Overview for: Applications of LES & Wall modeling
Parviz Moin, George Ilhwan Park, Brian Pierce

Need for LES and wall modeling
- RANS not predictive for complex flows (e.g. separation, unsteadiness, mixing, etc.)
- For certain quantities of practical interest LES is required (e.g., pressure fluctuations)
- Improvements on RANS (DES, DDES, D^N^ES) are not robust, require significant parameter tuning
- LES offers parameter free, predictive solution, but still requires important innovative research
- But, not all LES' are equal

Current research problems
- Numerics
  - LES has special constraints on the mesh quality
  - Numerical dissipation/dispersion
  - Grid generation
  - Moving mesh
- Robustness
  - Parameter free (no tuning of model coefficients)
  - Stable solutions (higher order conservation) with polyhedral mesh
- Large problems and HPC
  - Scaling of large calculations in low-Mach (3-4% flop efficiency)
  - Wall modeling for high Re external aerodynamics including roughness.
    Not as critical for internal separated flows
- Multi-physics
  - Capturing dynamics of interfaces
  - Conjugate heat transfer
  - Fluid structure interaction
A comprehensive DNS database to investigate measures of roughness and LES wall models
L. Chan, M. MacDonald, D. Chung, N. Hutchins, A. Ooi (University of Melbourne)
I. Bermejo-Moreno, B. Pierce, G. I. Park (Center for Turbulence Research)

Background
- Motivation: understanding and predicting flow over complex 3D roughness, e.g. biofouling, wild fires.
- Previous studies:
  - 2D roughness (Nakayama, Hori & Street 2004)
  - Fractal roughness (Anderson & Meneveau 2011)

Research Issue
- Aim: to simulate flow over roughness without gridded roughness (wall model).
- What level of detail is sufficient for 1st- and 2nd-order statistics?

Research Approach and Methods
- 1) DNS database
  - Pipe flow
  - Gridded 3D roughness
  - Unstructured code CDP
  - Get drag coefficient
- 2) Apply wall model
  - Set drag coefficient
  - DNS (isolate SGS model and numerics)
  - Focus on filter-scale effects
  \[ \Delta_1 > \Delta_2 > \ldots \]

Expected Outcome
- Quantification of filter-scale effects.
- Criterion for statistical “resolution” of roughness.
- Vision: downloadable library of drag coefficients.
- Possible collaborations:
  - Dynamic non-equilibrium wall model
  - Dynamic slip boundary condition
Analysis of the shock boundary layer interaction at high Reynolds number involving transition and turbulence
Marianna Braza and Damien Szubert, Juan Alonso and Ik Jang

Background
- Laminar vs. turbulent boundary layer (effects on skin friction)
- Laminar vs. turbulent shock-wave / boundary layer interaction (effects in unsteady dynamics, separation)
  - Optimal transition location?
- (Limited) experimental results available

Research Issue
- Most of the experimental geometry taken in account at high Reynolds number \((Re = 34 \times 10^6 \text{m}^{-1}, Re_\theta \approx 2000)\)
- Very thin B/L (seeding and resolution issues for PIV measurements, particularly in laminar B/L)
- Measurements of unsteadiness (same issue as previous point) : frequencies, amplitudes
- Predict/modelling laminar and transitional B/L

Research Approach and Methods
- Up to now : (U)RANS and DDES, for transitional and fully turbulent B/L by use of the Navier-Stokes Multi-Block code (structured, finite volumes, Memcom format database)
- LES (code at CTR) for laminar and transitional test case
- Modelling of AVJG (air vortex jet generator), RVG (rod vortex generator)

Expected Outcome
- DDES / LES comparisons
- Transition modelling
- Control devices modelling
DNS/LES Simulations of Separated Flows at High Reynolds Numbers
P. Balakumar, Flow Physics and Control Branch, NASA LaRC, Parviz Moin

Background
- Prediction of separated flows with existing RANS turbulence models is still not very satisfactory. It is difficult to accurately capture both the separation and reattachment points (i.e., the size of the separation bubble). The computed Reynolds stresses were 2 to 3 times smaller than measured values. LES are suitable for massively separated flows. We want to apply this technique for massively separated flows at high Reynolds numbers and to problems that interests to NASA.

Research Issue
- Implement LES technique into the existing NS code and perform LES simulations for separated flows at high Reynolds numbers. Investigate suitability of different models and grid requirements.
- Based on the findings LES will be used to simulate relevant aerodynamic problems (e.g. Airfoils, juncture flows and shock-BL interactions).

Research Approach and Methods
- N-S code is available. Upwind WENO, KE preserving, Compact schemes. RK time int. 
- DNS data is available for \( Re_b = 2800 \) and for \( Re_b = 10595 \), computations are being performed.
- Perform LES simulations with different SGS models

Expected Outcome
- Computations of massively separated flows using LES: Grid requirements, effects of different models: Are there new or better models or approaches possible?
- CTR: George Ilhwan Park, Brian Pierce, and other participants at the Summer Program
DNS/LES Study of Unsteady Wing/Flap for Precision Control in Enhanced Carrier Landing
YikLoon Lee, David B. Findlay (NAVAIR, Patuxent River MD) Prof. Juan Alonso (CTR-Host)

Background
- This research supports a new and better method for carrier landing that utilizes lift from moving flap for control.
- DNS/LES is usually applied to non-moving bodies. Here, moving flap is an essential flow characteristic.

Research Issue
- Design grids for wing & flap, move flap sinusoidally, compute lift, study gap effect, observe flow separation.
- Research issues:
  - inter-grid/region boundary condition
  - 6th order compact scheme, & accuracy for curvilinear grid
  - scales multi-algorithm code with problem size, time step, grid resolution required
  - visualization
- Two ways to contribute.
  - Algorithmic – multi-algorithm moving-body code on many cores that scales reasonably
  - Results – as data for F/A-18 RANS calc.

Expected Outcome
- New direction – Computed lift, not experimental, will be used to compare with NAVAIR RANS results.
- Seek CTR expertise in a range of issues in DNS/LES to help establish new NAVAIR in-house capability.

Research Approach and Methods
- An internal compressible flow code designed for moving bodies with various types and range of motion.
- Extent of DNS region (alternative: as large as code and HPC allows).
- Parallel compact schemes at partition boundaries (alternative: non-compact schemes?)
- Static results (Fig.)
Wall-resolved large Eddy simulation in refinery ribbed pipes

Julien Bodart (1), Manqi Zhu (2), T. Poinso (2,3) Host in CTR: Julien Bodart

Background
- Ribbed tubes are used to improve heat transfer efficiency and chemical selectivity. One key issue is to minimize the additional pressure loss due to ribs.
- Turbulent smooth tubes have been extensively studied, but little is known about ribbed tubes.
- Our objective is to study the wall flow in turbulent ribbed tubes and to identify possible paths for modelling.

Research Issue
- Experimental data are very disperse, and numerical investigations are rare and only based on RANS.
- Standard wall laws do not describe the complex work for turbulent wall flow in ribbed tubes.
- Wall Resolved LES require high quality and refined meshes, leading to high CPU cost.

Research Approach and Methods
- Wall Resolved LES ($y^+ = 1$) are used to analyse the wall flow structure and propose wall flow modelling (currently running).
- Models are tested in Wall Modeled LES ($y^+ = 10$)
- Two codes are used: AVBP (CERFACS) and CHARLES (CTR)
  - comparison of results
  - tests of available wall models in CHARLES

Expected Outcome
- WRLES of smooth and ribbed pipes with codes AVBP and CHARLES.
- Analysis of wall flow in ribbed pipes.
- Wall model(s) adapted to ribbed pipes, implementation and test with (possibly) both codes.

(1) ISAE/DAEP, Toulouse University, France   (2) CERFACS, France   (3) IMFT, CNRS, France
Background

- Successful design of high efficiency compact compression systems depends on reliable predictive tools.
- State-of-the-art 3D RANS simulations often yield inaccurate predictions due to their lack of ability to capture laminar-to-turbulent transition, as well as their erroneous predictions of turbulent boundary layer separation.
- While wall-resolved LES has been applied successfully for 2D cascades, cost of simulations for 3D configurations is still prohibitive.
- Wall-modeled LES is promising, yet its application to turbomachinery has not been widely explored.

Research Issue

- The objective of CFD for turbomachinery is to accurately predict the overall pressure ratio, efficiency, choke and stall margin.
- Good overall predictions require correctly capturing transition, shock location, shock boundary layer interaction, boundary layer separation and the size of separation bubble and wake thickness, end-wall flows and tip-gap vortices.
- Ability of wall-modeled LES to capture these flow features - especially transition, shock BL interaction and BL separation will be explored.
- As a well documented canonical case, NASA Rotor 37 will serve as initial benchmark.

Research Approach and Methods

- NASA Rotor 37 - transonic axial flow rotor, at 70% span: relative Mach ~1.45, Reynolds number: 1.33M
- Compressible LES solver: Charles, Cascade Technologies
- Wall model: integral constrained equilibrium wall model
- Correctly predicting laminar to turbulent transition using a wall modeled LES may be challenging.
- Sensitivity studies to grid refinement, inflow disturbances, and wall-model formulation (e.g. transition sensor) are required.

Expected Outcome

- Wall-modeled LES will be proven to capture dominant flow features in a turbomachinery rotor, at a manageable computational cost.
- Setting up best-practices for wall-modeled LES in turbomachinery (e.g. grid resolution, inlet turbulence, etc.)
- Identify what flow features have first-order impact on the overall performance and which of those are incorrectly captured in RANS simulations.
- Collaboration with CTR and Summer Program participants focused on LES wall modeling, transition, shock boundary layer interaction, and roughness.
Large Eddy Simulations of Steam Turbine Control Stage for Estimation of Steam Force on Rotating Blades
[Hyun-joong Kim, Hoon Lee and Doosan Heavy Industries & Construction, Dookyun Kim, Frank Ham Gianluca Iaccarino]

Background
- Partial admission is used to control load in the 1st stage of high pressure turbine* and it increases stage efficiency at part load operation via avoiding throttling.
- Under partial admission, steam is admitted to rotor blade through only a part of its annulus inlet, or so called “active arc”. This non-uniformity gives the rotor rapid & huge load fluctuations that may cause structural & fatigue failure.
- It is important to estimate the excitation forces acting rotor blades to improve reliability.

Research Issue
- LES is essential to predict high frequency excitation forces due to unsteady flows which URANS cannot capture because of the presence of a complex flow response
- Identification of flow-pattern transitions, intermittency and potential time-lag at the border of the inactive arc where rapid velocity change is occurred

Research Approach and Methods
- CFD SW: CHARLES (Cascade Compressible LES code) & Fluent (RANS, SST k-ω)
- Gust analysis is used to model time-dependent velocity distribution of partial arc admission as an inlet disturbance of single rotor passage
- Inlet velocity for single rotor passage is from the result of 360° RANS analysis

Expected Outcome
- More precise frequency and amplitude of pressure oscillation on rotor surface for mechanical analysis than URANS result
- Detailed vortex patterns around the rotor in control stage
- We hope that this research will be a touchstone for adopting state-of the-art LES technology of CTR into supercritical steam turbine.

* 1st stage of high pressure turbine = control stage