Overview of BModes
(Code to Compute Blade and Tower Modes for Onshore & Offshore Turbines)

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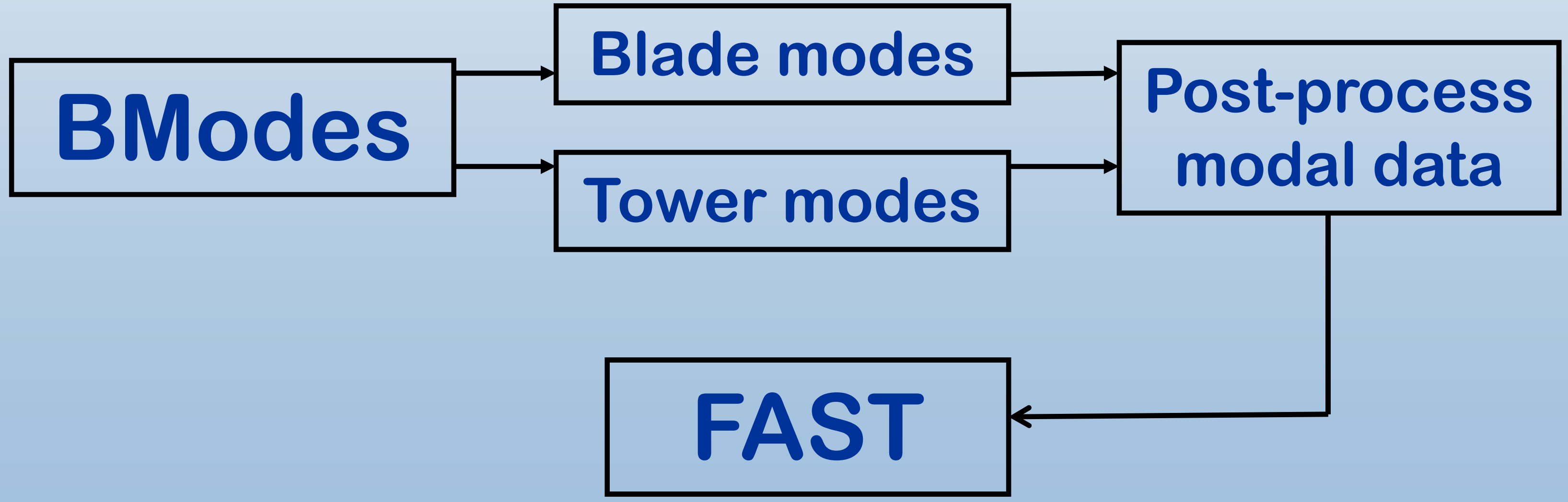
Motivation for BModes Development

- Structural characterization
- Blade model updating (system ID problem)
- Modal-based codes, such as FAST, need modes of towers and blades to build wind turbine models:



BModes Usage for Blades

- Given:
  - Blade distributed geometric & structural properties
  - Rotational speed
  - Tip inertia properties
  - Precone; pitch control setting
- Computes:
  - Modal frequencies
  - Coupled mode shapes

    (each natural mode: coupled flap + lag + twist + axial motion)

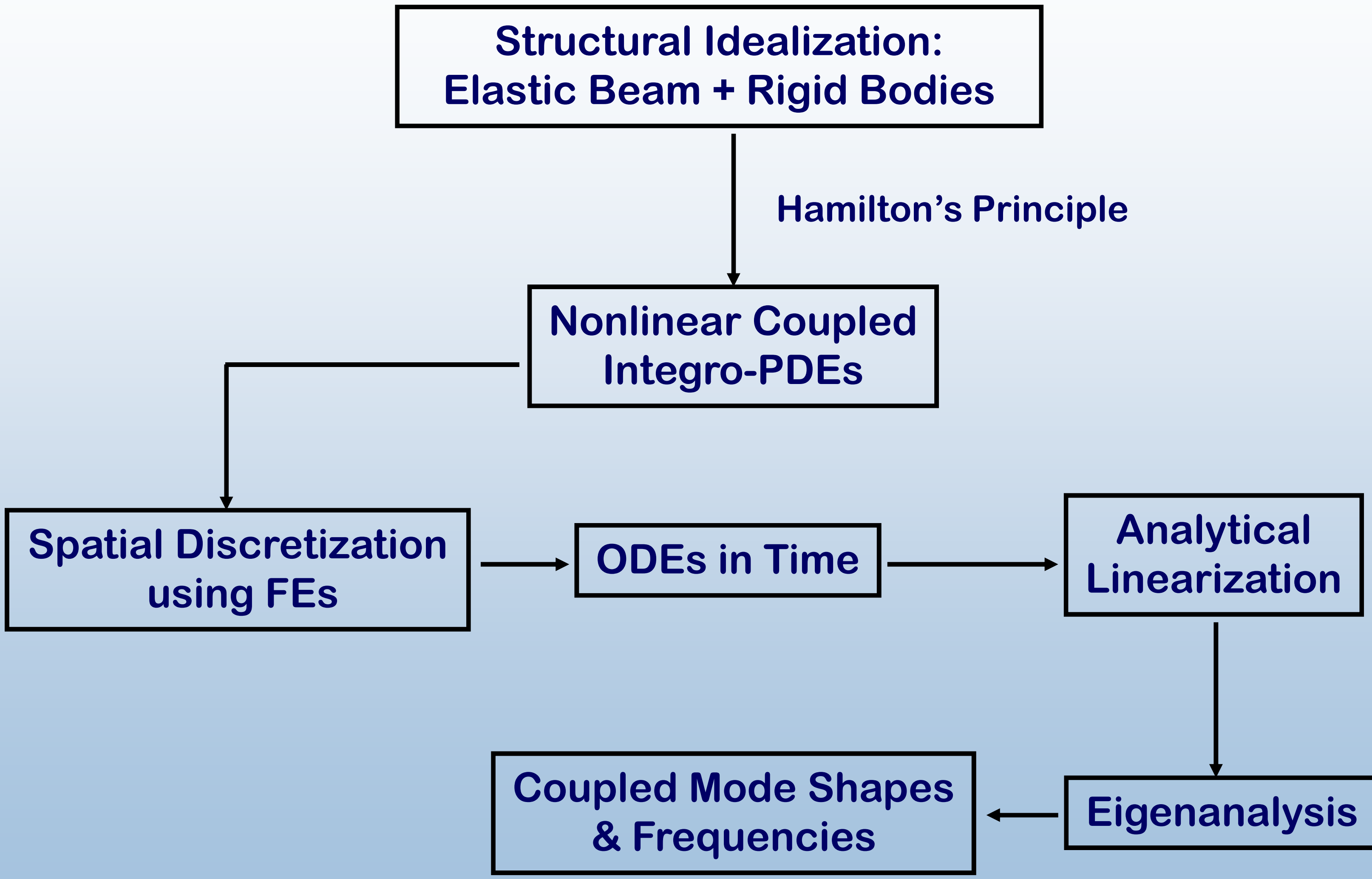
BModes Usage for Towers

- Tower configurations that BModes can model:
  - Land-based tower
    - With tower-top inertia
    - with or without tension-wires support
  - Offshore tower :
    - supported by monopile in elastic foundation (no multi-pod supports)
    - supported by floating-platform (TLP, barge or spar-buoy with mooring lines)

BModes Usage for Towers (cont'd)

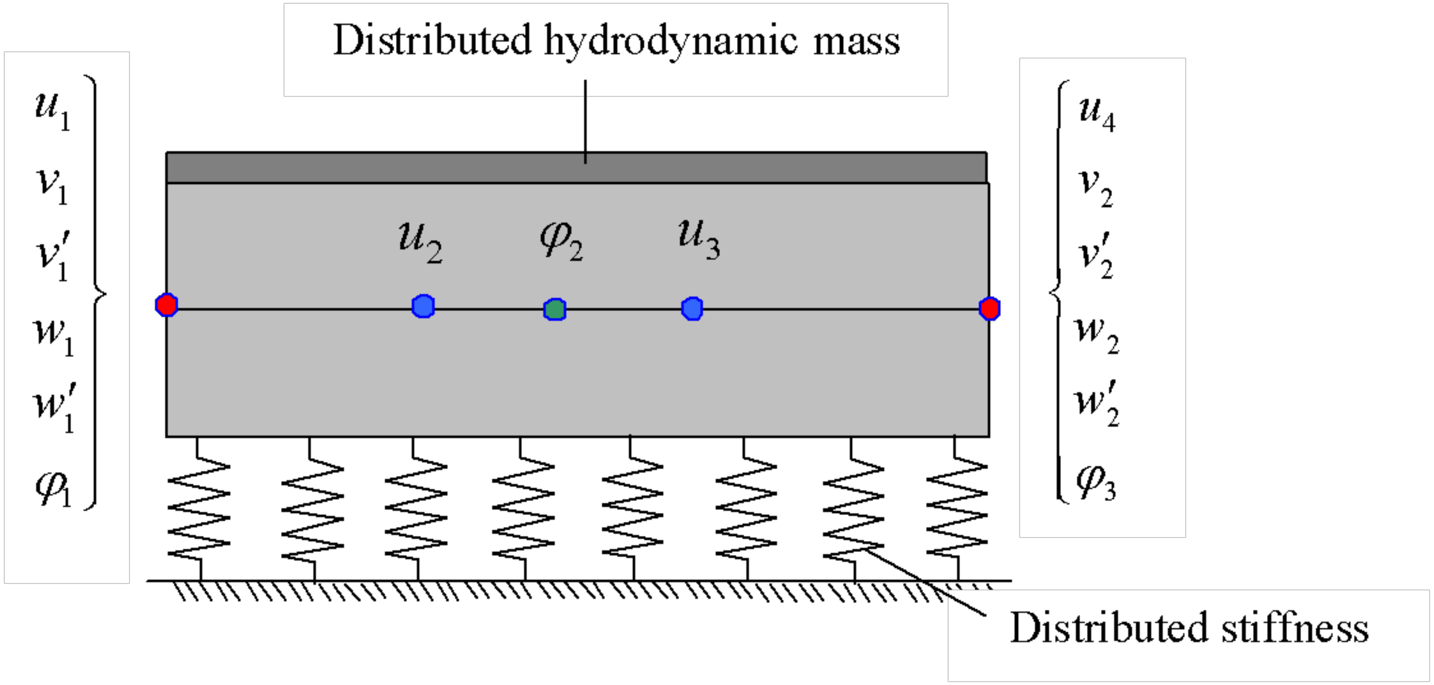
- **Given:**
  - Tower distributed geometric & structural properties
  - Tower-head inertias and c.m. offsets from tower top
  - Tension-wires stiffness and geometric layout
  - Floating-platform hydrodynamic & hydrostatic properties + mooring lines 6x6 stiffness matrix
  - Monopile foundation elastic properties
  - Hydrodynamic added mass on submerged part of the elastic tower
- **Computes:**
  - Modal frequencies & coupled mode shapes (coupled → fore-aft + side-side + twist + axial motion)

Technical Approach



Finite Element Used in BModes

Uses 15-dof finite element with two external and three internal nodes



Salient Features of BModes

- Rotational effects (centrifugal, Coriolis, tennis-racket, etc) included
- Finite-element assembly specialized to handle spatial-integral terms
- Arbitrary distributed beam properties
- Provision for precone & pitch control setting
- Potential to handle a complex range of boundary conditions
- Linearized equations derived analytically

BModes: Other Applications

- Experimental validation or code-to-code verification of blade & tower components
- Modal reduction
- Physical interpretation of dynamic couplings
- Aid modal-based stability analysis
- Modal-based fatigue analysis

BModes Validation

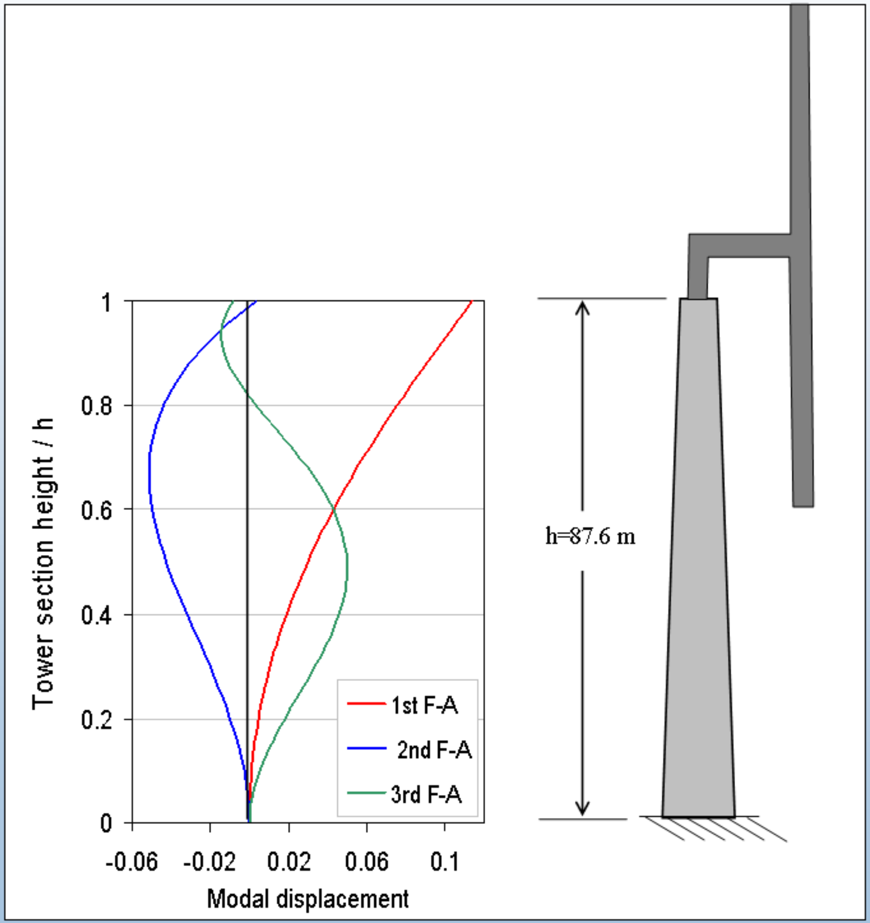
- **For blades:**
  BModes validated extensively using models ranging from a rotating string to realistic blades.
- **For towers:**
  Verification in progress.

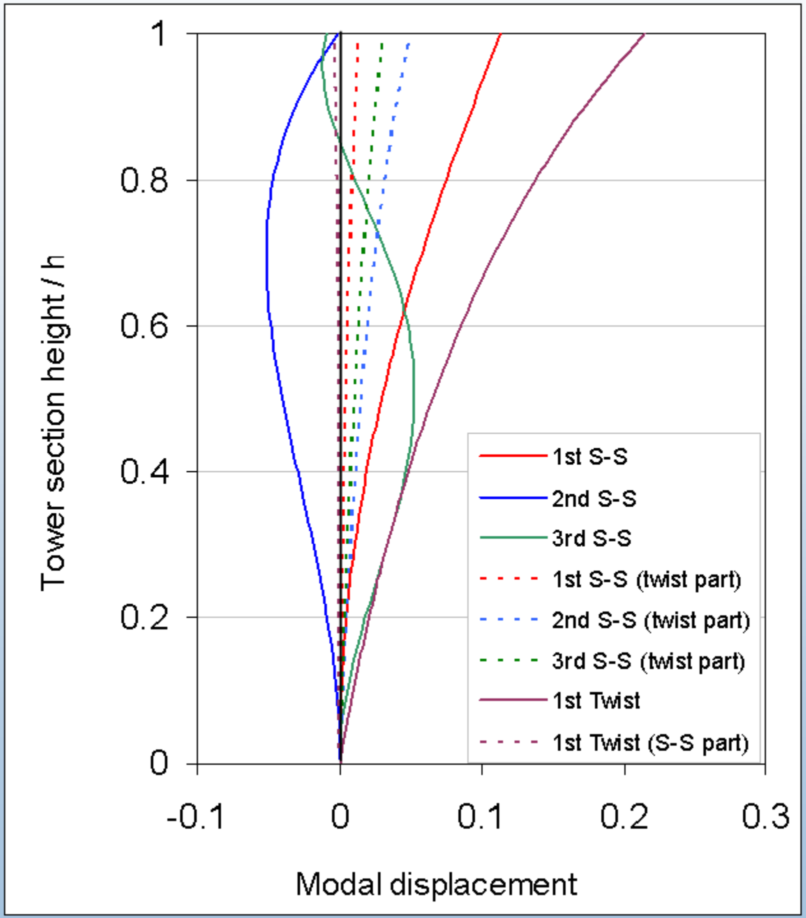
Sample Results for Towers (NREL 5MW Turbine)

Land-Based Tower: Modal Frequencies

Mode Number	Mode Type	Without Head Mass Frequency (Hz)			With Head Mass Frequency (Hz)		
		BModes	ADAMS	Diff	BModes	ADAMS	Diff
1	1st SS	0.8913	0.8904	0.001	0.3291	0.3188	0.010
2	1st FA	0.8913	0.8904	0.001	0.3324	0.3218	0.011
3	2ndSS	4.3743	4.3437	0.031	1.8805	1.8820	0.002
4	2nd FA	4.3743	4.3435	0.031	2.2432	2.2391	0.004
5	3rd SS	11.3911	11.1856	0.205	4.6526	4.7244	0.072
6	3rd FA	11.3911	11.1843	0.207	4.9865	5.1833	0.197
7	1st Torsion	11.9656	11.4448	0.521	1.4703	1.4763	0.006
8	1st Axial	16.5217	16.5222	0.001	8.1311	7.9375	0.194
9	4th SS	21.8655	21.1146	0.751	11.3142	11.2678	0.046
10	4th FA	21.8655	21.1093	0.756	11.4591	11.4719	0.013
11	2nd torsion	27.7783	26.1221	1.656	17.9632	17.9535	0.010
12	5th SS	35.8273	33.8392	1.988	21.7054	21.3291	0.376
13	5th FA	35.8273	33.8236	2.004	21.7625	21.4419	0.321
14	2nd Axial	43.4596	42.1715	1.288	30.2109	30.1182	0.093
15	3rd Torsion	44.8623	43.4578	1.405	35.3975	34.5078	0.890
16	6th SS	53.2770	48.9445	4.332	35.6336	34.5830	1.051
17	6th FA	53.2770	48.9071	4.370	35.6636	35.3740	0.290
18	4th Torsion	62.2312	58.6564	3.575	52.9449	50.5171	2.428

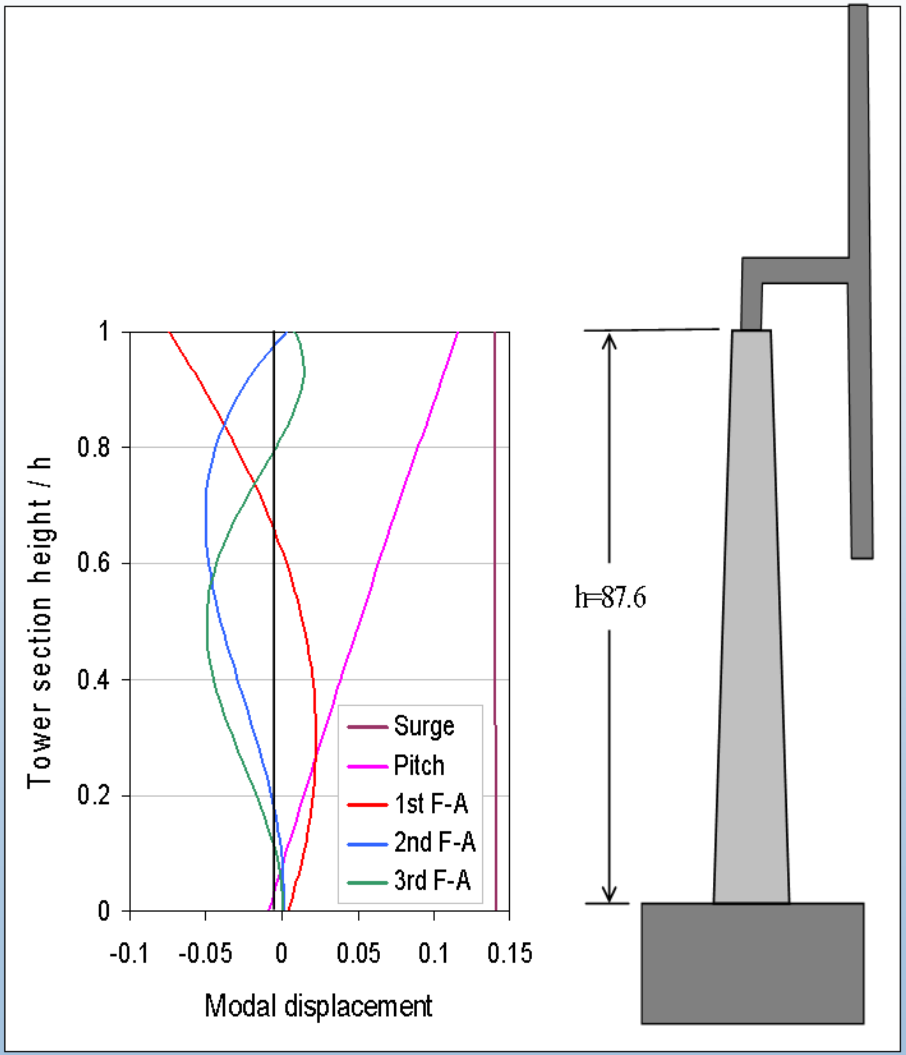
Land-Based Tower: Mode Shapes



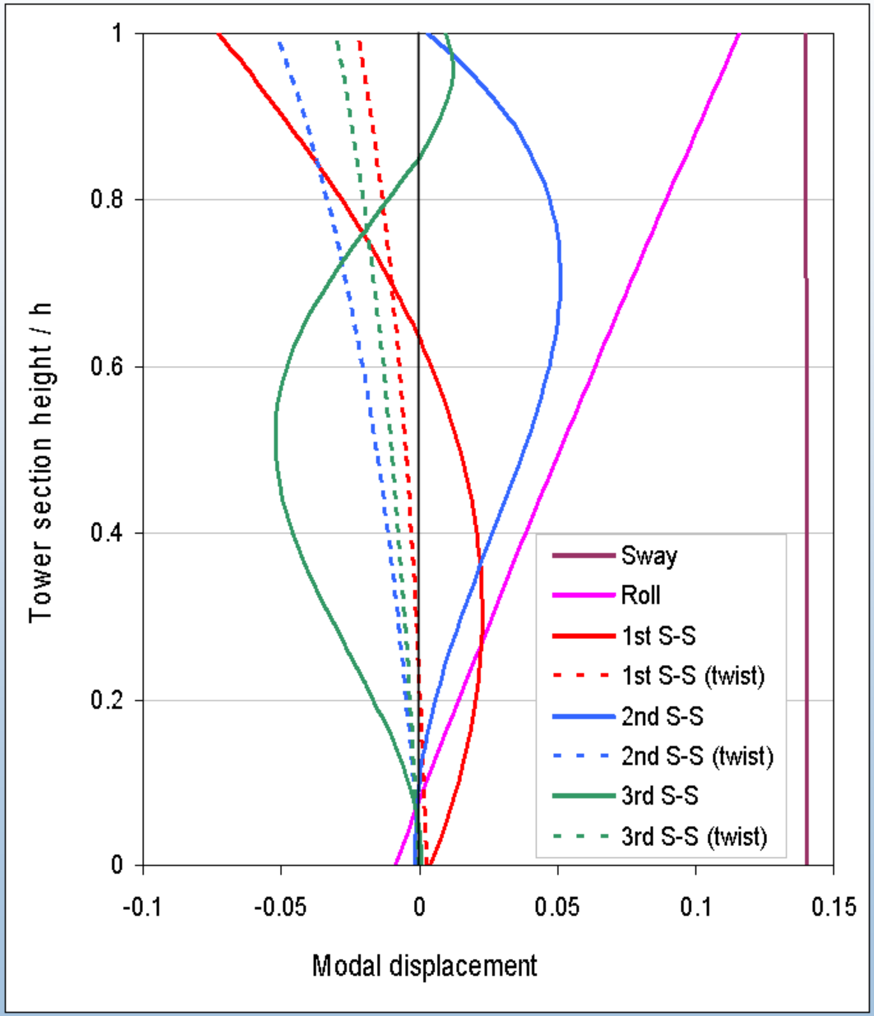


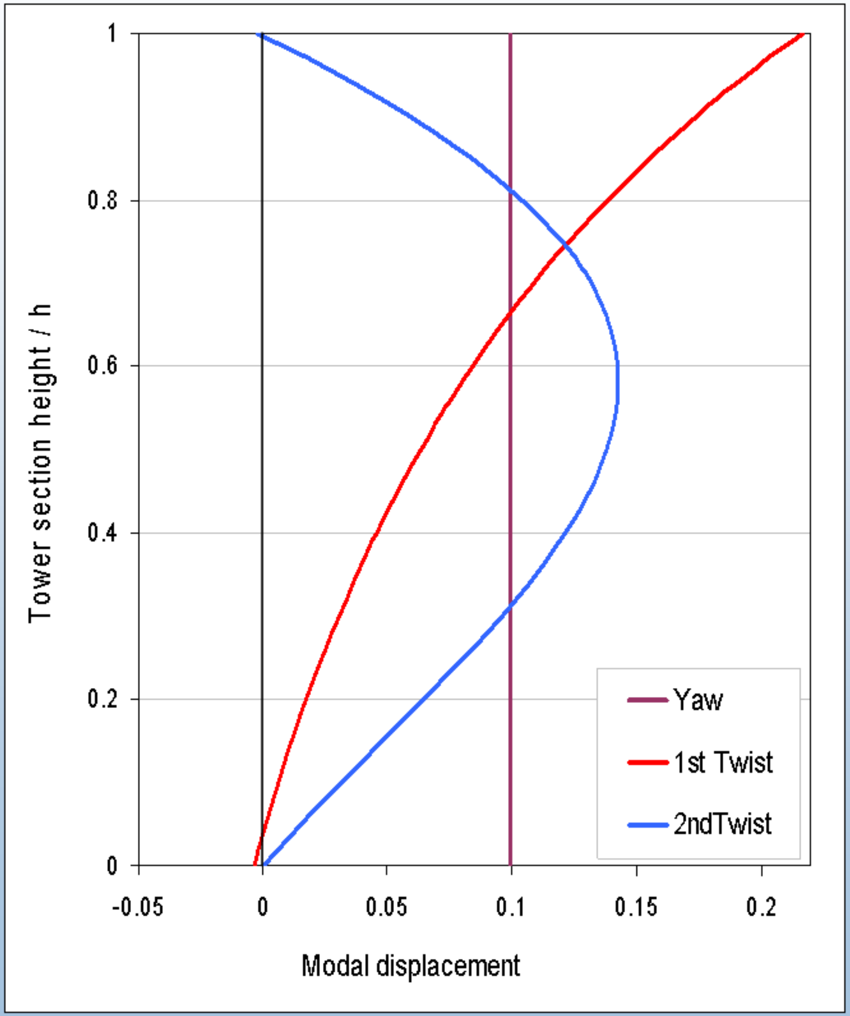
Barge-Supported Turbine Modes

		Frequency (Hz)			
		BModes			ADAMS
Mode Number	Mode Type	Platform Inertia Only	Platform Inertia + Hydrostatic & Mooring Stiffness	Full Platform Model	Full Platform Model
1	Surge	0.0000	0.0081	0.0076	0.0076
2	Sway	0.0000	0.0081	0.0076	0.0076
3	Yaw	0.0000	0.0206	0.0198	0.0198
4	Roll	0.0000	0.1106	0.0978	0.0966
5	Pitch	0.0000	0.1109	0.0980	0.0968
6	Heave	0.0000	0.2576	0.1283	0.2463
7	1st SS	0.7349	0.7671	0.5489	0.5374
8	1st FA	0.7494	0.7820	0.5556	0.5440
9	1st Torsion	1.4836	1.4836	1.4826	1.4890
10	2nd SS	1.9943	1.9962	1.9270	1.9327
11	2nd FA	2.3652	2.3666	2.2942	2.2950
12	3rd SS	4.7559	4.7562	4.7011	4.7742
13	3rd FA	5.0799	5.0801	5.0293	5.2260
14	1st Axial	8.5014	8.5017	8.2186	8.2759
15	4th SS	11.3835	11.3835	11.3542	11.3138
16	4th FA	11.5280	11.5280	11.4983	11.5167
17	2nd Torsion	17.9683	17.9683	17.9679	17.9639
18	5th SS	21.7584	21.7584	21.7406	21.3760

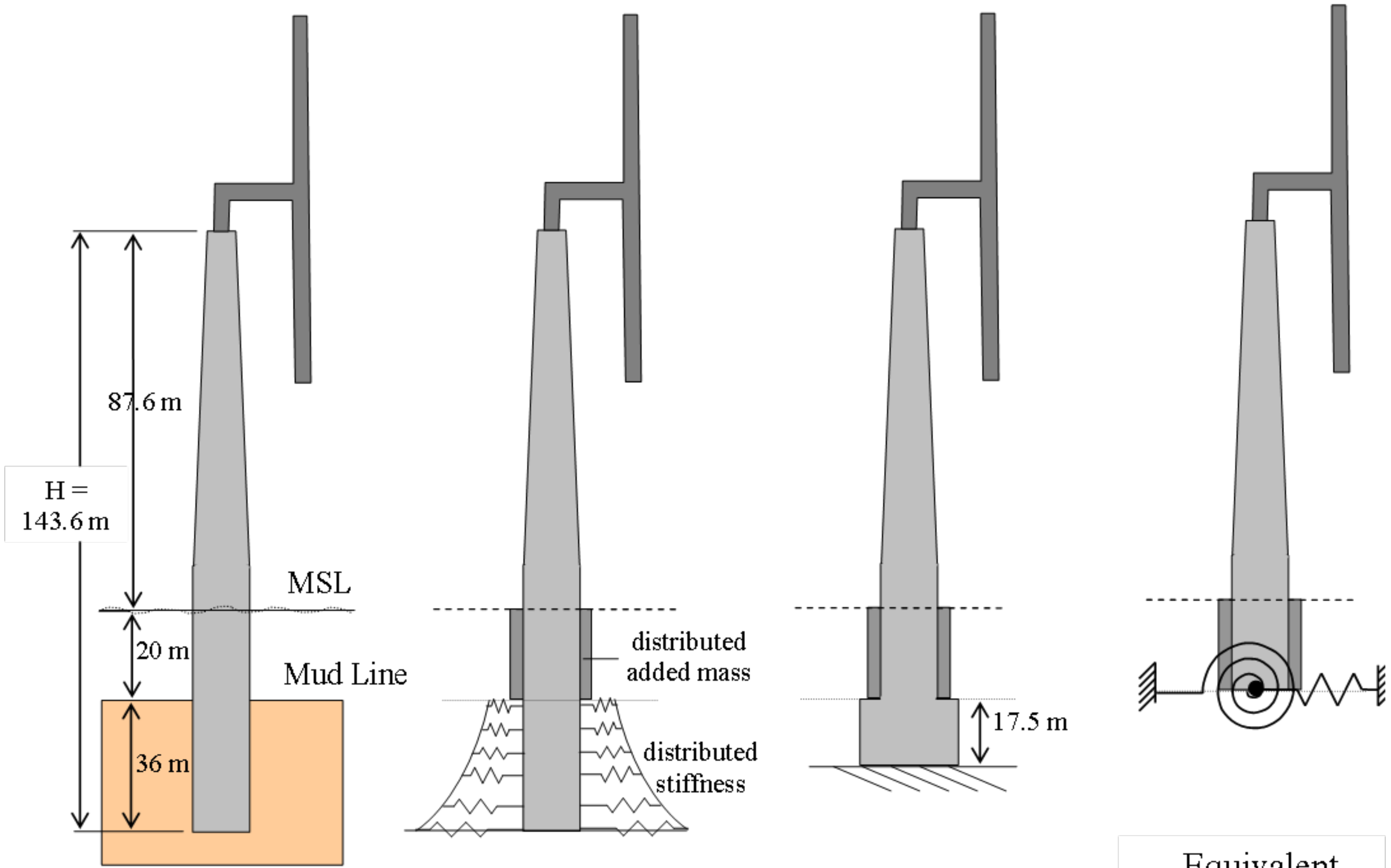


Barge-Supported Turbine Modes





Monopile-Supported Turbine: Equivalent Models



Monopile Support

Distributed Spring Model (DS)

Equivalent Fixity Model (EF)

Equivalent Coupled-Spring Model (ECS)

OC3-HyWind-Spar-Buoy Turbine Modal Frequencies

Mode Number	Mode Type	Frequency (Hz)		
		BModes	ADAMS	FAST
1	Surge	0.0081	0.0070	0.0080
2	Sway	0.0081	0.0081	0.0080
3	Heave	0.0324	0.0312	0.0324
4	Roll	0.0362	0.0340	0.0342
5	Pitch	0.0363	0.0341	0.0343
6	Yaw	0.1205	0.1211	0.1210
7	SS-1	0.4816	0.4763	0.4573
8	FA-1	0.4908	0.4855	0.4733
9	Twist	1.5697	1.5710	---
10	SS-2	2.0524	2.0539	3.9664
11	FA-2	2.5540	2.5491	4.2527
12	SS-3	6.0022	5.9987	---

Future Plans

- Introduce upgrades
- Complete verification. Release BModes-3 along with new user's manual.
- Integrate BModes with CFD (collaboration with NASA)
- Provide for composites
- Integrate with FAST
- Extend formulation for curved blades.