ERCOFTAC SIG15 TEST CASE
ベンチマーク報告

http://www.ercoftac.org/fileadmin/user_upload/bigfiles/sig15/database/index.html

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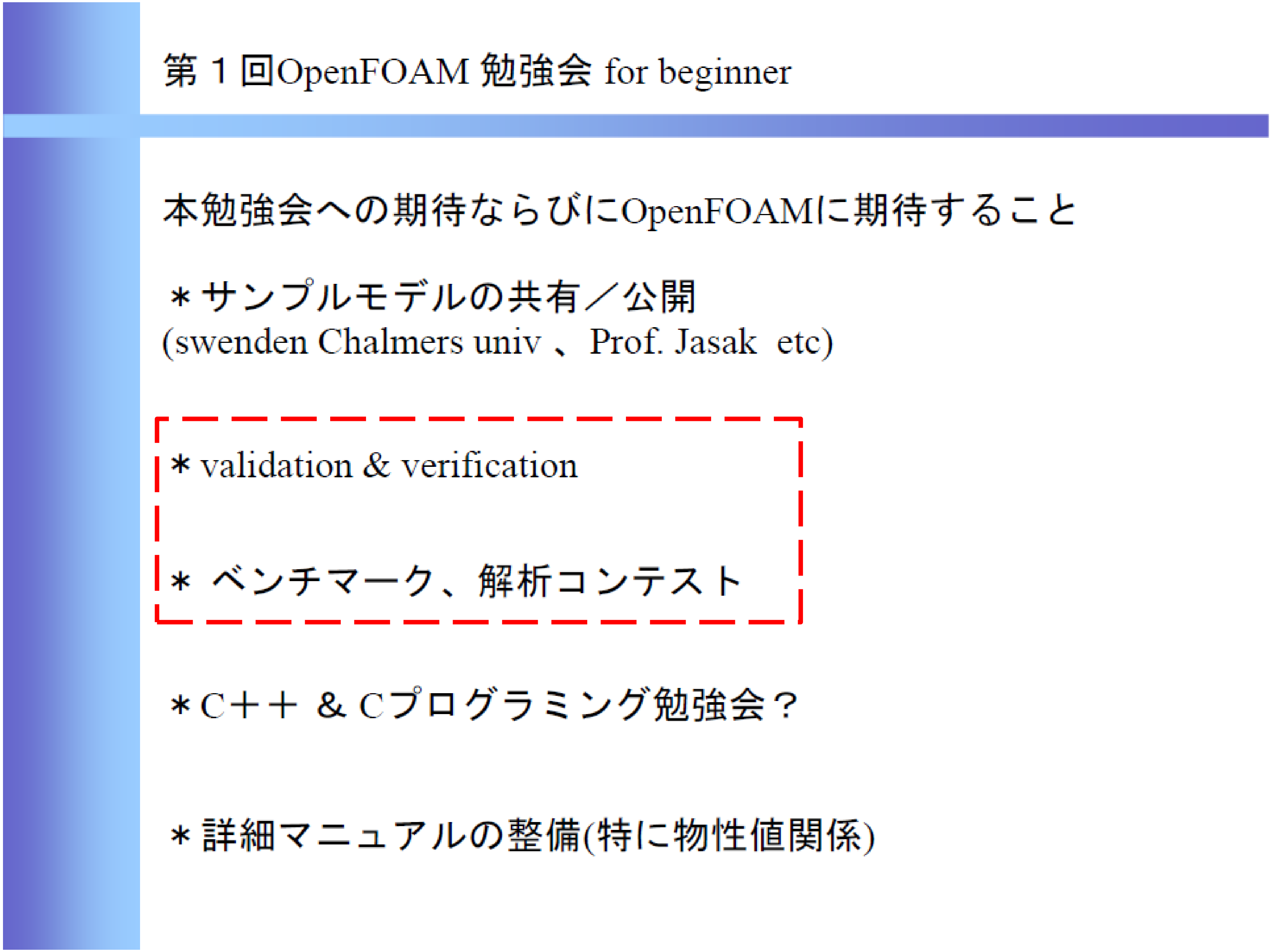
本報告のきっかけ・・・昨年の第1回初心者向け勉強会にて



第１回OpenFOAM 勉強会 for beginner

本勉強会への期待ならびにOpenFOAMに期待すること

＊サンプルモデルの共有／公開
(swenden Chalmers univ 、 Prof. Jasak etc)

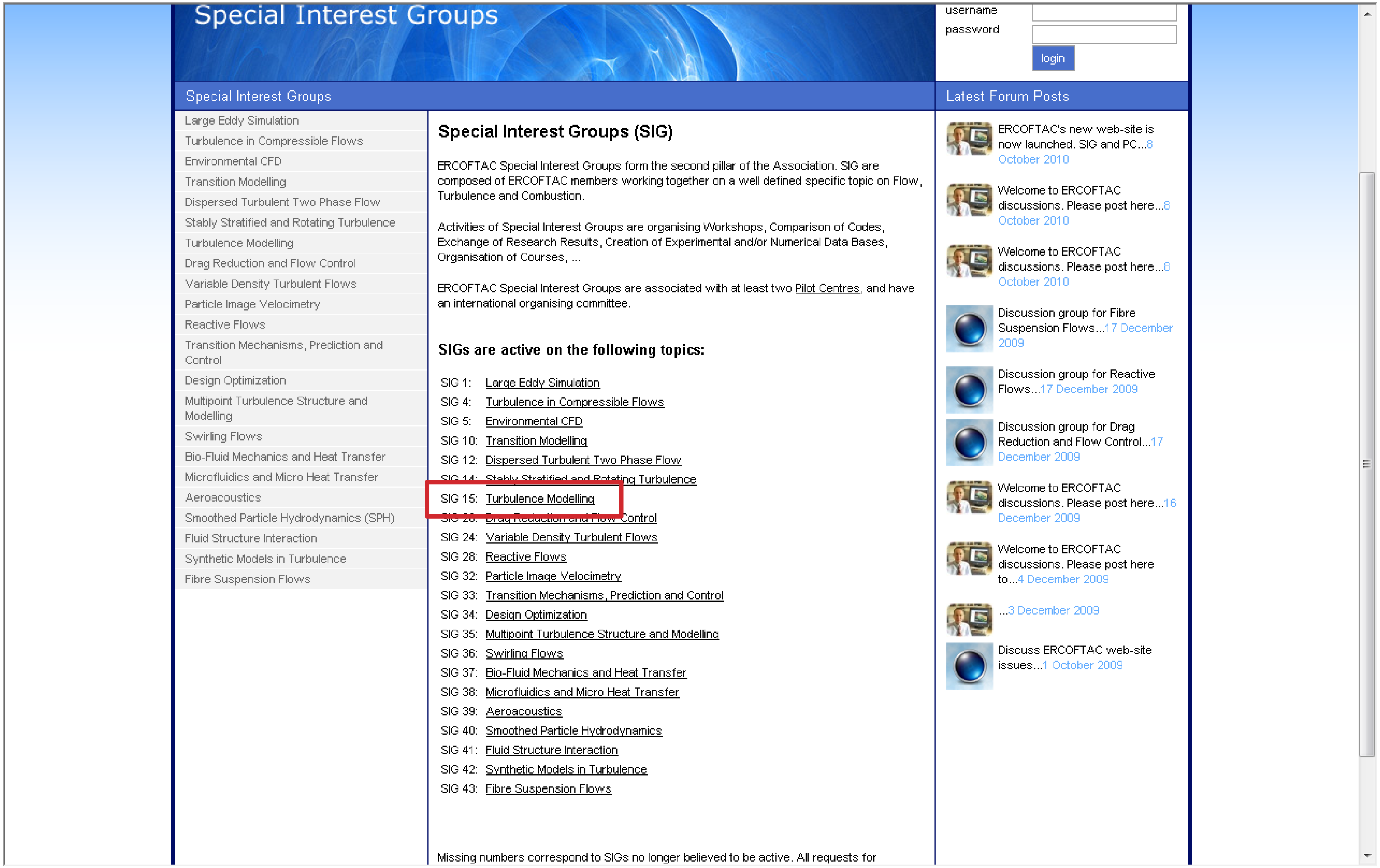
＊validation & verification

＊ ベンチマーク、解析コンテスト

＊C＋＋ ＆ Cプログラミング勉強会？

＊詳細マニュアルの整備(特に物性値関係)

ERCOFTAC(European Research Community of Flow, Turbulence and Combustion)
・・・テーマごとにグループ分けされていて、研究活動が行われている(燃焼・混相・粒子法etc)。
その中の乱流モデリングのグループ(SIG15)が過去に開催したworkshopにおいて実施されたベンチマークのデータベースがある（この他にマンチェスター大が管理するClassic版も→富原さん@関西）



- Large Eddy Simulation
- Turbulence in Compressible Flows
- Environmental CFD
- Transition Modelling
- Dispersed Turbulent Two Phase Flow
- Stably Stratified and Rotating Turbulence
- Turbulence Modelling
- Drag Reduction and Flow Control
- Variable Density Turbulent Flows
- Particle Image Velocimetry
- Reactive Flows
- Transition Mechanisms, Prediction and Control
- Design Optimization
- Multipoint Turbulence Structure and Modelling
- Swirling Flows
- Bio-Fluid Mechanics and Heat Transfer
- Microfluidics and Micro Heat Transfer
- Aeroacoustics
- Smoothed Particle Hydrodynamics (SPH)
- Fluid Structure Interaction
- Synthetic Models in Turbulence
- Fibre Suspension Flows

Special Interest Groups (SIG)

ERCOFTAC Special Interest Groups form the second pillar of the Association. SIG are composed of ERCOFTAC members working together on a well defined specific topic on Flow, Turbulence and Combustion.

Activities of Special Interest Groups are organising Workshops, Comparison of Codes, Exchange of Research Results, Creation of Experimental and/or Numerical Data Bases, Organisation of Courses, ...

ERCOFTAC Special Interest Groups are associated with at least two Pilot Centres, and have an international organising committee.

SIGs are active on the following topics:

SIG 1: Large Eddy Simulation
SIG 4: Turbulence in Compressible Flows
SIG 5: Environmental CFD
SIG 10: Transition Modelling
SIG 12: Dispersed Turbulent Two Phase Flow
SIG 14: Stably Stratified and Rotating Turbulence
SIG 15: Turbulence Modelling
SIG 20: Drag Reduction and Flow Control
SIG 24: Variable Density Turbulent Flows
SIG 28: Reactive Flows
SIG 32: Particle Image Velocimetry
SIG 33: Transition Mechanisms, Prediction and Control
SIG 34: Design Optimization
SIG 35: Multipoint Turbulence Structure and Modelling
SIG 36: Swirling Flows
SIG 37: Bio-Fluid Mechanics and Heat Transfer
SIG 38: Microfluidics and Micro Heat Transfer
SIG 39: Aeroacoustics
SIG 40: Smoothed Particle Hydrodynamics
SIG 41: Fluid Structure Interaction
SIG 42: Synthetic Models in Turbulence
SIG 43: Fibre Suspension Flows

Missing numbers correspond to SIGs no longer believed to be active. All requests for

ERCOFTAC's new web-site is now launched. SIG and PC...8 October 2010

Welcome to ERCOFTAC discussions. Please post here...8 October 2010

Welcome to ERCOFTAC discussions. Please post here...8 October 2010

Discussion group for Fibre Suspension Flows...17 December 2009

Discussion group for Reactive Flows...17 December 2009

Discussion group for Drag Reduction and Flow Control...17 December 2009

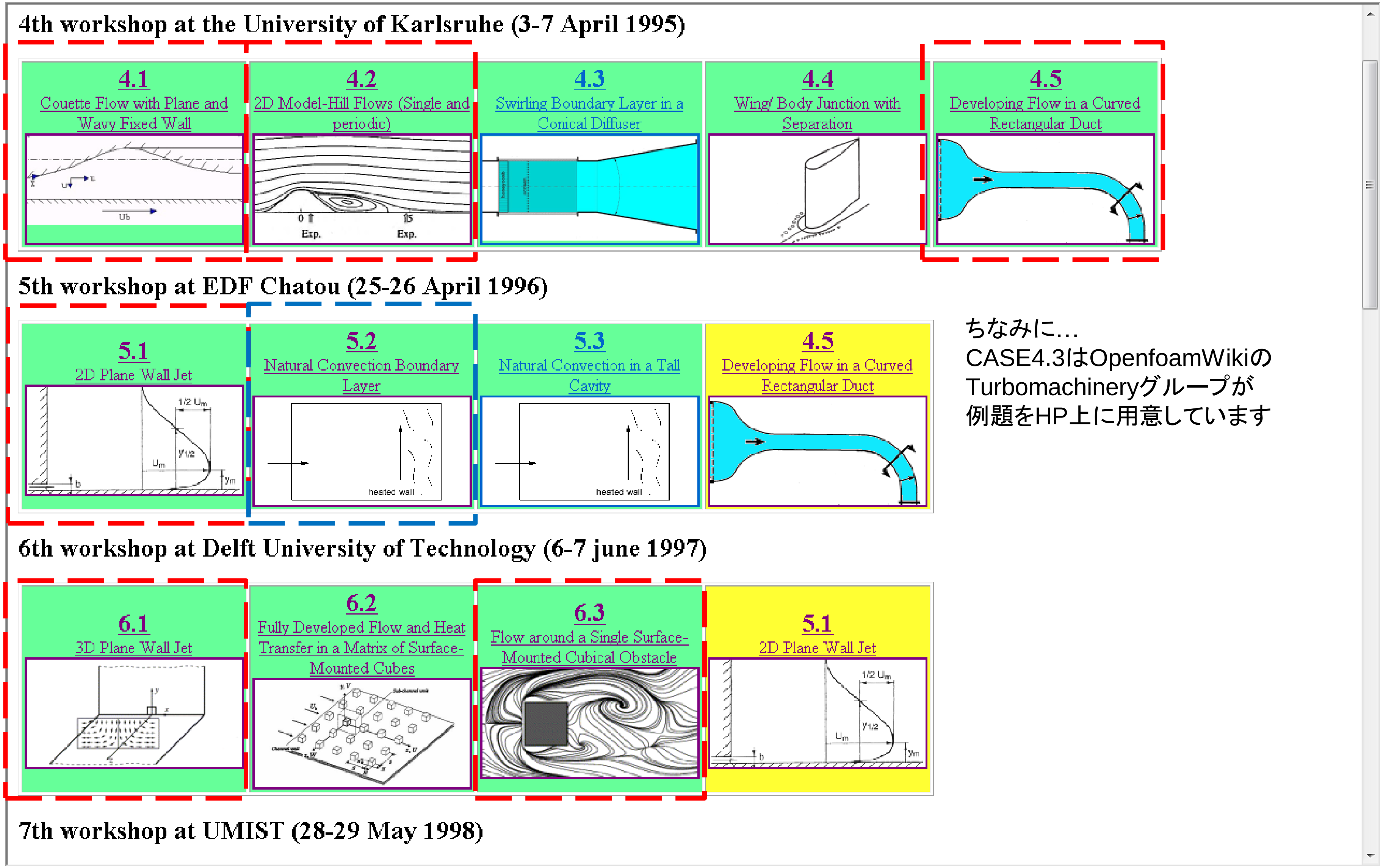
Welcome to ERCOFTAC discussions. Please post here...16 December 2009

Welcome to ERCOFTAC discussions. Please post here to...4 December 2009

...3 December 2009

Discuss ERCOFTAC web-site issues...1 October 2009

とりあえず、ケースファイル作りに精を出しており、検証はあまり進まず（赤線枠内が解析済み）
以下は**4TH WORKSHOP**から**6TH WORKSHOP**まで、このぐらいまでは割と基礎的な流れがメイン
青枠のケースは機能改良が必要だったり、境界条件がよくわかってなくて、不完全なものです



4th workshop at the University of Karlsruhe (3-7 April 1995)

4.1	4.2	4.3	4.4	4.5
Couette Flow with Plane and Wavy Fixed Wall	2D Model-Hill Flows (Single and periodic)	Swirling Boundary Layer in a Conical Diffuser	Wing/ Body Junction with Separation	Developing Flow in a Curved Rectangular Duct

5th workshop at EDF Chatou (25-26 April 1996)

5.1	5.2	5.3	4.5
2D Plane Wall Jet	Natural Convection Boundary Layer	Natural Convection in a Tall Cavity	Developing Flow in a Curved Rectangular Duct

6th workshop at Delft University of Technology (6-7 june 1997)

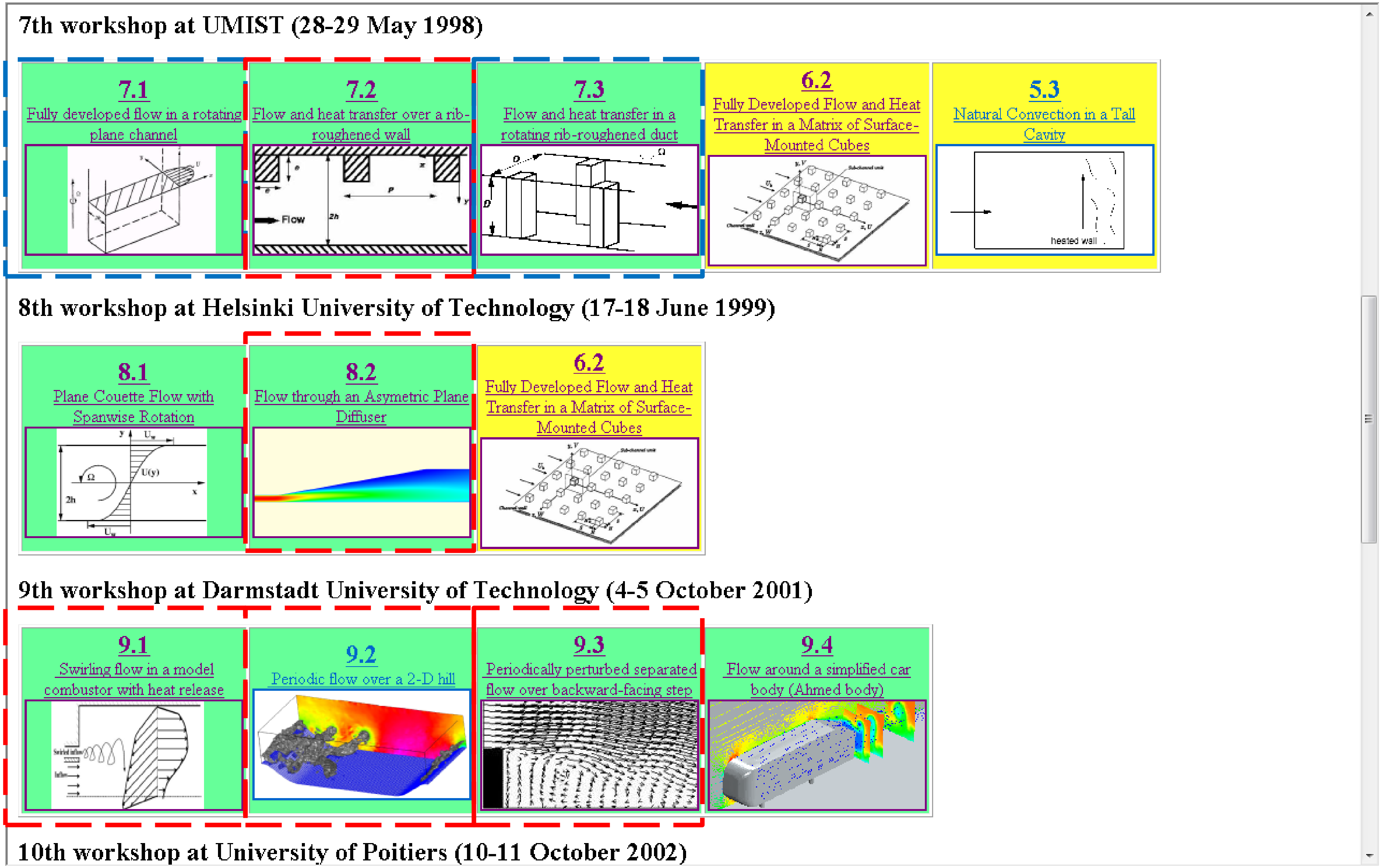
6.1	6.2	6.3	5.1
3D Plane Wall Jet	Fully Developed Flow and Heat Transfer in a Matrix of Surface-Mounted Cubes	Flow around a Single Surface-Mounted Cubical Obstacle	2D Plane Wall Jet

7th workshop at UMIST (28-29 May 1998)

ちなみに…
CASE4.3はOpenfoamWikiの
Turbomachineryグループが
例題をHP上に用意しています

以前までは流れ方向周期境界条件のモデリングがうまくいかず（**CASE6.2,7.2, 7.3, 9.2**など）

→掲示板で大渕様･高木先生に色々ご教授して頂き、最終的に今野先生に頂いたモジュールで解析は一応完了



7th workshop at UMIST (28-29 May 1998)

7.1 Fully developed flow in a rotating plane channel

7.2 Flow and heat transfer over a rib-roughened wall

7.3 Flow and heat transfer in a rotating rib-roughened duct

6.2 Fully Developed Flow and Heat Transfer in a Matrix of Surface-Mounted Cubes

5.3 Natural Convection in a Tall Cavity

8th workshop at Helsinki University of Technology (17-18 June 1999)

8.1 Plane Couette Flow with Spanwise Rotation

8.2 Flow through an Asymetric Plane Diffuser

6.2 Fully Developed Flow and Heat Transfer in a Matrix of Surface-Mounted Cubes

9th workshop at Darmstadt University of Technology (4-5 October 2001)

9.1 Swirling flow in a model combustor with heat release

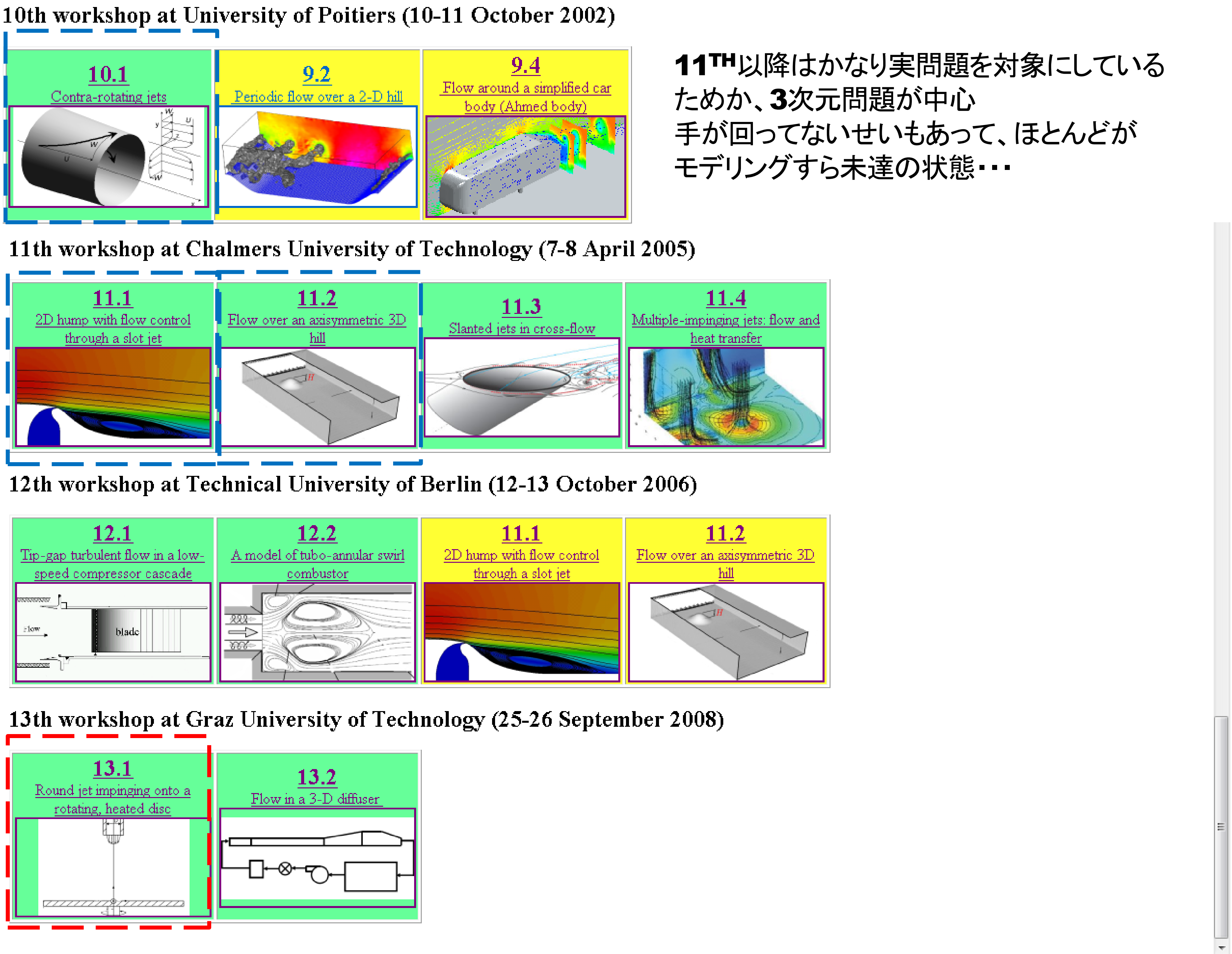
9.2 Periodic flow over a 2-D hill

9.3 Periodically perturbed separated flow over backward-facing step

9.4 Flow around a simplified car body (Ahmed body)

10th workshop at University of Poitiers (10-11 October 2002)

11TH以降はかなり実問題を対象にしているためか、3次元問題が中心
手が回ってないせいもあって、ほとんどがモデリングすら未達の状態・・・



10th workshop at University of Poitiers (10-11 October 2002)

10.1 Contra-rotating jets

9.2 Periodic flow over a 2-D hill

9.4 Flow around a simplified car body (Ahmed body)

11th workshop at Chalmers University of Technology (7-8 April 2005)

11.1 2D hump with flow control through a slot jet

11.2 Flow over an axisymmetric 3D hill

11.3 Slanted jets in cross-flow

11.4 Multiple-impinging jets: flow and heat transfer

12th workshop at Technical University of Berlin (12-13 October 2006)

12.1 Tip-gap turbulent flow in a low-speed compressor cascade

12.2 A model of tubo-annular swirl combustor

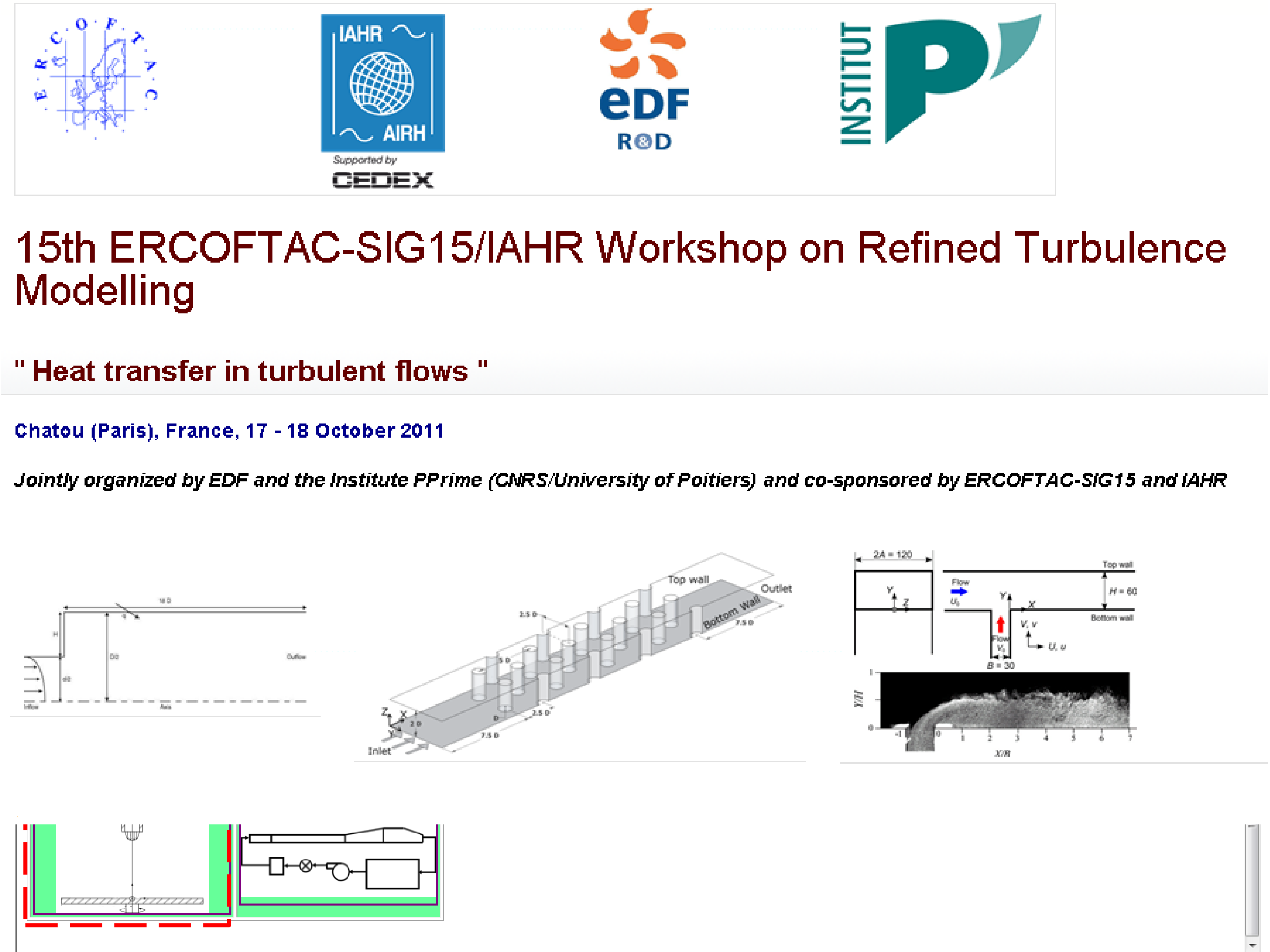
11.1 2D hump with flow control through a slot jet

11.2 Flow over an axisymmetric 3D hill

13th workshop at Graz University of Technology (25-26 September 2008)

13.1 Round jet impinging onto a rotating, heated disc

13.2 Flow in a 3-D diffuser



15th ERCOFTAC-SIG15/IAHR Workshop on Refined Turbulence Modelling

" Heat transfer in turbulent flows "

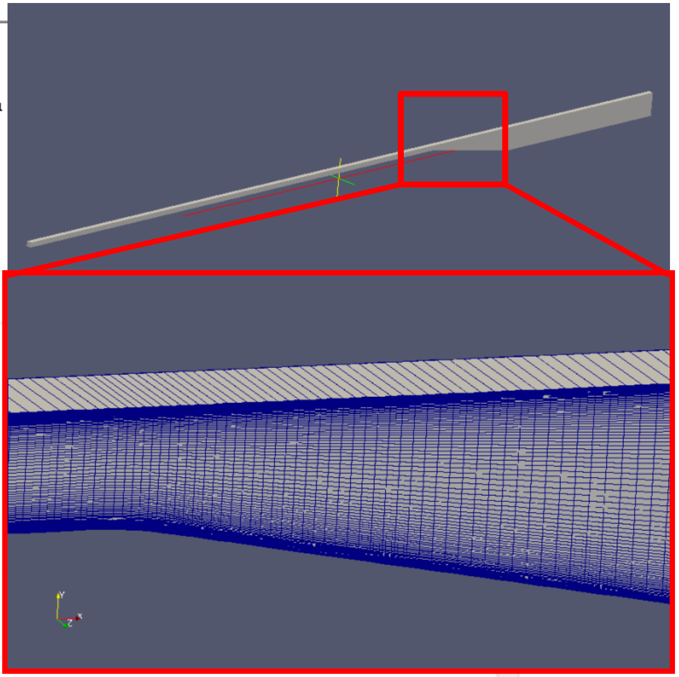
Chatou (Paris), France, 17 - 18 October 2011

Jointly organized by EDF and the Institute PPrime (CNRS/University of Poitiers) and co-sponsored by ERCOFTAC-SIG15 and IAHR

Top wall
Outlet
Bottom Wall
Inlet
2A = 120
Flow
Top wall
H = 60
Bottom wall
B = 30
Y/H
X/B

解析例1

CASE 8.2: FLOW THROUGH AN ASYMMETRIC PLANE DIFFUSER



Diffuser geometry:

The *x*- and *y*-axes are taken in the streamwise and straight-wall normal directions, respectively. The origin of the *x*-axis is located at the intersection
axis originates from the bottom wall of the downstream channel. Figure 1 illustrates the configuration.

U_{in}=20 m/s
H=0.015 m
Re=20000

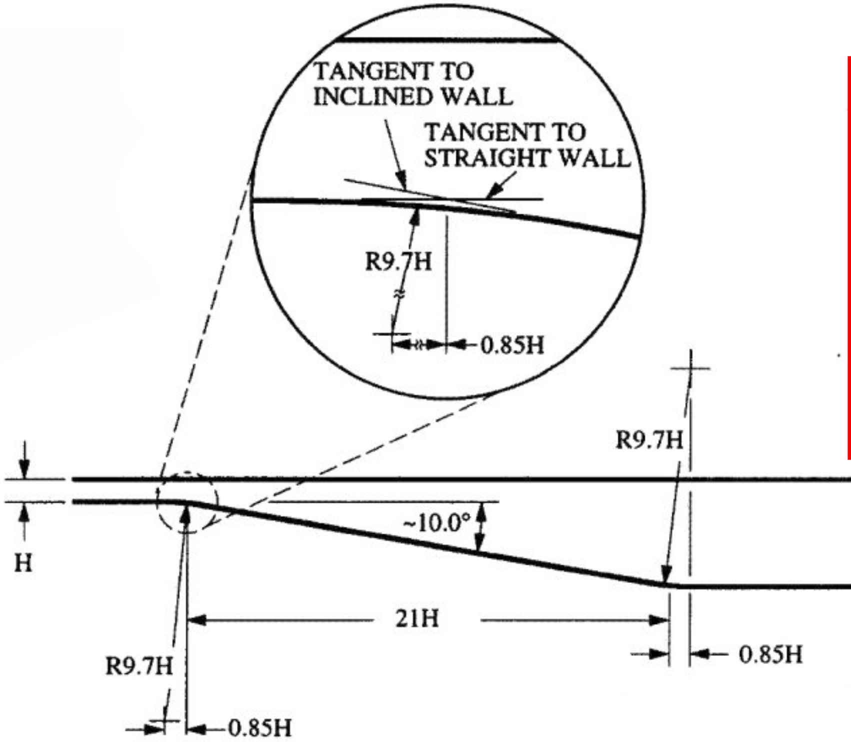

TANGENT TO INCLINED WALL
TANGENT TO STRAIGHT WALL
R9.7H
0.85H
R9.7H
~10.0°
H
4.7H
21H
0.85H
R9.7H
0.85H

Fig. 1. The geometrical description of the diffuser, from Buice and Eaton.

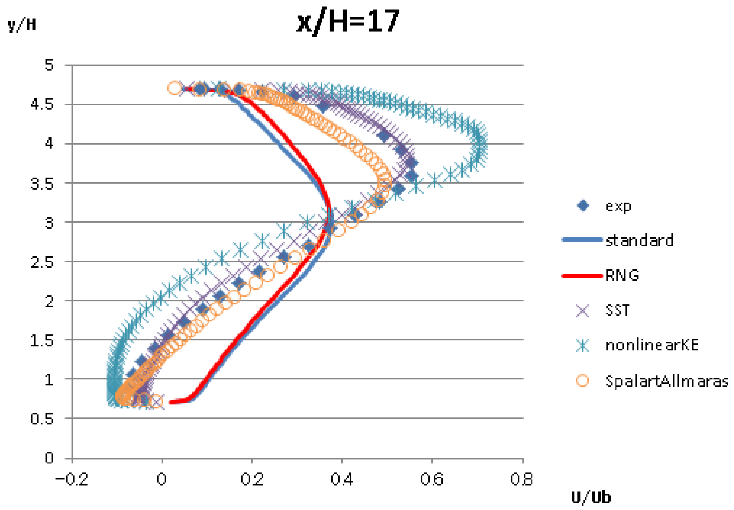
y^+≒1

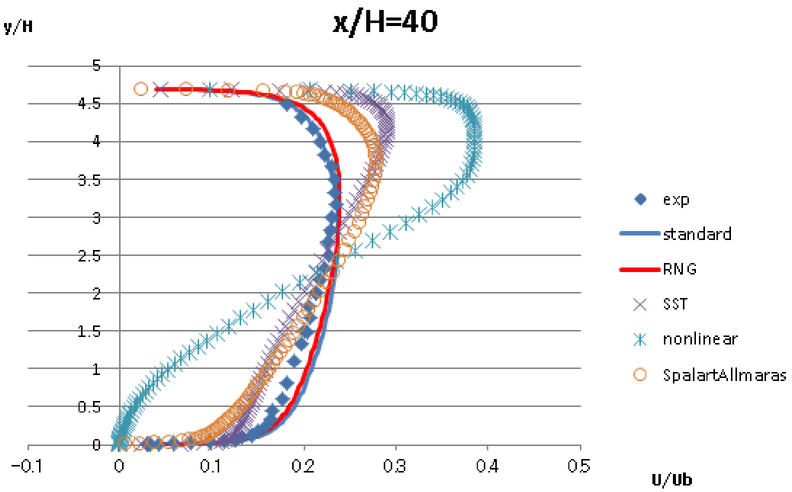
Instructions for Computers

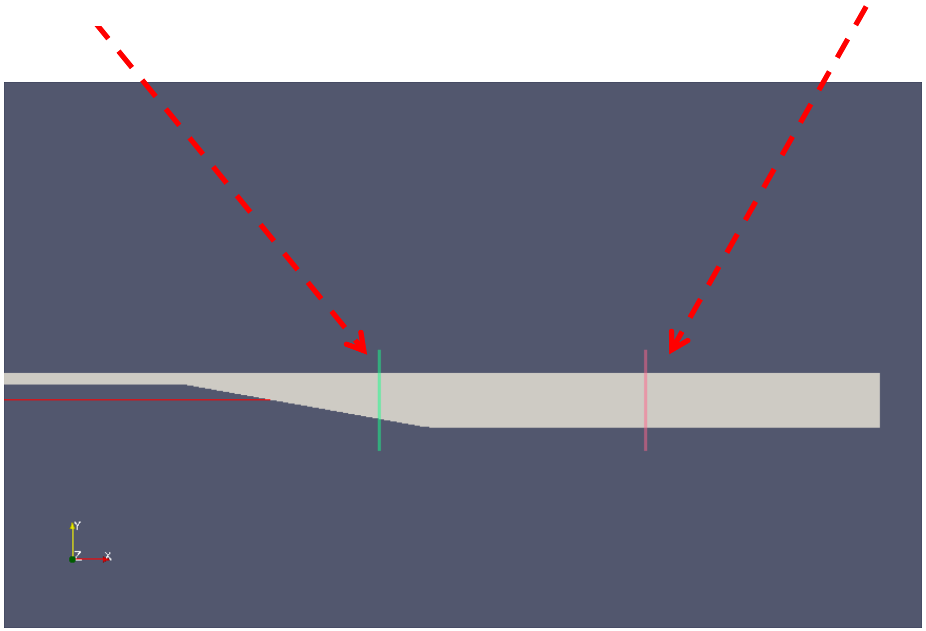
※メッシュは以下のページにあるものを流用（約30000cell)
http://cfd.mace.manchester.ac.uk/Saturne/WebHome

流速分布：斜面上は**SST**、**SA**が良好　→　逆に後流では標準、**RNG**が良好

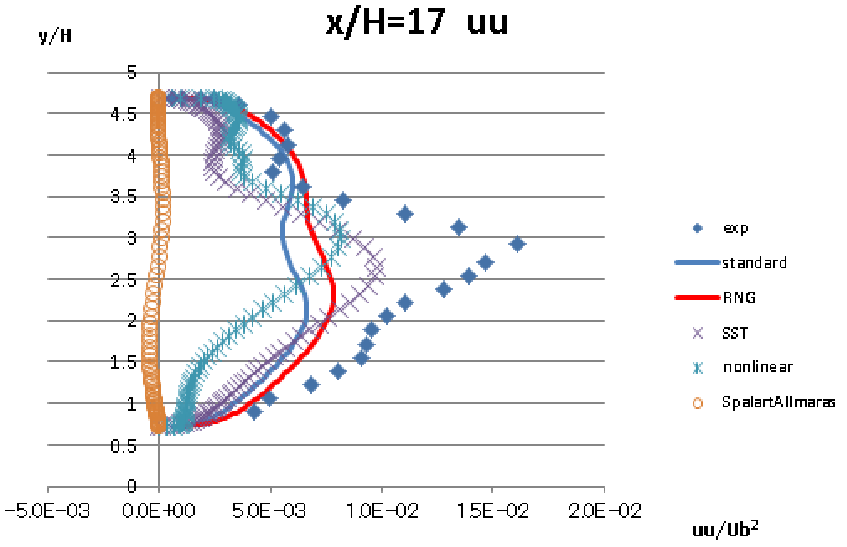
未収束**(**標準、**RNG**、**Shih)**、収束**(SST**、**SA)**した結果を比較するのに難がある･･･？

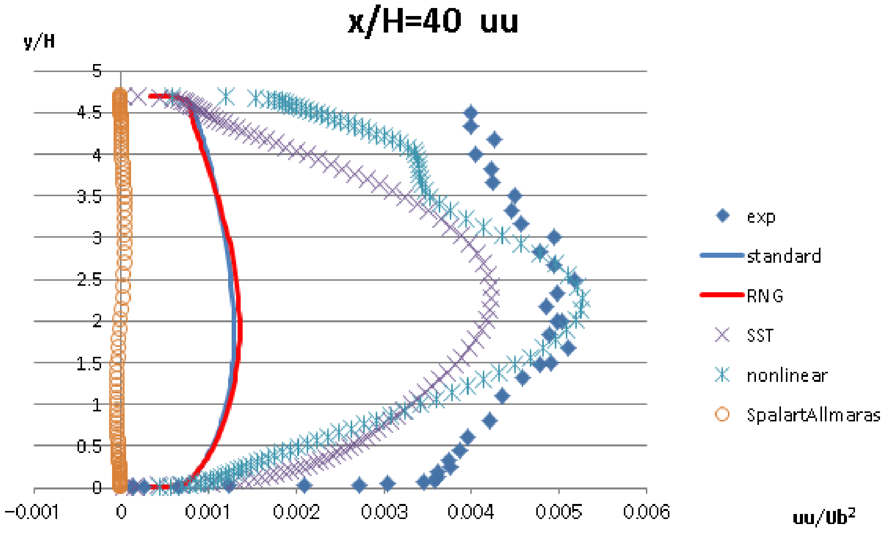


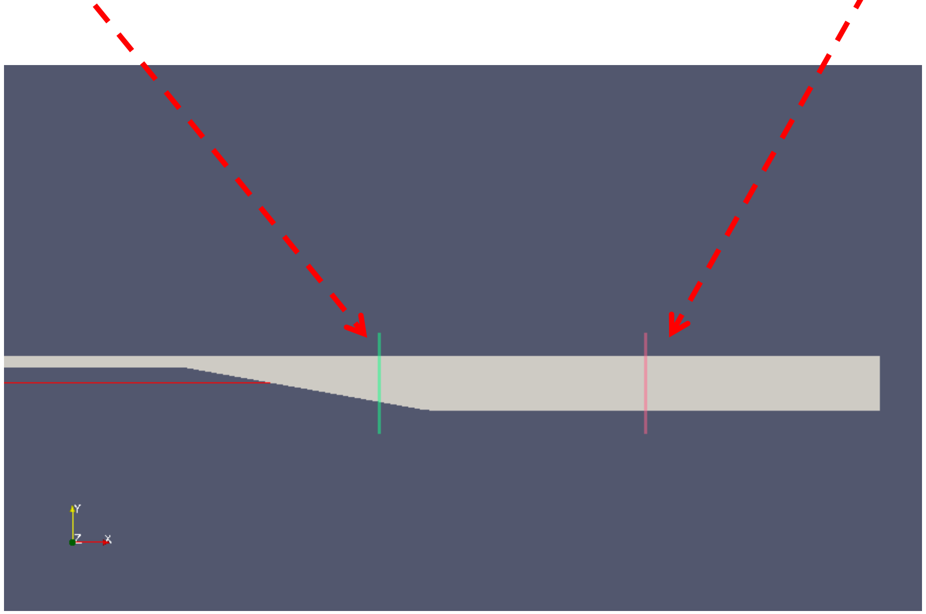




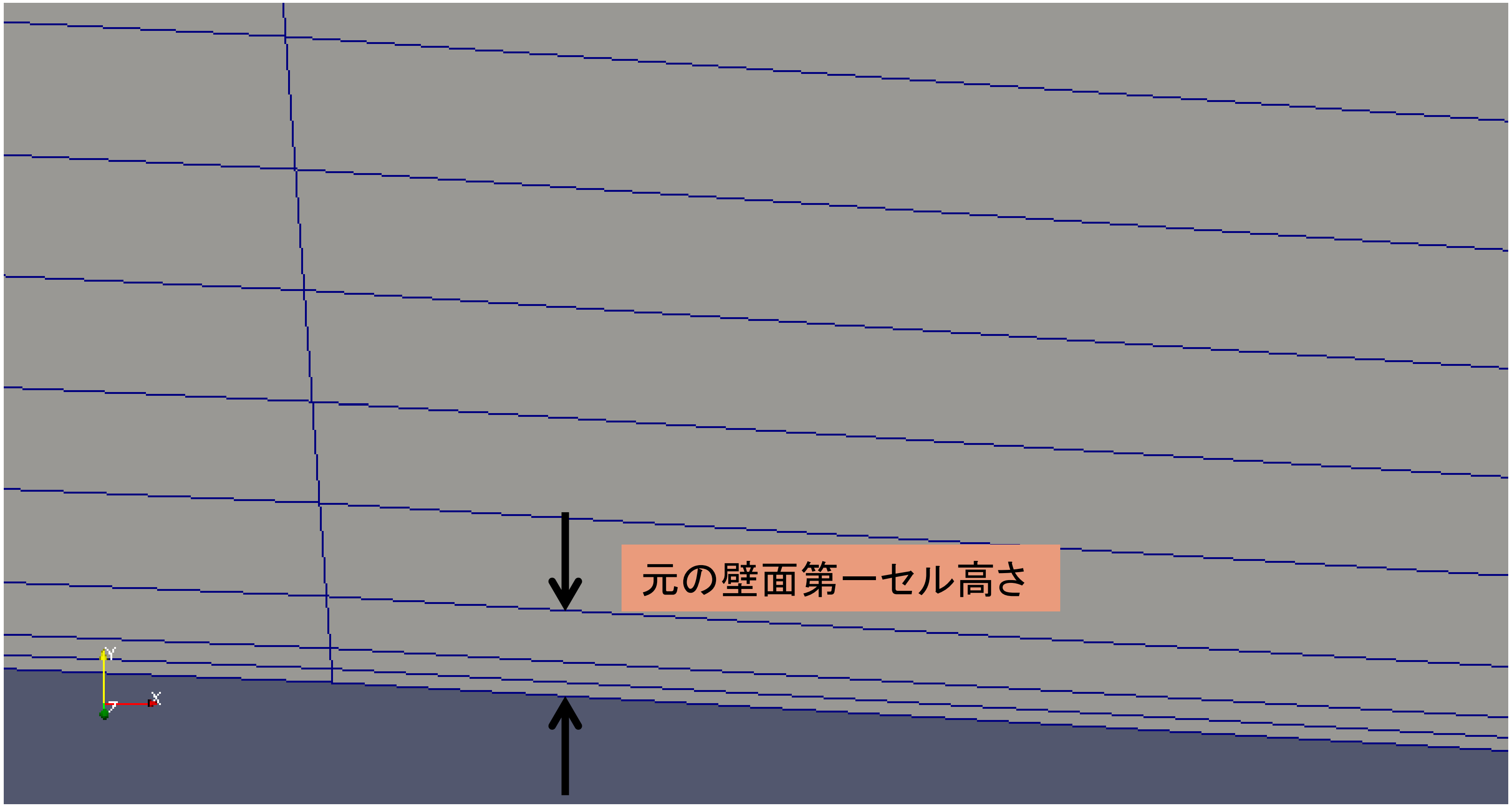
Re応力分布：いずれも定量的には合わず、**SA**はそもそも**NG**なのだろうか？





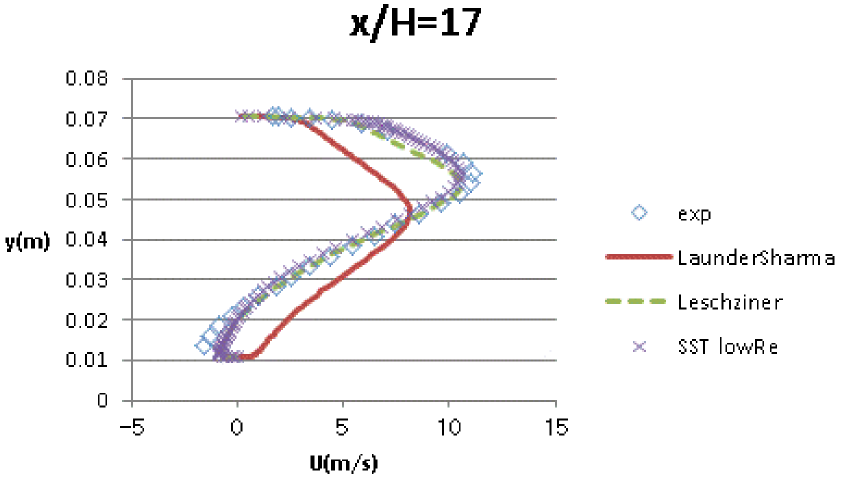


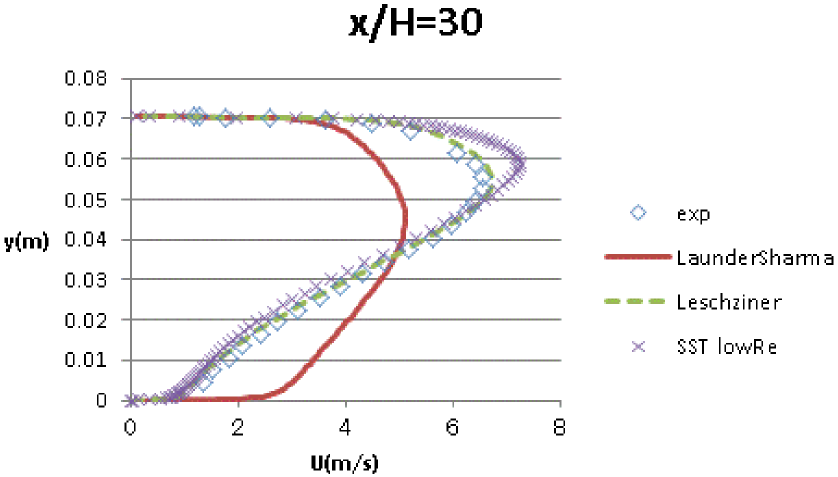
メッシュは高Reモデルで用いていたものの壁面第一セルを
RefineWallLayerでさらに3層に細分化
→yPlusは上下壁面とも、max0.3程度

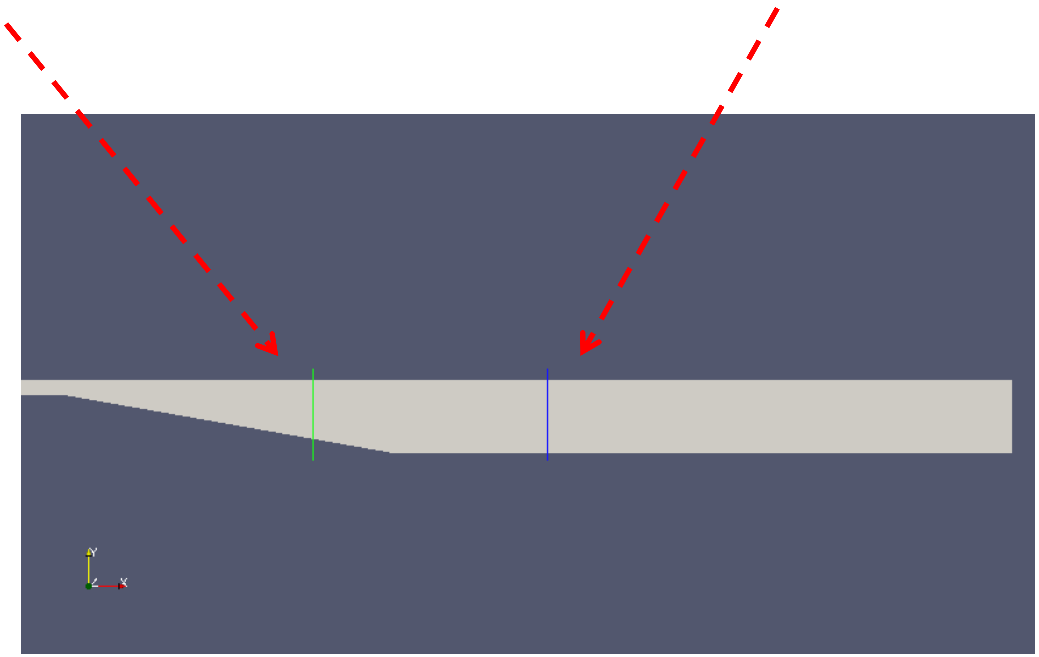


※低Re数モデル使用時にはyPlusRASでy+を計算できません
→CFD-onlineにあったplusPostRANSUtilityというツールを使っています
スレッド「y+ and u+ values with low-Re RANS turbulence models:utility+testcase」

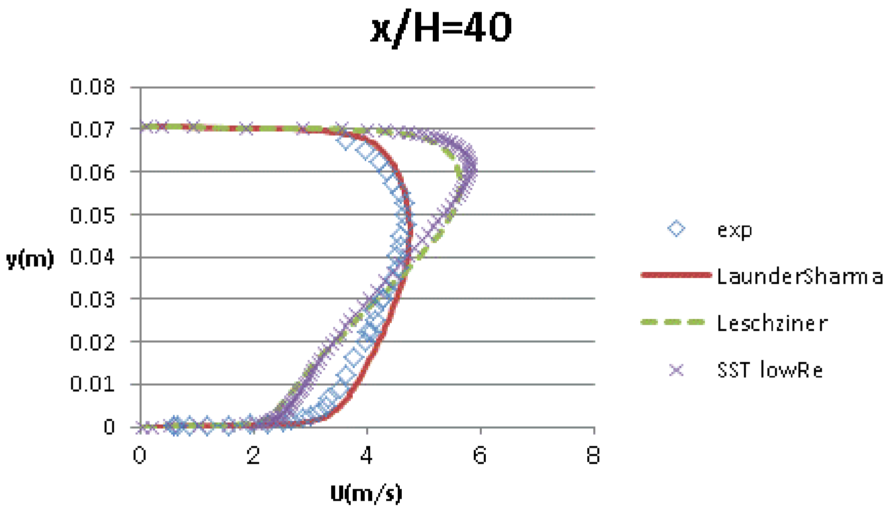
低レイノルズモデルによる流速分布（ここで示している3つのモデルはいずれも収束しています→**TOL1E-6**）
斜面上、及びその近傍は低レイノルズ数型SST、LIEN-LESCHZINERモデル良好

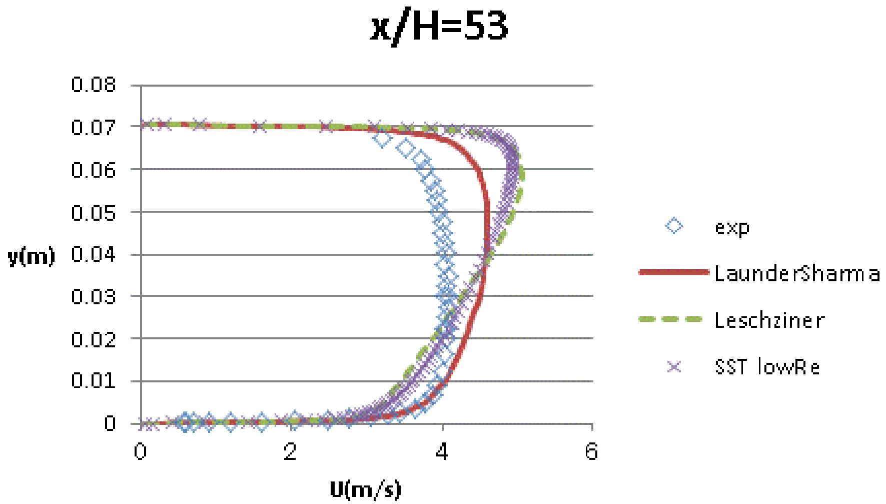


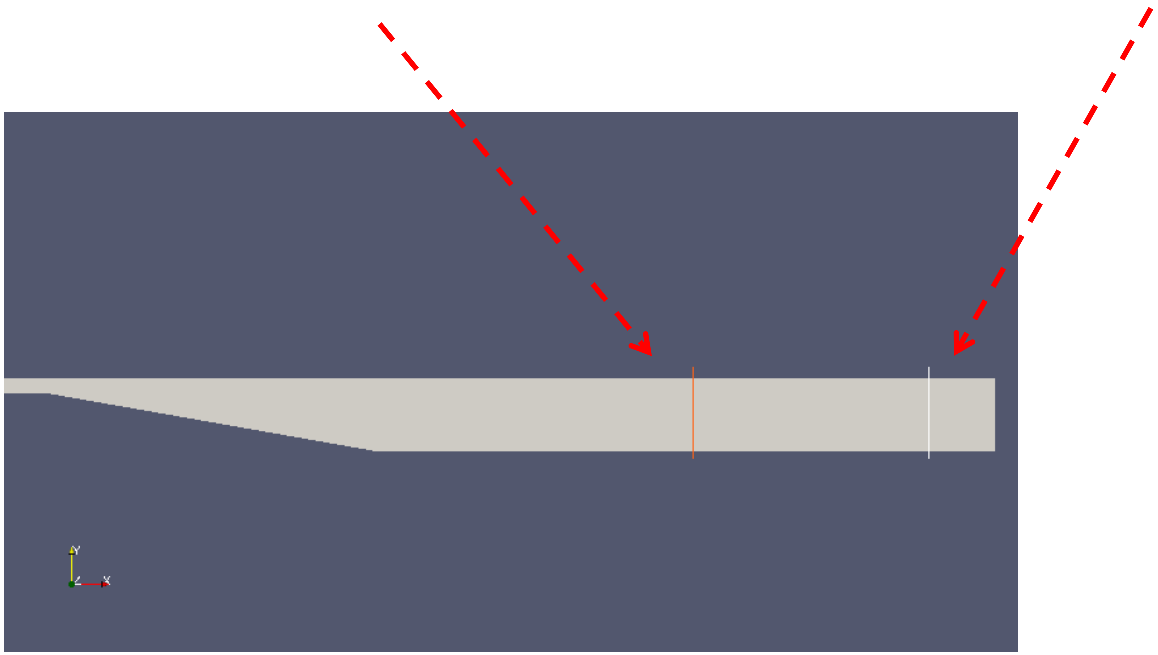




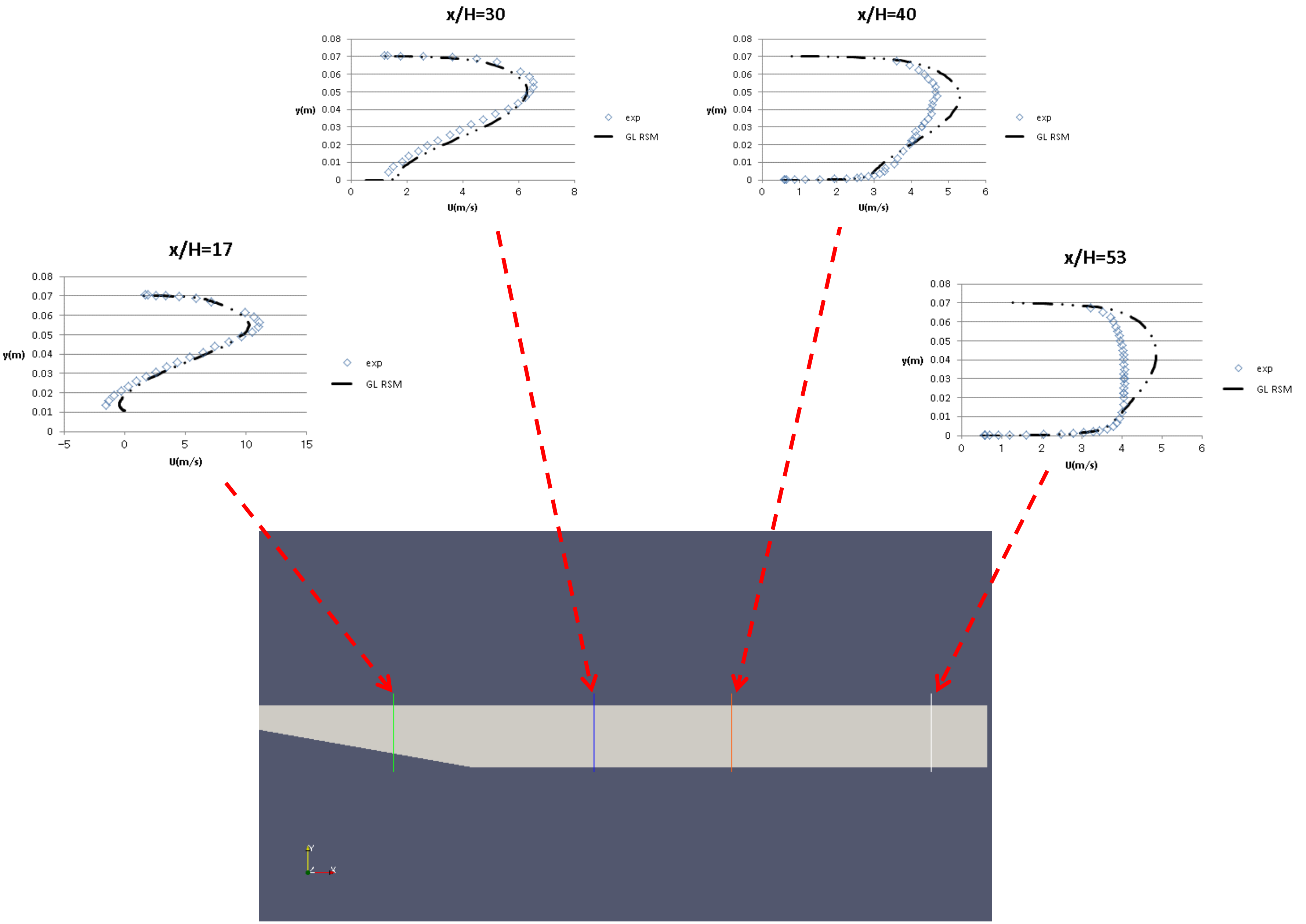
低レイノルズモデルによる流速分布
LAUNDER-SHARMAは高REモデル（標準、RNG）同様に後流側で実験に近い結果に


x/H=40


x/H=53

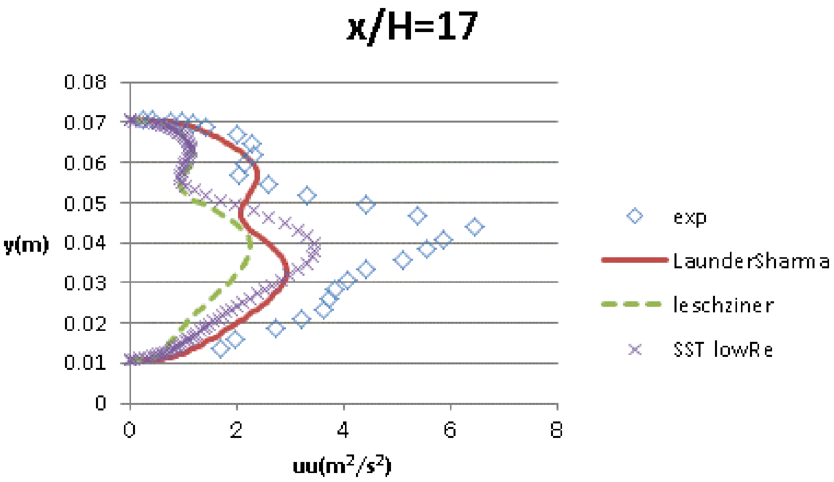


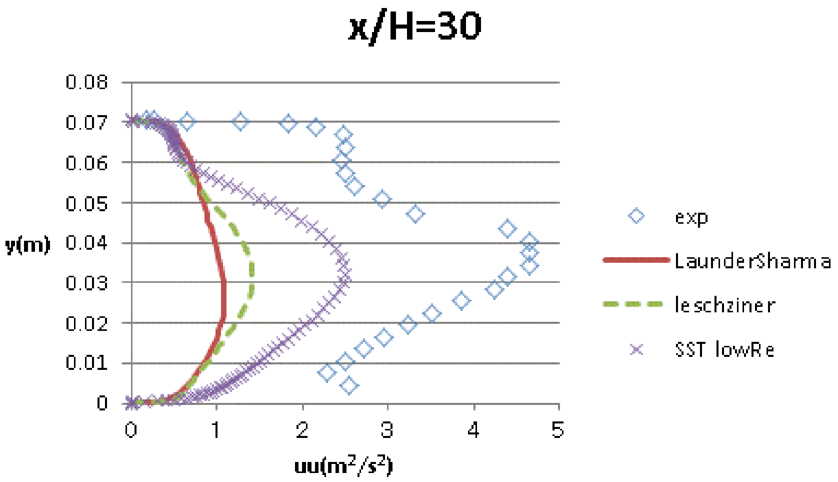
(補足)GIBSON – LAUNDER RSTMによる流速分布:逆圧力勾配の予測は問題無し

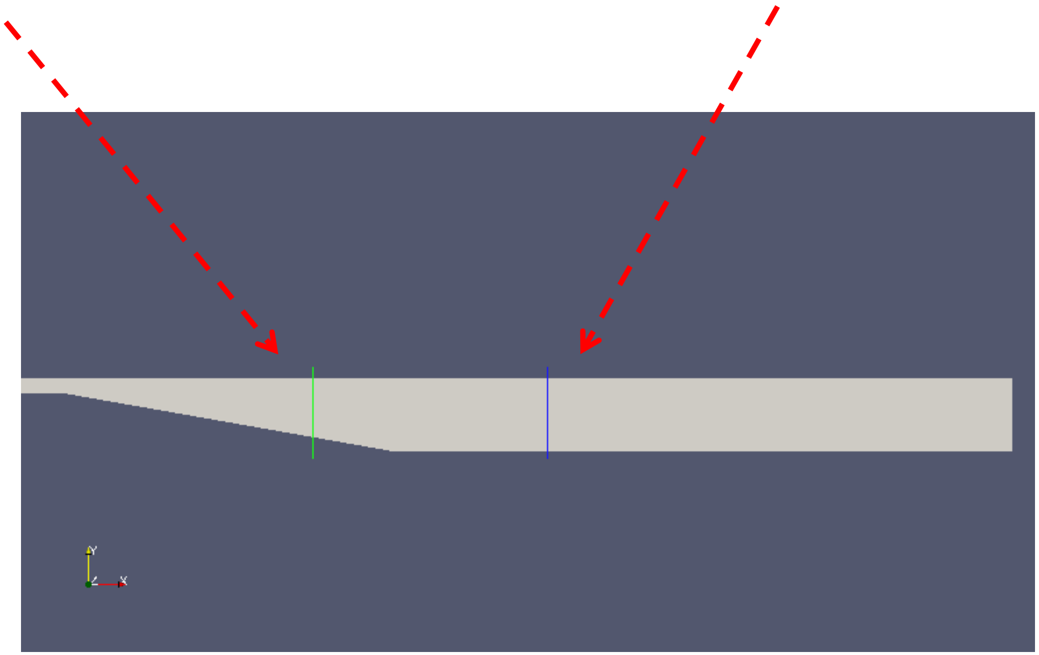


Re応力分布

ここでのモデルでは低レイノルズ型**SST**が実験値に近い

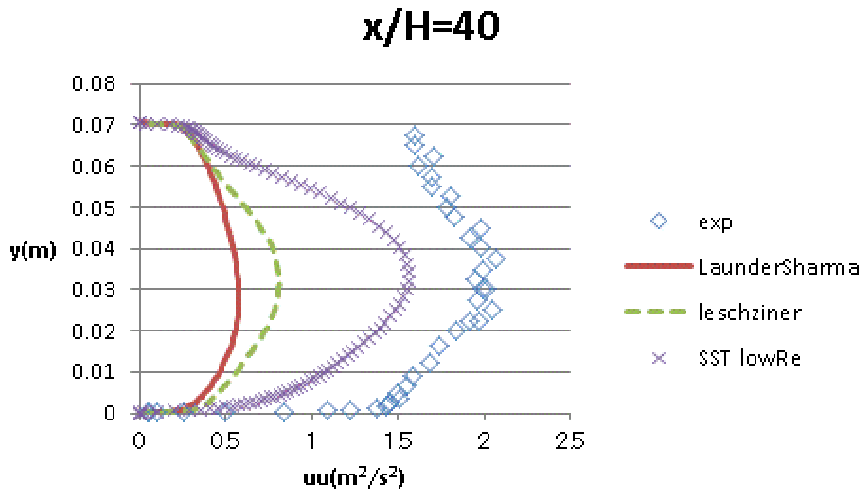

x/H=17

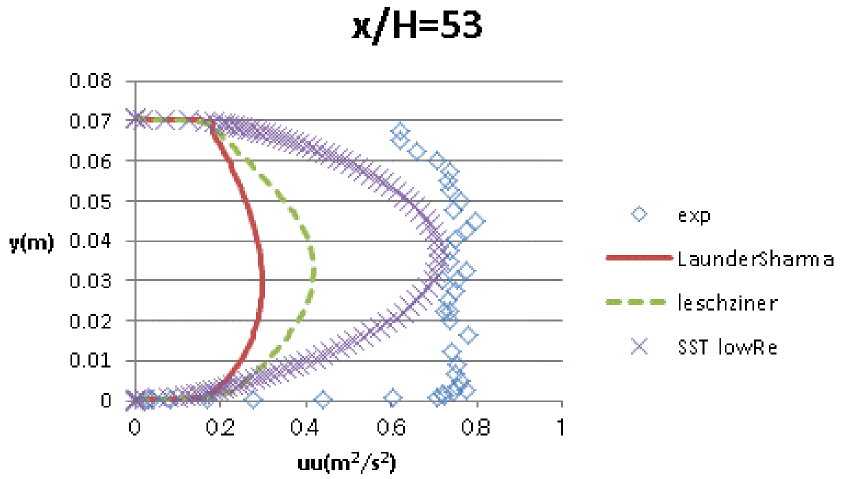

x/H=30

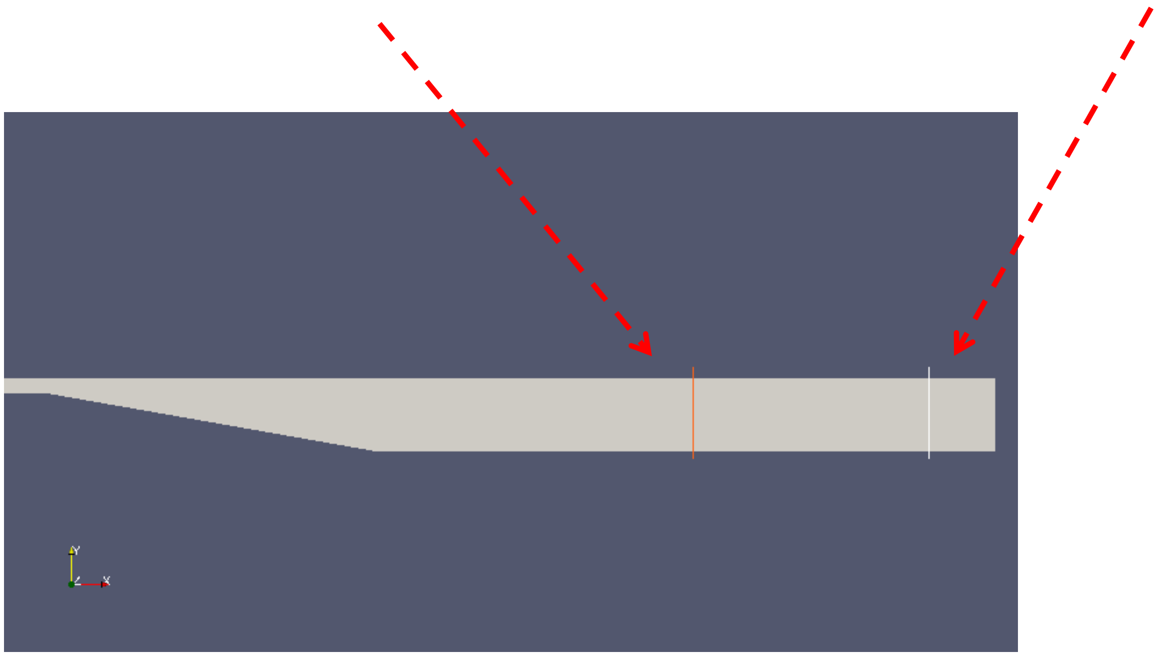


Re応力分布

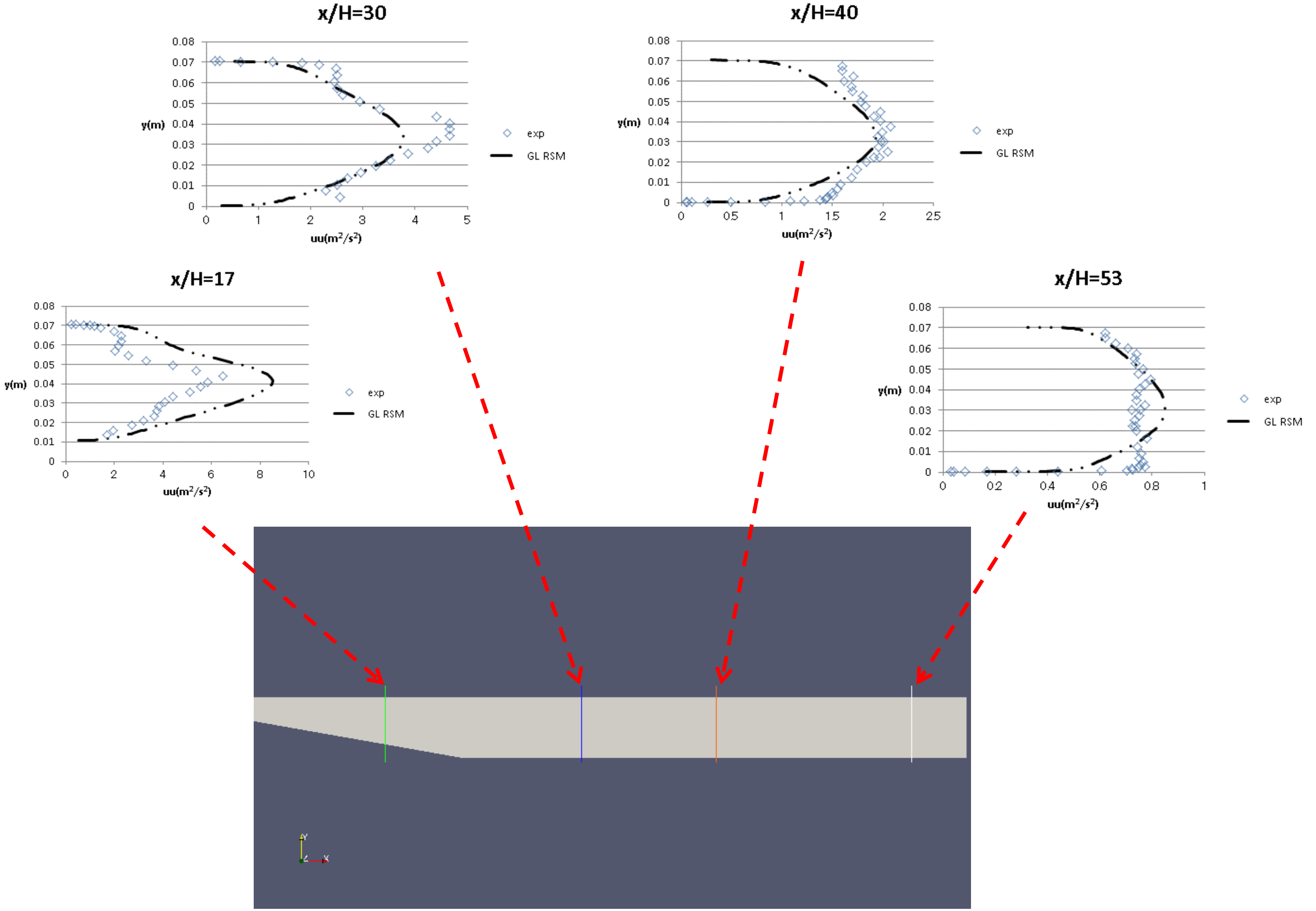
後流でも同様の傾向、標準的な**2**方程式モデルでは**Re**応力予測が厳しい・・・非線形モデルの適用？





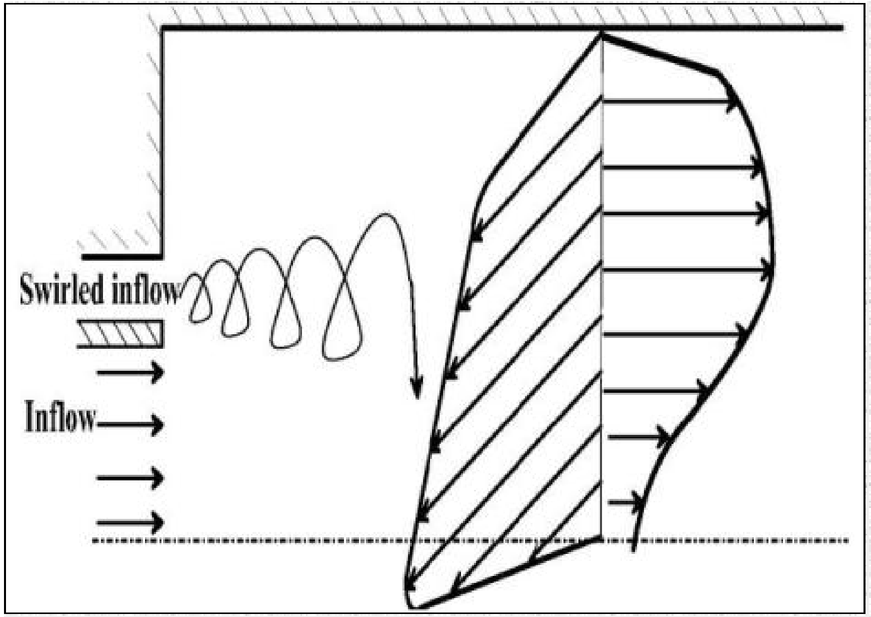


（補足）GIBSON－LAUNDER RSTMによる**Re**応力分布：さらに渦粘性モデルとの違いが明確に

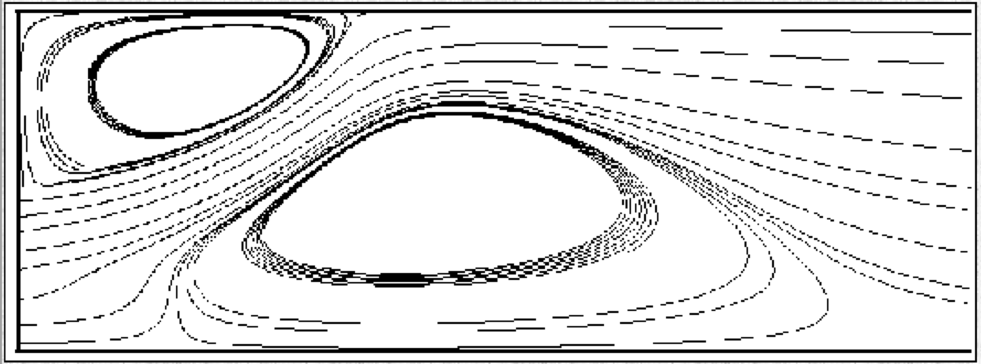


解析例2

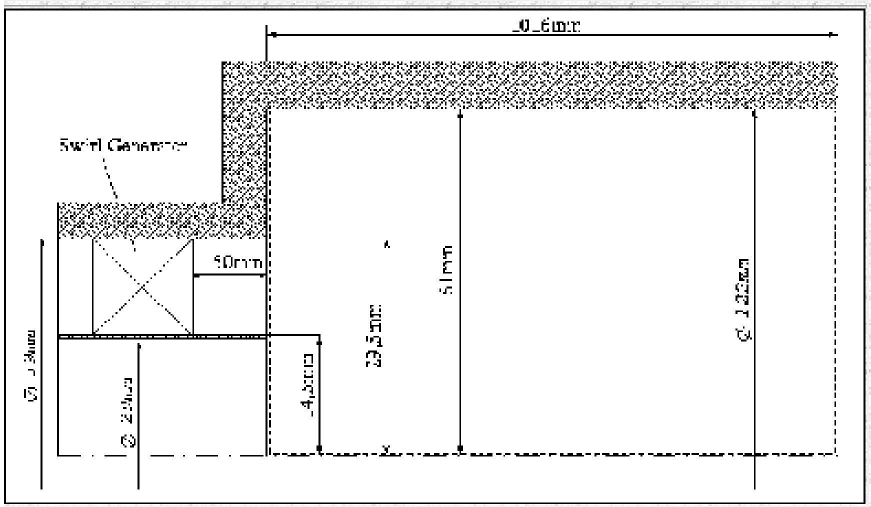
CASE 9.1: SWIRLING FLOW IN A MODEL COMBUSTOR WITH HEAT RELEASE


Swirled inflow
Inflow

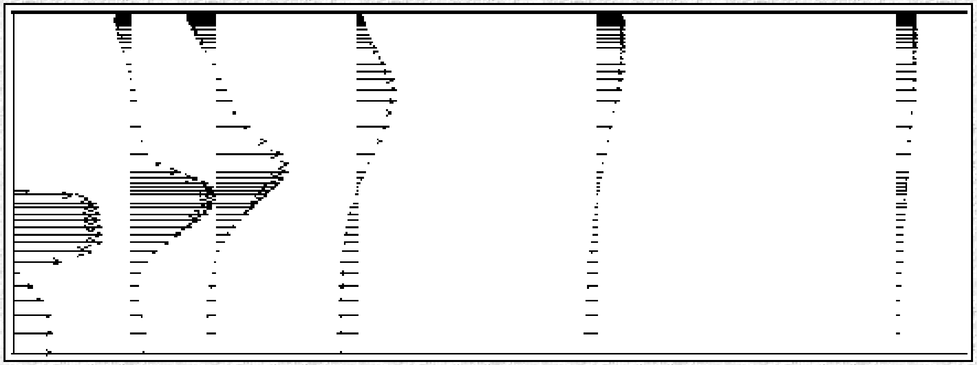
Schematic of the swirling flow in a model combuster



Typical Streamlines


Swirl Generator
50mm
51mm
Ø 122mm

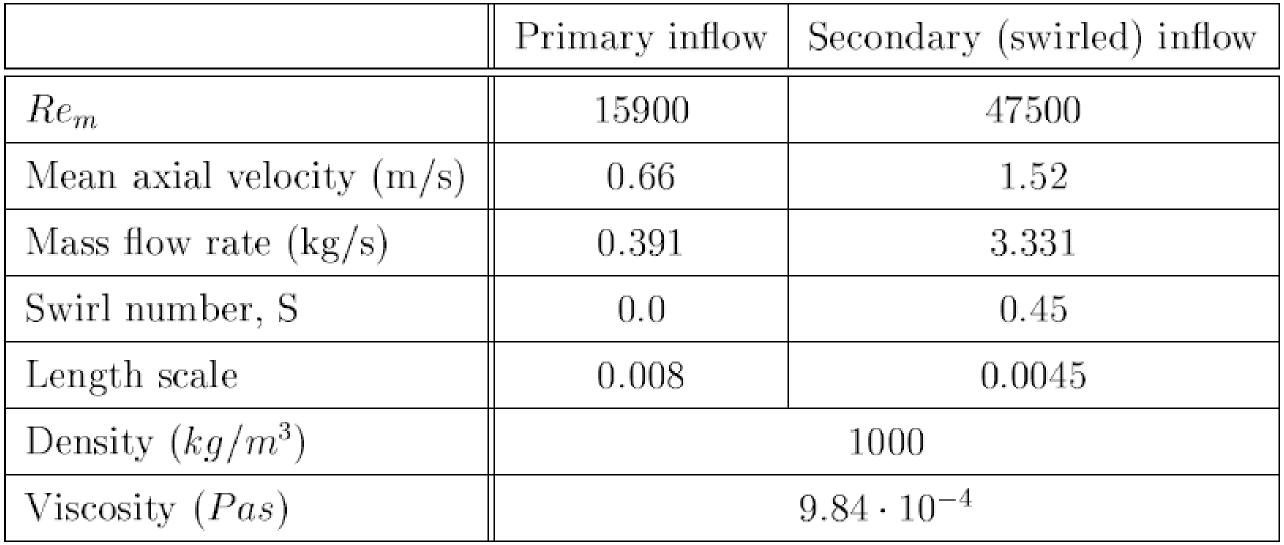
Test Case Geometry



Axial Velocity

解析条件

Table 1 Characteristic flow properties



	Primary inflow	Secondary (swirled) inflow
Re_m	15900	47500
Mean axial velocity (m/s)	0.66	1.52
Mass flow rate (kg/s)	0.391	3.331
Swirl number, S	0.0	0.45
Length scale	0.008	0.0045
Density (kg/m^3)	1000	
Viscosity (Pas)	$9.84 \cdot 10^{-4}$	

※赤枠部分が計算領域

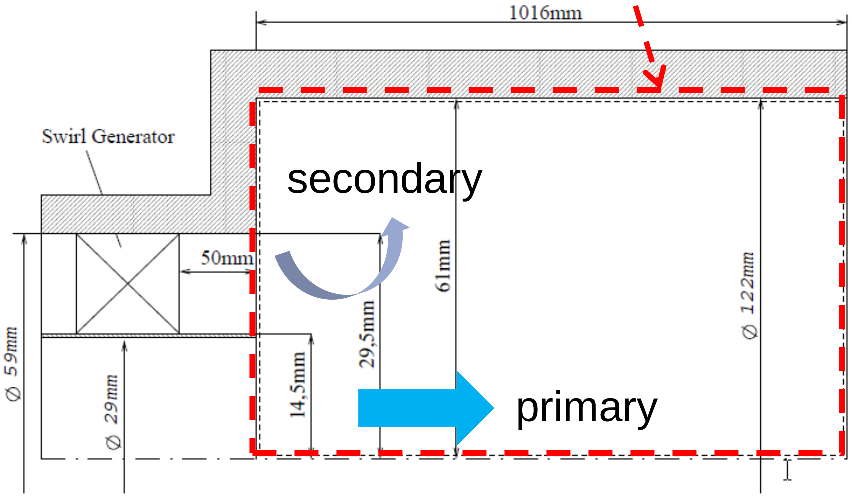
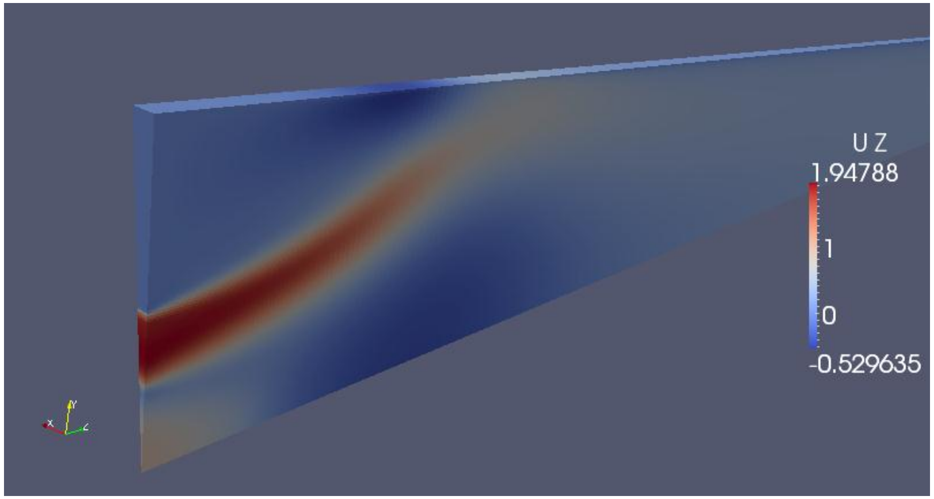

1016mm
Swirl Generator
secondary
50mm
61mm
Ø 122mm
29,5mm
14,5mm
primary
Ø 59mm
Ø 29mm

Fig. 2 Description of the combustor geometry


U Z
1.94788
1
0
-0.529635

軸対称モデル（24000cell、壁関数使用）

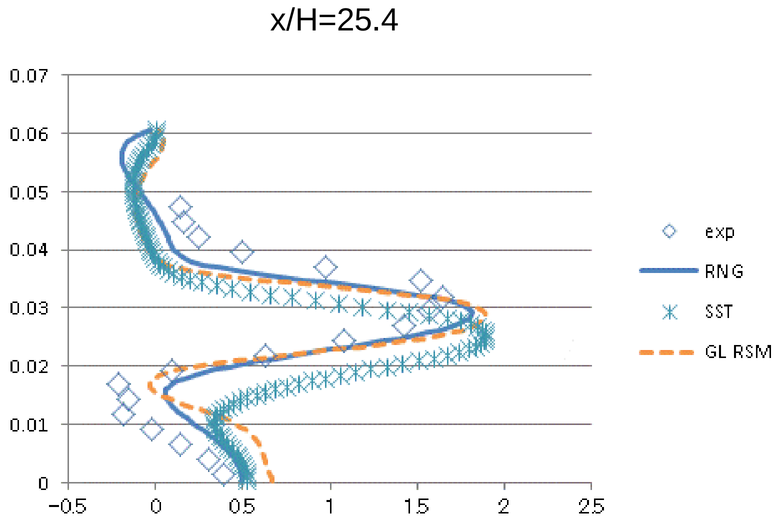
流入条件：実験データによる旋回流をOpenTurboにて再現（本家turboグループのツール)

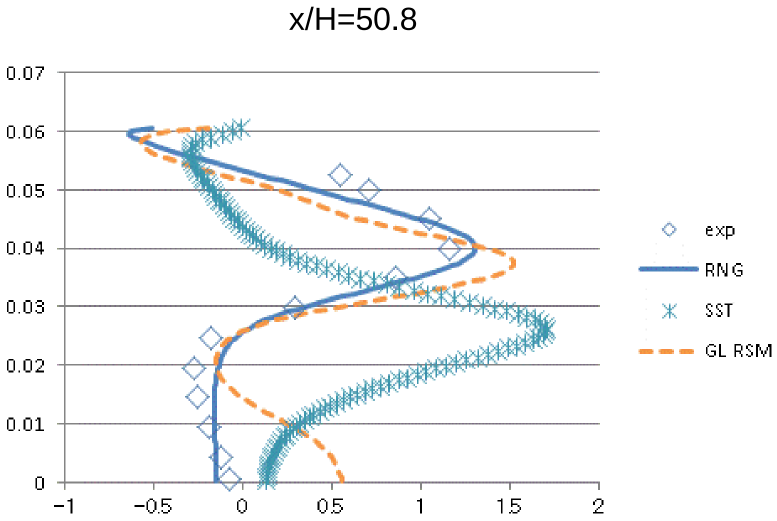
```
inlet
  {
      type            profile1DfixedValue;
      fileName        "inlet.csv";
      fileFormat      "turboCSV";
      interpolateCoord "R";
      fieldName       "Velocity";
      fieldScaleFactor 1;
```

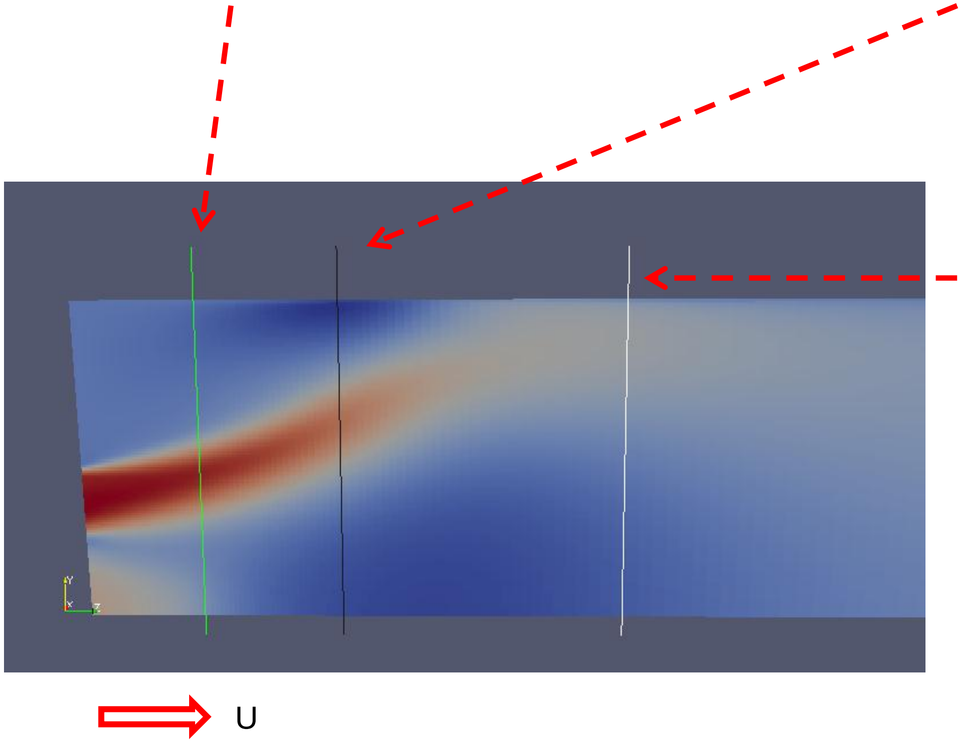
※Re応力についてはこのツールに未対応のため、
TimeVaryingMappedFixedValueを使用

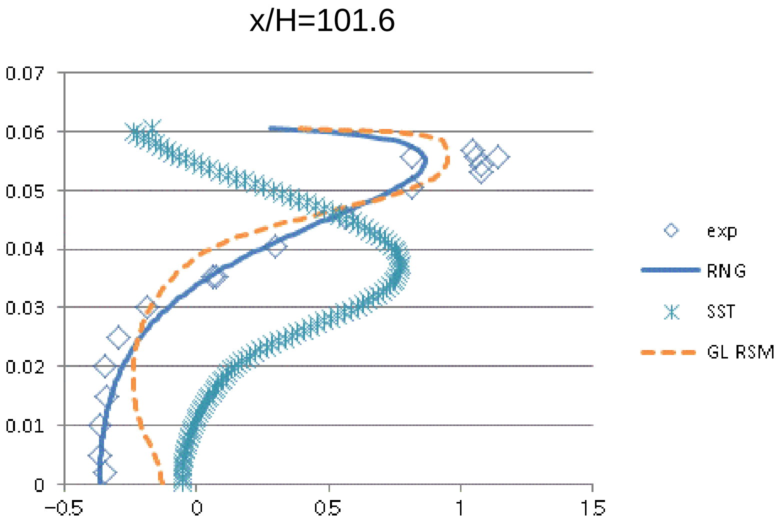
```
[Data]
 R [ m ], Velocity Axial [ m s^-1 ], Velocity Radial [ m s^-1 ], Velocity Circumferential [ m s^-1 ], Pressure [ Pa ], Turbulence Kinetic Energy [ m^2 s^-2 ], Turbulence Eddy Dissipation [ m^2 s^-3 ], Turbulence Specific Dissipation Rate [ s^-1 ]
0.0E+0,   8.75E-01, 0.0E+0,   0.0E+0,   0.0E+0,   1.01E-02, 9.40E-02, 9.3069E+00
1.10E-03, 8.75E-01, 0.0E+0,   0.0E+0,   0.0E+0,   1.01E-02, 9.40E-02, 9.3069E+00
3.20E-03, 8.75E-01, 5.00E-03, 0.0E+0,   0.0E+0,   1.0950E-02, 1.01E-01, 9.2237E+00
5.1750E-03, 8.63E-01, 2.00E-02, 0.0E+0,   0.0E+0,   1.24E-02, 1.22E-01, 9.8387E+00
7.0750E-03, 8.28E-01, 3.50E-02, 0.0E+0,   0.0E+0,   1.47E-02, 1.68E-01, 1.1429E+01
8.8750E-03, 7.70E-01, 5.00E-02, 0.0E+0,   0.0E+0,   1.79E-02, 2.61E-01, 1.4581E+01
1.0580E-02, 6.07E-01, 5.50E-02, 0.0E+0,   0.0E+0,   2.22E-02, 4.60E-01, 2.0721E+01
1.2150E-02, 4.67E-01, 4.50E-02, 0.0E+0,   0.0E+0,   1.0870E-01, 1.0960E+00,   1.0083E+01
1.3550E-02, 2.92E-01, 1.00E-02, 0.0E+0,   0.0E+0,   1.1245E-01, 3.5410E+00,   3.1490E+01
1.4750E-02, 1.17E-01, 0.0E+0,   0.0E+0,   0.0E+0,   8.50E-02, 1.1140E+01, 1.3106E+02
1.5850E-02, 3.50E-01, 4.00E-02, 4.20E-01, 0.0E+0,   6.30E-02, 8.5640E+00,   1.3594E+02
1.7050E-02, 1.1780E+00,   1.28E-01, 8.20E-01, 0.0E+0,   1.02E-01, 1.7090E+00,   1.6755E+01
1.8450E-02, 1.68E+00,   2.17E-01, 9.90E-01, 0.0E+0,   5.30E-02, 1.1090E+00,   2.0925E+01
2.00E-02, 1.9250E+00,   2.50E-01, 1.02E+00,   0.0E+0,   2.93E-02, 7.46E-01, 2.5461E+01
2.16E-02, 1.95E+00,   2.50E-01, 1.00E+00,   0.0E+0,   2.47E-02, 6.94E-01, 2.8097E+01
2.32E-02, 1.94E+00,   2.30E-01, 9.25E-01, 0.0E+0,   2.51E-02, 7.22E-01, 2.8765E+01
2.48E-02, 1.91E+00,   2.00E-01, 8.30E-01, 0.0E+0,   3.4750E-02, 9.16E-01, 2.6360E+01
2.6350E-02, 1.8670E+00,   1.80E-01, 7.20E-01, 0.0E+0,   3.32E-02, 1.3540E+00,   4.0783E+01
2.7750E-02, 1.82E+00,   1.50E-01, 6.60E-01, 0.0E+0,   3.58E-02, 2.4480E+00,   6.8380E+01
2.8950E-02, 1.17E+00,   8.00E-02, 3.00E-01, 0.0E+0,   4.16E-02, 6.3330E+00,   1.5224E+02
2.95E-02, 0.0E+0,   0.0E+0,   0.0E+0,   0.0E+0,   0.0E+0,   0.0E+0,   0.0E+0
```

流速分布（**U**） **CASE8.2**とは反対に**RNG**モデルが良好、**SST**モデルは特に入口から離れると誤差大


x/H=25.4

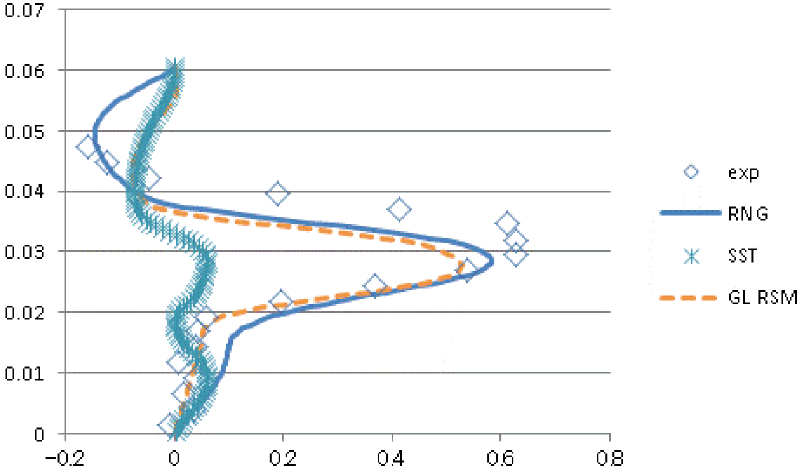

x/H=50.8



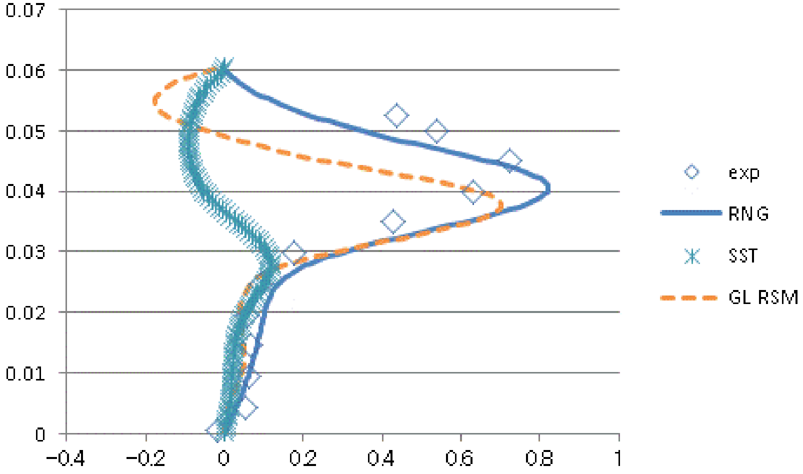

x/H=101.6

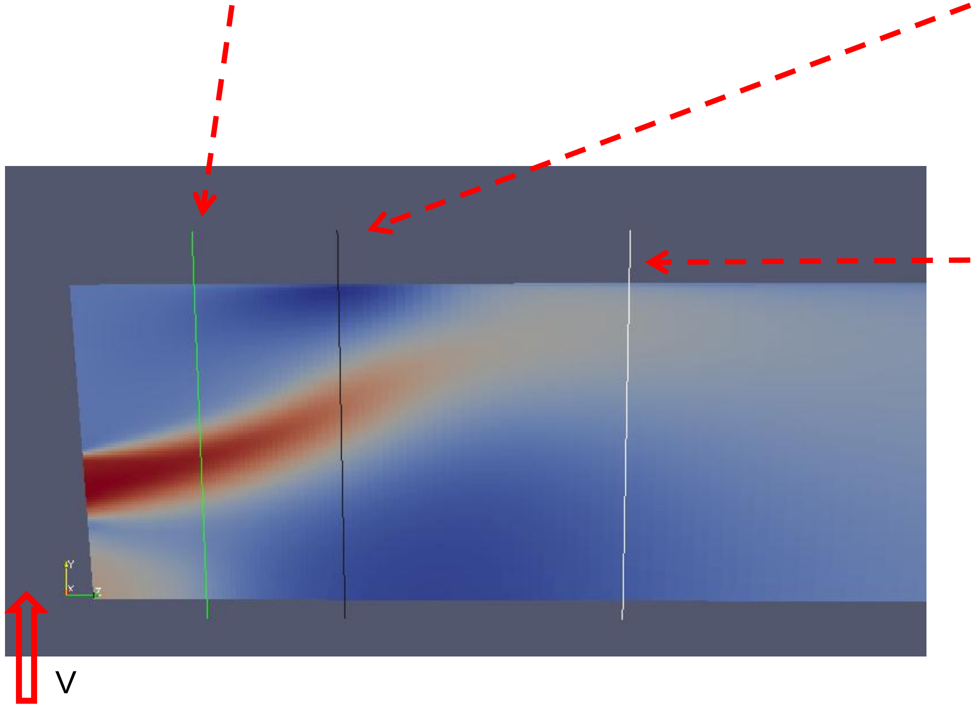
流速分布（V） U成分同様にRNGモデル良好

x/H=25.4

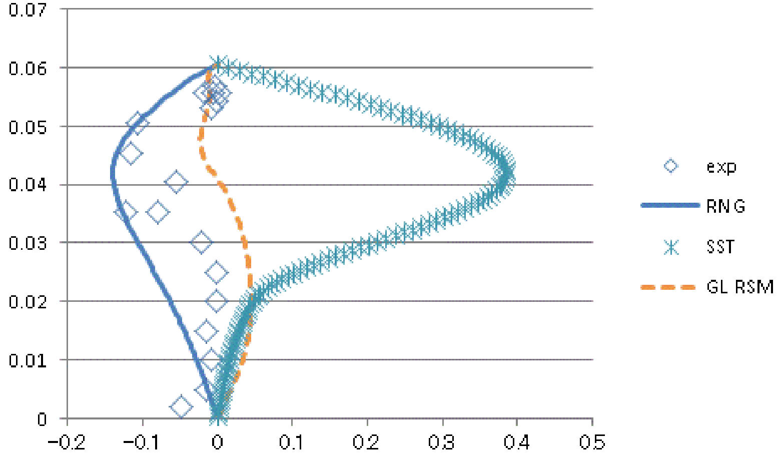


x/H=50.8



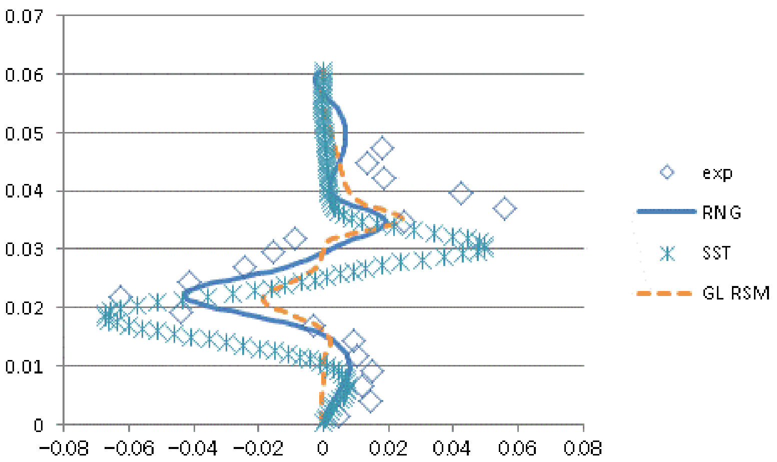


x/H=101.6

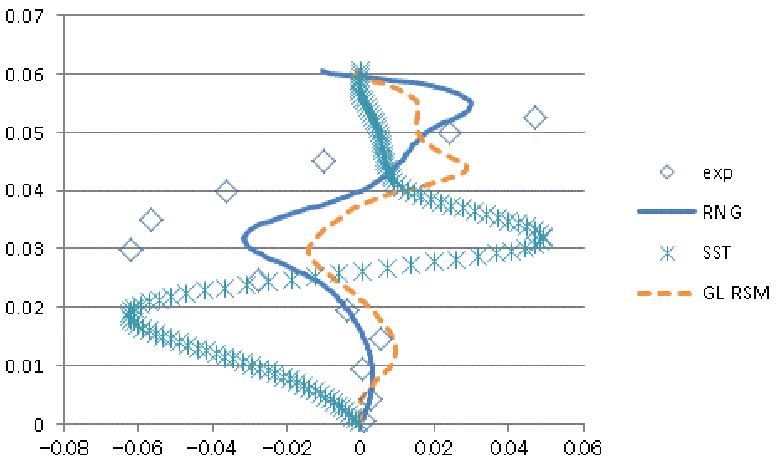


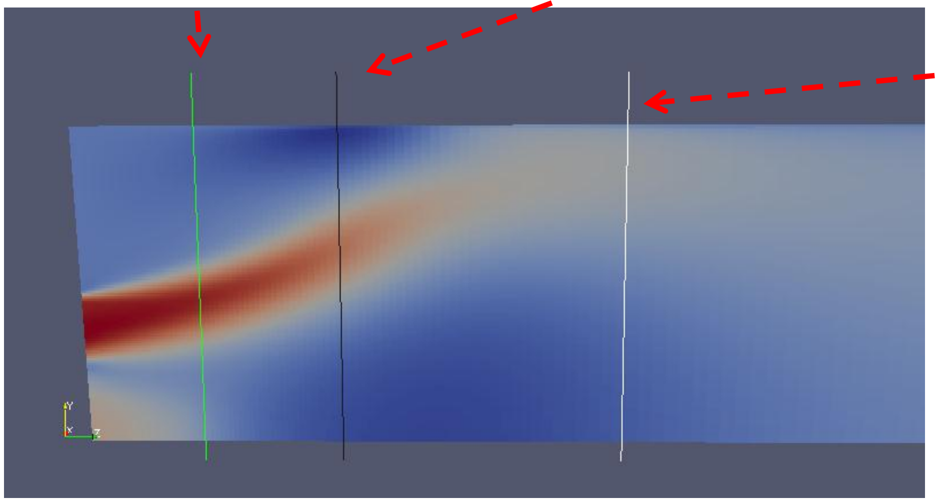
Re応力分布（**UV**） 定量的な予測は困難？渦粘性モデルならば旋回流は**3**次の非線形モデルが必要

x/H=25.4

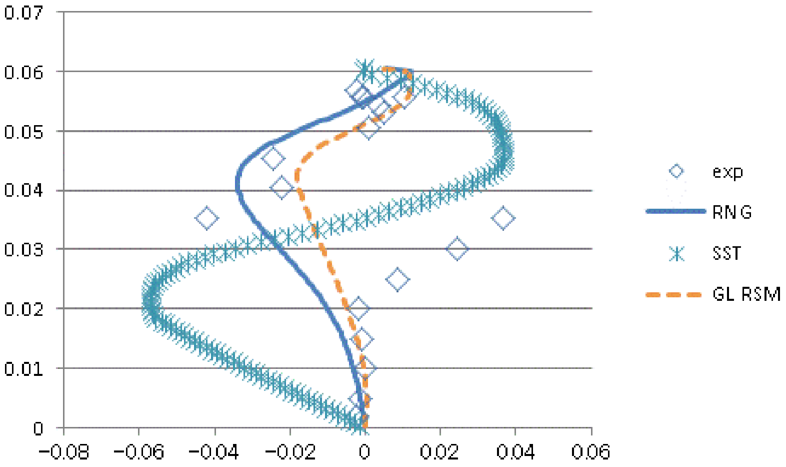


x/H=50.8





x/H=101.6



今後

①Test caseを一通り揃えたいが･･･

・3Dモデルの場合は解析にも時間がかかり、中々取り掛かれない
（計算環境：Windows 7 64bit 上でVMWare + DEXCS 2010 64bit
CPU:AMD Phenom 1055T ,memory:8GB ）

・wikiページに順次upしています（現在4ケース、その他数ケースを近日中に）

http://www.ofwikija.org/index.php/OpenFOAM%E5%8B%89%E5%BC%B7%E4%BC%9A_for_beginner

・ご協力頂ける方、募集中
→ 特に申し出等必要なく、気が向いて解析してみたモデルをupして頂いても
一向に構いません。Upされているモデルをご自分で検証、もしくは商用コードと
比較された等ありましたら、是非掲示板等でご報告頂けると助かります。

・並行して、乱流モデルのチェック・改良も進めています（V2F、遷移モデル等々）

②初心者の方はまず、このような単相・非圧縮のベンチマークデータをOFで
解析できるように訓練すると、ある程度やってるうちに色々覚えていくので
お奨めです（別にこのベンチマークへの勧誘という訳ではありませんが･･･）