Available online at www.elixirpublishers.com (Elixir International Journal)

Thermal Engineering

Elixir Thermal Engg. 89 (2015) 36827-36830

ISSN: 2229-712X

Steady state Laminar, Incompressible flow over a Backward Facing Step (BFS)

Ramesh Chandra Mohapatra
Department of Mechanical Engineering, Government College of Engineering, Keonjhar, Odisha, India.

ARTICLE INFO

Article history:
Received: 3 November 2015;
Received in revised form:
30 November 2015;
Accepted: 4 December 2015;

Keywords
Backward-Facing Step,
Computational Fluid Dynamics (CFD),
Laminar Flow,
Outflow Boundary Condition.

ABSTRACT

Fluid flow in a backward – facing step (BFS) geometry is one of the most important bench mark problems used in computational fluid dynamics (CFD). It consists of an out flow boundary condition. In the present work, the laminar, incompressible flow over backward facing step is being calculated using computational fluid dynamics. The Reynolds number taken for the simulation is 800. For Re = 800, the momentum and energy solutions at various downstream locations are compared with the bench mark results and found to be in good agreement with bench mark results.

Introduction

Fluid flow over a backward-facing step is fundamental in design & geometry and is found in a variety of engineering applications. It is one of the most important problems used in computational fluid dynamics (CFD). It has an outflow boundary condition applicable at any downstream location, so that the extent of computational domain can be minimized. Results indicating the separation and reattachment locations of the re-circulation zones in the steady state solutions are presented for 2D simulation. The Navier-stocks equations provide a widely applicable mathematical description for the analysis of fluid motion.

Literature review

Numerous experimental and numerical studies have been developed to investigate laminar flow over a backward-facing step. Pollard [1] numerically studied the entrance effect for an axisymmetric expansion and found insignificant differences. Armaly et al. [2] have published experimental data for a backward facing step with expansion ratio of 2. Kim and Moin [3] have tested 3D, BFS problem using a functional step method. Sohn [4] used FIDAP, the commercial course to study a few laminar and turbulent flow problem. Thangam and Knight [5] studied the effect of step height on the downstream flow. Gartling [6] has used the finite element method (FEM) to obtain an accurate solution for a steady 2-D incompressible flow over a backward-facing step, with the intention to provide benchmark data in a format that can be used for testing and evaluation of outflow boundary conditions. Kaiktsis et al. [7] found 3D transient structures for laminar flow over a backward facing step at Re = 800. Dyne and Heinrich [8] studied the same BFS problem and investigated the Nusselt number (Nu) distribution along the wall. Comini et al [9] solved the incompressible 2D flow BFS problem by a stream function – vorticity formulation using finite element method (FEM). Han et al. [10] have applied artificial far-field boundary conditions upstream and downstream to the present flow configuration for a low Reynolds number using a vorticity-stream function methodology. Barton [11] considered the effect of inlet channel length before the expansion in the BFS problem and predicted that at low Re, the reattachment length is reduced due to channel presence. Davidson and Nielson [12] presented the role of the expansion ratio in determining the reattachment length for various Re. Biswas et al. [13] have reported 2D as well as 3D BFS results. They reported the formation of Moffat eddies as Re approaches zero.

Problem definition

The problem involving a steady state laminar, incompressible flow over an isothermal two-dimensional backward-facing step is a standard test problem that has been addressed by numerous authors using a wide variety of numerical methods. As shown in figure 1, the downstream channel was defined to have unit height‘H’ with a step height and upstream inlet region set equally to H/2. For the purpose of generating the base line solution to this problem the downstream channel length was taken as L = 30H i.e the channel extends 60 step heights from the inlet. The coordinate system for describing locations in the channel is centred at the step corner.

For the backward-facing step geometry, no slip boundary conditions are imposed on the step and the upper and lower channel walls. The inlet velocity with the X- coordinate being defined as positive in the downstream direction and the Y-coordinate across the channel.For the backward-facing step geometry, no slipboundary conditions are imposed on the step and the upper and lower channel walls.

The inlet velocity field was specified as a parallel flow with a parabolic horizontal component given by $u(y) = 24y(0.5 - y)$ for $0 \le y \le 0.5$ at the channel inlet and zero natural boundary conditions are imposed in channel outlet. The Reynolds number of 800 is based on the channel height of H= 1 and the average inlet velocity of where, umax=1.5 in a parabolic profile.

Tele:
E-mail addresses: rameshmohapatra75@gmail.com

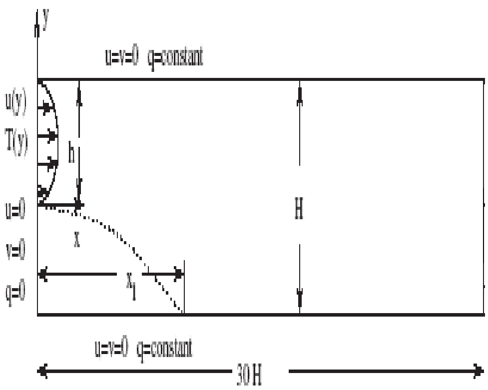
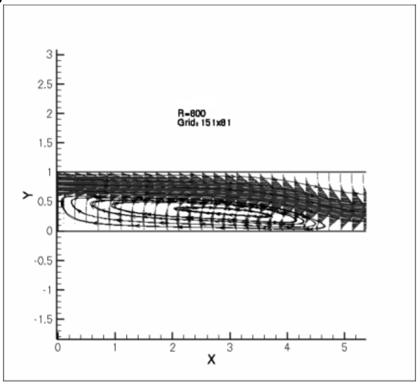


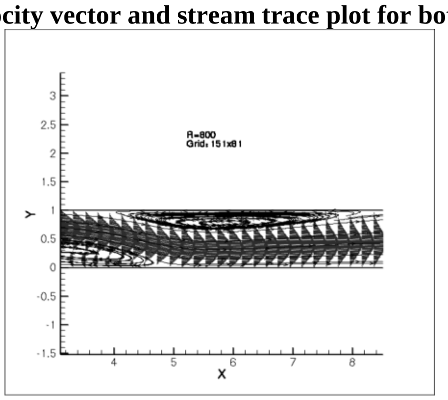
Figure 1. Backward facing step geometry with channel dimensions and boundary condition

Results and Discussion

In the present work 151×81 grid points and Re = 800 have been used for all calculations. The velocity vectors along with the primary vortex on the bottom wall and the top wall vortex are shown in figure 2 (a) and 2 (b) respectively. These plots are full scale, but only show the first 11 step heights of the channel since few phenomena occur downstream of this point. The flow separates at the step corner and forms a large recirculation zone with a reattachment point on the lower wall approximately 9 step heights downstream. A second recirculation zone forms on the upper wall beginning approximately 8 step heights downstream and terminating at 17 step heights.



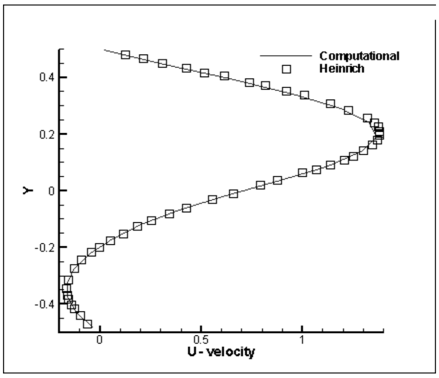
2 (a). Velocity vector and stream trace plot for bottom wall



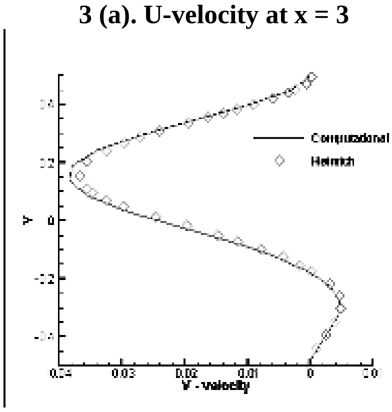
2 (b). Velocity vector and stream trace plot for top wall

Figures 3 (a) to 3 (c) show the stream wise velocity (U-velocity component), cross stream wise velocity (V- velocity component) and temperature profiles at x=3 respectively. These profiles demonstrate the flow conditions in the primary circulation region. Results from the present study (computational) are in good agreement with those of Dyne and Heinrich. A similar analysis can be performed at x = 7 which is a representative of the flow conditions in the secondary circulation region. Figures 4 (a) and 4 (c) demonstrate the stream wise velocity (U- velocity component) and temperature profiles at x = 7 with a good agreement between the present study (computational) and Dyne and Heinrich.Figure 4 (b) demonstrates cross stream wise velocity (V- velocity component) at x = 7 with a large discrepancy between the present study (computational) and Dyne and Heinrich.

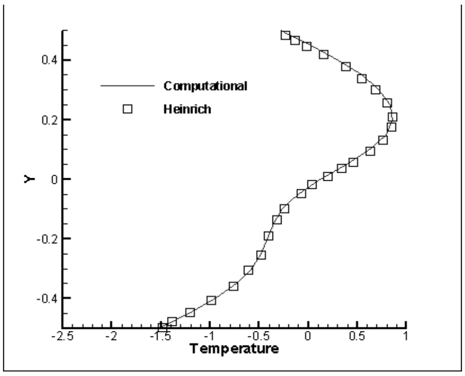
At the downstream of the recirculation regions x = 15 which represents the flow fully develops. Here the thermal entrance effects are quite obvious, as the temperature profile is of asymmetric with respect to the centre line of the channel. Figures 5 (a) to 5 (c) demonstrate the stream-wise velocity (U-velocity component), cross stream-wise velocity (V-velocity component) and temperature profiles at x = 15 with a good agreement between the present study (computational) and those of Dyne and Heinrich.The results obtained from the present computational study are compared with the results obtained from Gartling. On comparison it has been found that for x = 7 and x = 15 the stream wise velocity (U – velocity component) shown in figure 6 (a) and figure 7 (a) obtained from present study (computational) have a good agreement with the results obtained from Gartling. But the cross stream-wise velocity (V – velocity component) at x = 7 shown in figures 6 (b) found from present study (computational) has a quite large deviation when compared with Gartling results. On the other hand the cross stream-wise velocity (V – velocity component) at x = 15 obtained from present study (computational) has a good agreement with the results of Gartling.



3 (a). U-velocity at x = 3

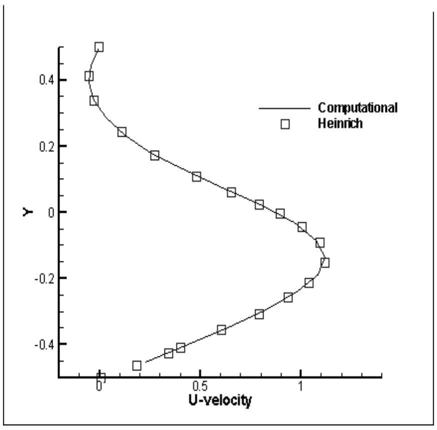


3 (b). V- velocity at x = 3

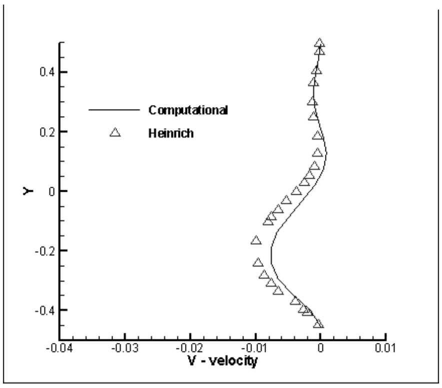


3 (c). Temperature profile at x = 3

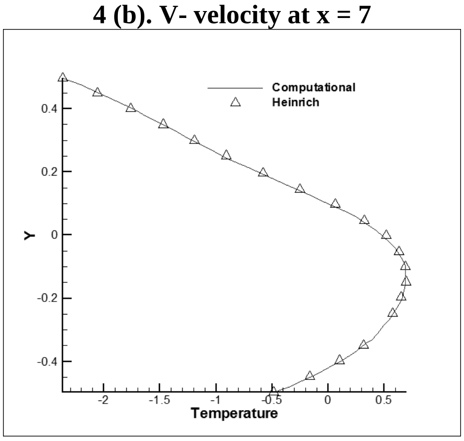
Figure 3. Comparison of (a) U- velocity, (b) V- velocity and (c) Temperature profile with Dyne and Heinrich at x = 3



4 (a). U-velocity at x = 7

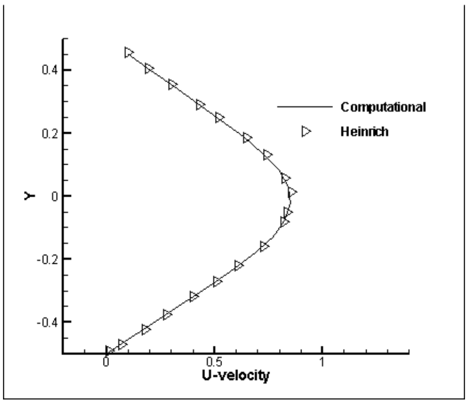


4 (b). V- velocity at x = 7

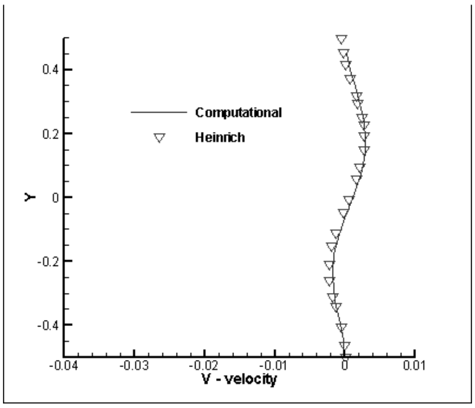


4 (c). Temperature profile at x = 7

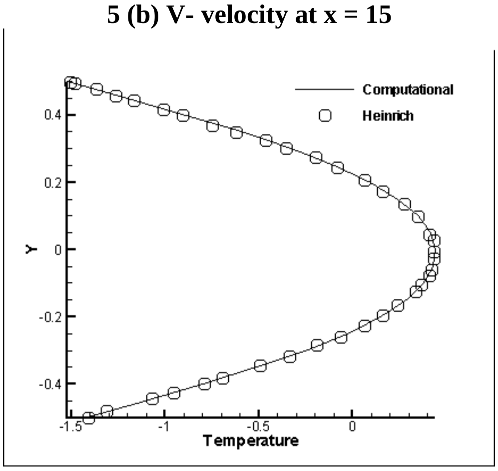
Figure 4. Comparison of (a) U- velocity, (b) V- velocity and (c) Temperature profile with Dyne and Heinrich at x = 7



5 (a) U-velocity at x = 15

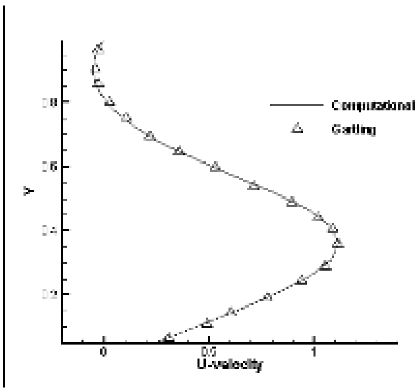


5 (b) V- velocity at x = 15

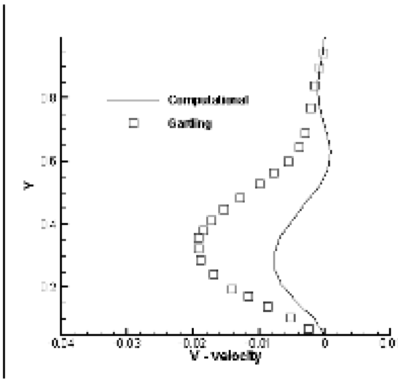


5 (c) Temperature profile at x = 15

Figure 5. Comparison of (a) U- velocity, (b) V- velocity and (c) Temperature profile with Dyne and Heinrich at x = 15

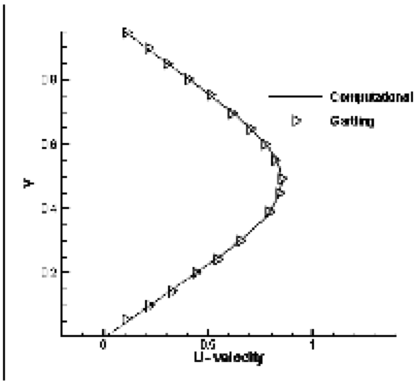


6 (a) U-velocity at x = 7

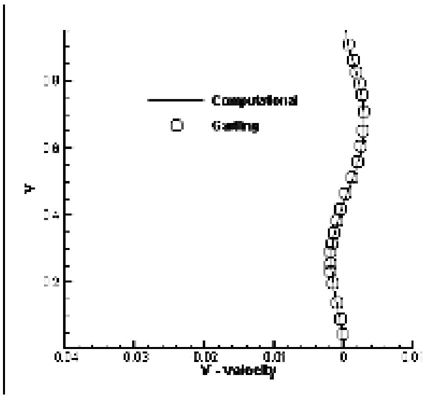


6 (b) V- velocity at x = 7

Figure 6. Comparison of (a) U- velocity and (b) V- velocity with Gartling at = 7



7 (a) U-velocity at x = 15



7 (b) V- velocity at x = 15

Figure 7. Comparison of (a) U- velocity and (b) V- velocity with Gartling at = 15

Conclusion

A study of backward-facing step problem has been done. The primary reattachment length is has been studied and the discrepancy of the V- velocity is reported. The energy equation is solved and found to be in good agreement with Dyne and Heinrich. For locations at x = 3 and x = 15, it is found that the computed results are in good agreement with the results of Dyne and Heinrich and also with Gartling. Immediately after reattachment of primary vortex, i.e at x = 7, the U- velocity computed results are found to be in good agreement with the results of Dyne and Heinrich as well as with Gartling. However, the predicted V- velocity has a large deviation. It feels that the deviation in the V- velocity leads to the deviation in the primary vortex reattachment.

References

[1] B.F.Armaly, F.Dust, J.S.F. Pereira and B. Schonung, Experimental and theoretical investigation of backward-facing step flow. Journal of Fluid Mechanics, 1983; 127: 473-496

[2] J Kim, P Moin. Application of a fractional-step method to incompressible Navier–Stokes equations.Journal of Computational Physics 1985; 59:308 –323.

[3] J Sohn. Evaluation of fidap on some classical laminar and turbulent benchmarks.International Journal for Numerical Methods in Fluids 1988; 11:1469 –1490.

[4] DK Gartling. A test problem for outflow boundary conditions-flow over a backward-facing step.International Journal for Numerical Methods in Fluids 1990; 11:953–967.

[5] A Kaiktsis, LGE Karniadakis, SA Orsag. Onset of three dimensionality, equilibria and early transition in flow over a backward-facing step.Journal of Fluid Mechanics 1991; 231:501– 528.

[6] BR Dyne, JC Heinrich. Flow over a backward-facing step: a bench mark problem for laminar flow with heat transfer. Benchmark Problems for Heat Transfer Codes HTD-V 1992; 222:73 –76.

[7] G Comini, M Manzan, C Nonino. Finite element solution of the stream function—vorticity equations for incompressible two-dimensional flows. International Journal for Numerical Methods in Fluids 1994; 19: 513–525.

[8] IE Barton. The entrance effect of laminar flow over a backward-facing step geometry. International Journal for Numerical Methods in Fluids 1997; 25:633–644.

[9] L Davidson, PV Nielsen. A study of laminar backward-facing step flow (unpublished work), http:==www.tfd.chalmers.se=lada. 1997.

[10] G Biswas, M Breuer, F Durst. Backward-facing step flows for various expansion ratios at low and
moderate Reynolds numbers. Journal of Fluids Engineering 2004; 126:362–374.