UNIVERSITI PUTRA MALAYSIA

NUMERICAL STUDY OF TWO-DIMENSIONAL STEADY INCOMPRESSIBLE LAMINAR FLOW OVER A BACKWARD-FACING STEP AT MODERATE REYNOLDS NUMBER

YOGESWARAN A/L SINNASAMY

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By

YOGESWARAN A/L SINNASAMY

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May 2012

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This thesis describes the application of computational techniques to numerically investigate the 2D steady incompressible laminar flow over a backward-facing step moderate range of Reynolds number. This study comprisestwo parts; the influence of under relaxation factors (URFs) on convergence characteristics of solution for the transport equation and velocities (*x*- and *z*- directions) for the URFs values between 0.05 and 1.0 was examined. In the first part of study, a model of sudden expansion channel was constructed and simulations were performed by using PHOENICS;a Computational Fluid Dynamics (CFD) software. The values of error percentage of pressure and velocities variables of 430 simulations have been tabulated. Based on these values, graphical technique was applied to determine the best combinations of URFs for momentum and pressure correction equations have been conducted by concentrating on convergence criteria less than 1×10^{-6} and the assessment of interpolation solution for convective and diffusive terms in the transport equation. We found that for $u_p$between 0.1 and 1.0, the best combined URFs for velocities is

between 0.1 to 0.5 to achieve lower err (*p*) within shorter time period. Meanwhile, to achieve lower err (*w*) during the computation, the URFs are between 0.6 and 0.8.We also found that the recommended values of u_p to achieve lower err (*u*) during the computation are between 0.6 and 1.0.In this second part of study, a model of sudden expansion channel based on Erturk (2008) has been constructed. The streamlines-contours of each simulation have been plotted and main recirculation complex have been identified. The locations of the separation and reattachment points in the main reattachment zone and other recirculation zones on the bottom and upper surfaces of the sudden expansion channel were quantitatively determined. For range of Reynolds numbers between 100 and 3000, HYBRID and UPWIND schemes have been used and 60 simulations were performed. At lower range of Reynolds number between 100 and 500, 12nonlinear schemes based on QUICK, FROMM and CUS scheme used to perform simulation and the streamlines of each simulation have been plotted and their main reattachment zone and other separation and reattachment zones were compared. The schemes used in this second part of study are SMART, HQUICK, UMIST, CHARM, VAN1, VAN2, OSPRE, VANALB, SUPBEE, MINMOD, KOREN and HCUS. It was found that the length of main reattachment zone is increasing when the Reynolds number is increased gradually from 100 to 1200. For beyond of Re = 1200, the flow exhibits more complex flow structure.

Abstraktesis yang dikemukakankepadaSenatUniversiti Putra Malaysia sebagaimemenuhisebahagiankeperluanuntukijazah Master Sains

KAJIAN BERANGKA PEMBELAJARAN KE ATAS ALIRAN DUA DIMENSI NYAH MAMPAT DAN MANTAP DALAM ALUR PENGEMBANGAN MENDADAK PADA JULAT NILAI NOMBOR REYNOLDS YANG SEDERHANA

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Thesis inimenerangkanaplikasitekniksimulasibagikajianberangka yang melibatkanaliran 2D nyahmampatdanmantapkeatastanggamenghadapkebelakangpadajulatnombor Reynolds yang sederhana.Kajianiniterbahagikepadaduabahagian, iaitupengaruhbawahfaktorpengendurankeatasciri-ciripenumpuanbagipersamaan-persamaan yang melibatkanhalajupadaarah*x*danzbagijulatbawahfaktorpengenduran di antara 0.05 dan 1.0. Dalambahagianpertamakajianini, sebuahmodel alurpengembanganmendadakdiciptadansimulasidijalankandenganmenggunakanperisi anPHOENICS Computational Fluid Dynamics.Nilai-nilairalatbagitekanandanhalaju yang diperolehidaripadakesemua 430 simulasitelahdirekodkan. Berdasarkanpadagraf-graf yang dihasilkandenganmenggunakan data-data yang diperolehimelaluisimulasi-simulasiinibagipersamaan momentum dantekanantelahdikenalpastiyang mempunyaiciripenumpuan yang kurangdaripada

1 x 10^{-6}danpenilaiankeataspenyelesaianfaktor-faktorkonveksidandifusi di dalampersamaanpengangkutan. Dalambahagiankeduaini, model alurpengembanganmendadak yangdihasilkanolehErturk (2008) telahdijadikansebagaipanduanuntukmenghasilkan model dalambahagianini.Garisan-garisan jet aliranbagisetiapsimulasitelahdiplotkandankawasanpusaranutamadikenalpastibagisetiap plot yang dihasilkan. Kedudukanbagititik-titikperpisahandanpercantumansemuladalamkawasanpusaranutamadan lain-lain pusaranpadapermukaanbawahdanataspermukaan-permukaanalurpengembanganmendadakditentukan. Bagijulatnombor Reynolds yang di antara 100 dan 3000, sebanyak 60 simulasitelahdijalankandenganmenggunakanskema-skema HYBRID dan UPWIND. Bagijulatnombor Reynolds yang di antara 100 dan 500, skema-skema yang berasaskan QUICK, FROMM dan CUS telahdigunakan. Untukjulatnombor Reynolds yang kecilini, sebanyak 12 yang bersifatbukanlinear telahdigunakan. Bagijulatnombor Reynolds yang keciliaitu di antara 100 dan 500, sebanyak 70 simulasitelahdijalankandenganmenggunakanskema-skema yang berikut; SMART, HQUICK, UMIST, CHARM, VAN1, VAN2, OSPRE, VANALB, SUPBEE, MINMOD, KOREN dan HCUS. Garisan-garisan jet aliranbagisetiapsimulasitelahdiplotkandankawasanpercantumanutamadankawasan-kawasanpusaran yang lain telahdibandingkan. Bagisetiappeningkatanbaginombor Reynolds bermuladaripada 100 sehingga 1200, didapatipanjangbagikawasanpusaranutamameningkat. Baginombor-nombor Reynolds yang lebihdaripada 1200, didapatikawasanpusarandangarisan-garisan jet aliranmenunjukkansuatusituasi yang kompleks.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for the quotations and citations which have been duly acknowledged. I also declare that it has not been previously and currentlyis not submitted for any other degree at UniversitiPutra Malaysia or other institutions.

YOGESWARAN A/L SINNASAMY

Date: 25 May 2012

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