Turbulence Modeling Effects

Aeroelastic Prediction Workshop 2

January 2 2016
San Diego

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Outline

• Overview of turbulence model classes and models used by workshop analysts
• Overview of Reynolds stress models
• Effect of turbulence models on one of the static cases
  • Case 3A (Mach = 0.85, AOA = 5 deg, Gas: R-134a)
• Effect of turbulence models on one of the dynamic cases
  • Case 2 (Mach = 0.74, AOA = 0 deg, Gas: R-12)
• Summary and future outlook
RANS Turbulence Model Classes

- Linear eddy viscosity models (LEVM)
  - Based on the Boussinesq assumption
  - Involves the solution of one or more partial differential equations (could also be algebraic)
- Non-linear eddy viscosity models (NLEVM) and algebraic explicit Reynolds stress models (EARSM)
  - Based on a linear model as the background model
- Reynolds stress models (RSM, also known as second-moment closure models)
- Hybrid RANS/LES (sometimes also known as DES)
## Turbulence Models Employed

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Spalart Allmaras Turbulence Model

- The standard model heavily relies on calibration to a wide range of experimental data.
- Has advantage over other models when applied to attached flows.
- Suffers from excessive separation at junction flows and has shortcoming when simulating unsteady flows involving considerable separation.
- Has many versions, each developed to address certain issues.
Example of Excessive Separation around Junction: Static Case 3A
The original version is considered the standard version

Also has many versions

The most popular two equation model

Like all linear models, the main shortcomings are its difficulty to accurately predict unsteady flows involving massive separation and flows involving streamline curvature
Reynolds Stress Models

- RSM are not based on the Boussinesq assumption and therefore the assumption that the turbulent shearing stress is proportional to the rate of mean strain is dropped.
- Exact transport equations for the Reynolds stresses are derived from the Navier-Stokes equation and the models are based on the solution of these equations.
- The production term does not require approximations.
  - The production term is primarily responsible for the anisotropy and the selective response of turbulence to different strain types.
- RSM are becoming more affordable.
RSM Varieties Considered

- SSG/LRR-\(\omega\) (AIAA J. 2015)
  - Omega based model
  - Uses a blend of two pressure-strain models, the LRR model is activated in the near wall region while the SSG model is activated further away
- MCL (AIAA J. 1999)
  - A modification for compressible flow of the Craft-Launder closure model (TCL)
  - Employs a cubic pressure-strain model
  - Topology free (no need for wall distance)
Predicted Junction Flow by the SSG/LRR-ω Model: Static Case 3A
Turbulence Model Effects on Shock Prediction: Static Case 3A

SA-Edwards

\( y/b = 0.6 \)
Turbulence Model Effects on Shock Prediction: Static Case 3A

SST-2003

\( y/b = 0.6 \)
Turbulence Model Effects on Shock Prediction: Static Case 3A

SSG/LRR-ω

$y/b = 0.6$
Turbulence Model Effects
Convergence of Static Case 3A

![Graph showing the convergence of different turbulence models over iterations.](image-url)
Turbulence Model Effects
Convergence of Static Case 3A

![Graph showing lift coefficient convergence for SA, SST, and SSG/LRR-ω models](image-url)
Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate

![Graph showing lift coefficient over time step]
Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate

Lift coefficient vs. Time step graph
Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate
Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate
Turbulence Model Effects on Static Case
Inviscid Splitter Plate, MCL Model, Time-Accurate
Turbulence Model Effects
Flutter, Mach = 0.74, AOA = 0.0

First mode
Turbulence Model Effects
Flutter, Mach = 0.74, AOA = 0.0

Second mode
Summary

- Results concerning the prediction of the most challenging static case may significantly vary (case 3A, Mach = 0.85, AOA = 5)
  - All LEVM converge to a steady flow
  - SA and SGG/LRR-$\omega$ fail to predict the correct shock locations
  - SST predicts the (average?) shock location
  - MCL model fails to converge to a steady flow
    - Time accurate simulations result in shock oscillations that are similar to the experiment
- LEVM have very little effect on flutter case 2
Future Outlook

- Recent results show that adding a second nonlinear term to the linear Reynolds stress tensor — the so-called quadratic constitutive relation (QCR) — may alleviate the excessive junction flow separation problem
  - SA-Edwards-QCR2000
  - SST-2003-QCR2000
- Since Reynolds stress models become more affordable, they may provide other means for accurately simulating complex, unsteady, massively separated flows
- Hybrid models?
Thank You