

IEA Annex XXIII

Offshore Code Comparison Collaborative (OC3)

10th Full Committee Meeting

Risø National Laboratory
Roskilde, Denmark

March 13, 2009, 9:00 – 16:00

Agenda

NOTE: Actual agenda times differed from planned.

9:00 Welcome and Introductions (All)

9:15 Review the OC3 Project

- Review IEA Annex XXIII, the OC3 project, and OC3 Phases I through III (JJ)

9:45 Phase IV (Floating) Model

- Review the model, load cases, and output parameters (JJ)

10:15 Break

10:30 Phase IV Participant Status and Initial Results

- Discuss the floating wind turbine research, modeling approaches, and status of each participant (All)
- Present and discuss the initial (Rev. 1) results (All)

12:00 Lunch

13:00 Phase IV Future Planning

- Discuss possible refinements to the model (JJ/All)
- Discuss the remaining load cases and output parameters (JJ/All)
- Identify the conference for a Phase IV paper/presentation (All)

14:30 Break

14:45 Wrap-Up

- Discuss the final OC3 report (JJ)
- Schedule next meeting(s) (All)
- Discuss possible follow-on projects (All)
- Any other items of business (All)

16:00 Adjourn

Attendees:

José Azcona	JA	CENER, Spain
Gunjit Bir	GB	NREL, USA
Ivar Fylling	IF	Marintek, Norway
Zhen Gao	ZG	NTNU, Norway
Jason Jonkman	JJ	NREL, USA
Bjarne Kallesøe	BK	Risø-DTU, Denmark
Madjid Karimirad	MK	NTNU, Norway
Martin Kohlmeier	MK	University of Hannover, Germany
Torben Larsen	TL	Risø-DTU, Denmark
Karl Jacob Maus	KM	Norwegian University of Life Sciences, Norway
James Nichols	JN	Garrad Hassan, UK
Tor Anders Nygaard	TN	Norwegian University of Life Sciences, Norway
Hyunchul Park	HP	Pohang University of Science and Technology (POSTECH), Korea
Javier Pascual Vergara	JP	Acciona Energia, Spain
Patrick Passon	PP	Rambøll Wind Energy, Denmark
Rune Rubak	RR	Siemens Wind Power, Denmark
Jan Quappen	JQ	University of Stuttgart, Germany
Fabian Vorpahl	FV	Fraunhofer Institute – IWES, Germany
Jesper Winther Stærdahl	JW	Siemens Wind Power, Denmark

Apologies for Absence:

Sandy Butterfield	SB	NREL, USA
Anders Hansen	AH	Risø-DTU, Denmark

Minutes:

Welcome and Introductions (All)

JJ – Welcomes everyone to the meeting and thanks TL and Risø-DTU for hosting it.

All – Introduce themselves. Most attendees know each other from prior meetings.

Review the OC3 Project

JJ – Gives a brief review of the OC3 project. The Offshore Code Comparison Collaboration (OC3) operates under Subtask 2 of IEA Annex XXIII, which is an annex that covers critical research areas relating to offshore wind energy. The OC3 project was established as an international forum for offshore wind code verification. The project tests a number of aero-hydro-servo-elastic offshore wind turbine simulation codes using a series of benchmark models and simulations. Phase I considered the NREL 5-MW baseline wind turbine on a monopile with rigid foundation. Phase II considered the same turbine on a monopile with flexible foundation.

Phases III considered the same turbine on a tripod. Phase VI will consider the NREL 5-MW turbine on a spar-buoy-type floating platform. Load case simulations have been chosen to test different features of the model, with complexity increasing in each case. Results from Phases I through III are summarized. Most of the code-to-code comparisons have agreed quite well. Differences have been traced back to differences in model fidelity, aerodynamic implementation, discretization, and numerical problems.

IF – Questions to the group the proper way to account for buoyancy in fixed-bottom offshore structures and why one would integrate the pressure over the surface of the body instead of simply applying a volume integration with a correction for end effects?

TL – Suggests that for stiff structures, it is far easier to model the buoyancy with a direct pressure integration.

JJ – Adds that when one directly integrates the hydrostatic pressure that includes the instantaneous wave elevation, they capture both the hydrostatic buoyancy and the change in buoyancy from the passing waves—the latter of which is one contribution of the wave excitation force (the other contribution to the wave excitation force is the wave inertia force).

JJ – Stops the discussion here and refers the group to the minutes from the Esbjerg meeting, in which we had a very similar discussion.

Phase IV (Floating) Model

JJ – Gives a presentation on the floating system developed for use in Phase IV of OC3. The specifications of the conceptual Hywind spar for a 5-MW turbine were obtained from StatoilHydro and JJ “sanitized” the data so that it is acceptable for public distribution. Aspects of the original Hywind design were also adapted by JJ so that the platform design is appropriate for supporting the NREL 5-MW baseline turbine. So, the OC3 system is a modified version of the conceptual Hywind system, now known as the OC3-Hywind system. The presentation covered an overview, the tower properties, the floating platform structural properties, the floating platform hydrodynamic properties, the mooring system properties, the control system properties, and the initial load case simulations and output parameters. The presentation also explained the three modifications to the OC3-Hywind system that have been made since the system was first presented at our meeting in Esbjerg last September. These modifications pertained to (1) the platform inertias, (2) the mooring system, and (3) the platform hydrodynamic damping (all indicated by “New!” in the presentation).

JW and TL – Request that in addition to the complete model (Option 1), the simplified linear model (Option 2), and the simplified nonlinear load-displacement model (Option 3), which were supplied by JJ, a fourth mooring system model option should be made available. JW and TL request that Option 4 be a 1D nonlinear load-displacement model for a single mooring line (this is in contrast to Option 3, which is a 6D nonlinear load-displacement model for the complete mooring system). JW suggests that the data for this model should be supplied in MIMOSA format, which gives the fairlead total tension, fairlead horizontal tension, and anchor (total = horizontal) tension as a function of horizontal displacement of the fairlead. JJ agrees to supply the data for Option 4 based on a mooring analysis with NREL’s FAST code.

ACTION: JJ – Will derive the 1D nonlinear load-displacement data for a single mooring line and make the data available to the OC3 group for those that want to pursue Option 4.

Phase IV Participant Status and Initial Results

TL – Highlights the important features of HAWC2, which is an aeroelastic tool developed at Risø-DTU that uses a combined multibody and FE structural-dynamics model, including constraints. HAWC2 includes many important features for modeling wind turbines, including BEM-based aerodynamics, dynamic stall, wake meandering, large-displacements, blade torsion, etc. Recent work has been done to introduce a Morison-formulation-based hydrodynamics model for general space-frame-type support structures, and an improved eigensolution for floating offshore systems. Mooring lines can be modeled by importing nonlinear force-displacement curves from an external code, like MIMOSA. HAWC2 is being applied to the modeling of a two-bladed wind turbine installed offshore with a Poseiden floating wave energy device.

GB – Is developing a code called BModes, which can calculate the coupled mode shapes of offshore support structures (among other applications), including towers attached to monopiles with flexible foundations and floating platforms. Verification of the model with ADAMS has been done for several different offshore support structures. The introduction of gravitational stiffening is the next major upgrade planned.

JW – Is developing the capability of modeling floating spar-type wind turbines with Siemens' BHawC code for use in modeling the Hywind system in collaboration with StatoilHydro. BHawC is a nonlinear FE-based aero-elastic code. Hydrodynamic effects are included using strip theory and only linear damping is included. Mooring effects are included by using nonlinear springs supplied by StatoilHydro (derived from MIMOSA), by augmenting the platform mass to account for mooring system inertia (with different masses in each direction), and by augmenting the platform damping in yaw (for mooring line hydrodynamic damping). JW is verifying their BHawC model by comparing its responses to the responses obtained by a model in HAWC2 coupled with Simo-Riflex (as is being run by StatoilHydro).

JN – Is expanding the capabilities of GH Bladed so that it can better model floating wind turbines. JN has added the ability to include large rigid-body displacements of the system on which the structural modes are superimposed. Hydrodynamic effects are modeled using a Morison's formulation. Mooring effects are included by introducing a nonlinear set of 6x6 stiffness matrices. These new features will be verified within OC3 Phase IV.

IF – Is modeling the Hywind and OC3-Hywind systems in both the frequency- and time-domains. MIMOSA is used for the frequency-domain analysis. Simo is used for the time-domain analysis and has been extended recently to include a BEM implementation for the rotor aerodynamics and a four-body rigid-body model of the wind turbine (rotor, nacelle, tower, and spar bodies connected by springs). The BEM model has been verified via comparison to FAST-generated results. Simo includes a linear potential flow hydrodynamics model, including slow-drift forces. The results show considerable dynamic behavior of the mooring system.

MK – Describes his Ph.D. work in which he is modeling the Hywind and OC3-Hywind systems. The elastic modes of the tower and spar buoy have been modeled with ABAQUS. The mooring

system has been modeled with the nonlinear FE model within DeepC (Simo-Riflex). The frequency response of the system has been modeled and compared with three different hydrodynamic models: a DeepC-based panel model, a DeepC-based Morison's model, and a HAWC2-based Morison's model.

JA/JP – Describe the EOLIA project for deepwater offshore wind, which is a project in collaboration between CENER, Acciona, and other partners. The project includes a number of work packages that focus on extending the capabilities of FAST with AeroDyn and HydroDyn, including introducing torsional DOFs in the blades and tower, the DYSTOOL dynamic stall code, mooring line dynamics models, and 2nd order hydrodynamics. The models will be applied to the analysis of different floating platform concepts, verified within OC3 and by comparison to Simo-Riflex, and validated with experimental data (e.g., wave tank tests).

MK – Presents an overview of his simulation model for Phase III and Phase IV. MK is coupling the tools WaveLoads, ADAMS, and AeroDyn. WaveLoads generates the wave kinematics (linear or higher-order) and hydrodynamics loads on the structure via Morison's equation. ADAMS models the structural-dynamics of the wind turbine and support structure using a multi-body dynamics representation. The ADAMS models of the wind turbine are created by the FAST-to-ADAMS preprocessor. AeroDyn computes the aerodynamic loads on the wind turbine. Future work will be aimed at improving the hydrodynamic and buoyancy loading on moveable substructures and adding models for mooring system restoring.

TN – Presents his initial Phase IV results using the 3Dfloat code. 3Dfloat is a nonlinear FE-based code with 12-DOF Bernoulli-Euler beam elements, with geometric nonlinearities accounted for by a co-rotation approach. The drivetrain and turbine blades are currently modeled as rigid. Aerodynamic loads are calculated using unsteady BEM based on the AERFORCE subroutine library. Hydrodynamic loads are calculated using Morison's equation, plus buoyancy. Turbine controllers similar to other codes are included. The mooring system is modeled with finite elements also. A model of the NREL offshore 5-MW baseline turbine + OC3-Hywind Phase IV platform has been developed, with the results compared to those of JJ from FAST. Most everything compares quite well, with the biggest difference in element (2,4) of the linearized restoring matrix from all mooring lines. Future work will be aimed at implementing the evaluation of damping ratios, introducing flexible blades, and importing wind and wave fields.

All – Examine the initial Phase IV load case simulation results obtained to date. So far, results have been submitted by JJ with the FAST and ADAMS codes, by JN with GH Bladed, by JA with SESAM (with hydrodynamics both by a Panel and Morison's method), by TL with HAWC2, and by IF with Simo. The load cases run so far include a full-system eigenanalysis and a full-system static equilibrium solution.

For the eigenanalysis, all codes agree on the heave frequency. Also, all the codes agree on the surge, sway, and yaw frequencies, except for GH Bladed, which overpredicts the frequencies. JN – Explains how GH Bladed's eigensolver fails at low frequencies and that they are still trying to resolve the problem.

For the pitch and roll frequencies, the predictions from HAWC2 and Simo are higher than the predictions from the other codes (with HAWC2 being higher than Simo).

TL – Is unsure what is causing the difference in the HAWC2 model. TL also mentions that HAWC2 neglects gravity while linearizing, which is important for the restoring of a deep-drafted spar. However, including gravitational restoring will push the natural frequencies in pitch and roll even higher.

Fewer of the codes predict the natural frequencies of the flexible body modes, including the tower and blade bending modes. For the codes that do, all codes predict similar blade bending natural frequencies, with only a slight discrepancy in the 2nd blade bending frequencies, which have been seen in earlier Phases of OC3 (and are related to the tower-torsion DOF). For the tower-bending natural frequencies, FAST, ADAMS, and HAWC2 agree quite well whereas the predictions from GH Bladed are high.

For the static equilibrium case, the mooring line tensions/angles at the fairlead agree quite well for those codes that output them. But there are some differences in the static equilibrium position of the platform and in the tower-top and tower-base loads. The biggest outlier is the static heave displacement prediction from HAWC2, which predicts that the platform will sink nearly 1 m whereas all of the other codes predict virtually no settling.

All – Will continue to improve their models and submit updated simulation results.

Phase IV Future Planning

JJ – Gives a presentation discussing possible (1) refinements to the Phase IV (OC3-Hywind) model, (2) load case simulations to complete Phase IV, and (3) conferences where a paper summarizing Phase IV might be published/presented. Discussions were had on each of these topics and are summarized below:

(1) Refinements to the OC3-Hywind model

JJ – Explains how the only property of the OC3-Hywind system that has yet to be characterized is the relationship between the incident wave kinematics (including the wave elevation) and wave excitation forces. There is a dilemma here that we have not seen in the previous phases of OC3. In summary, for those who apply linear potential-flow theory (augmented with viscous drag), their wave excitation force calculations require that they know the amplitudes and phases of each frequency component of the incident waves. And for those who are given the wave kinematics and apply Morison's formulation, their hydrodynamic forces must be supplemented with a heave force. JJ proposes three options to address this dilemma: (1a) to have one OC3 member define the wave kinematics and supply to all while having everyone implement a time-domain convolution to obtain the heave force (see the presentation for details), (1b) to have one OC3 member define the wave kinematics and supply to all while having everyone approximate the heave force as the change in buoyancy brought about by direct integration of the hydrostatic pressure dependent on the time-varying wave elevation, (2) to have one OC3 member define both the wave kinematics and heave forces and supply to all, and (3) to each his own.

TL – Suggests that a fourth option, Option 1c, could be to have one OC3 member define both the wave kinematics and the amplitudes and phases of each wave component and apply to all. This will aid those who choose to apply linear potential-flow theory. And for those who apply

Morison's formulation, they can define their own way to supplement Morison's formulation with a heave force calculation, such as by choosing the approach from Option 1b.

All – Agree that Option 1c is the best.

ACTION: TL and JN – Will check into whether it is possible to output, in addition to the time-domain wave kinematics (including the wave elevation), the amplitude and phase of the wave components in the frequency domain from HAWC2 and GH Bladed, respectively. One of them will then generate the data for the selected load case simulations (see point 2 below), and supply the data to the OC3 group.

(2) Load Case Simulations to Complete Phase IV

JJ – Presents his proposal for load cases that should be simulated in completion of Phase IV. These include, DLCs 4.1, 4.2 and 5.1 through 5.3 from the previous phases, and new loads cases including those that will test the system's frequency response, the system's damping, and the system's instabilities. (See the presentation for details about these load cases).

All – Agree after much discussion that DLCs 4.1, 4.2 and 5.1 through 5.3 from the previous phases, and at least two new loads cases will be considered. The first new load case will be used to test the OC3-Hywind's frequency response, as proposed by JJ. This load case will consider steady, uniform, nonsheared winds at rated (11.4m/s), regular Air waves with different frequencies in each simulation, the turbine control system and all DOFs enabled, and will simulate until a periodic steady-state condition is reached. The output will be the amplitudes of the platform motions (i.e., time-domain-generated Response Amplitude Operators). The second load case will be used to test the OC3-Hywind system's damping, by modeling the free-decay tests that have already been presented with the FAST code by JJ.

ACTION: JJ – Will add these load cases to the load case definition matrix and simulation results spreadsheets and send the spreadsheets to the OC3 group.

ACTION: All – Will then run these additional simulations for our code-to-code comparisons.

(3) Phase IV Conference Paper

JJ – Suggests the European Offshore Wind (EOW) 2009 Conference and the 2010 AIAA Aerospace Sciences Conference as two potential candidates for a venue where we can publish/present a paper summarizing Phase IV.

All – Agree that EOW 2009 was approaching too quickly.

All – Agree that we should bring up this question at a later date.

ACTION: All – Select an appropriate conference where we can publish/present a paper summarizing Phase IV.

Wrap-Up

JJ – Discusses how the final paper will be simply a concatenation of the four conference papers generated by each Phase of the OC3 project, with any updates to the results that are available. The final paper will give everyone a chance to publish their OC3 simulations, even if they couldn't provide results in time for the publications of the papers regarding the results of the individual Phases.

ACTION: All – Send any new simulation results from Phases I - IV to JJ when completed.

The **next net-meeting** is scheduled for **Tuesday, May 19, 2008** at 3pm local German time. We will use this net-meeting to discuss the load case simulations for Phase IV.

The **next physical meeting** is tentatively scheduled for **Thursday, September 17, 2009** in Stockholm, Sweden. This is the day immediately following the European Offshore Wind (EOW) 2009 Conference, which is taking place in Stockholm on September 14-16. This is the last physical meeting planned for the OC3 project.

ACTION: TL – Will contact a local company in Stockholm to see if they are willing to host this meeting. If no one is willing to host the OC3 meeting, JJ will book a meeting room at the EOW venue or in a nearby hotel.

Possible follow-on projects that could be started after Phase IV has been completed were discussed outside of the scheduled meeting time. These projects include additional code-to-code comparisons and code-to-test-data exercises. NREL would like to participate in such follow on projects, but wants to give up the leadership of the project to another institute who is willing to accept the leadership responsibilities. FV from the Fraunhofer Institute IWES of Germany has expressed interest in leading at least a project involving the code-to-code comparisons for a fixed-bottom jacket support structure. This topic will be discussed more a future OC3 meeting.

ACTION: All – Bring up the issue of OC3 follow-on projects at a future meeting.