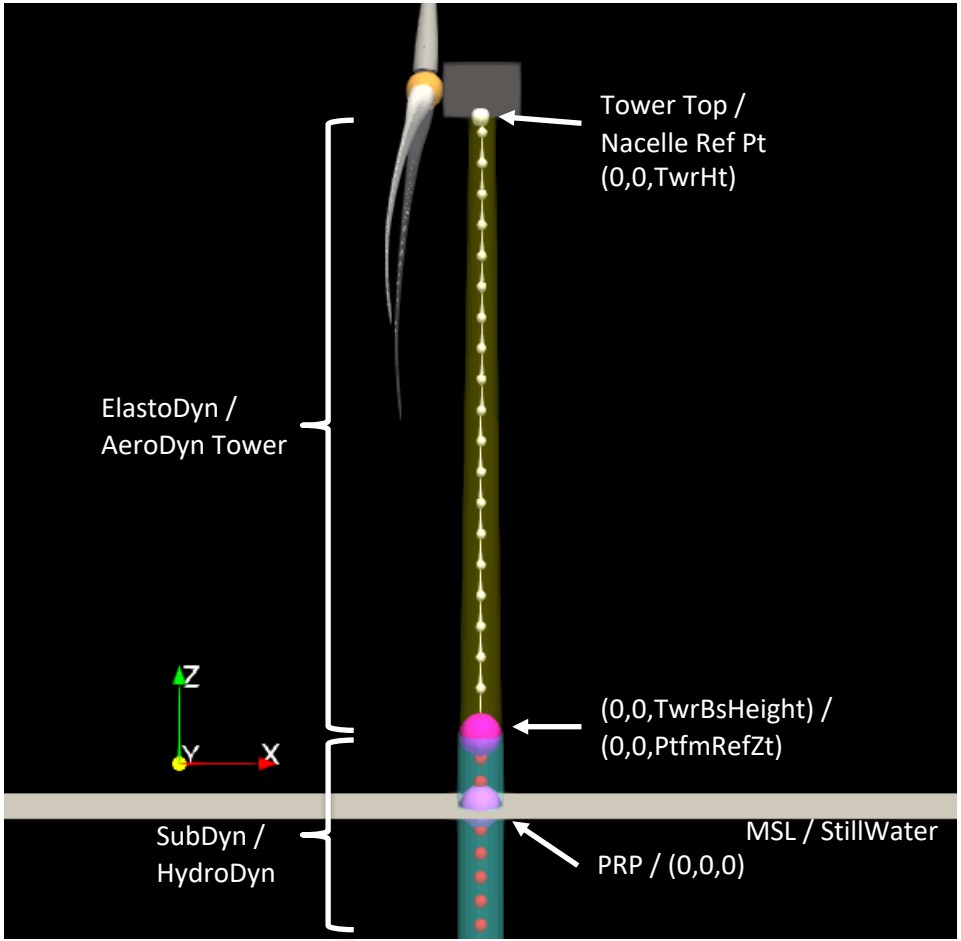
OpenFAST coordinate systems

Andy Platt
HFM workshop
February 1, 2024

Photo from iStock-627281636

ElastoDyn Tower



ElastoDyn:

- TwrHt – height above MSL/ground
- TwrBsHeight – height above MSL/ground
- PtfmRefZt - platform connection to tower

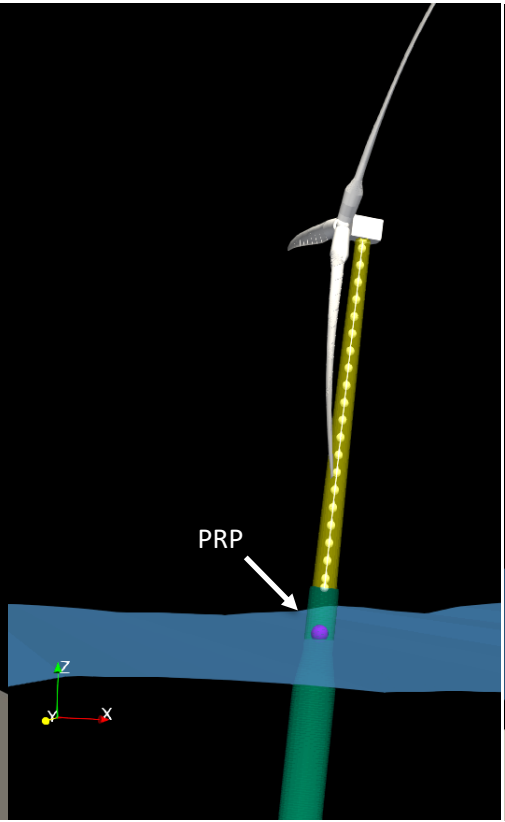
HydroDyn / SeaState:

- MSL – mean sea level (0 m)
- MSL2SWL – offset from MSL to still water
- PRP – principle reference point for HydroDyn. Used for single body potential flow (internally used).

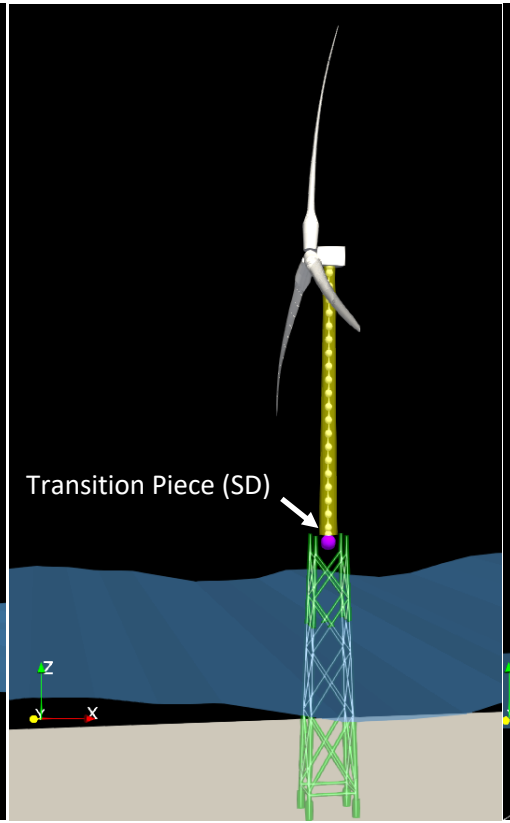
IEA 15 (v1.1.8) Monopile

- TwrHt: 144.386 m
- TwrBsHeight: 15.0 m
- MSL2SWL: 0.0 m

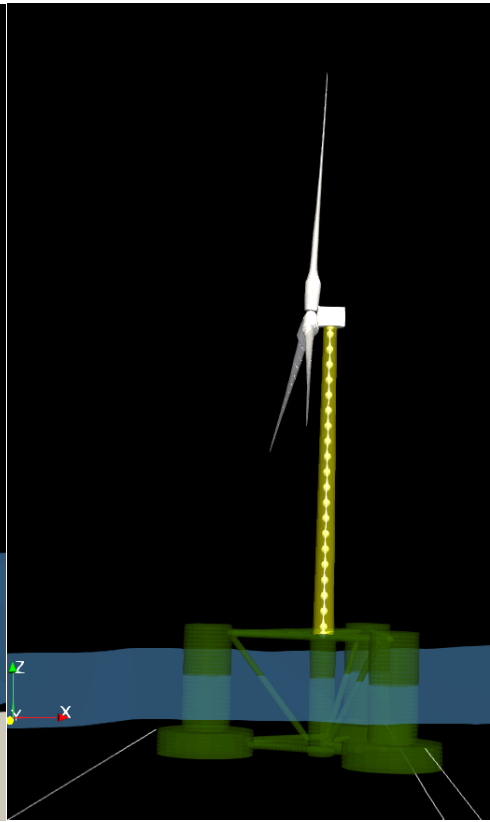
5MW_Land
- TwrHt: 87.6 m
- TwrBsHeight: 0.0 m



5MW_OC3Spar
- TwrHt: 87.6 m
- TwrBsHeight: 10.0 m



5MW_OC4Jckt
- TwrHt: 88.15 m
- TwrBsHeight: 20.15 m



5MW_OC4Semi
- TwrHt: 87.6 m
- TwrBsHeight: 10.0 m

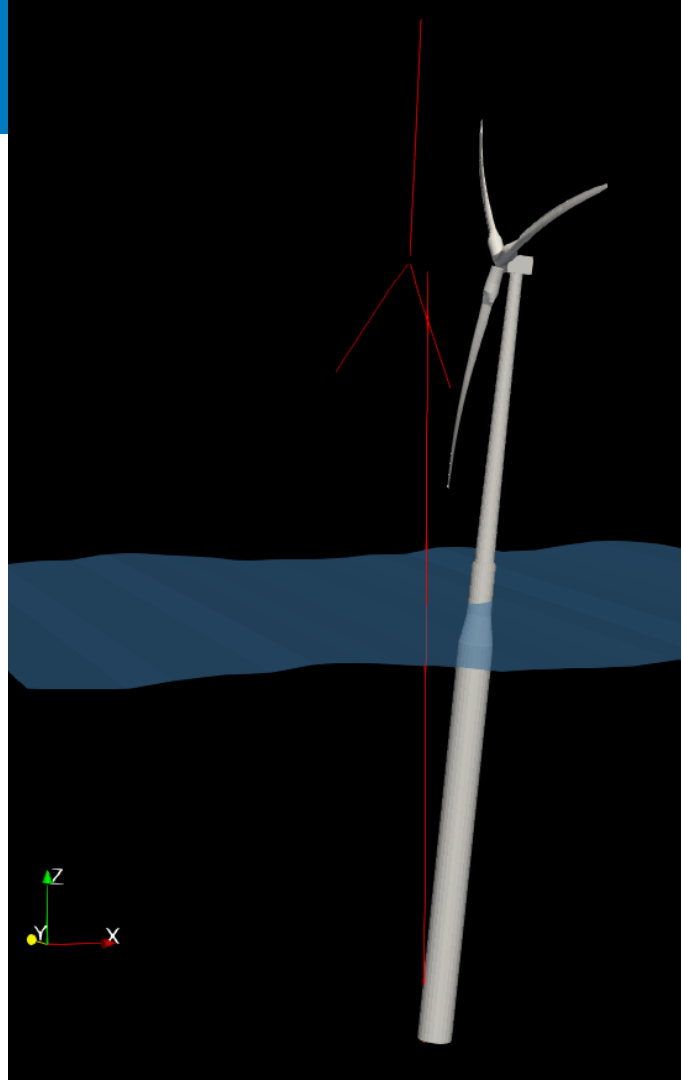
OpenFAST reference frame

Equivalent initial conditions:

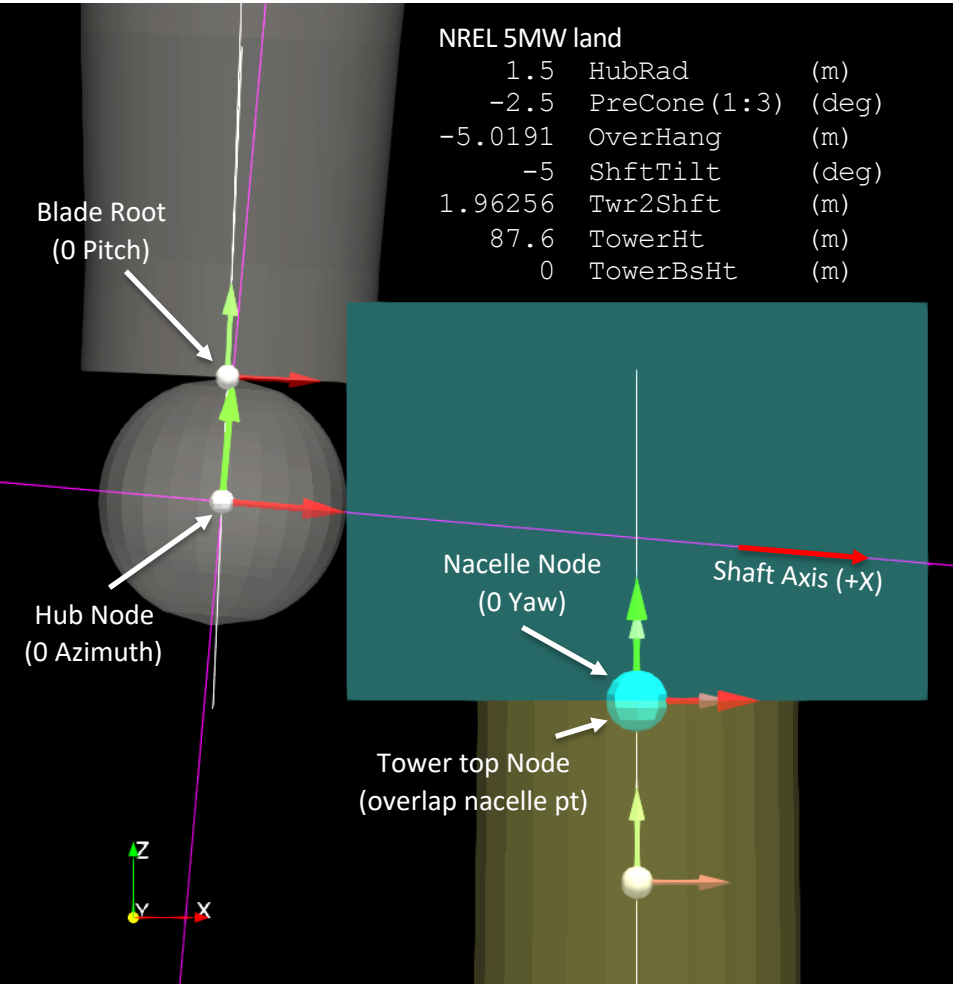
```
---------------------- INITIAL CONDITIONS --------------------------------
  0   OoPDefl     - Initial out-of-plane blade-tip displacement (m) [not BD]
  0   IPDefl      - Initial in-plane blade-tip deflection (m)       [not BD]
  0   BlPitch(1)  - Blade 1 initial pitch (deg)
  0   BlPitch(2)  - Blade 2 initial pitch (deg)
  0   BlPitch(3)  - Blade 3 initial pitch (deg)
  0   Azimuth     - Initial azimuth angle for blade 1 (deg)
  0   NacYaw      - Initial or fixed nacelle-yaw angle (deg)
  0   TTDspFA     - Initial fore-aft tower-top displacement (m)
  0   TTDspSS     - Initial side-to-side tower-top displacement (m)
  0   PtfmSurge   - horizontal surge translational displacement of platform (m)
  0   PtfmSway    - horizontal sway translational displacement of platform (m)
  0   PtfmHeave   - vertical heave translational displacement of platform (m)
  0   PtfmRoll    - roll tilt rotational displacement of platform (deg)
  0   PtfmPitch   - pitch tilt rotational displacement of platform (deg)
  0   PtfmYaw     - yaw rotational displacement of platform (deg)
```

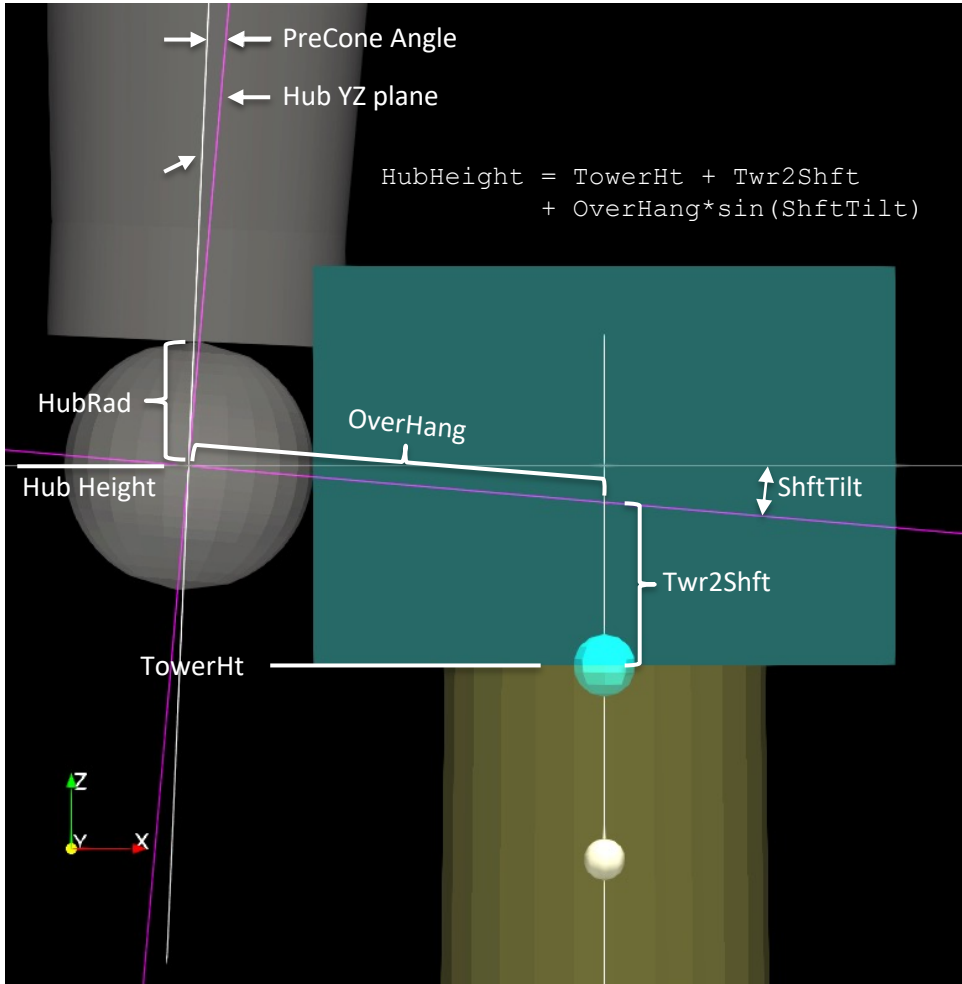
Included in reference frame

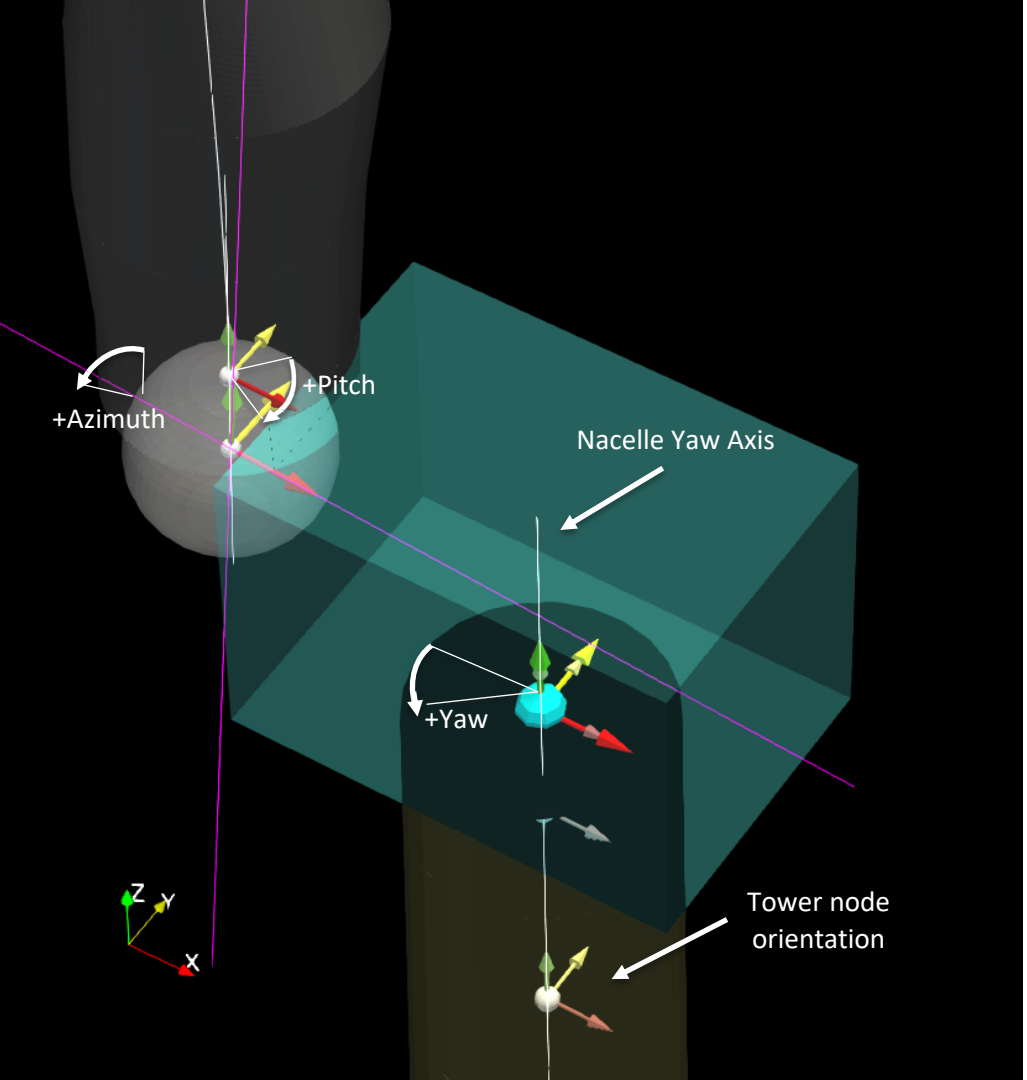
```
---------------------- TURBINE CONFIGURATION ---------------------------------
HubRad      PreCone(1:3).    AzimB1Up
OverHang    ShftTilt         Twr2Shft
TowerHt     TowerBsHt        PtfmRefzt
```



Hub location

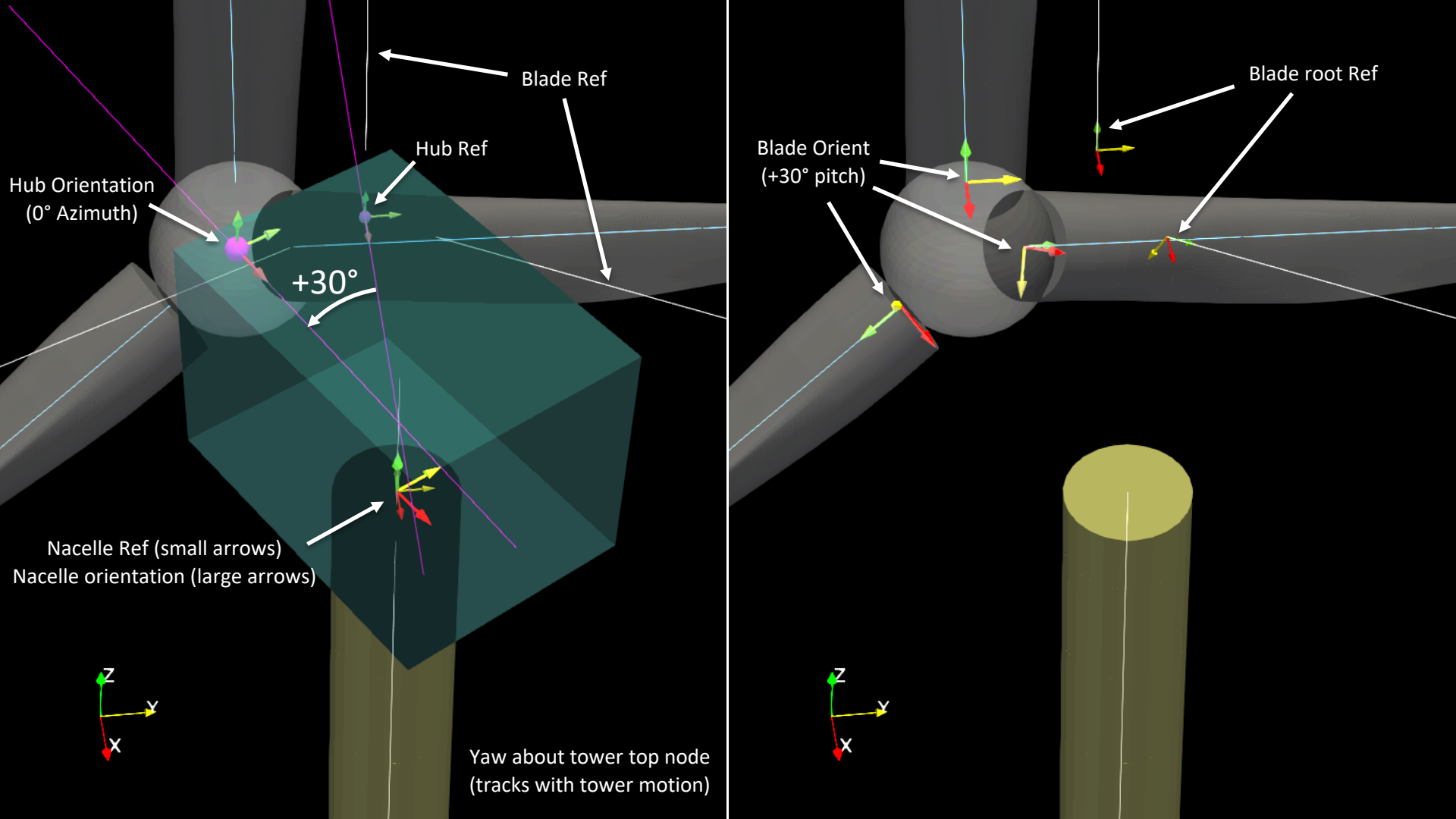






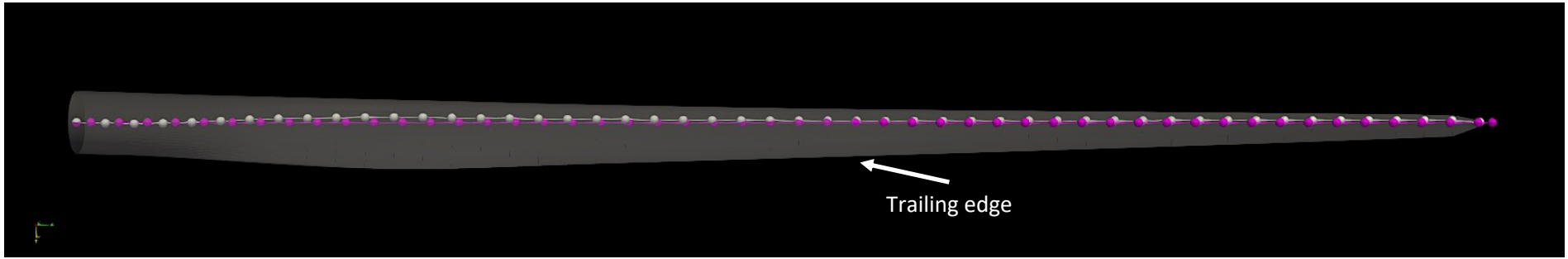
Coordinate frames:

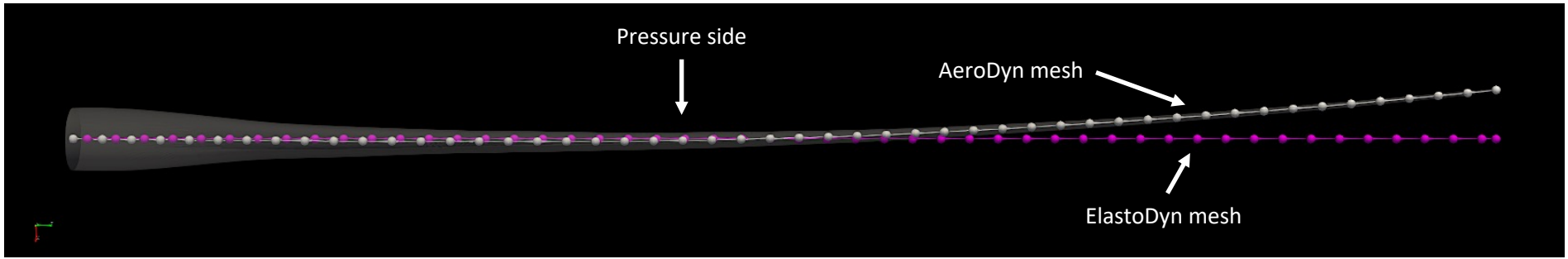
- Tower – reference frame aligned with global frame, attached at `TowerBsHt` to ground/SubDyn/HydroDyn
- Nacelle – attached to top node of tower, rotates about tower top local Z axis
- Yaw – about tower top node Z axis (right hand rotation)
- Hub – rotates about shaft X axis, follows rotor azimuth (right hand rotation)
- Blade root mesh – attached to hub with cone angle, offset by hub radius along coned angle. Blade pitches about local Z axis (*left hand rotation*)
- AD/ED/BD blade - attaches to blade root mesh, first node Z axis aligns to root mesh Z axis.


Blade Ref
Hub Ref
Hub Orientation
(0° Azimuth)
+30°
Nacelle Ref (small arrows)
Nacelle orientation (large arrows)
Z
Y
X
Yaw about tower top node
(tracks with tower motion)
Blade root Ref
Blade Orient
(+30° pitch)
Z
Y
X

ElastoDyn blades

IEA15





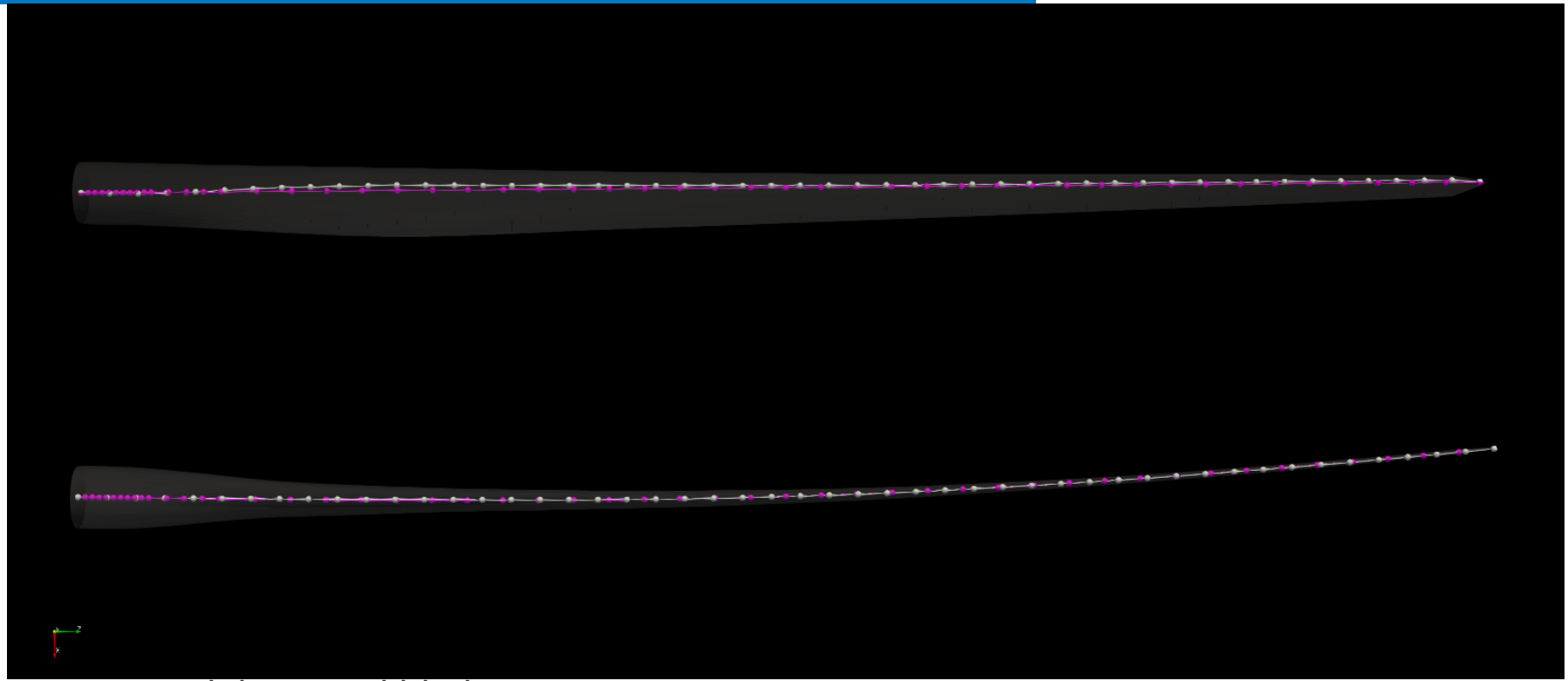
ElastoDyn models structuraly straight blades

- 2 Flap modes, 1 Edge mode, no torsion
- Mass and stiffness along straight blade

ElastoDyn is **not** ideally suited for

- Highly flexible blades
- Lots of prebend/precurve

BeamDyn blades



BeamDyn models curved blades

- Geometrically exact beam theory
- Mass and stiffness curvature defined by keypoints

OpenFAST timesteps

- For ElastoDyn:
  - 5e-3 land, maybe smaller floating
- For BeamDyn:
  - Depends on the model
    - IEA15/IEA22 + steady: 4e-5
    - IEA15/IEA22 + turbulent: 1e-5
      - IEA22 still fails on occasion
  - *Wish I had better guidance to give here.*
  - OpenFAST v5.0 will include tight-coupling
    - Timesteps up to 0.005 with BeamDyn

OpenFAST roadmap

- *X.Y.Z*
  - *X* – major new features or restructuring. New input files
  - *Y* – minor new features. New input files
  - *Z* – bugfix, no input file changes

- 3.x series ends with 3.5.*z*
  - 3.5 LTS
    - 3.5.3 – in progress (backports of fixes)

- 4.0 (end Feb. 2024?)
  - Includes FSI
  - 4.0 or 4.1 LTS

- 5.0 (end April 2024?)
  - Tight coupling solver
  - 5.*Y* not planned yet

www.nrel.gov

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from iStock-627281636

NREL
Transforming ENERGY

- Figures generated with
  - IEA 15, v1.1.8 (https://github.com/IEAWindTask37/IEA-15-240-RWT/releases/tag/v1.1.8)
  - OpenFAST 3.5.2,gcc 10.5.0 , double precision
  - ROSCO 1.8
  - Paraview 5.11.1