Session 12:
Overset and Rotorcraft Simulations

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Learning Goals

- What this will teach you
  - Static and dynamic simulations using overset meshes (general)
  - Overview of setup for overset, articulated-blade rotorcraft simulations
    - Rigid Blades
    - Elastic Blades / Loose Coupling to Rotorcraft Comprehensive Codes
  - Overview of actuator-disc models for rotorcraft (not overset)
- What you will not learn
  - Rotorcraft Comprehensive Code set up and operation
  - SUGGAR++ operation (Ralph Noack will cover tomorrow)
- What should you already know
  - Basic time-accurate and dynamic-mesh solver operation and control
  - Rudimentary rotorcraft aeromechanics (collective, cyclic…)

Part I – Overset Simulations

Setting

- Background
  - Many (most?) moving-body problems of interest involve large relative motion - rotorcraft, store separation are prime examples
    - Deforming meshes can accommodate only limited relative motion before mesh degenerates
    - Single rigid mesh can accommodate only one body, and not relative motion
    - Use overset grids to overcome these limitations - not to overcome complex geometry per se – that's why we use unstructured grids!
- Compatibility
  - FUN3D requires both DiRTlib and SUGGAR++ codes from PSU
  - Grid formats: VGRID, AFLR3, FieldView (FV)
- Status
  - AFLR3 and FieldView meshes not exercised much to date
  - Bodies in contact / emerging bodies - no near-term plans

Overset Mesh Simulations – General (1/3)

- Configuring FUN3D (*only as a reminder, except to note compile scripts*)
  - Compile / install DiRTlib and SUGGAR; available scripts (download from FUN3D website) make it easy
  - When configuring FUN3D, use **`--with-dirtlib=/path/to/dirtlib`** and **`--with-suggar=/path/to/suggar`**
  - FUN3D will expect to find the following libraries in those locations:
    - **`libdirt.a, libdirt_mpich.a`** and **`libp3d.a`** (these may be soft links to the actual serial and mpi builds of DiRTlib)
    - **`libsuggar.a`** and **`libsuggar_mpi.a`** (may be soft links)
    - Scripts do this automatically – they put links to all archives in one spot, so **`/path/to/dirtlib = /path/to/suggar`**
- Grids (remember z is "up" for FUN3D)
  - A *composite* overset grid is comprised of 2 or more *component* grids - independently generated - but with similar cell sizes in the fringe areas
  - SUGGAR++ is used to create the composite mesh

Overset Mesh Simulations – General (2/3)

- Boundary conditions:
  - SUGGAR++ needs BC info for each *component* grid - set either via the SUGGAR++ input XML file OR an auxiliary file for each *component* grid; SUGGAR++ will output this auxiliary file for the *composite* mesh
  - FUN3D also needs BC info for the *composite* grid; depending on grid type, file names / content may differ slightly between FUN3D / SUGGAR

	VGRID grid	FV grid	AFLR3 grid
FUN3D	grid.mapbc (standard VGRID file)	grid.mapbc (***not*** same as VGRID)	grid.mapbc (***not*** same as VGRID)
SUGGAR++	grid.mapbc (standard VGRID file)	grid.ext.suggar_mapbc (***not*** same as VGRID)	grid.ext.suggar_mapbc (***not*** same as VGRID)

  - "ext" is the FUN3D grid extension, e.g.: grid.fvgrid_fmt, grid.r8.ugrid
  - AFLR3 / FV grids: suggar_mapbc file has extra column; FUN3D ignores

```
3                           ! number of boundaries (patches)
1 5000 Box         farfield ! patch_index, fun3d_bc, family_name, suggar_bc
2 4000 Wing_Surf   solid
3 -1   Wing_FarFld overlap
```

Overset Mesh Simulations – General (2/3)

- Boundary conditions (cont):
  - set BC type to -1 in component-grid "mapbc" files for boundaries that are set via interpolation from another mesh

Grid Courtesy Eric Lynch, GA Tech

Overset Mesh Simulations – General (3/3)

- Create an XML input file for SUGGAR++
  - Ralph Noack will provide *all* the details tomorrow; however must show some XML here to show certain FUN3D-specific points
  - Set the name for the **<composite_grid>** and **<domain_connectivity>** files to the name of your FUN3D project
  - Can mix and match component grid types (VGRID, FV, AFLR) and select one of the types for the composite grid - but recall VGRID only supports tetrahedra
- Run SUGGAR++ and make sure it all works as expected. You should now have a **`[project].dci`** file; this <u>**d**</u>omain <u>**c**</u>onnectivity <u>**i**</u>nformation file contains all necessary overset data for solver interpolation between the nonmoving component meshes
- Good idea to use the “gviz” tool from PSU to view composite mesh assembly, holes points, fringe points, etc.

Overset Mesh Simulations – Static (1/2)

- Running FUN3D with static overset meshes:
  - Add **`--overset`** to any other CLOs you may have and run as usual
  - In screen output, should see:

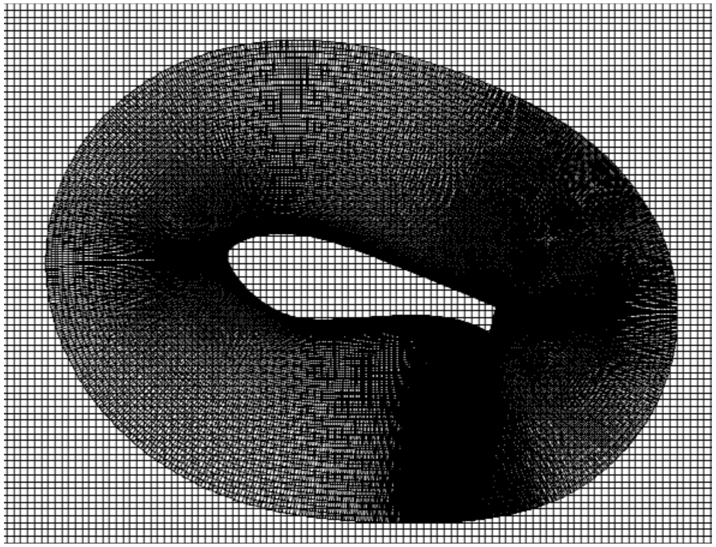
```
Reading DCI data:  ([project].dci)
Loading of dci file header took Wall …
Opening filename:      ([project].g21) (repeated nproc times !)
Loading of dci file took Wall Clock time = 5.324230 seconds
Using DiRTlib version 1.40 for overset capability
DiRTlib developed by Ralph Noack, Penn State University Applied Research
Laboratory
```

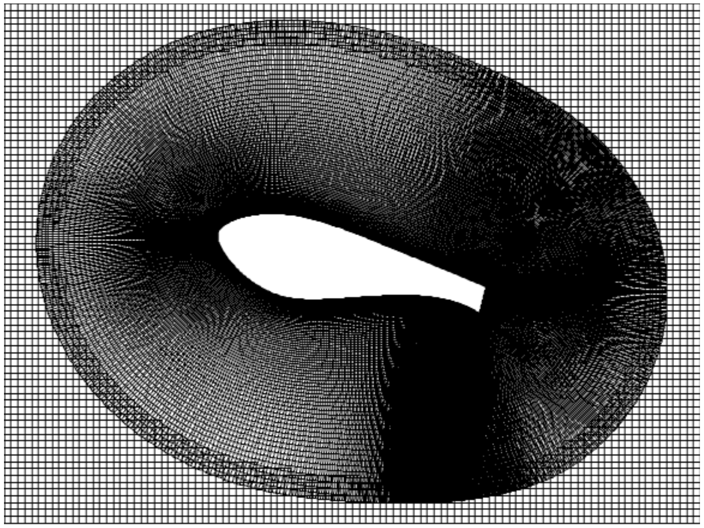
  - Followed by the usual FUN3D output, ending with **`Done.`**
  - If you request visualization output data for an overset case, "iblank" data will automatically be output to allow blanking of the hole / out points for correct visualization of the solution / grid in Tecplot

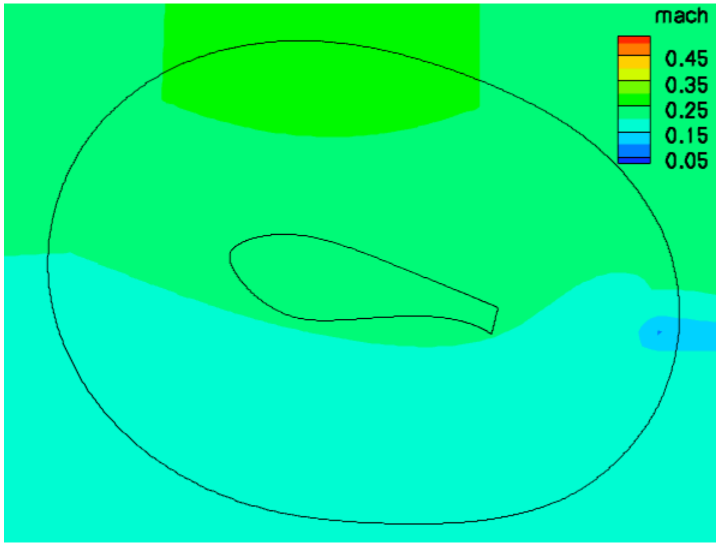
Overset Mesh Simulations – Static (2/2)

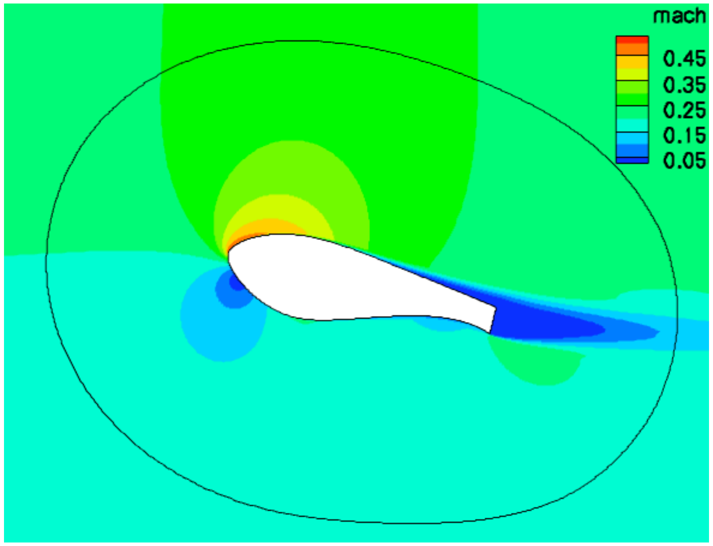
without iblank

with iblank









Overset Mesh Simulations – Dynamic (1/4)

- SUGGAR++ setup
  - Starting with a static-grid XML file:
    - Add **`<dynamic/>`** to **`<body>`** elements that are to move, e.g.

```
<body name="wing">
  <volume_grid name="wing" style="vgrid_set" filename="wing"/>
</body>
<body name="store">
  <dynamic/>
  <volume_grid name="store" style="vgrid_set" filename="store"/>
</body>
```

    - Note: better to use a self-terminated **`<dynamic/>`** rather than **`<dynamic>`** … **`</dynamic>`** since if there are any **`<transform>`** elements in between, SUGGAR++ won't apply them unless explicitly told to
  - Use SUGGAR++ to generate the initial (t = 0) composite grid; let's assume you called the XML file **`Input.xml_0`**

Overset Mesh Simulations – Dynamic (2/4)

- In the FUN3D **`moving_body.input`** file
  - Define the bodies and specify motion as usual; boundary numbers correspond to those in the *composite* mesh mapbc file, accounting for any boundary lumping that may be selected at run time
  - use the component body names from the **`Input.xml_0`** file
  - Add name of the xml file used to generate the t = 0 composite mesh:

```
&composite_overset_mesh
  input_xml_file = 'Input.xml_0'
/
```

- Running FUN3D
  - Use CLOs **`--overset --moving_grid --dci_on_the_fly`**
  - The last tells FUN3D to call libSUGGAR++ routines to compute new overset data when the grids are moved; if this CLO is not present, solver will try to read the corresponding dci file from disk

Overset Mesh Simulations – Dynamic (3/4)

- Running FUN3D (cont)
  - Note: for dynamic meshes, the *component* grids (and any "suggar_mapbc" files) must be available (can be soft linked) in the FUN3D run directory, in *addition* to the t = 0 *composite*-grid files
  - When using **`--dci_on_the_fly`**, must specify *one* additional processor for SUGGAR++ (in future, will be able to use more)
    - The *first* processor gets assigned the SUGGAR++ task
    - *This processor must have enough memory for entire overset problem* (same as needed for SUGGAR++ alone)
  - Other overset-grid CLOs

`--dci_period N` periodic motion over N steps (default **`0`**)

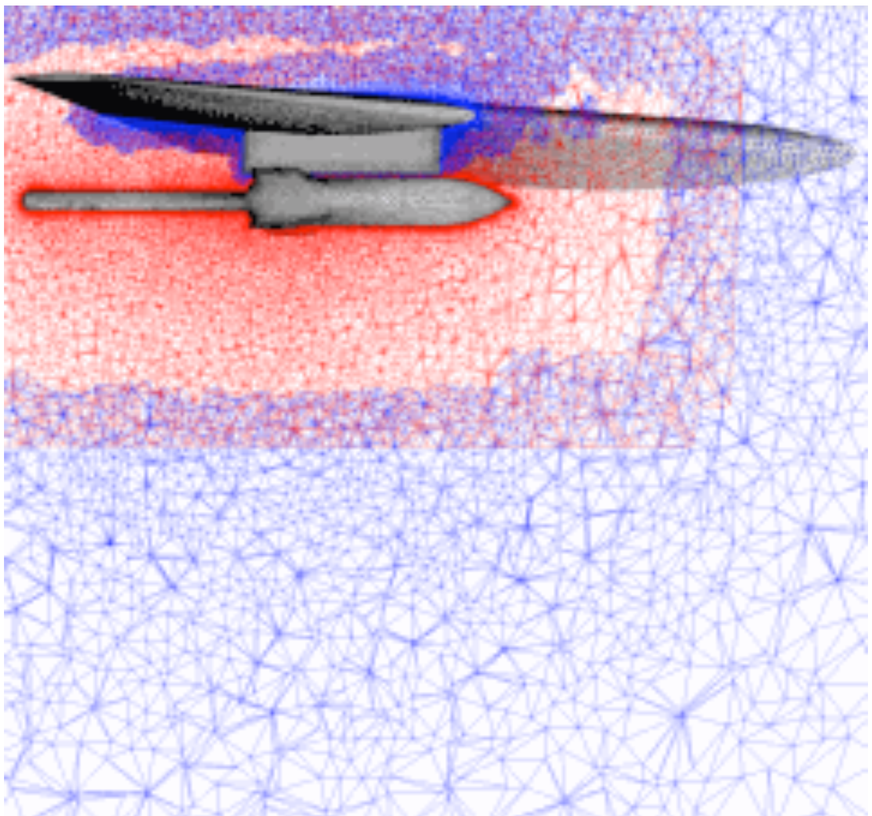
`--dci_freq N` compute dci data only every N^{th} step (**`1`**)

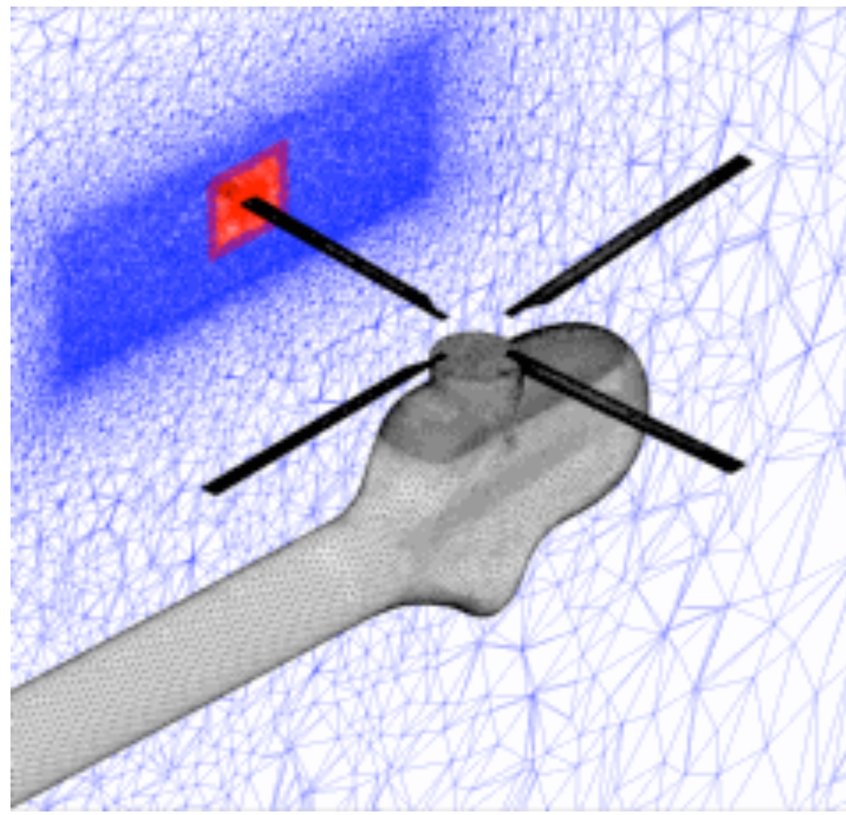
`--reuse_existing_dci` use existing files if present, even with **`--dci_on_the_fly`** (**`.F.`**)

`--grid_motion_and_dci_only` create dci files; no flow solve (**`.F.`**)

Overset Mesh Simulations – Dynamic (4/4)

- As always, can use animation to verify; these were done ex post facto, but GVIZ has motion replay options too





Part II – Rotorcraft Simulations

Trained Professionals. Closed Course. Do Not Attempt At Home.

Setting

- Background
  - FUN3D can model a rotor with varying levels of fidelity/complexity
    - As an actuator disk - when only the overall rotor influence is needed
    - As rotating, articulated-blade system (cyclic pitch, flap, lead-lag), with or without aeroelastic effects - if detailed airloads are needed
      - Trim and aeroelastic effects require coupling with a rotorcraft “comprehensive” code
    - As a steady-state problem for rigid, isolated, fixed-pitch blades in a rotating noninertial frame (not covered here)
- Compatibility
  - Coupling to the CAMRAD comprehensive code; other codes usable with appropriate middleware (not supplied)
- Status
  - Coded for multiple rotors, but largely untested
  - Only “loose” (periodic) coupling incorporated to date
  - *Still an emerging capability; expect changes*

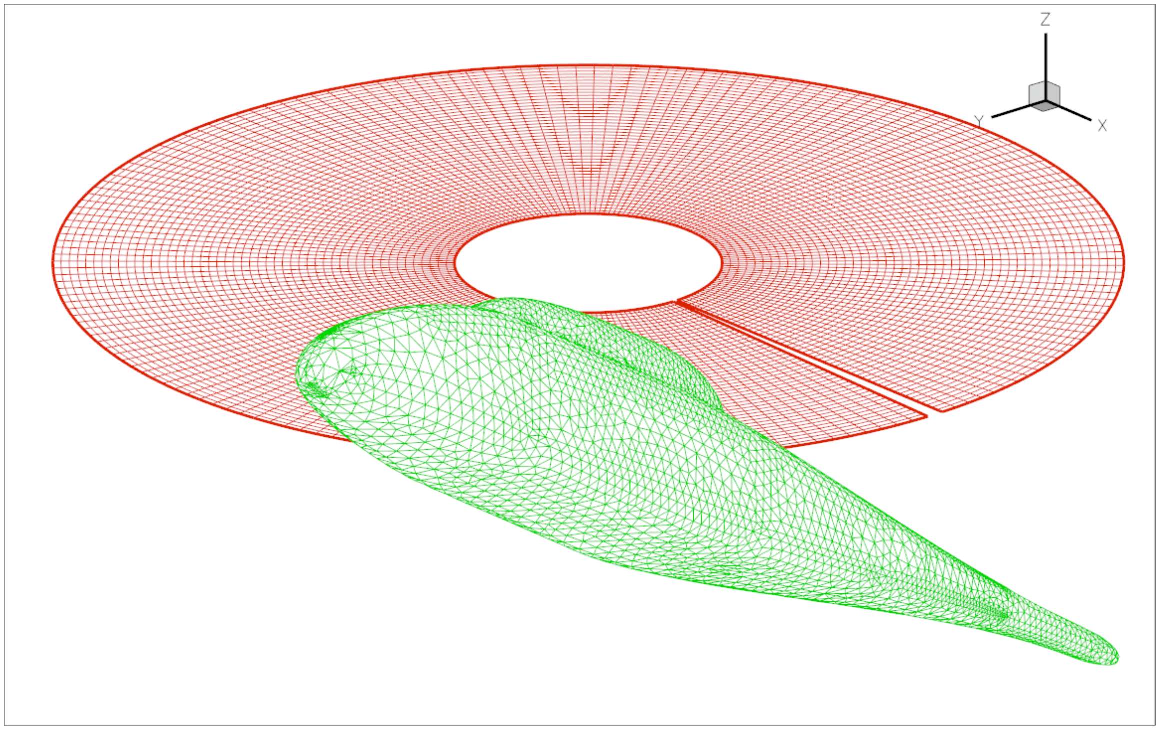
Time-Averaged Actuator-Disk Simulations (1/2)

- Actuator disk method utilizes momentum/energy source terms to represent the influence of the disk (pressure jump)
  - Original implementation by Dave O’Brien (GIT Ph.D. Thesis)
  - HI-ARMS implementation (SMEMRD) by Dave O’Brien ARMDEC adds trim and ability to use C81 airfoil tables (*Not covered in training*)
- Simplifies grid generation – disk is embedded in computational grid (note some refinement in the vicinity of actuator surface needed for accuracy - but, Dave O’Brien recommends that delta-s of grid > delta-s disk)
- Any number of actuator disks can be modeled
- Different disk loading models available
  - **`RotorType = 1`** actuator disk
    - **`LoadType = 1`** constant (specified thrust coefficient C_T)
    - **`LoadType = 2`** linearly increasing to blade tip (specified C_T)
    - **`LoadType = 3`** blade element based (computed C_T)
  - **`RotorType = 2`** actuator blades (time-accurate) **Not Functional**

Time-Averaged Actuator-Disk Simulations (2/2)

- Actuator disk implementation runs orthogonal to the standard steady-state flow solver process (compressible and incompressible)
  - Standard input grid formats for the volume grids
  - Standard solver input deck (**`fun3d.nml`**)
  - Standard output is available (**`project.forces`**, **`project_hist.tec`**, **`project_tec_boundary.plt`**)
  - Want to see similar solution convergence as for a standard steady-state case
- Actuator disk model is activated in the command line by **`mpirun nodet_mpi --rotor`**
  - Rotor input deck file (**`rotor.input`**) is required in the local directory
  - **`rotor.input`** contains disk geometry and loading specifications
  - The disk geometry and loading are output in plot3d format in files **`source_grid_iteration#.p3d`** and **`source_data_iteration#.p3d`**

Incompressible Robin/Actuator Disk



Advance Ratio = 0.051 (Vinf/Vtip)
Thrust coefficient C_T = 0.0064
Angle of attack = 0 deg
Shaft angle = 0deg

`rotor.input` File

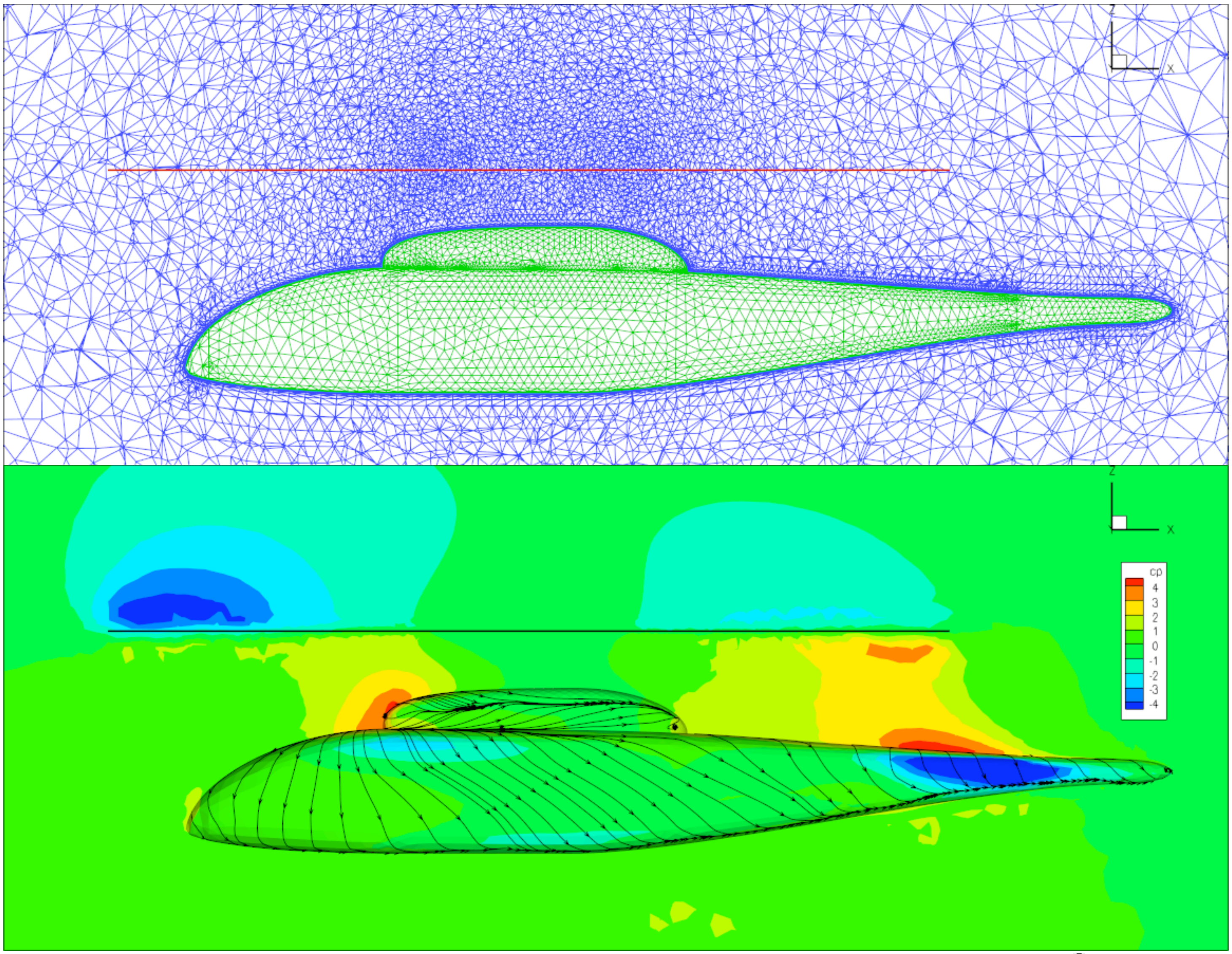
- Constant/linear loading needs only a subset of the data in the file

```
  # Rotors   Uinf/Uref  Write Soln  Force Ref  Moment Ref    ! Below we set Uref = Uinf
         1      1.000        1500   0.001117    0.001297    ! Adv Ratio = Uinf/Utip
=== Main Rotor =============================================  ! So here Utip/Uref = 1/AR
Rotor Type  Load Type    # Radial   # Normal  Tip Weight
         1          2          50        180         0.0
  X0_rotor   Y0_rotor    Z0_rotor       phi1        phi2        phi3
     0.696        0.0       0.322       0.00        -0.0        0.00
 Utip/Uref ThrustCoff   PowerCoff       psi0 PitchHing/R      DirRot
     19.61     0.0064       -1.00        0.0         0.0           0
  # Blades  TipRadius  RootRadius BladeChord FlapHinge/R LagHinge/R
         4      0.861       0.207      0.066       0.051       0.051
 LiftSlope  alpha, L=0        cd0        cd1         cd2
       0.0       0.00       0.002       0.00        0.00
    CL_max     CL_min      CD_max     CD_min       Swirl
      0.00       0.00        0.00       0.00           0
    Theta0 ThetaTwist    Theta1s    Theta1c   Pitch-Flap
       0.0       0.00         0.0        0.0        0.00
 # FlapHar      Beta0      Beta1s     Beta1c
         0        0.0         0.0        0.0
    Beta2s     Beta2c      Beta3s     Beta3c
       0.0        0.0         0.0        0.0
  # LagHar     Delta0     Delta1s    Delta1c
         0        0.0         0.0        0.0
   Delta2s    Delta2c     Delta3s    Delta3c
      0.0         0.0         0.0        0.0
```

Key:
Required for constant loading
Required for blade element
Not implemented
(all must have a values)

- Note Vref=Vtip is bad choice for incompressible flow - suggest using rotor induced velocity

Incompressible Robin/Actuator Disk



Things To Look For In Screen Output

- If Force_ref = $1/(Vtip/Vref)^2/(\pi R^2)$ and
  Moment_ref= $1/(Vtip/Vref)^2/(\pi R^3)$

  Rotor force summary in standard output:

```
Rotor Force Summary:
  Rotor  1   Grid Forces:Fx=  0.0000E+00Fy=  0.0000E+00Fz=  6.4008E-03
  Rotor  1  Grid Moments:Mx= -1.5898E-17My=  8.6398E-18Mz=  0.0000E+00
  Rotor  1  Shaft Forces:H =  0.0000E+00Y =  0.0000E+00T =  6.4008E-03
  Rotor  1 Shaft Moments:Mh= -1.5898E-17My=  8.6398E-18 Q=  0.0000E+00
```

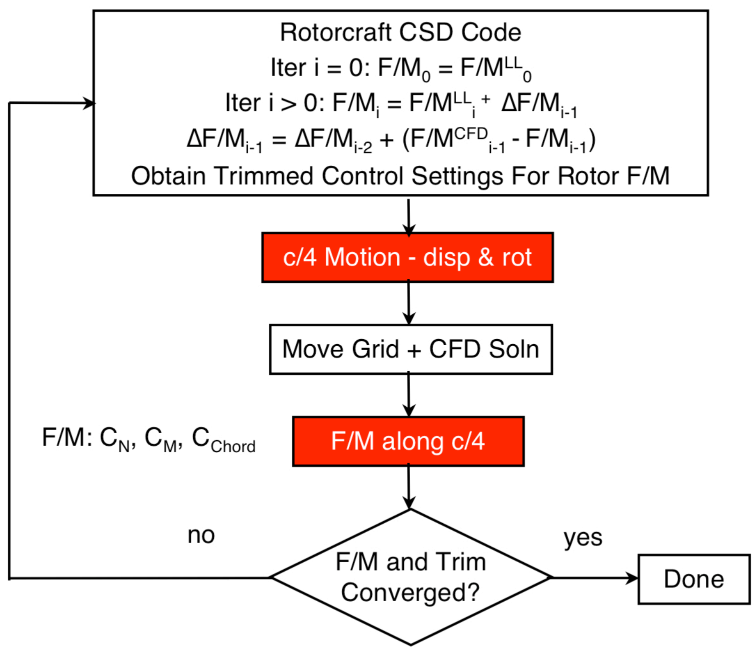
- Note that the force coefficients in project.forces and project_hist.tec are flow boundary forces only (no actuator disk forces) which have been normalized in the fixed wing fashion

Articulated-Blade Simulations

- Relies on the use of overset grids; blades may be rigid or elastic
- Elastic-blade cases (or *trimmed* rigid-blade cases) must be coupled to a rotorcraft Computational Structural Dynamics (CSD, aka comprehensive) code such as CAMRAD, DYMORE, RCAS…
  - The CSD code provides trim solution in addition to blade deformations
  - The interface to the CSD code is through standard OVERFLOW **`rotor_N.onerev.txt`** and **`motion.txt`** type files
  - Interface codes (middleware) for CAMRAD are maintained and distributed by Doug Boyd, NASA Langley (d.d.boyd@nasa.gov)
  - FUN3D has several postprocessing utility codes tailored to CAMRAD
- A coupled elastic-blade simulation is about as complicated as it gets with the FUN3D flow solver
  - There are *many* small details that must be done correctly; we don't have time to cover them all here
  - Novice users of FUN3D will want to start with simpler problems!

CFD/CSD – Loose (Periodic) Coupling

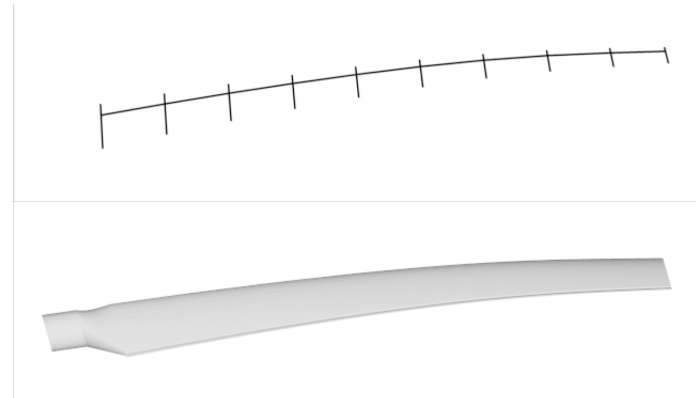
Coupling Process



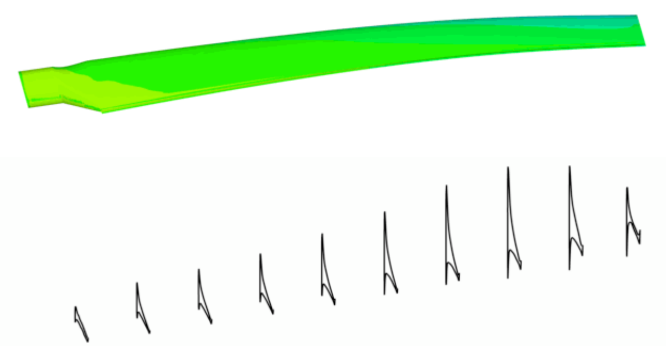
motion.txt and rotor_onerev.txt files common to FUN3D and OVERFLOW

CFD/CSD loose coupling implemented via shell script with error checking

CSD -> CFD



CFD -> CSD

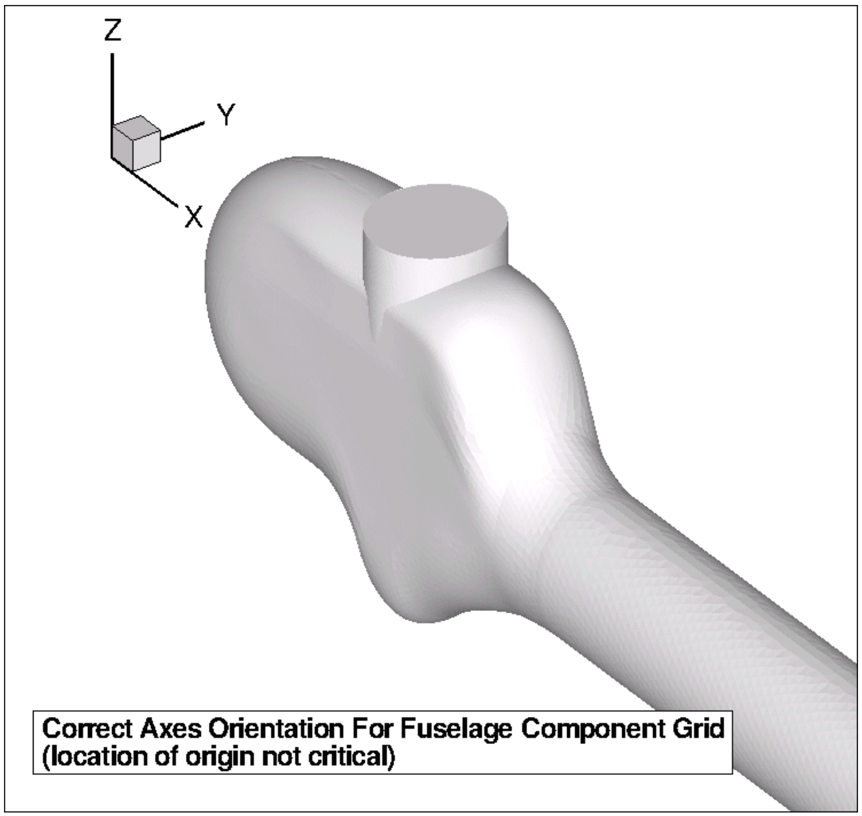


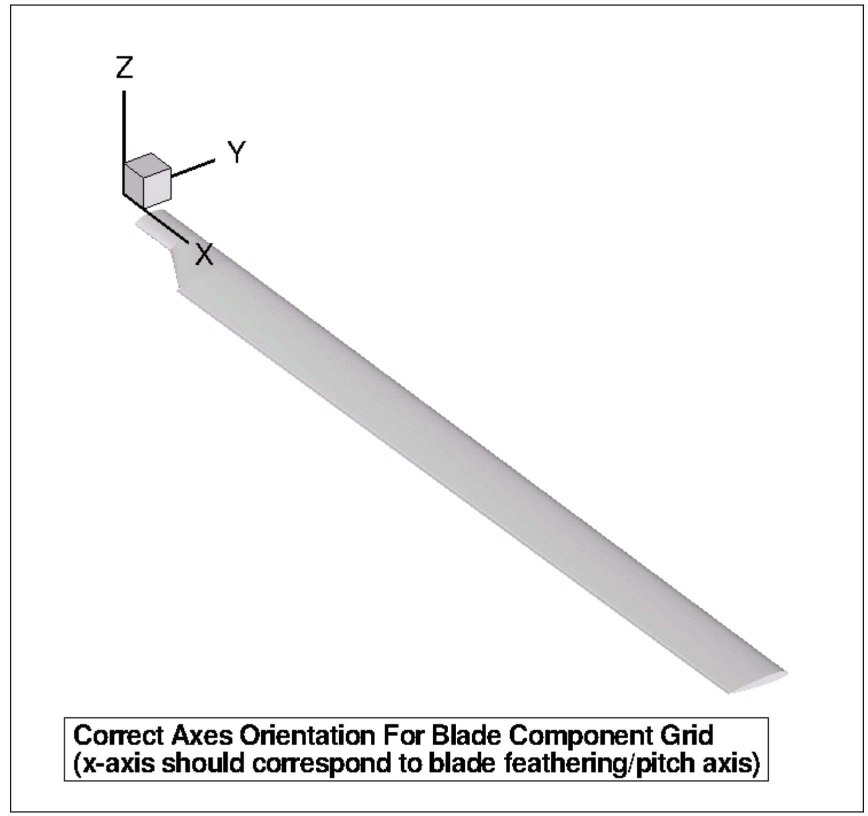
`dci_gen` Preprocessor (1/8)

- A rudimentary code to simplify rotorcraft setup (/utils/Rotocraft/dci_gen)
  - Uses libSUGGAR++ routines
  - Takes a single blade grid and a single fuselage / background grid (extending to far field) and assembles them into an N-bladed rotorcraft
  - Creates the SUGGAR++ XML file (**`Input.xml_0`**) needed by FUN3D
  - Generates, using libSUGGAR++ calls, the initial (t = 0) dci file and composite grid needed by FUN3D
  - Generates the composite-grid "mapbc" files needed by FUN3D
  - Component grids *must* be oriented as shown on following slide
    - Blade must have any "as-built" twist incorporated
    - If grids do not initially meet the orientation criteria, can use SUGGAR++ to rotate them *before* using **`dci_gen`**
- Don't *have* to use **`dci_gen`**; could create the XML file by hand and run SUGGAR++; a more complex setup could start with **`dci_gen`**, hand edit the resulting XML file, then follow with SUGGAR++

`dci_gen` Preprocessor (2/8)

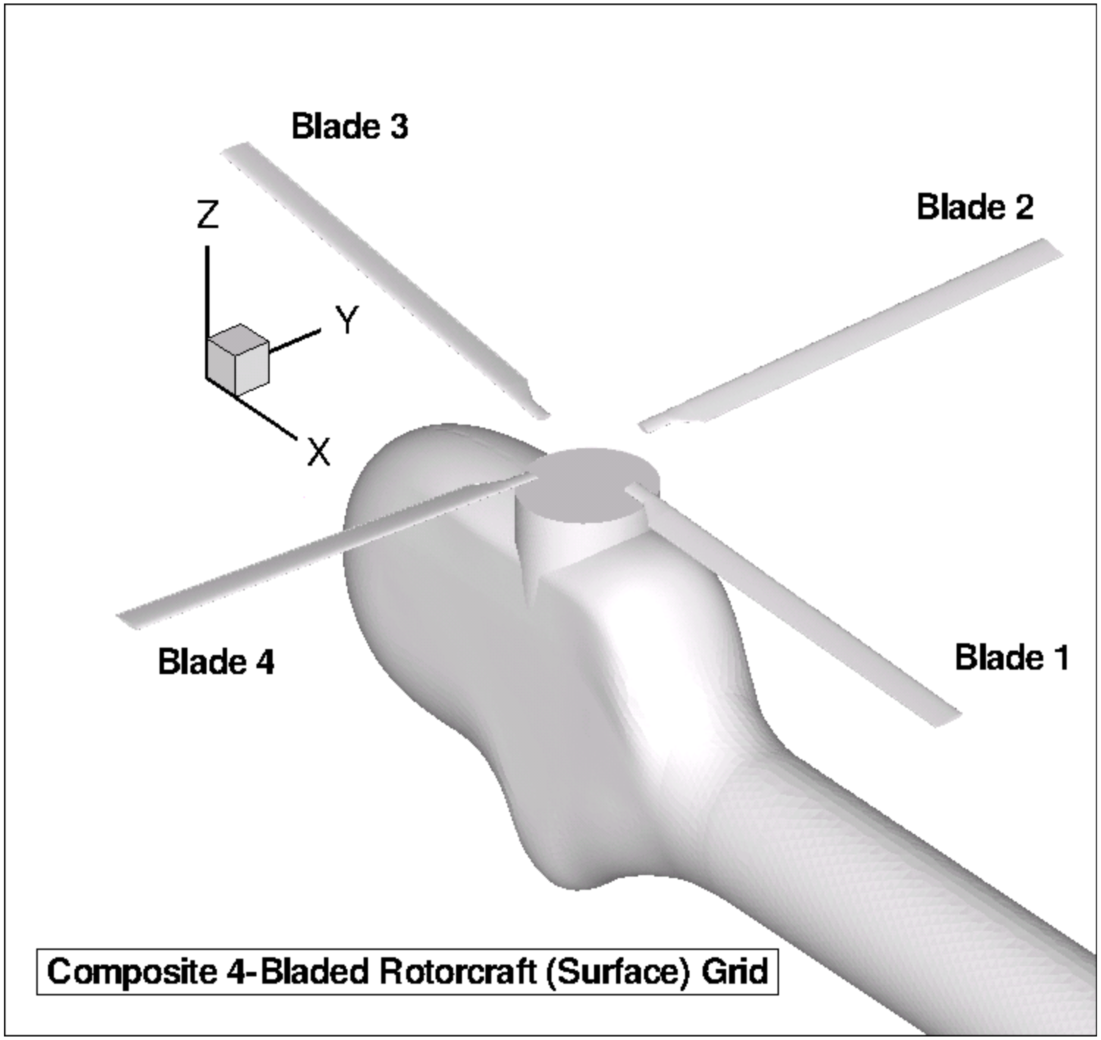
HART II *Component* Grids





`dci_gen` Preprocessor (3/8)

HART II *Composite* Grid



dci_gen Preprocessor (4/8)

- Requires the **rotor.input** file (also required by flow solver - more later)
- Creates the initial composite mesh with the blades at *zero collective, zero cyclic, zero flap*; however, the rotor is tilted according to **phi2** (shaft tilt); resulting mesh and dci file can then be used for multiple flight conditions
- FUN3D will "pop" the blades into the correct t = 0 position at the start of simulation, based either on the collective, cyclic, etc. data in **rotor.input** (rigid) or on the data in the **"motion.txt"** file (elastic)
- For *rigid, untrimmed* blades, **rotor.input** gives a complete definition of the blade motion - **dci_gen** can create dci data for *all* blade positions a priori; this can be done in "embarassingly parallel" manner, faster than can be done from within the flow solver
- **dci_gen** will prompt the user for input; example next slide
- **dci_gen** will read (if present) a file called **manual_hole_commands** that can be used to add problem-specific additional XML commands to aid the computation of overset connectivity data

dci_gen Preprocessor (5/8)

- Usage: **./dci_gen** first echos **rotor.input**, then prompts for input:

```
Enter a project name: (e.g. robin)
uh60_alw_isolated_c2_ft
Enter the name of the fuselage grid: (e.g. robin_fuse)
empty_box_coarse2_uh60_ft
Enter the type of fuselage/background grid: vgrid, aflr3, or fvuns
aflr3
Is this grid formatted (enter f) or unformatted (enter u)
f              ! This question NOT asked if type = vgrid
Is this grid single precision (enter s)or double precision (enter d)
d              ! This question NOT asked if type = vgrid
For multiple rotors, the first rotor should be the main rotor
Additional rotors spin with gear ratios relative to rotor 1
Enter the name of the blade grid for rotor 1: (e.g. robin_blade)
uh60_alw_blade_tab_c2_t2_ft
Enter the type of blade grid: vgrid, aflr3, or fvuns
aflr3
Is this grid formatted (enter f) or unformatted (enter u)
f              ! This question NOT asked if type = vgrid
Is this grid single precision (enter s)or double precision (enter d)
d              ! This question NOT asked if type = vgrid
Enter initial psi, final psi, and psi increment values for the first rotor
0.0 0.0 1.0    ! Just initial azimuth - elastic blades
```

`dci_gen` Preprocessor (6/8)

- After data summary and echo of XML commands, should see:

```
*** Computing DCI data
*** Finished DCI file: uh60_alw_isolated_c2_ft.dci

psi(rotor 1) =    0.0000

 Orphan Info:
   Found      0 orphans because of hole cut failures
   Sort added 0 orphans because of poor quality donors

 SUGGAR++ Resource Requirements:
   Wall Clock Time 488.004623 seconds
   Memory Usage    3180 Mbytes

** Finished Creating DCI Files **
```

`dci_gen` Preprocessor (7/8) *skip - FYI*

- In some cases we may supply a **`manual_hole_commands`** file, with, for example, the entries shown below; without this file, the red elements below would *not* have appeared in resulting **`Input.xml_0`** file shown on the next slide, and the overlap connectivity might suffer:

```
<global>
  <thin_cut set_to="out"/>
  <donor_quality value="0.9" />
  <minimize_overlap keep_inner_fringe="yes"/>
</global>
    <volume_grid name="hartii_rotor_test">
      <skip_overlap_opt set_dsf_value="0.0"/>
    </volume_grid>
```

- Alternatively to **`manual_hole_commands`**, run **`dci_gen`**, modify resulting **`Input.xml_0`**, and run SUGGAR++ “by hand”

`dci_gen` Preprocessor (8/8) *skip - FYI*

- The resulting `Input.xml_0` file is (greatly edited to fit) :

```
<global>
 <thin_cut set_to="out"/>
 <donor_quality value="0.9" />
 <minimize_overlap keep_inner_fringe="yes"/>
  <output>
    <composite_grid style="unsorted_vgrid_set" filename="hartii_test"/>
    <domain_connectivity style="unformatted_gen_drt_pairs" … />
  </output>
  <body name="complete">
   <body name="rotor1_blade1">
    <dynamic/>
     <transform>
          …
     </transform>
      <volume_grid name="hartii_rotor_test" … >
       <skip_overlap_opt set_dsf_value="0.0"/>
      </volume_grid>
    </body>
    <body name="fuselage">
      <volume_grid name="hartii_box_test" …">
      </volume_grid>
    </body>
  </body>
</global>
```

`moving_body.input` File

- For rotorcraft, need only define blades as moving bodies and set the initial XML file; actual *motion* info comes from **`rotor.input`** and **`motion.txt`**

```
&body_definitions
  n_moving_bodies = 4,              ! 4 blades
  body_name(1) = 'rotor1_blade1',  ! name is set by *dci_gen* - must use unaltered
  n_defining_bndry(1) = 1,         ! number of boundaries that define this blade
  defining_bndry(1,1) = 2,         ! index 1: boundry number index 2: body number
  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',
/                                   ! NOTE: motion_driver() should NOT be specified
&composite_overset_mesh
  input_xml_file = 'Input.xml_0'    ! use file generated by dci_gen
/
```

`rotor.input` File

- Articulated rotors need only a subset of the data (website defines variables)

```
 # Rotors   Uinf/Uref  Write Soln   Force Ref Momment Ref    ! Below we set Uref = Utip
        1       0.245        1500         1.0         1.0    ! Adv Ratio = Uinf/Utip
=== Main Rotor ============================================= ! So here Uinf/Uref = AR
Rotor Type  Load Type    # Radial    # Normal  Tip Weight
         1          1          50         180         0.0
  X0_rotor   Y0_rotor    Z0_rotor        phi1        phi2        phi3
       0.0        0.0         0.0        0.00         0.0        0.00
 Utip/Uref ThrustCoff   PowerCoff        psi0  PitchHinge      DirRot
       1.0     0.0064       -1.00         0.0      0.0466           0
  # Blades  TipRadius  RootRadius  BladeChord   FlapHinge    LagHinge
         4    26.8330      2.6666       1.741      0.0466      0.0466
 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
       0.0       0.00         0.0         0.0        0.00
 # FlapHar      Beta0      Beta1s      Beta1c
         0        0.0         0.0         0.0
    Beta2s     Beta2c      Beta3s      Beta3c
       0.0        0.0         0.0         0.0
  # LagHar     Delta0     Delta1s     Delta1c
         0        0.0         0.0         0.0
   Delta2s    Delta2c     Delta3s     Delta3c
       0.0        0.0         0.0         0.0
```

Key:
Required for rigid and elastic
Required for untrimmed rigid
Unused (must have a value)

Nondimensional Input (1/2)

KEY POINT

- Typically define the flow reference state for rotors based on the tip speed; thus in **`rotor.input`**, set **`U`**$_{\mathtt{tip}}$**`/U`**$_{\mathtt{ref}}$ **`= 1.0`** (data line 4)
- This way, **`U`**$_{\mathtt{inf}}$**`/U`**$_{\mathtt{ref}}$ (data line 1) is equivalent to **`U`**$_{\mathtt{inf}}$**`/U`**$_{\mathtt{tip}}$, which is the Advance Ratio, and is usually specified or easily obtained
- Since the reference state corresponds to the tip, the **`mach_number`** in the **`fun3d.nml`** file should be the tip Mach number, and the **`reynolds_number`** should be the tip Reynolds number
- Nondimensional rotation rate: not input directly, but it is output to the screen; you might want to explicitly calculate it up front as a later check:

$\Omega^* = U^*_{tip} / R^*$ (rad/s, R^* the rotor radius)

and recall $\Omega = \Omega^* (L^*_{ref} / L_{ref}) / a^*_{ref}$ (compressible) from yesterday

so with $a^*_{ref} = U^*_{ref} / M_{ref}$ and taking $L^*_{ref} = R^*$

$\Omega = M_{ref} (U^*_{tip} / U^*_{ref}) / R$ (compressible)

$\Omega = U^*_{tip} / U^*_{ref} / R$ (incompressible)

Nondimensional Input (2/2)

- Nondimensional time step:

  time for one rev: $T^* = 2\pi / \Omega^* = 2\pi R^* / U^*_{tip}$ (s)

  and recall $t = t^* a^*_{ref} (L_{ref} / L^*_{ref})$ (compressible) from yesterday

  so with $L^*_{ref} = R^*$ we have

  $T = a^*_{ref}(R/R^*) 2\pi R^* / U^*_{tip} = 2\pi R / (M_{ref} U^*_{tip} / U^*_{ref})$ (nondim time / rev)

  For N steps per rotor revolution:

KEY POINT

$\Delta t = 2\pi R / (N M_{ref} U^*_{tip} / U^*_{ref})$ (compressible)

$\Delta t = 2\pi R / (N U^*_{tip} / U^*_{ref})$ (incompressible)

- Note: the azimuthal change per time step is output to the screen in the `Rotor info` section. Make sure this is consistent, to a high degree of precision (say at least 4 digits), with your choice of N steps per rev – you want the blade to end up very close to 360 deg. after multiple revs!
- Formulas above are general, but recall we usually have ref = tip, at least for compressible flow

Blade Surface "Slicing"

- Boundary surface (rotor blade) slicing is *required* for coupled CFD/CSD simulations; also useful for rigid-blade cases - this is what generates the data in **`rotor_1.onerev.txt`**

```
$slice_data
 replicate_all_bodies    = .true.          ! do the following the same on all blades
 output_sectional_forces = .false.         ! just lots of data we usually don't need
 tecplot_slice_output    = .false.         ! ditto
 slice_x(1)              = .true.,         ! x=const slice - in original blade coords
 nslices                 = -178,           ! no. slices; "-" means give start and delta
 slice_location(1)       = 2.8175,         ! x-location to slice (starting slice)
 slice_increment         = .13416666666    ! delta slice location each successive slice
 n_bndrys_to_slice(1)    = 1,              ! 1 bndry to search
 bndrys_to_slice(1,1)    = 2,              ! indicies:(slice,bdry) lumping made life easy
 slice_frame(1)          = 'rotor1_blade1', ! ref. frame in which to slice - use body name
 te_def(1)               = 20,             ! look for 2 corners in 20 aft-most segments
 le_def(1)               = 30,      ! search 30 fwd-most pts for one most distant from TE
 chord_dir(1)            = -1,             ! Recall goofy original blade coord system
/
```

- Note: "slicing" useful for applications other than rotorcraft; see website

CAMRAD Considerations

- User must set up basic CAMRAD II scripts; the **`RUN_LOOSE_COUPLING`** script provided with FUN3D requires 3 distinct, but related CAMRAD scripts
  - **`basename_ref.scr`**
    - Used to generate the reference motion data used by CAMRAD
    - Set this file to use rigid blades; zero collective/cyclic; no trim
  - **`basename_0.scr`**
    - Used for coupling/trim cycle "0"
    - Set up for elastic blades with trim; use CAMRAD aerodynamics exclusively (no delta airloads input); simplest aero model will suffice
  - **`basename_n.scr`**
    - Used for all subsequent coupling/trim cycles
    - Set up for elastic blades with trim; use same simple CAMRAD aerodynamics but now with delta airloads input
- Sample scripts (basename: **`hart`**) are provided in **`utils/Rotorcraft`**; 1st 2-4 executable lines of each script show tailoring required to use with **`RUN_LOOSE_COUPLING`** script

Untrimmed Rigid-Blade Simulations

- Overview of the basic steps

1. Prepare rotor blade and fuselage grids, with proper axis orientation
2. Set up the **`rotor.input`** file based on desired flight conditions
3. Run the **`dci_gen`** utility to create a composite mesh and initial dci data
4. Set up **`fun3d.nml`** and **`moving_body.input`** files
5. Optionally set up the **`&slice_data`** namelist in the **`fun3d.nml`** file
6. Run the solver with the following command line options (in addition to any other appropriate ones, like **`--temporal_err_control`**)

   ```
   --moving_grid --overset --overset_rotor --dci_on_the_fly
    --dci_period 360 --reuse_existing_dci
   ```

   If optional step 5 is used, add the following (N as desired, typically 1)

   ```
   --slice_freq N --output_comprehensive_loads
   ```

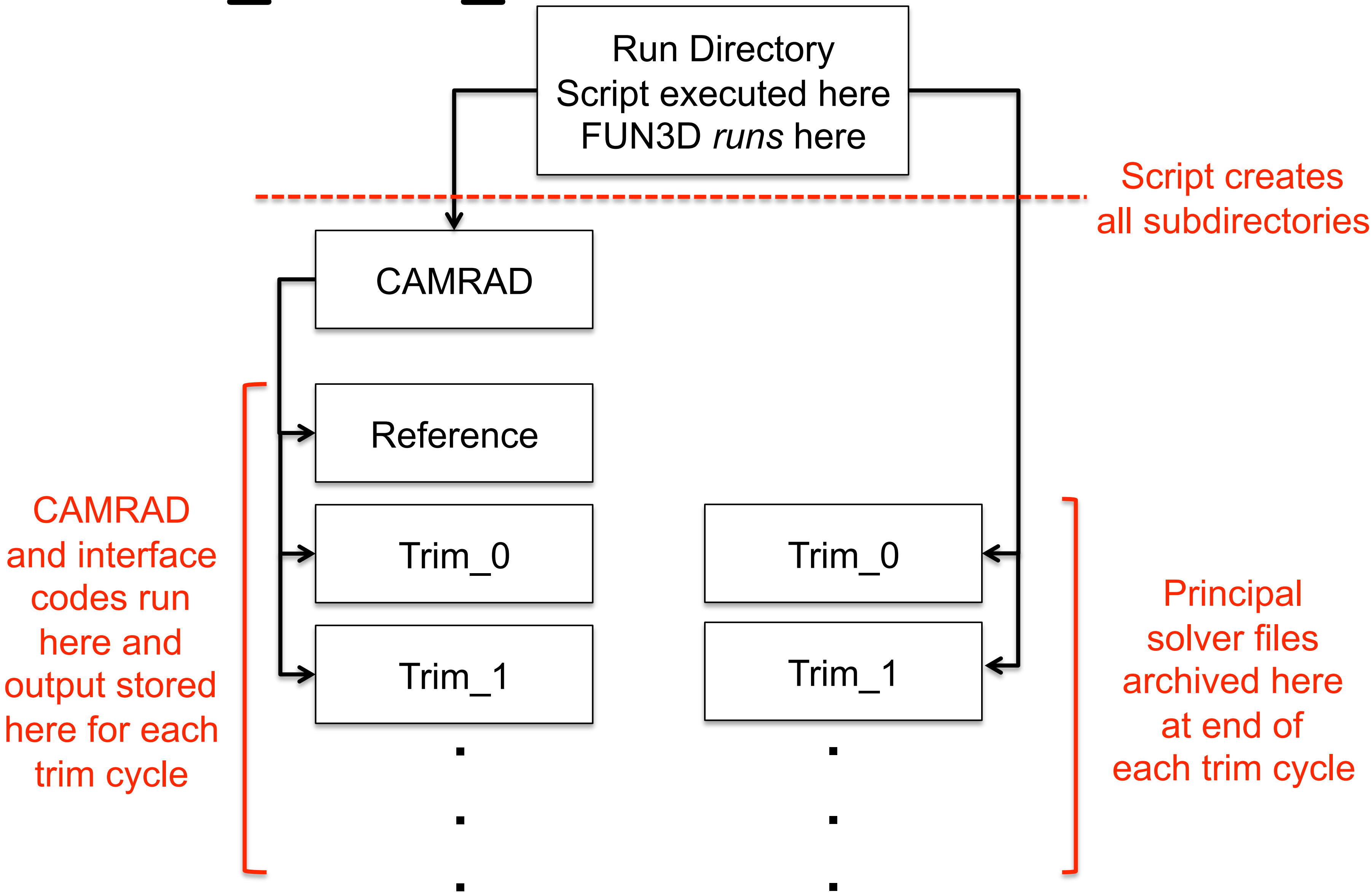
7. Number of time steps required is case dependent – usually at least 3 revs

Trimmed, Elastic-Blade Simulations

- Overview of the basic steps; steps 1-4 are the same as for the untrimmed rigid-blade case; use of CAMRAD is assumed

5. Set up the `&slice_data` namelist; *not optional*
6. Set up the 3 CAMRAD run script templates
7. Set up the `RUN_LOOSE_COUPLING` run script (a c-shell script geared to PBS environments); user-set data is near the top – sections 1 and 2
8. Set up the `fun3d.nml_initial` and `fun3d.nml_restart` files used by the run script; typically set the time steps in the initial file to cover 2 revs, and $2/N_{blade}$ revs in restart version
9. If using the run script make sure all items it needs are in place; script checks for missing items, but it gets old having to keep restarting because you forgot something!
10. Number of coupling cycles required for trim can vary, but 8-10 is typical for low-moderate thrust levels; high thrust cases near thrust boundary may require 10-15; user judges acceptable convergence

RUN_LOOSE_COUPLING Directory Tree



Things To Look For In Screen Output (1/2)

- Rotor info section lists some basic data:

```
 Rotor info, rotor  1
   Number of blades                    :     4
   Nondimensional rotation rate        :     0.02493199
   Azimuth change (deg) per time step  :     1.00000000 ! make sure its accurate
   Tip Mach number (hover)             :     0.66900000
   Advance ratio                       :     0.24500000
   Tip radius                          :    26.83300000
   Force/Moment reference area         :  2261.97777779
   Force/Moment reference length       :    26.83300000
   Moment reference x-center           :     0.00000000
   Moment reference y-center           :     0.00000000
   Moment reference z-center           :     0.00000000
   Note: force/moment reference data above
         supercedes any other input values
```

- If running elastic blades:

```
Reading CAMRAD motion file for rotor  1: camrad_motion_data_rotor_1.dat
 nspan =  100
 npsi  =   24
 Enforcing periodicity in CAMRAD motion data
```

- Note: `camrad_motion_data_rotor_1.dat` is what FUN3D calls `motion.txt`

Things To Look For In Screen Output (2/2)

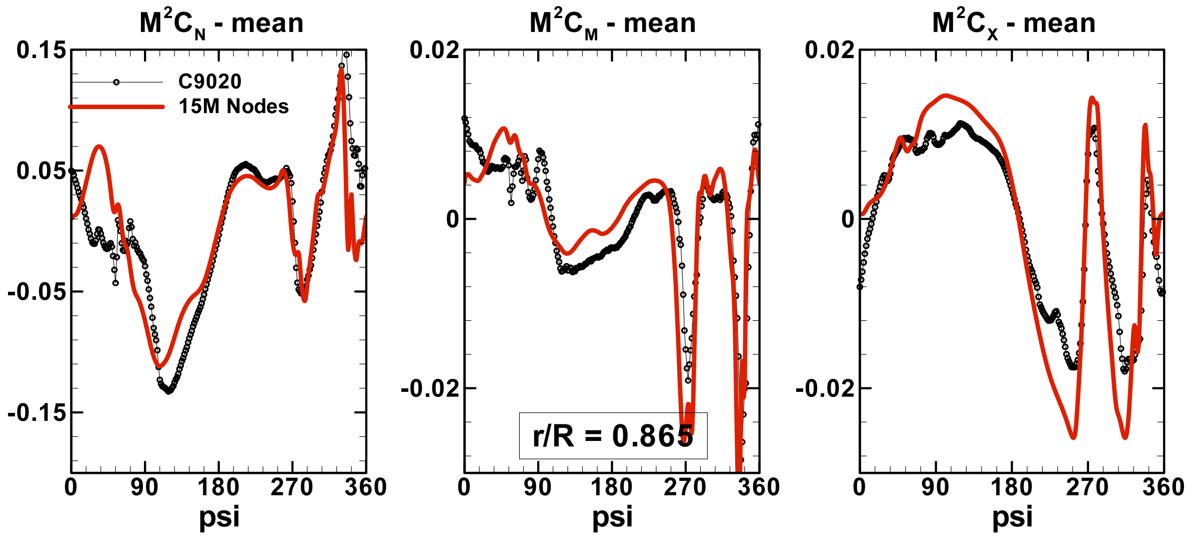
- Running average of integrated blade loads at the end of each time step:

```
Rotor Forces and Moments, Rotor  1
Averages over   180 steps
  Inertial Axes
    Cx  :  -0.000124
    Cy  :  -0.000328
    Cz  :   0.009951
    Cmx :   0.000013
    Cmy :  -0.000049
    Cmz :  -0.000663
  Nonrotating Shaft Axes
    Cx  :  -0.000124
    Cy  :  -0.000328
    Cz  :   0.009951
    Cmx :   0.000013
    Cmy :  -0.000049
    Cmz :  -0.000663
  Wind Axes
    Cl  :   0.009949
    Cd  :  -0.000212
Performance Parameters
    Thrust, Ct      :   0.009951
    Torque, Cq      :   0.000663
```

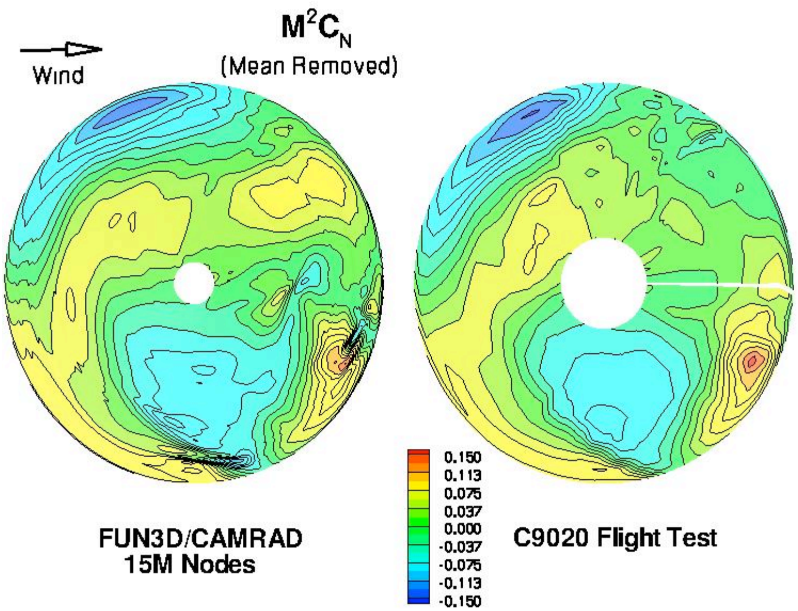
Postprocessing (1/2)

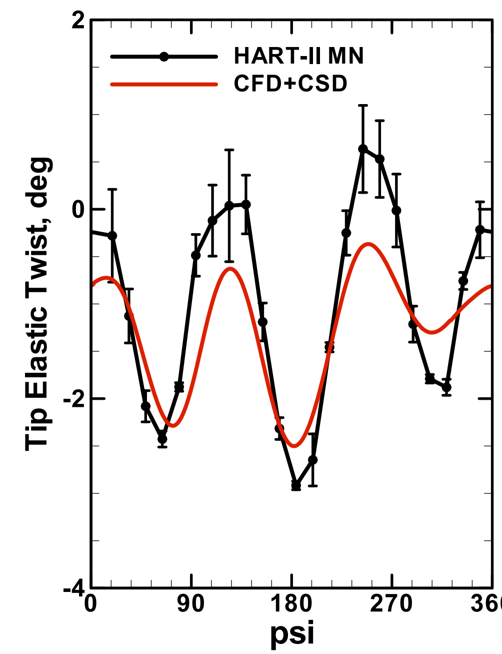
- For elastic blades, or rigid blade cases with optional "slicing" and **`--output_comprehensive_loads`**, the following files are output;
  - **`rotor_1.onerev.txt`** (OVERFLOW standard, airloads F/M data)
  - **`motion_rotor_1.onerev.txt`** (similar to above, but motion data)
- Utility code **`process_rotor_data.f90`**, with input file **`process_rotor_data.input`** (code and sample input in utils/Rotorcraft)
  - Extracts aero and displacement data into a number of Tecplot files:
    - **`airloads_polarplot_rotor_1.dat`**
    - **`sectional_forces_vs_azimuth_rotor_1.dat`**
    - **`sectional_forces_vs_radius_rotor_1.dat`**
    - **`computed_qc_position_vs_azimuth_rotor_1.dat`** (section c/4 positions
    - **`computed_qc_position_vs_radius_rotor_1.dat`** and section pitch)
    - **`mean_sectional_forces_vs_radius_rotor_1.dat`**
  - "forces" and "polarplot" have M^2C_N, M^2C_M, and M^2C_x data
  - The first three files also have equivalent "mean removed" versions

Postprocessing (2/2)



Sample Plots Possible Via process_rotor_airloads.f90 Output





List of Key Input/Output Files

- Beyond basics like **fun3d.nml**, **[project]_hist.tec**, etc.:
- Input
  - **moving_body.input**
  - **Input.xml_0** (dynamic overset; no standard name)
  - **[project].dci** (all overset)
  - **rotor.input** (all R/C)
  - **camrad_motion_rotor_N.dat** (aka **motion.txt**, coupled R/C)
  - **case_ref.scr**, **case_0.scr**, **case_N.scr** (coupled R/C)
- Output
  - **rotor_1.onerev.txt** (articulated R/C)
  - **motion_rotor_1.onerev.txt** (articulated R/C)

FAQ's

- How long does it take (esp. as regards to coupled rotorcraft simulations)?
  - If you have to ask you can't afford it !
  - Currently (April 2010), a 7 million node UH-60 simulation, which required 10 coupling cycles to converge to trim targets, takes approximately 72 hrs on 96(+1) processors of a 3.0 GHz P4 Dual Core 4GB GigE cluster - same cluster used in interactive sessions
  - Expect future speedup from implementation of parallel SUGGAR++ processing

What We Learned

- How to set up and run static and dynamic overset meshes in FUN3D
  - To fully utilize, requires knowledge of SUGGAR++, for which training will be provided tomorrow
- Rotorcraft simulations
  - Actuator disk models for basic influence of rotor
  - Moving, articulated blades for detailed airloads analysis - much more expensive and involved
    - Assemble the composite grid with **`dci_gen`**; takes most of the work out of setting up the SUGGAR++ XML file, using an input file you later need for FUN3D
    - Rigid blades (untrimmed) can be run without coupling to a comprehensive code
    - Coupled FUN3D / CAMRAD solutions a huge step up in complexity!