FUN3D v13.4 Training

Session 6: 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|.lr8|.b8|.lb8].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, component force tracking or transition, to name a few examples.

Dimensionalization

Non- and otherwise

- The nondimensionalization 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.

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

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

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

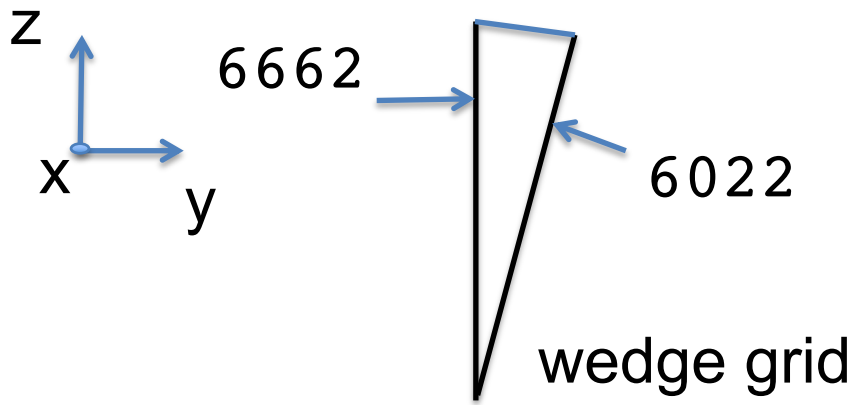
Useful for cross-checking auxiliary boundary condition data.

Boundary Condition List

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

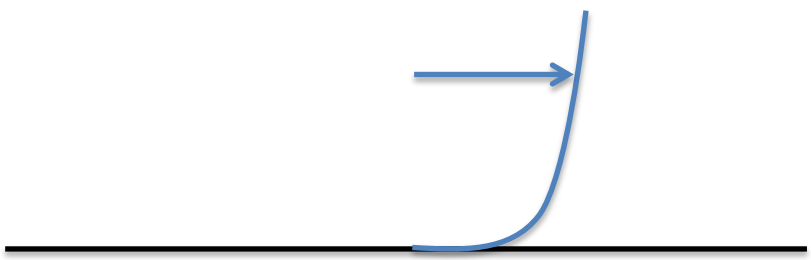
Symmetry

- `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

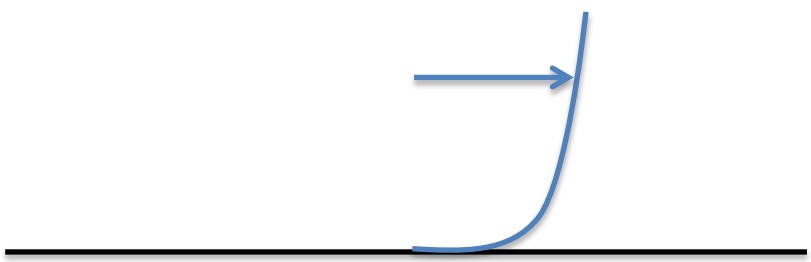
Auxiliary information

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
     /
```

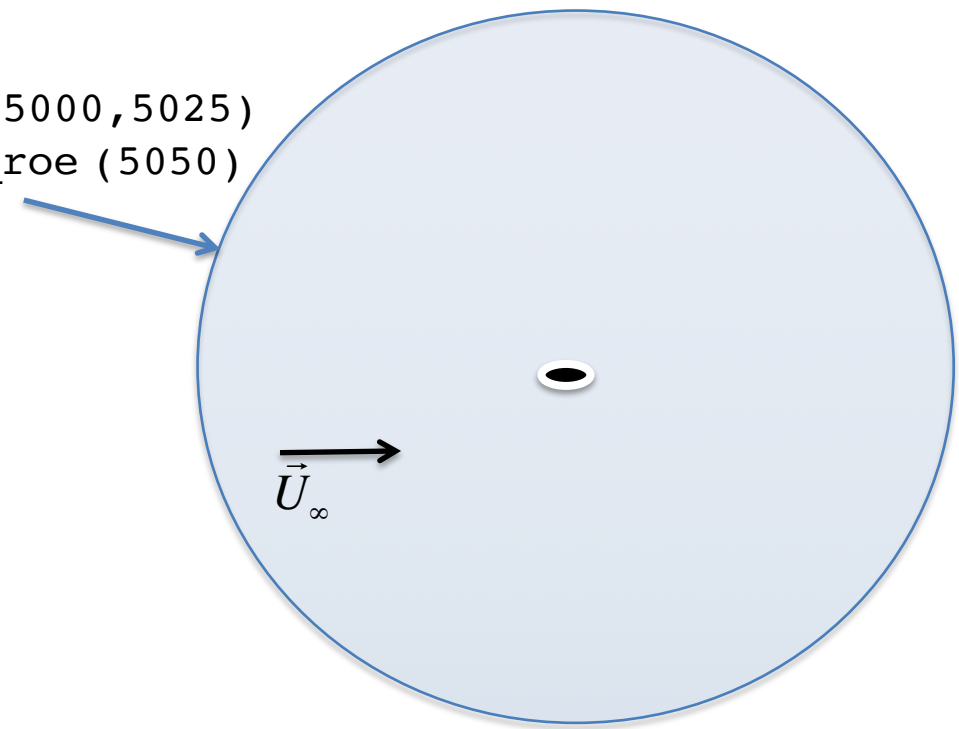


Farfield

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
- Basically have 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.
  - `fwm_nrbc (5060)`, non-reflecting outflow bc
  - Auxiliary information required:

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

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)`, calorically perfect gas path
  - `rcs_jet_plenum (7021)`, generic gas path
  - Auxiliary information required:

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

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

  - Flow direction is normal to the inflow face (default assumption).
  - Applicable for inflow Mach < 1.
  - Auxiliary information required when using the generic gas path version: (User manual, also contact Kyle Thompson or fun3d_support)

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.

- Massflow
  - `massflow_in (7036)`, calorically perfect gas path
  - Auxiliary information required:

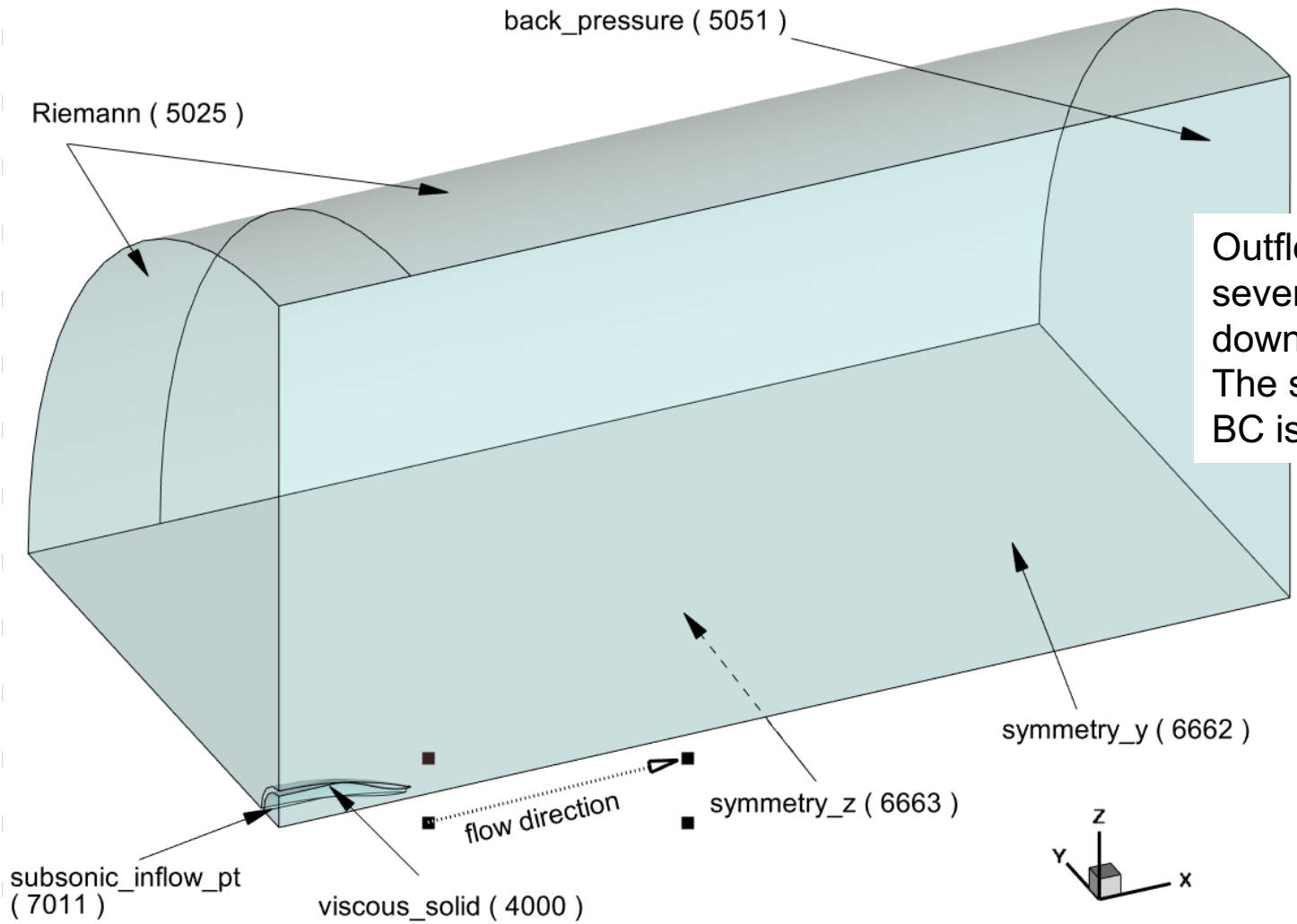
$$\text{massflow(ib)} = \tilde{\dot{m}}_{\text{boundary}} \Big/ \tilde{\rho}_\infty \tilde{a}_\infty$$

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

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

Nozzle flow strategies

Static jet case



Outflow boundary several jet diameters downstream of exit. The static pressure BC is highly reflective.

Nozzle flow strategies

arn2.mapbc and fun3d.nml

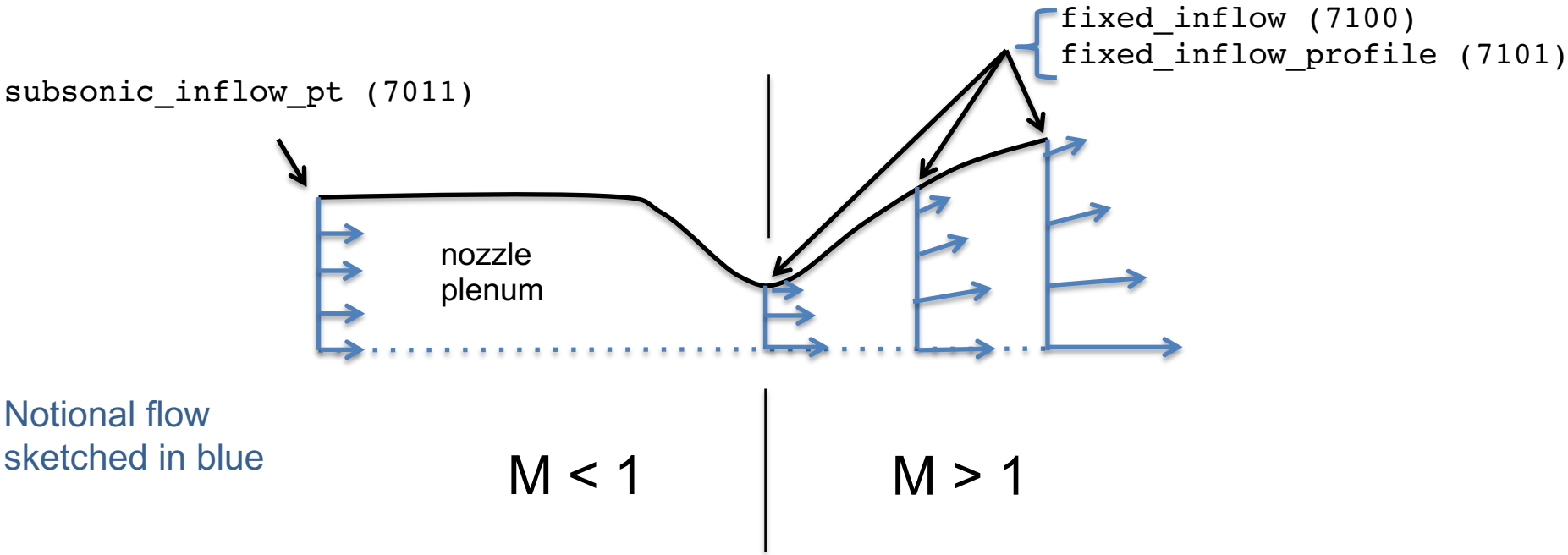
```
$ cat arn2.mapbc
   9 number of boundaries
   1    7011   nozzle plenum inflow boundary
   2    5025   farfield
   3    5025   farfield
   4    5051   outflow boundary
   5    4000   viscous solid
   6    6663   z-symmetry
   7    6662   y-symmetry
   8    5025   freestream inflow
   9    4000  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

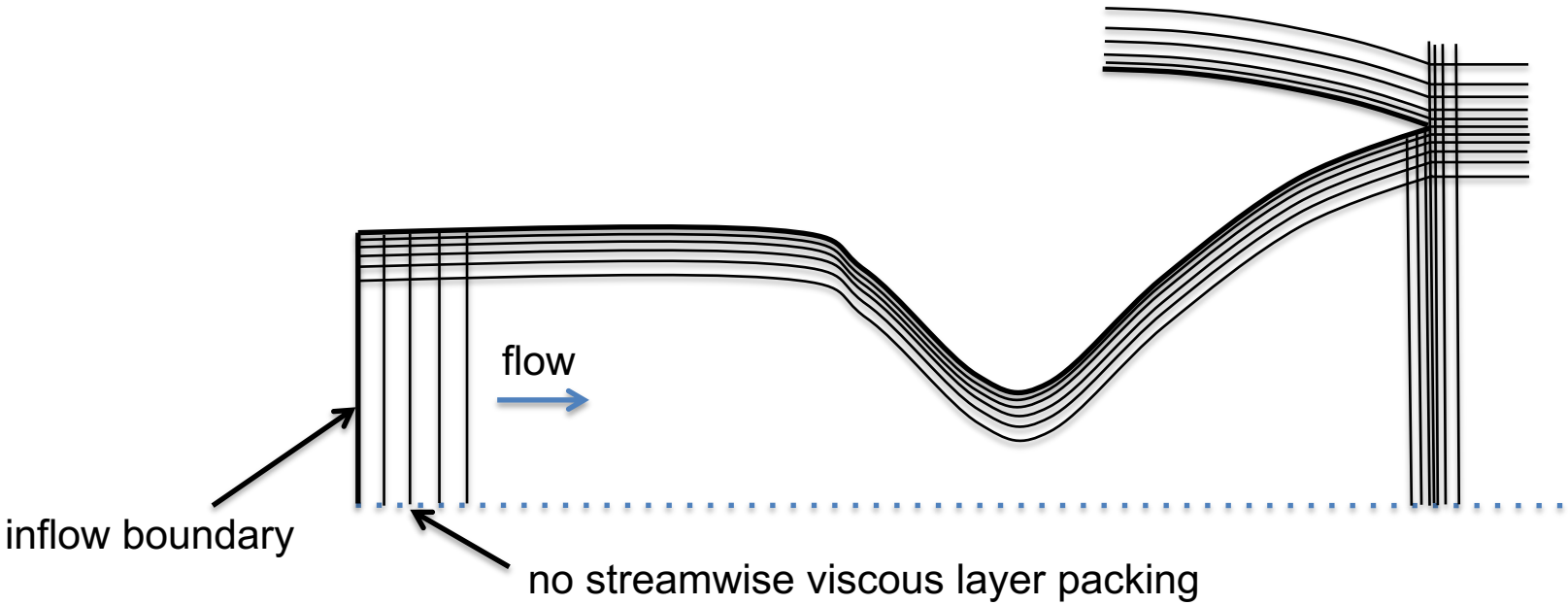
- Supersonic, but…

X Radial gradient due to boundary layer

X Off-axis component due to geometry

Nozzle flow strategies

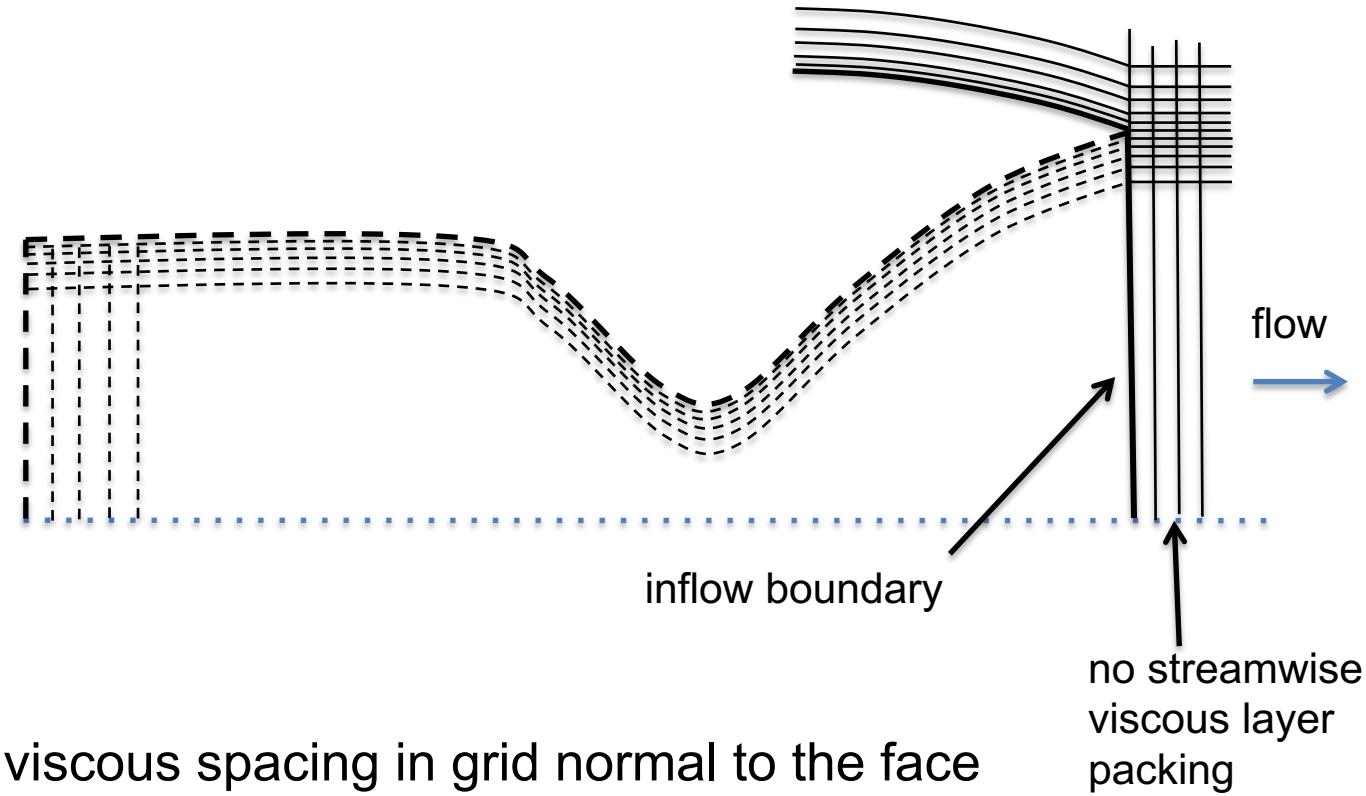
Scenarios for modeling a supersonic jet



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

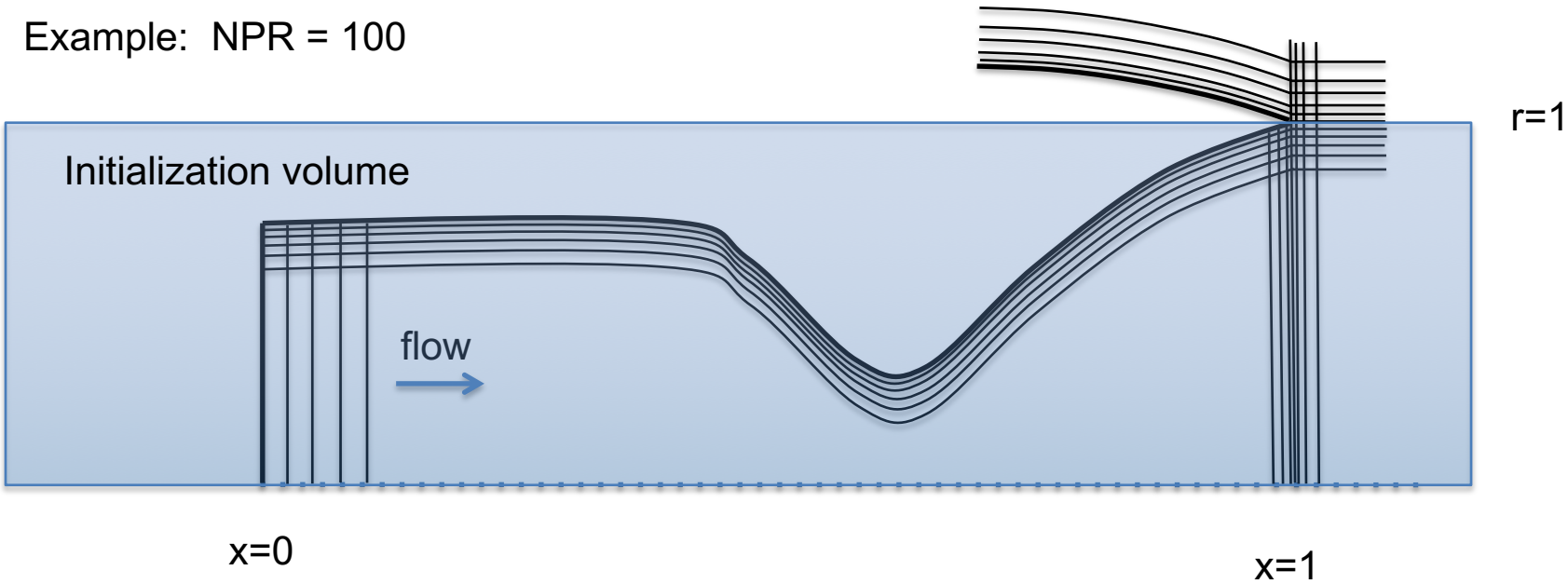


No viscous spacing in grid normal to the face for either the subsonic or the supersonic inflow boundaries

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)`

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

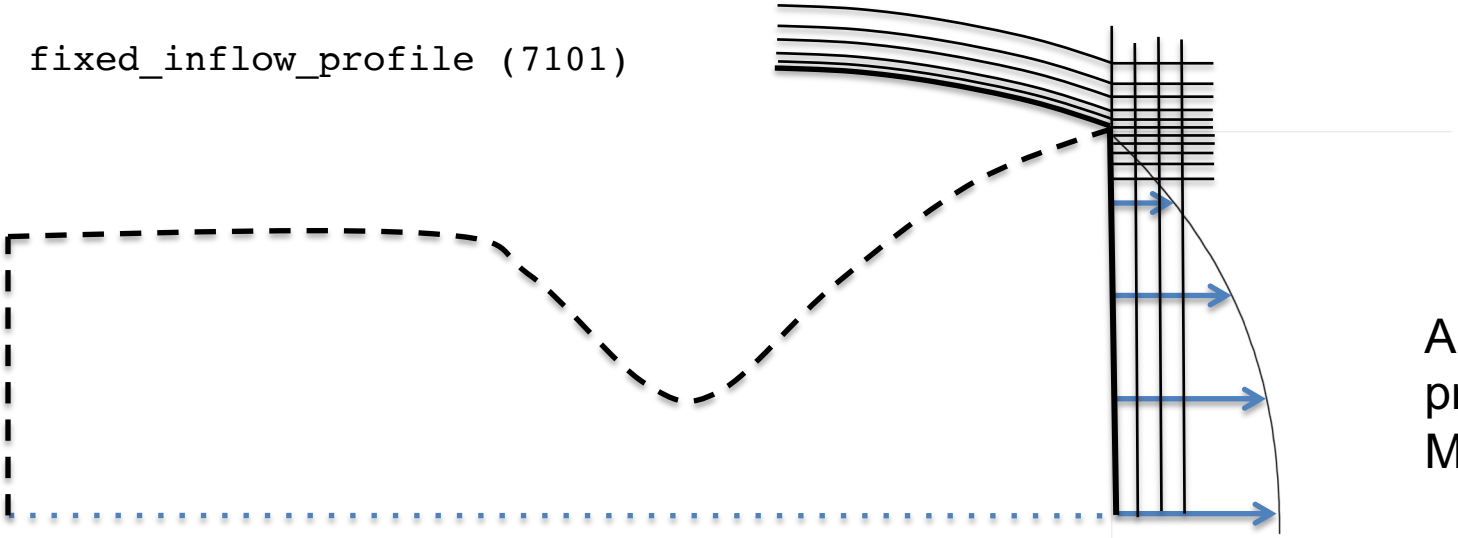
`fixed_inflow_profile (7101)`

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

Nozzle flow strategies

fixed_inflow_profile

fixed_inflow_profile (7101)



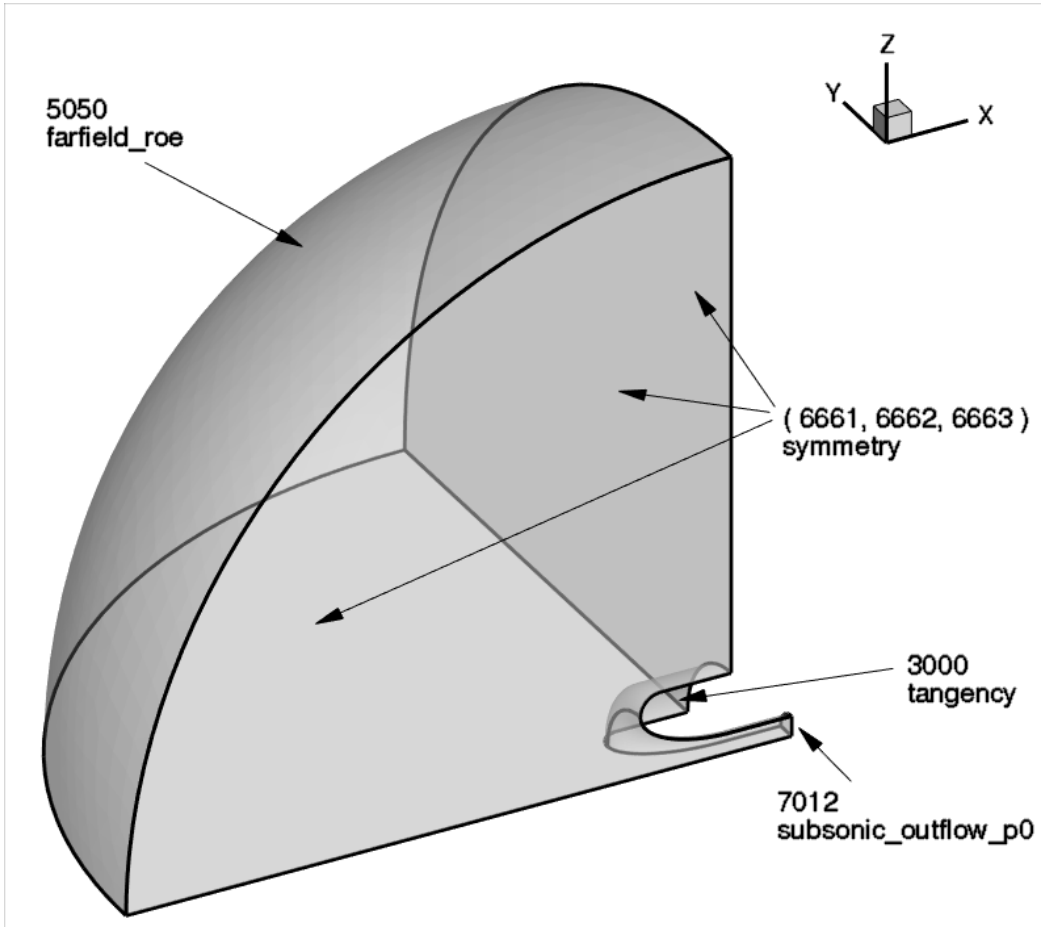
Approximate profile of a Mach 2 jet

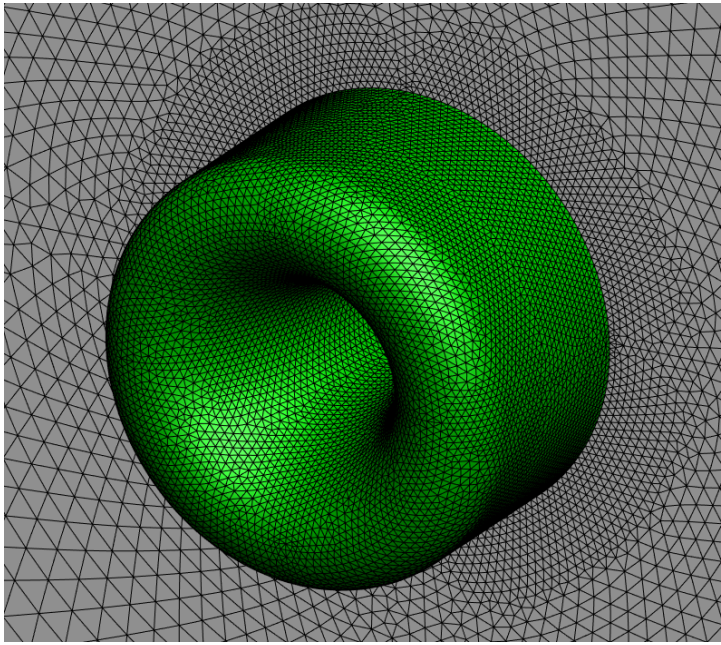
```
&boundary_conditions
  patch_center(1,:)     =-2.0,0.,0.
  patch_scale(1)        = 1.
  profile_rho_coef(1,0)= 1.
  profile_u_coef(1,0)   = 2.
  profile_u_coef(1,1)   = 0.
  profile_u_coef(1,2)   = -1.
  profile_u_coef(1,3)   = -1.
  profile_p_coef(1,0)   = 0.714
/
```

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

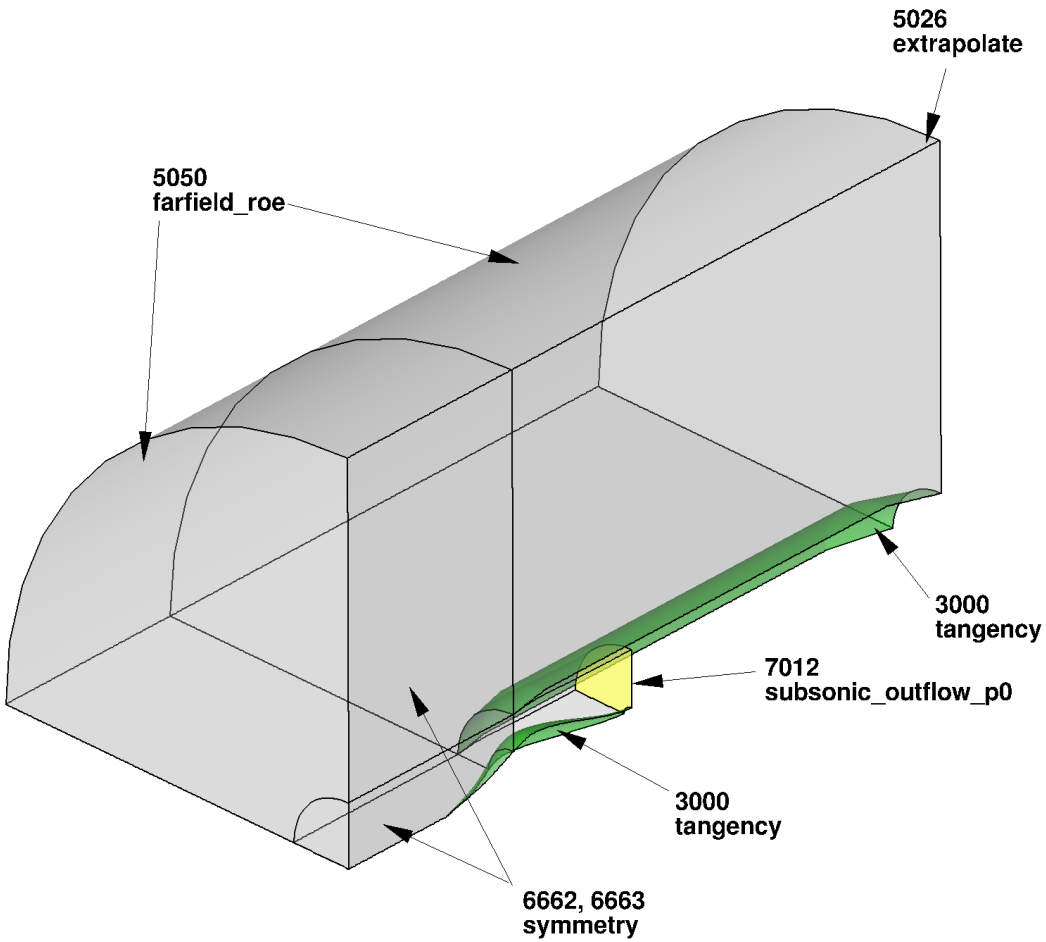
```
#Tue Apr  8 12:48:03 2008
#bell2.mapbc
Patch #        BC            Family   #surf   surfIDs        Family
#-----------------------------------------------------------------
1              7012          1              0            0        inlet
2              5050          1              0            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
```

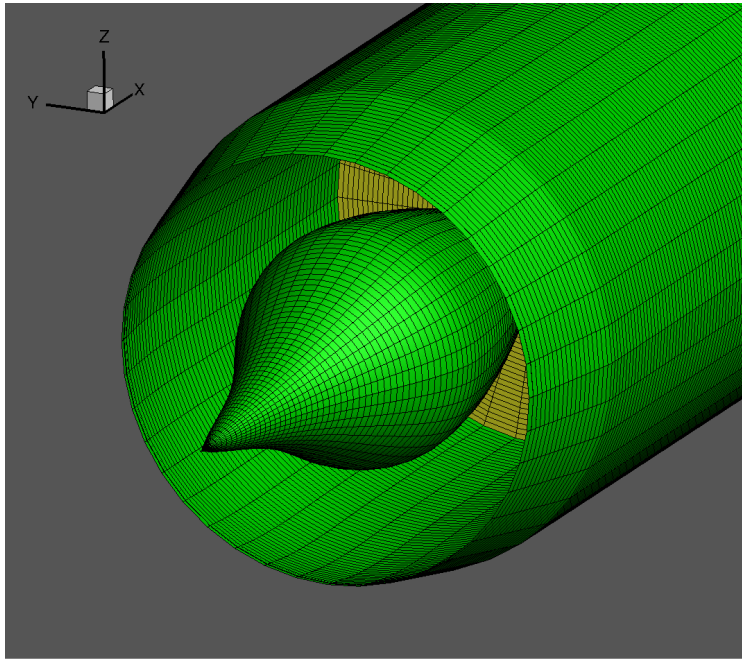
fun3d.nml

```
&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





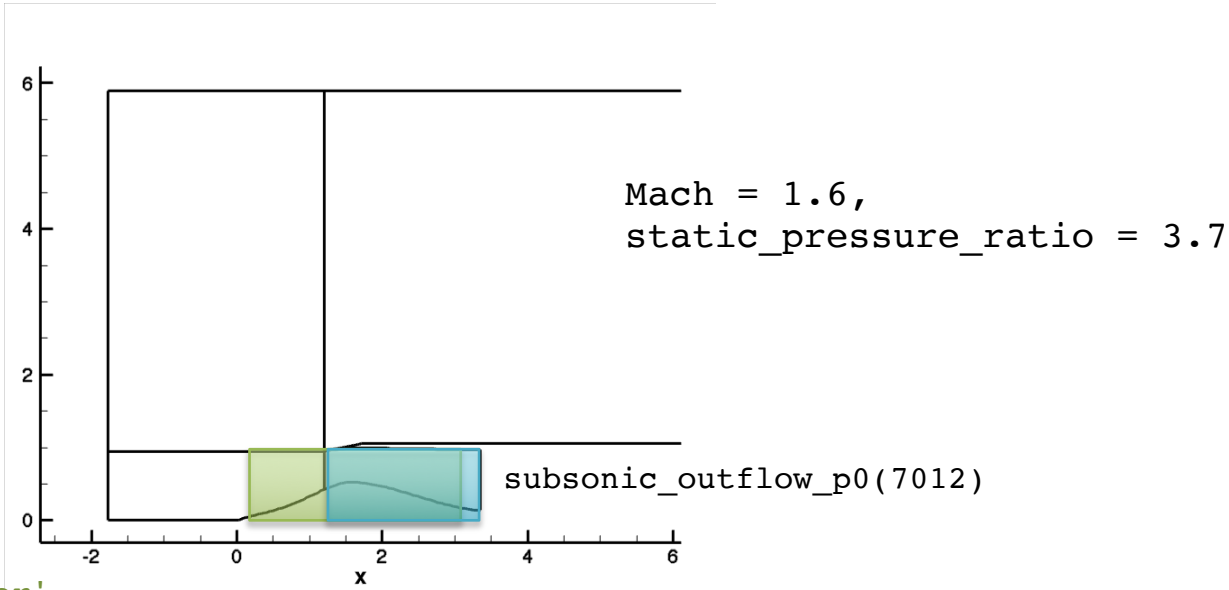

```
&reference_physical_properties
   mach_number        = 1.6
   temperature_units  = 'Kelvin'
   temperature        = 216.0
 /
 &boundary_conditions
  static_pressure_ratio(18) = 3.7
 /
```

Inlet flow strategies

Supersonic inlet

Flow initialization

flow



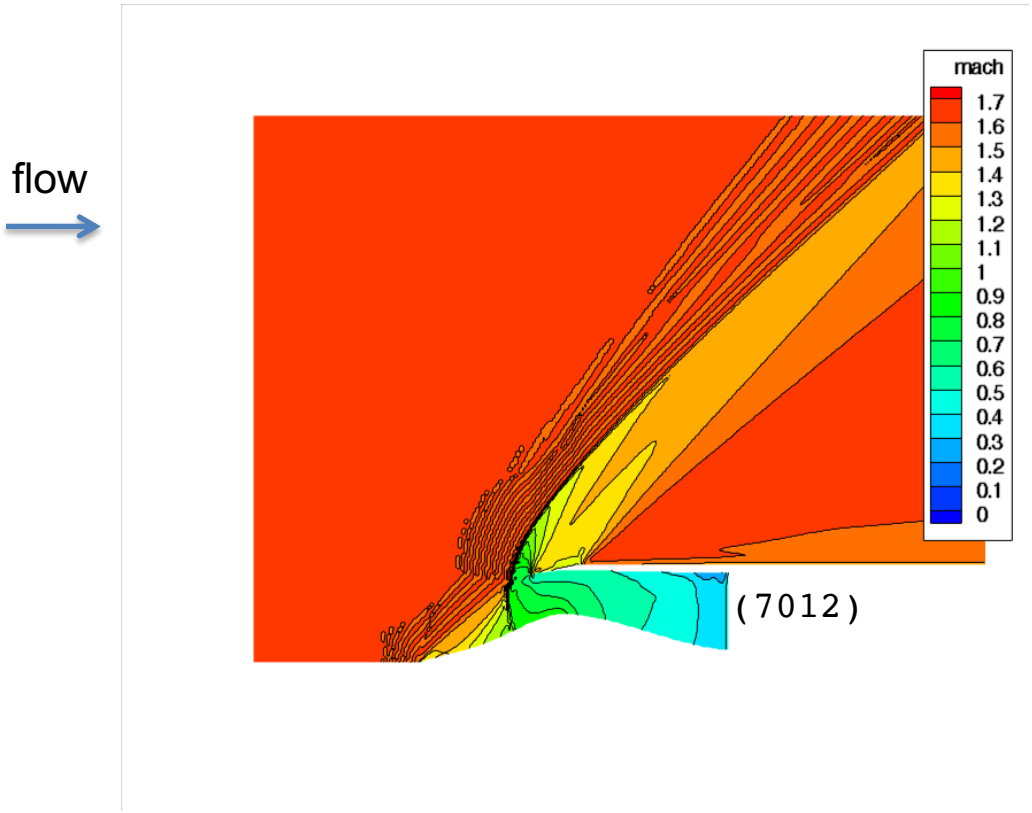

```
 &flow_initialization
 number_of_volumes = 2
! Inlet 1
   type_of_volume(1) = 'cylinder'
     point1(:,1) = 0.0,0.,0.
     point2(:,1) = 3.0,0.,0.
     radius(1)   = 0.90
     u(1)        = 1.0
 ! Inlet 2
   type_of_volume(2) = 'cylinder'
     point1(:,2) = 1.0,0.,0.
     point2(:,2) = 3.0,0.,0.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



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 V13.4 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