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A Detailed Look into the 2017 SNAME OC-8 Comparative Wind Load Study

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Abstract

This paper documents the results from the 2017 Society of Naval Architects and Marine Engineers (SNAME) OC-8 Panel Comparative Wind Load Study. Initial unpublished results were presented at a one-day panel at the 2017 SNAME Maritime Convention; however, the final results are brought together for the first time in this paper.

A blind, comparative study was organized through the SNAME OC-8 Panel in 2017 to assess the relative accuracy and repeatability of existing wind load estimation methods. Twenty-five companies and organizations throughout the world participated in this study, which encompassed three available wind load estimation methods: empirical building block procedures, wind tunnel testing, and Computational Fluid Dynamics (CFD). To permit an 'apples-to-apples' comparison, the same representative semisubmersible design was used by all participants, including a single physical model shipped consecutively to each of the five wind tunnel facilities participating in the study.

The most significant finding from the study is the remarkably low variability in wind tunnel and CFD results relative to the empirical building block method incorporated in the U.S. Code of Federal Regulations (CFR), classification rules, and industry codes for stability calculations. Moreover, only wind tunnel and CFD results were able to accurately quantify the contribution of a lifting force and its effect on the overturning moment. The lessons learned from the comparative study will be incorporated into a long-awaited revision to SNAME's wind tunnel testing guideline, and has inspired the development of a new industry guideline which will broadly address wind load estimation methods in design, including the use of CFD throughout the design spiral.

Introduction

Current U.S. regulation of floating offshore production platform stability mandates that final wind load estimates be completed using a traditional building block method. The empirical building block procedure simplifies the flow interaction problem by use of standard shape coefficients assigned to the dominant structural components. During preliminary design, the empirical building block procedure is ideal for quickly generating preliminary wind load estimates. Not surprisingly, empirical method procedures have been known to both over-predict (Numata 1976) and under-predict (Boonstra 1982, Miller 1982) the wind overturning moment as compared with wind tunnel test results. For this reason, it is common for wind tunnel test results and experience (chiefly gleaned from wind tunnel tests of similar platforms) to guide the development of more accurate empirical building block models.

Wind tunnel testing, as the name implies, involves physical measurements of the wind loads (drag and lift forces & overturning moment) acting on a scale model. Systematic wind tunnel testing is the de facto industry standard for accurately predicting forces and moments on offshore units. Nevertheless, wind tunnel test results are not currently accepted by U.S. regulatory authorities for use in stability calculations.

CFD, simply stated, is the numerical equivalent of wind tunnel testing. With CFD, the fluid domain in a virtual wind tunnel is discretized, and the Navier-Stokes equations which govern the air flow over the model are numerically solved; the forces and moments acting on the virtual model are solved directly from the pressure forces acting on the model's surface. More recent advances in computing resources have allowed CFD applications to extend beyond the realm of academia and into industry. While CFD promises to be an important tool in offshore wind load estimation, the offshore industry lacks a means of assuring the accuracy and repeatability of the results (i.e., short of direct comparison against wind tunnel measurements).

In 2016, the SNAME OC-8 Panel first recognized the need to broadly and contexually assess the relative accuracy and repeatability of available wind load estimation methods. The desire from the Panel's perspective was to better understand the real-world variability in wind load estimates for an identical model using (1) the same method (e.g., CFD estimates produced by Contractor A vs. Contractor B), and (2) the variability between wind load estimation methods (i.e., CFD vs. wind tunnel vs. empirical building block models). In response, the SNAME OC-8 Panel organized a 'first-of-its-kind' comparative wind load study to benchmark the relative accuracy and repeatability of the three wind load estimation methods for a representative semisubmersible. To enable a true 'apples-to-apples' comparison, model geometry was simplified to the point where the exact same geometry (without further simplification or modification) could be used directly by all three methods.

The comparative wind load study sought to achieve three principal objectives:

- Provide a direct comparison of wind loads for an identical geometry using all three available estimation methods
- Serve as a blind validation of the revised SNAME T&R Bulletin 5-4 (Guidelines for Wind Tunnel Testing of Mobile Offshore Drilling Units (MODUs) and Floating Offshore Installations (FOI))
- Provide a foundation for the development of an original SNAME guideline intended to broadly address wind load estimation for offshore floating systems throughout the entire design spiral

The central finding of the study was the remarkably low variability of the experimental (wind tunnel) and numerical (CFD) results relative to the empirical method. The identification of erroneous experimental data in the study also suggests the value of adopting a simple verification model to ensure the accuracy of wind tunnel results.

Set-up

Model Selection & Simplification. A representative semisubmersible was selected for the SNAME OC-8 Panel Comparative Wind Load Study. Model geometry was adapted from the Houston Offshore Engineering's Paired-Column (PC) semi. Topsides and hull geometry were simplified to a point where only rudimentary shapes remained and the exact same geometry could be used by all three wind load estimation methods without further modification.

A 1:240 scale was dictated by the model test facilities. Tests were performed for a typical in-place operating condition. To control for variability among the different wind tunnel facilities, the same physical model (above water portion only) was shipped to and tested by each of the five wind tunnel participants. Several topsides elements of the plastic polycarbonate model were made removable to facilitate experimentation in which the impact on wind forces and moments through removal of representative topsides components could be systematically studied. Surface roughness from the three-dimensional printing process was left in-place and no additional surface roughness was added by any of the wind tunnel test facilities.

The CAD geometry (Fig. 1) was given to all CFD and empirical method participants. From a CFD perspective, the objective was to replicate the wind tunnel model, as opposed to the full-scale model, assuming an unbounded fluid domain. The CFD participants directly imported, without further modification, the provided CAD geometry to the meshing software used to discretize the fluid domain. From an empirical method perspective, the provided geometry had to be deconstructed and rebuilt within the various software packages, as discussed later in the paper.

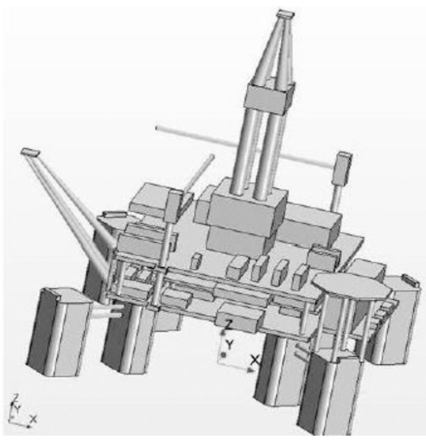

Figure 1—Geometrically simplified adaptation of HOE's Paired-Column (PC) semisubmersible

Wind Profile. The target mean wind speed profile is the NPD (Norwegian Petroleum Directorate) model, which is given as:

$$U(z) = U(z_{ref}) * \left[1 + 0.0573 * \sqrt{1 + 0.15 * U(z_{ref})} * \ln\left(\frac{z}{z_{ref}}\right)\right]$$

where U(z) is the wind speed [m/s] as a function of height, z_{ref} is the reference height above the mean water level, and $U(z_{ref})$ is the design wind speed at the reference height. The dynamic pressure at the reference height, q_{ref}, is given as:

$$q_{ref} = \rho * U(z_{ref})^2/2$$

Wind Loads. All wind loads are normalized by the following equations:

$$C_F * S = \frac{F_{ms}}{q_{ref}} \quad ; \quad C_M * S * L = \frac{M_{ms}}{q_{ref}}$$

where C_F and C_M are the (drag and lift) force and moment coefficients about the origin, S is the projected area, L is the characteristic (reference) length, and F_{ms} and M_{ms} are the force and moment magnitude in model-scale. To ensure consistency, the overturning moment is reported about the axis at the waterline, as opposed to an axis below the waterline coinciding with the center of lateral resistance.

There exists only uniform scaling of measured loads between model-scale and full-scale. Even though the Reynolds number for the wind tunnel model and full-scale do not match, no correction is applied as allowed for in the (1988) SNAME T&R Bulletin 5-4.

The presented measures of variability in reported wind loads, or data scatter, is standard deviation (σ) and relative standard deviation (σ_r) – the standard deviation divided by the mean value, expressed as a percentage.

Coordinate System. Two reference frames are generally used for defining wind loads. The first is the wind coordinate system with the x-axis aligned with the direction of wind flow and the z-axis taken as positive upwards. The second is the body fixed coordinate system which remains fixed to the model as it rotates. For the comparative study, the origin of coordinates is located on the horizontal plane comprising the design waterline at the geometric center of the model. Before the model is rotated, the wind and body fixed coordinate systems are identical. At 0n heading, flow first encounters the north side of the structure, where the flare boom is located. The direction of the wind for other headings is depicted in Fig. 2.

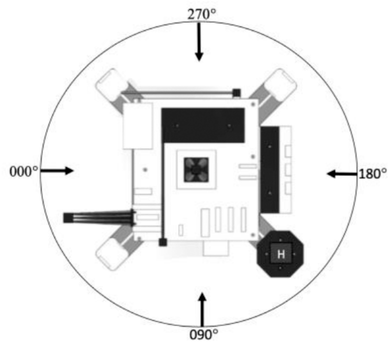

Figure 2—Relative wind headings

For the comparative study, wind forces and moments are presented in the wind coordinate system rather than the body axis. Results expressed in the wind coordinate system provide ready insight into how the forces and moments vary with wind direction and can be readily compared with calculations (Miller 1982).

Methods/Process

The wind load comparative study was organized into three working groups, one for each wind load methodology. Altogether, 25 organizations representing a wide spectrum of industry stakeholders contributed to this original study.

The comparative study fixed parameters were provided to the participants and are listed as follows:

- Model geometry: CAD model provided to all CFD and empirical method participants; physical model supplied to each wind tunnel
- NPD wind profile with reference velocity of 51.4 m/s (100 knots) at 10 m height (full-scale)
- Unbounded fluid domain (as a target)

Otherwise, participants produced wind loads for the representative semisubmersible in an uncoached manner, as detailed in following subsections. Submitted data was stripped of identity prior to blind, initial comparison.

Empirical Methods Program. The empirical methods working group consisted of eleven individual participants representing the following stakeholder groups: classification societies, operators, engineering companies, and research institutions. Each participant was provided an identical geometric model and asked to provide wind load estimates by use of their own in-house practice; some participants replicated the geometry as nearly as possible (Fig. 3(a)), while others grouped details together thereby further simplifying the model (Fig. 3(b)).

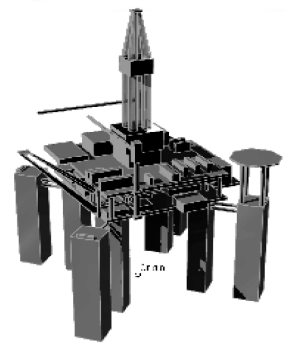

Figure 3(a)—Detailed model

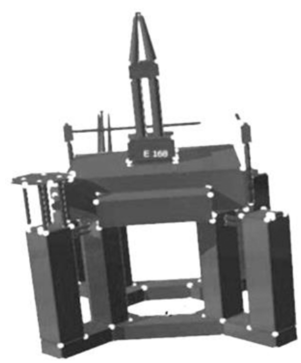

Figure 3(b)—Rationalized model

The flexibility afforded to the participants led to the use of three distinct model types. The first (and simplest) was the two-dimensional spreadsheet model, which typically accompanies concept design. The second type (e.g., ABS EagleWind) uses three-dimensional geometries to rigorously model each individual 'block' as the platform is rotated and heeled. The third type (e.g., WINDOS) expands the three-dimensional model by including theoretical and empirical corrections that account for shielding of in-line structures and for lift forces on elevated, inclined decks (Walree 1991).

Initial empirical method results to the comparative study were submitted blind. The uniqueness of the eight-column geometry made it difficult for the participants to directly apply past experience. In an effort to reduce the initial variability of calculated wind loads, results were compared and participants shared lessons-learned in an open-forum discussion. Following this collaboration, participants were given an opportunity to revisit their wind load model and submit a second-round estimate. With the three-dimensional empirical models, the second-round estimates (as a group) exhibited a similar degree of data scatter as with the first-round.

The two-dimensional spreadsheet estimates have been omitted from the comparative study results reported herein owing to the variability of the constituent geometries and to the large observed data scatter. The remaining empirical method data contributed to the comparative study is summarized in Table 1:

Table 1—Empirical Methods Program

No.	Participant	Round	Program	Model Detail
1	A	I	GHS	Detailed
2	B	II	WINDOS	Detailed
3	C	I	WINDOS	Detailed
4	C	I	WINDOS	Detailed
5	D	I	WINDOS	Detailed

No.	Participant	Round	Program	Model Detail
6	D	II	EagleWind	Detailed
7	E	II	EagleWind	Detailed
8	E	II	EagleWind	Rationalized

CFD Program. Ten organizations, relying on individual best practices, provided CFD data for the SNAME OC-8 Panel Comparative Wind Load Sudy. The following stakeholder groups were represented: classification societies, operators, engineering companies, research institutions, and academia. In the absence of an industry guideline, the intent was to quantify the 'real-world' accuracy of CFD relative to wind tunnel testing based on current industry practice, and the 'real-world' variability in CFD estimates from one participant to the next. The performance of numerical convergence studies (used to confirm that results are independent of modeling parameters, such as mesh size) was encouraged but not required.

With only the target wind profile and model geometry specified, individual preference and best practice informed all other modeling aspects including, but not limited to, the following:

- CFD software
- Turbulence model (e.g., RANS or LES) and solution type (steady or unsteady)
- Means of generating the target wind profile
- CFD fluid domain size and boundary condition mathematical definitions
- CFD mesh type, refinement, and size
- CFD solver settings

The CFD data contributed to the comparative study is summarized in Table 2:

Table 2—CFD Program

Participant	Software (Solver)	Mesh Size (*10^6)	Turbulence Model(s)	Experience (yrs.)	
				CFD	Software
A	ANSYS Fluent	36.5	k-ω RANS	11	9
B	ANSYS Fluent	77	LES / WALE SGS model	30	30
C	Foam-Extend	12.8	k-ω RANS	2.5	2.5
D	OpenFOAM	32	k-ω RANS	8	7
E	ReFresco	14	k-ω RANS	5	2
F	STAR-CCM+	–	k-ω RANS	3	10
G	STAR-CCM+	9.5	k-ω RANS	5	3
H	STAR-CCM+	39.4	k-ω URANS, IDDES	6	4
I	STAR-CCM+	62.9	k-ω RANS, URANS	15	5
J	STAR-CCM+	11.9	SA RANS, k-N RANS	27	6

Note: Only participant 'H' provided two sets of data where the results were unique enough to regard as being separate.

Wind Tunnel Program. The primary objective of the wind tunnel program was for five independent and established wind tunnels to produce above waterline force and moments for the eight-column semisubmersible model. To control for variability, the same physical model was shipped to and tested by each wind tunnel. Four of the five participant wind tunnels are of the boundary layer (BL) type, commonly referred to as wind engineering tunnels. One participant is a low-speed aeronautical research tunnel (LS-Aero). Boundary layer type wind tunnels are characterized by a long section upwind to the model where a well-developed boundary layer profile is created by a floor arrangement of spires and blocks. In contrast to the former, a low-speed aeronautical tunnel usually has a shorter length between the test and contraction sections—a design that lends itself to uniform flow with less boundary layer development at the walls. When testing offshore platforms, a low-speed aeronautical tunnel is able to simulate the target air-sea atmospheric boundary layer by use of horizontal bars arranged at uneven intervals in an upwind, vertical plane. Both type tunnels can be either open or closed circuit. Closed circuit design offers superior flow control and precludes the external setting (e.g., temperature, wind) from influencing test conditions. The open circuit design, with inlet and outlet open to the external setting, has its advantages in construction cost and flow visualization, among others. The particulars for the five wind tunnel facilities that participated in the SNAME OC-8 Panel Comparative Wind Load Study are provided in Table 3:

Table 3—Wind tunnel particulars

Type	**BL**	**BL**	**BL**	**BL**	**LS-Aero**
Circuit	Closed	Open	Open	Closed	Closed
Test Section(height × width) [m]	12.0 × 2.5	1.8 × 2.6	1.83 × 1.83	2.4 × 4.8	2.1 × 3.1
Blockage Ratio	0.4	2.8	3.5	1.0	1.8
Max speed (m/s)	12	7.5	45	45	89.4
Max Re/m (*10^6)	0.82	0.51	3.08	3.08	6.12

The differences associated with tunnel type and design may have negligible effect on offshore platform wind load estimates given adherence to validated guidelines. Historically, one of the major holdbacks to the general acceptance of wind tunnel testing on offshore platforms is the absence of a validated governing industry standard. The present study, conducted in accordance with a draft of the upcoming revision to SNAME T&R Bulletin 5-4, attempts to close this gap. This revision includes several new features intended to improve the accuracy and repeatability of wind tunnel testing:

- Elimination of Reynolds number (Re) corrections
- Tighter tolerances on wind profile simulation
- Adoption of standard nomenclature, data reduction, and data reporting

It is largely impossible to achieve dynamic similitude with the full-scale offshore platform during scale model testing. The next best thing is to perform a convergence study to demonstrate that the measured parameters are insensitive to changes in Re. Each wind tunnel participating in the study recorded force and moments for the model for a range of reference velocities at least 25% greater than or less than the nominal velocity used for the remainder of the testing. This test was repeated at three separate headings (0°, 30°, 45°) at zero inclination. Each wind tunnel produced well-converged loads, which indicates negligible Reynolds number dependence, i.e., C_F/C_M is independent of Re.

Each wind tunnel constructed a unique atmospheric boundary layer profile simulation system to achieve the target NPD wind profile. The permitted velocity deviation from the target NPD profile was set, as stated in the draft guidelines, at +/- 2.5%; or, approximately +/- 5% dynamic pressure. All wind tunnels achieved satisfactory profiles (Fig. 4). As demonstrated in Fig. 4, the percentage wind speed deviation (from the target) was largest at the height of the columns. In practice, considerably more effort is required to match the target profile near the boundary, where the wind velocity is much lower and precision is not as critical.

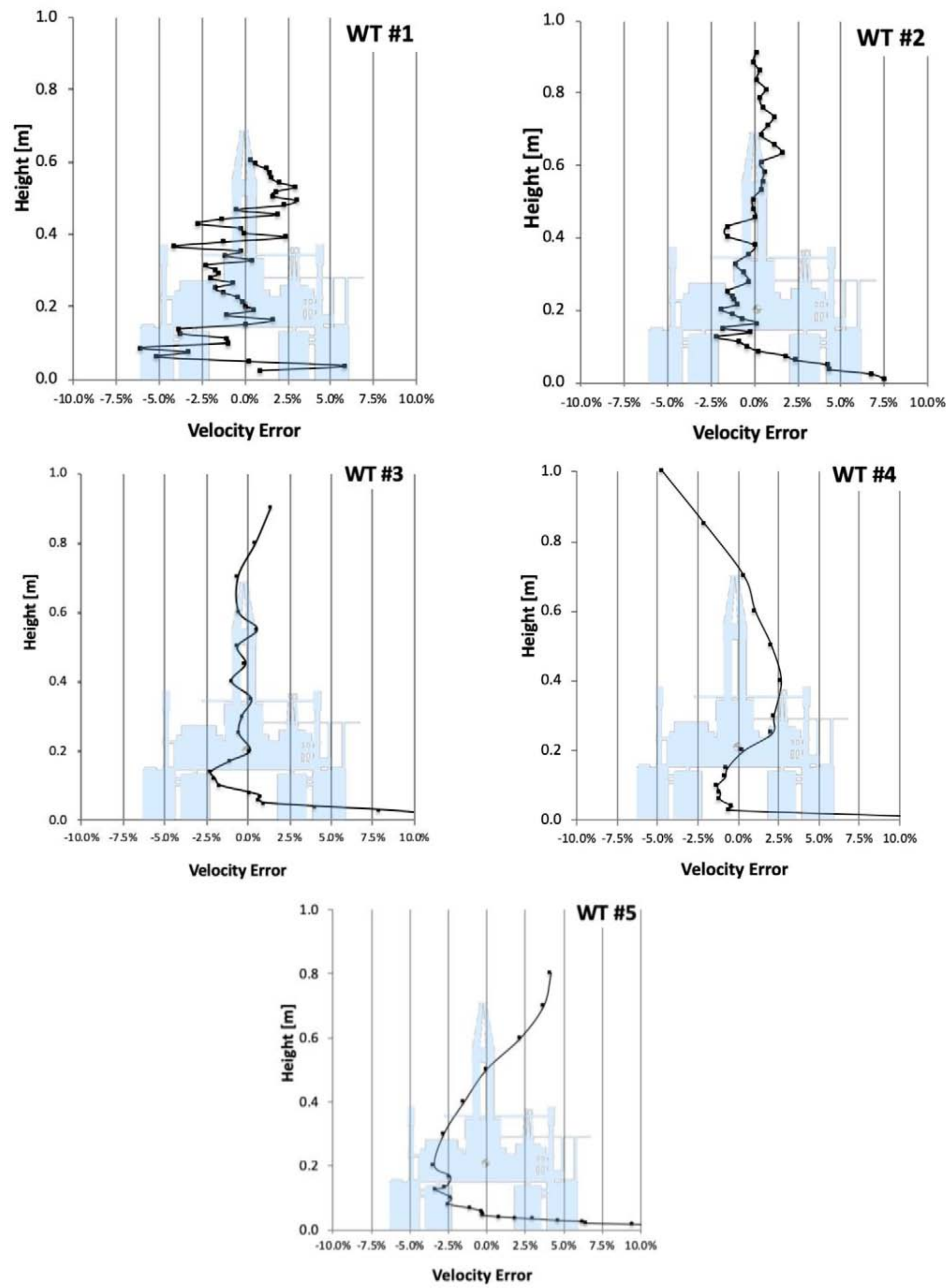

Figure 4—Wind tunnel boundary layer profiles, percentage velocity error w/ respect to NPD target

It was readily apparent during the initial data comparison that at least some of the data from two wind tunnels was erroneous. These errors, obvious outliers when compared with the full data set, had to do with a reference velocity measurement error and an isolated procedural error. In each case, the missteps were identified and remedial testing produced satisfactory data which has been reported herein in lieu of the original (erroneous) data.

Once testing for the comparative study had concluded, replicate wind tunnel tests were carried out in two of the five wind tunnels. The goal of the follow-on testing was to determine the experimental repeatability of a single wind tunnel relative to the agreement in wind loads from one facility to the next. The replicate wind tunnel test velocity profiles and wind load results are presented in a later, dedicated subsection.

Results

Key results from the comparative study are presented in the following three subsections, organized as follows:

- Empirical methods, CFD, and wind tunnel results for an even-keel condition at a range of relative wind headings
- Empirical methods, CFD, and wind tunnel results for the critical wind heading, 135E (helideck oriented in the upwind direction) at 0°, 5°, 10°, 15°, and 20° inclinations
- Replicate wind tunnel tests at the same facility (with similar but not identical test set-ups)

All force and moment data is plotted in non-dimensional form. Mean values for each of the three methodologies are presented as trendlines. The standard deviations are presented alongside the means. Presentation of lift force data is limited to wind tunnel and CFD because the empirical method is inherently incapable of quantifying the lift force.

Rotation at even-keel. Forces and moments were reported at 15° heading intervals for a full rotation of the model at even-keel. The model's symmetric qualities lent to a consistent pattern of wind loads with each quarter-rotation of the model. Therefore, the presentation of wind loads for the even-keel condition is limited to a representative 135° to 180° heading range. Mean values of the force components and overturning moment for the critical heading, 135° at even-keel are provided in a bar graph (Fig. 8) to facilitate a readily-made comparison between methodologies.

The following observations can be made from the comparative plots for rotation at even-keel condition:

- For the drag force (Fig. 5): The wind tunnel and CFD mean values are in strong agreement. In comparison, the empirical method overpredicts the wind-induced drag force by approximately 40%. The standard deviation of the empirical method is three times greater than that of the wind tunnel and CFD results.
- For the lift force (Fig. 6): For the wind tunnel and CFD results, the magnitude of the lift force is 20% of the mean magnitude of the drag force. The wind tunnel mean values are marginally greater than the CFD values. The lift force average standard deviations are consistent to those of the drag component (although the relative standard deviation of the lift force is quite large because of the relatively small magnitude of the lift force).
- For the overturning moment (Fig. 7): The convergence of the wind tunnel and the CFD mean values is consistent to drag and lift. The empirical method mean values overpredict the overturning moment by approximately 50% relative to the wind tunnel and the CFD mean values. The average standard deviation of the empirical method data is three times greater than the wind tunnel and CFD.

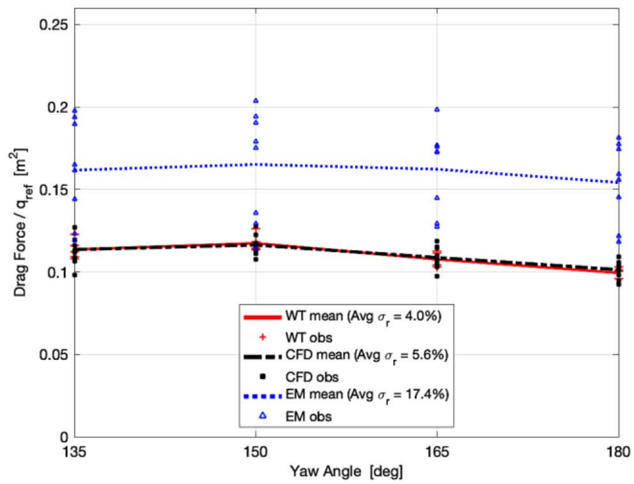

Figure 5—Even-keel condition – Drag force

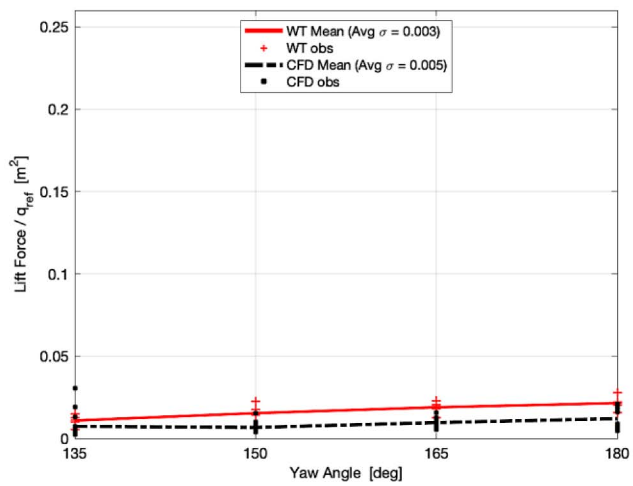

Figure 6—Even-keel condition – Lift force

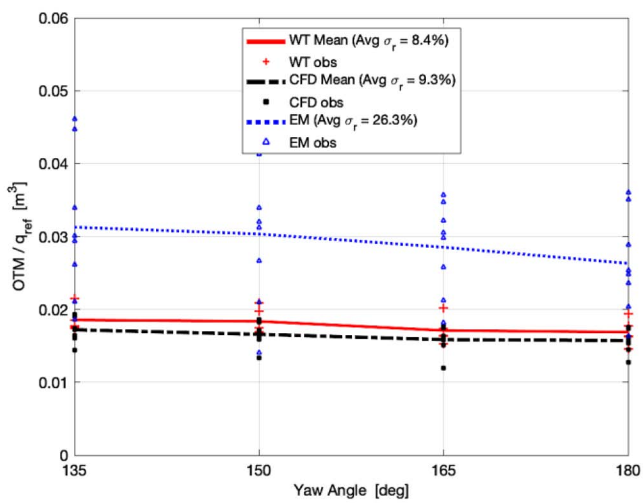

Figure 7—Even-keel condition - Overturning moment

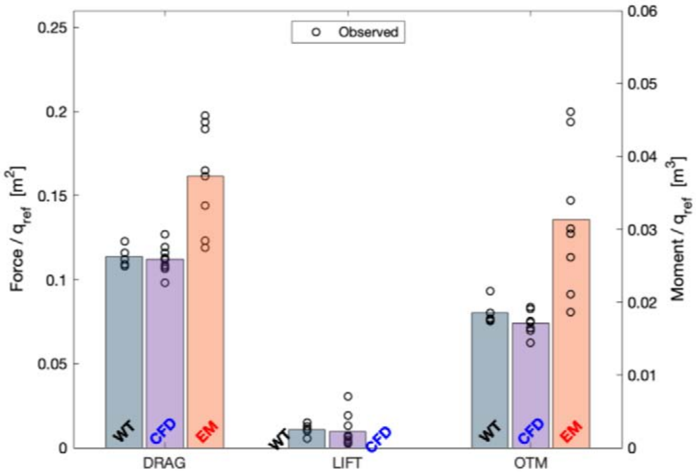

Figure 8—Even-keel condition at critical heading (135°) - drag, lift & overturning moment mean values

Critical heading with various heel angles. Individual contributions are plotted at 5I heel intervals, ranging from the even-keel condition (0 inclination) to the maximum, 20 inclination (the model is first rotated, and then heeled). Wind load mean values at maximum inclination are provided in a bar graph (Fig. 12) to facilitate a readily-made comparison between methodologies.

The following observations can be made from the heel sweep comparative plots:

- For the drag force (Fig. 9): Wind tunnel and CFD mean values are in strong agreement, remaining within 5% of each other. The empirical method mean values are consistently at least 30% larger.
- For the lift force (Fig. 10): Wind tunnel and CFD mean values demonstrate strong convergence for the even-keel condition, but agreement slightly diminishes with increasing heel angle. Wind tunnel and CFD (relative) standard deviations are 16% and 11%, respectively. At maximum inclination, the lift force magnitude is approximately 75% of the drag force. The presented average relative standard deviations do not include data for zero inclination because of the vanishing mean lift force.
- For the overturning moment (Fig. 11): The empirical method mean value is approximately 50% more than the wind tunnel and CFD mean values. However, two of the eight total empirical method data sets closely track the wind tunnel and CFD results. At the maximum inclination, these two data sets actually under-predict the moment relative to both, wind tunnel and CFD mean values. The average standard deviation of the empirical method results is approximately five times greater than the wind tunnel and the CFD results.

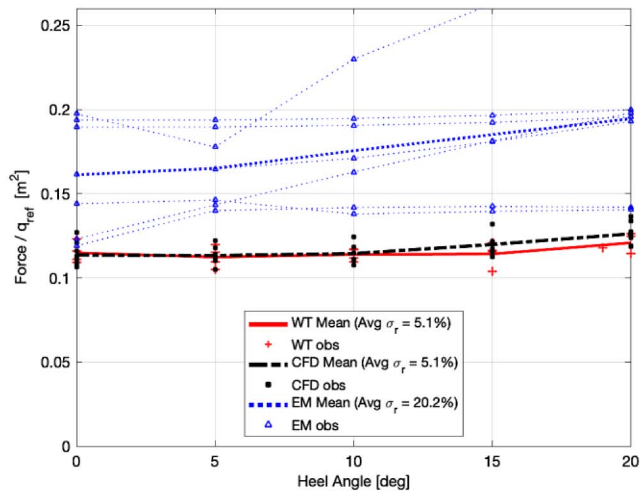

Figure 9—Critical heading – Drag force

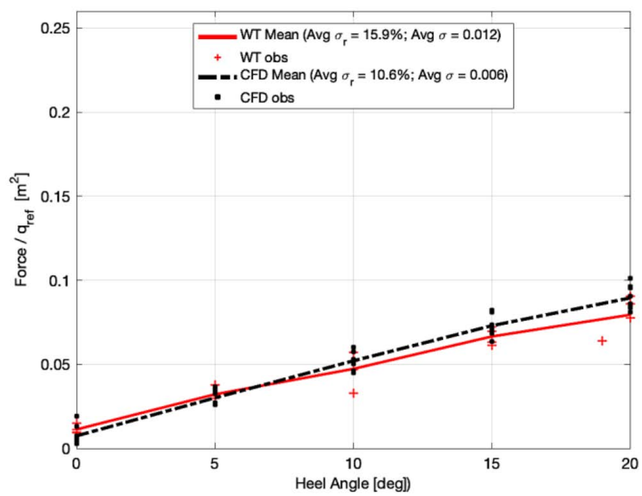

Figure 10—Critical heading – Lift force

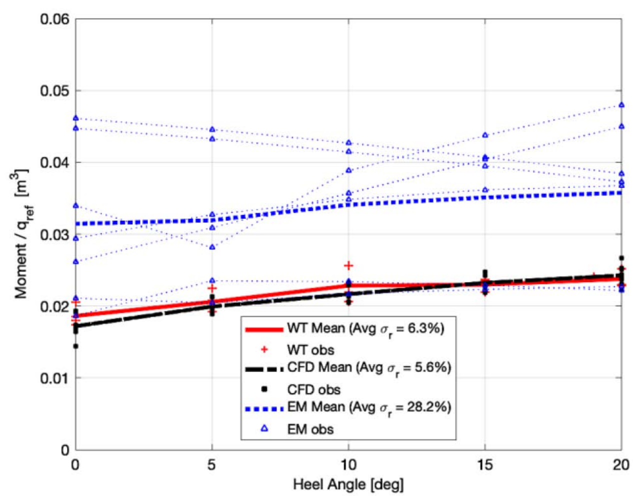

Figure 11—Critical heading – Overturning moment

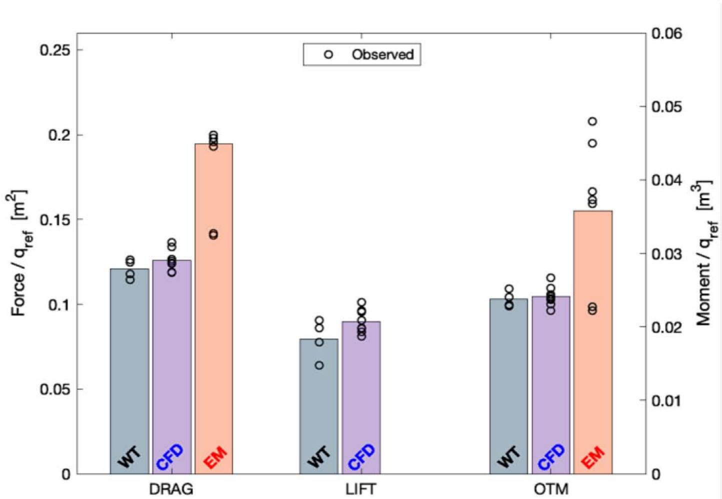

Figure 12—Max heel (20°) at critical heading – drag, lift & overturning moment mean values

Wind Tunnel Repeatability Study. As a follow-up to the comparative wind load study, the same physical semisubmersible model was retested by two of the original five wind tunnel participants. The impetus for replicate testing was to assess the variability of results from a single wind tunnel facility.

Achieving similar wind tunnel results requires reproducing a similar experimental set-up, including the time-intensive process to model the target atmospheric boundary layer. The interim one-year between initial and replicate tests ensured that the wind tunnel set-up would be similar, but not identical, to the original test setup.

Boundary layer profiles and the percentage velocity deviation from the respective targets are presented in Fig. 13. The corresponding drag forces and overturning moments for the 0° to 180° heading range at even-keel are compared in Figs. 14(a) **and** 14(b). The accompanying lift forces (not shown) exhibited an equivalent degree of precision. Next, lift forces for the various inclined orientations at heading 135° are presented in Fig. 15. Figs. 14 and 15 include a solid trendline with error bars representing the mean, maximum and minimum values, respectively, from the initial round of testing involving all five wind tunnels.

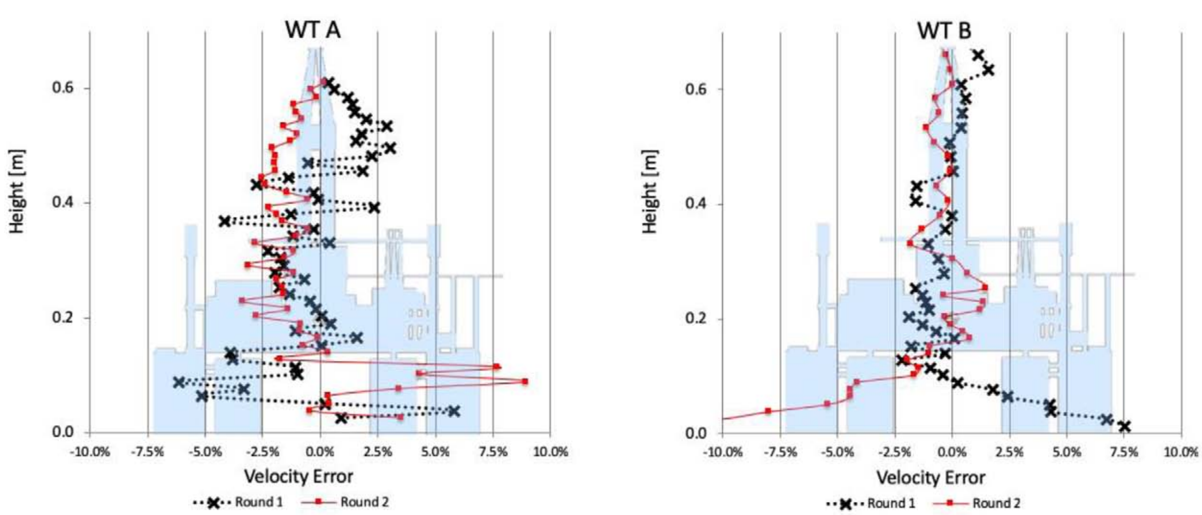

Figure 13—Boundary layer profiles – Rounds 1 & 2

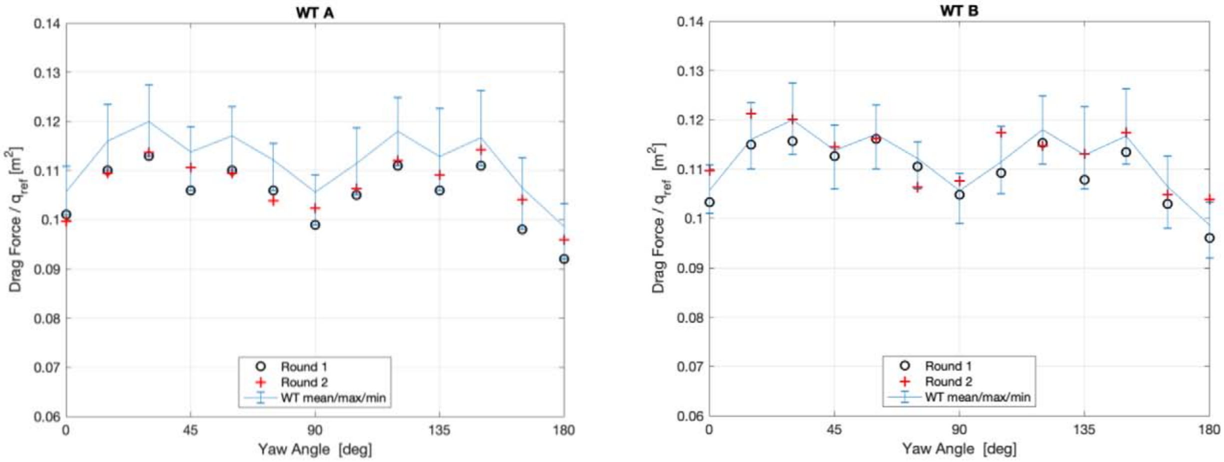

Figure 14(a)—Even-keel condition – Drag force

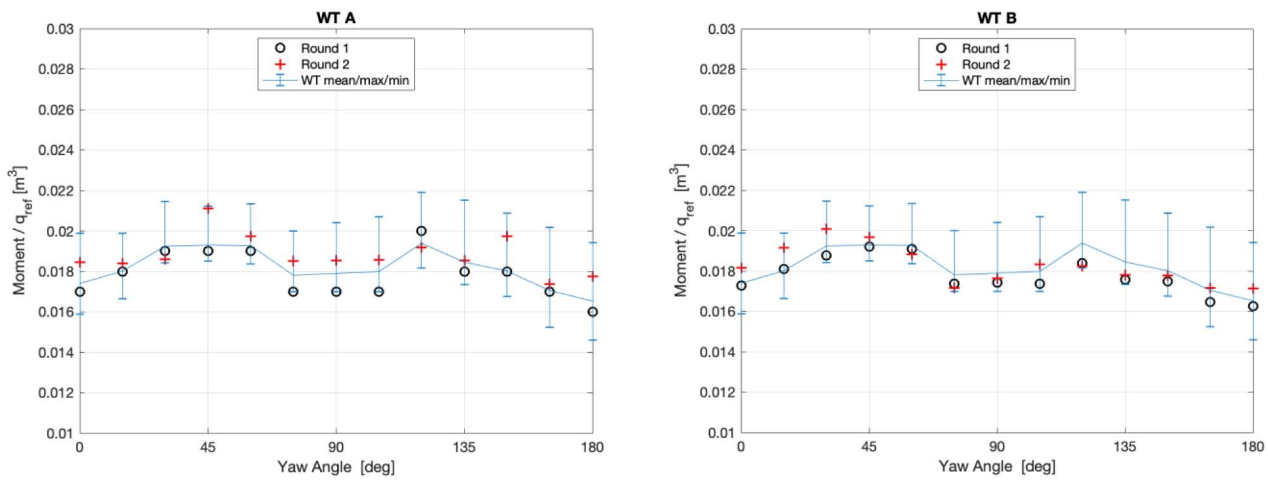

Figure 14(b)—Even-keel condition – Overturning moment

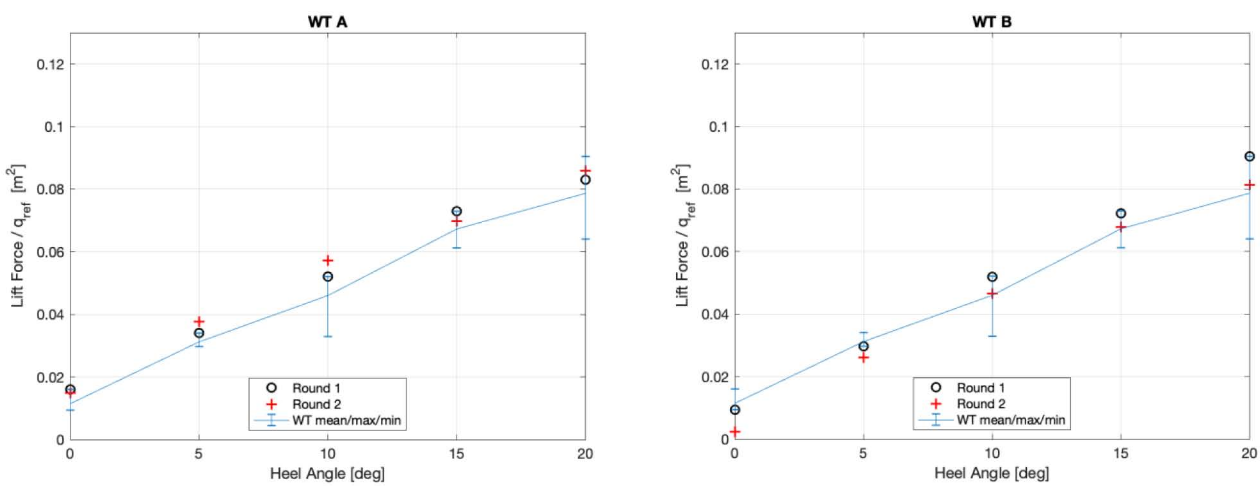

Figure 15—Critical heading – Lift Force

The following observations can be made from the wind tunnel repeatability study plots:

- The variability in replicate testing at a single wind tunnel facility is similar to the variability between different wind tunnel facilities

- The boundary layer profiles produced by Wind Tunnel A are less consistent than those produced by Wind Tunnel B. Nevertheless, the respective forces and moments are replicated with similar consistency. This suggests that the model is not overly sensitive to smaller variations in the boundary layer profile (i.e., with the target +/- 2.5% velocity error band).

Conclusion

This report of the SNAME OC-8 Panel Comparative Wind Load Study for offshore floating platforms is a pioneering comparison of three approaches to wind load estimation; namely, the empirical building block method, the wind tunnel test, and Computational Fluid Dynamics (CFD). The rigorous assessment of available wind load estimation approaches is supported by a large data-set and diversity among the 25 study participants. Significant among the findings is a remarkably low variability and thus consistency in wind tunnel and CFD results relative to the traditional empirical building block method specified in the U.S. Code of Federal Regulations (CFR), classification rules, and industry codes for stability calculations. Importantly, only wind tunnel and CFD results were capable of quantifying the lifting force and its effect on the overturning moment.

Historically, regulatory acceptance of wind tunnel testing has been hampered by the lack of a governing industry standard. The present study, conducted in accordance with a draft of the upcoming revision to SNAME T&R Bulletin 5-4, attempts to close this gap. The close agreement of wind loads for the studied geometry from one facility to the next (and for replicate testing at the same facility) evidences the accuracy and repeatable results of wind tunnel tests.

It is important to highlight the fact that some of the data initially provided by two of the wind tunnel facilities was shown to be clearly erroneous when compared with the full data set; further investigation pinpointed an erroneous reference velocity measurement and a procedural error as the causes. Both errors can be avoided through the adoption of a simple benchmark test to objectively validate the wind load measurements and post-processing performed by any given wind tunnel facility, which will be included in the upcoming revision to the 1988 SNAME T&R Bulletin 5-4.

The present study highlights CFD as a promising new technology for the offshore industry in the estimation of wind loads. The CFD results presented herein are largely indistinguishable from the wind tunnel measurements for the studied geometry. Ongoing industry efforts, including those of the SNAME OC-8 Panel, are focused on developing an industry standard to ensure the accuracy and repeatability of CFD wind load estimates for a variety of hull forms and orientations.

The empirical methods wind load estimates reported herein are considerably higher than the corresponding wind tunnel and CFD estimates for the studied geometry, and there exists a high degree of variability (or data scatter) among the various participants. While somewhat surprising, these takeaways are consistent with the literature survey summarized earlier in the paper. On-going efforts of the SNAME OC-8 Panel are focused on better understanding (and then reducing) the large variability observed in the empirical methods wind load estimates.

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Symbols & Nomenclature

IDDES = Improved Delayed Detached Eddy Simulation
k–ω = turbulence model: turbulent kinetic energy (k) - specific rate of dissipation (ω)
LES = large eddy simulation
RANS = Reynolds-Averaged Navier-Stokes
URANS = Unsteady Reynolds-Averaged Navier-Stokes

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