FUN3D v12.7 Training

Session 5: Boundary Conditions

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PROBLÈMES SANS FRONTIÈRES

PROBLEMS WITHOUT BOUNDARIES

…is no problem at all…

Boundary Conditions

…but real problems have boundaries…

- Define the problem
- Solve the problem
- Cause problems

- Boundary condition list
- Usage
- Examples

Problem setup

Required files

- project name grid file: typically
  `project_name[.r8,.b8].ugrid`
- namelist input: `fun3d.nml`
- boundary conditions: `project_name.mapbc`
  - Contains list of boundaries ("in order") and the boundary condition to be associated with each one.
  - Keeping all the boundaries for a particular mesh separate (i.e. not lumping) can make for rather large and sometimes difficult to manage mapbc files.

Caveat: Not lumping boundaries, though, allows the user to retain a finer control over simulation parameters such as differing inflow/outflow conditions or transition, to name a few examples.

Dimensionalization

Non- and otherwise

- The non-dimensionalization of the field variables, in the calorically perfect gas path, results in the ratio of Reynolds number and Mach number appearing in the transport equations.

$$\frac{\mathrm{Re}_L}{M_\infty} = \frac{\tilde{\rho}_\infty \tilde{a}_\infty}{\tilde{\mu}_\infty} \qquad \tilde{\mu}_\infty = \tilde{\mu}_{std}\left(\frac{\tilde{T}_{std}+C}{\tilde{T}_\infty + C}\right)\left(\frac{\tilde{T}_\infty}{\tilde{T}_{std}}\right)^{3/2} \qquad \tilde{a}_\infty = \sqrt{\gamma R \tilde{T}_\infty}$$

- This ratio, along with the reference temperature, completely determines the flow conditions of the simulation. Tilde denotes a dimensioned parameter.

$$\tilde{u}_\infty = M_\infty \tilde{a}_\infty$$

$$\tilde{\rho}_\infty = \frac{\mathrm{Re}_L}{\tilde{u}_\infty}\tilde{\mu}_\infty$$

$$\tilde{p}_\infty = \tilde{\rho}_\infty R \tilde{T}_\infty$$

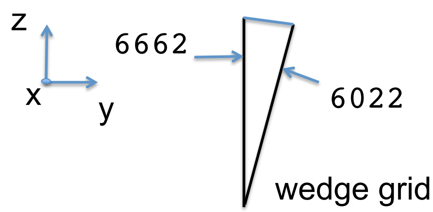
Useful for cross-checking auxiliary boundary condition data.

Boundary Condition List

- Boundary condition name (boundary condition number)
- Auxiliary data
- Limits
- Not a complete list

Symmetry

- `symmetry_x (6661)`, y-z plane
- `symmetry_y (6662)`, x-z plane
- `symmetry_z (6663)`, x-y plane
- `tangency (3000)`, tangential flow
- `symmetry_x_strong (6021)`, zero velocity in x-mom.eqn.
- `symmetry_y_strong (6022)`, zero velocity in y-mom.eqn.
- `symmetry_z_strong (6023)`, zero velocity in z-mom.eqn.



Wall

- `viscous_wall (4000)`, y+ < 5, $u_{wall} = v_{wall} = w_{wall} = 0$
- `viscous_weak_wall (4110)`, y+ < 5, τ_{wall} calculated
- `viscous_wall_function (4100)`, y+ < 500, τ_{wall} modeled

Wall

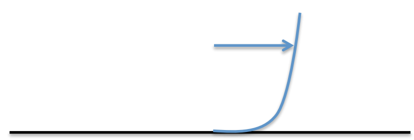
Auxiliary information

Adiabatic wall input for bc 4000

```
&boundary_conditions
   wall_temp_flag(1) = .true.
   wall_temperature(1) = -1.0
 /
```

Wall function input for bc 4100

```
&turbulent_diffusion_models
       turbulence_model = 'sa','sst'
       wall_function  = 'dlr'
       use_previous_utau  = T
     /
```

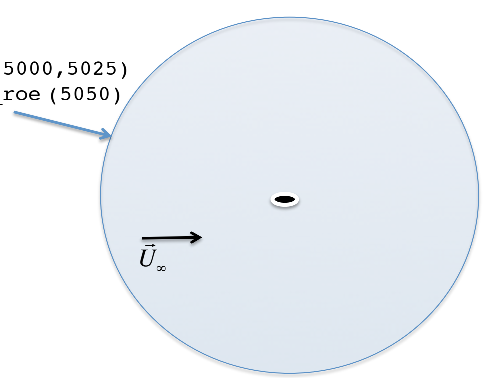


Farfield

Farfield boundaries use information from the `fun3d.nml` namelist parameter `mach_number (5000,5025,5050).`

$$\rho_\infty = 1, u_\infty = Mach, v_\infty = 0, w_\infty = 0, p_\infty = 1/\gamma$$

`riemann (5000,5025)`
`farfield_roe (5050)`



How far is far enough?
- Problem dependent
- No gradients

Outflow

- Extrapolation
  - `extrapolate (5026)`, both perfect and generic gas paths
  - all 5 primitive variables extrapolated, applicable for outflow Mach >= 1.
- Static pressure
  - `back_pressure (5051)`, extrapolates when local Mach >= 1.
  - `subsonic_outflow_p0 (7012)`, only applicable when local Mach < 1.
  - Auxiliary information required:

$$\text{static\_pressure\_ratio(ib)} = \tilde{p}_{\text{boundary}} / \tilde{p}_{\infty}$$

The static pressure ratio (SPR) is the requested static pressure on boundary `ib`, divided by the free stream static pressure.

Inflow

- Total pressure, total temperature
  - `subsonic_inflow_pt (7011)`, both perfect and generic gas paths
  - Auxiliary information required:

$$\text{total\_pressure\_ratio(ib)} = \tilde{p}_{\text{total,boundary}} / \tilde{p}_{\infty}$$

$$\text{total\_temperature\_ratio(ib)} = \tilde{T}_{\text{total,boundary}} / \tilde{T}_{\infty}$$

  - Flow direction is normal to the inflow face (default assumption).
  - Applicable for inflow Mach < 1.

Inflow

- Fixed inflow
  - `fixed_inflow (7100)`, calorically perfect gas path
  - Auxiliary information required:

$$\text{q\_set(ib,1:5)} = (\rho, u, v, w, p)_{\text{boundary}}$$

Strictly applicable for inflow Mach >= 1.

  - `rcs_jet_plenum (7021)`, generic gas path
  - Auxiliary information required: (contact Peter Gnoffo, fun3d_support)
- Massflow
  - `massflow_in (7036)`, calorically perfect gas path
  - Auxiliary information required:

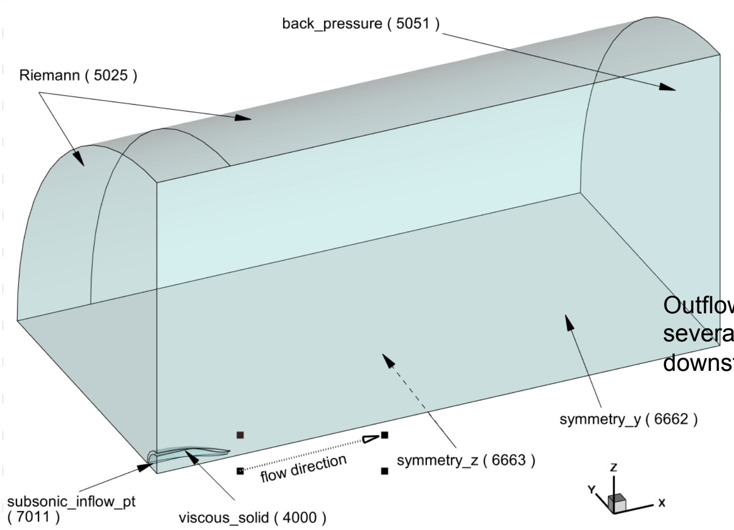
$$\text{massflow(ib)} = \tilde{\dot{m}}_{\text{boundary}} / \tilde{\rho}_\infty \tilde{a}_\infty$$

$$\text{total\_temperature\_ratio(ib)} = \tilde{T}_{\text{total,boundary}} / \tilde{T}_\infty$$

  - `massflow(ib)` will be in units of mesh squared

Nozzle flow strategies

Static jet case



Outflow boundary several jet diameters downstream of exit

Nozzle flow strategies

arn2.mapbc and fun3d.nml

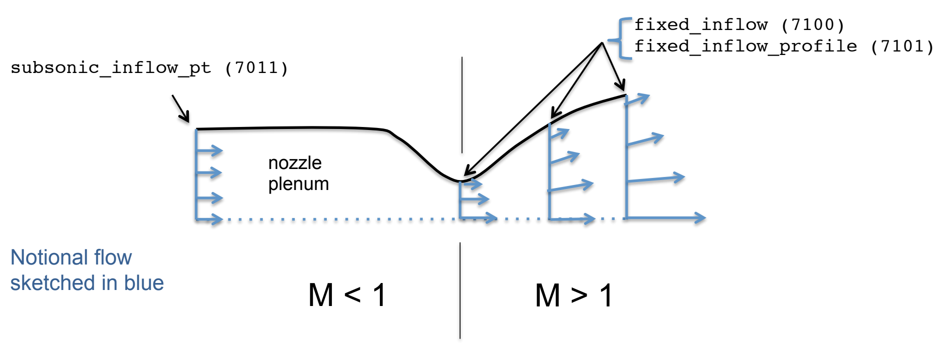
```
$ cat arn2.mapbc
  9 number of boundaries
  1   7011  nozzle plenum inflow boundary
  2   5025  farfield
  3   5025  farfield
  4   5051  outflow boundary
  5   4000  viscous solid
  6   6663  z-symmetry
  7   6662  y-symmetry
  8   5025  freestream inflow
  9   4000  viscous solid

 &boundary_conditions
   total_pressure_ratio(1)     = 1.357
   total_temperature_ratio(1)  = 1.764
   static_pressure_ratio(4)    = 1.0
 /
```

Note: Do not lump boundaries by type, if there are several inflow or outflow boundaries that require separate settings…

Note 2: This low a pressure ratio would typically not require special volume initialization.

Nozzle flow strategies

Scenarios for modeling a supersonic jet



- Subsonic
- Uniform
- Typically no flow angularity
- Well posed flow state, particularly with choked flow

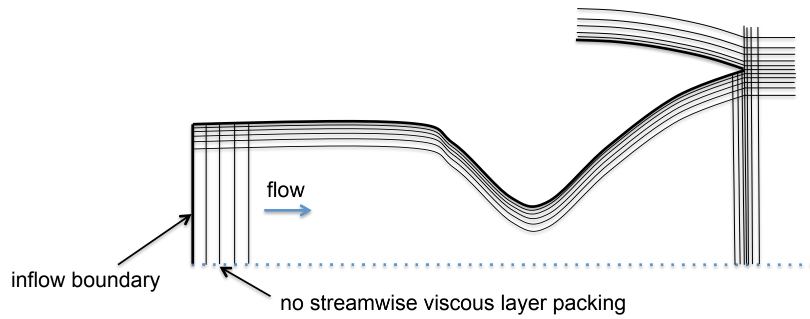
- Supersonic, but…

X Radial gradient due to boundary layer

X Off-axis component due to geometry

Nozzle flow strategies

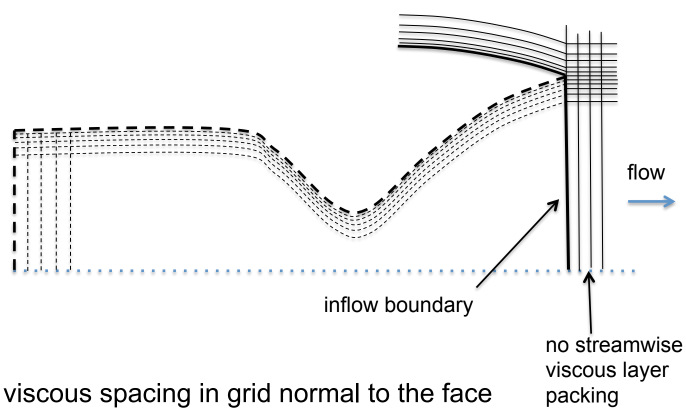
Scenarios for modeling a supersonic jet



No viscous spacing in grid normal to the face for either the subsonic or the supersonic inflow boundaries

Nozzle flow strategies

Scenarios for modeling a supersonic jet

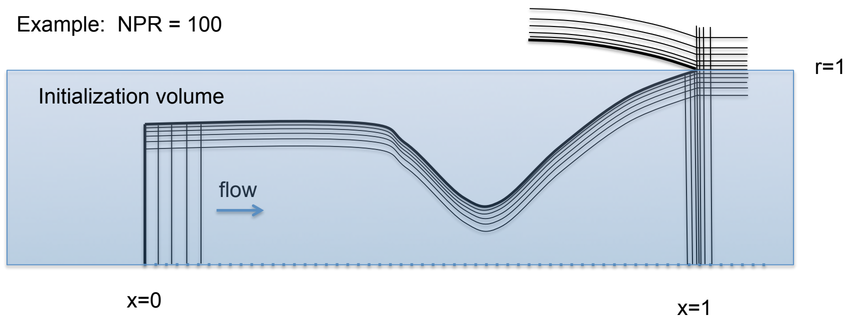


No viscous spacing in grid normal to the face for either the subsonic or the supersonic inflow boundaries

Nozzle flow strategies

Scenarios for modeling a supersonic jet

Example: NPR = 100




```
&flow_initialization
  number_of_volumes = 1
  type_of_volume(1) = 'cylinder'
  point1(1,:) = -0.2,0.,0.
  point2(1,:) =  1.2.,0.,0.
  radius(1)   = 1.0
  rho(1)      = 100.
  u(1)        = 0.1
/
```

Solution startup can often be facilitated by using flow initialization

Nozzle flow strategies

fixed inflow namelist parameters

`fixed_inflow (7100)`

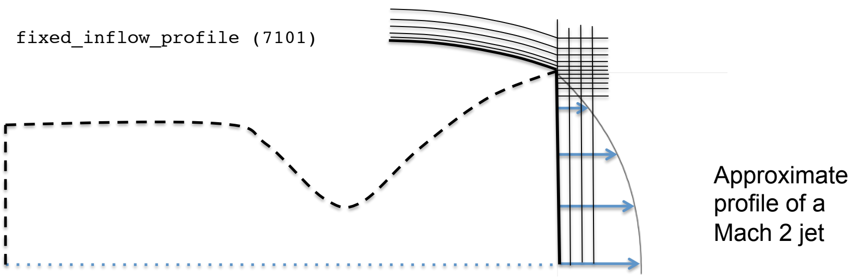
$$\rho = q\_set(ib,1)$$
$$u = q\_set(ib,2)$$
$$v = q\_set(ib,3)$$
$$w = q\_set(ib,4)$$
$$p = q\_set(ib,5)$$

`fixed_inflow_profile (7101)`

$$\rho = \sum_{n=0}^{6} profile\_rho\_coef(ib,n) * r^n$$
$$u = \sum_{n=0}^{6} profile\_u\_coef(ib,n) * r^n$$
$$p = \sum_{n=0}^{6} profile\_p\_coef(ib,n) * r^n$$
$$r = \sqrt{(p(1:3) - patch\_center(ib,1:3))^2}$$

Nozzle flow strategies

`fixed_inflow_profile`

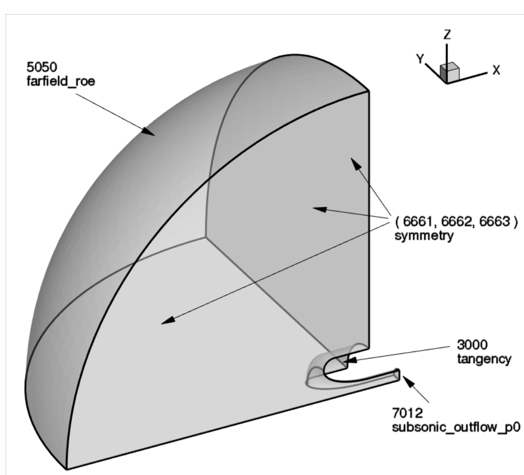


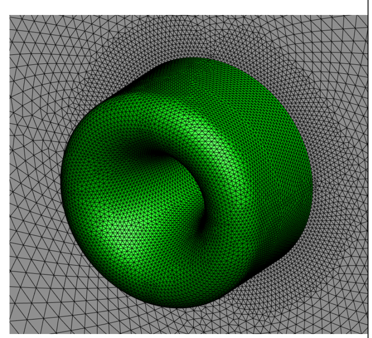

```
&boundary_conditions
  patch_center(1,:)    =-2.0,0.,0.
  patch_scale(1)       = 1.
  profile_rho_coef(1,0)= 1.
  profile_u_coef(1,0)  = 2.
  profile_u_coef(1,1)  = 0.
  profile_u_coef(1,2)  = -1.
  profile_u_coef(1,3)  = -1.
  profile_p_coef(1,0)  = 0.714
/
```

This sample namelist creates a profile constant in density and pressure, and cubic in velocity, centered on (-2.,0.,0.) and physically scaled by the factor of 1. for boundary 1.

Inlet flow strategies

Bell mouth





```
&reference_physical_properties
  mach_number        = 0.20
  temperature_units  = 'Rankine'
  temperature        = 390.0
/
&boundary_conditions
 static_pressure_ratio(1) = 0.95
/
```

Inlet flow strategies

Bell mouth

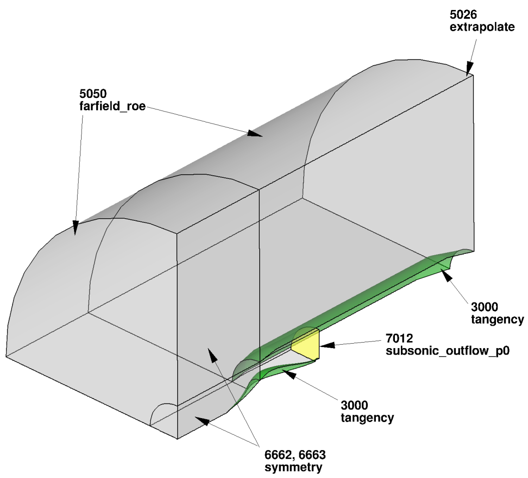
```
#Tue Apr  8 12:48:03 2008
#bell2.mapbc
Patch #         BC            Family   #surf   surfIDs         Family
#--------------------------------------------------------------------------
1               7012          1               0            0        inlet
2               5050          1               0            0        freestream inflow
3               6662          1               0            0        symmetry_y
4               6663          1               0            0        symmetry_z
5               5050          2               1            8        farfield roe
6               3000          5               0            0        bellmouth
7               3000          5               0            0        bellmouth
```

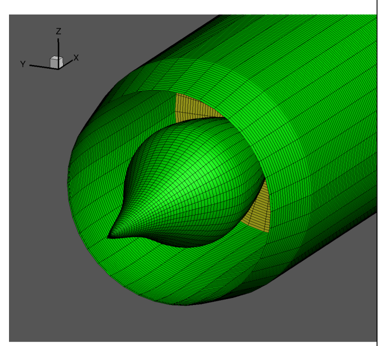
fun3d.nml

```
&governing_equations
   viscous_terms         = 'inviscid'
/

&reference_physical_properties
   temperature_units  = 'Rankine'
   mach_number        = 0.20
   reynolds_number    = 1.0e+5
   temperature        = 390.0
/

&boundary_conditions
 static_pressure_ratio(1)  = 0.95
/
```


Inlet flow strategies

Supersonic inlet





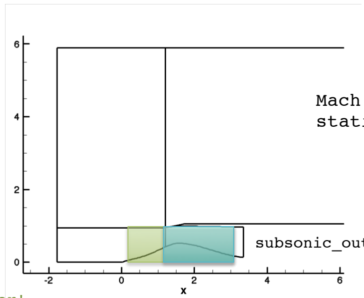

```
&reference_physical_properties
   mach_number        = 1.6
   temperature_units  = 'Kelvin'
   temperature        = 216.0
/
&boundary_conditions
 static_pressure_ratio(18)  = 3.7
/
```

Inlet flow strategies

Supersonic inlet

Flow initialization

flow →




```
&flow_initialization
number_of_volumes = 2
! Inlet 1
   type_of_volume(1) = 'cylinder'
     point1(:,1) = 0.0,0.,0.
     point2(:,1) = 3.0,0.,0.
     radius(1)    = 0.90
     u(1)         = 1.0
 ! Inlet 2
   type_of_volume(2) = 'cylinder'
     point1(:,2) = 1.0,0.,0.
     point2(:,2) = 3.0,0.,0.
     radius(2)    = 0.90
     u(2)         = 0.6
 /
```

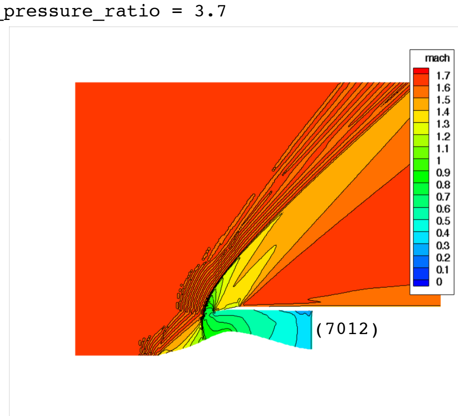
Solution startup can often be facilitated by using flow initialization. In this case, it is just about required…

Inlet flow strategies

Supersonic inlet

```
Mach = 1.6
static_pressure_ratio = 3.7
```

flow →



Additionally, aggressive CFL ramping is sometimes required. In this case, to push the shock out of the inlet.

```
&boundary_conditions
    static_pressure_ratio(18) = 3.70
/
&nonlinear_solver_parameters
 time_accuracy      = 'steady'
 schedule_iteration = 1  200
 schedule_cfl       = 1. 500.
/
```

Boundary conditions

- References
  - Inflow/Outflow Boundary Conditions with Application to FUN3D, Jan-Renee Carlson, NASA/TM-2011-217181, October 2011.
  - FUN3D V12.7 User manual

http://fun3d.larc.nasa.gov/chapter-1.html#user_manual

EOF

- Listed available boundary conditions (slightly abridged)
- Along with some typical usage
- Tips on heading off (mostly startup) problems