MAE 210B – WQ 2018

Bluff-Body Turbulence Research Project Lit Study

Catalano, P a,\*, Meng Wang b, Gianluca Iaccarino b, Parviz Moin. Numerical simulation of the flow around a circular cylinder at high Reynolds numbers.

* Filename: catalano2003numerical
* Abstract:
  + results are compared with those obtained from steady and unsteady Reynolds-averaged Navier–Stokes (RANS)
  + LES solutions are shown to be considerably more accurate than the RANS results

Menter, F.R. and Egorov, Y. A Scale-Adaptive Simulation Model using Two-Equation Models. 2005.

* Filename: menter2005scaleadaptive
* Abstract
  + **Scale-Adaptive Simulation (SAS) concept**
  + von Karman length-scale allows SAS models to dynamically adjust to resolved structures in a URANS simulation
  + results in a LES-like behavior in unsteady regions of the flowfield
  + standard RANS capabilities in stable flow regions
  + allows the SST model to be operated in a SAS mode
* Introduction
  + URANS is insufficient for modeling separated flow
    - **Overly dissipative**
  + DES works but has issues
    - Grid refinement can cause artificial flow phenomena
    - User must be well informed, DES is not plug-and-play
  + SAS overview
    - KE1E model is a direct result of the transformation of the high Reynolds number version of the k-ε model to a one- equation model, using equilibrium assumption
    - Von Karman length-scale introduces dynamic behavior
      * the model adjusts to the already resolved scales in a dynamic way and **allows the development of a turbulent spectrum** in the detached regions.
* Test Cases
  + Decaying homogeneous isotropic turbulence
    - Turbulence decays according to 5/3 law, not overly dissipative like URANS
  + **Flow over cylinder**

Schwing, A, Candler, Graham.

* Filename: schwing2015detachededdy
* Abstract:
  + numerical simulation of supersonic, subsonic, and transonic flows over a bluff body **(orion capsule)**
  + Compare RANS/DES to wind tunnel test
  + **DES matches experiment better than RANS**
* Wind Tunnel Test
  + 7.66%-scale Orion MPCV
  + NASA Ames Unitary Plan Wind Tunnel
  + Mach = 0.5, 0.95, 1.4
  + AoA = 140-170 deg
  + ReD = 1.89-5.3e6
* Computational Methodology
  + US3D, unstructured, finite volume, navier-stokes
* Results
  + Mach=0.5
    - Most unsteady of tested machs
    - **DES makes most accurate pressure prediction in separated wake**
      * **But not always most accurate for integrated loads**
      * Integrated loads depend on prediction of separation
    - Shoulder separation
      * DES predicts 3-dimensionality best
      * RANS misses the width of the suction peak
    - Integrated quantities
      * **RANS is most accurate in predicting lift**
        + **Depends on prediction of separation**
      * **RANS is less accurate in predicting drag** 
        + **(lower wake pressures)**
    - General outlook
      * RANS predicts pressure poorly due to high dissipation

Elkhoury, M. Assessment of turbulence models for the simulation of turbulent flows past bluff bodies.

* Filename: elkhoury2016assessment
* Abstract
  + Assessment of **novel one-equation turbulence model**
  + Compare to SA, SST-SAS
  + Unsteady, **3D flow over square cylinder**
  + Use case: comparable results to LES with fewer computational resources used

Liu, Yue, Xiaorong Guan \*, Cheng Xu. A production limiter study of SST-SAS turbulence model for bluff body flows.

* Filename: liu2017production
* Abstract
  + **production limiter** considering the efforts of strain rate tensor and rotation tensor is proposed for the Scale- Adaptive Simulation method (SAS).
  + two other limiters only considering strain or vorticity are also conducted for comparison

Murakami, S. COMPARISON OF VARIOUS TURBULENCE MODELS APPLIED TO A BLUFF BODY.

* Filename: murakami1993comparison
* Abstract:
  + shortcoming of the eddy viscosity modelling in the k-epsilon model is scrutinized in **comparison with the results of algebraic second-moment closure model** (ASM)
  + A new LES model with variable Smagorinsky constant is then presented.
  + **Flow around a cube, very old**

Robertson E., V. Choudhuryb, S. Bhushana,b,∗, D.K. Walters. Validation of OpenFOAM numerical methods and turbulence models for incompressible bluff body flows.

* Filename: robertson2017validation
* Abstract
  + verification and validation study was performed using the open source computational fluid dynamics solver OpenFOAM version 2.0.0 for incompressible bluff body fluid flows
  + flow over a backward facing step, a **sphere in the subcritical regime**, and delta wing with sharp leading edge

Rodriguez, I., RICARD BORELL2, ORIOL LEHMKUHL1,2, CARLOS D. PEREZ SEGARRA1 and ASSENSI OLIVA. Direct numerical simulation of the flow over a sphere at Re = 3700.

* Filename: rodriguez2011direct
* Abstract
  + **direct numerical simulation** of the flow over a **sphere** is performed
  + sub-critical regime at Re=3700
  + flow separates laminarly near the equator of the sphere and transition to turbulence occurs in the separated shear layer
  + a large number of turbulence statistics are computed and **compared with previous experimental and numerical data**

Rai, Man Mohan. TOWARDS DIRECT NUMERICAL SIMULATIONS OF TURBULENT WAKES.

* Filename: rai2008towards
* Abstract
  + three direct numerical simulations (DNS) of transitional/turbulent cylinder wakes are presented here.
  + A high-order accurate, upwind-biased, iterative-implicit, finite-difference scheme is used to solve these equations
  + **Example of very crude DNS**

Spalart, P. Detached-Eddy Simulation

* Filename: spalart2008detachededdy
* Abstract:
  + **Detached-eddy simulation (DES)** was first proposed in 1997 and first used in 1999
  + initial motivation of high– Reynolds number, massively separated flows, **better than RANS, LES**
  + Its principal weakness is its response to ambiguous grids, in which the wall-parallel grid spacing is of the order of the boundary-layer thickness
  + Separation is the essential flow feature motivating DES, with the expectation that the boundary layer is treated with RANS and is quasi-steady, but the free shear layer it feeds develops LES content.
* Basics
  + Run simulations with **complete** geometry of complex, bluff bodies
    - Full-scale aircraft, cars
    - Flight Reynolds number
    - Good accuracy
* Conceptual History
  + DES combined LES and RANS, spurred by the belief that each alone was powerless to solve the problem at hand (Spalart et al. 1997).
  + The **objection to pure LES centers on computational cost**
  + RANS predicts boundary layers well**, not so much separation**
  + A second motivation for DES over RANS: even if RANS were accurate, would **need unsteady information for** engineering purposes (e.g., vibration and noise).
  + **A working definition** is that the boundary layer is treated by RANS, and regions of massive separation are treated with LES
* Types of Simulation for Massive Separation
  + URANS
    - drag and lift fluctuations were overpredicted by URANS, although shedding frequency was accurate
    - URANS : running a transport equation turbulence model, in unsteady mode and with periodic spanwise conditions.
    - **URANS largely suppresses three-dimensionality, but not completely**
    - in a complex geometry, **sometimes the DES grid and time step only allow, effectively, URANS** near the smaller components.
  + **DES solutions** with different base RANS models **are not sensitive to model choice in the LES region** (as opposed to the RANS region, particularly if separation occurs).
* Strengths
  + Solve delta wing accurately
  + Correctly predict laminar/turbulent separation of sphere
  + Applications
    - Bluff bodies
    - **Aerodynamic noise**
* Weaknesses
  + The criticism of URANS mentioned above (namely that the approximate PDE that is solved is known, but the exact PDE it is meant to approximate is not) does not truly apply to DES
  + **literature reflects a desire for an approach that is somehow more justified and mathematically defined than DES**
    - The energy split can be adjusted in different regions, but this increases the decision load for the user.
  + Is SAS better?
    - With RANS-LES hybrids, it has even been proposed to dispose with any length scale of the nature of a filter width or grid scale.
    - Menter et al.’s (2003) model differs from traditional RANS in its use of a higher derivative of the velocity field, which is highly active on short scales.
    - **the SAS work is motivated by the disruptive effects of grid spacing in DES with ambiguous grids**
  + Order of accuracy
    - **An order of accuracy has not even been proposed for a simulation using both modes within DES**
  + Grid Induced Separation
    - Grid causes DES to separate BL
    - Menter & Kuntz (2002) proposed a solution applicable to the SST model called shielding, in which the DES limiter is disabled as long as the flow is recognized as a boundary layer,
    - Spalart made delayed DES
    - **Either modification successfully prevents GIS by extending the RANS region**, exploiting a history effect
* Recent Proposals
  + Zonal DES
    - In zonal DES, the user explicitly marks different regions as RANS or as DES
    - **Motivation: fully safe from grid induced separation**
    - Compared with DES, ZDES appears simultaneously more powerful and less self-sufficient.
  + Delayed Detached-Eddy Simulation
    - DDES detects boundary layers and prolongs the full RANS mode, even if the wall-parallel grid spacing would normally activate the DES limiter.
    - **DDES is likely to be the new standard version of DES.**
  + Improved delayed DES (IDDES)
    - approach is also nonzonal and aims at resolving log-layer mismatch in addition to MSD
    - new definition of grid spacing Delta, new empirical functions
* Numerical Requirements
  + most effective schemes are structured and hybrid, not only in their treatment of turbulence, but also in their numeric
  + An advantage of DES is the **ease of programming and application.** Potentially, it is activated directly from the menu of turbulence models in many of the vendor CFD codes. This is **a double edged advantage**, as users not invested in turbulence and/or too trusting of the experts could accept results without verifying LES content, grid resolution, time step, time sample, and so on.

Forsythe, James, Kyle D. Squires, Kenneth E. Wurtzler, Philippe R. Spalart. Detached-Eddy Simulation of the F-15E at High Alpha.

* Filename: forsythe2004detachededdy
* Abstract:
  + **Detached-eddy simulation (DES)** is used to predict the **massively separated flow around an F-15E at 65-deg** angle of attack
  + chord-based **Reynolds number of 13.6 × 106** and **Mach number of 0.3**
  + unstructured grids with the commercial solver Cobalt
  + DES predictions are assessed via **comparison to Boeing’s stability and control database** as well as to solutions of the Reynolds-averaged Navier–Stokes (RANS) equations
  + DES predictions of the lift, drag, and pitching moment, which were averaged over as many as 150 inertial timescales, **agree with the data more favorably** than the RANS results, **but both methods are within 10% of** the database
  + The **cost of DES was approximately seven times higher** than the steady RANS calculations on the same grid.

Smith. Numerical investigation of the flow over a golf ball in the subcritical and supercritical regimes

* Filename: smith2010numerical
* Abstract:
  + direct numerical simula- tions (DNS) are conducted to understand the role of surface dimpling on the flow over a non-rotating golf ball
  + ubcritical flow at a Reynolds number of 2.5 104 and a supercritical case at a Reynolds number of 1.1 105

Cimarelli, Andrea \*, Adriano Leonforte, Diego Angeli. Direct numerical simulation of the flow around a rectangular cylinder at a moderately high Reynolds number.

* Filename: cimarelli2018direct
* Abstract
  + Direct Numerical Simulation (DNS) of the flow around a rectangular cylinder (elongated)
  + Reynolds number Re = 3000

Taylor, Z.J., a, E. Palombi a, R. Gurka a,b, G.A. Kopp. Features of the turbulent flow around symmetric elongated bluff bodies.

* Wind tunnel test of elongated bluff bodies

Hangan, H. Vickery, B.J. A wake model for two-dimensional (sharp-edged) bluff bodies.

* Filename: hangan1997wake
* Abstract
  + two-dimensional wake model for turbulence profiles is developed for (sharp-edged) bluff bodies based on similarity (self-preservation) and universality (different shapes)
  + **Empirical (experiment-based)** wake model

References from 2017

Ravindra G. Devi, Joseph Mathew, Peeush K. Bishnoi, Computations of turbulent near wakes of axisymmetric bodies

* Comparison of turbulence models over ellipsoid and sphere
  + K-epsilon, k-omega, Reynolds stress model
  + Before and after separation
  + Compare to experimental data
  + Previous studies have concerned LES and DNS
    - But RANS is an industry standard, it need its own studies
    - This paper provides that
* Solutions using CFX-5 finite volume solver
  + Grid made with unigraphics and ICEMCFD, unstructured
* Table 1 – compare global properties: drag coefficient, separation location, etc
* Turbulent intensity – Fig 4-6
  + No explanation of how calculated or which model used (probably RSM)

Catalanoa, Pietro, MengWangb, GianlucaIaccarinob, ParvizMoin, Numerical simulation of the flow around a circular cylinder at high Reynolds numbers

* Simulate flow around circular cylinder
  + Show LES is better than URANS
* Qualitative results
  + Compare wake contours
* Quantitative results
  + Compare mean flow velocities
  + Compare force coefficient time histories
* No turbulent parameter analysis

H.F. Lam\*, H.Y. Peng, Study of wake characteristics of a vertical axis wind turbine by two- and three-dimensional computational fluid dynamics simulations

* Filename: lam2016study
* Simulate flow past vertical axis wind turbine (entire structure, not just blades)
  + Transition SST (4-eqn) and DES
  + Validate with PIV data
* Previous work
  + Ferreria: PIV of real wind turbine
  + McLaren: 2-D Unsteady Reynolds Averaged Navier Stokes (URANS) with Shear Stress Transport (SST) turbulence closure on turbine blades
* Computational modeling
  + Mach < 0.3, use incompressible URANS
  + Use SST for resolving turbulent flow
    - Blends k-omega in close-wall with k-epsilon in far field
    - Transition SST: improved 4 eqn model
      * Accurately predict separated flow transition
  + Use Improved delayed DES (IDDES) to verify sensitivity to turb. Model
    - Based on SST, but also DES
  + SIMPLEC pressure-velocity coupling scheme
  + Sensitivity studies performed
    - 1st then 2nd order schemes
    - time step study
    - grid sensitivity study
    - Use wake stream velocity to check convergence – fig 6
    - Validate convergence by comparison to PIV
  + Wake profiles of SST and IDDES were identical
    - Not sensitive to turbulence model
    - Use SST for further analyses
* 3D SST Results
  + presented turbulence intensities are average of intensities in all 3 directions
  + Plot mean velocities and average turbulent intensities of 2D/3D cases
    - Plot profiles along different horizontal and vertical lines (HLs and VLs)
      * Note the orientation of the axes so that horizontal/vertical are intuitive
    - Horizontal line mean flow (fig 8, 9) and turb. Intensity (fig 10)
    - vertical line mean flow (fig 11, 12) and turb. Intensity (fig 13)