FUN3D v12.4 Training

Session 17: Rotorcraft Simulations

Bob Biedron

Session Scope

- What this will cover
  - Overview of actuator-disc models for rotorcraft
  - Overview of setup for overset, articulated-blade rotorcraft simulations
    - Rigid Blades
    - Elastic Blades / Loose Coupling to Rotorcraft Comprehensive Codes
- What will not be covered
  - Rotorcraft Comprehensive Code set up and operation
  - All the many critical setup details
- What should you already know
  - Basic time-accurate and dynamic-mesh solver operation and control
  - Rudimentary rotorcraft aeromechanics (collective, cyclic…)

Introduction

- 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
  - Coupled to the CAMRAD II and RCAS comprehensive codes
- Status
  - Coded for multiple rotors, but largely untested
  - Far less experience / testing with RCAS than with CAMRAD II

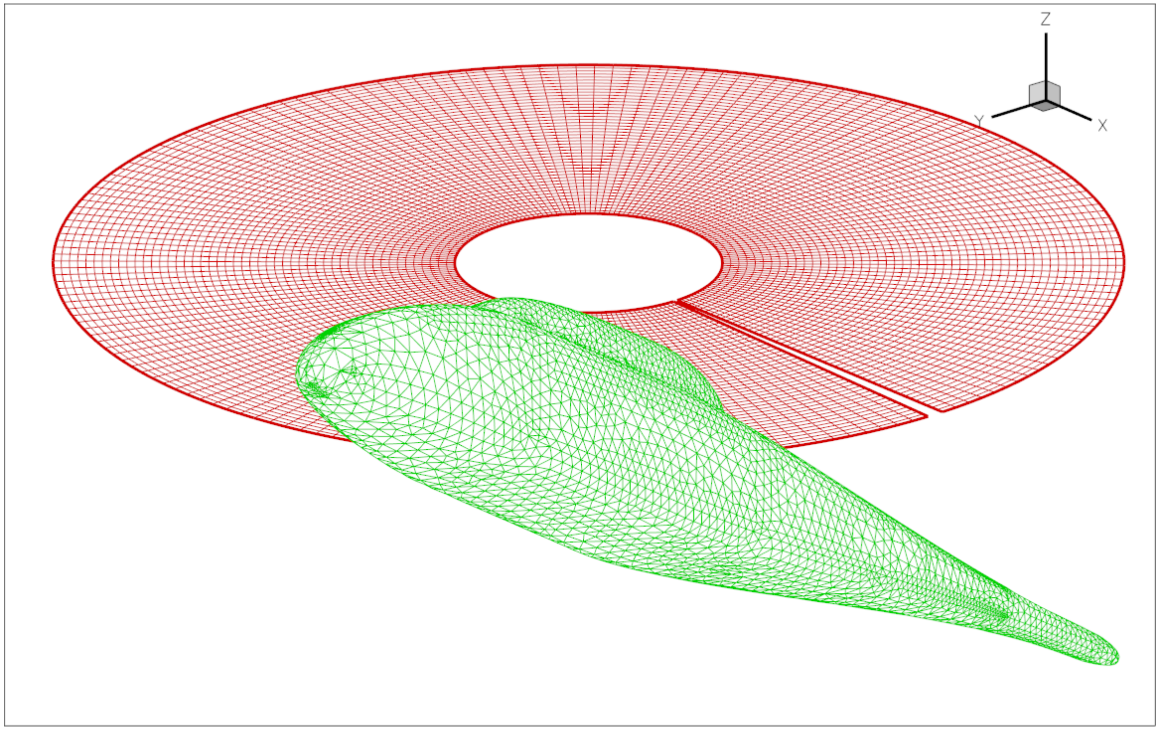
Time-Averaged Actuator-Disk Simulations (1/2)

- 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*)
- Simplifies grid generation – disk is embedded in computational grid (note some refinement in the vicinity of actuator surface needed for accuracy)
- 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 similar solution convergence as 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

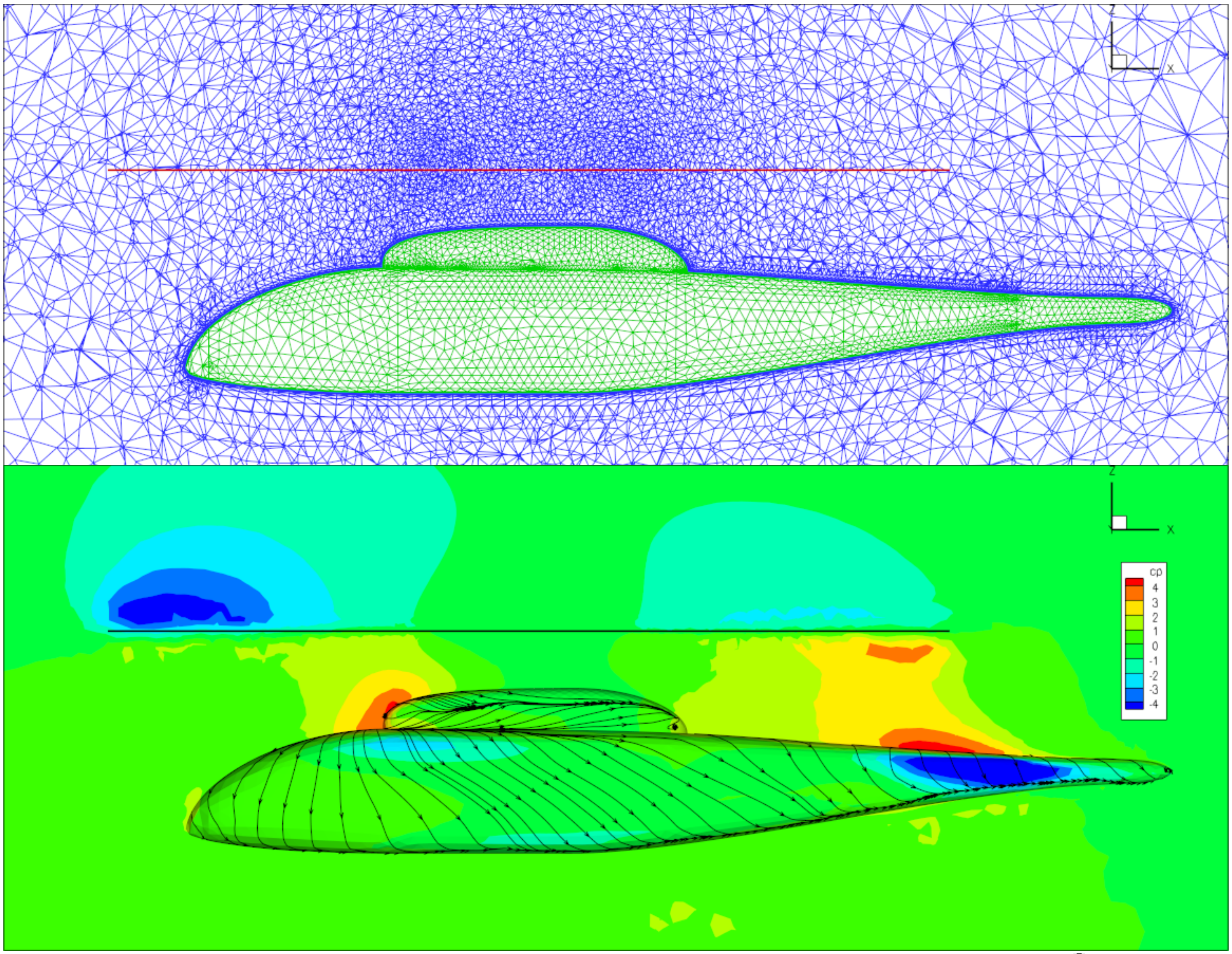
- Constant/linear loading needs only a subset of the data in the file

```
 # 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

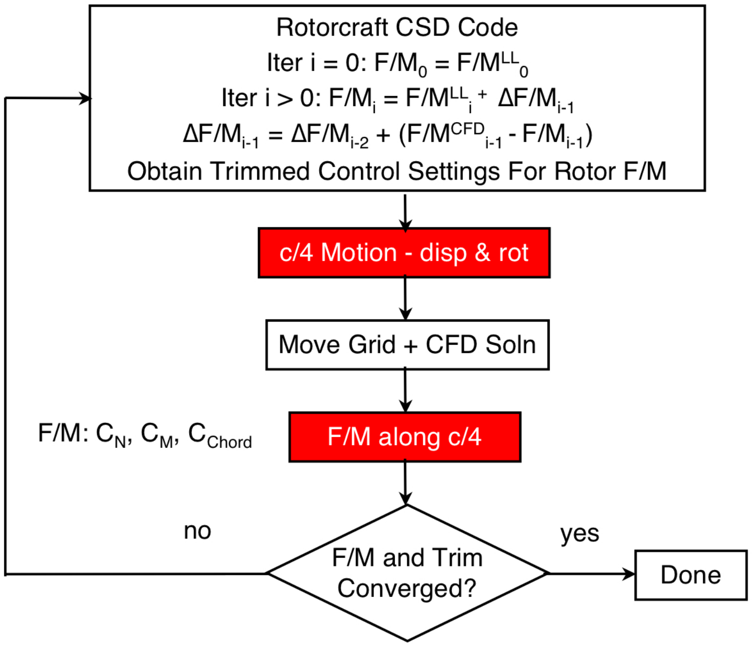


Articulated-Blade Simulations

- 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 or 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 for CAMRAD are maintained and distributed by Doug Boyd, NASA Langley (d.d.boyd@nasa.gov)
  - RCAS coupling does not require any interface codes
  - FUN3D has several postprocessing utility codes tailored to CAMRAD
- This 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

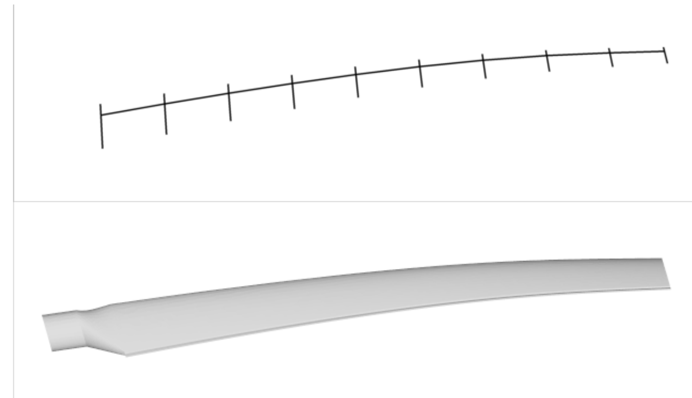
Coupling Process



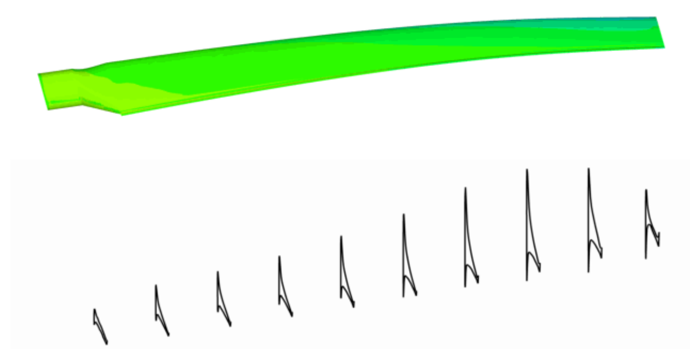
motion.txt and rotor_onerev.txt files common to FUN3D and OVERFLOW

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

CSD -> CFD



CFD -> CSD

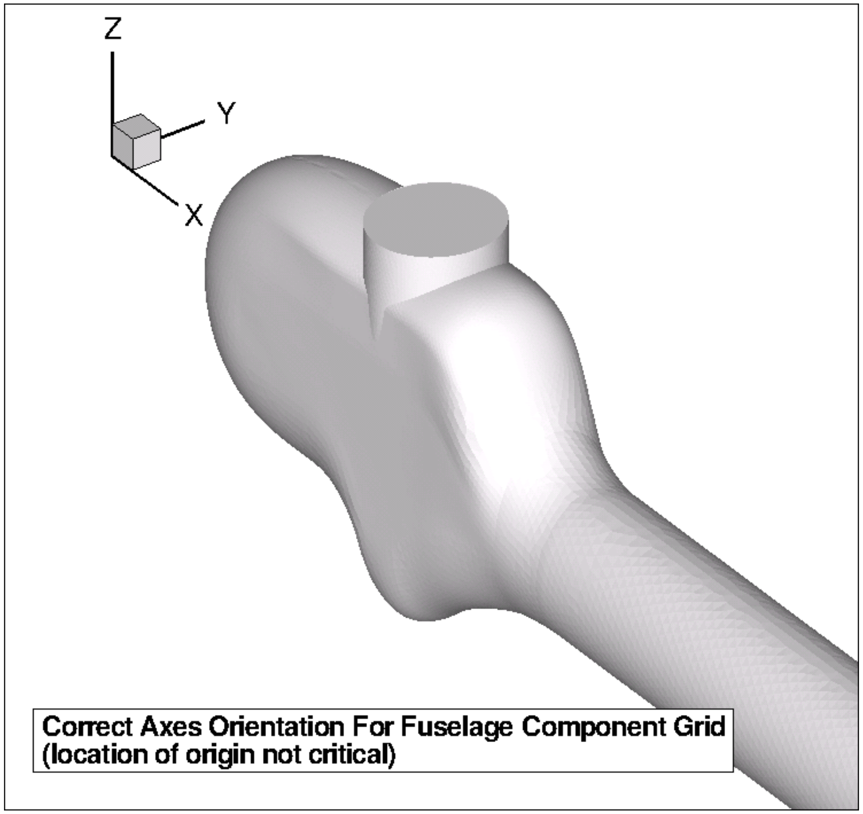


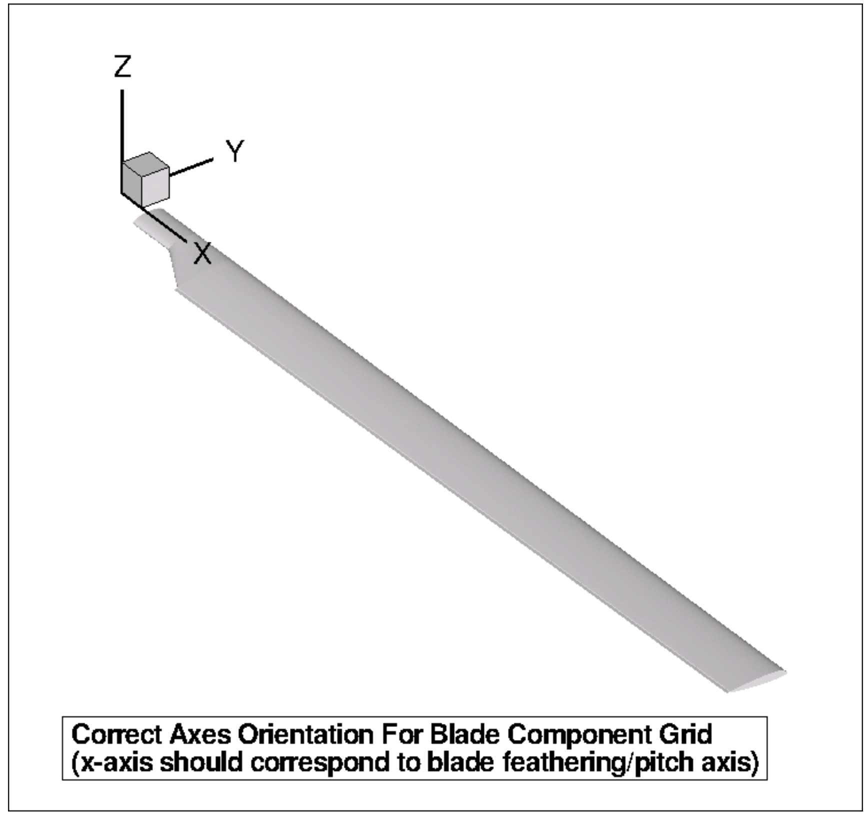
`dci_gen` Preprocessor (1/8)

- 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`**

`dci_gen` Preprocessor (2/8)

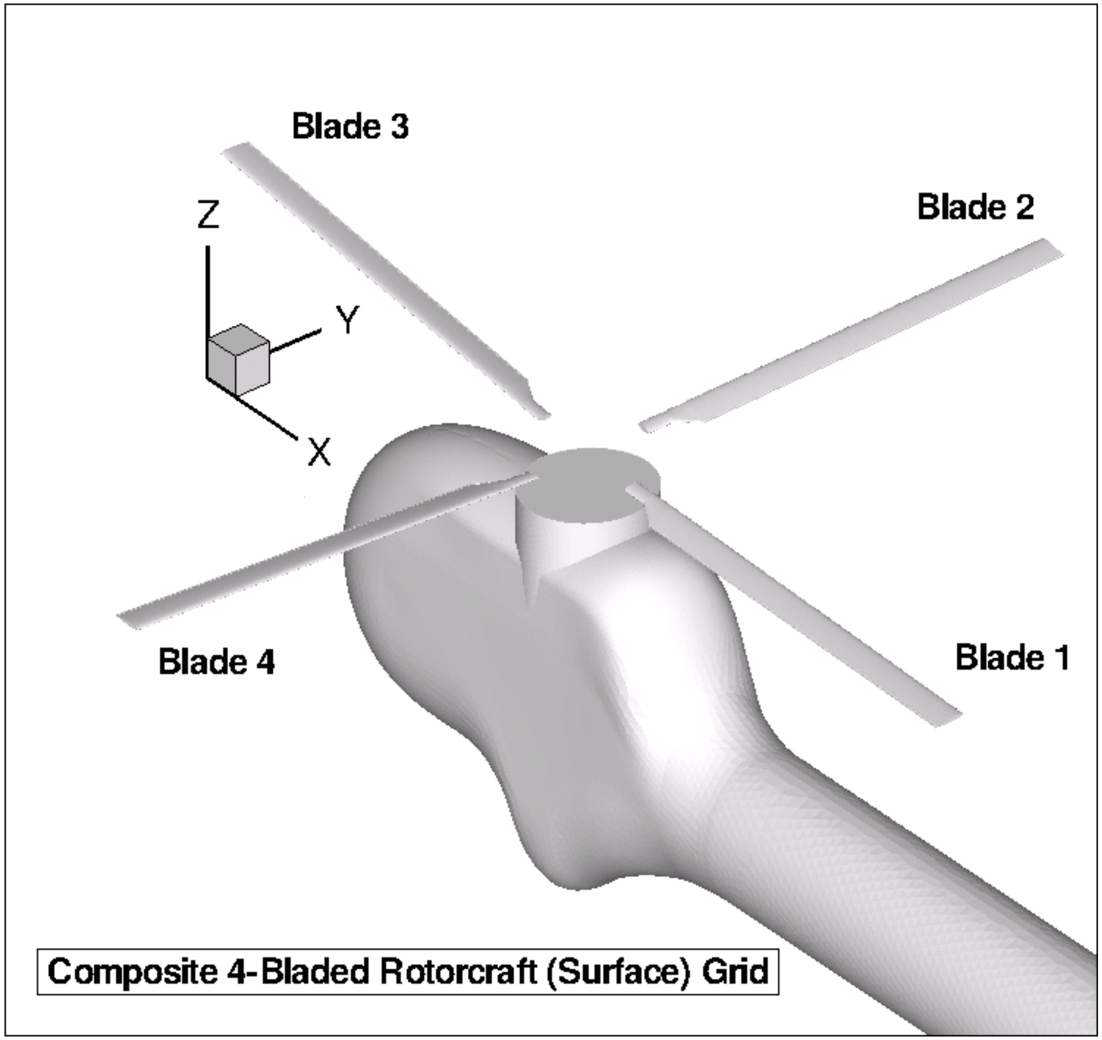
HART II *Component* Grids





dci_gen Preprocessor (3/8)

HART II *Composite* Grid



`rotor.input` File

- Articulated rotors need only a subset of the data (manual 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)

- Typically define the flow reference state for rotors based on the tip speed; thus in **`rotor.input`**, set **`Utip/Uref = 1.0`** (data line 4)
- This way, **`Uinf/Uref`** (data line 1) is equivalent to **`Uinf/Utip`**, 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)

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)

  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:

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

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

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
     ```

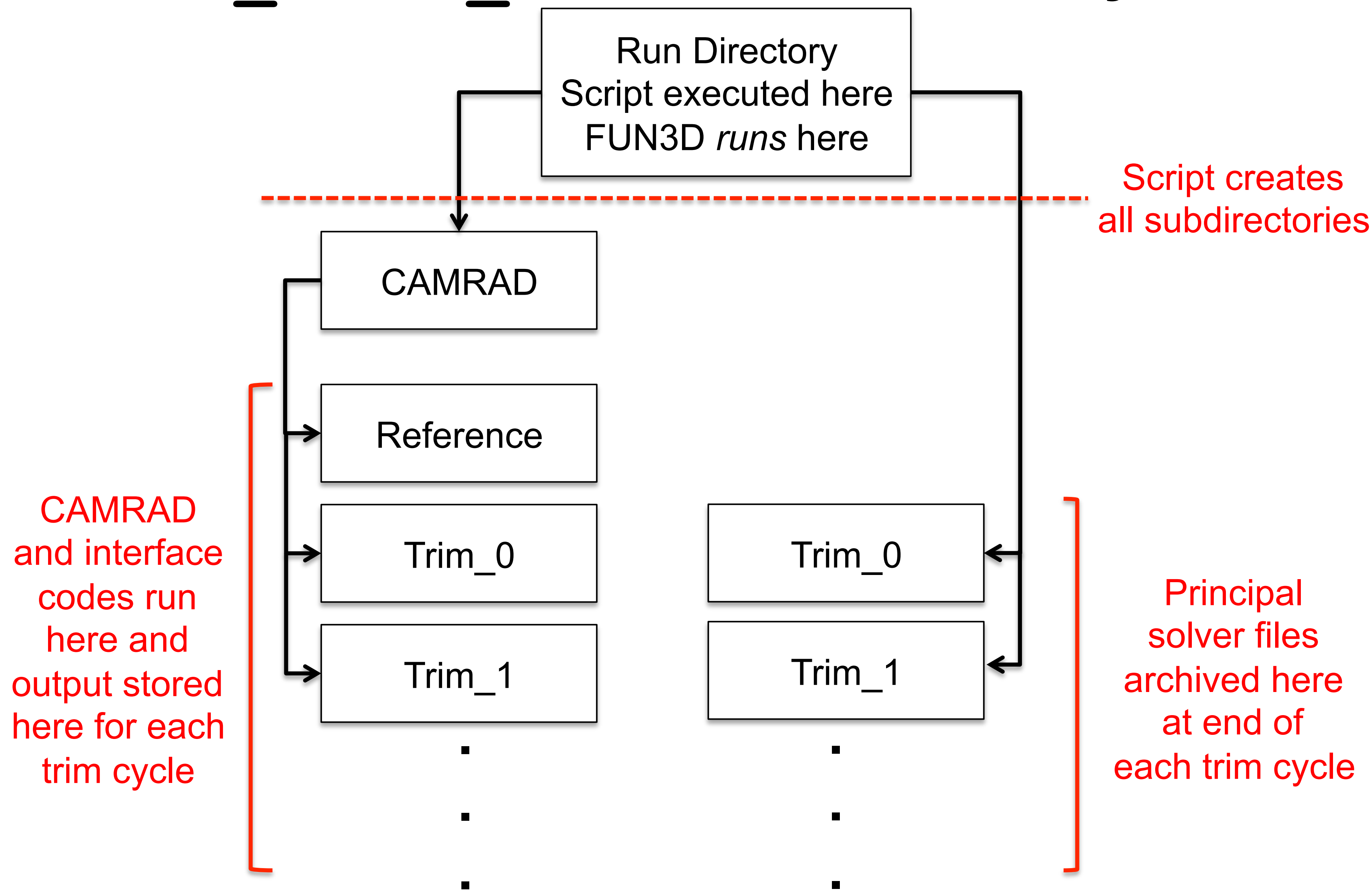
  7. Number of time steps required is case dependent – usually at least 3 revs

Trimmed, Elastic-Blade Simulations

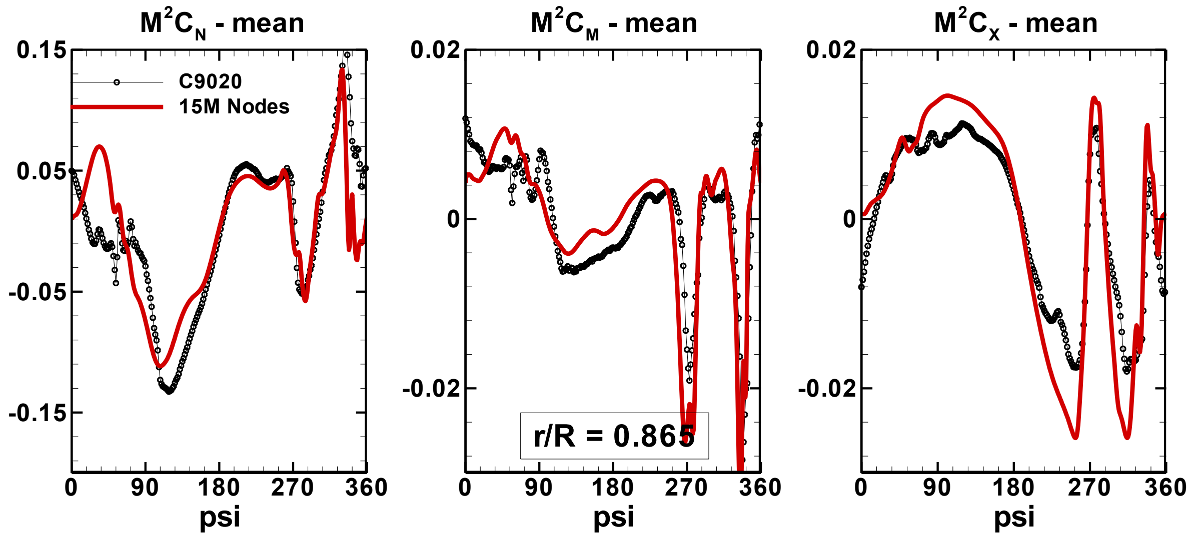
- Overview of the basic steps; steps 1-4 are the same as for the untrimmed rigid-blade case; use of CAMRAD is assumed

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

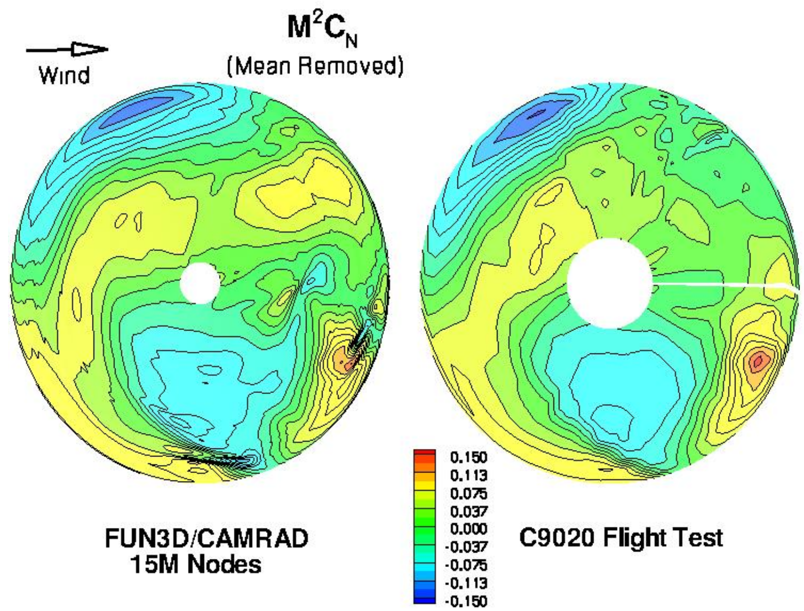
`RUN_LOOSE_COUPLING` Directory Tree

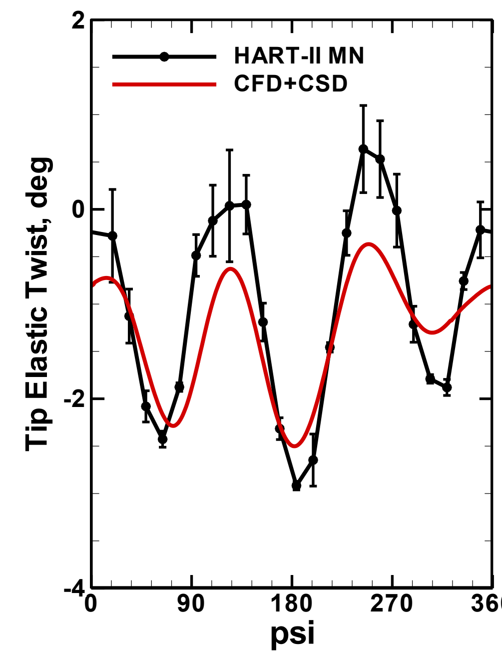


Postprocessing



Sample Plots Possible Via process_rotor_airloads.f90 Output





The End