FUN3D v12.7 Training

Session 6: Turbulent Flow Simulations

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Learning Goals

- Discuss some broad guidelines for turbulence models.
- List of available turbulence models (calorically perfect gas)
- Discuss the typical namelist parameters used.
- Show some sections of fun3d.nml namelists used for turbulent flow simulations.
- The detailed theory of turbulence models will not be covered in this session.
- Pros and cons of each model will not be discussed either due to time limitations.
  - All of the models will likely work some of the time.
  - But none of the models will work all of the time.

The List

Steady flow simulations

- One-equation
  - Spalart-Allmaras (`sa`), Recherche Aerospatiale, No. 1, 1994.
  - Negative Spalart-Allmaras (`sa-neg`), ICCFD7-1902, 2012.
- Two-equation
  - Menter-SST (`sst`), AIAAJ (32), 1994.
  - Menter-SST with vorticity source term (`sst-v`), NASA-TM-103975, 1992.
  - Menter-SST from 2003 (`sst-2003`), Turbulence, Heat and Mass Transfer 4.
  - Wilcox k-omega (`wilcox2006`), AIAAJ (46), 2008.
  - Wilcox k-omega (`wilcox1998`), Turbulence Modeling for CFD, 1998.
  - Wilcox k-omega (`wilcox1988`), AIAAJ (26), 1988.
  - Nonlinear k-omega (`EASMko2003-S`),J Aircraft (38), 2001.

The List

Steady flow simulations

- Four-equation
  - Langtry-Menter transition model (`gamma-ret-sst`), AIAA-2005-0522.
- Seven-equation
  - Wilcox Stress-omega RSM (`WilcoxRSM-w2006`), Turbulence Modeling for CFD, 2006.
  - SSGLRR-RSM (`SSGLRR-RSM-w2012`), AIAA Journal, Vol. 53, No. 3, 2015, pp. 739-755.

Other references and detailed explanations of the models can be found at the turbulence modeling website:

`http://turbmodels.larc.nasa.gov`

The List

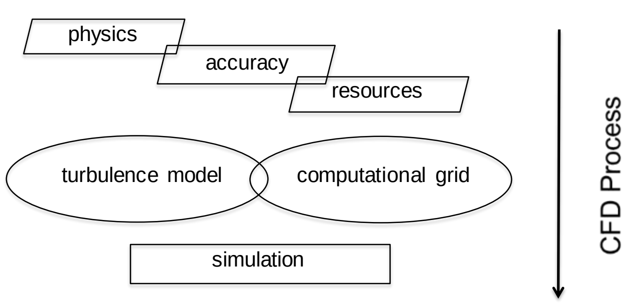
Time accurate flow simulations

- One-equation
  - Detached eddy simulations, (`des`, `des-neg`), TCFD (20), 2006.
- Two-equation
  - Hybrid RANS-LES (`hrles`), AIAA-2008-3854.

General usage guidelines

Do we even need to perform a turbulent flow simulation?

- Flow physics
  - What physics need to be simulated/predicted?
    - high speed flow -> *possibly* largely laminar
    - corner flow -> *possibly* anisotropic turbulence
    - blunt body wake -> *possibly* large eddy simulations
- Computational requirements
  - to evaluate the grid's resolution required for a certain accuracy



http://www.stanford.edu/class/me469b/handouts/turbulence.pdf, slide 51

General usage guidelines

- Appropriate spacing of the mesh on viscous solid walls must be used.
  - Generally accepted spacing is between .1 and 2.5 wall units.
  - Using wall functions, generally accepted spacing is between 0.1 and 250 wall units.
  - Many problems may have multiple scales, so no one physical distance for the first node spacing will suit the whole problem.
- Generate a mesh with appropriate resolution to model the problem (within the limits of the available computational resources).
  - Try not to expand the mesh spacing too quickly away from a viscous wall.
  - Typically the more curvature in the physical geometry, the higher concentration of mesh.
- One-equation models like Spalart-Allmaras tend to be very robust, cover a very wide range of flow situations and are a compromise between simplicity and accuracy.
- Multi-equation models like the Menter-SST or RSM require more computational resources, but are more physically complete and can, possibly, add more accuracy to the solution…though YMMV.

General usage guidelines

- Solutions to a steady state are adequate for many problems.
- Depending upon the physics of the simulation, though, time-accurate solutions may be required.

Namelists

fun3d.nml

For turbulent flow simulations, depending upon the turbulence model and problem the following namelists within fun3d.nml are used.

- **&governing_equations**
- **&turbulent_diffusion_models**
- **&spalart**
- **&gammaretsst**

Spalart-Allmaras

fun3d.nml

```
&governing_equations
  eqn_type      = 'cal_per_compress'
  viscous_terms = 'turbulent'
/

&turbulent_diffusion_models
  turbulence_model    ='sa'  !default
 ! current 1-eqn options: 'sa-neg', 'des','des-neg'
  turb_compress_model ='none'
 ! current options: 'ssz' ! (Ref. AIAA-95-0863, Shur et al.)
/
```

Spalart-Allmaras

fun3d.nml

```
&spalart
turbinf    = 3.0
  ! free stream value for spalart model
ddes       = .false.
  ! for activating delayed DES model
ddes_mod1 = .false.
  ! Mod to DDES, Ref. AIAA Paper 2010-4001
sarc       = .false.
  ! Ref. AIAAJ, Vol.38, No.5, 2000, pp.784-792.
sarc_cr3 = 1.0
  ! constant associated with SARC model
/
```


Menter-SST

fun3d.nml

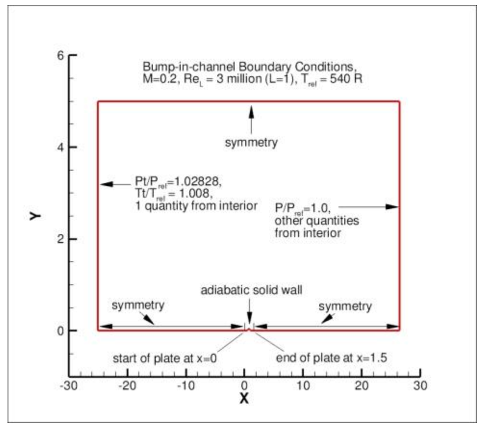
```
&governing_equations
  eqn_type       = 'cal_per_compress'
  viscous_terms = 'turbulent'
/
&turbulent_diffusion_models
  turbulence_model    ='sst'
!other options: 'sst-v', 'sst-2003', 'gamma-ret-sst'
! 'hrles'
/
&gammaretsst
  set_k_inf_w_turb_intsty_percnt = 0.2 ! (percent)
  set_w_inf_w_eddyviscosity      = 1.0 ! (nondim)
  transition_4eqn_on             = .true.
   ! toggles transition
/
```

Sample fun3d.nml

Subsonic bump using S-A

http://turbmodels.larc.nasa.gov/bump.html

```
&project
  project_rootname = 'bump_3levelsdown_177x81
/
&reference_physical_properties
 mach_number                 = 0.2
 reynolds_number             = 3000000.0
 temperature                 = 540.0
 temperature_units           = 'Rankine'
/
&turbulent_diffusion_models
 turbulence_model            = 'sa'
/
&nonlinear_solver_parameters
 schedule_iteration          = 1      250
 schedule_cfl                = 10.    250.
 schedule_cflturb            = 10.    250.
/
&boundary_conditions
 total_pressure_ratio(3)     = 1.02828
 total_temperature_ratio(3)  = 1.008
 static_pressure_ratio(4)    = 1.0
/
```



Sample fun3d.nml

Time accurate simulation using a S-A based DES model

```
&turbulent_diffusion_models
      turbulence_model    = 'des'
/

&nonlinear_solver_parameters
      time_accuracy          = '2ndorderOPT'
      time_step_nondim       =  0.10
      pseudo_time_stepping = 'on'
      subiterations          = 10
      schedule_iteration     = 1 100
      schedule_cfl           = 5. 5.
      schedule_cflturb       = 5. 5
 /
```

Details of running a time accurate simulations are covered in Session 11.

EOF

Turbulent flow simulations with Fun3D

Several turbulence model options are available in V12.7

Namelist nomenclature has been discussed.

Caveats:
Meshing and turbulence model decisions are highly dependent on the degree of fidelity and accuracy desired.

The desired aspects, though, may not fit inside the resources available.