Technical Summary for NSL GM-19-02

Study Title	Wind Tunnel Experiments for Offshore Oil and Gas Downwash
Report Title	Offshore oil and gas platform and drilling rig downwash: comparison of wind tunnel and American Meteorological Society-US Environmental Protection Agency Regulatory Model (AERMOD) simulations
Report Number(s) (OCS Study)	OCS Study BOEM 2023-050
Completion Date of Report	24 April 2023
Number of Pages	193
Award Number(s)	140M0120C0008
Sponsoring OCS Region or Office	Bureau of Ocean Energy Management New Orleans Office Office of Environment, GM 663D 1201 Elmwood Park Boulevard New Orleans, LA 70123
Applicable Planning Area(s)	Outer Continental Shelf (westward of 87° 30' W longitude in the Gulf of Mexico)
Fiscal Year(s) of Study Funding	FY 2020: $380,344 FY 2021: $40,320
Costs by Fiscal Year	FY 2020: $75,208 FY 2021: $179,155 FY 2022: $166,301
Cumulative Project Cost	$420,664
Project Manager(s)	John J. Carter
Affiliation of Project Manager(s)	Vice-President, CPP Inc.
Address of Project Manager(s)	7365 Greendale Road Windsor, CO 80550
Principal Investigator(s)	Ron L. Petersen; John J. Carter
Keywords	offshore platform wake; downwash; wind tunnel model; wind velocity; turbulence; stack exhaust concentration; porous structure; platform downwash

ABSTRACT: Wind tunnel measurements of the downwash around actual and generic offshore platform models were completed to understand the overwater turbulent flow and dispersion around these porous elevated structures. New predictive equations for mean wind speed deficit and wake turbulence enhancement are proposed. These new equations include variation with height. The wind tunnel model included turbulent wind flow and exhaust concentration measurements. The measurements were compared with American Meteorological Society-US Environmental Protection Agency Regulatory Model (AERMOD) and improved AERMOD predictions.

BACKGROUND: The Outer Continental Shelf Lands Act (OCSLA) requires that offshore oil and gas structures comply with the National Ambient Air Quality Standards (NAAQS). The current approved model for assessing NAAQS is a software program called AERMOD with PRIME (Plume Rise Model Enhancements), which was intended to model overland dispersion around solid monolithic obstacles, such as buildings. PRIME has equations for predicting horizontal and vertical dispersion in a building wake, wake extent, recirculation cavity extent, and plume rise. Updates by RL Petersen between 2016 and 2018 (PRIME2 discussed by Petersen and Guerra, 2018) corrected known problems and extended the theory to more complex structures. The United States Environmental Protection Agency (USEPA) Office of Research and Development has also conducted independent wind tunnel testing and proposed model enhancements.

OBJECTIVES:

1. Identify and experimentally model various representative offshore oil and gas structures;
2. Design and test wind tunnel models at 1:200 length scaling;
3. Collect and analyze wind tunnel data of downwash velocities and concentrations downwind of the models;
4. Compare measurements with predictions by AERMOD; and
5. Identify potential improvements to AERMOD.

METHODS: A review of offshore platform types and a database with dimensions of platforms in service was used to identify representative platforms. Four actual platform types and a generic porous model were fabricated at 200 times smaller than actual size and tested in an atmospheric boundary-layer wind tunnel. An ethane-nitrogen mixture was emitted from a brass tube located above the characteristic height of each platform and served as a tracer gas to model platform stack emissions. Three-component turbulent wind velocities and tracer concentrations downwind of each platform were simultaneously measured, respectively, with a 12-hole pressure probe (Aeroprobe Omniprobe) and a flame ionization detector (Cambustion HFR-200). Flow visualization was also completed for all platforms. The PRIME2 equations and original PRIME equations were compared with wind tunnel measurements. Both theories were modified to obtain better agreement with observations. The updated equations can potentially be used in AERMOD to model platform type structures and the results of a preliminary evaluation are discussed.

RESULTS: The study sampled the four-dimensional concentration and velocity fields downwind of the following platforms: Generic Platform with two porosities and three platform heights; Jackup; Semisubmersible; and Small and Medium Platforms. To our knowledge, this is the first database with sufficient data to define plume rise, horizontal and vertical dispersion, velocity field and turbulence field in a porous offshore platform wake. The measured mean velocity deficit (UD), lateral (SV) and vertical (SW) turbulence enhancement, and dispersed concentration (C/Q) fields were compared with predictions by AERMOD. The variation of maximum UD with downwind distance was similar to current PRIME theory for the generic, small, and semisubmersible platforms, whereas larger values than the current PRIME theory were seen for the Jackup and Medium platforms. For the generic platform, porosity had little effect on UD. Maximum SW and SV (vertical and lateral turbulence increase) values for all platforms were higher than the current PRIME theory. For the generic platform, maximum SW and SV values tended to be higher with a lower porosity. Maximum ground-level concentrations, plume rise and dispersion versus downwind distance vary significantly with wind direction and platform type. This is due to many factors, such as isolated structures on the platform, the overall porosity of the platform and legs that extend above and below the platform, corner vortices and platform height. Improvements to AERMOD will have to account for this complexity. Also, BPIPPRM will have to be modified or some other method developed to determine the appropriate building dimension inputs for these complex structures. The Gaussian distribution fits the concentration data well.

CONCLUSIONS: AERMOD with PRIME or PRIME2 needs modification in order to be an appropriate tool for predicting dispersion downwind of offshore oil and gas platforms. A new velocity deficit (UD) and turbulence enhancement formulation (SV and SW) is needed for platform structures that combines PRIME and PRIME2 formulations with a modified vertical distribution that accounts for platform porosity and leg height. Measured turbulence enhancement and velocity deficit contours at each downwind distance tended to be Gaussian-shaped and a Gaussian-like distribution could replace the current theory in PRIME for more accurate wake dispersion predictions.

STUDY PRODUCT(S):

1. BOEM study report: Carter JJ, Beyer-Lout A, Lin W, Lawton T, Fleckenstein K, Paumier JO, Petersen, RL (CPP Inc, Windsor, CO). 2023. Offshore oil and gas platform and drilling rig downwash: comparison of wind tunnel and American Meteorological Society-US Environmental Protection Agency Regulatory Model (AERMOD) simulations. New Orleans (LA): US Department of the Interior, Bureau of Ocean Energy Management. 193 p. Contract No.: 140M0120C0008. Report No.: OCS Study BOEM 2023-050.
2. Appendixes for this study, listed and described below, are available from BOEM on request. Contact BOEMEnviroStudies@boem.gov for text Appendixes A through H and Appendix M.
3. Appendix I is a set of Computer-Aided Design (CAD) files, which are available from BOEM on request (contact espis@boem.gov); and a Microsoft® Excel spreadsheet that describes volumetric porosities, available at https://opendata.boem.gov/CPP14256_Appendix_I_-_Volumetric_Porosities.xlsx.
4. Appendix J, Wind Tunnel Data, is a Microsoft® Excel spreadsheet available at https://opendata.boem.gov/CPP14256_Appendix_J_Wind_Tunnel_Processed_Data.xlsx.
5. Appendixes K and L are available on request from BOEM. Enquiries about the Appendix I and J data products can be sent to the Data Manager at CPP Inc (wlin@cppwind.com). Contact espis@boem.gov for the following: Matlab codes (Appendix K); and Flow Visualization video files (Appendix L).

   Appendixes are as described:

   1. Appendix A: review of actual platforms and model selection notes
   2. Appendix B: compilation of wind tunnel test conditions for all cases
   3. Appendix C: documentation of wind tunnel test procedures
   4. Appendixes D through H: full compilations of results for all tested models
   5. Appendix I: computer-aided design files for platform model geometries and linked data product
   6. Appendix J: wind tunnel raw data and linked data product.
   7. Appendix K: Matlab code for calculations and plots
   8. Appendix L: flow visualization videos
   9. Appendix M: general primer on wind tunnel model methodology

REFERENCE:

Petersen RL, Guerra SA. 2018. PRIME2: Development and evaluation of improved building downwash algorithms for rectangular and streamlined structures. J Wind Eng Ind Aerodyn. [accessed 2022 July 10]; 173: 67–78; https://doi.org/10.1016/j.jweia.2017.11.027.