Relative assessment of fatigue loads for offshore wind turbine support structures

DeepWind'2015

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Overview

Motivation

- Computational effort is a significant issue for time domain analyses of offshore wind turbines (OWTs)
- Standards require (minimum) 60 minute simulation lengths[1,2]
- Many evaluations of the system needed for certification and design optimization

[1] International Electrotechnical Commission (2009). Wind Turbines – Part 3: Design Requirements for Offshore Wind Turbines, International Standard, IEC 61400-3. 132 pp.

[2] Det Norske Veritas (2013). Design of offshore wind turbine structures, Offshore Standard, DNV-OS-J101. 214 pp.

Idea

- Reduce the required simulation length for accurate fatigue assessment?

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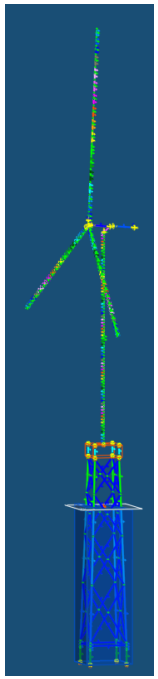
- Predict the damage equivalent load (DEL) of a full length simulation from a shorter segment
- Use simple statistical methods to adjust for fluctuations on shorter time scales

Setup



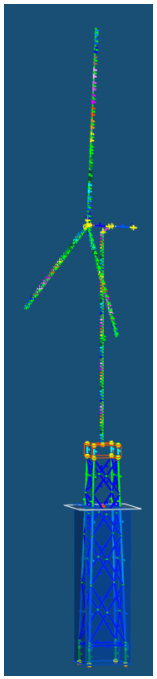
- OWT model is UpWind jacket from OC4 project[3]and NREL 5MW turbine[4]
- Full length 60 minute simulation run in FEDEM[5]at 4 different wind speeds, using 4 different realizations for each wind speed

[3] Vorpahl F., Popko W. and Kaufer D. (2011). Description of a Basic Model of the 'Upwind Reference Jacket' for Code Comparison in the OC4 Project under IEA Wind Annex XXX, IEA Wind Annex XXX.

[4] Jonkman J., Butterfield S., Musial W. and Scott G. (2009). Definition of a 5-MW reference wind turbine for offshore system development. NREL/TP-500-38060, National Renewable Energy Laboratory.

[5] Fedem Technology AS. (2014). Fedem User's Guide, Release 7.1. Fedem Technology AS: Trondheim, Norway.

Setup



- OWT model is UpWind jacket from OC4 project[3]and NREL 5MW turbine[4]
- Full length 60 minute simulation run in FEDEM[5]at 4 different wind speeds, using 4 different realizations for each wind speed
- Two alternate designs with different outer diameters were also tested:
  - One design with diameters increased by 10%
  - One design with diameters increased by 20%

[3] Vorpahl F., Popko W. and Kaufer D. (2011). Description of a Basic Model of the 'Upwind Reference Jacket' for Code Comparison in the OC4 Project under IEA Wind Annex XXX, IEA Wind Annex XXX.

[4] Jonkman J., Butterfield S., Musial W. and Scott G. (2009). Definition of a 5-MW reference wind turbine for offshore system development. NREL/TP-500-38060, National Renewable Energy Laboratory.

[5] Fedem Technology AS. (2014). Fedem User's Guide, Release 7.1. Fedem Technology AS: Trondheim, Norway.

Approach

- Use the first 10 minutes of simulation time and calculate the axial force DEL in legs and braces
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- Logarithmic transformation and linear regression of DEL vs time used to extrapolate to 60 minutes
- Four different schemes for utilizing the 10 min segment, see Table 1.

Table 1 : Prediction schemes

Names	Description
PS1	DEL5 + DEL10
PS2	5DEL2 + DEL10
PS3	2DEL5 + DEL10
PS4	5DEL2 + 2DEL5 + DEL10

Prediction lines, PS1 and PS2, brace at water level

Figure 1 : PS1, wind speed 8 m/s, four realizations

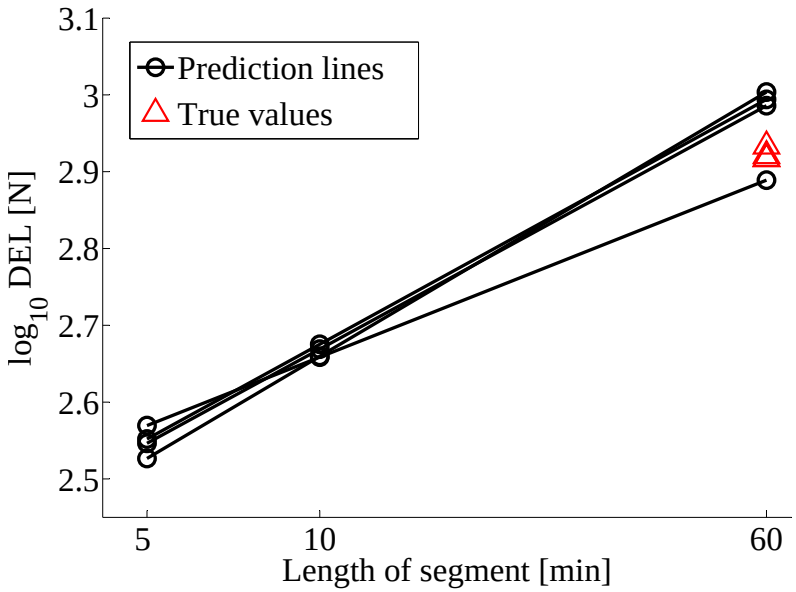
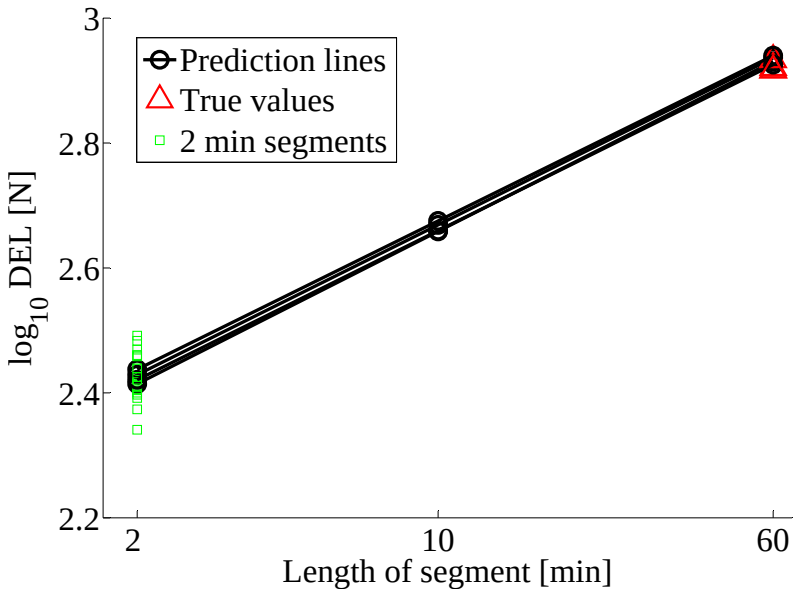


Figure 2 : PS2, wind speed 8 m/s, four realizations



Prediction lines, PS3 and PS4, brace at water level

Figure 3 : PS3, wind speed 8 m/s, four realizations

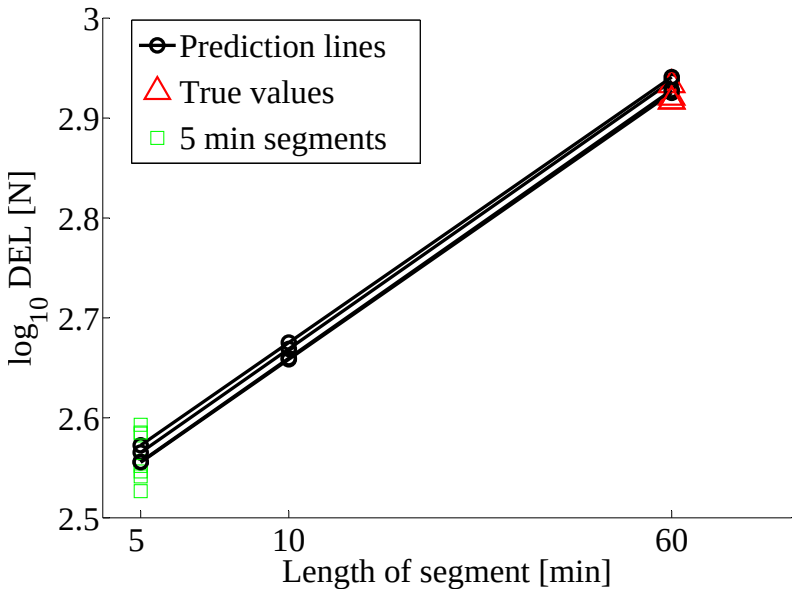
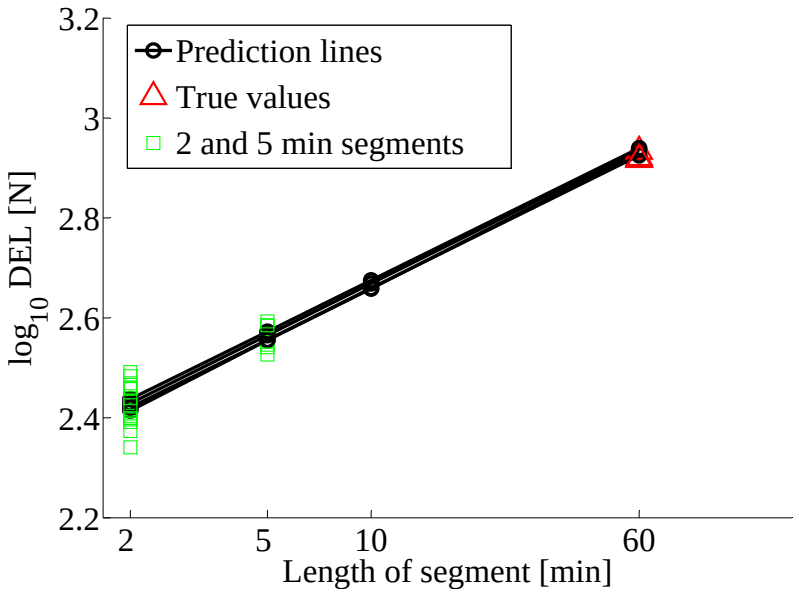


Figure 4 : PS4, winds speed 8 m/s, four realizations



Mean deviation from true values, PS1 and PS4

Figure 5 : PS1

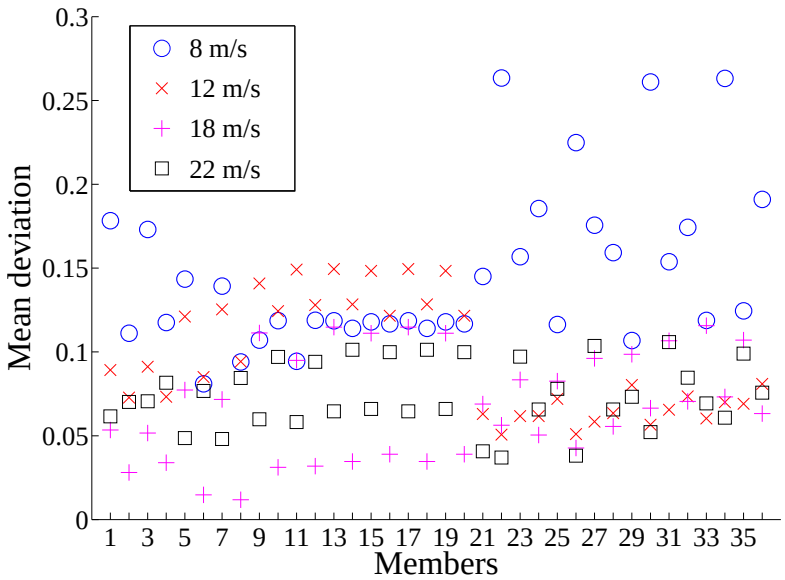
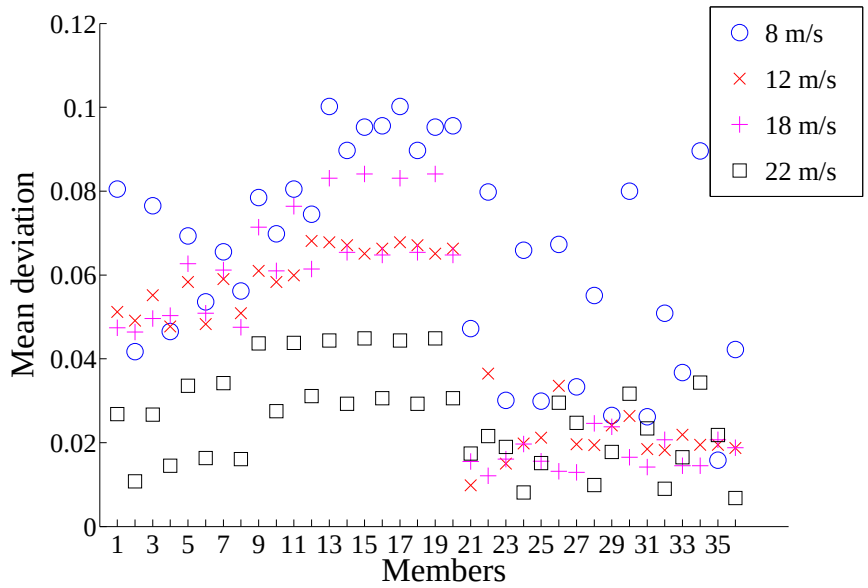


Figure 6 : PS4



Prediction lines PS4, alternate designs

Figure 7 : 10% larger diameter, wind speed 8 m/s, four realizations

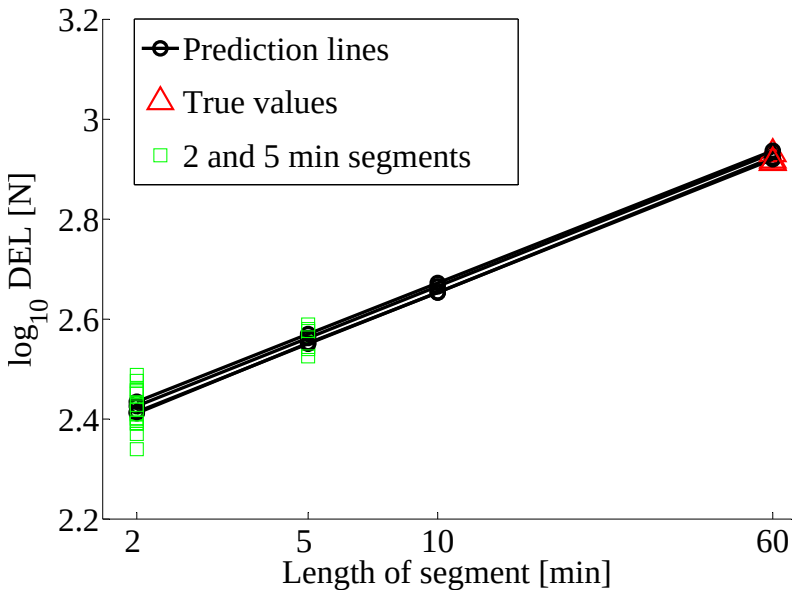
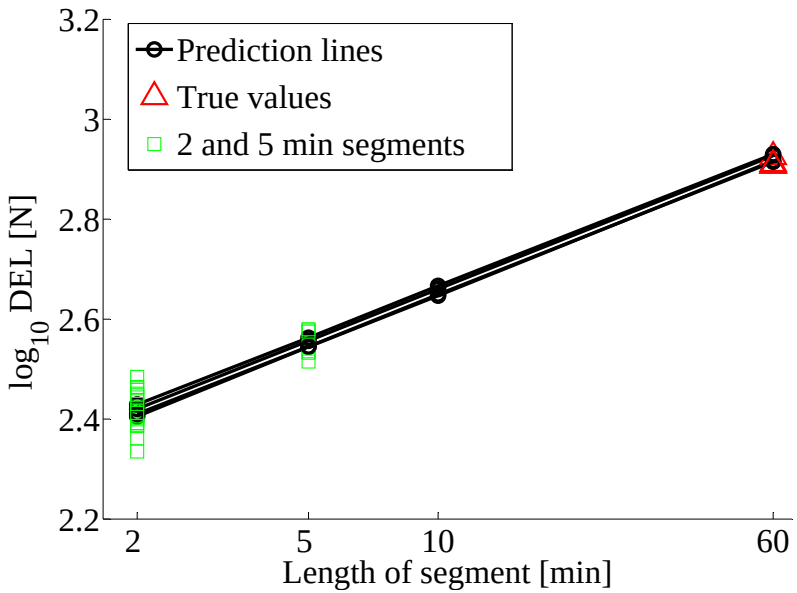


Figure 8 : 20% larger diameter, wind speed 8 m/s, four realizations



Selected results

Table 2 : Wind speed 22 m/s, brace at water level

Model, scheme	True mean [N]	Predicted mean [N]	Mean deviation (% of true value)
Base model, direct scaling of DEL10	1715	5538	223
Base model, PS1	1715	1533	11
Base model, PS2	1715	1696	2.4
Base model, PS3	1715	1698	2.4
Base model, PS4	1715	1696	2.3
10% increased outer diameter, PS4	1696	1686	2.4
20% increased outer diameter, PS4	1688	1670	2.4

Conclusion

- PS2, PS3, PS4 give good estimates, PS1 less so
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- All methods show great improvement compared with direct scaling
- Methods are stable with respect to changing the design
- Promising for an optimization context
- Less accurate (up to 12% error) for wind speeds below rated and leg elements, might limit applicability somewhat

Outlook

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- Check stability of methods when changing design in a non-systematic way
- Significant increase in accuracy if segment is increased to 15 minutes?
- Possibility of using an initial 60 minute simulation to 'tune' the method and then use 10 minute segments with changed design and 'tuned' estimates

Supplementary 1: Some equations

DEL expression:

$$\text{DEL} = \left(\frac{\sum_i n_i F_i^m}{N_{\text{eq}}} \right)^{1/m}$$

Linear regression equation after logarithmic transformation:

$$\log_{10}(\text{DEL}) = a \log_{10}(t) + b$$

Supplementary 2: Linear regression lines using entire length

Figure 9 : Example 1

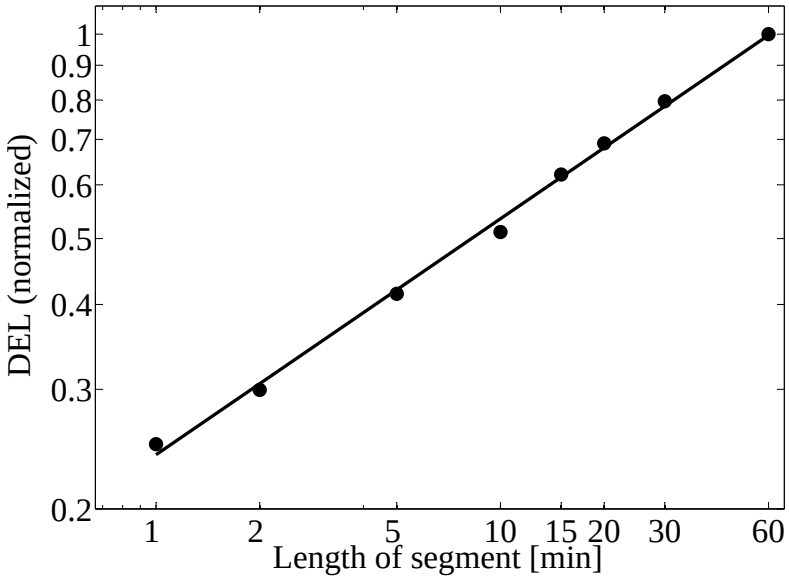
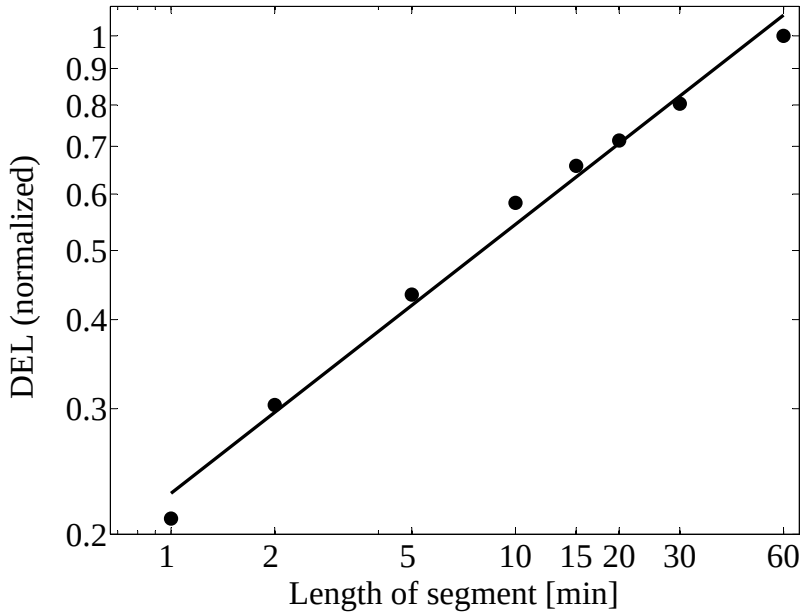


Figure 10 : Example 2



Supplementary 3: Mean deviations for schemes PS2 and PS3

Figure 11 : PS2

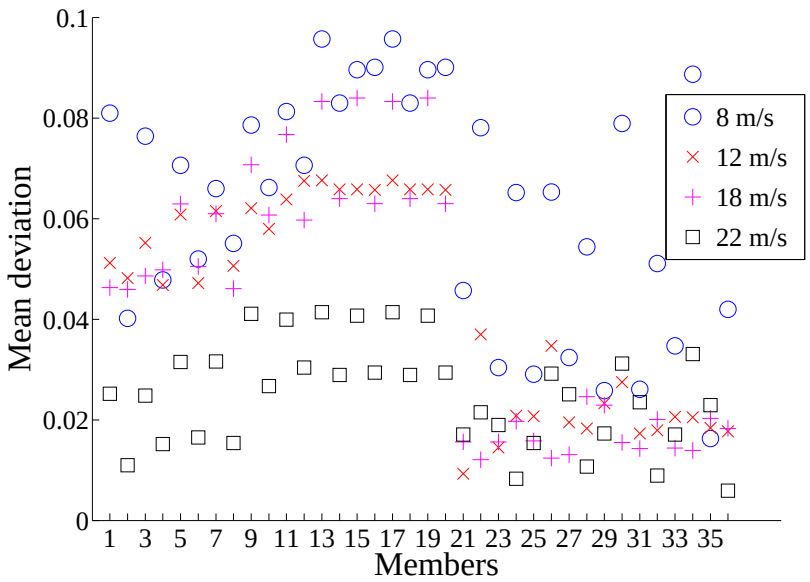
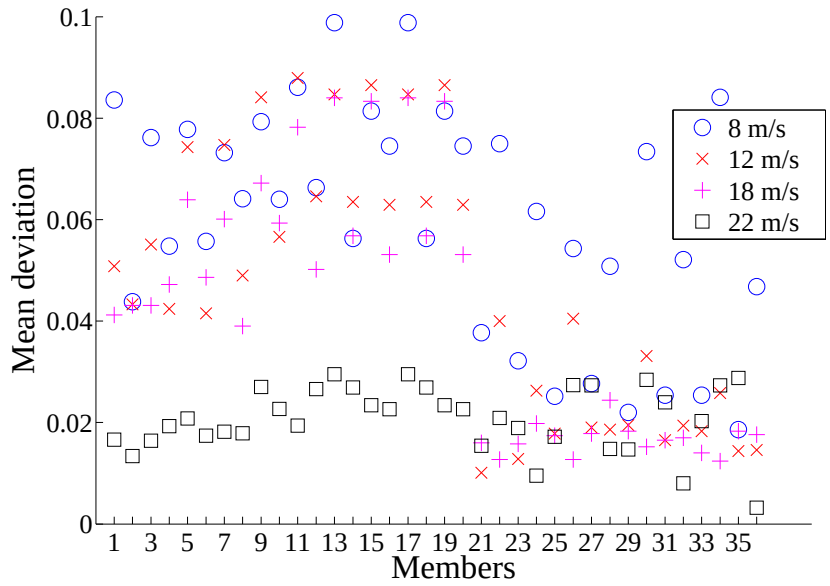


Figure 12 : PS3



Supplementary 4: Mean deviations for alternate models

Figure 13 : 10% increase

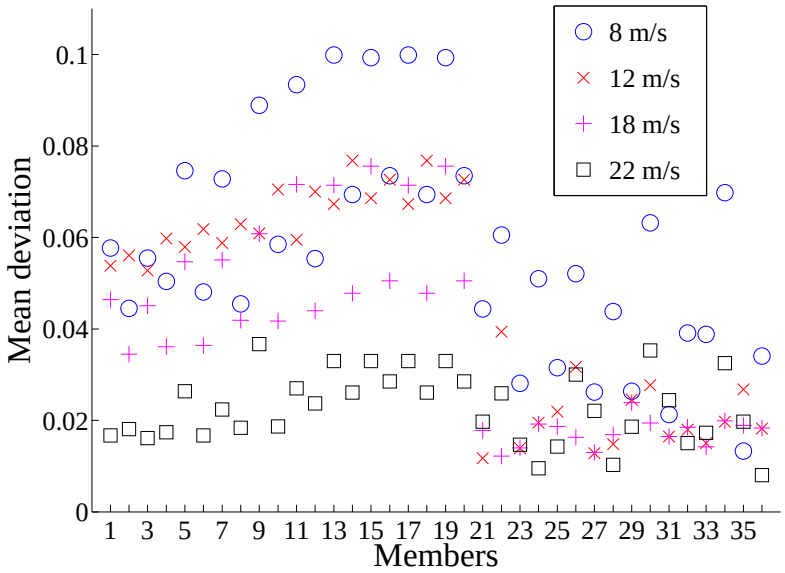
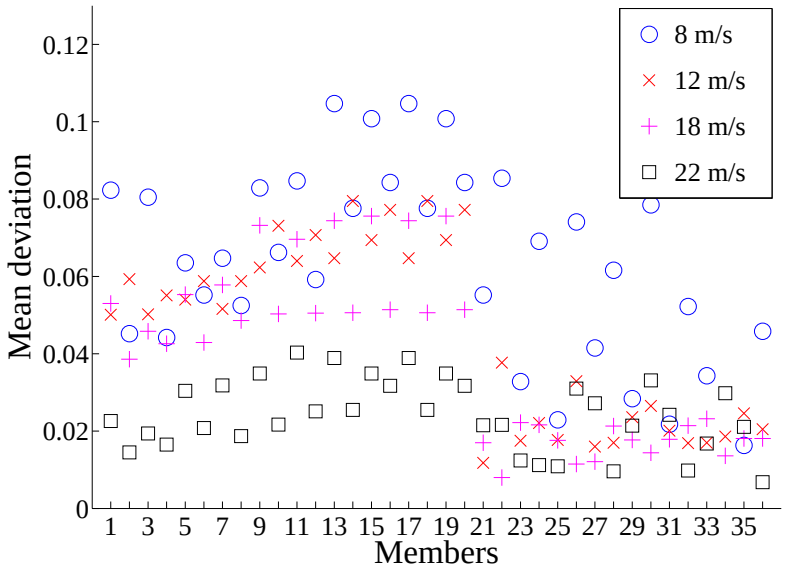


Figure 14 : 20% increase



Supplementary 5: Extended version of Table 2

Table 3 : Wind speed 22 m/s, brace at water level

Model, scheme	True mean [N]	Predicted mean [N]	Standard deviation true [N]	Standard deviation predicted [N]	Mean deviation (% of true value)
Base model, simple scaling of DEL10	1715	5538	13.45	121.8	223
Base model, PS1	1715	1533	13.45	22.26	11
Base model, PS2	1715	1696	13.45	38.46	2.4
Base model, PS3	1715	1698	13.45	39.35	2.4
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10% increased outer diameter, PS4	1696	1686	14.85	39.46	2.4
20% increased outer diameter, PS4	1688	1670	11.04	40.32	2.4