FUN3D
Fully Unstructured Navier-Stokes

Current Release: **12.4-70371**
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6. ANALYSIS

6.1. FLOW SOLVER NAMELIST INPUT

Questions about any of the following can be emailed to FUN3D Support.

To run the FUN3D solver, you will need to pre-process your grid using the included Party utility. Once you have successfully run your grid through Party, running the flow solver is simply a matter of setting up the input namelist file, `fun3d.nml`, which is described in detail below.

Note that *as of* release 10.5.0, this namelist file replaces the old input deck, `ginput.faces`. If you have an old `ginput.faces` file, there is a translator called `ginput_translator` in the `utils/Namelist_new` directory that reads `ginput.faces` and writes out a corresponding file `fun3d.nml` (as well as a more descriptive file `fun3d.long.nml` if preferred, which must be renamed to be `fun3d.nml` before using). If a `ginput.faces` file does not exist, then `ginput_translator` will create a `fun3d.nml` file with default values in it. IMPORTANT NOTE: as new namelists and parameters are added to the `fun3d.nml` file, these will generally **not** be output by the translator program. In other words, `ginput_translator` gives only all defaults for namelist parameters associated with the original `ginput.faces` deck, but it will not keep up with subsequently-added parameters. As users get used to the new namelist method and ginput.faces fades into history, the need for the translator program will go away.

In the new namelist input, the perfect gas and generic gas input parameters have been combined to a greater degree than was done in the old `ginput.faces` input deck. However, it should be noted that the earliest versions of this new namelist mostly do no more than mimic the `ginput.faces` file capabilities. Thus, in many instances certain parameters work **only** for generic cases or **only** for ideal-gas cases. As time passes, it is hoped to merge the capabilities better, and remove many of these restrictions and special cases. Thus, it is likely that changes may occur in `fun3d.nml` as it is worked and revised. The reason for having the `input_version` parameter in namelist `&version_number` (in the file) is to help keep track of any significant changes that take place. It is also possible that the naming convention and/or usage of `fun3d.nml` may change at some point in the future. Any such changes will be documented.

Please report any problems, inconsistencies, issues, etc. with the new `fun3d.nml` input to FUN3D Support.

Documentation for the old `ginput.faces` can still be found in Ginput.faces Type Input Running with the old `ginput.faces` can be recovered by hardwiring the parameter `namelist_ginput = .false.` in routine io.f90. If you set this, then FUN3D will look for and read `ginput.faces` like it used to, instead of using the new `fun3d.nml` file.

A typical namelist file (with lots of comments) is shown here:

```
! This file contains namelists used for specifying inputs to
! FUN3D. For this version, the following namelists apply (if a
! namelist is not present, its variables take on their default
! values):
!    version_number
!    project
!    governing_equations
!    reference_physical_properties
!    force_moment_integ_properties
!    inviscid_flux_method
!    turbulent_diffusion_models
!    nonlinear_solver_parameters
!    linear_solver_parameters
!    code_run_control
```

```
!    special_parameters
!    component_parameters
!

&version_number
   input_version =    2.2
                      ! version number of namelist file
                      ! (ginput.faces: N/A)
                      ! DEFAULT varies
   namelist_verbosity = "off"
                      ! current options: on, off, suppress_all
                      ! (ginput.faces: N/A)
                      ! DEFAULT=off
/

&project
   project_rootname = "default_project"
                      ! DEFAULT=default_project
                      ! (ginput.faces: PROJECT_NAME)
   case_title = "fun3d_case_name"
                      ! DEFAULT=fun3d_case_name
                      ! (ginput.faces: CASE TITLE)
   part_pathname = " "
                      ! (ginput.faces: N/A)
                      ! DEFAULT=" " (blank)
/

&governing_equations
   eqn_type = "cal_perf_compress"
                      ! current options: cal_perf_compress,
                      ! cal_perf_incompress, generic
                      ! (ginput.faces: INCOMP)
                      ! DEFAULT=cal_perf_compress
   prandtlnumber_molecular =   0.72
                      ! (ginput.faces: PRANDTL)
                      ! currently does nothing for generic path
                      ! DEFAULT=0.72
   artificial_compress =    15.0
                      ! artificial compressibility factor, only
                      ! used when solver = cal_perf_incompress
                      ! (ginput.faces: XMACH when INCOMP=1)
                      ! DEFAULT=15.0
   viscous_terms = "turbulent"
                      ! current options: inviscid, laminar,
                      ! turbulent (ginput.faces: IVISC)
                      ! DEFAULT=turbulent
   chemical_kinetics = "finite-rate"
                      ! current options: frozen, finite-rate
                      ! (ginput.faces: CHEM_FLAG)
                      ! does nothing for cal_perf paths
                      ! DEFAULT=finite-rate
   thermal_energy_model = "non-equilib"
                      ! current options: frozen, non-equilib
                      ! (ginput.faces: THERM_FLAG)
                      ! does nothing for cal_perf paths
                      ! DEFAULT=non-equilib
/

&reference_physical_properties
   gridlength_conversion =    1.0
                      ! sets L_REF for generic generic gas only
                      ! DEFAULT=1.0
   !
   !-------------------------------------------------------------
   ! User must choose either NONDIMENSIONAL or DIMENSIONAL input:
   ! (one set is read and one is ignored depending on
   ! dim_input_type), Note, however, that temperature is always
   ! input as a dimensional number
   !-------------------------------------------------------------
   dim_input_type = "nondimensional"
                      ! options: nondimensional, dimensional-SI
                      ! (ginput.faces: N/A)
                      ! DEFAULT=nondimensional
   temperature_units = "Kelvin"
                      ! options: Kelvin, Rankine
                      ! (ginput.faces: N/A)
                      ! DEFAULT=Kelvin
   !-------------------------------------------------------------
   ! NONDIMENSIONAL INPUT:
   !        (generic             : do not use)
   !        (cal_perf_compress   : specify mach_number,
   !                               reynolds_number)
   !        (cal_perf_incompress: specify reynolds_number only)
   !-------------------------------------------------------------
   mach_number =   0.2
```

```
                     ! (ginput.faces: XMACH)
                     ! only used if
                     ! dim_input_type=nondimensional
                     ! currently does nothing for generic path
                     ! DEFAULT=0.2
   reynolds_number =    1000000.0
                     ! based on reference length of 1 grid_unit
                     ! (ginput.faces: RE)
                     ! only used if
                     ! dim_input_type=nondimensional
                     ! currently does nothing for generic path
                     ! DEFAULT=1.e6
   !-------------------------------------------------------------
   ! DIMENSIONAL INPUT:
   !        (generic            : specify velocity and density)
   !        (cal_perf_compress  : do not use)
   !        (cal_perf_incompress: do not use)
   !-------------------------------------------------------------
   velocity =    30.0
                     ! in m/s (ginput.faces: V_INF for generic)
                     ! only used if
                     ! dim_input_type=dimensional-SI
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=30.0
   density =   0.1
                     ! in kg/m^3
                     ! (ginput.faces: RHO_INF for generic)
                     ! only used if
                     ! dim_input_type=dimensional-SI
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.1
   !-------------------------------------------------------------
   !
   temperature =    273.0
                     ! in temperature_units
                     ! (ginput.faces: TREF in Rankine for
                     ! cal_perf paths, T_INF in Kelvin for
                     ! generic)
                     ! DEFAULT=273.0
   temperature_walldefault =   0.0
                     ! in temperature_units;
                     ! must be specified for generic
                     ! (ginput.faces: T_WALL for generic);
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.0
   angle_of_attack =   0.0
                     ! in degrees (ginput.faces: ALPHA)
                     ! DEFAULT=0.0
   angle_of_yaw =   0.0
                     ! in degrees (ginput.faces: YAW)
                     ! DEFAULT=0.0
/

&force_moment_integ_properties
   area_reference =    1.0
                     ! area used to nondimensionalize forces and
                     ! moments, in scaled_grid_units^2
                     ! (ginput.faces: SREF)
                     ! DEFAULT=1.0
   x_moment_length =    1.0
                     ! length (in x-direction) used to nondimensionalize mom
                     ! about y, in scaled_grid_units
                     ! (ginput.faces: CREF)
                     ! DEFAULT=1.0
   y_moment_length =    1.0
                     ! length (in y-direction) used to nondimensionalize mom
                     ! about x and about z, in scaled_grid_units
                     ! (ginput.faces: BREF)
                     ! DEFAULT=1.0
   x_moment_center =   0.0
                     ! in scaled_grid_units (ginput.faces: XMC)
                     ! DEFAULT=0.0
   y_moment_center =   0.0
                     ! in scaled_grid_units (ginput.faces: YMC)
                     ! DEFAULT=0.0
   z_moment_center =   0.0
                     ! in scaled_grid_units (ginput.faces: ZMC)
                     ! DEFAULT=0.0
/

&inviscid_flux_method
   flux_limiter = "none"
                     ! current options: none, barth, venkat,
                     ! minmod, vanleer, vanalbada, smooth,
                     ! hminmod, hvanleer, hvanalbada, hsmooth
```

```
                     ! (ginput.faces: IFLIM)
                     ! DEFAULT=none
   first_order_iterations =            0
                     ! number of iterations or sub-iterations
                     ! run 1st order (ginput.faces: NITFO)
                     ! DEFAULT=0
   flux_construction = "roe"
                     ! current options: vanleer, roe, hllc,
                     ! aufs, central_diss, ldfss, dldfss, stvd,
                     ! stvd_modified; only roe allowed for
                     ! cal_perf_incompress (ginput.faces: IHANE)
                     ! DEFAULT=roe
   rhs_u_eigenvalue_coef =   0.0
                     ! (ginput.faces: EIG0 for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.0
   lhs_u_eigenvalue_coef =   0.0
                     ! (ginput.faces: EIG0_IMP for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.0
/

&turbulent_diffusion_models
   turb_model = "sa"
                     ! current options: sa, des, sst,
                     ! sst-v, abid-ke, hrles, gamma-ret-sst
                     ! (ginput.faces: IVISC or TURB_MODEL_TYPE)
                     ! DEFAULT=sa
   turb_intensity =   2.0E-003
                     ! Tu = sqrt(2k/(3uinf^2)), k=turb K.E.
                     ! (ginput.faces: TURB_INT_INF for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.002
   turb_viscosity_ratio =   0.210438
                     ! mu_t/mu_molecular
                     ! (ginput.faces: TURB_VIS_RATIO_INF
                     ! for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.210438
   re_stress_model = "linear"
                     ! current options: linear or nonlinear
                     ! (ginput.faces: REYNOLDS_STRESS_MODEL for
                     ! generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=linear
   turb_compress_model = "off"
                     ! current options: on, off
                     ! (ginput.faces: TURB_COMP_MODEL for
                     ! generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=off
   turb_conductivity_model = "off"
                     ! current options: on, off
                     ! (ginput.faces: TURB_COND_MODEL for
                     ! generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=off
   prandtlnumber_turbulent =   0.9
                     ! (ginput.faces: PRANDTL_TURB for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=0.9
   schmidtnumber_turbulent =    1.0
                     ! not used by cal_perf paths
                     ! (ginput.faces: SCHMIDT_TURB for generic)
                     ! currently does nothing for cal_perf paths
                     ! DEFAULT=1.0
/
   !---------------------------------------------------------------
   ! ADDITIONAL INPUT FOR SPALART AND DDES TURBULENCE MODEL
   !---------------------------------------------------------------
&spalart
   turbinf = 3.0,
                    ! free stream value for spalart model variable
                    ! (DEFAULT changed from 1.341946 to 3.0 as of
                    ! version 12.3)
   ddes = .true.,
                    ! used for activating delayed DES (DDES) model
                    ! (DEFAULT=.false.)
   ddes_mod1 = .true.,
                    ! used for modification of DDES model
                    ! (Ref. AIAA Paper 2010-4001)
                    ! (DEFAULT=.false.)
   sarc = .true.,
                    ! used to invoke SARC model
                    ! (Ref. AIAA Journal Vol. 38, No. 5, 2000,
```

```
                     ! pp. 784-792.)
                     ! (DEFAULT=.false.)
   sarc_cr3 = 1.0,
                     ! constant associated with SARC model
                     ! (DEFAULT=0.6)
/
   !-------------------------------------------------------------
   ! ADDITIONAL INPUT FOR GAMMA-RET-SST TURBULENCE MODEL
   !-------------------------------------------------------------
 &gammaretsst
   set_k_inf_w_turb_intsty_percnt = 0.2
                     ! if used, overrides the default k_inf by
                     ! using input turb intensity (percent)
   set_w_inf_w_eddyviscosity = 1.0
                     ! if used, overrides the default w_inf by
                     ! using input eddy viscosity (nondim)
   transition_4eqn_on = .true.,
                     ! if .false., turns off transition part of model
                     ! (DEFAULT=.true.)
/

 &nonlinear_solver_parameters
   time_accuracy = "steady"
                      ! current options: steady, 1storder,
                      ! 2ndorder, 2ndorderOPT, 3rdorder,
                      ! 4thorderMEBDF4, 4thorderESDIRK4
                      ! (ginput.faces: ITIME)
                      ! DEFAULT=steady
   time_step_nondim =   0.0
                      ! only used if time_accuracy is NOT steady;
                      ! for cal_perf_compress path, dt is
                      ! nondimensionalized via: dt*a_ref/L,
                      ! where L = unit 1 of grid; for generic
                      ! and cal_perf_incompress, dt is
                      ! nondimensionalized via: dt*u_ref/L
                      ! (ginput.faces: DT)
                      ! DEFAULT=0.0
   pseudo_time_stepping = "on"
                      ! current options: on, off
                      ! (ginput.faces: PSEUDO_DT)
                      ! DEFAULT=on
   subiterations =            0
                      ! only used if time_accuracy is NOT steady
                      ! (ginput.faces: SUBITERS)
                      ! DEFAULT=0
   schedule_number =          2
                      ! number of CFL ramping schedules to input
                      ! (ginput.faces: N/A)
                      ! minimum value = 1, maximum value = 10
                      ! currently MUST = 2
                      ! DEFAULT=2
   schedule_iteration =           1          50
                      ! iteration numbers (input schedule_number
                      ! of these) for CFL ramping schedule
                      ! (ginput.faces: IRAMP equivalent to use of
                      ! schedule_number=2, schedule_iteration=
                      ! 1,IRAMP)
                      ! schedule_iteration(1) MUST = 1
                      ! DEFAULT=1,50
   schedule_cfl =    200.0        200.0
                      ! CFL numbers (input schedule_number of
                      ! these) for CFL ramping schedule
                      ! (ginput.faces: CFL1, CFL2 equivalent to
                      ! use of schedule_number=2, schedule_cfl=
                      ! CFL1,CFL2)
                      ! DEFAULT=200.0,200.0
   schedule_cflturb =    50.0        50.0
                      ! turb CFL numbers (input schedule_number
                      ! these) for CFL ramping schedule
                      ! (ginput.faces: CFLTURB1, CFLTURB2
                      ! equivalent to use of schedule_number=2,
                      ! schedule_cfl=CFLTURB1, CFLTURB2)
                      ! currently does nothing for generic path
                      ! DEFAULT=50.0,50.0
   invis_relax_factor =    2.0
                      ! not used by cal_perf paths
                      ! (ginput.faces: RF_INV for generic)
                      ! DEFAULT=2.0
   visc_relax_factor =    1.0
                      ! not used by cal_perf paths
                      ! (ginput.faces: RF_VIS for generic)
                      ! DEFAULT=1.0
 /

 &linear_solver_parameters
```

```
   meanflow_sweeps =           15
                     ! number of Gauss-Seidel sub-iterations for
                     ! the linear problem at each time step
                     ! (ginput.faces: NSWEEP)
                     ! DEFAULT=15
   turbulence_sweeps =          10
                     ! same, for turbulence; not used by generic
                     ! path (ginput.faces: NCYCT)
                     ! DEFAULT=10
   line_implicit = "off"
                     ! current options: on, off
                     ! (ginput.faces: NSWEEP negative)
                     ! DEFAULT=off
/

&code_run_control
   steps =          500
                     ! number of time steps or multigrid cycles
                     ! to run the code (ginput.faces: NCYC)
                     ! DEFAULT=500
   stopping_tolerance =   1.0E-015
                     ! absolute value of the RMS residual at
                     ! which the solver will terminate early
                     ! (ginput.faces: RMSTOL)
                     ! DEFAULT=1.e-15
   restart_write_freq =         250
                     ! frequency of restart write based on time
                     ! steps or multigrid cycles
                     ! (ginput.faces: ITERWRT)
                     ! DEFAULT=250
   restart_read = "on"
                     ! current options: off, on,
                     ! on_nohistorykept
                     ! (ginput.faces: IREST)
                     ! DEFAULT=on
   jacobian_eval_freq =          10
                     ! frequency of jacobian evaluation based on
                     ! time steps or multigrid cycles
                     ! (ginput.faces: JUPDATE)
                     ! DEFAULT=10
/

&special_parameters
   large_angle_fix = "off"
                     ! fix to neglect viscous fluxes in cells
                     ! containing angles equal to 178 degrees or
                     ! more; current options: on, off
                     ! (ginput.faces: IVGRD)
                     ! DEFAULT=off
/

&flow_initialization
  number_of_volumes = 0
                     ! number of initialization volumes
                     ! DEFAULT=0
  type_of_volume(n)='none'
                     ! volume definition index
                     !   Current options:
                     !   'box, 'sphere', 'cylinder', 'cone'
                     ! DEFAULT='none'
  pmin(1:3,n) = 0.0, 0.0, 0.0
                     ! coordinates of lower corner of box (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  pmax(1:3,n) = 0.0, 0.0, 0.0
                     ! coordinates of upper corner of box (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  center(1:3,n)= 0.0, 0.0, 0.0
                     ! coordinates of center of sphere (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  radius(n)=0.0
                     ! radius of sphere (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  point1(1:3,n) = 0.0, 0.0, 0.0
                     ! center of endpoint 1 of cylinder (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  point2(1:3,n) = 0.0, 0.0, 0.0
                     ! center of endpoint 2 of cylinder (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  radius(n) =   0.50
                     ! radius of cylinder (n)
                     ! DEFAULT=0.0
  point1(1:3,n) = 0.0, 0.0, 0.0
                     ! center of endpoint 1 of cone (n)
                     ! DEFAULT= (0.0,0.0,0.0)
  point2(1:3,n) = 1.0, 0.0, 0.0
```

```
                        ! center of endpoint 1 of cone (n)
                        ! DEFAULT= (0.0,0.0,0.0)
  radius1(n) = 0.10
                        ! radius of endpoint 1 of cone (n)
                        ! DEFAULT=0.0
  radius2(n) = 1.00
                        ! radius of endpoint 2 of cone (n)
                        ! DEFAULT=0.0
  rho(n) = 1.0
                        ! Density (n)
                        ! DEFAULT=1.0
  c(n) = 0.9
                        ! speed of sound (n)
                        ! DEFAULT=1.0
  u(n) = 0.4
                        ! u veloicty (n)
                        ! DEFAULT=0.0
  v(n) = 0.0
                        ! v velocity (n)
                        ! DEFAULT=0.0
  w(n) = 0.0
                        ! w velocity (n)
                        ! DEFAULT=0.0
/

&component_parameters
  number_of_components = 1
                        ! number of individual components to be tracked
                        ! DEFAULT=0
  component_count(n)   = 3
                        ! number of boundaries to be included in each component
                        ! DEFAULT=0
  component_list(n)    = '2,3,9'
                        ! string list of boundary numbers for component_count(n
                        ! DEFAULT=''
  component_name(n)    = 'body'
                        ! name used in file header of component force tracking
                        ! DEFAULT=''
  allow_flow_through_forces = .true.
                        ! allows for nozzle and inlet boundaries to be included
                        ! DEFAULT = .false.
 /
```

The comments given above describe the default for each parameter, and also give the corresponding entry from the old `ginput.faces` file. The comments in the file are not necessary. With this type of input file, leaving out or misspelling any namelist (the category parameter defined with an ampersand "&" preceding its name) will result in default values being used for all of the parameters within that namelist. For example, if the namelist name `linear_solver_parameters` were to be misspelled as `linear_solver_parameter` (missing "s"), then all parameters within that namelist that you think you are specifying would be ignored, and they would assume their default values. This is one good reason to always leave `namelist_verbosity = on`, so the top of the screen output has a record not only of what you input, but also what the code is using as well. Leaving out any parameter within a namelist results in the default value for that parameter being used. Misspelling or misusing any particular parameter will typically cause FUN3D to issue an error and stop.

Note that the above namelist file contains many input variables, but in general it is not necessary to list them all. One can instead rely on the fact that most of the defaults are often desired, and only those variables that are **different** from the defaults need to be given. The following might be an example of a typical namelist file for a calorically-perfect FUN3D run:

```
 &version_number
    input_version =    2.2
 /
 &project
    project_rootname = "my_project"
 /
 &reference_physical_properties
    mach_number =   0.84
    reynolds_number =    6200000.0
    temperature =    252.5
    angle_of_attack =   13.7
 /
 &force_moment_integ_properties
    area_reference =    500.2
    x_moment_length =    16.444
    y_moment_length =    2.2
    x_moment_center =   0.25
 /
 &inviscid_flux_method
```

```
   flux_limiter = "smooth"
/
&turbulent_diffusion_models
   turb_model = "sst-v"
/
&nonlinear_solver_parameters
   schedule_iteration =     1     150
   schedule_cfl =        25.0   200.0
   schedule_cflturb =    10.0    50.0
/
&code_run_control
   steps =   2000
   restart_read = "off"
/
&component_parameters
   number_of_components    = 1
   component_count(1)      = 2
   component_list(1)       = '1, 5'
   component_name(1)       = 'InletCowl'
   allow_flow_through_forces = .true.
/
```

Each of the namelists is described below. The defaults for each parameter can be found in the first sample file above.

NAMELIST &VERSION_NUMBER

input_version	The version number of the namelist file.
namelist_verbosity	Determines how namelist information from `fun3d.nml` is written to the screen output. When `on`, the file `fun3d.nml` is echoed to the screen output along with a list of **all** namelist parameters (including defaults). Additional information and warnings (if necessary) are also given. This setting (`on`) is the recommended option, because the user can check to see all of the parameters being used by the code, whether explicitly being specified in the namelist file or implicitly being used by default. When `off`, only the input file `fun3d.nml` is echoed. When `suppress_all`, all writing of `fun3d.nml` information to screen output is suppressed. Quotes are needed around the character string.

NAMELIST &PROJECT

project_rootname	The project name for the grid. For example, all grid part files and solution files have this rootname as part of their filename. Quotes are needed around the character string.
case_title	User-defined title for the case. Quotes are needed around the character string.
part_pathname	Either absolute path or relative path from the current working directory to the location of the grid (part) files. Quotes are needed around the character string.

NAMELIST &GOVERNING_EQUATIONS

eqn_type	Equation type being solved, for example `cal_perf_compress` for calorically perfect compressible, `cal_perf_incompress` for calorically perfect incompressible, `generic` for generic gas. Quotes are needed around the character string.
prandtlnumber_molecular	Molecular Prandtl number.
artificial_compress	Artificial compressibility factor (beta), only used when `eqn_type` = `cal_perf_incompress`.
viscous_terms	Describes viscous term usage, for example `inviscid` for no viscous term (Euler), `laminar` for Navier-Stokes with no turbulence model, `turbulent` for Navier-Stokes with turbulence model. Quotes are needed around the character string.
chemical_kinetics	Describes the chemical kinetics, only used when `eqn_type` = `generic`, for example `frozen` for chemically frozen flow, `finite-rate` for finite-rate chemically-reacting flow. Quotes are needed around the character string.
thermal_energy_model	Describes the thermal energy model, only used when `eqn_type` = `generic`, for example `frozen` for frozen thermal energy treatment, `non-equilib` for non-equilibrium thermal energy. Quotes are needed around the character string.

NAMELIST &REFERENCE_PHYSICAL_PROPERTIES

gridlength_conversion	Conversion factor to scale the grid by. (generic gas only)
dim_input_type	Type of input, for example `nondimensional` or `dimensional-SI`. The user's choice here determines whether Mach number and Reynolds number are input (for nondimensional), or dimensional velocity and density are input (for dimensional). Note, however, that temperature is always input as a dimensional quantity. Quotes are needed around the character string.
temperature_units	Units for temperature, for example `Kelvin` or `Rankine`. Quotes are needed around the character string.
mach_number	Reference Mach number, velocity/speed-of-sound. Only used if `dim_input_type = nondimensional`.
reynolds_number	Reference Reynolds number, per unit 1 of the grid. For example, If your Reynolds number is based on the MAC(Mean Aerodynamic Chord), and the grid is constructed so that the MAC is one, then the appropriate value for this is the full freestream Reynolds number. If the grid is constructed so that the MAC is in inches, then this must be set to the Reynolds number divided by the MAC in inches. Only used if `dim_input_type = nondimensional`.
velocity	Reference velocity, in m/s, only used if `dim_input_type = dimensional-SI`.
density	Reference density, in kg/m$^{3\wedge}$, only used if `dim_input_type = dimensional-SI`.
temperature	Reference temperature, in units of `temperature_units`.
temperature_walldefault	Wall temperature, currently only used for `eqn_type = generic`.
angle_of_attack	Freestream angle of attack in degrees.
angle_of_yaw	Freestream angle of yaw (side-slip) in degrees.

NAMELIST &FORCE_MOMENT_INTEG_PROPERTIES

area_reference	Reference area used for non-dimensionalization of forces and moments, in `scaled_grid_units`2.
x_moment_length	Reference length in x-direction, used to nondimensionalize moments about y, in `scaled_grid_units`.
y_moment_length	Reference length in y-direction, used to nondimensionalize moments about x and z, in `scaled_grid_units`.
x_moment_center	X-coordinate location of moment center, in `scaled_grid_units`.
y_moment_center	Y-coordinate location of moment center, in `scaled_grid_units`.
z_moment_center	Z-coordinate location of moment center, in `scaled_grid_units`.

NAMELIST &INVISCID_FLUX_METHOD

flux_limiter	Flux limiter used, for example `none` for no limiter, `barth` for Barth limiter, `venkat` for Venkatakrishnan limiter, `minmod` for min-mod limiter, `vanleer` for van Leer limiter, `vanalbada` for van Albada limiter, `smooth` for smooth limiter, `hminmod` for hypersonic-minmod limiter, `hvanleer` for hypersonic-van Leer limiter, `hvanalbada` for hypersonic-van Albada limiter, `hsmooth` for hypersonic-smooth limiter, and `hvenkat` for hypersonic-Vankatakrishnan limiter, For hypersonic flows computed using the calorically perfect gas path the `hvanleer` or `hvanalbada` flux limiters are recommended. Please note that use of the h-series of flux limiters automatically turns on a heuristic pressure based limiter that is used to augment the selected flux limiter. When using a mixed element grid (where the near wall grid is made up of either hexes or prisms) the wall heat transfer and skin friction can be improved by selecting the `hminmod`, `hvanleer`, `hvanalbada`, `hsmooth`, or `hvnekat` limiters and invoking the command line option `--limit_near_walls_less`. This option causes these flux limiter to be automatically "turned off" as the grid approaches the wall. However use of this option on tetrahedral grids near the wall can make the wall heat transfer and skin friction worse. Use of this option may cause a decrease in robustness so use it with caution. When using the `barth`, `venkat`, `hminmod`, `hvanleer`, `hvanalbada`, `hsmooth`, or `hvnekat` limiter, the

command line option `--freeze_limiter xx` may also be of use. This option freezes the value of the limiter throughout the flow field after `xx` number of timesteps. This can be useful in improving convergence that typically stalls or "rings" when using a limiter. Note the reconstruction is evaluated at each time step with the current "frozen" value of the limiter, however if the reconstruction fails due to the extrapolation to the cell face, the limiter is allowed to be recomputed at these selected points. Finally, when restarting a solution that has used a frozen limiter, if you wish to continue freezing the limiter for the restart, you must specify `--freeze_limiter 0`. Quotes are needed around the character string.

first_order_iterations Number of first-order iterations prior to employing second order spatial accuracy. Note: for time accurate cases (`time_accuracy` not `steady`), this is the number of first-order accurate sub-iterations to run for each time step.

flux_construction Method for constructing the flux, for example `vanleer` for van Leer flux vector splitting, `roe` for Roe flux difference splitting, `hllc` for HLLC, `aufs` for AUFS, `central_diss` for central differencing with scalar dissipation, `ldfss` for LDFSS, `dldfss` for Dissipative LDFSS, `stvd` for STVD, `stvd_modified` for modified STVD. Roe's scheme is suggested, but you may find that others converge better for some cases. Please note for hypersonic flows computed using the calorically perfect gas path the `dldfss` scheme is recommended. For incompressible flow, the only valid option is `roe`. Jacobians are van Leer by default. Other Jacobians can be selected with `--roe_jac`, `--hllc_jac`, `--aufs_jac`, or `--cd_jac` command line options. Quotes are needed around the character string.

rhs_u_eigenvalue_coef Eigenvalue coefficient for RHS, currently only used for `eqn_type = generic`. See notes in the Hypersonics section.

lhs_u_eigenvalue_coef Eigenvalue coefficient for LHS, currently only used for `eqn_type = generic`. See notes in the Hypersonics section.

NAMELIST &TURBULENT_DIFFUSION_MODELS

turb_model Name of turbulence model, for example `sa` for Spalart-Allmaras one-equation model, `des` for Detached-Eddy Simulation (DES) used in conjunction with the Spalart-Allmaras model, `sst` for Menter SST two-equation k-omega model (strain producton), `sst-v` for Menter SST two-equation k-omega model (vorticity production), `abid-ke` for Abid two-equation k-epsilon model, `hrles` for hybrid RANS-LES model of AIAA-2008-3854, `gamma-ret-sst` for 4-eqn Langtry-Menter transition model of AIAA J 47(12):2894-2906, 2009. Quotes are needed around the character string.

turb_intensity Freestream turbulence intensity, Tu = sqrt(2k/(3 uinf2^)), where k is the turbulent kinetic energy, currently only used for `eqn_type = generic`.

turb_viscosity_ratio Freestream ratio of turbulent viscosity to molecular viscosity, currently only used for `eqn_type = generic`.

re_stress_model Defines whether linear or nonlinear stresses are employed in the turbulence model, currently only used for `eqn_type = generic`. Quotes are needed around the character string.

turb_compress_model Defines whether a turbulence compressibility model is employed (`on` or `off`), currently only used for `eqn_type = generic`. Quotes are needed around the character string.

turb_conductivity_model Defines whether a turbulence conductivity model is employed (`on` or `off`), currently only used for `eqn_type = generic`. Quotes are needed around the character string.

prandtlnumber_turbulent Turbulent Prandtl number, currently only used for `eqn_type = generic`.

schmidtnumber_turbulent Turbulent Schmidt number, currently only used for `eqn_type = generic`.

NAMELIST &NONLINEAR_SOLVER_PARAMETERS

time_accuracy Defines the temporal scheme, for example `steady` for steady state (non-time-accurate) runs, `1storder` for time-accurate first order backward

differencing, `2ndorder` for time-accurate second order backward differencing, `2ndorderOPT` for optimized second order backward differencing (scheme is in between second-order and third-order accurate in time "BDF2opt"), `3rdorder` for time-accurate third order, `4thorderMEBDF4` for time-accurate fourth order of type MEBDF4, `4thorderESDIRK4` for time-accurate fourth order of type ESDIRK4. Quotes are needed around the character string.

`time_step_nondim` Physical time step, used only for `time_accuracy` not `steady`. The nondimensionalization of this parameter depends on `eqn_type`: for `cal_perf_compress` it is "dt a_ref/L", where a_ref is the reference speed of sound and L is unit 1 of the grid; for `cal_perf_incompress` or `generic` it is "dt u_ref/L", where u_ref is the reference velocity.

`pseudo_time_stepping` Defines whether pseudo-time stepping is used (`on` or `off`). When used, the value of the time term (or the pseudo-time term for time-accurate runs) varies spatially according to a local "CFL constraint". This is the default method for `time_accuracy` = `steady`, and it is also generally used for time-accurate runs as well (because its use typically allows larger physical time steps to be taken than might otherwise be possible). When running time-accurately and ramping the CFL of the pseudo time term, the final CFL will be obtained only if `subiterations` >= the number of iterations over which the CFL number is ramped. By the end of a **convergent** subiteration process for time-accurate runs, the pseudo time term drops out, giving the correct temporal discretization. Quotes are needed around the character string.

`subiterations` Number of subiterations applied to solve the implicit time integration, only used for `time_accuracy` not `steady`.

`schedule_number` Number of CFL ramping schedules to input (for changing the CFL number during a run), currently must be = 2.

`schedule_iteration` Iteration numbers at which desired CFL numbers are defined (input `schedule_number` of these). The parameter `schedule_iteration` (1) must = 1, because it defines the starting CFL number at iteration number 1. The actual CFL number is determined by a linear ramp from `schedule_cfl` (1) at iteration `schedule_iteration` (1) to `schedule_cfl` (2) at iteration `schedule_iteration` (2).

`schedule_cfl` CFL numbers (input `schedule_number` of these). The parameter `schedule_cfl` (1) is the CFL number desired at `schedule_iteration` (1), and `schedule_cfl` (2) is the CFL number desired at `schedule_iteration` (2), etc. For example, if you wish to start the run at a CFL number of 10 and ramp up to a CFL number of 200 at iteration number 50, then `schedule_iteration` (1)=1, `schedule_iteration` (2)=50, `schedule_cfl` (1)=10, `schedule_cfl` (2)=200.

`schedule_cflturb` CFL numbers for turbulence equations (input `schedule_number` of these). Not used for `eqn_type` = `generic`.

`invis_relax_factor` Relaxation factor for inviscid terms, used only for `eqn_type` = `generic`. See notes in the Hypersonics section.

`visc_relax_factor` Relaxation factor for viscous terms, used only for `eqn_type` = `generic`. See notes in the Hypersonics section.

NAMELIST &LINEAR_SOLVER_PARAMETERS

`meanflow_sweeps` Number of Gauss-Seidel sub-iterations for the linear problem at each time step.

`turbulence_sweeps` Number of Gauss-Seidel sub-iterations for the turbulence model equations linear problem at each time step. Not used for `eqn_type` = `generic`.

`line_implicit` Defines whether implicit line sweeps are employed (`on` or `off`). If used, it is suggested to have previously invoked the command line option `--partition_lines` when preprocessing with `party`. This will minimize the number of implicit lines which may be cut by the partitioning. Quotes are needed around the character string.

NAMELIST &CODE_RUN_CONTROL

`steps` Number of time steps or multigrid cycles to run the code.

`stopping_tolerance` Absolute value of the RMS (root mean square) residual at which the solver will terminate early.

`restart_write_freq` Frequency of restart write based on time steps or multigrid cycles. The

solution and convergence history will be written to disk every `restart_write_freq` time steps.

`restart_read` Defines restart usage, for example `off` for no reading of old restart files (i.e., run from scratch, with the flow initialized as freestream), `on` for continuation run from a restart file (flow is initialized by using the previous solution information, and the convergence history will be concatenated with the prior solution history), `on_nohistorykept` for continuation run but disregarding the previous history of residuals, forces, moments, etc. Quotes are needed around the character string.

`jacobian_eval_freq` Frequency of jacobian evaluation based on time steps or multigrid cycles. After the first 10 iterations, Jacobians are updated every `jacobian_eval_freq` iterations.

NAMELIST &SPECIAL_PARAMETERS

`large_angle_fix` Fix to neglect viscous fluxes in cells containing angles equal to 178 degrees or more (`on` or `off`). This flag is seldom required. However, you may encounter cases on meshes with poor cell quality where the computation will suddenly give NaNs during the solution process. This is due to unusually large angles in the grid causing gradients in the viscous fluxes to blow up. (Watch for bad angles reported by the preprocessor.) Quotes are needed around the character string.

NAMELIST &FLOW_INITIALIZATION

This namelist entry in `fun3d.nml` is optional and is used for user-specified initialization of compressible flows in INCOMP=0 path under `&flow_initialization`.

This namelist allows the user to specify regions in the field with freestream quantities other than those defined by the `fun3d.nml` (or `ginput.faces` prior to release 10.5.0) input file. If a grid point is contained within a region, it will be initialized as requested when the flow solver is first started.

Regions can be boxes, spheres, cylinders, and conical frustums. The box region is defined by diagonal end points. The sphere region is specified by a point and a radius. The cylinder region is defined by a radius and two points that define the cylinder axis, while the conical frustum adds a second radius to define a linear variation along the axis.

There can be as many regions as desired, and they may overlap each other as well as boundaries in the mesh. Each subsequent region in this file will supersede the regions listed before it in the event that a mesh point is contained in more than one region. Any special boundary conditions normally used by the solver will override these user-specified quantities (no-slip boundary conditions, specified mass flux, etc).

The initialization data is provided in terms of density, sound speed, and velocity components, non-dimensionalized in the usual FUN3D convention. Freestream quantities in the solver are normally given by the following:

```
rho0 =  1.0
c0   =  1.0
u0   =  XMACH * cos(alpha) * cos(yaw)
v0   = -XMACH * sin(yaw)
w0   =  XMACH * sin(alpha) * cos(yaw)
```

For more details on the non-dimensionalization scheme, see the information provided at the CFL3D homepage , which uses the same scheme as FUN3D.

For an example, see the `&flow_initialization` entry in `fun3d.nml` in the `FUN3D` source code directory.

Note: Previously the initialization geometry and data were read from the `user_vol_init.input`.

Note: This initialization method was first made available in v10.2.0, and prior to v10.3.2, the file was named `user_box_init.input` because only box-shaped regions were allowed.

NAMELIST &COMPONENT_PARAMETERS

This namelist entry in `fun3d.nml` is optional and is used for user-specified tracking of the forces and moments for groups of boundaries. With the inclusion of the command line option `--track_group_forces`, the forces and moments for each component will be written in the file `[project_rootname]_[component_name(n)]_component.dat`.

number_of_components	Number of collections of boundaries to be tracked.
component_count(n)	Number of boundaries to be tracked under component n.
component_list(n)	String list of boundary numbers to be tracked under component n.
component_name(n)	Name to be used in filename for component n.
allow_flow_through_forces	Default is only solid surfaces to be included in force tracking. If inlet or nozzle forces are desired, `allow_flow_through_forces` must be set to .true.

NAMELIST &TWO_D_TRANS

This namelist is optional and is used to Specify a 2d transition location with CLO `--turb_transition`. You can use either a upper and lower airfoil patch specification or if you only have a single airfoil patch, use a z value to test for the upper and lower surface. The transitional patches must still be specified with a negative boundary number in the mapbc file. (This namelist is valid for Version 11.4 and higher.)

use_2d_values	Enable 2d transition_specification if .true. The default is .false.
upper_x_location	Upper x location to use if use_2d_values is .true. Default is 0.0
lower_x_location	Lower x location to use if use_2d_values is .true. Default is 0.0
use_z_value	Flag to enable use of z test for upper and lower airfoil. The default is .false.
upper_patch	Upper patch number to use if use_z_value is .false. Default is 1
lower_patch	Lower patch number to use if use_z_value is .false. Default is 1
z_location	The z location to use if use_z_value is .true. Default is 0.0

DIFFERENCES FROM EARLIER FUN3D.NML NAMELIST VERSIONS

`input_version` = 2.2 – changed `pseudo_time_stepping` default from `off` to `on`. (It should always be `on` when `time_accuracy` = `steady`.)

6.2. RUNNING THE FLOW SOLVER

You can expect the solver to use approximately 300 words of memory per grid point. For example, a grid with one million mesh points (about 6 million tetrahedra) would require approximately 2.4 gigabytes of memory using 8-byte words. This amount will increase slightly with the number of processors (i.e., partitions), as there is an increasing amount of boundary data to be exchanged. Different solution algorithms will also affect the amount of memory required. For example, the full Jacobians required for a tightly-coupled solution of the turbulence model will increase the memory requirement significantly.

When you are ready to run an analysis, and you have set up the file `fun3d.nml` (or `ginput.faces` for release 10.4.1 or before) as described above, enter the following at the command prompt:

```
nodet
```

To run the MPI version of the solver on 16 processors, you would use the command:

```
mpirun -np 16 nodet_mpi
```

Depending on your local configuration, you may also need additional arguments to `mpirun`, such as `-nolocal` and `-machinefile [file]`. See your MPI documentation or system administrator for more information on such options. If you have processed your grid and set up the input deck correctly, you will then see the solver start to execute. A detailed description of the output files is given below. Upon completion, you can either restart your job where it left off, or combine the partitioned solution files into global solution information using the postprocessing feature of Party.

COMMAND LINE OPTIONS

These options are specified after the executable name (e.g. nodet, nodet_mpi, party, etc). These commands are always preceded by `--` (double minus). More than one option may appear on the command line (each option proceeded by a `--`). You can always see a listing of the available command line options in any of the codes in the FUN3D suite by using the command line option `--help` after the executable name, e.g.:

./nodet_mpi `--help`

or

./party `--help`

etc.

The options are then listed in alphabetical order, along with a short description and a list of any auxiliary parameters that might be needed, and then the code is stopped. Specific examples of the use of command line options may be found throughout this manual.

Input Files

`[project]_part.n`

These files contain the grid information for each of the `n` partitions in the domain. They are generated using the Party utility.

`fun3d.nml` (for release 10.4.1 and before, this was `ginput.faces`)

This file is the input deck for the solver. The name must not be modified.

`[project]_flow.n` (Optional)

These files contain the binary restart information for each `n` grid partitions. They are read by the solver for restart computations, as well as by party for solution reconstruction and plotting purposes.

`stop.dat` (Optional)

This file is intended to aid the user in gracefully halting the execution of the solver if needed. At the end of every iteration, the solver will look for this file. If the file is present, it must contain a single ASCII integer. If this integer is greater than zero and less than the number of iterations already performed, the solver will dump the current solution and halt execution. The `stop.dat` file is removed just before the execution is halted.

`movin_body.input` (Time-dependent, moving grid cases only)

(replaces `grid_motion.schedule` of Versions 10.0 through 10.2.0)

This namelist file is used to specify grid motion as a function of time, and is used in conjunction with the command line option `--moving_grid` . See the moving grids section below for a more detailed description of this file.

A template for this file may also be found in the FUN3D_90 source code directory.

`rotor.input` (For rotor/propeller computations only)

This file is used for specifying input quantities related to rotor/propeller combinations, and is used in conjunction with the command line option `--rotor` . See the rotorcraft section below on this capability for a more detailed description of this file.

A template for this file may also be found in the FUN3D_90 source code directory.

`solution.schedule` (Optional, for specifying generalized relaxation patterns)

This input deck allows for very general control over the various relaxation schemes and where they are to be applied across the domain.

A template for this file may be found in the FUN3D_90 source code directory.

`remove_boundaries_from_force_totals` (Optional)

This file is for specifying boundaries that are NOT to be included in the calculation of force and moment totals. If this file is not present, then all solid boundaries are included in the force and moment totals. This file is useful, for example, in situations where there may be a mounting sting on a wind tunnel model, but only the forces on the model are actually of interest. Note that the forces on the specified boundaries are still computed, and appear in the [project].forces file, they are just not added to the totals.

A template for this file may be found in the FUN3D_90 source code directory.

Output Files

`[project]_flow.n`

These files contain the binary restart information for each `n` grid partitions. They are read by the solver for restart computations, as well as by party for solution reconstruction and plotting purposes.

`[project]_hist.dat`

This file contains the convergence history for the RMS residual, lift, drag, moments, and CPU time, as well as the individual pressure and viscous components of each force and moment. The file is in Tecplot format.

`[project]_subhist.dat`

For time accurate computations only. This file contains the sub-iteration convergence history for the RMS residuals. The file is in Tecplot format.

`[project]_time_animation.tec` (introduced version 10.0)

For time accurate computations only, in conjunction with the command line option `--animation_freq` . This file contains an animation the grid and solution on selected boundaries in Tecplot format. See the animation of unsteady flows section for more information.

`[project].forces`

This file contains a breakdown of all the forces and moments acting on each individual boundary group. The totals for the entire configuration are listed at the bottom.

Test Case

To ensure that you have installed and are running the solver correctly, a couple small test cases are included in the distribution. Go into these directories and just type `make`. You may find that the last one or two digits vary on different machines/compilers, but your results should look very similar.

Boundary Layer Transition Location Specification

There is an option in FUN3D to specify transition which is based on the idea of turning off the turbulent production terms in “laminar” regions of the grid. This is the same approach taken in CFL3D and NSU3D. FUN3D results from this approach for a DLR-F6 transonic cruise condition are shown in AIAA Paper 2004-0554 in the Publications section. For this option however, you have to generate a grid with the transition location specified by having “laminar” and “turbulent” boundaries defined upstream and downstream of the transition location. When you specify the type for a laminar boundary use a negative number for the viscous boundary types in the boundary definition file. For example, a viscous solid boundary would be defined a `-4` instead of a `4` in the `[project].mapbc` file for a VGrid mesh. In the flow solver, the field nodes will look at the type of boundary closest to that field node to decide whether or not it is a laminar or turbulent node. To invoke specified transition for a specific run you must use the command line option `--turb_transition`, e.g.:

```
mpirun -np 16 nodet_mpi --turb_transition
```

If you run the flow solver without the `--turb_transition`, it will default to fully turbulent even though you have the laminar boundaries defined. Note this option is only valid for perfect gas SA turbulence model and for non-moving grid cases.

As of Version 11.4 you can visualize the laminar and turbulent volume nodes by outputting a integer variable (iflagslen) via the &sampling_output_variables or &volume_output_variables. If the volume node is “laminar” the iflagslen value will be negative. If “turbulent”, it will be positive. This allows the user to check the specification of the transition location.

As of Version 11.4 can also specify a 2d transition x-location with CLO—turb_transition. You can use either a upper and lower patch specification or if only have a single airfoil patch, use a z value to test for the upper and lower surface. The transitional patches must still be specified with a negative boundary number in the mapbc file.

The new specifications are given in the fun3d.nml namelist &two_d_trans. For use with a separate upper and lower patch number, an example of the namelist is:

```
  &two_d_trans
    use_2d_values = .true.
    use_z_value   = .false. !default
    upper_patch = 1
    lower_patch = 2
    upper_x_location = 0.05
    lower_x_location = 0.25
 /
<pre>

For use with a single upper and lower airfoil patch, an example of the
namelist is:

<pre>
  &two_d_trans
    use_2d_values = .true.
    use_z_value   = .true.
    upper_x_location = 0.05
    lower_x_location = 0.25
    z_location = 0.0
 /
<pre>
```

6.3. Rotorcraft

FUN3D is capable of modeling a rotating blade system using different levels of approximation. In order of increasing complexity/fidelity/cost, rotor systems may be analyzed using either a **time-averaged actuator disk**, or via **first principles modeling** of the moving, articulated, rotor blades using overset, moving grids.

The actuator method utilizes momentum/energy source terms to represent the influence of the rotating blade system. Use of the source terms simplifies grid generation, since the actuator surfaces do not need to be built into the computational grid. However, the computational grid should have some refinement in the vicinity of the actuator surfaces to obtain accurate results.

Running An Actuator Surface Rotorcraft Solution In FUN3D

[This capability was originally implemented by Dave O'Brien, at the time a PhD candidate at Georgia Tech. Note FUN3D v11.0 and higher also contains the actuator disk library subsequently developed by Dave for the DoD HI-ARMS/CREATE/HELIOS project: Software Module for Engineering Methods of Rotor Dynamics (SMEMRD) version 1.3.1. The FUN3D team does not provide technical support/documentation for the DoD modules; users must contact Dave O'Brien for help. The DoD modules add the ability to trim to thrust values and the ability to read in airfoil lookup tables. This version of the actuator disk model is triggered through the use of the `--hiarms_rotor` command line option.]

The actuator surface routines are triggered through the use of the `--rotor` command line option, e.g:

```
mpirun -np 16 nodet_mpi --rotor
```

Once the rotor option has been invoked, FUN3D will search for the rotor input deck file, `rotor.input`. This file is located in the `FUN3D_90` directory and is required along with the standard input file, `fun3d.nml` (or `ginput.faces` prior to release 10.5.0).

The two main parameters used by the actuator surface solution are `mach_number` in `fun3d.nml` (`XMACH` in `ginput.faces` in release 10.4.1 and before) and `Adv_Ratio` in `rotor.input`. These two parameters affect the force coefficient calculations. To non-dimensionalize the forces with the rotor tip speed set `XMACH=Tip Mach Number` and `Adv_Ratio=V_freestream/V_tip`. To non-dimensionalize the forces with the freestream velocity set `XMACH=Freestream Mach Number` and `Adv_Ratio=1.0`. For incompressible solutions `XMACH` is the artificial compressibility parameter (suggested value = 15.0), but the `Adv_Ratio` will still affect the force non-dimensionalization as described above.

Sample Rotor Input Deck

A sample `rotor.input` file is shown below for a conventional main rotor / tail rotor helicopter.

```
  # Rotors  Vinf_Ratio  Write Soln  Force Ref  Moment Ref
        2         1.0          50        1.0         1.0
=== Main Rotor ============================================================
Rotor Type   Load Type    # Radial    # Normal  Tip Weight
         1           0          50         720         0.0
  X0_rotor    Y0_rotor    Z0_rotor        phi1        phi2        phi3
      0.00        0.00        0.00        0.00       -5.00        0.00
  Vt_Ratio  ThrustCoff   PowerCoff        psi0  PitchHinge      DirRot
     6.666       0.005       -1.00        0.00        0.00           0
  # Blades   TipRadius  RootRadius  BladeChord   FlapHinge    LagHinge
         4        1.00        0.00        0.05        0.00        0.00
 LiftSlope  alpha, L=0         cd0         cd1         cd2
      6.28        0.00       0.002        0.00        0.00
    CL_max      CL_min      CD_max      CD_min       Swirl
      1.50       -1.50        1.50       -1.50           0
    Theta0  ThetaTwist     Theta1s     Theta1c  Pitch-Flap
      5.00       -2.00        0.00        0.00        0.00
 # FlapHar       Beta0       Beta1s      Beta1c
         0        0.00        0.00        0.00
    Beta2s      Beta2c      Beta3s      Beta3c
      0.00        0.00        0.00        0.00
  # LagHar      Delta0     Delta1s     Delta1c
         0        0.00        0.00        0.00
   Delta2s     Delta2c     Delta3s     Delta3c
      0.00        0.00        0.00        0.00
=== Tail Rotor ============================================================
Rotor Type   Load Type    # Radial    # Normal  Tip Weight
         1           0          50         720         0.0
  X0_rotor    Y0_rotor    Z0_rotor        phi1        phi2        phi3
      1.00        0.00        0.00      -90.00        0.00        0.00
  Vt_Ratio  ThrustCoff   PowerCoff        psi0  PitchHinge      DirRot
     3.333       0.001       -1.00        0.00        0.00           0
  # Blades   TipRadius  RootRadius  BladeChord   FlapHinge    LagHinge
         3        0.20        0.00        0.01        0.00        0.00
 LiftSlope  alpha, L=0         cd0         cd1         cd2
      6.28        0.00       0.002        0.00        0.00
    CL_max      CL_min      CD_max      CD_min       Swirl
      1.50       -1.50        1.50       -1.50           1
    Theta0  ThetaTwist     Theta1s     Theta1c  Pitch-Flap
      8.00        0.00        0.00        0.00        0.00
 # FlapHar       Beta0       Beta1s      Beta1c
         0        0.00        0.00        0.00
    Beta2s      Beta2c      Beta3s      Beta3c
      0.00        0.00        0.00        0.00
  # LagHar      Delta0     Delta1s     Delta1c
         0        0.00        0.00        0.00
   Delta2s     Delta2c     Delta3s     Delta3c
      0.00        0.00        0.00        0.00
```

The header line is where the user specifies the number of rotors, the rotor advance ratio, and how often to output the plot3d loading file. The remainder of the file is in a block structure, where each block represents the inputs for one rotor. The first line of each block is a text line that can be edited to keep the rotors organized for the user.

Header Line Inputs

`#Rotors` Number of actuator surfaces to create. The number of variable blocks must match the number of rotors specified.

`Vinf_Ratio` Ratio of V_freestream to V_force_ref, where V_freestream is the freestream velocity and V_force_ref is the velocity used for force normalization. If V_force_ref = V_tip, as is typical for rotorcraft applications, then Vinf_Ratio = Advance ratio. Note that if V_force_ref = V_tip, then the mach_number in the `fun3d.nml` file should correspond to the tip mach number, rather than the freestream mach number.

`WriteSoln` Specifies how many iterations to run before writing the Plot3D rotor loading data. The suggested value is `Write Soln = NCYC`.

`Force Ref` Conversion factor to allow user to obtain forces in desired units; = 1.0 for standard FUN3D nondimensional force coefficients; = (L_ref x L_ref x a_ref x a_ref) / (pi x R x R x V_tip x V_tip) to get standard rotorcraft nondimensional force coefficients; = rho_ref x a_ref x a_ref x L_ref x L_ref to get dimensional forces

`Moment Ref` Conversion factor to allow user to obtain moments in desired units

Actuator Surface Inputs

`RotorType` Type of rotor model to apply. `Rotor Type=1` models the rotor as an actuator disk. `Rotor Type=2` models the rotor as actuator blades [In development].

LoadType Type of loading to apply to the rotor model. `Load Type=1` constant pressure jump. `Load Type=2` linearly increasing pressure jump. `Load Type=3` blade element based loading. `Load Type=4` user specified loading.

#Radial Number of sources to distribute along the blade radius. Suggested value is `# Radial=100`.

#Normal Number of sources to distribute in the direction normal to the radius. Suggested value is `# Normal=720` for `Rotor Type=1` (one source every 0.5 degrees). Suggested value is `# Normal=20` for `Rotor Type=2`.

TipWeight Hyperbolic weighting factor for distributing sources along the blade radius. Input range is 0.0 to 2.0, values larger than 2.0 concentrate too many sources at the blade tip. Suggested value is `Tip Weight=0.0` (uniform distribution)

Rotor Reference System Placement and Orientation

X0_rotor The *x* coordinate of the hub (a.k.a. center of rotation).

Y0_rotor The *y* coordinate of the hub (a.k.a. center of rotation).

Z0_rotor The *z* coordinate of the hub (a.k.a. center of rotation).

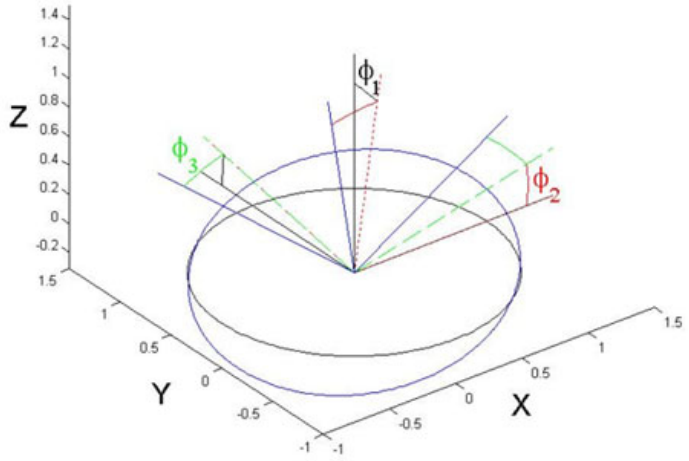
phi1 The first Euler angle describing a rotation about the *x* axis.

phi2 The second Euler angle describing a rotation about the $a_{2\sim}$ axis.

phi3 The third Euler angle describing a rotation about the $b3\sim$ axis.

The Euler angles are one of the more confusing inputs in the rotor input deck. These angles must be input correctly to obtain the correct orientation of the source based actuator disk. The angles should all be input in degrees.

The following example will attempt to explain how to determine these angles. The picture below depicts the rotations `phi1 = 10`, `phi2 = -15`, and `phi3 = 15`. Initially, the thrust is assumed to be in the *z* direction and the disk in located in the *x-y* plane. The first rotation of phi1 about the *x_ axis takes the _x,y_,_z* system to the $a\_1\sim,\_a2,a3\sim$ system shown in red below. The second rotation of phi2 about the $a_{2\sim}$ axis takes the $a\_1,\_a2,a\_3\sim$ *system to the* $\_b1\sim,b\_2,\_b3\sim$ system shown in green below. The final rotation of phi3 about the $b_{3\sim}$ axis takes the $b\_1,\_b2,b3\sim$ system to the rotor reference system shown in blue below. The black circle represents the initial disk orientation and the blue circle represents the final disk orientation. In general `phi1` and `phi2` are sufficient to define the thrust orientation. `phi3` only serves to change the location of the zero azimuth angle for the rotor.



Rotor Loading Parameters

Vt_Ratio* The ratio of the tip speed to the velocity used for force normalization, V_force_ref; if V_force_ref is V_freestream, then Vt_Ratio = 1 / Advance Ratio

ThrustCoff The rotor thrust coefficient. $C_{T\sim} = \text{Thrust} / (\text{Density}_{\sim ref} \times \pi \times R^{2\wedge} \times (\text{Omega}_{Dim} \times R)^{\wedge 2})$ Used when `Load Type=1` or `Load Type=2`. Note: The blade element model does not trim to specified thrust coefficient.

PowerCoff The rotor power coefficient [Not implemented].

Blade Parameters

psi0 The initial azimuthal position of blade 1; usually (always?) 0

PitchHinge	The radial position of the blade pitch hinge (normalized by tip radius).
#Blades	The number of rotor blades, only used for `Load Type=3`.
TipRadius	The radius of the blade.
RootRadius	The radius of the blade root, used to account for the cutout region.
BladeChord	The chord length of the blade, only used for `Load Type=3`. The can only handle rectangular blade planforms.
FlapHinge	The radial position of the blade flap hinge (normalized by tip radius).
LagHinge	The radial position of the blade lag hinge (normalized by tip radius).

Blade Element Parameters, only used when Load Type=3

LiftSlope; alpha,L=0	Used to compute the lift coefficient.
cd0, cd1, cd2	Used to compute the drag coefficient.
CL_max, CL_min	Limiters to control the lift coefficient beyond the linear region.
CD_max, CD_min	Limiters to control the drag coefficient.
Swirl	`Swirl=0` neglects the sources terms that create rotor swirl. `Swirl=1` includes the swirl inducing terms.

$CL = LiftSlope \times (alpha - alphaL{=}0_)$

$CD = cd0 + cd1 \times alpha + cd2\sim \times alpha^2$

Pitch Control Parameters, only used when Load Type=3

Theta0	Collective pitch in degrees, defined at r/R=0.
ThetaTwist	Linear blade twist.
Theta1s	Longitudinal cyclic pitch input in degrees.
Theta1c	Lateral cyclic pitch input in degrees.
Pitch-Flap	Pitch-Flap coupling parameter, not implemented.

$Theta = Theta0 + ThetaTwist \times r/R + Theta1c \times \mathbf{cos}(psi) + Theta1s \times \mathbf{sin}(psi)$

Prescribed Flap Parameters

#FlapHar	Number of flap harmonics to include, valid input range is 0 to 3
Beta0	Coning angle in degrees
Beta1s, Beta1c	Fist flap harmonics
Beta2s, Beta2c	Second flap harmonics
Beta3s, Beta3c	Third flap harmonics

$Beta = Beta0 + Beta1s \times \mathbf{sin}(psi) + Beta1c \times \mathbf{cos}(psi) + Beta2s \times \mathbf{sin}(2\ psi) + Beta2c \times \mathbf{cos}(2\ psi) + Beta3s \times \mathbf{sin}(3\ psi) + Beta3c \times \mathbf{cos}(3\ psi)$

Prescribed Lag Parameters

#LagHar	Number of lag harmonics to include, valid input is 0 to 3
Delta0	Mean lag angle in degrees
Delta1s, Delta1c	Fist lag harmonics
Delta2s, Delta2c	Second lag harmonics
Delta3s, Delta3c	Third lag harmonics

$Delta = Delta0 + Delta1s \times \mathbf{sin}(psi) + Delta1c \times \mathbf{cos}(psi) + Delta2s \times \mathbf{sin}(2\ psi) + Delta2c \times \mathbf{cos}(2\ psi) + Delta3s \times \mathbf{sin}(3\ psi) + Delta3c \times \mathbf{cos}(3\ psi)$

Running An Overset, Moving Mesh Rotorcraft Solution In FUN3D

UNDER CONSTRUCTION

Warning: information incomplete, subject to change, or perhaps even just plain wrong!

This is a very advanced application and it is recommended that the user have experience running basic **Time Accurate** cases and simpler **Moving Grid** cases without the complications of overset

meshes.

Overset grid applications require the **SUGGAR++** and **DiRTlib** libraries developed by Ralph Noack. The user should gain experience with the SUGGAR++ code for simpler overset cases before embarking on the more complex rotorcraft problem.

Overset, moving mesh rotorcraft solutions can be divided into those involving rigid blades and those involving flexible (aeroelastic) blades. The latter case is quite complex, and requires the use of a "comprehensive" rotorcraft structural dynamics (CSD) code such as **CAMRAD II** or **Dymore** . The CSD code provides the structural model for the blade deformation, and furnishes trim algorithms for determining the basic rotor settings such as the collective and cyclic pitch angles. Currently, only the "loose coupling" approach has been implemented, limiting the analysis to hover or steady level flight.

Basic Steps – Rigid Blades

The following are the primary steps required to run a rotorcraft simulation in which the blades are treated as being rigid.

1) Set up the rotor.input and moving_body.input files

2) Generate the component fuselage/background and rotor blade VGRID meshes

3) (Optional) Set up the &slice_data namelist in the `fun3d.nml` file to extract airloads data along the reference blade

4) Generate the composite mesh with the rotor blades in the t=0 position using the `dci_gen` utility code

6) Run the flow solver for one rotor revolution, using `--dci_on_the_fly` to generate the overset connectivity files; you may optionally use—dci_period NP for this first run (required for subsequent runs), where NP is the number of time steps taken to complete one revolution (e.g. 360 for 1 deg. motion per time step)

7) Run the flow solver for a number of additional rotor revolutions, either without `--dci_on_the_fly` (i.e reuse the dci from step 6), or with `--reuse_existing_dci` in addition to `--dci_on_the_fly`; you also need to use —dci_period NP for any revolution beyond the first one, where NP is the number of time steps taken to complete one revolution

8) (Optional) Post process the rotor airloads data from step 3 using the `process_rotor_data` utility code

Note: Steps 6) and 7) above can be combined into a single run by first ensuring that the **only** dci file in the run directory is the initial one (i.e. the [project].dci file), and then using the combination `--dci_on_the_fly --reuse_existing_dci --dci_period NP` command-line options. This will create the required dci files during the first revolution (since they don't exist), and then reuse them on subsequent revolutions. If the `--reuse_existing_dci` command-line option is omitted, new dci files will be generated each revolution (unnecessary for rigid blades undergoing cyclic motion).

In addition to the command-line options for the flow solver given above, all overset, moving-grid, rigid-blade rotorcraft cases with FUN3D will also require

```
--moving_grid --overset_rotor
```

And one may also choose to use (optional steps 3 and 8 above)

```
--slice_freq 1 --output_comprehensive_loads
```

Basic Steps – Elastic Blades

The following are the primary steps required to run a rotorcraft simulation in which the blades are treated as being elastic, and thus the flow solver is coupled to an external CSD code.

1) Set up the rotor.input and moving_body.input files

2) Generate the component fuselage/background and rotor blade VGRID meshes

3) Set up the &slice_data namelist in the `fun3d.nml` file to extract airloads data along the reference blade (Required)

4) Generate the composite mesh with the rotor blades in the t=0 position

5a) Set up and run the comprehensive rotorcraft code to generate reference motion data

5b) Set up and run the comprehensive rotorcraft code using only the comprehensive code's built-in linear aerodynamics model

5c) Generate a blade motion file from the comprehensive code data

6a) Run the flow solver for 1 rotor revolutions, using `--dci_on_the_fly` to generate the overset

connectivity files; you may optionally use—dci_period NP for this first run (required for subsequent runs), where NP is the number of time steps taken to complete one revolution (e.g. 360 for 1 deg. motion per time step)

6b) Run the flow solver for 1-2 additional revolutions, either without `--dci_on_the_fly` (i.e reuse the dci from step 6a), or with `--reuse_existing_dci` in addition to `--dci_on_the_fly` and `--dci_period NP`

7a) Generate a "delta airloads" file for the comprehensive rotorcraft code

7b) Set up and run the comprehensive rotorcraft code using the current "delta airloads"

8) Go back to step 5c and repeat until "delta airloads" converge and trim targets are met; on subsequent cycles through step 6, run the flow solver for 2/Nblades revolutions each time, using `--dci_on_the_fly` (i.e. recompute the dci data) and `--dci_period NP`

Note: The **first** pass through Steps 6a) and 6b) above can be combined into a single run by first ensuring that the **only** dci file in the run directory is the initial one (i.e. the [project].dci file), and then using the combination `--dci_on_the_fly --reuse_existing_dci --dci_period NP` command-line options. This will create the required dci files during the first revolution (since they don't exist), and then reuse them on subsequent revolutions. Note that for subsequent coupling cycles, for which only partial revolutions are completed in a given run, do not use `--reuse_existing_dci`, as new dci files are needed when the blade motion/shape changes.

In addition to the command-line options for the flow solver given above, all overset, moving-grid, elastic-blade rotorcraft cases with FUN3D will also require

```
--moving_grid --overset_rotor --comprehensive_rotor_coupling 'camrad' --
slice_freq 1
```

For elastic/coupled blade analysis, a sample PBS run script `RUN_LOOSE_COUPLING` is provided in the utils/Rotorcraft directory. This script removes much of the tedium of running a coupled rotorcraft analysis "by hand" as outlined above. The run script is set up to work with the CAMRAD II comprehensive code, although the changes to the script to work with other comprehensive codes should be relatively minor.

Aerodynamic data **from** FUN3D to the comprehensive code is provided via the FUN3D output file `rotor_N.onerev.txt` (N the rotor number). This file has the same form and function as the corresponding file that is output from the OVERFLOW code.

Blade motion data **to** FUN3D from the comprehensive code is provided via the FUN3D input file `camrad_motion_data_rotor_N.dat` (N the rotor number). Despite the name difference, this file has the same form and function as the `motion.txt` file used by the OVERFLOW code.

Note that CAMRAD does not directly use the `rotor_N.onerev.txt` file. To utilize the `rotor_N.onerev.txt` file to generate the "delta airloads" file actually used by CAMRAD, an intermediate translation code is required. Likewise, CAMRAD does directly output the `camrad_motion_data_rotor_N.dat` file needed by FUN3D; again, an intermediary code is required. Suitable intermediary codes (`gen_delta_for_cii` and `gen_motion_for_cfd`) have been written for OVERFLOW/CAMRAD coupling and can be used with FUN3D/CAMRAD as well. These intermediary codes may be requested from:

Doug Boyd (NASA Langley Aeroacoustics Branch)

The `RUN_LOOSE_COUPLING` script relies on the above-mentioned conversion codes.

Utility Codes / Scripts / Files

The FUN3D suite includes several utility codes in the utils/Rotorcraft directory:

`dci_gen.f90`	Uses (lib)SUGGAR++ to create a composite rotorcraft mesh from component rotor blade and fuselage/background grids
`dci_gen.input`	A sample input file for the dci_gen code
`RUN_DCI_PARALLEL`	A run script for the dci_gen code
`process_rotor_data.f90`	Reads the `rotor_N.onerev.txt` file and corresponding `motion_rotor_N.onerev.txt` file and generates Tecplot files for plotting airloads and motion data
`RENUMBER_DCI_FILES`	A script to renumber existing dci files so that a set of dci files generated for one time step can be reused with a different time step
`RUN_LOOSE_COUPLING`	A script to run a loosely coupled CFD/CSD elastic-blade rotorcraft simulation
`hart2_ref.scr`	Sample CAMRAD run scripts set up for compatibility with the

hart2_0.scr	RUN_LOOSE_COUPLING script
hart2_n.scr	

Subset of rotor.input Variables Used for "First Principles" Rotorcraft Cases

Of the parameters in the `rotor.input` file described **above**, only the following are needed for overset, moving mesh cases; zeroes may be entered for all other values. Note that for flexible-blade simulations the pitch, flap and lag harmonics are not used, although the pitch, flap and lag hinge locations **are** used. For flexible-blade simulations, the pitch, flap and lag motions are accounted for in the motion file provided (indirectly) by the comprehensive rotorcraft code.

No. Rotors, Vinf_Ratio

X0_Rotor, Y0_Rotor, Z0_Rotor

phi2

Vt_Ratio, PitchHinge

No. Blades, TipRadius, RootRadius, BladeChord, FlapHinge, LagHinge

Theta0, Theta1s, Theta1c (ignored for elastic blades)

No. FlapHar, Beta0, Beta1s, Beta1c (ignored for elastic blades)

Beta2s, Beta2c, Beta3s, Beta3c (ignored for elastic blades)

No. LagHar Delta0, Delta1s, Delta1c (ignored for elastic blades)

Delta2s, Delta2c, Delta3s, Delta3c (ignored for elastic blades)

Rotation speed and time step

In the discussion below, it is assumed that the geometry represented by the grid is unscaled relative to the actual configuration; e.g. if the actual rotor radius is 26.833 ft., then the corresponding rotor radius in the grid used for computations is also 26.833.

The non-dimensional rotor rotation rate is not set directly by the user, but rather via a combination of `Vt_Ratio` and `TipRadius` values in the `rotor.input` file, and the `mach_number` value in the `fun3d.nml` file:

omega = vt_ratio x mach_number / r_tip (compressible flow)

omega = vt_ratio / r_tip (incompressible flow)

where omega is in radians (per unit nondimensional time).

To set the value of `time_step_nondim` in the `fun3d.nml` input file, first decide on the desired azimuthal resolution for each time step, dpsi. A value of dpsi of 1 degree per time step is usually a reasonable starting point.

The nondimensional time step may be determined using

dpsi = omega x time_step_nondim x 180 / pi

So that

time_step_nondim = dpsi x pi / 180 x r_tip / vt_ratio / xmach (compressible)

time_step_nondim = dpsi x pi / 180 x r_tip / vt_ratio (incompressible)

Tip: As a check, the resulting non-dimensional rotation rate and azimuth change per time step are output to the screen in the "Rotor info" section. Make sure this output value matches your desired value to a fair degree of precision, to ensure that the rotor blades are accurately positioned at each time step. Inaccuracies can occur if, for example, you base your calculation of time_step_nondim on a value of r_tip = 26.8330 but in the rotor.input file you have a value of r_tip = 26.8333

Subset of moving_body.input Variables Used for "First Principles" Rotorcraft Cases

As with all **moving body simulations**, a `moving_body.input` file is required. However, the `moving_body.input` file for rotorcraft cases is primarily used to **define the moving bodies** (the rotor blades) as particular boundary surfaces within the mesh, while the blade motion is specified in the

rotor input deck described **above** . The value of Vt_ratio sets the rotation rate of the rotor while the values of the theta, beta, and delta variables set the pitch, flap and lag motions of the blades. Note: for elastic blades, the pitch, flap and lag motions are **not** set via the `rotor.input` file, but rather via a separate "blade motion" file; Vt_ratio does set the rotation rate, however. This differs from the usual moving body case wherein the body motion is specified in the `moving_body.input` file. For rotorcraft cases, the `motion_driver` variable should **not** not be specified in the **`&body_definitions`** namelist, and the `&forced_motion` namelist should be omitted entirely.

A sample `moving_body.input` file for a single 4-bladed rotor is shown below

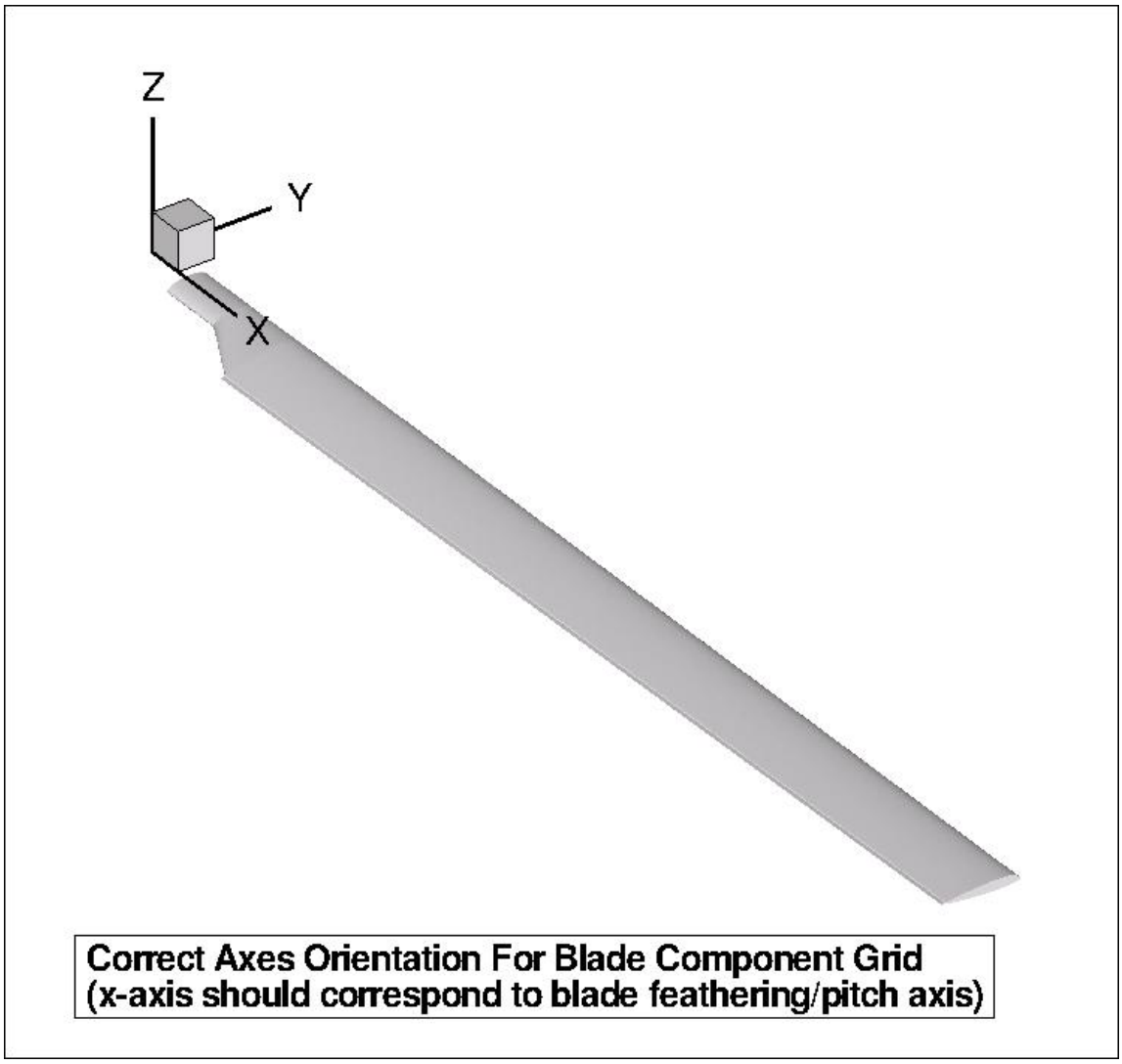
```
&body_definitions
  n_moving_bodies = 4,              ! 4 blades
  body_name(1) = 'rotor1_blade1',   ! name is set by *dci_gen* - must use unalt
  n_defining_bndry(1) = 1,          ! number of boundaries that define this bla
  defining_bndry(1,1) = 2,          ! index 1: boundary number index 2: body nu
  mesh_movement(1) = 'deform',      ! blades are elastic
  body_name(2) = 'rotor1_blade2',
  n_defining_bndry(2) = 1,
  defining_bndry(1,2) = 4,
  mesh_movement(2) = 'deform',
  body_name(3) = 'rotor1_blade3',
  n_defining_bndry(3) = 1,
  defining_bndry(1,3) = 6,
  mesh_movement(3) = 'deform',
  body_name(4) = 'rotor1_blade4',
  n_defining_bndry(4) = 1,
  defining_bndry(1,4) = 8,
  mesh_movement(4) = 'deform',
/
&composite_overset_mesh
  input_xml_file = 'Input.xml_0'   ! generated by *dci_gen*
/
```

Create the Component Meshes

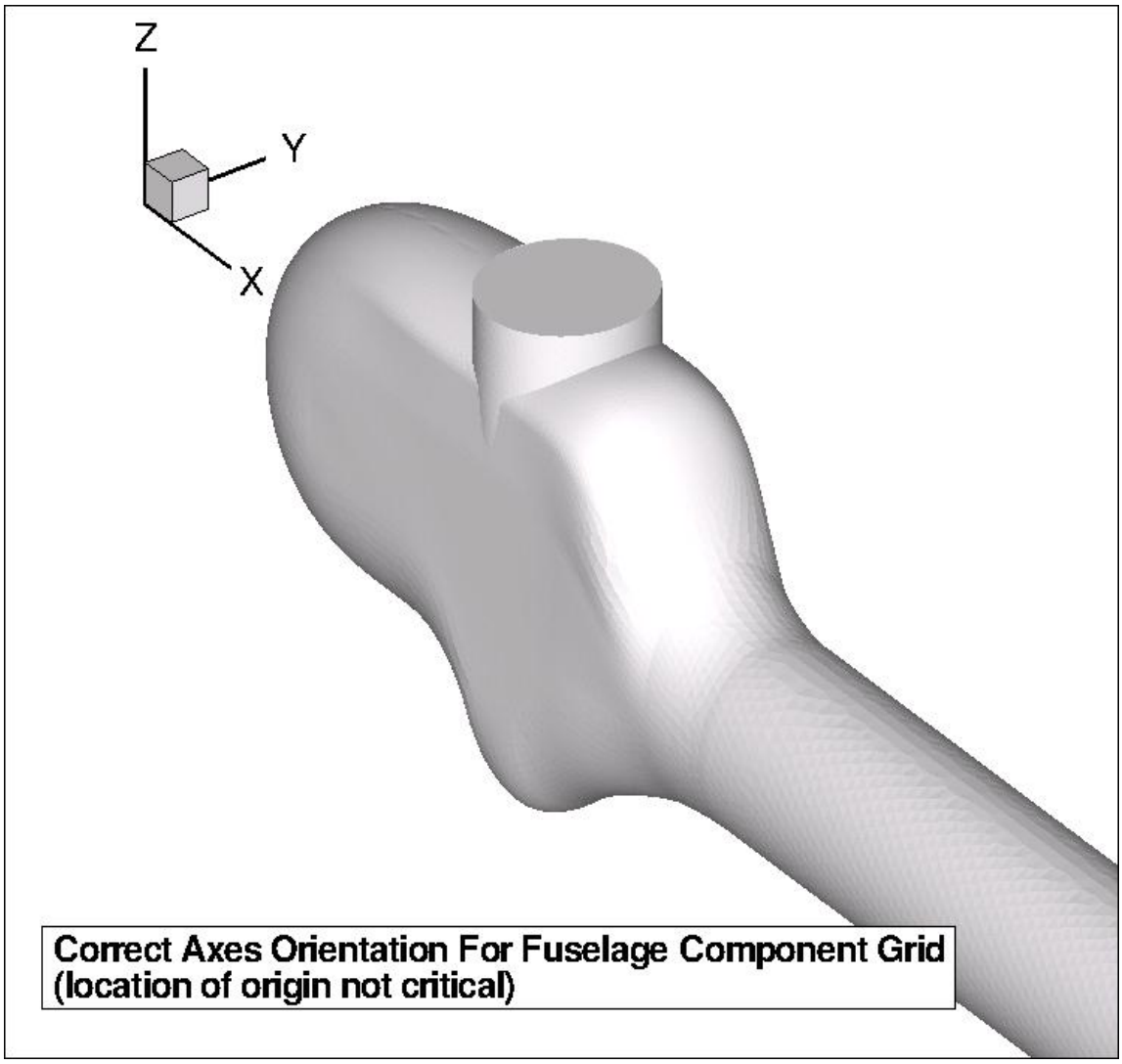
At this point in time, only VGRID meshes can be utilized. The component meshes for a single-rotor simulation are 1) a fuselage/background mesh and 2) a mesh around a **single** rotor blade. At this point in time, the assumption is that all blades on a given rotor are identical. If more than one rotor is present, with a blade geometry that differs from the first rotor, additional component rotor blade mesh(es) may be used to define the additional rotor(s). The fuselage/background mesh defines the region of space surrounding the rotor, and may or may not contain an actual fuselage geometry – i.e. the fuselage/background mesh can simply be an empty box (or other simple shape) mesh if one wishes to analyze an isolated rotor. Whether or not an actual fuselage is modeled, it is important that the fuselage/background mesh have sufficient mesh density in the region of the rotor disk so that 1) the appropriate flow features can be resolved, and 2) that high-quality interpolation stencils can be obtained between the background mesh and the blade meshes. In particular, fine rotor meshes and a coarse background mesh in the vicinity of the rotor disk is a poor practice.

NOTE: The mapbc file for the component blade grid must have the outer boundaries set with a BC type of -1, rather than the usual characteristic farfield type 3. The value of -1 is used to indicate to SUGGAR++ that this is an overset boundary. The fuselage/background grid should have the usual type 3 BC at its outer boundaries.

The component meshes are required to be oriented in specific directions. The fuselage/background mesh must be in the standard FUN3D orientation, i.e. with the x-axis in the (nominal) flow direction and the z-axis "up". The y-axis should then be oriented following the right-hand rule. The blade mesh must be oriented such that the x-axis runs out the span of the blade. The y-axis must point in the "anti-chordwise" direction, i.e. from the trailing edge to the leading edge. The z-axis then points "up" following the right-hand rule. The origin of the blade axis system should be chosen such that the x-axis corresponds to the blade feathering/pitch axis. These required orientations for the component grids are shown in the next two figures.



Correct Axes Orientation For Blade Component Grid (x-axis should correspond to blade feathering/pitch axis)



Create the Composite Mesh

A utility code, **dci_gen**, is provided with the FUN3D suite of codes, in the **`utils/Rotorcraft`** directory. Compiling of the utility code is performed with a top-level "make" in your configuration directory; alternatively in the configuration directory, cd to utils/Rotorcraft and type make there. **NOTE** you will have had to configure with the `--with-suggar` option (see **SUGGAR++**).

Before using **dci_gen**, the `rotor.input` file should be set up. For rigid-blade analysis, the collective/cyclic data in `rotor.input` is used to position the blades in the composite mesh at the correct orientation at t=0. If this is a simulation with elastic blades, an initial "motion.txt" file must also be available. For those familiar with the OVERFLOW code for rotorcraft applications, this is the same file, with the same format, as used with OVERFLOW. However, with FUN3D, this initial "motion.txt" file must have a very specific name (at the time of writing): `camrad_motion_data_rotor_N_t0.dat` (N the rotor number). The required motion file may be the result from an initial comprehensive code analysis using the CSD code's internal aerodynamics module, i.e. the initial step in a coupled CFD/CSD coupling. In this case additional motion files will generated later as the coupling progresses. Alternatively, you may have a final motion file resulting from some other process; in this case you will have only one motion file, but that motion file must still be named `camrad_motion_data_rotor_N_t0.dat` for **dci_gen**. In the case of elastic blades, the orientation of the blades at t=0 is determined from this initial motion file, rather than from the `rotor.input` file.

Upon execution, **dci_gen** will prompt the user for input:

1) a project name (for the assembled, composite grid)
2) the name of the VGRID component fuselage grid
3) the name of the VGRID component blade grid for the first rotor (if multiple rotors, additional component blade grid names will be requested)
4) the initial_azimuth, final_azimuth and azimuthal_increment

5) whether or not the blades are considered rigid

6) if more that one rotor was specified, the gear ratio to rotor 1 for each additional rotor

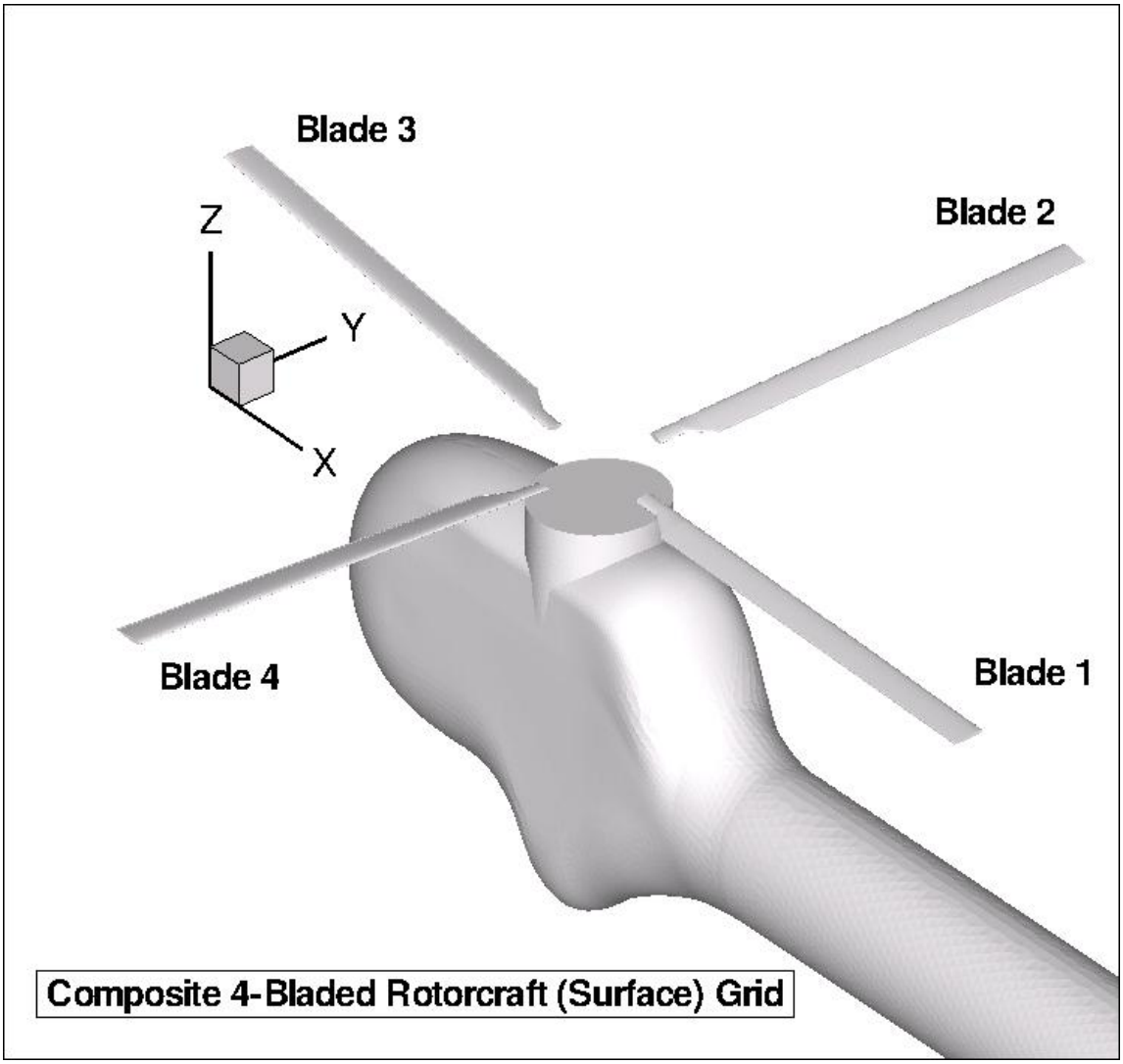
If the blades are rigid, then the specified final_azimuth could larger than the initial_azimuth (some multiple of the increment), and **dci_gen** would generate multiple dci files, one for each azimuth. There is even a provision for doing so in parallel. However, the easiest process, and the only one described here, is to set initial_azimuth = final_azimuth = 0. In this case, only one dci file is generated, corresponding to psi = 0. Subsequent dci files are then generated "on the fly" when running running FUN3D. For elastic blades, this is the only approach available (i. e. only the psi=0 dci file created up front, others computed "on the fly")

dci_gen will read your `rotor.input` file (and if elastic, the "motion.txt" file), take the component **VGRID** meshes that you specify, and create SUGGAR++ xml commands to position the blade grid at appropriate locations and orientations around the rotor disk (e.g. at 90 deg. locations for a 4-bladed rotor, with appropriate pitch settings, etc.). This xml file will be named `Input.xml_0`, and is the xml file that should be specified as the `input_xml_file` in the `&composite_overset_mesh` namelist of the `moving_body.input` file. **dci_gen** will then use (lib)SUGGAR++ to generate both a composite mesh and the corresponding dci file for the rotor in the initial position, at t=0. In the composite mesh, blade 1 will be aligned with the axis of the fuselage (the x-axis), as shown below.

dci_gen will also set up a mapbc file for the composite grid. In this mapbc file you should find/verify that the BCs from the original blade component grid have been replicated `nblade` times, and in particular the overset BC (-1) should appear for each blade. The family names of the blade and outer boundaries will be prepended by rotorN_ (N the rotor number) and appended by the blade number. For example, if the family name for the blade surfaces in the blade component grid was "Blade", then in the composite mapbc file, the blades will have family names "rotor1_Blade1", rotor1_Blade2", etc. The BCs and family names of the fuselage/background grid will be unchanged from the component-grid mapbc file.

Domain connectivity files (dci files) will be generated for each azimuthal angle psi from the initial to the final value, with the specified increment. A composite mesh is generated **only** if the initial psi value is zero.

Below is the resulting 4-bladed composite geometry created from the blade and fuselage component geometries shown above.



6.4. Hypersonics

Main Solver Input File

Subsequent to release 10.4.1, the old input file `ginput.faces` was replaced by a namelist file. Many of the input parameters for hypersonic (generic gas) cases are given there, as described in the Flow Solver Namelist Input section.

The generic gas path can currently accommodate perfect-gas, equilibrium gas, and mixtures of thermally-perfect species in chemical and/or thermal non-equilibrium. The user specifies the gas model in a separate file called `tdata` to be defined later.

Note that in the generic gas path, the turbulent model equations are solved in a fully coupled manner with the other conservation laws.

Two options are available for second-order spatial accuracy using mixed elements. When `flux_construction` = `roe`, then the right and left states are reconstructed to second-order using primitive variable gradients computed using least squares from the right and left nodes. These gradients may in turn be limited according to the standard definition of `flux_limiter` in FUN3D. When `flux_construction` = `stvd`, then the right and left states use the nodal values (first-order-formulation) but a second-order, anti-dissipative correction is introduced using a STVD (Symmetric Total Variation Diminishing) formulation involving the same nodal values of gradients. In this case there is no limiting of gradients, other than that occurring in the STVD formulation. The `stvd` option is recommended for mixed element cases. The `roe` option engages a sub-iteration to accommodate thermodynamic variables with the reconstructed states that sometimes broadcasts warning messages when the sub-iterations fail to achieve a target residual in a fixed number of sub-iterations.

In the case of a pure tetrahedral element grid `flux_construction` = `multidm` is recommended. In this option, the inviscid flux is computed within a tetrahedral element using information from the

three-dimensional stencil of nodes defining the element. It provides far superior results for heating and shear across high aspect ratio tetrahedral cells than any of the edge-based reconstruction methods tested to date. Heating and shear are still best simulated using a semi-structured grid across the boundary layer and orthogonal to the wall – but if such a grid is not available it is recommended to convert the grid to a pure tets using the command line option `--make_tets` and use `flux_construction = multidm`.

Mach number and Reynolds number per grid unit are computed from the fundamental inputs of `velocity`, `density`, and `temperature`.

If a non-constant wall temperature boundary condition is specified (see Boundary Conditions for Generic Gas Option) then the parameter `temperature_walldefault` serves only to initialize the surface boundary condition.

The flag `chemical_kinetics` is engaged only in the case of multiple species defined in file tdata. If `chemical_kinetics` is set to `frozen` for chemically frozen flow then the chemical source term is never called and species mass fractions can only be changed through the action of diffusion. If it is set to `finite-rate` for chemically reacting flow then the chemical source term is called and species mass fractions change by kinetic action of dissociation, recombination, ionization, and de-ionization. The flag `thermal_energy_model` is set to `frozen` for thermally frozen flow or to `non-equilib` for thermally active flow (flow in thermal non-equilibrium). This flag is engaged only when a thermal non-equilibrium model is specified in the file `tdata`; otherwise thermal equilibrium is assumed. If it is set to `frozen` for thermally frozen flow then the thermal energy exchange source term is never called and the modeled modal temperatures (vibrational, electronic) can be changed only by the action of conduction. (Translational temperature still evolves through the action of flow work but this energy is never transferred to internal energy modes.) If it is set to `non-equilib` then the source term models particle collisions in which particle internal energy in the translational, rotational, vibrational, and electronic modes can be exchanged.

The parameter `invis_relax_factor` is a relaxation factor on the update, dq, to the conservative flow variables q. Before an update, dq is divided by the maximum value of five limiting factors including `invis_relax_factor`. The first four limiting factors are computed internally and designed to limit the rate of change of pressure, density, temperature, and velocity. If `invis_relax_factor` is set to `1.0`, no further limiting is engaged. The parameter `visc_relax_factor` is a relaxation factor that multiplies only the viscous Jacobian. Its value should be set to `1.0`; it is retained here as a place holder for future research. The parameter `rhs_u_eigenvalue_coef` is the eigenvalue limiter. It acts only on the evaluation of the eigenvalues used on the right-hand-side convective portion of the residual using Roe's method. If eigenvalues are less than `rhs_u_eigenvalue_coef` times the local sound speed then a formula due to Harten is employed to smoothly limit the eigenvalue. Numerical tests show that the heating and solution quality near the wall are severely compromised using eigenvalue limiting when tetrahedra are used throughout. The parameter value should be set to `1.e-30` (it must be positive definite) in this case. It is retained as an input parameter in case it is needed, as in the structured grid approach of LAURA, when prismatic elements are introduced. The parameter `lhs_u_eigenvalue_coef` is also an eigenvalue limiter but is applied only in the evaluation of the inviscid Jacobian (left-hand-side) by Roe's method. Recommended values between `.001` and `1.0` provide a more well-determined matrix. Larger values enhance robustness with the possible penalty of slower convergence, particularly in stagnation regions.

Gas Model Input File: tdata

The file `tdata` defines the gas model. Information in this file is likely to change from one application to another, depending on the flow regime, velocity, and atmospheric composition. It contains a list of key words, sometimes followed by numeric values, which identify components of the gas model. One or more spaces must separate keyword and values when appearing on the same line. Spaces may appear to the left or right of any key word. The first line of the file must not be blank. Options for perfect-gas, equilibrium gas, and mixtures of thermally perfect gases can be accommodated. An example of the input data file `tdata` used for each will be presented.

Perfect Gas

The perfect-gas option is engaged with any of the following keywords: `perfect_gas`, `PERFECT_GAS`, `Perfect_Gas`, `Perfect_gas`.

If no further data is provided in this file, this single line `tdata` file will assume the following parameter values in SI units for air:

```
gamma      1.4
mol_wt     28.8
suther1    0.1458205E-05
suther2    110.333333
prand      0.72
```

Here, gamma is the gas specific heat ratio, mol_wt is the gas molecular weight, prand is the gas Prandtl number, and suther1 and suther2 are the first and second Sutherland's viscosity coefficients where

```
mu = suther1*T**(3/2)/(T +suther2)
```

These values can be modified and explicitly defined in the tdata using the species_properties namelist by placing the keyword &species_properties in the second line of tdata followed by the gas parameters and / at the last line of the file. For example,

```
perfect_gas
&species_properties
gamma = 1.4
mol_wt = 28.0
suther1 = 0.1E-05
suther2 = 110.3
prand   = 0.7
/
```

Equilibrium Gas

To engage the Tannehill curve fits for thermodynamic and transport properties of equilibrium air the following keyword should be used in the first line of the tdata file:

```
equilibrium_air_t
```

To use a table look-up capability for equilibrium gases the following keyword should be placed in the tdata file:

```
equilibrium_air_r
```

Table look-up data for air is contained in the files eq_air_coeffs.asc and eq_air_lk_up.asc which may be found in the PHYSICS_MODULES directory. Note that this option still uses the Tannehill transport properties. No additional inputs or files are required to engage the Tannehill option for equilibrium air.

Mixture of Thermally Perfect Gases

```
two
N2  .767
N
O2 .233
O
NO
H2
N2
H2O
H
OH
```

The first entry of the file may contain an optional flag which identifies the thermal model. If no thermal flag is present or if the flag says one, One, or ONE then the gas is in thermal equilibrium (a one-temperature model). If there is no thermal flag then the first line of this file must contain species information as described in the next paragraph; this file cannot begin with a blank line. If the flag says two, Two, or TWO then the gas is modeled using a two-temperature model. The two temperature model assumes energy distribution in the translational and rotational modes of heavy particles (not electrons) are equilibrated at temperature *T* and all other energy modes (vibrational, electronic, electron translational) are equilibrated at temperature T_V. No other thermal models are currently available; however, the source code is written to accommodate an arbitrary number of additional thermal degrees of freedom.

Subsequent file entries include species names, appearing exactly as defined in the master data file species_thermo_data (see below). If a value appears to the right of the species name, separated by one or more spaces, then that value denotes the mass fraction of the species at an inflow boundary. If no value appears to the right of the species name then that species is not present on inflow but may be produced through chemical reactions elsewhere in the flow field.

Multiple instances of inflow boundaries can be accommodated. However, this option is not yet been exercised. For example, air may flow in from an inlet boundary and fuel may flow in from a separate inflow port. A blank line (line (7) in the example) separates instances of inflow boundary conditions. If new species are introduced in subsequent instances they are automatically initialized to zero at any previous inflow boundary. They are also available as a reactant throughout the entire flow field.

Thermodynamic Data Input File

The file `species_thermo_data` is the master file for species thermodynamic data. Here is a sample.

```
C
&species_properties
molecule = .false.
ion = .false.
elec_impct_ion = 11.264 ! Moore ? 4.453 in mars.F
siga = 7.5e-20, 5.5e-24, -1.e-28
mol_wt = 12.01070
/
3
 0.64950315E+03 -0.96490109E+00  0.25046755E+01 -0.12814480E-04
 0.19801337E-07 -0.16061440E-10  0.53144834E-14  0.00000000E+00
 0.85457631E+05  0.47479243E+01   200.000  1000.000
-0.12891365E+06  0.17195286E+03  0.26460444E+01 -0.33530690E-03
 0.17420927E-06 -0.29028178E-10  0.16421824E-14  0.00000000E+00
 0.84105978E+05  0.41300474E+01  1000.000  6000.000
 0.44325280E+09 -0.28860184E+06  0.77371083E+02 -0.97152819E-02
 0.66495953E-06 -0.22300788E-10  0.28993887E-15  0.00000000E+00
 0.23552734E+07 -0.64051232E+03  6000.000 20000.000
gamma_air
&species_properties
molecule = .true.
ion = .false.
mol_wt = 28.8
suther1 = 0.1458205E-05
suther2 = 110.333333
prand   = 0.7
/
1
0.00000000E+00  0.00000000E+00 0.10000000E+01  0.00000000E+00
0.00000000E+00  0.00000000E+00  0.00000000E+00  0.00000000E+00
0.00000000E+00  0.00000000E+00   0.0  100000.000
```

A species record consists of the species name, a species properties namelist, the number of thermodynamic property curve fit ranges, and the curve fit coefficients for each range.[1]

[1] B. J. McBride and S. Gordon, “Computer Program for calculation of Complex Chemical Equilibrium Compositions and Applications”, NASA RP 1311, June 1996.

6.5. Time Accurate – Basics/Fixed Geometry

Introduction

The basic input parameters for running fixed-mesh, time-dependent cases, are described under **Flow Solver Input Deck** . This section describes other essential information needed to run fixed-mesh time-dependent cases, and time-dependent cases in which the geometry moves.

Nondimensionalization
Temporal Order of Accuracy
Temporal Error Controller
Animation of Unsteady Flows

Nondimensionalization

A description of the nondimensionalization is under construction; in the interim, the description given in the **CFL3D documentation** will suffice. For compressible flows, the two codes use exactly the same nondimensionalization. Note that for incompressible flow (for which CFL3D has no counterpart), the reference velocity is the freestream velocity, rather than the freestream speed of sound.

Temporal Order of Accuracy

Currently, the available time-advancement schemes in FUN3D are multistep, backward difference (BDF) schemes. Second-order accuracy (itime = 2) has been the order of choice for a long time, although in Version 10.0, third order (itime = 3) and an "in between" second and third order scheme ("BDF2opt", itime = -3) were added. Note that the third-order scheme is not guaranteed to be stable; in practice this is usually not a problem, but in a few cases the lack of guaranteed stability has lead to solutions which diverge after a very long time. The BDF2opt is guaranteed to be stable and hence is recommended if accuracy higher than second order in time is needed. Bear in mind that for practical applications, solution accuracy is likely to be limited by low grid resolution, so a high-order time advancement may not lead to improved overall accuracy. First order accuracy in time is rarely used. A possible exception being to reproduce steady state convergence while running in unsteady mode – as may be needed for static aeroelastic applications, for example. With a very large time step (e.g. 1.e20) and first-order time accuracy (itime=1), the time-accurate path will converge exactly as the steady state path (itime=0).

Temporal Error Controller

The name is somewhat misleading, in that this controller addresses *one* source of temporal errors, namely, insufficient subiterations. As described in the **Flow Solver Input Deck** section, the user must specify the number of subiterations in pseudo time in between each physical time step. Ideally, enough subiterations should be used to converge the mean flow and turbulence residuals to machine zero. That of course is prohibitively expensive, so a more reasonable number of subiterations must be used. The question then is, how many subiterations are enough? It has also been observed that a certain points during unsteady simulations, subiterations converge faster, and conversely slower at other times in the simulation. Using a fixed number of subiterations sufficient for the harder portions means there will be an excess of iterations on the easier portions, thereby wasting CPU time.

The temporal error control options seeks to mitigate these issues by providing a well-founded cutoff. When using the controller, a reasonably large number of subiterations is specified, perhaps 25 to 75. The error controller itself is invoked with the command line option

```
--temporal_err_control TOL
```

where TOL is a real valued tolerance. Limited calibration studies suggest a value of 0.05 to 0.1 is reasonable. When run with this command line option, the solver will obtain an estimate of the temporal error, and when the x-momentum and turbulence residuals drop below TOL times the estimated error, the subiteration loop will terminate. If the tolerance is not reached by the end of the specified number of subiterations, a warning message is printed.

Animation of Unsteady Flows

This information has been moved to Flow Visualization Output Directly From Flow Solver

6.6. Time Accurate – Moving Geometry

Introduction

This section describes the capability for simulating flows with moving/changing geometry. It is strongly recommended that the user become familiar with time-dependent stationary-geometry simulations before attempting moving-geometry cases.

Moving Bodies/Grids – General Information
Post-Processing/Repartitioning Moving Grid Cases
Defining Moving Bodies
Specified Body Motion
Specified Observer Motion (for animation)
Body Motion via File Input
6DOF Motion
Aeroelastic Motion (Mode Based)
Sample moving_body.input Files
Mesh Deformation

Moving Bodies/Grids – General Information

NOTE: this is an active area of development, so implementation or input details may change with time.

The ability to move the grid as a rigid body (no deformation) was introduced in Version 10.0; prior versions have no provisions for moving geometries. Later versions have increased capability for deforming meshes, thereby allowing some distinction between “body motion” and “grid motion”. The current nomenclature is such that one specifies the motion of a “body” (a collection of one or more solid surfaces within the grid), and associates with that body a mechanism for moving the surrounding grid points – either rigidly, so that all points move in concert with the body, or in a deforming manner so that points near the body move in concert with the body, but points far away move little, if at all.

Grid motion is enabled via the command line option

```
--moving_grid
```

In addition to this command line option, an additional file is required to specify the details of the body motion, and to specify how the grid is moved to accommodate the motion of the body.

The `--moving_grid` command line and moving_body.input file are also required for postprocessing moving grid solutions with party. Contrary to earlier versions of the flow solver, the part files are not modified as the grid is moved. Thus the part files always contain the grid at is was at t=0; the restart (flow) files now contain the mesh coordinates for the current position. Thus it is not possible to restart old moving grid solutions with the current solver.

Data in the moving_body.input file is used to define the motion of one or more “bodies”, which are user-defined collections of solid boundaries in the mesh. Grid motion is specified to accommodate the motion of the bodies: either rigid (all nodes of the mesh rotate/translate in unison with the body) or deforming (the mesh locally deforms to accommodate the motion of the solid body). Rigid mesh movement is very fast compared to a flow solution; mesh deformation requires the iterative solution to an elasticity PDE, and can range in cost from a fraction of a (time-accurate) flow solve to more than a (time-accurate) flow solve, depending on the stiffness of the elasticity PDE. Mesh deformation requires additional input files compared to rigid mesh motion, and is discussed further in the **Mesh Deformation** section

Two useful commandline options, especially for complex mesh movements, are

```
--grid_motion_only
```

which moves the grid without solving the flow equations, and

```
--body_motion_only
```

which moves only the body without solving the elasticity equations or the flow equations. These options will generally be used with the **Animation of Unsteady Flows** capability so that the resulting body/grid motion can be visualized. The first option, `--grid_motion_only` is all that is needed for checking rigid mesh motion input data, as the cost of moving all mesh points is very small, and there is no chance of generating negative volumes during the course of moving. For deforming meshes, `--body_motion_only` should be used first to verify that the desired body motion has been input; this process runs very quickly (relative to a flow solve). Once the body motion is verified, the case can be rerun with `--grid_motion_only` to verify that the mesh can be deformed to follow the specified body motion without generating negative volumes. See the section on **Mesh Deformation** for more information. Once the body/mesh motion input data has been verified are correct, the flow solution may be carried out.

If the command line option `--moving_grid` is invoked, the file `moving_body.input` must be present in the project directory. This file may contain data for one or more of the following namelists:

&body_definitions – defines which mesh surfaces define the moving bodies

&forced_motion – specifies body motion as a function of time

&observer_motion – specifies motion of an observer as a function of time for animation purposes

&motion_from_file – specifies **rigid** grid (and body) motion via a file containing a 4×4 transform matrix as a function of time; allows general, user-defined motion, compared to the limited types of motions available in the `&forced_motion` namelist

&surface_motion_from_file – specifies body motion from one or more files; **must** be used with deforming mesh option; the surface itself may be rigid or deforming; allows general, user-defined motion, compared to the limited types of motions available in the `&forced_motion` namelist

&sixdof_motion – specifies mass/inertial properties for bodies with 6DOF motion

&aeroelastic_modal_data – specifies modal data for static/dynamic aeroelastic analysis via time integration of the structural dynamics equations within FUN3D (Version 10.4 and higher)

&composite_overset_mesh – specifies component meshes to associate with moving and non-moving bodies in the simulation – only used if overset grids are utilized. See **Overset Grids** for more information.

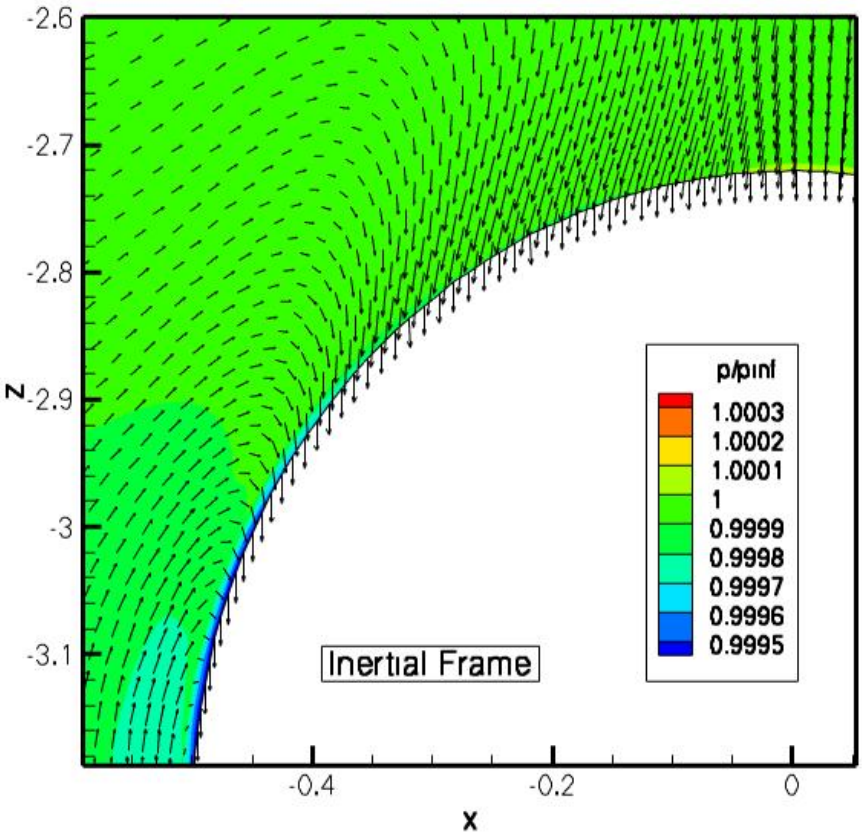
Descriptions of the variables in each namelist, and their default values, are given in subsequent sections. Note that because the data are in namelists, only data that is different from the default typically need be specified. The exception is that some data for the body_definitions namelist MUST be specified to define the body of interest (e.g. the default number of bodies is 0 and must be changed); data for the other namelists may be optional depending on the application.

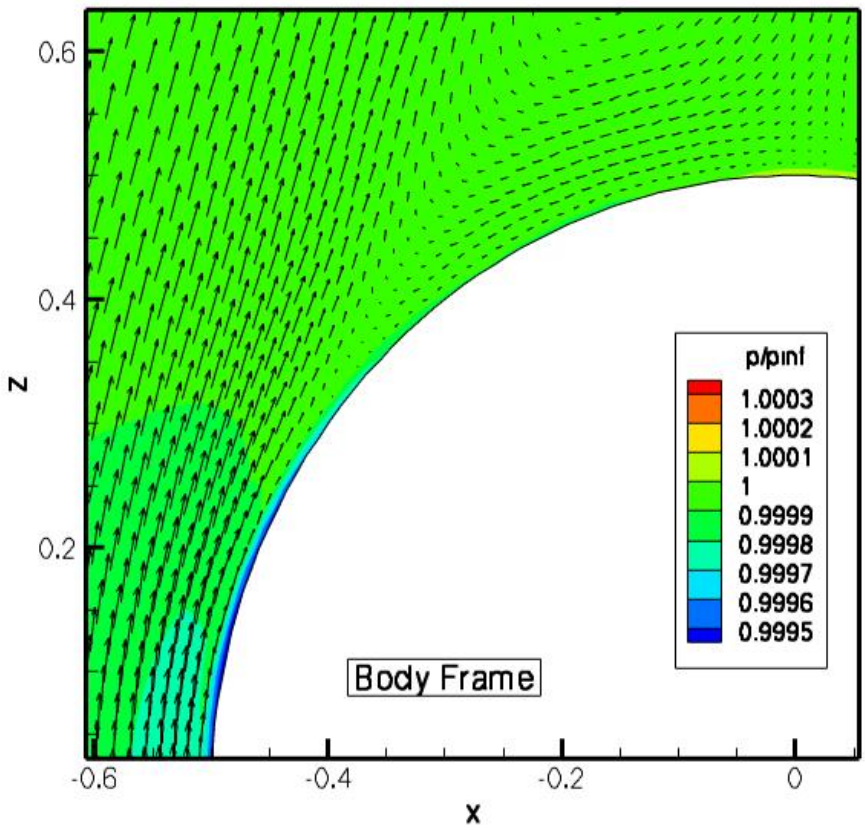
Sample moving_body.input files and the resulting body/grid motions are given below (animations of the motion require **Flash Player** to view).

Post-Processing/Repartitioning Moving Grid Cases

To post-process (or repartition) moving grid cases using party, you must use the command line option `--moving_grid`.

For versions 10.4 and higher, in the post-processing mode, party will give the option of viewing the results in the inertial frame or in a moving-body frame. Note: the choice is only meaningful for specified motion cases or 6DOF cases; for aeroelastic and surface-from-file cases, both options give the inertial-frame view. Below, pressure contours and velocity vectors from a falling (6DOF) cylinder case are shown from both the inertial and body frames. Pressure, being a scalar, appears the same in both views. The fluid velocity at the surface in this viscous flow problem must be identical to the surface velocity: in the inertial frame, this is the instantaneous body velocity (in -z direction); in the body frame, the body (and hence fluid) velocity is zero.





Defining Moving Bodies

The following namelist, which is input via the `moving_body.input` file, is used to specify one or more bodies as collections of boundary surfaces within the mesh. This namelist is required for all moving body/mesh cases, i.e. whenever the `--moving_grid` command line option is invoked. The input structure is fairly general in that the motion of multiple bodies may be specified, and connections between various bodies may be specified via family trees. For example, a wing-flap system may be defined such that the flap is a child of the wing. Thus the flap inherits any motion specified for the wing, and may have its' own motion specified on top of that. For example, the wing may be specified to translate up and down, and the flap to rotate about a hinge line such that the net motion of the flap is a combination of translation and rotation. Such a wing-flap system is given in one of the examples below.

A (G) following a variable description means that this is a global descriptor, i.e. applicable to all moving bodies; a (B) following a variable description means that the data may be specified for each moving body

&body_definitions namelist

n_moving_bodies	Number of bodies in motion (G) (Default: 0)
body_name	Name to identify the body (B) (Default: '')
parent_name	Name of the parent body (B) (Default: '' [indicates inertial ref. frame as parent])
n_defining_bndry	Number of boundaries that define the body (B) (Default: 0)
defining_bndry	List of n_defining_bndry boundaries that define the body (B) (Default: 0)
motion_driver	Mechanism by which body motion is driven (B) (Default: 'none' Options: 'forced', '6dof', 'surface_file', 'motion_file', 'aeroelastic')
mesh_movement	Type of grid movement associated with body motion (B) (Default: 'static' Options: 'rigid', 'deform')
x_mc	X-coordinate of moment center at t=0 (B) (Default: xmc from input file)
y_mc	Y-coordinate of moment center at t=0 (B) (Default: ymc from input file)

z_mc	Z-coordinate of moment center at t=0 (B) (Default: zmc from input file)
s_ref	Reference area (non-dimensional) for force/moment normalization (B) (Default: sref from input file)
c_ref	Reference length (non-dimensional) for force/moment normalization (B) (Default: cref from input file)
b_ref	Reference length (non-dimensional) for force/moment normalization (B) (Default: bref from input file)
move_mc	Flag to move (1) or leave the moment center fixed in space(0) (B) (Default: 1)
dimensional_output	Logical flag to output the body state data (displacements, velocities, and aero forces for each body) in dimensional form for forced or 6DOF motions (G) (Default: .false.)
body_frame_forces	Logical flag to output the (aerodynamic) forces/moments on the body in the body-frame (G) (Default: .false. i.e. output forces/moments in inertial frame)
ref_length	Reference length for converting to dimensional output (G) (Default: 1.0 ft.)
ref_density	Reference density for converting to dimensional output (G) (Default: 0.002378 slug/ft/ft/ft)
ref_velocity	Reference velocity for converting to dimensional output (G) (Default: 1117.0 ft/sec)
output_transform	Output 4×4 transform matrix at each time step for each body (G) (Default: .false.)

Specified Body Motion

The following namelist, which is input via the `moving_body.input` file, is used to specify how the body is defined via the `&body_definitions` namelist move as a function of time. Note that this is one of several ways body motion may be specified, and is appropriate if the desired body motion may be described as a simple rigid-body translation or rotation, with constant velocity or sinusoidally-varying displacement. For specified motions not amenable to such basic descriptions, either a 4×4 transform matrix for the (rigid) body may be specified at each time step, or the (rigid or deforming) body surface points may be specified at each time step (see **Body Motion via File Input**), so that any desired motion can in principle be defined (including shape-morphing bodies).

A (B) following a variable description means that the data may be specified for each moving body

&forced_motion namelist

rotate	Type of rotational motion 0=none, 1=constant rotation rate, 2=sinusoidal (B) (Default: 0) For type 2, theta = rotation_amplitude x sin(2 x pi x rotation_freq x t), where t=nondimensional time
rotation_rate	Rotation rate (non-dimensional) associated with rotate=1 (B) (Default: 0.0)
rotation_freq	Rotation reduced frequency (non-dimensional) associated with rotate=2 (B) (Default: 0.0)
rotation_phase	Rotation phase shift (degrees) associated with rotate=2 (B) (Default: 0.0)
rotation_tphase	Rotation phase shift (degrees) applied to transform matrix (B) (Default: 0.0)
rotation_amplitude	Rotation amplitude (degrees) associated with rotate=2 (B) (Default: 0.0)
rotation_origin_x	X-coordinate of rotation center (B) (Default: 0.0)
rotation_origin_y	Y-coordinate of rotation center (B) (Default: 0.0)
rotation_origin_z	Z-coordinate of rotation center (B) (Default: 0.0)
rotation_vector_x	X-component of unit vector along rotation axis (B) (Default: 0.0)
rotation_vector_y	Y-component of unit vector along rotation axis (B) (Default: 1.0)
rotation_vector_z	Z-component of unit vector along rotation axis (B) (Default: 0.0)
rotation_start	Start time (non-dimensional) of rotational motion (B) (Default: 0.0)
rotation_duration	Duration (non-dimensional) of rotational motion (B) (Default: 1.0e99)
translate	Type of translational motion 0=none, 1=constant translation rate, 2=sinusoidal (B) (Default: 0) For type 2, displacement = translation_amplitude x sin(2 x pi x translation_freq x t), where t=nondimensional time
translation_rate	Translation rate (non-dimensional) associated with translate=1 (B) (Default: 0.0)
translation_freq	Translation reduced frequency (non-dimensional) associated with translate=2 (B) (Default: 0.0)

translation_phase	Translation phase shift (degrees) associated with translate=2 (B) (Default: 0.0)
translation_tphase	Translation phase shift (degrees) applied to transform matrix (B) (Default: 0.0)
translation_amplitude	Translation amplitude (grid units) associated with translate=2 (B) (Default: 0.0)
translation_vector_x	X-component of unit vector along translation axis (B) (Default: 0.0)
translation_vector_y	Y-component of unit vector along translation axis (B) (Default: 1.0)
translation_vector_z	Z-component of unit vector along translation axis (B) (Default: 0.0)
translation_start	Start time (non-dimensional) of translational motion (B) (Default: 0.0)
translation_duration	Duration (non-dimensional) of translational motion (B) (Default: 1.0e99)

Output Data

In version 10.4 and higher, specified body motion (`&forced_motion` namelist) will result in the following ASCII output files being generated (below, in filenameBody_N, N is the body number):

PositionBody_N.hst	Contains "CG" (rotation center) position and Euler angles (pitch, roll, yaw) as functions of time; default output is non-dimensional; Tecplot format. Note that Euler angles have multiple singularities and are non-unique!
VelocityBody_N.hst	Contains linear and angular velocity components of the CG (rotation center) as functions of time; default output is non-dimensional; Tecplot format.
AeroForceMomentBody_N.hst	Contains the aerodynamic forces and moments (about the specified moment center) acting on the body as functions of time; default output is non-dimensional; Tecplot format.
TransformMatrixBody_N.hst	(Optional) Contains the 4×4 transform matrix for the body as a function of time; format is described in the file header. Output only if `output_transform = .true.` in namelist `&body_definitions`. A similar file, `TransformMatrixObserver.hst` (for the motion of the observer frame) is also output if `output_transform = .true.`

Note: these files are created from scratch if `irest=0` or `irest=-1`; any existing files with these names are overwritten. The files are appended to (if they exist) when restarting with `irest=1`. If they have been deleted before restarting with `irest=1` they will be created but the preceding history will be lost.

In addition to the above files, the [project]_hist.dat file contains the x, y, and z components of the specified rotation vector, as well as the position of the rotation origin as functions of time. Except for special cases, the rotation vector components will differ from the Euler angles. Note that the data in this file is for body 1 **only**, and is also output from versions prior to 10.4.

Specified Observer Motion (for animation)

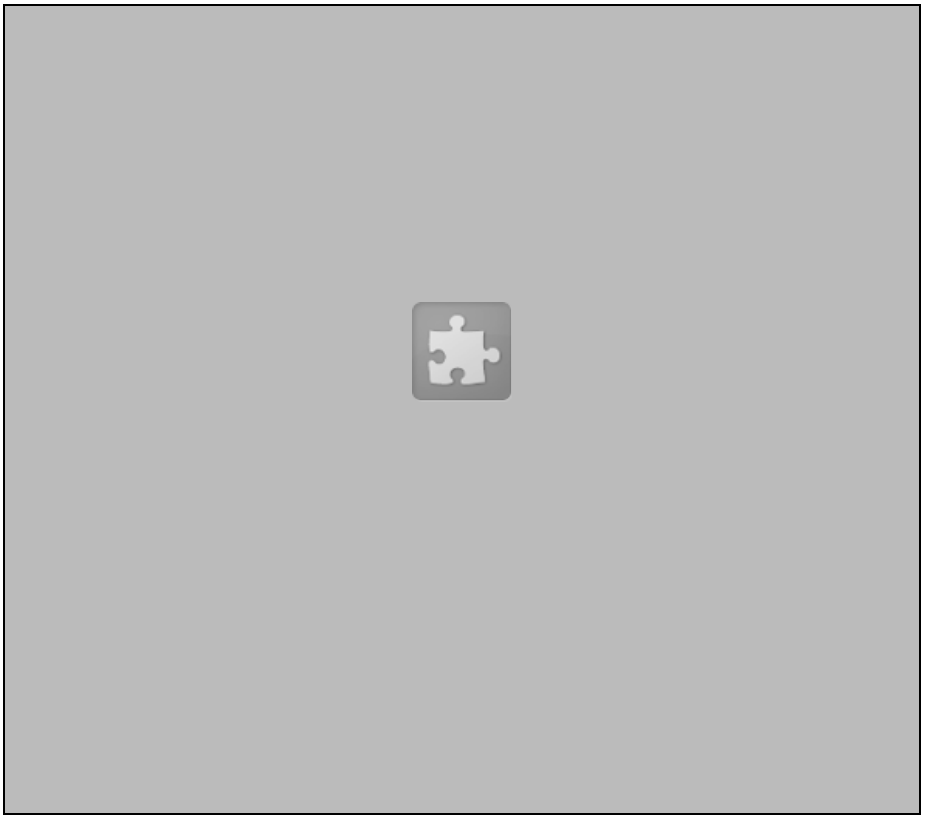
The following namelist, which is input via the `moving_body.input` file, is used to specify the motion of an observer. This optional namelist is only used when requesting **Flow Visualization Output Directly From Flow Solver** for cases that involve moving bodies, and is **not available in versions prior to 10.4**. If the observer_motion is specified, then the resulting animation will be from the observer's reference frame rather than the (default) inertial reference frame. This capability may be used for, among other things, assessing relative motions in complex dynamic motions (e.g. insuring that the cyclic pitch in a rotor simulation is correctly enforced). The data to specify observer motion is analogous to specifying body motion; the observer motion is applied on a global basis (G).

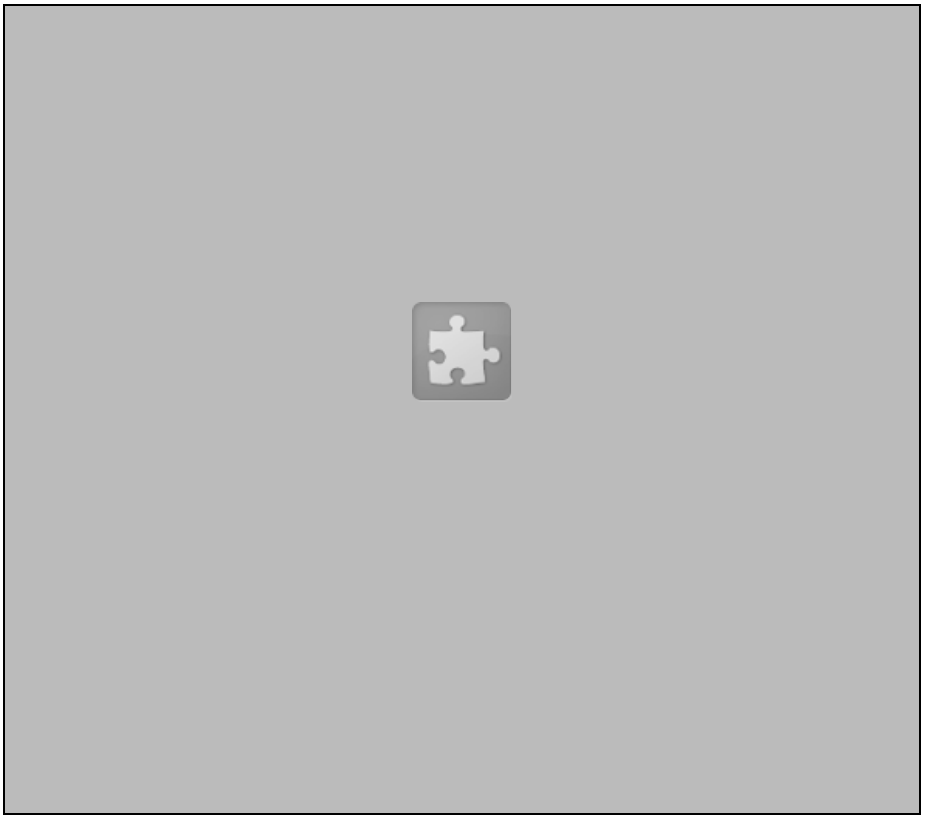
&observer_motion namelist

ob_parent_name	Parent reference frame for observer (G) (Default: '' [indicates inertial ref. frame]
ob_rotate	Type of rotational motion 0=none, 1=constant rotation rate, 2=sinusoidal (G) (Default: 0)
ob_rotation_rate	Rotation rate (non-dimensional) associated with rotate=1 (G) (Default: 0.0)
ob_rotation_freq	Rotation reduced frequency (non-dimensional) associated with rotate=2 (G) (Default: 0.0)
ob_rotation_phase	Rotation phase shift (degrees) associated with rotate=2 (G) (Default:

	0.0)
ob_rotation_tphase	Rotation phase shift (degrees) applied to transform matrix (G) (Default: 0.0)
ob_rotation_amplitude	Rotation amplitude (degrees) associated with rotate=2 (G) (Default: 0.0)
ob_rotation_origin_x	X-coordinate of rotation center (G) (Default: 0.0)
ob_rotation_origin_y	Y-coordinate of rotation center (G) (Default: 0.0)
ob_rotation_origin_z	Z-coordinate of rotation center (G) (Default: 0.0)
ob_rotation_vector_x	X-component of unit vector along rotation axis (G) (Default: 0.0)
ob_rotation_vector_y	Y-component of unit vector along rotation axis (G) (Default: 1.0)
ob_rotation_vector_z	Z-component of unit vector along rotation axis (G) (Default: 0.0)
ob_translate	Type of translational motion 0=none, 1=constant translation rate, 2=sinusoidal (G) (Default: 0)
ob_translation_rate	Translation rate (non-dimensional) associated with translate=1 (G) (Default: 0.0)
ob_translation_freq	Translation reduced frequency (non-dimensional) associated with translate=2 (G) (Default: 0.0)
ob_translation_phase	Translation phase shift (degrees) associated with translate=2 (G) (Default: 0.0)
ob_translation_tphase	Translation phase shift (degrees) applied to transform matrix (G) (Default: 0.0)
ob_translation_amplitude	Translation amplitude (grid units) associated with translate=2 (G) (Default: 0.0)
ob_translation_vector_x	X-component of unit vector along translation axis (G) (Default: 0.0)
ob_translation_vector_y	Y-component of unit vector along translation axis (G) (Default: 1.0)
ob_translation_vector_z	Z-component of unit vector along translation axis (G) (Default: 0.0)

If it is desired to have the observer in the frame of a moving body whose motion is specified, or results from 6DOF motion, then all that is needed is to set ob_parent_name equal to the name of that body (in quotes), without any further `&observer_motion` data. There may be cases in which there is no body with the desired motion, in which case the `&observer_motion` parameters above can be used to specify the motion relative to the ob_parent_name reference system. Note: a body whose motion is specified via file input, or whose motion is the result of aeroelastic motion, **cannot** be used as the ob_parent_name.





Body Motion via File Input

There are currently two ways to specify arbitrary body/grid motion via user-supplied files to describe the motion. The first is applicable to rigid-body motion with either rigid or deforming meshes. The second is applicable to either rigid or deforming bodies but must be used in conjunction with the deforming mesh motion.

1) Specifying the 4×4 Transform Matrix as a Function of Time – Rigid Body / Rigid or Deforming Grid

To utilize this option, you must set `motion_driver = 'motion_file'` in the `&body_definitions` namelist. In addition, at least some data in the `&motion_from_file` namelist must be specified:

&motion_from_file namelist

`n_time_slices_file` Number of time steps at which the transform matrix will be supplied (B)
(Default: 0)

repeat_time_file	Non-dimensional time at which the specified motion will repeat (B) (Default: 1.e99)
motion_file	Name of the file containing the 4×4 transform matrix of the body (B) (Default: '' – a valid file name MUST be specified by the user)
motion_file_type	Type of motion file: 'transform_matrix', the 4×4 transform matrix, or 'inverse_transform_matrix', the inverse of the transform matrix (B) (Default: 'transform_matrix')

As used in FUN3D, the 4×4 transform matrix at time t is defined so as to take the body from its position at t=0 in the inertial frame to its current position. The inverse transform does the opposite, i.e. maps the body from its current position to its position at t=0. If the body undergoes a rotation of theta (radians) about a point that **at t=0** is given by (x0,y0,z0), and rotates about an (instantaneous) axis defined by the unit vector (nx,ny,nz), and furthermore undergoes a translation that moves the rotation center (center of gravity) by an amount (dx,dy,dz) from its initial position (x0,y0,z0) to its current position (xcg,ycg,zcg), then the transform matrix M is given by:

```
M = r11   r12   r13    -(r11*x0+r12*y0+r13*z0)+x0 + dx
    r21   r22   r23    -(r21*x0+r22*y0+r23*z0)+y0 + dy
    r31   r32   r33    -(r31*x0+r32*y0+r33*z0)+z0 + dz
     0     0     0                      1
```

where the pure rotational components of M are given by:

```
r11 = (1 - cost)*nx*nx +    cost
r12 = (1 - cost)*nx*ny - nz*sint
r13 = (1 - cost)*nx*nz + ny*sint
r21 = (1 - cost)*ny*nx + nz*sint
r22 = (1 - cost)*ny*ny +    cost
r23 = (1 - cost)*ny*nz - nx*sint
r31 = (1 - cost)*nz*nx - ny*sint
r32 = (1 - cost)*nz*ny + nx*sint
r33 = (1 - cost)*nz*nz +    cost
```

and where:

```
cost = cos(theta)
sint = sin(theta)
```

Note that the 4th row of the transform matrix should always be (0,0,0,1).

The instantaneous center of gravity (rotation center) is given by:

```
xcg = x0 + dx
ycg = y0 + dy
zcg = z0 + dz
```

See also Recent Enhancements To The FUN3D Flow Solver For Moving-Mesh Applications (p 6-7).

File Format:

The transform file(s) are ASCII files. The transform file contains 9 (nine) header lines (which are ignored but must be present), and for each of the `n_time_slices_file` steps, a line with the value of the non-dimensional time, a line with the x,y,z coordinates of the body "center of gravity" (center of rotation), and four lines defining each row of the 4×4 transform matrix.

Note: The input transform option does not directly support parent-child motions. All input transforms must be specified relative to the inertial frame. This also implies that in the `&body_definitions` namelist, `parent_name = ''` for any body for which `motion_driver = 'motion_file'`

The following is an example of an input 4×4 transform file:

```
4x4 Transform Matrix For Body   1
Written as:
  loop over time steps
    write() simulation_time
    write() xcg, ycg, zcg
    do i=1,4
      write() transform_matrix(i,j),j=1,4)
```

```
    end do
  end time step loop
   0.0000000000E+00
   0.2500000000E+00   0.0000000000E+00   0.0000000000E+00
   0.1000000000E+01   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00
   0.0000000000E+00   0.1000000000E+01   0.0000000000E+00   0.0000000000E+00
   0.0000000000E+00   0.0000000000E+00   0.1000000000E+01   0.0000000000E+00
   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00   0.1000000000E+01
   0.3228110000E+00
   0.2500000000E+00   0.0000000000E+00   0.0000000000E+00
   0.9999968340E+00   0.0000000000E+00   0.2516342349E-02   0.7914986049E-06
   0.0000000000E+00   0.1000000000E+01   0.0000000000E+00   0.0000000000E+00
  -0.2516342349E-02   0.0000000000E+00   0.9999968340E+00   0.6290855872E-03
   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00   0.1000000000E+01
   0.6456220000E+00
   0.2500000000E+00   0.0000000000E+00   0.0000000000E+00
   0.9999873485E+00   0.0000000000E+00   0.5030185447E-02   0.3162865712E-05
   0.0000000000E+00   0.1000000000E+01   0.0000000000E+00   0.0000000000E+00
  -0.5030185447E-02   0.0000000000E+00   0.9999873485E+00   0.1257546362E-02
   0.0000000000E+00   0.0000000000E+00   0.0000000000E+00   0.1000000000E+01

etc.
```

The file format is the same regardless of whether `motion_file_type` is 'transform_matrix' or 'inverse_transform_matrix'

It may be noted that this file format is identical to that generated when `output_transform = .true.` in the `&body_definitions` namelist. So, if the `motion_file_type` is 'transform_matrix' and the file contains the transform at times corresponding exactly to each time step in the simulation, the output transform file can be compared (to machine precision) against the input transform file to verify that the input data has been read correctly.

As implied above, the time increments in the `motion_file` need not correspond to the time step specified in the `fun3d.nml` file; however, it is recommended that this be the case. If the time increments in the `motion_file` do not correspond to the time step specified in the `fun3d.nml` file, the specified transforms are "interpolated" to the time dictated by the time step. Interpolated is quoted because in fact transform matrices cannot be directly interpolated. Rather, the transforms are first converted into quaternions, the quaternions (and centers of gravity/rotation) are linearly interpolated and then recast as the required transform matrix. This interpolation process has not been widely tested at this point in time.

2) Specifying the Body as a Function of Time – Rigid or Deforming Body / Deforming Grid

NOTE: this option requires that **Mesh Deformation** be used for grid movement.

If the `&surface_motion_from_file` namelist is specified in the `moving_body.input` file, i then the solver will attempt to read in the specified number of files for the body:

&surface_motion_from_file namelist

`n_time_slices` Number of files defining motion of the body (B) (Default: 0)
`repeat_time` Non-dimensional time at which motion in files will repeat (B) (Default: 1.e99)

The names of the file(s) containing the surface data as a function of time MUST adhere to the naming convention given below. The points defining the surface(s) in the file(s) must correspond to the surface(s) defined in the `&body_definitions` namelist. Generally speaking, the time span covered by these files should either encompass the time span of the current run, or the period of motion if the body motion is cyclic. The exception to this is for **static aeroelastic cases**, where the flow solver is only periodically coupled to a structural solver; in this case only one surface file is read in (for any one body) at the start of a run, and the TIME data is ignored (and in fact is not required).

The time values given in the files need not correspond to increments of time as specified by the parameter `time_step_nondim` in `fun3d.nml` (DT in the ginput.faces in release 10.4.1 and before) (though it is probably best to do so). For example, if DT=1.0, then as the code executes, the **non-dimensional** time runs as 0.0, 1.0, 2.0, 3.0… The times specified at the top of the surface files (see below) might be 0.0, 2.5, 5.0, 7.5… In this case the positions defined in the files are linearly interpolated in time to the current solver time.

Surface File Naming Convention:

{project}.bodyN_timestepM

where:

N is the body number, 1…Number of Moving Bodies

M is the file number, 1…Number of Surface Files Defining Boundary Motion

File Format:

The surface files are ASCII Tecplot files, in FEPOINT format. A time value must appear in the title line as indicated below. An exception to the requirement of a time value appearing in the title line is if there is only one surface file specified for the current run for the current body; in that case the time value is optional, and is ignored if present. The file must contain the variables X, Y, Z, and ID for each point on the surface, where ID is the GLOBAL node number of the surface point; see below for instructions how to generate a baseline tecplot file containing the required ID information. While the surface file must have X, Y, Z and ID as the first 4 values as shown, additional variables may also be present – they will be ignored.

The following is an example of an input surface file:

```
TITLE="MyTitle"
VARIABLES = "X" "Y" "Z" "ID"
ZONE T = "TIME 0.563380281690E+02", I = 27379 J =  54616, F=FEPOINT
    0.749999803300000E+00     0.332401000000000E-02     0.568688647000000E-03
    0.749999709200000E+00     0.466716000000000E-02     0.581249831300000E-03
    0.749999596400000E+00     0.614341000000000E-02     0.594249581500000E-03
    0.749999463300000E+00     0.773828000000000E-02     0.608274493500000E-03
    0.749999306600000E+00     0.945972000000000E-02     0.623389823100000E-03
    0.749999122200000E+00     0.113178000000000E-01     0.639686203200000E-03
    0.749998905500000E+00     0.133233000000000E-01     0.657242011700000E-03

 many lines of similar x,y,z,id data deleted

   -0.179577227400000E+00     0.126451000000000E+01    -0.150364604100000E+00
   -0.180001486000000E+00     0.123791000000000E+01    -0.148198832700000E+00
   -0.179293826000000E+00     0.129235000000000E+01    -0.152598086400000E+00
     24130     24058     24057     24057
     24058     24059     23940     23940
     24129     24130     24056     24056
       337      2573       335       335
     23966     23967     23916     23916
     24059     24061     24060     24060
     24126     24129     24128     24128

 many lines of similar face connectivity data deleted

      1218      1193      1192      1192
      1142      1130      1718      1718
     24910     24899     25991     25991
     24899     24910     24909     24909
```

The characters TIME in the zone title may be upper or lower case, but the word time followed by value for time MUST appear in the zone title. Also in the ZONE T line is the number of data points to follow, while J is the number of elements (triangles and/or quads) on the surface.

Since the user specifies the surface motion, the values of X,Y, and Z at different points in time must obviously be known. What the user will not know a priori is the correct value of ID for each node. However, the user may generate a template file for the surface in the original position as it appears in the input grid/part files by first obtaining a static-grid solution (1 steady-state iteration would be sufficient) and then post-process that solution with party to generate a MASSOUD file (TECPLOT option 3, then sub-option 2) containing the initial (t=0) file with the correct ID information. The ID data remains fixed with time even though the X,Y,Z data change, so this MASSOUD file may be used as input into a user-developed program to generate the subsequent surface motion files for the particular case at hand. NOTE: the MASSOUD file generated by party will not follow the required naming convention for moving-body specification and so must be appropriately renamed; also, the title line will not have the requisite time value and must be edited accordingly.

6DOF Motion

Note: Use of the 6DOF capability requires linking to third-party software. The required 6DOF libraries are available from Nathan Prewitt

Note: all 6DOF input is dimensional, and refers to values at t=0; the values of ref_length, ref_velocity, ref_density from the `&body_definitions` namelist are used for non-dimensionalization of the input data, so they must be set consistently with the 6DOF input data.

For 6DOF cases, the `--grid_motion_only` and `--body_motion_only` are probably not particularly useful predictors of the subsequent motion, unless the aerodynamic loads (not computed when either

option is invoked) have very little impact on the dynamics.

A (B) after the description indicates the data may be specified for each body; (1-3,B) indicates one or all of 3 (x,y,z) components may be specified for each body. For example body_lin_vel(2,3) would be input to specify an initial y-component of velocity for body 3.

&sixdof_motion namelist

mass	Mass of the body (B) (Default: 1.0)
cg_x	X-coordinate of CG (B) (Default: 0.0)
cg_y	Y-coordinate of CG (B) (Default: 0.0)
cg_z	Z-coordinate of CG (B) (Default: 0.0)
i_xx	Moment of inertia about x axis (B) (Default: 1.0)
i_yy	Moment of inertia about y axis (B) (Default: 1.0)
i_xx	Moment of inertia about z axis (B) (Default: 1.0)
i_xy	Moment of inertia about x-y axis (B) (Default: 0.0)
i_xz	Moment of inertia about x-z axis (B) (Default: 0.0)
i_yz	Moment of inertia about y-z axis (B) (Default: 0.0)
body_lin_vel	Components of linear velocity (1-3,B) (Default: 0.0, 0.0, 0.0)
body_ang_vel	Components of angular velocity (1-3,B) (Default: 0.0, 0.0, 0.0)
euler_ang	Euler angles (1-3,B) (Default: 0.0, 0.0, 0.0)
gravity_dir	Normalized components of the gravity vector (G) (Default: 0.0, 0.0, -1.0)
gravity_mag	Magnitude of the gravity vector (G) (Default: 32.2)
n_extforce	Number of imposed external forces, excluding gravity (B) (Default: 0)
n_extmoment	Number of imposed external moments (B) (Default: 0)
file_extforce	File specifying external forces (B) (Default: '')
file_extmoment	File specifying external moments (B) (Default: '')

Output Data

6DOF body motion (`&sixdof_motion` namelist) will result in the following output files being generated (below, in filenameBody_N, N is the body number):

PositionBody_N.hst	Contains CG position (as specified in `&sixdof_motion`) and Euler angles (pitch, roll, yaw) as functions of time; default output is non-dimensional; Tecplot format. Note that Euler angles have multiple singularities and are non-unique!
VelocityBody_N.hst	Contains linear and angular velocity components of the CG as functions of time; default output is non-dimensional; Tecplot format.
AeroForceMomentBody_N.hst	Contains the aerodynamic forces and moments (about the CG) acting on the body as functions of time; default output is non-dimensional; Tecplot format. Note: the aero forces and moments in the output file are non-dimensionalized in the standard fashion for aerodynamics; this is not the same way they are non-dimensionalized for the 6DOF equations
ExternalForceMomentBody_N.hst	Contains any user-specified external forces and moments acting on the body as functions of time; default output is non-dimensional (6DOF non-dimensionalization); Tecplot format.

Note: these files are created from scratch if `irest=0` or `irest=-1`; any existing files with these names are overwritten. The files are appended to (if they exist) when restarting with `irest=1`. If they have been deleted before restarting with `irest=1` they will be created but the preceding history will be lost.

Aeroelastic Motion (Mode-Based)

NOTE: this option requires that **Mesh Deformation** be used for grid movement.

Note: the implementation of the modal aeroelastic analysis in FUN3D follows nearly exactly the implementation in CFL3D, so interested parties may find some useful supplemental information on pp 191-223 of the **CFL3D Tutorial**.

A (G) following a variable description means that this is a global descriptor, i.e. applicable to all aeroelastic bodies; (B) means that the data may be specified for each body; (M,B) means the data may

be specified for each mode associated with each body. For example, freq(4,2) would specify the frequency of mode 4 for body 2.

The modal aeroelastic capability is available in Version 10.4 and higher

&aeroelastic_modal_data namelist

nmode	Number of aeroelastic modes used to represent the structural deformation (B) (Default: 0)
plot_modes	Logical flag to generate tecplot files of each mode shape added to the body surface to help insure validity of input modal surface data (G) (Default: .false.)
single_modal_file	Logical flag to read all mode shapes from a single file for each body (G) (Default: .false. i.e. each mode in a separate file for each body)
grefl	Scale factor between CFD grid units and structural dynamics equation units (B) (Default: 1.0)
uinf	Free stream velocity, in structural dynamics equation units (B) (Default: 0.0)
qinf	Free stream dynamic pressure, in structural dynamics equation units (B) (Default: 0.0)
gdispl0	Generalized displacement of specified mode at starting time step; used to perturb mode for excitation of dynamic response (Default: 0.0)
gvel0	Generalized velocity of specified mode at starting time step; used to perturb mode for excitation of dynamic response (Default: 0.0)
gforce0	Generalized force of specified mode at starting time step; used to perturb mode for excitation of dynamic response (Default: 0.0)
gmass	Generalized mass of specified mode (M,B) (Default: 0.0)
freq	Frequency of specified mode, rad/sec (M,B) (Default: 0.0)
damp	Critical damping ratio (z) of specified mode (M,B) (Default: 0.0)
moddfl	Type of time-varying perturbation of specified mode: 0, no perturbation; <0, modal displacement and velocity set to 0; 1, harmonic (sinusoidal); 2, Gaussian pulse; 3, Step pulse; 5, ROM input (M,B) (Default: 0)
moddfl_amp	Amplitude of perturbation of specified mode (M,B) (Default: 0.0)
moddfl_freq	Frequency of perturbation of specified mode if moddfl=1; half-width of Gaussian pulse if moddfl=2 (M,B) (Default: 0.0)
moddfl_t0	Time (dimensional) at which sinusoidal perturbation starts if moddfl=1; time about which Gaussian pulse is centered if moddfl=2; start time of step pulse if moddfl=3 (M,B) (Default: 0.0)
moddfl_add	Flag to determine whether perturbation is to be added (1) to any existing static aeroelastic solution or whether the perturbation replaces (0) the static aeroelastic solution (if one exists) (M,B) (Default: 0, replace)

In addition to the `&aeroelastic_modal_data` namelist, one or more files containing the modal surface definitions must be provided. FUN3D accepts two types of modal files: 1) each mode associated with an aeroelastic body is in a separate file or 2) all modes associated with an aeroelastic body are contained in the same file. The points defining the modal surface(s) in the file(s) must correspond to the surface(s) defined in the `&body_definitions` namelist.

In addition, for ROM (Reduced Order Model) analysis (triggered by moddfl=5), an additional file, called rom_inputs_bodyN.dat (N the body number), must be available. Rather than give an example of a rom_inputs_bodyN.dat file, the following code snippet shows how the file is read:

```
!       read number of time steps and starting time step from the rom data fil
        read(iu,*) ncyc_rom, nstart_rom

!       read number of modes in the rom data file
        read(iu,*) nmodes_rom_file

!       read the list of modes to (potentially) be used for rom
        read(iu,*) (rom_data(body)%rom_mode(nm), nm=1,nmodes_rom_file)

!       read the rom excitation data (modal displacement and velocity)
        do timestep = 1,ncyc_rom
          do nm=1,nmodes_rom_file
            nm1 = rom_data(body)%rom_mode(nm)
            read(iu,*,iostat=istop) rom_data(body)%gen_disp(nm1,timestep),
                                    rom_data(body)%gen_vel(nm1,timestep)
          end do
        end do
```

where ncyc_rom is the number of timesteps contained in the file, and nstart_rom is the timestep at which to start the ROM excitation for the current run. Thus nstart_rom should be 1 for the first run, and if all time steps are not completed in a single run, then nstart_rom should be set to last_time_step_of_previous_run + 1 for the next run. Any modes with moddfl=5 in the moving_body.input file must appear in the rom_inputs_bodyN.dat file (in both the rom_mode list and the excitation data).

Modal Surface File Naming Convention:

1) Separate file for each mode:

{project}.bodyN_modeM

2) All modes in one file:

{project}.bodyN_all_modes

where:

N is the body number

M is the mode number

File Format:

The modal surface files are ASCII Tecplot files, in FEPOINT format. The file must contain the variables X, Y, Z and ID as the first four variables, where X, Y, Z define the baseline surface and ID is the GLOBAL node number. For the single-mode-per-file format, these are followed by the modal coordinates XMD, YMD, ZMD; for the all-modes-in-one-file format, XMD1, YMD1, ZMD1, XMD2, YMD2, ZMD2, etc, follow.

The following is an example of a modal surface file (containing a single mode):

```
title="Mode 1"
variables = "x" "y" "z" "id" "xmd" "ymd" "zmd"
zone t = mode1, i =    176, j =     88,f=fepoint
  0.160000000000E+02  0.000000000000E+00  0.000000000000E+00      9377  0.0000
  0.160000000000E+02 -0.640000000000E+02  0.000000000000E+00      9442  0.0000
  0.158624877930E+02  0.000000000000E+00 -0.195790082224E-01      9571  0.0000
  0.158624877930E+02  0.000000000000E+00  0.195790082224E-01      9572  0.0000
  0.158624877930E+02 -0.640000000000E+02 -0.195790082224E-01      9639  0.0000
  0.158624877930E+02 -0.640000000000E+02  0.195790082224E-01      9640  0.0000
  0.156976051331E+02  0.000000000000E+00 -0.427785292272E-01      9769  0.0000

 many lines of similar x,y,z,id,xmd,ymd,zmd data deleted

  0.368598237408E-03 -0.640000000000E+02  0.139784077182E-01     19630  0.0000
  0.000000000000E+00  0.000000000000E+00  0.000000000000E+00     19759  0.0000
  0.000000000000E+00 -0.640000000000E+02  0.000000000000E+00     19824  0.0000
           1           2           5           3
           3           5           9           7
           7           9          13          11
          11          13          17          15
          15          17          21          19
          19          21          25          23
          23          25          29          27

 many lines of similar face connectivity data deleted

          16          18          14          12
          12          14          10           8
           8          10           6           4
           4           6           2           1
```

The starting point for generating a modal shape file as shown above is to first obtain a static-grid solution (1 steady state iteration would be sufficient) and then post-process that solution with party to generate a MASSOUD file (TECPLOT option 3, then sub-option 2) containing the baseline file with the correct X, Y, Z and ID information. This baseline file can then be used as input into a user-developed program to add the appropriate XMD, YMD, ZMD data for the case at hand (the X,Y,Z,ID data remain unchanged). NOTE: the MASSOUD file generated by party will not follow the required naming convention for modal file specification and so must be appropriately renamed.

Output Data

Aeroelastic body motion (`&aeroelastic_modal_data` namelist) will result in the following output files being generated (below, in filename_bodyN_modeM, N is the body number and M is the mode

number):

aehist_bodyN_modeM.dat Contains the generalized displacement, generalized velocity, and generalized force for mode M of body N as functions of time; the output is non-dimensional;. Tecplot format.

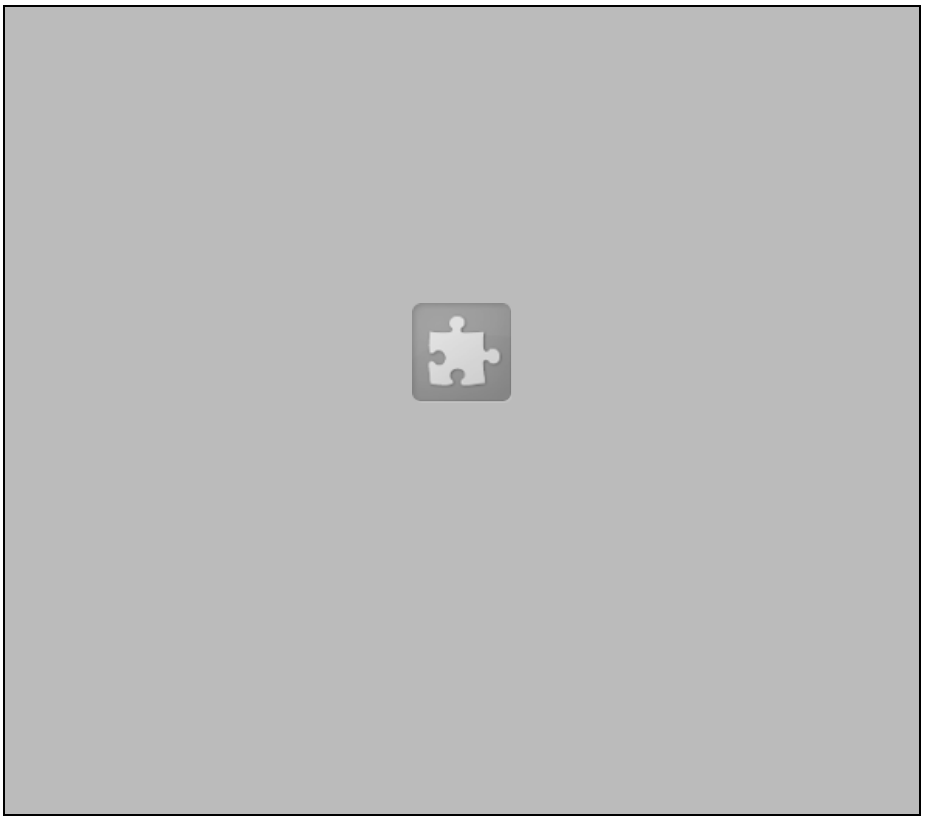
In addition, if the `plot_modes` variable is set to `.true.` in the `&aeroelastic_modal_data` namelist, then the following files are also output:

aesurf_bodyN_modeM.dat Contains the x, y, z coordinates of a surface created by adding the baseline (rigid) shape of body N to the input modal shape of mode M, read from the {project}.bodyN_modeM or {project}.bodyN_all_modes files. As such it is a tool for assessing if the modal shapes have been specified and read correctly. Tecplot format.

Sample moving_body.input Files

The first example constitutes a simple pitching airfoil, in which the mesh surrounding the airfoil moves rigidly with the airfoil. This example illustrates a shortcut: to indicate a body is made up of all solid surfaces in the mesh, without having to list each boundary surface, set n_defining_bndry = -1, and then use any integer number (0 is fine) for defining_bndry. Note that this shortcut is only applicable for n_moving_bodies = 1:

(Animation requires **Flash Player**'g to view)



```
&body_definitions
  n_moving_bodies = 1,         ! number of bodies in motion
  body_name(1) = 'airfoil',    ! name must be in quotes
  parent_name(1) = '',         ! '' means motion relative to inertial ref fram
```

```
  n_defining_bndry(1) = -1,    ! shortcut to specify all solid surfaces
  defining_bndry(1,1) =  0,    ! index 1: boundary number 2: body number; use
  motion_driver(1) = 'forced', ! 'forced', '6dof', 'surface_file', 'motion_fil
  mesh_movement(1) = 'rigid',  ! 'rigid', 'deform'
  x_mc(1) = 0.25,              ! x-coordinate of moment_center
  y_mc(1) = 0.0,               ! y-coordinate of moment_center
  z_mc(1) = 0.0,               ! z-coordinate of moment_center
  move_mc(1) = 1               ! move mom. cntr with body/grid: 0=no, 1=yes
/
&forced_motion
  rotate(1) = 2,                  ! rotation type: 1=constant rate 2=sinusoida
  rotation_rate(1) = 0.0,         ! rate of rotation
  rotation_freq(1) = 0.015489,    ! reduced rotation frequency
  rotation_amplitude(1) = 4.59,   ! max rotational displacement
  rotation_origin_x(1) = 0.25,    ! x-coordinate of rotation origin
  rotation_origin_y(1) = 0.0,     ! y-coordinate of rotation origin
  rotation_origin_z(1) = 0.0,     ! z-coordinate of rotation origin
  rotation_vector_x(1) = 0.0,     ! unit vector x-component along rotation axi
  rotation_vector_y(1) = 1.0,     ! unit vector y-component along rotation axi
  rotation_vector_z(1) = 0.0,     ! unit vector z-component along rotation axi
/
```

The second example is for a wing with a flap. The wing ('main') is constituted from boundary 1 in the mesh, while the flap ('flap') is constituted from boundary 2 in the mesh. The wing undergoes a plunging motion in the z-direction, while the flap undergoes a pitching motion about an axis parallel to its' leading edge. The flap is identified as a child of the wing, so that the complete motion of the flap consists of the inherited wing plunging motion plus the flap pitching motion. This 2-body motion cannot be accommodated with rigid mesh motion (unless overset, not considered here), so mesh_movement is chosen as 'deform':

(Animation requires **Flash Player**'g to view)

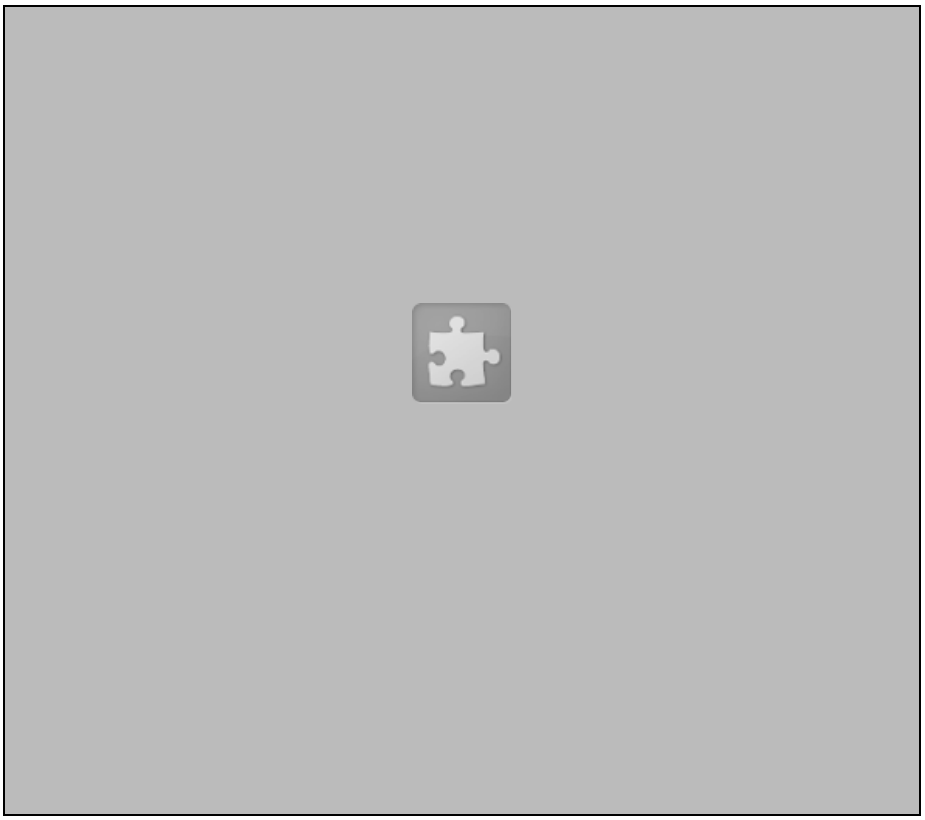
```
&body_definitions
  n_moving_bodies = 2,        ! number of bodies in motion
  body_name(1) = 'main',       ! name must be in quotes
  body_name(2) = 'flap',       ! name must be in quotes
  parent_name(1) = '',         ! '' means motion relative to inertial ref fram
  parent_name(2) = 'main',     ! '' means motion relative to inertial ref fram
  n_defining_bndry(1) = 1,     ! number of boundaries that define this body
  n_defining_bndry(2) = 1,     ! number of boundaries that define this body
  defining_bndry(1,1) = 1,     ! index 1: boundary number index 2: body number
  defining_bndry(1,2) = 2,     ! index 1: boundary number index 2: body number
  motion_driver(1) = 'forced', ! 'forced', '6dof', 'surface_file', 'motion_fil
  motion_driver(2) = 'forced', ! 'forced', '6dof', surface_file', 'motion_file
  mesh_movement(1) = 'deform', ! 'rigid', 'deform'
```

```
  mesh_movement(2) = 'deform', ! 'rigid', 'deform'
  x_mc(1) = 0.25,              ! x-coordinate of moment_center
  x_mc(2) = 0.25,              ! x-coordinate of moment_center
  y_mc(1) = 0.0,               ! y-coordinate of moment_center
  y_mc(2) = 0.0,               ! y-coordinate of moment_center
  z_mc(1) = 0.0,               ! z-coordinate of moment_center
  z_mc(2) = 0.0,               ! z-coordinate of moment_center
  move_mc(1) = 0,              ! do not move mom. cntr with body/grid
  move_mc(2) = 0               ! do not move mom. cntr with body/grid
/

&forced_motion
  translate(1) = 2,                ! translation type: 1=constant rate 2=sinus
  rotate(2) = 2,                   ! rotation type: 1=constant rate 2=sinusoid
  translation_freq(1) = 0.03,      ! reduced translation frequency
  rotation_freq(2) = 0.06,         ! reduced rotation frequency
  translation_amplitude(1) = -0.1, ! max translational displacement
  rotation_amplitude(2) = +5.00,   ! max rotational displacement
  rotation_origin_x(2) = 0.7798,   ! x-coordinate of rotation origin
  rotation_origin_y(2) = 0.0,      ! y-coordinate of rotation origin
  rotation_origin_z(2) = 0.0,      ! z-coordinate of rotation origin
  translation_vector_x(1) = 0.0,   ! unit vector x-component along translation
  rotation_vector_x(2) = 0.0885398,! unit vector x-component along rotation ax
  translation_vector_y(1) = 0.0,   ! unit vector y-component along translation
  rotation_vector_y(2) = 0.996073, ! unit vector y-component along rotation ax
  translation_vector_z(1) = 1.0,   ! unit vector z-component along translation
  rotation_vector_z(2) = 0.0,      ! unit vector z-component along rotation ax
/
```

The next example consists of a grid with two solid boundaries (boundaries number 2 and 3 in the mapbc file) representing two blades of a rotor. These two surfaces are grouped for the purpose of motion specification into 5 moving “bodies”: 1) ‘hub’ contains both blades and the surrounding mesh undergoes rigid mesh rotation at the angular speed of the rotor system; 2) ‘flap1’ is the first blade, and the surrounding mesh undergoes mesh deformation to accommodate a sinusoidal flapping motion about the blade root; 3) ‘blade1’ is used to specify a sinusoidal pitching motion about a spanwise axis of the first blade; 4) ‘flap2’ and; 5) ‘blade2’ specify the corresponding motions of the second blade. Thus the complete 5-body system defines a 2-bladed rotor undergoing a general rotation about a common axis, with simultaneous flapping and pitching of each blade. The rotation, flap, and pitch axes are all distinct. Each blade undergoes one flap and one pitch cycle for every rotation of the complete system. The flap and pitch amplitudes are both +/- 10 degrees.

(Animation requires **Flash Player**‘g to view)

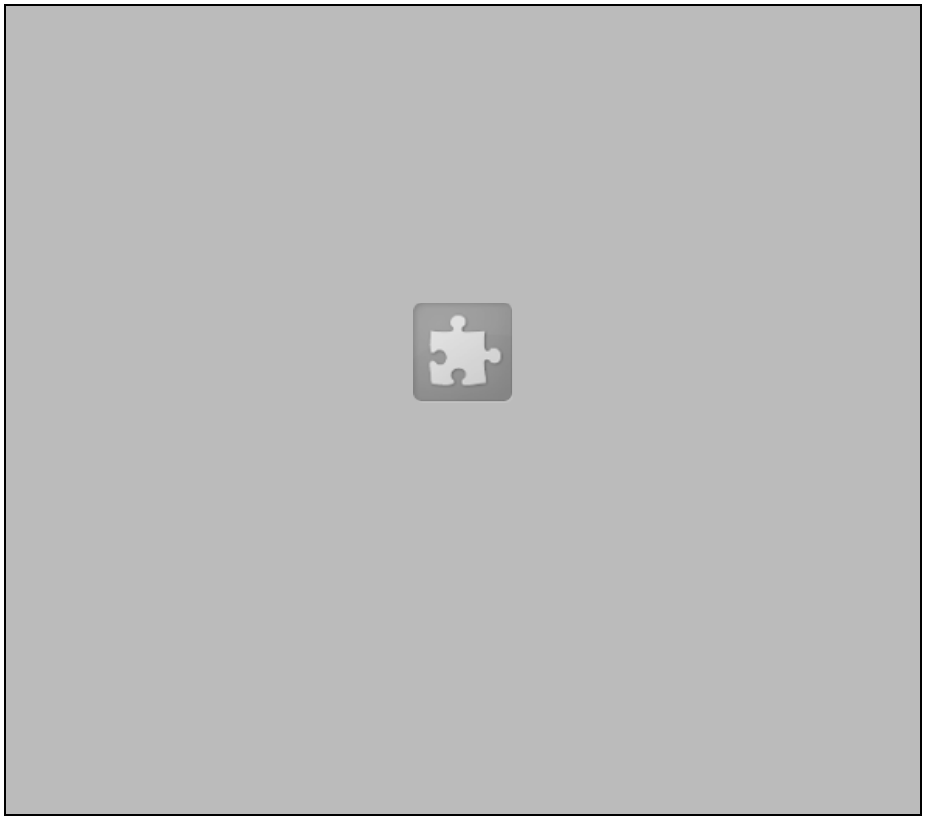


```
&body_definitions
  n_moving_bodies = 5,         ! number of bodies in motion
  body_name(1) = 'hub',        ! name must be in quotes
  body_name(2) = 'flap1'
  body_name(3) = 'blade1',
  body_name(4) = 'flap2'
  body_name(5) = 'blade2',
  parent_name(1) = '',         ! '' means motion relative to inertial ref frame
  parent_name(2) = 'hub'
  parent_name(3) = 'flap1',
  parent_name(4) = 'hub'
  parent_name(5) = 'flap2',
  n_defining_bndry(1) = 2,     ! number of boundaries that define this body
  n_defining_bndry(2) = 1,
  n_defining_bndry(3) = 1,
  n_defining_bndry(4) = 1,
  n_defining_bndry(5) = 1,
  defining_bndry(1,1) = 2,     ! index 1: boundary number index 2: body number
  defining_bndry(2,1) = 3,
  defining_bndry(1,2) = 2,
  defining_bndry(1,3) = 2,
  defining_bndry(1,4) = 3,
  defining_bndry(1,5) = 3,
  motion_driver(1) = 'forced', ! options: 'forced', '6dof', 'surface_file', 'm
  motion_driver(2) = 'forced',
  motion_driver(3) = 'forced',
  motion_driver(4) = 'forced',
  motion_driver(5) = 'forced',
  mesh_movement(1) = 'rigid',  ! options: 'rigid', 'deform'
  mesh_movement(2) = 'deform',
  mesh_movement(3) = 'deform',
  mesh_movement(4) = 'deform',
  mesh_movement(5) = 'deform',
/

&forced_motion
  rotate(1) = 1,               ! rotation type: 1=constant rate 2=sinusoidal
  rotate(2) = 2,
  rotate(3) = 2,
  rotate(4) = 2,
  rotate(5) = 2,
  rotation_rate(1) = -0.011712921516,
  rotation_freq(2) = 0.00186416935695,  ! reduced rotation frequency
  rotation_freq(3) = 0.00186416935695,
  rotation_freq(4) = 0.00186416935695,
  rotation_freq(5) = 0.00186416935695,
  rotation_amplitude(2) = +10.00,  ! flap blade 1
  rotation_amplitude(3) = +10.00,  ! pitch blade 1
  rotation_amplitude(4) = +10.00,  ! flap blade 2
  rotation_amplitude(5) = +10.00,  ! pitch blade 2
  rotation_origin_x(1) = 0.0,      ! x-coordinate of rotation origin
  rotation_origin_y(1) = 0.0,      ! y-coordinate of rotation origin
  rotation_origin_z(1) = 0.0,      ! z-coordinate of rotation origin
  rotation_origin_x(2) = -1.875,
  rotation_origin_y(2) = +6.75,
  rotation_origin_z(2) = 0.0589,
  rotation_origin_x(3) = -1.875,
  rotation_origin_y(3) = +6.75,
  rotation_origin_z(3) = 0.0589,
  rotation_origin_x(4) = +1.875,
  rotation_origin_y(4) = -6.75,
  rotation_origin_z(4) = 0.0589,
  rotation_origin_x(5) = +1.875,
  rotation_origin_y(5) = -6.75,
  rotation_origin_z(5) = 0.0589,
  rotation_vector_x(1) = 0.0,      ! unit vector x-component along rotation ax
  rotation_vector_y(1) = 0.0,      ! unit vector y-component along rotation ax
  rotation_vector_z(1) = 1.0,      ! unit vector z-component along rotation ax
  rotation_vector_x(2) = 1.0,
  rotation_vector_y(2) = 0.0,
  rotation_vector_z(2) = 0.0,
  rotation_vector_x(3) = 0.0,
  rotation_vector_y(3) = 1.0,
  rotation_vector_z(3) = 0.0,
  rotation_vector_x(4) = -1.0,
  rotation_vector_y(4) = 0.0,
  rotation_vector_z(4) = 0.0,
  rotation_vector_x(5) = 0.0,
```

```
  rotation_vector_y(5) = 1.0,
  rotation_vector_z(5) = 0.0,
/
```

The next example consists of a wing (comprised of boundaries 7-16 in the mapbc file) in which the surface motion is specified via a series of 73 files, each representing an instant of (non-dimensional) time between t=0 and t=1. The surface motion given by the files is repeated after the repeat_time of 1.0. Details describing the format for the surface motion files, as well as an example of such a file may be found in the section **Body Motion via File Input**



```
&body_definitions
  n_moving_bodies = 1,        ! number of bodies in motion
  body_name(1) = 'wing',      ! name must be in quotes
  parent_name(1) = '',         ! '' means motion relative to inertial ref fram
  n_defining_bndry(1) = 10,    ! number of boundaries that define this body
  defining_bndry(1,1) = 7,      ! index 1: boundary number index 2: body numbe
  defining_bndry(2,1) = 8,      ! index 1: boundary number index 2: body numbe
  defining_bndry(3,1) = 9,      ! index 1: boundary number index 2: body numbe
  defining_bndry(4,1) = 10,     ! index 1: boundary number index 2: body numbe
  defining_bndry(5,1) = 11,     ! index 1: boundary number index 2: body numbe
  defining_bndry(6,1) = 12,     ! index 1: boundary number index 2: body numbe
  defining_bndry(7,1) = 13,     ! index 1: boundary number index 2: body numbe
  defining_bndry(8,1) = 14,     ! index 1: boundary number index 2: body numbe
  defining_bndry(9,1) = 15,     ! index 1: boundary number index 2: body numbe
  defining_bndry(10,1) = 16,     ! index 1: boundary number index 2: body numb
  motion_driver(1) = 'surface_file',   ! 'forced', '6dof', 'surface_file', 'mo
  mesh_movement(1) = 'deform', ! 'rigid', 'deform'
  move_mc(1) = 0,              ! do not move mom. cntr with body/grid
/

&surface_motion_from_file
n_time_slices(1) = 73,      ! number of files defining motion for this body
repeat_time(1) = 1.0        ! time at which motion in files will repeat
/
```

Mesh Deformation

Mesh deformation is invoked from within the flow solver (as opposed to the stand-alone mesh deformation code used in the design process) when running in time accurate node (itime > 0) with the commandline option `--moving_grid` and the `mesh_movement` variable for one or more bodies defined in the `moving_body.input` file is set to `'deform'`. Mesh deformation is also invoked from within the flow solver if running in steady-state mode (itime=0) and the commandline option `--`

`read_surface_from_file` is specified, as would be the case for static aeroelastic computations (see **Aeroelastic Coupling** for more information).

An additional commandline option that is sometimes useful for problem mesh deformation cases is:

`--elasticity` INT

where INT signifies the variable used to set the modulus of elasticity: 1 (E=1/s [default], where s is the distance function used in the turbulence models) or 2 (E=1/vol). Generally speaking, the default is preferred, as the resulting system of equations tends to require fewer iterations to converge to a reasonable tolerance. However, if there are some small sliver cells located out in the field away from the body, and the default results in negative volumes, `--elasticity 2` may help. Note that for inviscid cases (more precisely, if all wall bcs are inviscid), the distance function s is not computed, and thus is not an appropriate choice. In version 10.4 and above, the flow solver checks to see if s if available, and if not, uses the volume instead.

To solve the elasticity PDE that governs mesh deformation, the Generalized Minimum Residual Method (GMRES) is used. Reasonable default control variables for the GMRES method have been chosen, and are listed below. However, there may be certain situations for which the default values need to be adjusted; this is done via a namelist called `elasticity_gmres` in the `fun3d.nml` file. Note to long-time users of mesh deformation with FUN3D: the data set by `elasticity_gmres` was formerly set in a file called `move_gmres.input` – should you happen to have this file in your run directory, the code will stop, advising you to use the `elasticity_gmres` namelist instead.

Optionally, a file `move_relaxation.schedule` may be used for further control of the PDE solution process; however, in practice this is never used.

&elasticity_gmres namelist

ileft	Flag for left preconditioning (0=no, 1=yes, Default: 1)
nsearch	Number of search directions (Default: 50, more will require extra memory, typically without benefit)
nrestarts	Number of restarts (Default: 10; more if convergence rate is slow)
tol	Convergence tolerance (Default: 10e-6)
show	Print the contents and values of the namelist (Default: .false.)

A note on **tol**: grids with tight spacing in the wake, as are typically found on structured "C-grid" meshes (but typically NOT found in unstructured meshes) will require much smaller values of **tol**, perhaps 10e-9 or smaller. Reaching the lower tolerances will require significantly more restarts.

move_relaxation.schedule data (optional, in practice never used)

This file is analogous to the optional relaxation.schedule file for the flow solver, except that the relaxation schedule prescribed in the move_relaxation.schedule file govern the solution of the linear system associated with the elasticity PDE rather than the linear system arising from the solution of flow equations. In some cases the relaxation schedule can improve convergence of the mesh deformation.

Number of Pre-Relaxation Schedules to Perform	Number of Pre-Relaxation Schedules to Perform (Recommended: 0)
Number of Global Schedules to Perform	Number of Global Schedules to Perform (Recommended: 1)
Number of Post-Relaxation Schedules to Perform	Number of Post-Relaxation Schedules to Perform (Recommended: 0)
Number of Steps	Number of steps for each of the pre-, global-, and post-relaxation schedules
Type	Type of relaxation to perform in the specified step (see example for full description)

Sample move_relaxation.schedule File

```
************************* HEFSS Relaxation Schedule ************************
*
*  This file lays out the relaxation schedule for the HEFSS solver in
*  terms of pre-relaxations, global relaxations, and post-relaxations
*
*  The step types are as follows:
*
*    Type 1:  Line-implicit relaxation through stretched grid regions
```

```
*    Type 2:  Point-implicit relaxation through entire domain
*    Type 3:  Point-implicit relaxation through boundary swaths
*    Type 4:  Point-implicit relaxation through entire domain - line region
*    Type 5:  Newton-Krylov through entire domain - line region
*    Type 6:  ILU(0) relaxation through entire domain
*    Type 7:  Global Newton-Krylov
*
*******************************************************************************
Number of Pre-Relaxation Schedules to Perform
0
Number of Global Schedules to Perform
1
Number of Post-Relaxation Schedules to Perform
0
                      ----- Pre-Relaxation Schedule -----
Number of Steps
0
Step         Type       Sweeps  Turb Sweeps
                    ----- Global Relaxation Schedule -----
Number of Steps
2
Step         Type       Sweeps  Turb Sweeps
   1            2            5            0
   2            7            0            0
                     ----- Post-Relaxation Schedule -----
Number of Steps
0
Step         Type       Sweeps  Turb Sweeps
```

6.7. Overset Grids

This section describes the capability to utilize overset meshes within FUN3D. Unlike structured grids, there is no compelling reason to use overset unstructured meshes unless the analysis involves moving bodies. For general information on moving bodies, see **Moving Grids**

NOTE: this is an active area of development, so implementation or input details may change with time.

Overset Grids – Overview
Static Grid Simulations
Dynamic Grid Simulations

Overset Grids – Overview

To use overset grids, the third-party libraries SUGGAR++ and DiRTlib are required. **See Chapter 2 of this manual for more information on where to obtain these libraries, which make targets should be compiled, and special soft-links that must be made for FUN3D to utilize these libraries**.

For overset grid applications, FUN3D Version 10.5 or higher is recommended; all information below is geared toward Version 10.5 and higher. This is an evolving capability, so usually it is best to have the latest release. When configuring the FUN3D suite for overset-grid applications, be sure to use the following:

```
--with-dirtlib=/path/to/dirtlib
--with-suggar=/path/to/suggar
```

where /path/to/dirtlib(suggar) is the path to your DiRTlib and SUGGAR++ executables. Note that if FUN3D is to be run in parallel, DiRTlib must also be configured for parallel execution, built against the same version of MPICH.

The process for using overset grids in FUN3D is to first create a composite mesh by running SUGGAR++ as a stand-alone process. It is beyond the scope of this web page to act as a detailed guide to the usage of SUGGAR++. Ralph Noack provides documentation with the SUGGAR++ distribution along these lines. However, the general idea is to generate two or more independent grids about individual bodies in a multibody system (e.g. a grid for a wing and a grid for a store in a store-separation problem, or a grid for a rotor blade and a grid for the fuselage in a rotorcraft problem). In the discussion that follows, these independent grids are referred to as component grids. The commands to position these component grids relative to one another, commands to affect hole cutting, etc, are set in the XML input file (typically called `Input.xml`) that SUGGAR++ reads. When executed with the XML commands, SUGGAR++ will perform the composite assembly of the

component grids, and will (with the appropriate XML command) dump out a composite mesh. As of this time, the only unstructured composite mesh format that SUGGAR++ can dump out that is also compatible with FUN3D is the VGRID tetrahedral format. Thus, the SUGGAR++ XML file that creates the initial composite mesh for FUN3D use must have:

```
<output>
  <unstructured_grid style="unsorted_vgrid_set" filename="project">
  </unstructured_grid>
</output>
```

where project is a name of the user's choice, and will become the name of the output composite VGRID set (e.g., `project.cogsg`, `project.iface`, `project.mapbc`, `project.bc`). It is this composite VGRID set that is processed by the PARTY preprocessor and utilized by FUN3D, rather than the individual component grids.

In principle, one of the other file formats that SUGGAR++ reads besides VGRID could be used for the input component grids and then a VGRID composite grid could be output using the XML syntax shown above. To date, FUN3D developers have only utilized input component grids in VGRID format. When using VGRID input component grids, the boundary conditions specified in the `.mapbc` files are set as usual, **except** for grids whose outer boundary in the composite mesh will need to be interpolated from another component mesh. Typically, in VGRID parlance, these outer boundaries are labeled "box" and usually have a characteristic boundary condition (type 3). For overset cases, such boundaries should be assigned a boundary condition type -1 to inform SUGGAR++ that it must compute interpolation coefficients for these boundary points. Note that the component mesh that serves as the "background" mesh should have its outer boundary conditions unchanged (e.g. type 3). After SUGGAR++ has been run, the `.mapbc` file for the resulting composite mesh will also have boundary condition type -1 for the interpolated boundaries. It is possible to not set the the boundary condition type to -1 for the interpolated outer boundaries in the component-grid `.mapbc` file(s), and instead use SUGGAR++ XML commands to specify those boundaries as overset. However this is not the recommended procedure, since then the corresponding boundaries in the composite-grid `.mapbc` file do not get marked as -1, and there is no "paper trail" on the FUN3D side that these boundaries are overset.

Once SUGGAR++ is successfully executed it will generate a `[project_name].dci` file. This file will later be read in by FUN3D. Likewise, the successful execution of SUGGAR++ will create the composite VGRID set (`[project_name].cogsg`, `[project_name].iface`, `[project_name].bc`, and `[project_name].mapbc`). This VGRID set must now be processed with PARTY in the usual way, with the exception that the following command-line option MUST be used:

```
--overset
```

NOTE: this same command-line option must be used when postprocessing with PARTY (in addition to `--moving_grid` if the case is a moving grid overset case). When PARTY offers the option to group boundaries, you will probably want to group boundaries by VGRID Family Type in order to simplify the amount of input required when **Defining Moving Bodies** for dynamic-grid applications. The boundaries that were assigned bc type -1 will appear with the name "overset_interp" in the `[project].part_info` file written by PARTY.

Static Grid Simulations

Static, overset grid simulations may be desired in order to provide a steady-state starting point for subsequent dynamic grid simulations. Once SUGGAR++ has been successfully run and the resulting composite mesh partitioned with PARTY, FUN3D is run with the command-line option

```
--overset
```

This will read in the `[project].dci` file, and use the data therein to provide communication of the flow solution between the various components of the composite overset mesh.

Dynamic Grid Simulations

This section only addresses the additional input needed for the utilization of overset grids in moving-grid applications; see **Moving Grids** for much additional information covering other required input.

For moving grids, a new dci file is required for each time step. The new dci files may either be created "on the fly" as FUN3D is run, or read in if they already exist. Most moving-body problems involve periodic motion, so the usual practice is to compute the required dci files "on the fly" during the first period of motion, and read the dci files computed during the first period for subsequent periods of motion. It requires much more time to compute the connectivity data than to read it, so this strategy should be used whenever appropriate. Certain types of motion are not periodic and cannot

benefit from this strategy – 6 DOF simulations are one example.

To compute the connectivity information on the fly, use the following command line when running FUN3D:

```
--dci_on_the_fly
```

When this command line is used, the code will compute and use the connectivity data for the current time step, and will also write out the data for the current time step N to the file

```
[project]N.dci
```

At the current time the code will overwrite an existing `[project]N.dci` file.

If the `--dci_on_the_fly` command-line option is not used, FUN3D will assume the required `[project]N.dci` files are available and will attempt to read them as needed.

For cases with periodic motion, first run enough time steps with the command-line option `--dci_on_the_fly` to create a sufficient number of dci files to cover the entire period. Say the number of time steps per period is NP. Subsequent runs should then be run with the command-line option

```
--dci_period NP
```

Once all the dci files have been created for period motion and the `--dci_period NP` is used, subsequent runs can be made with an arbitrary number of time steps – not necessarily NP steps per run.

When restarting, the flow solver will keep track of the last dci file computed or read during the last time step of the previous run, and will use this to determine the next dci file that needs to be created or read. No special commands or flags are needed to restart an overset mesh case.

IMPORTANT: For computing connectivity data "on-the-fly", the current paradigm in FUN3D is to have SUGGAR++ running as a concurrent process – currently a single, concurrent process. As a result, when the `--dci_on_the_fly` command-line option is used, the number of processors assigned to an MPI run must be 1 (one) greater than the number of partitions. For example, if the composite mesh has been partitioned into 64 parts, a total of 65 processors are required; e.g. `mpirun -np 65 nodet_mpi --dci_on_the_fly --overset`. In the machinefile list, the FIRST processor will be assigned to SUGGAR+. Furthermore, since the SUGGAR+ process requires that the entire mesh fit in core, the first processor in the machinefile list must have sufficient memory to contain the complete mesh. As an improved, parallel version of SUGGAR++ becomes available, this restriction on one memory-laden processor will be removed.

NOTE: When the `--dci_on_the_fly` command-line option is NOT used, such as when continuing a periodic simulation after all connectivity files have been created, then the number of processors must be set back to be identical to the number of grid partitions.

&composite_overset_mesh namelist

This namelist is input via the `moving_body.input` file – see **Moving Grids** for additional namelist input required for dynamic mesh simulations. Note that for versions 10.8 and higher, the `&composite_overset_mesh` namelist is greatly simplified and requires only the name of the xml file used previously for the static overset assembly.

FUN3D Version 10.8 and higher:

`input_xml_file` File containing XML commands for SUGGAR++; specify the same `Input.xml` file as was used to generate the initial composite grid with the "stand-alone" SUGGAR++ code

FUN3D Version 10.7 and lower:

A (G) following a variable description means that this is a global descriptor, i.e. applicable to all moving bodies; a (B) following a variable description means that the data may be specified for each moving body. Note: although there are defaults set for all namelist items, virtually all defaults must be overwritten with user-supplied data.

`n_component_grids` Number of component grids in the composite mesh (G) (Default: 0)

`ref_vgrid_set` Name of the component VGRID set for the body; must be same as the corresponding filename of the vgrid_set in the SUGGAR++ `Input.xml` file used to create the composite mesh (B) (Default: '')

`ref_vol_name` (Version 10.7) Name of the volume grid for the body; must be the same as the name of the volume_grid in the SUGGAR++ `Input.xml` file used to create

	the composite mesh (B) (Default: '')
ref_body_name	(Version 10.7) Name of the body; must be the same as the name of the body in the SUGGAR++ `Input.xml` file used to create the composite mesh; this same body name should be used in the **&body_definitions** namelist (B) (Default: '')
associated_body	Body number to associate with this component mesh (B) (Default: 0) (note: the non-moving background grid must be associated with body 0)
input_xml_file	(Version 10.7; in older versions: manual_hole_commands) File containing XML commands for SUGGAR++; typically used to "tweak" hole cutting beyond SUGGAR++'s default settings(G) (Default: '') NOTE: in version 10.7 an higher, one may use the same `Input.xml` file as was used to generate the initial composite grid with the "stand-alone" SUGGAR++ code; in prior versions of FUN3D the `manual_hole_commands` file was related to, but not syntactically the same as, a SUGGAR++ `Input.xml` file

6.8. Static Aeroelastic Coupling

This section describes how coupling between the FUN3D flow solver and an external structural model may be achieved. Typically, this capability would be used to incorporate the effects of static structural deflections in an aerodynamic analysis. In principle the coupling could also be performed in time accurate mode, allowing for dynamic structural interactions, but this is probably not practical due to the file I/O method of data transfer. For dynamic aeroelastic simulations, the **modal approach** is preferred.

It should be noted that static aeroelastic coupling in FUN3D requires third-party **middleware** that is **not** provided with the FUN3D suite. The middleware must serve two purposes (separate middleware codes may be utilized for each purpose if desired). First, the middleware must map the aerodynamic loads data output by FUN3D onto the FEM surface used by the external structural model, and second, middleware must map the surface deflections computed by the structural model back onto the surface grid for FUN3D, in a format described below. The middleware is responsible for performing these mapping tasks in a consistent manner.

Jamshid Samareh at NASA Langley can provide suitable middleware for this purpose.

In the sections below, two command-line options are described: `--write_aero_loads_to_file` and `--read_surface_from_file`. These command lines may be specified singly or in combination. For static aeroelastic simulations these options are usually used in combination. When starting from scratch (in what might be called the "zeroth coupling cycle"), with the surface is in the undeformed shape, the `--write_aero_aero_loads_to_file` option would be used by itself. Subsequent coupling cycles, where a new surface is available for input and new loads will be written on output, will require both command-line options. Alternatively for subsequent coupling cycles, the command line `--aeroelastic_external` will automatically enable both the `--read_surface_from_file` and `--write_aero_aero_loads_to_file` command line options.

Loads Output

Aerothermodynamic loads may be output from the flow solver by using the command line `--write_aero_loads_to_file`. In steady-state mode, this will create a file or files called `[project]_ddfdrive_bndryN.dat`, where `N` is the boundary number, with one file for each solid boundary in the mesh. Note that the boundary numbering will reflect any boundary lumping options that the user has selected in the `raw_grid` namelist. In time accurate mode the timestep is appended to the file name: `[project]_ddfdrive_bndryN_timestepM.dat` Static aeroelastic analysis is performed in steady-state mode.

In steady state mode, this file will be written at the end of the current run. In time accurate mode, a file will be written every time step. (This can be varied by changing the default value of `structural_coupling_freq` in the aeroelastic_module from 1 to the desired value and recompiling).

The `ddfdrive` file is a formatted Tecplot file containing the following variables in the "fepoint" format:

In the perfect gas path (`incomp = 0` or `1`):

```
variables="x","y","z","id","cp","cfx","cfy","cfz","temp","dtdn"
```

In the generic gas path (`incomp = 2`):

```
variables="x","y","z","id","cp","cfx","cfy","cfz","temp","heat_flux"
```

where `x`, `y`, `z` are the coordinates of each point on the aeroelastic surface; id is the node number in the global (raw) grid for each surface point; `cp` is the pressure coefficient; `cfx`, `cfy`, and `cfz` are the components of the local shear stress coefficient vector; `temp` is the wall temperature; `dtdn` is the wall temperature gradient (for the generic gas path, `heat_flux` is the local normal heat flux coefficient).

As mentioned above, by default one ddfdrive file is written for each solid boundary in the mesh. The user may elect to group selected boundaries into one or more "bodies" and output the aggregate bodies to individual ddfdrive files. Note: although multiple bodies can be output, on the **input** side of the static aeroelastic coupling process, only one body is allowed.

To have the aero loads data grouped into user selectable bodies, use the `aero_loads_output` namelist in the `fun3d.nml` file. For example, in a grid for which boundaries 3, 4, 5, 7, and 9 are solid boundaries, to group boundaries 3 and 9 into one body for output, use:

```
&aero_loads_output
n_bodies = 1               ! define one body
nbndry(1) = 2              ! body 1 consists of 2 boundaries
boundary_list(1) = '3, 9'  ! these boundaries
/
```

In this case the ddfdrive files will be named `[project]_ddfdrive_bodyB.dat` from a steady-state simulation and `[project]_ddfdrive_bodyB_timestepM.dat` from a time-accurate simulation, B being the body number. Again, although this output option supports more than one body, the corresponding input needed for static aeroelastic coupling, described next, supports only one body. That single body may be comprised of more than one surface, however.

Deflected Surface Input

The loads output as described above must be passed through an intermediate processing step (middleware) to interpolate/transfer them to the structural grid, as the structural grid typically differs from the CFD grid. Similarly, output deflections from the structural model must be transferred back to the CFD grid via middleware. Ultimately, a new surface definition must be provided to the flow solver in the form of an input file. This file must adhere to the following naming convention:

`[project].body1_timestep1`

The command-line option `--read_surface_from_file` (or `--aeroelastic_external` as noted above) will cause the flow solver to read in this new surface.

For static aeroelastic simulations, only one body is allowed, and static aeroelastic simulations are run in steady-state mode, so that the new surface is read once at the start of the current computation, at timestep 1. Each new CFD run within the CFD-structures coupling loop begins with "timestep" 1. Hence the body1_timestep1 extension to this surface file. In fact the naming convention is slightly more general, so that if the coupling were to be carried out in a time accurate manner, a new file `[project].body1_timestepM` would be read at each time step in the current CFD run, `1 <= M <= ncyc`.

Note: the default assumption is that a static aeroelastic surface is comprised of all solid surfaces in the mesh. To define an aeroelastic surface that is only a subset of all solid surfaces, use the namelist `&massoud_output` (this namelist governs several tasks, both input and output). For example, to be compatible with the `&aero_loads_output` example given above, this namelist would need to be:

```
&massoud_output
n_bodies = 1               ! define one (and only one body for input)
nbndry(1) = 2              ! body 1 consists of 2 boundaries
boundary_list(1) = '3, 9'  ! these boundaries
/
```

The user must make sure that the aeroelastic surfaces are defined properly, and consistent with the underling grid. If not, you will encounter error messages similar to

```
Error, pack_boundary_surfaces for body 1
Partition 1
  body has total of 50827 points
  found only        10601 points
  lmpi_conditional_stop, total stop with            1
```

The `[project].body1_timestep1` file is a formatted Tecplot file of the fepoint format, and is identical to that described the the Time Dependent Flows Section, under Surface File Format In steady state mode, where only one surface file is provided for the entire run of the flow solver, the time value is not required as part of the title line.

6.9. GINPUT.FACES TYPE INPUT

This is a description of the old method for input to FUN3D. As of release 10.5.0, the `ginput.faces` input deck has been replaced by a namelist file. See the Flow Solver Namelist Input section for details.

PERFECT GAS

A typical `ginput.faces` input deck:

```
CASE TITLE
     XMACH      ALPHA        YAW         RE       TREF    PRANDTL
     0.300      2.000      0.000      1.0e6      460.0      0.72
    INCOMP      IVISC      IFLIM      NITFO      IHANE      IVGRD
         0          0          0          0          2          0
      SREF       CREF       BREF        XMC        YMC        ZMC
   1.00000    1.00000    1.00000       0.25       0.00       0.00
      CFL1       CFL2      IRAMP  CFLTURB1  CFLTURB2
      10.0      200.0         50        1.0      50.0
      NCYC    ITERWRT     RMSTOL     IREST
       100         20      1.e-9          0
   JUPDATE     NSWEEP      NCYCT PSEUDO_DT
         3         15         10          1
     ITIME         DT  SUBITERS
         0        5.0          5
     NGRID   FMG_LEVS FMG_PRLNG        NU1        NU2
         1          1          1          1          1
  FAS_LEVS   FAS_CYCS       NGAM
         1          1          1
PROJECT_NAME:
'projectname'
```

The entries for each pair of lines is described in the following sections:

FREESTREAM CONDITIONS

XMACH This is the freestream Mach number for compressible flows. For incompressible flows, this is the artificial compressibility parameter, beta. For incompressible flows, the suggested value is `XMACH=15`.

ALPHA This is the freestream angle of attack in degrees.

YAW This is the freestream side-slip angle in degrees.

RE This is the freestream Reynolds number. For inviscid computations, this value is ignored. The input value depends on the reference length, and how the grid is dimensioned. If your Reynolds number is based on the MAC, and the grid is constructed so that the MAC is one, then the appropriate value for RE is the full freestream Reynolds number. If the grid is constructed so that the MAC is in inches, then `RE` must be set to the Reynolds number divided by the MAC in inches.

TREF This is the freestream reference temperature in degrees Rankine. The usual value is `460`.

PRANDTL This is the value of the Prandtl number. The usual value is `0.72`.

ALGORITHM

INCOMP This flag toggles the incompressible option. If `INCOMP=0`, then compressible flow is assumed with a freestream Mach number equal to `XMACH`. If `INCOMP=1`, then incompressible flow is used with an artificial compressibility factor of `XMACH`.

IVISC This controls the physics that you want. The valid options are: `0`:Euler, `2`:Laminar, `6`:Spalart-Allmaras model, `7`:DES with Spalart-Allmaras model, `8`:Menter's SST model.

IFLIM This controls the limiter for the reconstruction process. The valid options are: `0`:No limiter, `1`:Min-mod type, `2`:Venkatakrishnan limiter. We usually do without a limiter. However, for Mach numbers > about 1.2, you may need to use `IFLIM=1`. When using a limiter, the command line option `--freeze_limiter xx` may also be of use. This option freezes the value of the limiter throughout the flow field after `xx` number of timesteps. This can be useful in improving convergence that typically stalls or "rings" when using a limiter. Note

the reconstruction is evaluated at each time step with the current "frozen" value of the limiter, however if the reconstruction fails due to the extrapolation to the cell face, the limiter is allowed to be recomputed at these selected points. Finally, when restarting a solution that has used a frozen limiter, if you wish to continue freezing the limiter for the restart, you must specify `--freeze_limiter 0`.

NITFO This is the number of spatially first-order accurate time-steps to run prior to switching to second-order spatial accuracy. Note: for time accurate cases (`itime /= 0`), this is the number of first-order accurate sub iterations to run for each time step. The suggested value is `NITFO=0`.

IHANE This controls which flux function you want to use for the inviscid fluxes. The valid options are: `0`:Van Leer, `2`:Roe, `3`:HLLC, `4`:AUFS, `5`:central difference. Roe's scheme is suggested, but you may find that Van Leer converges better for some cases. For incompressible flow, the only valid option is `IHANE=2`. Jacobians are Van Leer by default. Other Jacobians can be selected with `--roe_jac`, `--hllc_jac`, `--aufs_jac`, or `--cd_jac` command line options.

IVGRD This flag is only relevant for viscous computations. If `IVGRD=1`, the viscous fluxes will be neglected in cells containing angles equal to 178 degrees or more (admittedly a hack). This flag is seldom required, however, you may encounter cases on meshes with poor cell quality where the computation will suddenly give NaNs during the solution process. This is due to unusually large angles in the grid causing gradients in the viscous fluxes to blow up. (Watch for bad angles reported by the preprocessor.) The suggested value is `IVGRD=0`.

Geometric References

SREF This is the reference area used for non-dimensionalization of forces and moments.

CREF This is the reference chord used for non-dimensionalization of moments.

BREF This is the reference span used for non-dimensionalization of moments.

XMC This is the *x* coordinate used for moment computations, in grid units.

YMC This is the *y* coordinate used for moment computations, in grid units.

ZMC This is the *z* coordinate used for moment computations, in grid units.

CFL Controls

Note: When running in time accurate mode (`itime /= 0`), the same definitions hold, except that they are applied over `IRAMP` sub iterations during each time step:

CFL1 This is the starting CFL number. The suggested value is `CFL1=1`. The actual CFL number is determined by a linear ramp from `CFL1` to `CFL2` over `IRAMP` time steps.

CFL2 This is the maximum CFL number. The suggested value is `CFL2=200`. The actual CFL number is determined by a linear ramp from `CFL1` to `CFL2` over `IRAMP` time steps.

IRAMP This is the number of time steps over which to linearly ramp the actual CFL number from `CFL1` to `CFL2`. The suggested value is `50`.

CFLTURB1 This is the starting CFL number for the turbulence equation. The suggested value is `CFLTURB1=1`. The actual CFL number is determined by a linear ramp from `CFLTURB1` to `CFLTURB2` over `IRAMP` time steps.

CFLTURB2 This is the maximum CFL number for the turbulence equation. The suggested value is `CFLTURB2=50`. The actual CFL number is determined by a linear ramp from `CFLTURB1` to `CFLTURB2` over `IRAMP` time steps.

Iteration Controls

NCYC This is the number of time steps to be run.

ITERWRT The solution and convergence history will be written to disk every `ITERWRT` time steps.

RMSTOL This is the absolute value of the RMS residual at which the solver will terminate early.

IREST This flag controls the restart option. If `IREST=0`, the flow is initialized as freestream. If `IREST=1`, the flow will be initialized by using the previous solution information, and the convergence history will be concatenated with the prior solution history. If `IREST=-1`, the flow will be initialized by using the previous solution information, but the convergence histories will *not* be concatenated.

Updates

JUPDATE After the first 10 iterations, Jacobians are updated every `JUPDATE` iterations. The suggested setting is `JUPDATE=3`.

NSWEEP Number of Gauss-Seidel sub iterations for the linear problem at each time step. The suggested value is `15`.

NCYCT Number of Gauss-Seidel sub iterations for the turbulence model linear problem at each iteration. The suggested value is `10`.

PSEUDO_DT Needs to be set to 1 for steady-state-type cases (`ITIME`=0). For time accurate cases, controls whether a pseudo time term is added to the physical (global) time step or not. Use `PSEUDO_DT=1` to add the term; otherwise use `PSEUDO_DT=0`. When added, the value of the pseudo time term varies spatially according to a local **CFL constraint**. Note that when ramping the CFL of the pseudo time term, the final CFL will be obtained only if subiters >= iramp. The psuedo time term typically allows larger physical time steps to be taken than might otherwise be possible. By the end of a **convergent** subiteration process, the pseudo time term drops out, giving the correct temporal discretization. The suggested value is `PSEUDO_DT=1`. [Introduced version 3.2.3.]

Time

ITIME Controls time accuracy: `0`:steady-state, `1`:the scheme is first-order accurate in time, `2`:the scheme is second-order accurate in time, `3`:the scheme is third-order accurate in time [Introduced version 10.0], `-3`:the scheme is in between second-order and third-order accurate in time ("BDF2opt") [Introduced version 10.0]. Before version 3.2.3: `1`:steady-state, `2`:the scheme is second-order accurate in time. The suggested value is the steady-state value. The physical time step is controlled by `DT` > 0.

DT This is the actual time step used for time-accurate computations (`ITIME` > 0). The value of `DT` will depend on your time-dependent problem. Before version 3.2.2, local time-stepping is used if `DT` < 0 so it was only used when `DT` > 0.

DTAU This is the pseudo-time step used for the sub iterations. [Removed version 3.2.3: now controlled by `PSEUDO_DT`, `CFL1`, `CFL2`]

SUBITERS The number of sub iterations applied to solve the implicit backward time formula.

Multigrid

NGRID, FMG_LEVS, FMG_PRLNG, FAS_LEVS, Multigrid parameters. This option is not complete—leave all parameters at their default: `1`.

Project Rootname

PROJECT_NAME Project name for the grid. It must be enclosed in single quotes.

Hypersonics

In the old `ginput.faces` input deck, a hypersonic (generic gas) case contained the same 21 lines of input information as ideal-gas cases (although not all parameters were used), plus an additional 10 lines specifically for generic gas at the end.

A sample of the input file, `ginput.faces`, is shown below. Line numbers are not part of the file.

```
1  CASE TITLE
2       XMACH      ALPHA        YAW         RE       TREF    PRANDTL
3       15.00       3.00     0.0000     4.00e5      200.0       0.72
4      INCOMP      IVISC      IFLIM      NITFO      IHANE      IVGRD
5           2          2          0          0          2          0
6        SREF       CREF       BREF        XMC        YMC        ZMC
7     1.00000    1.00000    1.00000       0.25       0.00       0.00
8        CFL1       CFL2      IRAMP   CFLTURB1   CFLTURB2
9      1.e+06     1.e+06        100    000.100    200.000
10       NCYC    ITERWRT     RMSTOL      IREST
11       1000         50     1.E-15          1
12    JUPDATE     NSTAGE      NCYCT
13         10         10         10
14      ITIME         DT       DTAU   SUBITERS
15          1     -5.000       .001         10
16      NGRID   FMG_LEVS  FMG_PRLNG        NU1        NU2
17          1          1          1          1          1
18   FAS_LEVS   FAS_CYCS       NGAM
19          1          1          1
20 PROJECT_NAME:
21 'cylinder'
22      V_INF     RHO_INF     T_INF    LEN_REF     T_WALL
23     5000.0     0.00100      200.        1.       500.
24  CHEM_FLAG THERM_FLAG TURB_MODEL_TYPE
```

```
25           0          0         0
26      RF_INV     RF_VIS      EIG0  EIG0_IMP
27         2.0        1.0  1.0e-30    5.e-02
28 TURB_INT_INF TURB_VIS_RATIO_INF  PRANDTL_TURB
29        0.01             0.1            0.9
30 REYNOLDS_STRESS_MODEL TURB_COND_MODEL  TURB_COMP_MODEL
31                0               0               0
```

The first 21 lines of the file have identical format to traditional perfect gas FUN3D specifications. However, some entries are ignored or play a different role if the generic gas path for hypersonic flow is selected. These differences will be explained subsequently but it is assumed that the user is already familiar with these first twenty-one (21) lines. If not, the user should consult the description of the `ginput.faces` file in the perfect gas section of the FUN3D users manual first. Additional parameters required for the generic gas path appear in lines (22) – (31). The format maintains the pattern of a list of parameter names on one line and the associated parameter values positioned under the respective name on the next line.

The generic gas path is selected when the input integer parameter `INCOMP` is set to `2` on line (5). Recall that the perfect gas, compressible path is selected when `INCOMP` is set to `0` and the incompressible path is selected when `INCOMP` is set to `1`. Lines (22)-(31) will only be read if `INCOMP` is set to `2` on line (5). The generic gas path can currently accommodate perfect-gas, equilibrium gas, and mixtures of thermally-perfect species in chemical and/or thermal non-equilibrium.The user specifies the gas model in a separate file called `tdata` to be defined later.

The parameter `IVISC` may be set to `0` (inviscid flow) or `2` (viscous flow). Other options used in FUN3D do not apply in the generic gas path (when `INCOMP` is set to `2`). Branches for laminar or turbulent flow using various models are controlled by the new parameter `TURB_MODEL_TYPE` to be defined subsequently. Because the turbulent model equations are solved in a fully coupled manner with the other conservation laws in the generic gas path the parameters which control relaxation of an independent set of turbulence equations, `CFLTURB1`, `CFLTURB2`, `NCYCT` in the perfect-gas path are ignored.

Two options are available for second-order spatial accuracy. The integer parameter `IHANE` from FUN3D on line (3) assumes a new role to define these options. Both options use Roe's averaging. If `IHANE` is set to `1` on line (4) then the right and left states are reconstructed to second-order using primitive variable gradients computed using least squares from the right and left nodes. These gradients may in turn be limited according to the standard definition if `IFLIM` in FUN3D. If `IHANE` is set to `2` on line (4) then the right and left states use the nodal values (first-order-formulation) but a second-order, anti-dissipative correction is introduced using a STVD formulation involving the same nodal values of gradients. In this case there is no limiting of gradients, other than that occurring in the STVD formulation.

In hypersonic applications, the inflow boundary conditions are given in terms of a uniform velocity (`V_INF`), mixture density (`RHO_INF`), and temperature (`T_INF`). These input parameter names appear on line (22) and associated values on line (23). The MKS system is used for these inputs; consequently, velocity must be entered in units of meters per second, density in units of kilograms per meter cubed, and temperature in degrees Kelvin. The grid scaling factor (`LEN_REF`) converts from grid units to meters in units of meters per grid unit. For example, if grid units are in inches then `LEN_REF` is set to 0.0254 (meters per inch). Mach number and Reynolds number per grid unit are computed from these fundamental inputs; consequently, the entries for Mach number (`XMACH`), Reynolds number (`RE`), reference temperature `TREF`, and Prandtl number (`PRANDTL`) from the perfect-gas path are ignored on line (3).

A wall temperature (`TWALL`) is also entered on line (23) in units of degrees Kelvin. If a non-constant wall temperature boundary condition is specified (see Boundary Conditions for Generic Gas Option) then this parameter serves only to initialize the surface boundary condition.

Three gas model flags are defined on lines (24) and (25). The flag name appears on line (24) and the associated value appears beneath it on line (25). The flag `CHEM_FLAG` is set to `0` for chemically frozen flow or to `1` for chemically reacting flow. This flag is engaged only in the case of multiple species defined in file `tdata`. If it is set to zero for chemically frozen flow then the chemical source term is never called and species mass fractions can only be changed through the action of diffusion. If it is set to one for chemically reacting flow then the chemical source term is called and species mass fractions change by kinetic action of dissociation, recombination, ionization, and de-ionization. The flag `THERM_FLAG` is set to `0` for thermally frozen flow or to `1` for thermally active flow (flow in thermal non-equilibrium). This flag is engaged only when a thermal non-equilibrium model is specified in the file `tdata`; otherwise thermal equilibrium is assumed. If it is set to zero for thermally frozen flow then the thermal energy exchange source term is never called and the modeled modal temperatures (vibrational, electronic) can be changed only by the action of conduction. (Translational temperature still evolves through the action of flow work but this energy is never transferred to internal energy modes.) If it is set to `1` then the source term models particle collisions in which particle internal energy in the translational, rotational, vibrational, and electronic modes can be exchanged. The flag

TURB_MODEL_TYPE engages various multi-equation turbulence models. This flag is set to 0 for laminar flow. Other models are under construction.

Four numerical parameters unique to the generic gas path are named on line (26) and set on line (27). Their names and intended function are inherited from the structured grid, hypersonic flow solver LAURA. As experience is gained with the generic gas path, the role of these numerical parameters has been modified. The parameter RF_INV is a relaxation factor on the update, *dq*, to the conservative flow variables *q*. Before an update, dq is divided by the maximum value of five limiting factors including RF_INV. The first four limiting factors are computed internally and designed to limit the rate of change of pressure, density, temperature, and velocity. If RF_INV is set to 1.0, no further limiting is engaged. The parameter RF_VIS is a relaxation factor that multiplies only the viscous Jacobian. Its value should be set to 1.0; it is retained here as a place holder for future research. The parameter EIG0 is the eigenvalue limiter. It acts only on the evaluation of the eigenvalues used on the right-hand-side convective portion of the residual using Roe's method. If eigenvalues are less than EIG0 times the local sound speed then a formula due to Harten is employed to smoothly limit the eigenvalue. Numerical tests show that the heating and solution quality near the wall are severely compromised using eigenvalue limiting when tetrahedra are used throughout. The parameter value should be set to 1.e-30 (it must be positive definite) in this case. It is retained as an input parameter in case it is needed, as in the structured grid approach of LAURA, when prismatic elements are introduced. The parameter EIG0_IMP is also an eigenvalue limiter but is applied only in the evaluation of the inviscid Jacobian (left-hand-side) by Roe's method. Recommended values between .001 and 1.0 provide a more well-determined matrix. Larger values enhance robustness with the possible penalty of slower convergence, particularly in stagnation regions.

Lines (28)-(31) contain parameter names and values for various multi-equation turbulence models. These models are under construction.

6.10. Flow Visualization Output Directly From Flow Solver

This section describes how to obtain solution output for flow visualization directly from the flow solver, without having to run party in the postprocessing mode. At the current time, only TECPLOT data output is supported; this is not to be considered as an endorsement of TECPLOT.

This capability is available in Version 10.7 and higher.

This capability is not currently available for the Generic Gas Option.

Beginning with Version 11.0, all of the options below may be used with a value of nsteps = 0 in the &code_run_control namelist within the fun3d.nml file. This will allow generation of visualization output without having to do additional timesteps/iterations on your existing solution – analogous to post processing with the old party code, only faster because multiple processors can be used. Of course, "existing solution" implies that the restart_read variable is set to something other than "off". Note however, if you set nsteps=0 you **MUST** use at least one of the command line options described below; otherwise an error message will be generated and the code will stop.

General Information
Output Variable Choices
Boundary Data Output
Sampling Surface Data Output
Volumetric Data Output
'Sliced' Boundary Data Output (less general than other options)

General Information

The FUN3D partitioning code, party, has long had a postprocessing capability in which the [project]_flow.N files generated by the flow solver are read, combined into a single global image of the solution, and then output via user-selected options for either surface or volumetric data, typically in TECPLOT or FIELDVIEW format. There are several drawbacks to the party postprocessing approach: 1) it is slow for large meshes since one processor must do all the work; 2) it requires a processor with a significant amount of memory if the problem size is large; 3) although there are a number of output options, the output is not particularly customizable for individual requirements in terms of which variables are output.

In FUN3D Version 10.7, some of these deficiencies are addressed by allowing output to be requested from the flow solver directly. At the present time, only TECPLOT-compatible data is output, but what data is output is customizable (see Output Variable Choices). There are 3 basic categories of output: boundary data, "sampling surface" data (on surfaces such as planes, boxes and spheres), and volumetric data. Depending on user requirements, these data may be output at specified frequencies

(i.e. every Nth time step / iteration) or only at the end of the execution. The processing of this data is done largely in parallel, and so is typically much faster than requesting similar output from party. Boundary data and sampling surface data are reduced to a single global image before output at a particular time step, although volumetric data is not. Thus, a solution for which volumetric data as requested will write out one file from each processor for each time step at which output is requested. TECPLOT's multiple file read option can be used to manage the large number of files, but the number of volumetric files written out from a time-dependent case can be quite large even if written infrequently.

The naming convention for each type of data output will be described below, but the file extension will either be .dat for ASCII files or .plt for binary files. Binary files are output when FUN3D is configured with TECPLOT's tecio library (See Third-Party Libraries – TECPLOT). Assuming you have configured FUN3D with the tecio libraries, you may still obtain ASCII output by specifying the command-line option `--ascii_tecplot_output`

By default, output occurs in the inertial reference frame; for stationary geometries, that is the only reference frame to consider. For moving bodies, it is also possible to request output in a reference frame moving with an observer, such that the resulting data is relative to the observer's reference frame, rather than the inertial frame. The observer could be fixed to one of the moving bodies or moving in some other way. See **Specifying Observer Motion**

Output Variable Choices

By default, the variables that are output from the flow solver are x,y,z and the primitive variables rho, u, v, w, and p. For overset meshes, iblank is also part of the default output. If these variables are not what is wanted, alternate data can be chosen via namelist input in a file called "namelist.input" ("fun3d.nml" in 10.9.0 and later); each output category (boundary data output, sampling surface data output or volumetric data output) has its own namelist – see the individual sections for details. The variables listed below are available for either boundary data output, sampling surface data output or volumetric data output. Boundary data output has a few additional variables that are available for output; these special variables are listed in that section. Most variable names should be relatively self-descriptive – a brief description is given in [ ] for completeness. Note that each variable must be spelled as shown below, i.e. pressure coefficient must be requested as cp and not Cp, c_p etc. Also note that all are input as logical variables, either .true. or .false. – e.g. cp = .true. All output variables are nondimensional.

```
x, y, z                      [grid coordinates]
u, v, w                      [velocity components]
p, cp                        [pressure, pressure coefficient]
mach                         [Mach number]
entropy                      [entropy]
vort_x, vort_y, vort_z       [components of vorticity]
vort_mag                     [magnitude of vorticity]
q_criterion                  [second invariant of the velocity-gradient tensor
iblank                       [grid blanking value (overset grid) - output as r
iflagslen                    [integer flag to indicate laminar volume nodes - 
imesh                        [associated component mesh number (overset moving
slen                         [distance from nearest solid surface]
turb1, turb2                 [turbulence variable (1 or 2 equation turb. model
mu_t                         [turbulent eddy viscosity]
mu_t_ratio                   [ratio of turbulent eddy viscosity and local lami
uuprime, vvprime, wwprime    [turbulent fluctuation
uvprime, uwprime, vwprime     velocity products]
volume                       [dual-cell volume]
res1, res2, res3, res4, res5 [mass, momentum(3) and energy residuals]
turres1, turres2             [turbulence residuals (1 or 2 equation turb. mode
res_gcl                      [geometric conservation law residual]
rho_tavg, p_tavg             [time-averaged density and pressure (version 10.8
u_tavg, v_tavg, w_tavg       [time-averaged velocity components (version 10.8 
rho_trms, p_trms             [time-rms density and pressure (version 10.8 and 
u_trms, v_trms, w_trms       [time-rms velocity components (version 10.8 and h
processor_id                 [processor number (starting at 0) on which node r
```

In addition, there are a few "short cut" names available – the variables in [ ] are covered by the short-cut name:

```
primitive_variables      [rho, u, v, w, p]
turbulent_fluctuations   [uuprime, vvprime....vwprime]
residuals                [res1, res2...res4, (res5)...turres1, (turres2)]
primitive_tavg           [rho_tavg, u_tavg, v_tavg, w_tavg, p_tavg (version 10
primitive_trms           [rho_trms, u_trms, v_trms, w_trms, p_trms (version 10
```

NOTE: If you do not desire one or more of the default variables, you must explicitly set those variables as false in the appropriate namelist. For example, to get x, y, z and pressure coefficient output instead of x, y, z, and rho, u, v, w, and p, set primitive_variables = .false. and cp = .true. In this example, use is made of the short cut name for the primitive variables, but alternatively they could be turned off individually.

Note that although any or all of these variables may be requested, there are combinations of input parameters and output variable requests that are simply incompatible. For example, if your input deck is set for laminar flow and you request turb1, turb2 or mu_t, the code will warn you you cannot have that output, and will carry on and output just the valid output requests. Likewise, if you request turb2 output from a 1-equation turbulence model, that will be denied. There are potentially numerous other incompatible output requests – hopefully all are caught.

Boundary Data Output

Boundary output is activated via the command-line option `-- animation_freq N`, where N = + / – 1,2,3… A "+" (or no) sign for N will cause the output to be generated every Nth time step/iteration. A "-" sign with any (non-zero) value of N will cause output to be written only at the end of a run. The behavior of the +/- sign is the same whether the case is time accurate or steady, but typically one would use "-" for steady-state (where only the final data is usually of interest) and "+" for unsteady flows.

To alter the default variable output (x, y, z, rho, u, v, w, p), the undesired variables must be turned off and the desired variables turned on in the `&boundary_output_variables` namelist in the `namelist.input` file (`fun3d.nml` for releases 10.9.0 and later). The example below illustrates the use of the namelist input to output only x and z, and rho, u, w, and cp on the boundary, as might be desired for a 2D case:

```
&boundary_output_variables
y = .false.
v = .false.
p = .false.
cp = .true.
/
```

Note that these variable selections in the `&boundary_output_variables` namelist apply ONLY to boundary output. Other output (e.g. sampling surface) will still contain default variables unless similar choices are made in the appropriate namelist.

By default, the `--animation_freq` command will cause output of solution data for all solid surfaces in 3D and on one y=const. symmetry plane in 2D. The user may alter this default output by setting the variable `number_of_boundaries` and providing a **string** with the list of desired boundaries in the variable `boundary_list`. Note that `number_of_boundaries` and `boundary_list` apply ONLY to boundary output.

(Note: in earlier versions this was accomplished by providing an file called "boundaries_to_animate" in the run directory; this is no longer supported)

For example, to output (default, primitive-variable) data on boundaries 2, 5, and 9-12:

```
&boundary_output_variables
number_of_boundaries = 6
boundary_list = '2,5,9,10,11,12'
/
```

All output boundaries are written to one file each time boundary data output is triggered.

The resulting boundary-data files will have the following naming convention:

```
[project]_tec_boundary_timestepT.dat (or .plt)  if N > 0
[project]_tec_boundary.dat           (or .plt)  if N < 0
```

where T is the time step or iteration number. Within the files, each boundary is written as a separate zone, and zones are identified as, for example:

```
zone T "time 0.0000000E+00 boundary 5"
```

where the time value is the integer iteration number for steady-state cases, and the current

(nondimensional) time for time-dependent cases.

In TECPLOT360-2008, zones may be parsed by time (i.e. type the word time in the parse box) in the Unsteady Flow Options dialog box if "Flow Solution is Steady-State" is not checked. Once zones are parsed by time, they may be animated by time level; this is very useful in animating cases with multiple boundaries, or if the files corresponding to each time step are not read into TECPLOT in order.

In addition to the variables listed in Output Variable Choices, the following variables are also available for output on boundaries:

```
uavg, vavg, wavg             [average off-surface velocity components (for str
yplus                        [friction length corresponding to minimum grid sp
cf_x, cf_y, cf_z             [skin friction components]
skinfr                       [skin friction magnitude, with sign]
cq                           [heat transfer coefficient - actually just dT/dn]
id_l2g                       [local-to-global node map - output as real value]
turbindex                    [turbulence index - see Recherche Aerospatiale 1:
```

NOTE The sign assigned to the skin friction magnitude (skinfr) is determined by the the sign of the inner product of the skin friction vector with the freestream velocity vector. This may or may not be a precise indication of separated flow.

The following "short cut" name is available – the variables in [ ] are covered by the short-cut name:

```
average_velocity          [uavg, vavg, wavg]
```

NOTE The formula used to obtain turbindex is strictly correct only for the SA model (which behaves as the 4th power of y near walls). For other models, which may behave differently, the turbindex is at best only an approximate (crude) indicator.

Sampling Surface Data Output

Sampling output (output on one or more basic surfaces such as planes, spheres, and boxes) is activated via the command-line option `--sampling_freq N`, where N = + / – 1,2,3… A "+" (or no) sign for N will cause the output to be generated every Nth time step/iteration. A "-" sign with any (non-zero) value of N will cause output to be written only at the end of a run. The behavior of the +/- sign is the same whether the case is time accurate or steady, but typically one would use "-" for steady-state (where only the final data is usually of interest) and "+" for unsteady flows.

To alter the default variable output (x, y, z, rho, u, v, w, p), the undesired variables must be turned off and the desired variables turned on in the `&sampling_output_variables` namelist in the `namelist.input` file (`fun3d.nml` for releases 10.9.0 and later). The example below illustrates the use of the namelist input to output the distance from the wall (used in turbulence models), along with the eddy viscosity, rather than the primitive variables, on the sampling surface:

```
&sampling_output_variables
primitive_variables = .false.
slen = .true.
mu_t = .true.
/
```

Note that these variable selections in the `&sampling_output_variables` namelist apply ONLY to sampling output. Other output (e.g. boundary data) will still contain default variables unless similar choices are made in the appropriate namelist.

The surfaces on which solution data is output must be specified by additional namelist input, described below

The resulting sampling-surface data files will have the following naming convention:

```
[project]_tec_sampling_geomG_timestepT.dat (or .plt)  if N > 0
[project]_tec_sampling_geomG.dat           (or .plt)  if N < 0
```

where G = 1,2,...number_of_geometries (as set via the `&sampling_output_variables` namelist) and T is the time step or iteration number. Within the files, a global image of the sampling surface is output, with the zone identified as, for example:

```
zone T "time 0.0000000E+00 geom 3"
```

where the time value is the integer iteration number for steady-state cases, and the current (nondimensional) time for time-dependent cases. See the note near the bottom of the boundary data output section for parsing by time level for animation of unsteady flows.

&sampling_parameters namelist

In addition to the `&sampling_output_variables` namelist, which is similar to those required for boundary and volumetric output, sampling-surface output requires additional data, which is input via a namelist called `&sampling_parameters`; this namelist input must appear in the `namelist.input` file (`fun3d.nml` for releases 10.9.0 and later). Details of the variables in this namelist are described below. A (G) implies that the input value is set once/applies to all output surfaces; and (S) indicates that variable must be specified for each surface.

Note: Boundary_point and volume_point sampling currently output a subset of the total sampling variable options, i.e. rho, u, v, w, p, cp, mach, temperature, entropy, slen, iflagslen, mu_t, mu_t_ratio, turb1, turb2, turres1 and turres2. This list is expected to be expanded in future releases. Output of Schlieren images contain only image intensity data and will not include any other requested sampling output variable data.

number_of_geometries	Number of geometries (sampling surfaces) to be output (G) (Default: 0)
type_of_geometry	Description of the geometry (S) (Default: 'none'; choices: 3D or volume geometries are 'box' and 'sphere'; 2D or planar geometries are 'quad', 'circle' , 'plane' and 'schlieren'; singular geometries are 'boundary_point' and 'volume_point' and 'isosurface' will extract data at a constant value throughout the flowfield.)
label	Alternate label of sampling output filename (S) `[project]_[label]_timestepT.dat (or .plt) if N > 0` or `[project]_{]label].dat (or .plt) if N < 0`
sampling_frequency	Sampling output is activated via the namelist option `sampling_frequency(ivol)=N`, where N = + / – 1,2,3… A "+" (or no) sign for N will cause the output to be generated every Nth time step/iteration. A "-" sign with any (non-zero) value of N will cause output to be written only at the end of a run. The behavior of the +/- sign is the same whether the case is time accurate or steady, but typically one would use "-" for steady-state (where only the final data is usually of interest) and "+" for unsteady flows. sampling_frequency[] = N (S) (Default: 0)
plane_center	x,y,z coordinates of the center of the plane, for type_of_geometry = 'plane' (S) (Default: 0.0, 0.0, 0.0)
plane_normal	x,y,z components of a unit vector to the plane (sign is immaterial), for type_of_geometry = 'plane' (S) (Default: 0.0, 0.0, 0.0)
box_lower_corner	x,y,z coordinates of the lower corner of the box, for type_of_geometry = 'box' (S) (Default: 0.0, 0.0, 0.0)
box_upper_corner	x,y,z coordinates of the upper corner of the box, for type_of_geometry = 'box' (S) (Default: 0.0, 0.0, 0.0)
sphere_center	x,y,z coordinates of the center of the sphere, for type_of_geometry = 'sphere' (S) (Default: 0.0, 0.0, 0.0)
sphere_radius	Radius of the sphere, for type_of_geometry = 'sphere' (S) (Default: 0.0)
circle_center	x,y,z coordinates of the center of the circle, for type_of_geometry = 'circle' (S) (Default: 0.0, 0.0, 0.0)
circle_normal	x,y,z components of a unit vector to the circle(sign is immaterial), for type_of_geometry = 'circle' (S) (Default: 0.0, 0.0, 0.0)
circle_radius	Radius of the circle, for `type_of_geometry = 'circle'` (S) (Default: 0.0)
corner1	x,y,z coordinates of the 1st corner of the quad, for type_of_geometry = 'quad'; corners proceed clockwise (S) (Default: 0.0, 0.0, 0.0)
corner2	x,y,z coordinates of the 2nd corner of the quad, for type_of_geometry = 'quad'; corners proceed clockwise (S) (Default: 0.0, 0.0, 0.0)
corner3	x,y,z coordinates of the 3rd corner of the quad, for type_of_geometry = 'quad'; corners proceed clockwise (S) (Default: 0.0, 0.0, 0.0)
corner4	x,y,z coordinates of the 4th corner of the quad, for type_of_geometry = 'quad'; corners proceed clockwise (S) (Default: 0.0, 0.0, 0.0)
number_of_points	Number of points to be sampled to be output for geometries boundary_points or volume_points (S) (Default: 0)
points	x,y,z coordinates of the points (S) (Default: 0.0, 0.0, 0.0)

number_of_rows	Number of pixels in window height (S) (Default: 0)
number_of_columns	Number of pixels in window width (S) (Default: 0)
window_height	Height of schlieren window (S) (Default: 0.0)
window_width	Width of schlieren window (S) (Default: 0.0)
window_center	x,y,z coordinates of the center of the schlieren window (S) (Default: (0.,0.,0.)
schlieren_aspect	Window normal vector alignment, either y or z axes. (S) (Default: none [blank])
blanking_list_count	Number of boundaries to search to blank schlieren image (S) (Default: 0)
blanking_list	List of boundaries to search to blank schlieren image (S) (Default: none [blank])
isosurf_variable	Flowfield variable used to visualize the iso-surface. (S) (Default: none [blank])
isosurf_value	Value of the flowfield variable to be visualized. (S) (Default: 0)
crinkle	Plot output surface(s) as crinkle surface (G) (Default: .false. [smooth])
print_boundary_data	Print data (for debugging?) (G) (Default: 0 [don't print])
snap_output_xyz	When snap_output_xyz is true, the coordinates of the points output are snapped to the boundary. When snap_output_xyz is false, the coordinates of the points output come from the namelist input. (G) (Default: .true.)
dist_tolerance	Distance, in mesh units, allowed to search for requested boundary point data. (G) (Default: 1.0e-3)
plot	Choice of TECPLOT or Fieldview output (S) (Default: 'tecplot'; alternate: 'fieldview' or 'serial_history')

In the example below, two planes of data are output;

```
&sampling_parameters
  number_of_geometries = 2,
  type_of_geometry(1)='plane',        ! start plane 1 data
  plane_center(1,1) = 3.5               ! x  2nd index is geom #
  plane_center(2,1) = 0.0               ! y
  plane_center(3,1) = 0.0               ! z
  plane_normal(1,1) = 1.0               ! xn
  plane_normal(2,1) = 0.0               ! yn
  plane_normal(3,1) = 0.0               ! zn
  type_of_geometry(2)='plane'
  plane_center(1,2) = 0.0             ! start plane 2 data
  plane_center(2,2) = 10.8333333333333
  plane_center(3,2) = 0.0
  plane_normal(1,2) = 0.0
  plane_normal(2,2) = 1.0
  plane_normal(3,2) = 0.0
/
```

In the next example, a range of geometries are output; this example also depicts a slightly more compact means of specifying the namelist data.

```
&sampling_parameters
  number_of_geometries = 10
!-applies only to boundary_point sampling--
      snap_output_xyz  = .true.
      dist_tolerance   = 0.1
!----------------------------------------
  type_of_geometry(1)='plane',
sampling_frequency(1) = -1
    plane_center(:,1)=4.0,0.0,0.0,
    plane_normal(:,1)=1.0,0.0,0.0,
!
  type_of_geometry(2)='quad',
sampling_frequency(2) =  1
    corner1(:,2)=-2.0,-5.0, 6.0,
    corner2(:,2)=-2.0,-5.0,-6.0,
    corner3(:,2)=-2.0 ,5.0,-6.0,
    corner4(:,2)=-2.0, 5.0, 6.0,
!
  type_of_geometry(3)='circle',
sampling_frequency(3) =  5
    circle_center(:,3) =  0.0, 0.0, 0.0,
    circle_normal(:,3) =  1.0, 0.0, 0.0,
    circle_radius(3) =  5.0,
!
      type_of_geometry(4) ='box'
    sampling_frequency(4) = 0
```

```
    box_lower_corner(:,4) = -5.1, -5.1, -5.1,
    box_upper_corner(:,4) =  5.1,  5.1,  5.1,
!
  type_of_geometry(5) = 'sphere'
sampling_frequency(5) = -1
   sphere_center(:,5) = 1.0, 1.0, 1.0
     sphere_radius(5) = 5.0
!
    type_of_geometry(6)   = 'boundary_points'
  sampling_frequency(6)   = -1
    number_of_points(6)   = 2
           points(:,6,1) = 0.036,0.1,1.0
           points(:,6,2) = 0.0123226,0.0325125,0.998785
!
     type_of_geometry(9)   = 'boundary_points'
   sampling_frequency(9)   = 1
        variable_list(9)   = 'p'
     number_of_points(9)   = 1
                 plot(9)   = 'serial_history'
            points(:,9,1) = 0.0123226,0.0325125,0.998785
!
     type_of_geometry(7) ='schlieren'
   sampling_frequency(7) = 10
       number_of_rows(7) = 100
    number_of_columns(7) = 100
        window_height(7) = 5.00
         window_width(7) = 5.00
      window_center(:,7) = 0.0,2.5,0.0
  blanking_list_count(7) = 1
        blanking_list(7) = '1'
     schlieren_aspect(7) = 'z'
!
     type_of_geometry(8) = 'isosurface'
   sampling_frequency(8) = -1
     isosurf_variable(8) = 'u'
        isosurf_value(8) = 0.1
!
    type_of_geometry(10)   = 'volume_points'
  sampling_frequency(10)   = -1
       variable_list(10)   = 'x,y,z,rho,u,p,cp'
    number_of_points(10)   = 3
           points(:,10,1) =-0.080,0.035,1.0
           points(:,10,2) =-0.080,0.230, 1.0
           points(:,10,3) =-0.080,0.42,1.0
/
```

Volumetric Data Output

Volumetric output (output for every point in the domain) is activated via the command-line option `--volume_animation_freq N`, where N = + / – 1,2,3… A ”+” (or no) sign for N will cause the output to be generated every Nth time step/iteration. A ”-” sign with any (non-zero) value of N will cause output to be written only at the end of a run. The behavior of the +/- sign is the same whether the case is time accurate or steady, but typically one would use ”-” for steady-state (where only the final data is usually of interest) and ”+” for unsteady flows.

Caution: volumetric data is not concatenated into a single global image for tecplot, as is done for boundary and sampling-surface data. Every processor writes its own file, for each timestep for which output is requested. Thus, a very large number of files may be generated for N > 0. Fieldview (fv) and CGNS (cgns) are written as a single image.

```
&volume_output_variables
export_to = 'tecplot' ! 'fv' and 'cgns' are other options
/
```

To alter the default variable output (x, y, z, rho, u, v, w, p), the undesired variables must be turned off and the desired variables turned on in the `&volume_output_variables` namelist in the `namelist.input` file (`fun3d.nml` for releases 10.9.0 and later). The example below illustrates the use of the namelist input to output the three components of vorticity, rather than the primitive variables, at each point in the field:

```
&volume_output_variables
primitive_variables = .false.
vort_x = .true.
vort_y = .true.
vort_z = .true.
/
```

Note that these variable selections in the `&volume_output_variables` namelist apply ONLY to volumetric output. Other output (e.g. boundary data) will still contain default variables unless similar choices are made in the appropriate namelist.

The resulting volume-data files will have the following naming convention:

```
[project]_partP_tec_volume_timestepT.dat (or .plt)  if N > 0
[project]_PartP_tec_volume.dat           (or .plt)  if N < 0
```

where P = 1,2,...nproc (number of processors) and T is the time step or iteration number. Within the files, a single zone is written, with the zone identified as, for example:

```
zone T "time 0.0000000E+00 processor 32"
```

where the time value is the integer iteration number for steady-state cases, and the current (nondimensional) time for time-dependent cases. See the note near the bottom of the boundary data output section for parsing by time level for animation of unsteady flows.

'Sliced' Boundary Data Output

A limited ability to take slices through **boundary surfaces** is available from within the flow solver. For example, spanwise cuts along a wing may be taken, and then the resulting pressure and skin friction data may be plotted at each station. This capability largely parallels that of the box5/box6 utility codes, with the added ability to handle unsteady flows in a simple fashion. This slicing capability is also essential for (and in fact developed for) use in rotorcraft solutions where the flow solver is coupled to an external Computational Structural Dynamics (CSD) code, such as CAMRAD.

Slices can only be taken at constant-coordinate positions (e.g. x=constant); for moving-body cases, the slices may be taken at constant-coordinate positions in a **body-fixed** coordinate system, in which case the slices will not generally be in constant coordinate planes in inertial space.

The sliced data is written to an ASCII formatted TECPLOT file with the naming convention:

{project}_slice.tec

The variables output to this file are: x, y, z, cp, cfx, cfy, cfz at each output time step. Note that unlike the solver-output options described in the previous sections, the output variables from boundary-surface slicing are **not** customizable by the user.

Slicing occurs in the inertial frame unless an alternate reference frame is specified. For stationary geometries, the inertial frame is the only option. For moving body cases, either the frame of one of the moving bodies (see **Defining Moving Bodies**) or an observer frame (see **Specifying Observer Motion**) may be more appropriate.

Surface data slicing is enabled within the flow solver with the command line option: `--slice_freq INT` where INT is the (integer) frequency at which the boundary data is sliced. The `--slice_freq` option operates exactly as `--animation_freq`

In addition to this command line option, specific instructions on where to take the slices must be provided through the namelist `&slice_data`, which in Version 11.1 and higher is input via `fun3d.nml` (in earlier versions of the code, this namelist was set via a file called `slice_global_bndry.input`)

An (S) following a variable description implies that the data may be specified for each slice; a (G) implies the data applies to all slices

&slice_data namelist

`nslices`	Number of slices to create (G) (Default: 0); if negative, then data for only one slice station need be input, along with a spacing increment, and all the data specified for the first station will be applied to subsequent stations, with the exception of the slice location, which will be set using the spacing increment
`slice_increment`	Increment in slice location between consecutive slice stations (G) (Default: 0.0); to be utilized with `nslices` < 0, in which case the value should be explicitly set, as the default increment will place all slices at the same location as the first slice; if `nslices` > 0, the value of `slice_increment` is unused
`tecplot_slice_output`	Output the sliced data (coordinates, Cp, Cf, etc) to a (formatted)

	Tecplot file, [project]_slice.dat, for animation. **Caution:** for unsteady flows with frequently written data at many slice locations, this file can become very large. (G) (Default: .true.)
output_sectional_forces	Output detailed force and moment data for each slice to a (formatted) file, [project].sectional_forces; this file contains F/M data like that in the [project].forces file, only for each and every slice. In addition, it contains geometrical data for each slice (le/te coordinates, moment center, etc.) **Caution:** for unsteady flows with frequently written data at many slice locations, this file can become very large. On the other hand, the data in the file, especially the geometry data, can be useful to assess whether the slicing is working as expected (G) (Default: .true.)
slice_frame	Name of the reference frame in which slice is to be taken (S) (Default: '' [indicates inertial frame]); for moving geometries, to specify the observer frame, use 'observer'; to specify the frame of a particular body, use 'body_name', where body_name is that specified in the **&body_definitions** namelist
replicate_all_bodies	An "easy button" to set similar slice stations on multiple bodies with minimal input beyond that required for slicing the first body. Particularly useful for rotorcraft applications where multiple blades are to be sliced. This variable duplicates the input slice info for all moving bodies, with the exception of `slice_frame` and the `bndrys_to_slice` data (G) (Default: .false.)
slice_x	Slice to be taken normal to x-direction (i.e. at x=constant) in the specified reference frame (S) (Default: .false.)
slice_y	Slice to be taken normal to y-direction (i.e. at y=constant) in the specified reference frame (S) (Default: .true.)
slice_z	Slice to be taken normal to z-direction (i.e. at z=constant) in the specified reference frame (S) (Default: .false.)
slice_location	Coordinate value at which slice is taken (S) (Default: 0.0)
n_bndrys_to_slice	Number of candidate boundaries to search while computing slice-plane intersections (S) (Default: all solid boundaries). Specifying which boundaries are candidates for slicing may speed up the slicing process; may also be used to filter out unwanted intersections or to slice non-solid boundaries
bndrys_to_slice	List of n_bndrys_to_slice boundaries that will be searched to compute the slice-plane intersection (S) (Default: all solid boundaries)
slice_group	Assign this slice to a particular group number; within a group, slice locations are expected to be given in ascending order; multiple slice groups can be used to circumvent this (S) (Default: 1)
te_def	number of points or line segments to consider when defining the "trailing edge" of the slice; a) a value of +1 defines the TE as the aft-most point – best for sharp trailing edges; b) a positive number > 1 initiates a search, over the aft-most te_def segments for "corners", after which the TE is taken as the average coordinate over all the detected corners – 2 corners are assumed to be the desired number and warnings are output if only 1 or more than 2 are found. Note that the value of te_def must be chosen judiciously – large enough to allow both corners to be found, but not so large as to cause excessive searching or for any non-trailing edge corners to be found - this option is best for and recommended only for squared-off trailing edges; c) a negative number indicates a parabolic fit of the aft-most abs(te_def) points – best for rounded/blunted trailing edges (S) (Default: +1 – declare the aft-most point as the trailing edge)
le_def	number of points to consider when defining the "leading edge" of the slice; a) a value of +1 defines the TE as the forward-most point – use if nothing else works or for special cases; b) a positive number indicates a search over the forward-most le_def points for the one that has the maximum distance from the previously-determined trailing edge – generally the best choice provided the trailing edge can be accurately located; c) a negative number indicates a parabolic fit over the forward-most abs(le_def) points (S) (Default: +30 – search the 30 forward-most points to find the one that has the maximum distance from the previously-determined trailing edge)
corner_angle	used in conjunction with te_def > 1; angles between adjacent sliced segments that are less than the corner_angle value will be considered as indicative of a corner between the two segments. For squared-off trailing edges, two and only two corners should be detected. (Default:

	120 – angles less than 120 degrees are considered corners)
chord_dir	Direction of local chord relative to the direction from leading edge to trailing edge; +1 indicates local chord in direction le -> te; -1 indicates local chord in direction te -> le (S) (Default: +1)
use_local_chord	Use the computed local (sectional) chord, based on the computed LE and TE locations, to normalize the sectional force and moment data; otherwise the input value of Cref will be used. (G) (Default: .true.)
slice_xmc	x-coordinate of the moment center in the specified reference frame (S) (Default: computed "quarter chord" of the slice)
slice_ymc	y-coordinate of the moment center in the specified reference frame (S) (Default: computed "quarter chord" of the slice)
slice_zmc	z-coordinate of the moment center in the specified reference frame (S) (Default: computed "quarter chord" of the slice)
xx_box_min	Minimum x-coordinate used to define a bounding box to constrain the slicing. (S) (Default: negative huge number – i.e. no bounding) Specifying bounding box surfaces can aid in filtering out unwanted intersections
xx_box_max	Maximum x-coordinate used to define a bounding box to constrain the slicing. (S) (Default: positive huge number – i.e. no bounding)
yy_box_min	Minimum y-coordinate used to define a bounding box to constrain the slicing. (S) (Default: negative huge number – i.e. no bounding)
yy_box_max	Maximum y-coordinate used to define a bounding box to constrain the slicing. (S) (Default: positive huge number – i.e. no bounding)
zz_box_min	Minimum z-coordinate used to define a bounding box to constrain the slicing. (S) (Default: negative huge number – i.e. no bounding)
zz_box_max	Maximum z-coordinate used to define a bounding box to constrain the slicing. (S) (Default: positive huge number – i.e. no bounding)

When slicing boundary surfaces, a file called `slice.info` is output that echos much of the above input data in more-or-less plain English; assuming the first pass through the slicing routines is successful, the file will also contain information about the number of points in the slice, etc.

Important Considerations for Determination of Leading And Trailing Edges

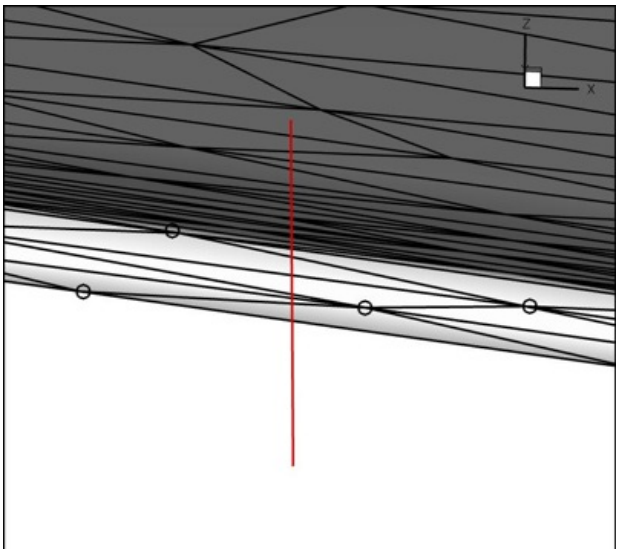
This is especially important for rotorcraft applications where airloads are usually examined (and provided to a CSD code, if applicable), in a section-aligned coordinate system.

The leading and trailing edge points determine the orientation of a section-aligned coordinate system; when slicing boundary data, the computed forces are computed in both the selected frame of reference, and in a section-aligned system. If the data in the section-aligned system is irrelevant to you, then you do not need to worry about choosing the detection parameters carefully – the default values should do something semi-reasonable, without complaint, in most situations.

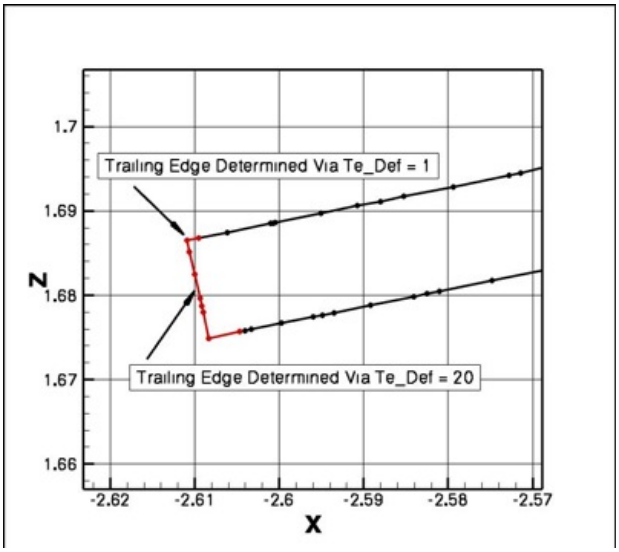
However, if resolution of forces and moments into a section-aligned system is important to you then there are a number of things to consider:

1) Make sure the chord direction (chord_dir) is correct; the default is that going from the LE to the TE is the same as traveling in the positive "chordwise" coordinate direction. For most applications this us the usual situation, however for rotorcraft applications this will generally **not** be the case (see **component_blade_orientation**) and you will want to set chord_dir = -1

2) Since the best option for determining the LE uses the TE location (le_def > +1), then care should be taken to get the TE correct. For **sharp** trailing edges, this is very simple since the default of te_def = +1 (i.e. use the aft-most point) is the best option. However, smoothly blunted or squared-off trailing edges are more finicky. Note that when the boundary surface of an unstructured mesh is sliced, the resulting section will be comprised of line segments determined by the intersection of the specified plane and the edges of the surface triangles. These segments and the points that make up the segments will not usually be the same as the surface points - typically there are more, as illustrated in the following two figures. Bear this in mind when setting te_def and le_def values. You will need enough segments to ensure that both corners are detected, bit not so many that other, non trailing-edge corners (if present) are detected. Another parameter that may be of use to aid in the detection of corners is the corner_angle; the default is 120 degrees (so an angle between segments < 120 degrees indicates a corner), and this seems quite reasonable for all cases considered so far, but unusual situations may require a different value.



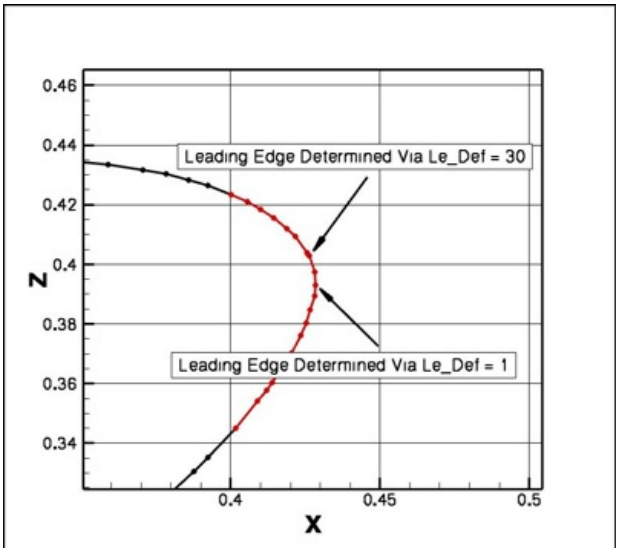
Above: View looking upstream from the trailing edge of a rotor blade mesh; the light-colored region is the squared-off trailing edge; the red line shows the location where an x=const slice will be taken; black circles indicate surface grid points that sit on the trailing edge.



Above: The resulting sliced section, zoomed in to the trailing edge region; the aft-most 8 segments (of the approx. 30 segments in this view) are shown in red. The computed trailing edge locations using two different te_def values are shown. The minimum te_def value at this particular station to pick up both corners would be 8, but a value of 20 was used to be safe and to allow for any station-to-station variations. Note that if the blade was pitched downward rather than upward, then the point chosen by te_def = 1 would be the lower corner, rather than the upper. Thus, when pitching up and down, te_def = 1 with squared-off trailing edges can lead to jumps in the trailing edge position as the section transitions from pitch up to pitch down. Depending on the thickness of the trailing edge, this can lead to jumps in the geometric pitch angle of a few tenths of a degree.

3) Smoothly-blunted (rounded) trailing edges should be done with either te_def = 1 (aft-most point) or via a parabolic fit of the aft-most abs(te_def) points; the latter option is probably better in general but will require some experimentation for the particular case at hand to choose the optimal number of points over which to fit the parabola.

4) The leading edge is typically easier to determine, again assuming a good trailing edge position has already been found. The default value of le_def = +30 (search the 30 forward-most points for the one furthest from the trailing edge) should do a decent job for most cases.



Above: A sliced section, zoomed in to the leading edge region; the forward-most 20 segments (of the approx. 30 segments in this view) are shown in red. The computed leading edge locations using two different le_def values are shown. In this case, both results are fairly close but le_def = 30 has picked out the true leading edge (as judged from the LE geometry at zero pitch angle).

5) Given that the leading edge and trailing edge detection schemes can be somewhat finicky, for cases that rely on accurate resolution of forces and moments into section-aligned coordinates (e.g. rotorcraft), then it is wise to spend some time up front to make sure that things are coming out as expected. To do this, inspect the [project].sectional_forces file for a particular slice station; at each station the computed leading and trailing edge coordinates will be output. Plot the corresponding station from the [project]_slice.dat, as done above, and make sure the computed coordinates are the correct ones. If many stations are sliced, it is impractical to inspect all of them in this manner, but it is good practice to spot check at least a few stations. For moving-geometry cases, try first running the case with—body_motion_only. That will allow output of the [project].sectional_forces and [project]_slice.dat files without the expense of a flow solve or mesh deformation; for spot checking you may want to have the slicing done infrequently, and perhaps with fewer stations than ultimately desired, as these output files can be huge.

6) While the [project].sectional_forces can be useful for spot checking, the data in the file is not in a format that is amenable to plotting. The FUN3D/utils/Rotorcraft directory contains a utility code that will read in the [project].sectional_forces and slice.info files and output TECPLOT files, for each slice group, containing force/moment data in the section-aligned coordinate system, as well as geometry data (LE, TE, and quarter-chord coordinates, and pitch angle).

7) After making sure that the LE and TE positions are being computed correctly, you may want to turn off one or both of the [project].sectional_forces and [project]_slice.dat files unless needed. For instance, in rotorcraft applications with coupling to external CSD codes, although the blade boundary surfaces must be sliced to generate the aerodynamic loads data for the CSD code, this information is actually passed to the CSD code by another file; the [project].sectional_forces and [project]_slice.dat files are not used.

8) Although the slicing process will work for multi-element airfoils, at this time the computation of the LE and TE is only done for the entire section, not each element individually.

6.11. Individual Component Force Tracking

This section describes how to obtain force and moment history files of groups of boundaries.

This capability is available in Version 11.4 and higher.

This capability is not currently available for the Generic Gas Option.

Beginning with Version 11.4, all of the options below may be used with the `&component_parameters` namelist within the `fun3d.nml` file. This will allow generation of individual tracking of groups of boundaries and is activated with the command line option of `--track_group_forces`..

General Information
Namelist Format

General Information

The individual component forces contain the three forces and moments and forces for each grouping of boundaries in addition to massflow, average velocity and pressure when requested.

The resulting component history files will have the following naming convention:

```
[project]_[component_name]_component.dat
```

and are written to every iteration the same as the [project]_hist.dat file. The files are in TECPLOT format.

By default, the variables that are output are

```
Iteration       [iteration number]
C<sub>x</sub>   [axial force]
C<sub>y</sub>   [lateral force]
C<sub>z</sub>   [normal force]
C<sub>M,x</sub> [moment around x-axis]
C<sub>M,y</sub> [moment around y-axis]
C<sub>M,z</sub> [moment around z-axis]
```

For flow-through boundaries,

```
Mass flow                    [mass flow through the boundary]
<greek>r</greek>             [average density]
u                            [average velocity]
p/p<sub>0</sub>              [average normalized pressure]
T                            [average temperature]
p<sub>t</sub>/p<sub>0</sub> [average normalized total pressure]
T<sub>t</sub>                [average total temperature]
Mach                         [average Mach number]
```

are also calculated and written to the component history file. All flow-through quantities are area-weighted averages.

Namelist Format

number_of_component	Number of groupings of boundaries to be output (G) (Default: 0)
component_count	Number of boundaries to be grouped.(S) (Default: 0)
component_input	String containing the boundary numbers for the group (S) (Default: none [blank string])
component_name	Name of component grouping (S) (Default: none [blank string])
allow_flow_through_faces	Allows calculation of flow-through quantities. (G) (Default: .false.)

NOTE: Flow through boundaries, including but not limited to 7011 (subsonic_inflow_pt), 5051 (back_pressure), 5052 (subsonic_outflow_mach), 7031 (massflow_out), 7036 (massflow_in) require `allow_flow_through_forces` to be set to .true. if mass flow and other average flow quantities are to be calculated..

In the example below, data are gathered for four groupings of boundaries;

```
 &component_parameters
  number_of_components=4
  component_count(1)=9
  component_input(1)='1,2,3,4,5,6,7,8,9'
  component_name(1)='airplane'
!
  component_count(2)=2
  component_input(2)='2,3'
  component_name(2)='wing'
!
  component_count(3)=3
  component_input(3)='4,5,6'
  component_name(3)='engine1'
!
  component_count(4)=3
  component_input(4)='7,8,9'
  component_name(4)='engine2'
  allow_flow_through_forces = .true.
```

```
/
```

6.12. Static Grid Transforms

Occasionally the situation arises in which a grid is in hand, but the orientation of the grid is inappropriate for the desired simulation. In such a situation, a static-grid transform may be applied to the grid before the flow solution is started. The original grid file is ***not*** changed by this transform – the same input/command line options for transformation must be applied for any subsequent restarts.

To invoke a static transform, the command line option `--grid_transform` must be specified. In addition, details of the transform must be prescribed in the `fun3d.nml` file via the `grid_transform` namelist.

&grid_transform namelist

ds	Displacement magnitude for translation (Default: 0.0)
sx	X-component of unit vector along translation axis (Default: 1.0)
sy	Y-component of unit vector along translation axis (Default: 0.0)
sz	Z-component of unit vector along translation axis (Default: 0.0)
theta	Rotation angle (degrees) (Default: 0.0)
tx	X-component of unit vector along rotation axis (Default: 1.0)
ty	Y-component of unit vector along rotation axis (Default: 0.0)
tz	Z-component of unit vector along rotation axis (Default: 0.0)
scale	Scale factor applied to grid (Default: 1.0)
transform	4×4 transform matrix as a means to specify more general transforms than can be accommodated by the parameters listed above; specification of a transform matrix (except for an identity matrix) supersedes all other variables in the namelist (Default: identity matrix)

The transform matrix is described on pp 6-7 in the paper Recent Enhancements To The FUN3D Flow Solver For Moving-Mesh Applications The 4th row of the matrix should always be (0,0,0,1).

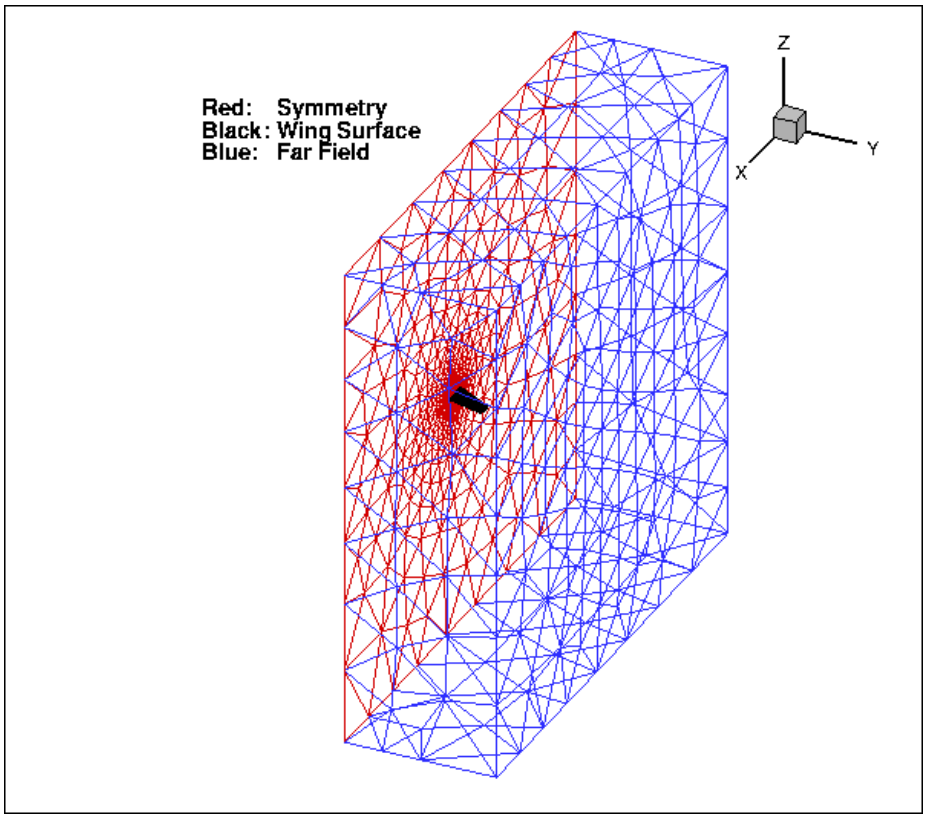
Rotations direction follows the right-hand rule along the rotation axis.

When specifying a static grid transform, the user should be cognizant of potential boundary condition issues, particularly with regard to symmetry conditions. If symmetry conditions are used, possible rotations are limited. For example, if a standard wing grid with a y=constant symmetry plane at the wing root (with BC 6662) is pitched about the y-axis, the symmetry condition is unchanged. However, if that same grid is rotated about the x-axis, by say, 30 degrees, then what was a y-constant plane is no longer on a constant-coordinate plane, and the code will fail. However, if the rotation was instead 90 degrees, then the y=constant plane would become a z=constant plane, for which the appropriate BC is 6663. In such a situation, where one type of constant-coordinate symmetry plane becomes another constant-coordinate symmetry plane, the flow solver will automatically swap the BCs. These situations require that precise +/- 90 degree rotations be specified.

A static transform may also be combined with the mirroring options to obviate some types of symmetry-plane issues. Mirroring is applied first (removing the symmetry plane), after which the mirrored grid is transformed.

For example, the 30 degree roll case described above could be accommodated with `--grid_transform --mirror_y` and the appropriate namelist data.

Original grid

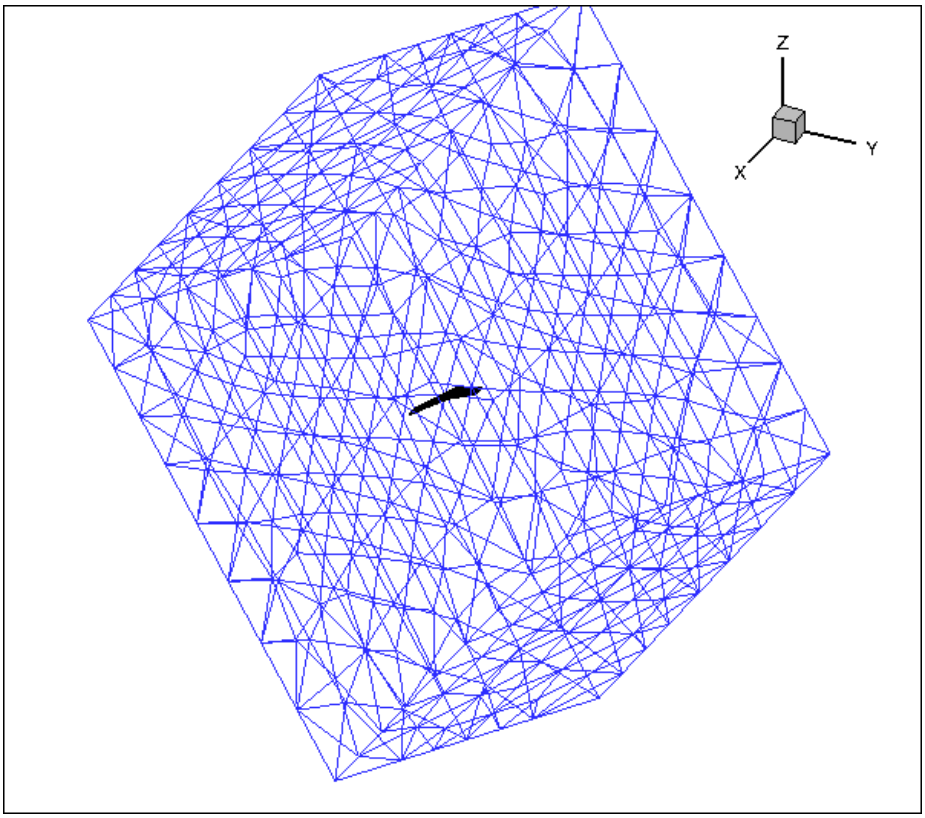


After mirroring and rotation using either

```
&grid_transform
 theta = 30.0
 tx = 1.0
 ty = 0.0
 tz = 0.0
/
```

or, directly specifying the transform matrix

```
&grid_transform
 transform(1,1) =  1.0
 transform(1,2) =  0.0
 transform(1,3) =  0.0
 transform(1,4) =  0.0
 transform(2,1) =  0.0
 transform(2,2) =  0.86602540E+00
 transform(2,3) = -0.5
 transform(2,4) =  0.0
 transform(3,1) =  0.0
 transform(3,2) =  0.5
 transform(3,3) =  0.86602540E+00
 transform(3,4) =  0.0
 transform(4,1) =  0.0
 transform(4,2) =  0.0
 transform(4,3) =  0.0
 transform(4,4) =  1.0
/
```



6.13. Noninertial Reference Frame

FUN3D can perform simulations in noninertial reference frame rotating at a constant rate. In addition to the constant rotation rate, the problem to be simulated must be one in which the freestream velocity is either 1) zero or 2) parallel to the axis of rotation. Within these constraints, the simulation in the noninertial reference frame can be run as a steady state problem. In contrast, using the standard, inertial reference frame would require the same problem to be run as an unsteady simulation, with the associated larger computational cost. The constraints mean use of the noninertial reference frame is fairly limited in scope. Typical uses would be the simulation of an isolated rotor in either hover or ascending/descending flight (no forward motion), or an aircraft performing a constant-rate roll about the wind axis.

Note that when using a noninertial reference frame, one must often specify an **alternate freestream condition**

Running A Noninertial Reference Frame Solution In FUN3D

To perform a simulation in a rotating noninertial reference frame, one or more command-line options are required. The optional command-line input specifies (up to) three components for the rotation vector, and (up to) three coordinates for the center of rotation. The default values for any component/coordinate not specified is zero.

The rotation vector may be specified using one or more of the following command-line options:

`--xrotrate_ni` xvalue (x-component of the rotation vector; default: 0.0)
`--yrotrate_ni` yvalue (y-component of the rotation vector; default: 0.0)
`--zrotrate_ni` zvalue (z-component of the rotation vector; default: 0.0)

The square root of xrotrate_ni$^{2\text{^} + \text{yrotrate_ni}}$2^ + zrotrate_ni^2 gives the nondimensional rotation rate (ignoring the RedCloth formatting nonsense, this should read as the sum of squares). The sense of the rotation follows the right-hand rule.

Note: for the noninertial reference frame to be utilized, at least one of the rotation vector components must be specified as nonzero.

The nondimensional rotation rate can be determined by following the information near the bottom of p. 24 in April 2010 Training Workshop notes on Time-Dependent and Dynamic-Mesh Simulations

The rotation vector passes through an origin whose coordinates are specified using one of more of the following command-line options:

`--xrotcen_ni` xvalue (x-coordinate of the rotation vector; default: 0.0)
`--yrotcen_ni` yvalue (y-coordinate of the rotation vector; default: 0.0)
`--zrotcen_ni` zvalue (z-coordinate of the rotation vector; default: 0.0)

These values are specified in terms of grid coordinates.

As an example, suppose you have a rotor in hover, rotating about the z-axis, with a nondimensional rotation rate of 0.00272. Then all that is required to specify the noninertial rotation is the command-line:

```
--zrotrate_ni 0.00272
```

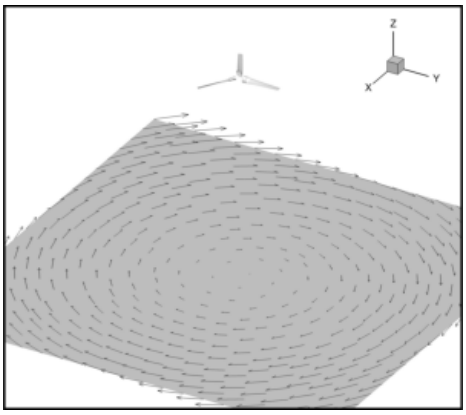
This minimal input takes advantage of the zero defaults for all noninertial data that is not explicitly specified.

If the same rotation vector was desired, but with the rotation centered about a point x=0.25 y=0.75 in the x-y plane, use the command line:

```
--zrotrate_ni 0.00272 --xrotcen_ni 0.25 --yrotcen_ni 0.75
```

(the center of rotation in the z direction is immaterial for rotations about an axis parallel to the z-axis, so the implied default 0 is used)

If the solution from a noninertial case is output for viewing, the **relative velocities in the noninertial frame** are output to the file (assuming you choose to output the velocity components). Thus, the output velocity will be zero on solid surfaces, and on farfield boundary surfaces will have an opposite sense to the direction of rotation in inertial space, as illustrated below on an outflow plane for a rotor with a counterclockwise rotation about the z-axis when viewed from above.



Specifying an Alternate Freestream Condition

In **FUN3D**, by default the freestream conditions (velocity components) for compressible flow are set by the Mach number, angle of attack, and yaw angles specified in the `fun3d.nml` file. For compressible flows, an input Mach number of 0 will quickly lead to numerical disaster, since the viscous terms scale inversely with Mach number (for incompressible flow, scaling does not depend on the Mach number). Likewise, the unit Reynolds number should correspond to the velocity associated with the input Mach number.

Consider a rotor in hover. In this case the freestream velocity is zero, but if we are running a compressible simulation, we cannot have an input Mach number of zero. In addition, the corresponding unit Reynolds number should not be based on zero velocity.

The solution is to base the input Mach number on a more sensible velocity, say the rotor tip speed (and base the unit Reynolds number on this same reference speed). Since we still need zero velocity in the freestream, the `--alternate_freestream` command line option is used to override the freestream velocity corresponding to the input Mach number:

```
--alternate_freestream 0.0
```

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