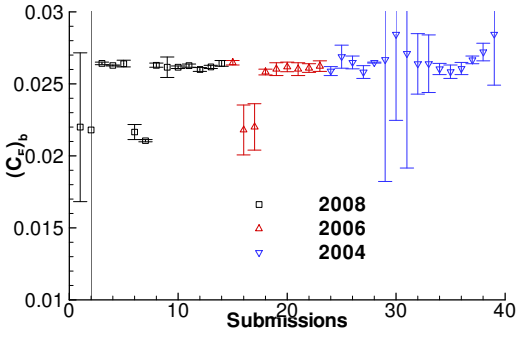
I


0.036
0.034
0.032
0.03
0.028
0.026
$(C_F)_b$
0
2
4
6
8
10
h_i/h_1

J

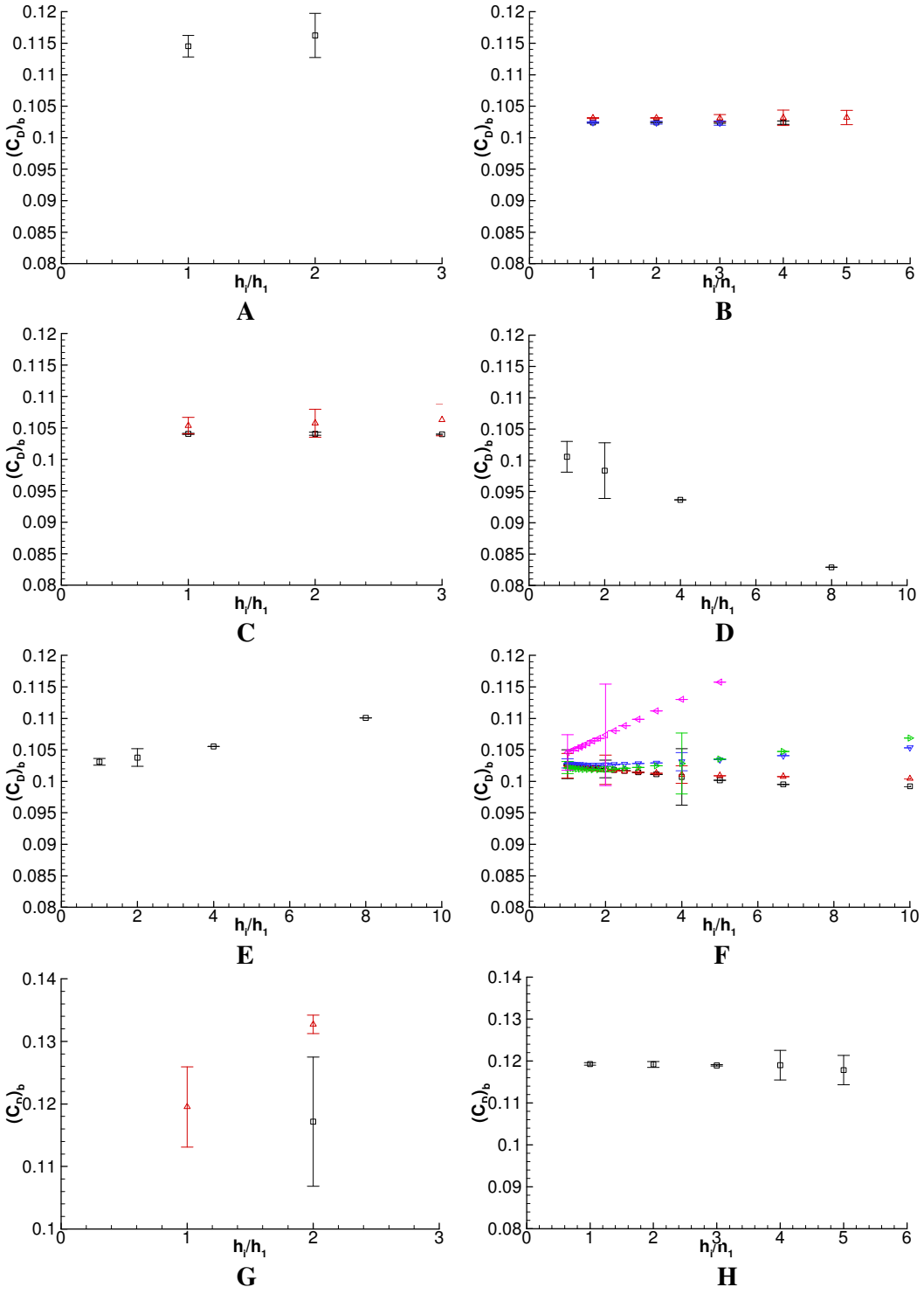

0.036
0.034
0.032
0.03
0.028
0.026
$(C_F)_b$
0
2
4
6
8
10
h_i/h_1

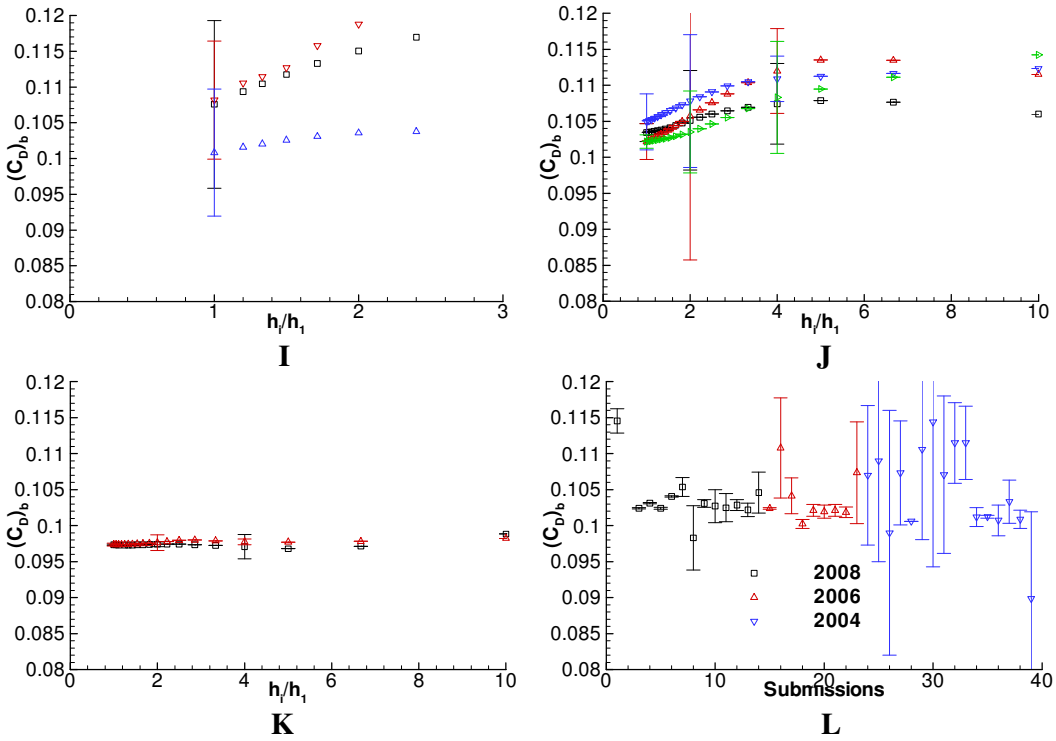
K


0.03
0.025
0.02
0.015
0.01
$(C_F)_b$
0
10
20
30
40
Submissions
2008
2006
2004

L

Pressure resistance of the (vertical part of) bottom wall




0.12
0.115
0.11
0.105
0.1
0.095
0.09
0.085
0.08
$(C_D)_b$
h_i/h_1
I
J
K
L
2008
2006
2004
Submissions