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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

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A SURVEY OF WIND LOADS ON OCEAN FACILITY STRUCTURES

by

N. T. TSAI

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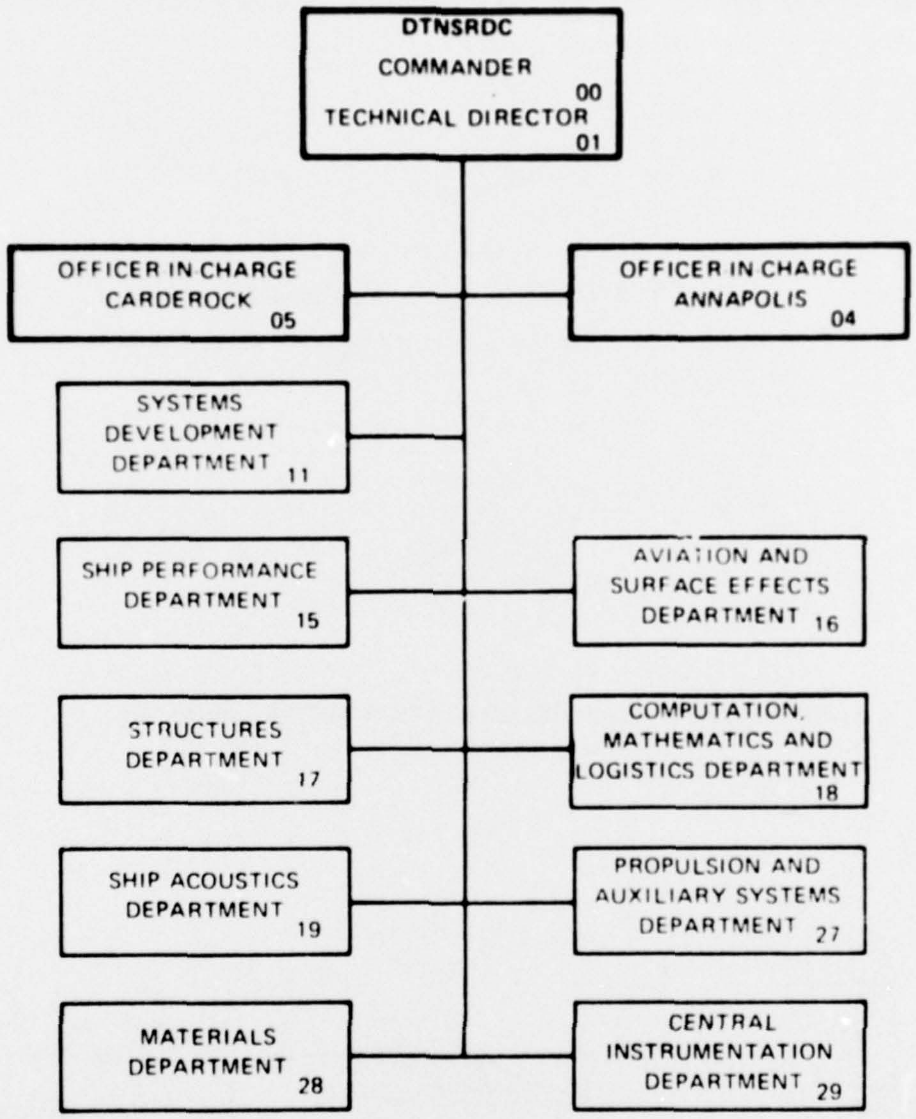

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→ A survey was conducted to compile and annotate the existing wind loads data applicable to ocean facilities structures, including ships, moored systems and offshore structures. After a survey of sources available at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), a bibliography on wind loads data was prepared. Data item summary sheets are given for representative wind loads data, including typical analytical methods and representative experimental methods. The survey revealed that →

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20. ABSTRACT (cont'd)

there is a lack of wind loads data on offshore structures and that a handbook on the wind loads on ocean facilities structures is needed for ocean engineering applications. This handbook could be part of a handbook on environmental forces which could include wind, wave and current loads on ocean structures.

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ABBREVIATIONS USED

ATMA - Association Maritime Technique et Aeronautique

BSRA - British Shipbuilding Research Association

DTMB - David Taylor Model Basin

EMB - Experimental Model Basin

JSTG - Jahrbuch des Schiffbautechnischen Gesselschaft

ISP - International Shipbuilding Progress

NSRDC - Naval Ship Research and Development Center

RINA - Royal Institution of Naval Architects

SNAME - Society of Naval Architects and Marine Engineers

ABSTRACT

A survey was conducted to compile and annotate the existing wind loads data applicable to ocean facilities structures, including ships, moored systems and offshore structures. After a survey of sources available at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC), a reference list on wind loads data was prepared. Data item summary sheets are given for representative wind loads data, including typical analytical methods and representative experimental methods. The survey revealed that there is a lack of wind loads data on offshore structures and that a handbook on the wind loads on ocean facilities structures is needed for ocean engineering applications. This handbook could be part of a handbook on environmental forces which could include wind, wave and current loads on ocean structures.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

Wind loads data on ocean facilities structures is one of the vital elements of design information needed in ocean engineering construction. For many fixed or floating offshore structures, wind forces constitute the sole threat to survival through environmental loading. For a surface vessel underway, the wind forces still have a significant effect on performance and survivability.

For many years, wind-tunnel experiments have been conducted to determine the wind loads on ocean structures, including ships, fixed or floating offshore structures, and construction platforms. The purpose of this report is to compile and annotate existing wind loads data applicable to ocean facilities engineering (OFE).

The survey is restricted to literature suitable for ocean engineering applications within the sources available to the David W. Taylor Naval Ship Research and Development Center (DTNSRDC). This excludes many offshore platforms and military structures, whose proprietary or security classifications prohibit their publication.

The effects of the wind field character on the wind loads have been discussed in some wind load studies. A considerable volume of literature exists on the description of the wind field above the undulating ocean surface. Because this survey is primarily concerned with wind forces, only a brief description of the wind field is presented in a later section. An extensive review of this subject is beyond the scope of the present survey.

The literature on wind loads can be classified into three parts, namely, wind loads on ships, wind loads on moored systems, and wind loads on offshore structures. The majority of the literature available is pertinent to surface ships for which many experimental investigations were conducted over the last forty years. Some of the materials reviewed contain information on one or more classes of ocean structures, however. Thus, the user should review the entire bibliography attached at the end of the report.

As a result of this survey, data item summary sheets were prepared for some of the typical studies for each category of wind loads data. They are grouped in "Wind Loads on Ocean Facilities Structures" together with a brief description. These summary sheets contain the source information, abstract, and areas of application related to ocean facility engineering. A general summary and recommendations in the area of wind loads design follows as a part of the results of this survey.

THE WIND FIELD ABOVE THE OCEAN

The existing data on the shape of the velocity profile of the wind above the ocean vary considerably. Generally a logarithmic profile occurs more frequently than others. The variability is not surprising when one thinks of the dynamics of the ocean environment. However, the engineer must make some assumptions as to the velocity profile if he is to calculate realistic wind loads. A simple power law has been used for the velocity distribution in many instances, namely,

$$\upsilon(\zeta) = \upsilon_{\alpha}(\zeta/\zeta_{\alpha})^{1/\gamma} \qquad [1]$$

where $\upsilon(\zeta)$ is the wind velocity at a distance ζ,

υ_{α} is the wind below the reference distance at ζ_{α} above the water surface,

γ is the constant,

ζ is the distance above the water surface.

The suggested value of the exponent γ for wind over water is 7, and the value of ζ_{α} is 10 meters. Given the design wind speed at 10 meters, the gradient velocity can be calculated and then the entire profile determined.

Three wind velocity gradients are compared in Figure 1. The sea surface wind velocity gradient is very close to that of the simple power law distribution. The wind velocity gradients in various wind tunnels depended on the test conditions under which wind loads of ships were measured and varied from facility to facility. Therefore, to compare the wind loads data from different facilities, a very careful evaluation of the wind velocity gradients is necessary.

The design wind speed will depend on the geographical location of the ocean structure. Both mean wind speed and extreme wind data are available in the literature for most locations. The maximum design wind speed on the ocean is frequently assumed to be 150 knots if no other information is available. In addition to wind magnitude and profile, information about wind gusts will help the designer to determine the maximum wind loads. The frequency of the turbulent gusts depends on the boundary condition and other physical instabilities. A gust factor of 1.5 has been selected as an empirical value. The gust factor is defined as the ratio between the wind gust speed and the maximum steady wind speed.

It should be emphasized here that this information on wind field above the ocean is based on sparse data, and that any final design should include a fairly large factor of safety. There is a need to compile existing wind data relevant to structural design and to coordinate future wind loads research programs by using specified wind data.

WIND LOADS ON OCEAN FACILITIES STRUCTURES

The wind load data may be classified into three general categories according to their areas of application. A brief description is presented here for each group of data with emphasis on the areas of interest to ocean facilities engineers. Since many of the references contain information suitable for all three categories of ocean structures, the user is encouraged to review the entire bibliography in his search for wind load data.

WIND LOADS ON SHIPS

Wind loads on ships have been under study for over forty years. The early work was conducted in water channels by towing inverted superstructures and hulls of ships to determine the resistances.[1-7] These data then were converted into wind loadings for various headings and velocities. Because of the restriction of the facilities and the undesirable effect of bow waves on the resistance, these experiments were conducted mostly at low speeds, up to 2 knots, in water. If the Reynolds number is used as a scaling rule, the results from the water can be used in wind speeds of 10 to 20 knots, depending on the size of the model. The paper by Hughes[3] is a typical report on these studies.

After large subsonic wind tunnels became available, the investigation of wind loads on ships truly was carried out in air. The wind-tunnel experiments conducted in the United States were mostly for naval ships. The 8-foot by 10-foot wind tunnel at the David Taylor Model Basin (now the

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[1]References are listed on Page 35

David W. Taylor Naval Ship Research and Development Center) was the facility generally available for these investigations.[8-13] Typical installations in the wind tunnel are shown in Figures 2 and 3. The wind loads in terms of lateral forces and yawing moment were measured through a rotating strut attached amidships. The rotating strut was attached to the mechanical load balance table beneath the tunnel floor. A ground board was installed under the model to simulate the surface of the sea.

Since 1960, most of the available wind load data on ships have been from sources outside of the United States and the emphasis has been on merchant ships since the emphasis in the shipbuilding industry abroad has been on those ships. The work carried out by Wagner of Germany is one of the most extensive and systematic investigations on this subject.[17, 18, 22] The variations in the superstructure configurations of two models, as tested by Wagner,[18] are shown in Figure 4. He found that topped derricks and extensive hauling equipment increase the resistance from ahead by about 28%, as compared with the normal condition. Other research was carried out in Europe,[14,16,20,21,23,26,29] and Japan[24] on various merchant ships.

In all the wind-tunnel experiments, the size of the model is limited only by the blockage effect at large angles of attack. The Reynolds number scale effect is not very significant as the flow over the complicated superstructure and ship hull is mostly in the turbulent region. Wind forces in the horizontal plane and yawing moment were measured against increments of yaw angle of the ship model. Experiments were carried out either in uniform wind or in gradient wind. The profile of the wind gradient depends on the characteristics of the wind tunnel and the manner in which the models are placed in the tunnel. For example, Shearer and Lynn[14] tested the model in the boundary layer close to the tunnel roof, while the experiments at DTMB were conducted with the model placed on a platform in the middle of the tunnel.

Together with the experimental studies, there are theoretical works to establish a wind loads formula in terms of the geometric character of the ship. With the experimental data as a baseline, Wilson and Roddy[25] developed a method to predict the wind resistance of cargo ships and tankers. Isherwood[28] analyzed the data of 49 sets of wind tunnel experiments with a data fitting procedure and developed a set of force and yawing moment coefficients for predicting the wind loads on any kind of ship. However, because of the difficulty in correlating the experimental data with full-scale measurements, these empirical models can be used only to estimate the wind loads on ships qualitatively. For example, the effect of the wind gradient on wind loads is still under investigation. Thus, the present models are considered inadequate as a general method for calculating wind loads on any ship. For ocean facilities engineers, careful consideration of the mission as well as the ship is needed in the calculation of wind loads with these empirical methods.

The following sheets contain summaries of data items of publications deemed representative of the wind loads data on ships. From the classical work of Hughes[3] to the recent analysis of wind loads data by Isherwood,[28] these data items are a good representation of the state-of-the-art.

Each summary sheet of a publication identifies it by title, author, source, and such miscellaneous information as number of pages, tables, figures, and number of references. The summary sheet also includes an abstract of the publication and indicates areas in Ocean Facility Engineering (OFE) in which the publication can be used.

IDENTIFICATION

Title : Model Experiment on the Wind Resistance of Ships
Author : G. Hughes
Source : Transactions of the Institution of Naval Architects
Date : July 1930
Miscellaneous: 16 pages, 6 tables, 4 references, 5 figures

ABSTRACT

This paper presents the results of one of the earliest investigations on wind loads of ships. Model tests were conducted in the William Froude National Experimental Tank to investigate the wind force acting upon the superstructures of ships for all directions. The tests were made in water by towing the ship models upside down at different speeds and at different angles to simulate various relative wind strengths and directions. The ship models tested were those of a tanker, a cargo steamer, and a liner. The results were then used to formulate a non-dimensional resistance coefficient applicable to the calculation of wind loads on other ships of known geometric shape.

OFE AREA OF APPLICATION

Wind loads data on ship models tested in this report can be used to estimate the wind load of similar ships.

IDENTIFICATION

Title : Wind Tunnel Tests to Determine Aerodynamic Forces and Moments on Ships at Zero Heel
Author : G. R. Mutimer
Agency : David Taylor Model Basin Report 956
Date : March, 1955
Miscellaneous: 31 pages, 3 references, 18 figures

ABSTRACT

This report presents a compilation of data on nine ship models tested at zero heel in the David Taylor Model Basin eight (8) by ten (10) foot wind tunnel during the years 1948 through 1953. The ships modeled are SS United States, SS Old Colony Mariner, USS Terrebonne Parish (LST 1156), USS Pennsylvania, USS Allen M. Sumner (DD 692), USS Roanoke (CL 145), USS Salem (CA 139), USS Essex (CV #9), and YTB 500. All data are plotted against angle of yaw with forces in pounds and the moments in pound-feet.

OFE AREAS OF APPLICATION

1. Wind Load data of the aforesaid nine ships.
2. Test procedure applicable to other ships.

IDENTIFICATION

Title	:	Wind Tunnel Tests to Determine Aerodynamic Forces and Moments on a 1/48 Scale Model SS-563 Class Submarine Heeled in Beam Winds
Author	:	G. R. Mutimer
Agency	:	David Taylor Model Basin Report 1032
Date	:	February, 1956
Miscellaneous	:	19 pages, 2 references, 9 figures, 1 table

ABSTRACT

A 1/48-scale model SS-563 class submarine heeled at various angles in beam winds was tested in the DTMB wind tunnel in order to determine the wind loads. The model was tested in heel angles of 0 to 60 degrees with wind directly abeam, 30 degrees ahead, and 30 degrees aft of the beam. The results are then compared with that computed by using an expression formulated by the Bureau of Ships. Some of the data closely approximates the theoretical expression for computing heeling moment. An apparent discrepancy in the heeling moment data makes it necessary to consider the heeling moment computed from side force data as more reliable.

OFE AREAS OF APPLICATION

1. Wind loads data on submarines in beam winds.
2. Test techniques in determining the heeling moment of ships in beam winds.

IDENTIFICATION

Title : Wind-tunnel Tests to Determine Aerodynamic Forces and Moments on a 1/198 Scale Forrestal Class Carrier at Zero Heel Angle
Author : Martin L. Cook
Agency : David Taylor Model Basin, Report C-726
Date : August, 1955
Miscellaneous: 10 pages, 4 figures, 4 references

ABSTRACT

Wind-tunnel tests were carried out at the David Taylor Model Basin to determine the mooring loads on a CVA-59 (Forrestal Class) Aircraft Carrier. Tests were made in May, 1955 in the eight (8) by ten (10) foot wind-tunnel at zero degrees heel angle and through a 360-degree yaw range. Complete force and moment data were recorded at each 10-degree increment of yaw. The results are in the form of forces in pounds and moments in pound-feet, plotted against angle of yaw.

OFE AREAS OF APPLICATION

1. Wind load data on Forrestal Class Aircraft Carriers.
2. Test procedure applicable to other ships in determining their wind loads.

IDENTIFICATION

Title : Wind Tunnel Tests to Determine Wind Loads on a 1:128 Scale Model of the AD-143 (T5 Tanker) Vessel
Author : Mark P. Schultz
Agency : David Taylor Model Basin Report 1468
Date : November 1960
Miscellaneous: 11 pages, 3 figures, 2 references

ABSTRACT

A 1:128 scale waterline model of a T5 tanker was tested in the wind tunnel at DTMB to determine model wind loads at various angles of relative wind. Six components of force and moment data are presented in coefficient form, based on model cross-sectional area and length,

as functions of yaw angle. Two different model configurations representing the laden and unladen conditions were tested. Force and moment measurements were taken every 10 degrees as the model was rotated in a counterclockwise direction from 0 to 180 degrees, and in increments of 20 degrees from 180 to 360 degrees.

OFE AREAS OF APPLICATION

1. Wind loads data on T5 tankers and similar oil tankers.
2. Test techniques presented are applicable to other ships.

IDENTIFICATION

Title : Wind Tunnel Tests on Models of Merchant Ships
Author : K. D. A. Shearer and W. M. Lynn
Agency : International Shipbuilding Progress
Date : February, 1961
Miscellaneous: 19 pages, 30 figures, 3 references, 4 tables

ABSTRACT

Wind-tunnel tests were conducted on 1/60 scale models of a tanker and two cargo ships and on 1/64 scale and 1/128 scale models of a modern passenger liner. Models with various loading conditions were tested with wind direction from 0 to 180 degrees off the bow. The models were tested in a wind gradient close to the wind tunnel roof. The test results are shown in a non-dimensional form using an ahead resistance coefficient K and are compared with some published data. Certain possible inaccuracies in applying the model results to the ship conditions are discussed.

OFE AREAS OF APPLICATION

1. Wind loads data on tankers and cargo ships are provided.
2. Experimental procedure is applicable to other ocean structures.

IDENTIFICATION

Title : Some Aspects of Bow-Thruster Design
Author : G. R. Stuntz and R. J. Taylor
Agency : SNAME Transactions, Volume 72
Date : 1964
Miscellaneous: 24 pages, 27 figures, 4 tables, 10 references

ABSTRACT

A drag coefficient of wind load on ships is presented as part of the calculation of loading conditions on ships. Data from several wind tunnel tests are compared with the calculated wind load from this drag coefficient. It shows a consistent relation between the wind direction and direction of resultant wind force. The drag coefficient was calculated with a uniform wind speed and with a wind-velocity gradient that closely duplicates those obtained by observation over the surface of the sea. The result shows that the tests in a uniform wind will yield greater forces than those obtained in tests in a wind gradient.

OFE AREA OF APPLICATION

Wind load calculation for passenger liner, tanker, and cargo ships.

IDENTIFICATION

Title : Measurement of the Wind Forces on a Series of Models of Merchant Ships
Author : R. W. Gould
Agency : National Physical Laboratory, Aero Report No. 1233
Date : April 1967
Miscellaneous: 17 pages, 3 tables, 28 figures

ABSTRACT

The object of the tests was to provide basic rules for the prediction of the wind force on a ship's superstructure without recourse to further model tests of each particular ship. The ship models comprised a passenger ferry, a distant-water trawler, a middle-water trawler, three general cargo ships in different arrangements and positions of superstructure and deckhouses, an oil tanker, and an ore carrier.

All models were tested in a gradient airstream which simulated the natural wind over an open sea; two of the models were tested also in a uniform wind. Results are presented as non-dimensional coefficients in the form of graphs, from which the wind forces and yawing moment on new ships can be predicted. The results are largely of use in calculating the wind loads on ships during mooring and docking manuevers.

OFE AREAS OF APPLICATION

1. Wind loads data for use on loads calculation of merchant ships.
2. Test method and data analysis approach are applicable to other structures in determining wind loads.

IDENTIFICATION

Title	: Wind Forces on Ship's Superstructures
Author	: B. Wagner
Agency	: Jahrbuch des Schiffbautechnischen Gesellschaft
Date	: December 1967
Miscellaneous	: 25 pages, 33 figures, 37 references, 4 tables

ABSTRACT

Wind tunnel tests were carried out with models of cargo and passenger liners and several of the more common special types of ships. The models were designed so that they could be combined in a variety of superstructures on the modular principle. The horizontal components of the wind forces and their moments of yaw and rolling moments with various oblique angles of incidence were measured under uniform wind conditions. The results indicate that topped derricks and extensive hauling equipment increase the resistance by about 28% from ahead and 5% from the side, compared with the normal condition (See Figure 4). Notes are given for the theoretical analysis and practical application of the results.

OFE AREAS OF APPLICATION

1. Wind tunnel test technique applicable to other ships and offshore structures.

2. Wind loads data on several typical merchant ships, including a hydrofoil.

IDENTIFICATION

Title : Wind Tunnel Tests for a 10000 dwt Cargo Ship with Various Superstructure Arrangements and Loading States
Author : B. Wagner
Agency : Institute für Schiffbau; Hamburg University Report 187
Date : December 1967
Miscellaneous: 63 pages, 7 references, 22 tables, 25 figures

ABSTRACT

Wind tunnel tests were conducted on a 1/125 scale model of a 10000 dwt cargo ship, with variations in the position of the superstructure in a number of load and trim conditions. The results of the tests indicate that the effect of different arrangements on the power coefficients is very small. The general conclusion is made that locating the superstructure toward the aft end of the model causes a displacement of the transverse center of gravity in the same direction, resulting in an increase in thrust coefficient. At high angles of incidence this effect is reversed when the hoists and loading equipment are removed.

OFE AREAS OF APPLICATION

1. Wind load data of a 10000 dwt cargo ship.

2. The effect of different superstructure arrangements on the wind load on the ship is small.

IDENTIFICATION

Title : Wind Tunnel Tests on a Model of a Car-Ferry
Author : G. Aertssen and P. E. Colin
Agency : International Shipbuilding Progress
Date : March 1968
Miscellaneous: 7 pages, 8 references, 2 tables, 16 figures

ABSTRACT

The paper describes the wind-tunnel tests on a model of the twin-screw cross-channel car ferry, Roi Baudouin. The results are given in the conventional non-dimensional form which is defined by the transverse projected area as well as in the form of the Hughes' coefficient K, which takes into account both the longitudinal projected area and an equivalent transverse area. The results are compared with other published data. The model and test procedures are described. The wind profile of Shearer and Lynn was simulated in the wind tunnel tests. Although the tests were carried out primarily to estimate the increase in power due to wind resistance, the data also provide information of the effect of wind on steering.

OFE AREAS OF APPLICATION

1. Wind load data on a car ferry.

2. Test techniques and data analysis method can be applied to other offshore structures.

IDENTIFICATION

Title : Estimating the Wind Resistance of Cargo Ships and Tankers
Author : C. J. Wilson and R. F. Roddy, Jr.
Agency : Naval Ship Research and Development Center Report 3355
Date : May 1970
Miscellaneous: 32 pages, 15 references, 4 figures

ABSTRACT

A study was made of the wind resistance of merchant ship designs, based on available experimental results. Various methods of estimating wind

resistance were evaluated. A proposed method which allows for natural wind gradients appears primising but is not recommended at this time due to the small amount of experimental data available. The method currently used at the DTNSRDC is recommended in the meantime. This method was used in the model full-scale powering correlation study on the data from several trials of cargo ships.

OFE AREAS OF APPLICATION

1. Method for estimating the wind resistance of cargo ships and tankers.
2. Method of correlation studies on model and trial data on wind loads.

IDENTIFICATION

Title : Wind Resistance of Merchant Ships
Author : R. M. Isherwood
Agency : *The Royal Institution of Naval Architects*
Date : 1973
Miscellaneous: 12 pages, 5 tables, 5 figures, 19 references

ABSTRACT

This paper describes and gives the results of an analysis of wind resistance experiments carried out at several different test establishments on models of a wide range of merchant ships. Equations are given for estimating the components of wind force and wind-induced yawing moment on any merchant ship form for a wind from any direction. The equations are shown to apply to independent data.

OFE AREAS OF APPLICATION

1. Equations are provided to estimate the components of wind force and moment on merchant ships.
2. Analytical procedure can be used to establish formula of wind loads on other classes of ships.

IDENTIFICATION

Title : The Effect of Wind on Three Types of Ships with Special Emphasis on the Container Ship
Author : G. Aertssen and P. E. Colin
Agency : Association Maritime Technique et Aeronautique
Date : 1973
Miscellaneous: 25 pages, 12 references, 3 tables, 18 figures

ABSTRACT

A comparison is made between wind tunnel tests of three types of merchant ships: a conventional cargo ship, a passenger car ferry, and a container ship. The container ship was subjected to extensive tests: a series without a deckload of containers, a series with one layer of containers on deck, and a series with three layers of containers on deck. Tests results are compared with predictions using the Isherwood method. All tests were conducted with and without velocity gradient.

OFE AREAS OF APPLICATION

1. Wind load data on three types of merchant ships.
2. The Isherwood method of predicting wind load can be used for other ships.

WIND LOADS ON MOORED SYSTEMS

Knowledge of wind loads on moored systems is needed to develop requirements for the safe mooring of ships. The experimental techniques used in determining the wind loads are similar to those used in determining the wind loads on surface ships. Earlier work conducted in the 8-foot by 10-foot wind tunnel at the David W. Taylor Naval Ship R&D Center[30-33] has been used extensively in the design of many deep ocean moorings[35, 37, 38, 41] as well as shallow water moorings.[42] The report of Long[33] contains one of the most extensive collections of wind loads on moored vessels, including both single and group configurations.

The results indicate that the maximum wind loads on a ship in a group moor may be different when the ship is alone in the wind. Wind loads on typical ship group moorings are shown in Figures 5 and 6. These loads can be used in the design of the anchoring systems such as the mooring line configuration and the anchor holding power. Altmann[43] compiled the wind and the current loads on most naval vessels in his report on mooring system designs for ships. For ships without experimental data, the wind loads were estimated based on the extrapolation of test data for a similar ship. The same approach was selected by Brown in his design of deep ocean ship moorings.[35, 37, 38, 44]

A study on the mooring arrangement of ships moored at dockside was conducted by Horton and Yagle.[39] Wind loads on ships were determined with a wind-tunnel experiment of the ship model. The minimum potential energy principle was used to analyze the cable tensions due to the wind loads. This study provides a unique case of wind loads on moored systems. One of the mooring arrangements investigated is shown in Figure 7.

The wind loads on two oceanographic and navigational ocean buoys (Figure 8) were investigated by Nath.[42] Both wind-tunnel experiments and analytical calculations were conducted. The drag force on the models was calculated by considering the various portions of the model individually. The total drag forces then were compared with the measured drag forces. Close agreement occurred for most of the experimental conditions, indicating that it is reasonable to proceed in such a manner for prototype buoy configurations.

The following sheets contain summaries of data items from publications deemed representative of the wind loads data on moored systems.

IDENTIFICATION

Title : Wind-tunnel Tests to Determine Air Loads on Multiple-Ship Moorings for Destroyers of the DD 692 Class
Author : M. E. Long
Agency : David Taylor Model Basin Report R-332
Date : December, 1945
Miscellaneous: 21 pages, 3 references, 2 tables, 16 figures

ABSTRACT

Wind-tunnel tests were conducted to determine the wind loads on models of destroyers of the DD 692 class, moored singly and in groups of two, four, and six abreast. The models were built at a linear ratio of 1 to 73.8. Tests were conducted on the single model at wind speeds of 75, 100, and 125 knots and on the group of models at 125 knots for a 360-degree range of yaw. Results are given in the form of curves which show the lateral and the longitudinal forces in pounds and the yawing moment in pound-feet for single models and for individual models in the group as a function of angle of yaw. Total forces and moments in the groups also are shown. Expressions for estimating the forces and moments in the full-scale destroyers and a method for extrapolating the test results to larger numbers of ships in line abreast are given.

OFE AREAS OF APPLICATION

1. Wind load data on DD 692 class destroyers.
2. Wind-tunnel test technique for ships moored in groups in determining the wind forces and moments.

IDENTIFICATION

Title : Wind-tunnel Tests to Determine Air Loads on Moored Floating Drydocks, Part I. The ARD-12 and AFD-1 in Various Configurations
Author : James E. Blalock and Frank A. Nickols
Agency : David Taylor Model Basin, Report C-130
Date : July, 1948
Miscellaneous: 27 pages, 14 figures, 2 tables, 2 references

ABSTRACT

This report presents the wind loads on floating drydocks of the ARD-12 and AFD-1 classes at the minimum draft, maximum draft, and maximum loaded draft with and without their controlling ships. Four models were tested. The ARD-12 class drydock and its controlling ship, the DD 692 class destroyer, were built to a 1/40 linear scale. The models were tested through 180 degrees of yaw at increments of 20 degrees. Extrapolation of model data to full-size and validity of the data are discussed in the appendix.

OFE AREAS OF APPLICATION

1. Wind loads data on floating drydocks.
2. Test procedure and data extrapolation method are applicable to other ships in determining their wind loads.

IDENTIFICATION

Title : Wind-tunnel Tests to Determine Air Loads on Moored Floating Drydocks, Part II. 1/145 Scale Model AFDB-4 Class Floating Drydock in Various Configurations
Author : Frank A. Nickols and James M. Lee
Agency : David Taylor Model Basin, Report C-235
Date : July, 1949
Miscellaneous: 23 pages, 23 figures, 6 tables, 4 references

ABSTRACT

Wind-tunnel tests were conducted to measure the air loads in the above-water portion of a 1/145 scale model drydock at minimum draft, partially

submerged draft, and maximum load draft with and without its controlling ship, a CV-9 class aircraft carrier. The approximate speed simulated was 128 knots. The symmetrical configurations were tested from 0 to 180 degrees of yaw while the asymmetrical configurations were tested up to 360 degrees of yaw. The angle of yaw increments were 20 degrees with intermediate 10 degree points taken where closer definition was desired. It was found that the wind loads on the seven pontoon AFDB-4 class floating drydocks were directly proportional to the amount of above-water portion of the drydock exposed to the wind.

OFE AREAS OF APPLICATION

1. Wind load data of AFDB-4 class floating drydocks.
2. Wind tunnel test technique applicable for OFE ships.

IDENTIFICATION

Title	: Wind tunnel Tests on Multiple Ship Moorings, Part III, Determination of Air Loads on Multiple Ship Moorings for Destroyers, Submarines, Liberty Ships, and Escort carriers
Author	: M. E. Long
Agency	: David Taylor Model Basin Report 830
Date	: July 1952
Miscellaneous	: 91 pages, 31 figures, AD 272433

ABSTRACT

Wind tunnel tests were conducted to determine the wind loads on a single or a group of ships. The ship models tested were DD-692 class destroyers, EC-2 class liberty ships, SS-212 class submarines and CVE-55 class escort carriers. Each class of ship was tested in the configuration of single and nest mooring. The wind profiles in the wind tunnel were measured at three locations in the test section. Boundary layer flow effect on the data and actual wind profiles are discussed. Force and moments age given in pounds and in pound-feet, respectively, as they were measured on the models.

OFE AREAS OF APPLICATION

1. The wind loads data have been incorporated into the design manual DM-26 of NAVFAC.

2. Test methods are applicable to other ocean facility structures.

IDENTIFICATION

Title	: Forces Induced on Moored Inactive USS Bunker Hill (CVS-17) by Winds at Bremerton, Washington, during the period July 1955 through April 1956
Author	: J. T. O'Brien, R. E. Jones, F. W. Taylor
Agency	: Naval Civil Engineering Laboratory, Port Hueneme, CA Tech Memo M-119
Date	: March 1957

ABSTRACT

Field measurements are presented giving the forces induced in the moorings of the CVS-17 by 66 selected winds of 13 to 30 knots speed. These measurements of lateral and longitudinal force and yaw moment acting on the ship are compared to the forces measured in a wind tunnel study of a scale model ship of the same class at DTMB. The forces measured on CVS-17 are about 2/3 of the scaled-up forces acting on the model.

OFE AREAS OF APPLICATION

1. Wind load data on Essex-class aircraft carriers.

2. The correlation of the wind loads on a full size ship to those of a model ship may be applicable to other ships.

IDENTIFICATION

Title : Techniques for the Design and Analysis of Multiple-Leg Deep-Ocean Ship Moorings
Author : D. F. Brown
Agency : Hydrospace Research Corporation
Date : September 1967
Miscellaneous: See Section 3 for Wind Loads

ABSTRACT

General equations for ship resistance and test data from a wind tunnel test were used to calculate the wind resistance as a function of heading and wind speed. These results then are used in the design of a multiple-leg deep-ocean ship mooring. The analysis did not consider complex dynamic resistances and moments due to oscillating wave loading. A design safety factor is usually selected to account for this effect.

OFE AREA OF APPLICATION

Method of calculation of the wind loads on ships from the wind tunnel test results.

IDENTIFICATION

Title : Analysis of Assumed Mooring Arrangement for Maritime Class Ships
Author : John L. Horton and Raymond A. Yagle
Agency : Marine Technology, SNAME
Date : July, 1968
Miscellaneous: 10 pages, 2 tables, 7 figures

ABSTRACT
An assumed but routine mooring arrangement for a standard Great Lakes ship--in this case a Maritime Class vessel--is analyzed to ascertain what wind conditions would be sufficient to establish the sequency necessary to cause parting of one line, followed by parting of second and third lines, and, finally, by full failure of the mooring arrangement. Wind tunnel tests on a model of the ship are reviewed, and application of the minimum potential energy principle used in the analysis is illustrated.

OFE AREAS OF APPLICATION

1. Wind load data on Maritime Class vessels.

2. Analytical method applicable to wind load calculation of ships moored at dockside.

IDENTIFICATION

Title : The Evaluation of Wind and Current Forces on Moored Vessels
Author : J. M. Ringelberg
Agency : Journal of Naval Engineers
Date : December 1968
Miscellaneous: 7 pages, 4 references, 3 tables, 10 figures

ABSTRACT

A simplified method for determining the magnitude of wind and current forces on moored vellels is presented. The longitudinal area and the transverse area of the parts of the ship above the waterline, the wind drag coefficients in the direction of wind, and the relative direction of resultant wind force are considered in the calculation of wind forces. Empirical graphs are drawn of the various relationships involved. A table is constructed with the aid of the graphs, from which the forces for various wind speeds can be derived. An example of the calculation method for a destroyer escort designed by the author is included in the paper.

OFE AREAS OF APPLICATION

1. The method for determining the wind loads on ships can be used in design work where an assessment of the force is needed.

2. Calculation of current force on ships also is presented.

IDENTIFICATION

Title : Forces on Ships Moored in Protected Waters
Author : Ronald Altmann
Agency : Hydronautics, Inc. Report TR 7096-1
Date : July 1971
Miscellaneous: 218 pages, 10 tables, 65 figures, 97 references

ABSTRACT

The results of a comprehensive study of the forces on moored ships is presented. The study is based on numerous wind tunnel and water channel force data obtained over a period of forty years. These data were converted to coefficient form suitable for predicting steady-state longitudinal drag, lateral force, and yaw moment on single or multiple-moored vessels subject to wind and currents at various headings. Vertical wind gradient, restricted channel, and near bottom effects are included in the study. Significant physical characteristics of naval ships have been compiled to assist in the computation of mooring load. Since the ships include most forms found in maritime commerce, the information should be of direct use in computing mooring forces in all ships.

OFE AREAS OF APPLICATION

1. Physical characteristics of various naval ships.
2. Wind load test data useful for steady mooring load calculations.
3. Current load on ships included.

WIND LOADS ON OFFSHORE STRUCTURES

There are little experimental data available on wind loads on offshore structures such as offshore mobile platforms or fixed offshore oil platforms. One possible reason is that these data are proprietary in nature. In general, wind load on offshore structures is closely related to onshore structures. However, the experimental data show that the ocean wave and the clearance between the platform deck and ocean surface have a significant effect on the wind loads.[54, 58] The configuration of two of the models tested are shown in Figure 9. The effects of the wave profile on the total wind force for those structures are shown in Figure 10. Wind tunnel test data on frame and truss structures, similar to offshore structures, are available in many reports, for example, the experimental reports on bridge models,[45] radio telescope models,[47] and tubular framework models.[60] Given the wind load on the components, the wind load on the offshore structure can then be calculated. Most text books on ocean structures also have analytical methods for wind loads calculation.[48,52,53,55,56,59] Recent technical conference reports[49-51, 57] on wind loads on structures contain much useful information in the area of wind field, data analysis, and experimental investigations applicable to offshore structures.

In general, experimental investigations should be conducted in the design process of large offshore structures. Both model and full-scale data on wind loads are needed to establish a prediction model for ocean facilities engineering applications.

Summaries of data items from publications deemed representative of the wind load on offshore structures follow.

IDENTIFICATION

Title	: Engineering Problems Related to the Design of Offshore Mobile Platforms
Author	: E. C. Rechtin, J. E. Steele, R. E. Scales
Agency	: SNAME Transactions
Date	: November 1957
Miscellaneous	: 30 pages, 40 references, 15 figures, 7 tables

ABSTRACT

The authors outline the problem of ascertaining the forces acting upon mobile drilling platforms operating in the Gulf of Mexico. An attempt was made to bring together and to develop workable theories on the forces generated by wind and waves. The first part of the problem of

determining the wind force is the estimation of the wind velocity which should be considered in the design. This includes the maximum speed and duration. The second part of the problem is the determination of the load applied to a given structure by a given velocity of wind. The determination of wind force by calculation involves a shape coefficient whose typical values are listed in the paper.

OFE AREA OF APPLICATION

Analytical method in estimating the wind load on offshore platforms.

IDENTIFICATION

Title	: Design Manual - Harbor and Coastal Facilities NAVFAC DM-26
Agency	: Naval Facilities Engineering Command
Date	: July, 1968
Miscellaneous	: See Sections 2, 3 of Chapter 7 for wind loads on ships

ABSTRACT

In this manual, design criteria are presented for facilities in Category Group 160 for use by experienced architects and engineers. The contents include design information for harbor, coastal protection, dredging, ship channels, fixed moorings, fleet moorings, and mooring design. In Section 2 and 3 of Chapter 7, the wind forces and yaw moment on several classes of ships are presented at different wind speeds and directions. Wind force data are available for CVE-55, SS-212, ARD-12, AFDL-1, AFDB-4, EC-2, DD-682, AO-143, and CVA-59 classes of ships. Equations are provided to calculate the wind loads on other naval ships.

OFE AREAS OF APPLICATION

1. Wind loads data and formulas available in determining the wind forces and moments on most naval ships.
2. Current loads on ships and mooring system hardware selection also are given for deep sea ocean facility applications.

IDENTIFICATION

Title : Ocean Engineering Structures
Author : J. Harvey Evans and John C. Adamchak
Agency : The MIT Press, Cambridge, Massachusetts
Date : May, 1969
Miscellaneous: See Chapters 1 and 2 on Ocean Environment and Structural Loadings

ABSTRACT

This text on ocean structures contains, in the first two chapters, the wind loads on ocean engineering structures. The wind forces are calculated in terms of a drag or shape coefficient empirically derived from model experiments of the structures. A few illustrative examples are given in the text. Also listed are the design values of the drag coefficients used by the American Bureau of Shipping for surface ship hull, rig, derrick, and girders. An extensive bibliography on ocean engineering structures is presented in the appendix.

OFE AREA OF APPLICATION

The formula and reference material can be used in estimating wind loads on ships and offshore structures.

IDENTIFICATION

Title : Wind Drag Coefficients for Bluff Offshore Ocean Platforms
Author : S. Thomas Aiston and John H. Nath
Agency : Offshore technology Conference Paper OTC 1068
Date : May, 1969
Miscellaneous: 8 pages, 9 figures, 10 references

ABSTRACT

This paper presents the wind-tunnel test data on bluff offshore ocean platforms. The wind drag coefficients were determined for the platforms. The results show that an overall drag coefficient of 0.9 may be used for design purposes in relatively thick boundary layer conditions, which is somewhat lower than published drag coefficients for standard land based buildings. It is recommended that each offshore ocean platform be tested in a wind-tunnel to determine its particular drag coefficients.

OFE AREAS OF APPLICATION

1. Drag coefficient of a typical offshore ocean platform is provided.
2. Test techniques can be used to determine the wind drag of other offshore facilities.

IDENTIFICATION

Title : Dynamic Analysis of Ocean Structures
Author : B. J. Muga and J. F. Wilson
Agency : Plenum Press, New York
Date : 1970
Miscellaneous: See Chapter 1 for Wind Loads

ABSTRACT

This book treats wind loadings on ocean structures in the first chapter. It attributes fifteen percent of the load on ocean structures to wind loadings. Equations of wind loadings and wind gust calculations are presented. The drag coefficient of several simple structural elements also are listed in the book. Illustrative examples of application on ocean structures are presented in other parts of the text.

OFE AREA OF APPLICATION

The formula of wind and wind loadings can be used to estimate the wind effect on ocean facilities structures.

IDENTIFICATION

Title	: An Experimental Study of Wind Forces on Offshore Structures
Author	: John H. Nath
Agency	: Technical Report for NSF Grant 4679, Colorado State University, Fort Collins, Colorado
Date	: August, 1970
Miscellaneous	: 95 pages, 11 tables, 64 figures, 25 references

ABSTRACT

Four basic structural shapes were tested in wind-tunnels of the Colorado State University to determine the wind forces acting on them. In addition to the structural models, some drag force determinations were made for two oceanographic buoys. This test verified that the pressure coefficients and the total drag coefficient are reduced for a structure when it is elevated on supports. The jet of air under the structure reduces the magnitudes of both the positive pressure on the upstream face of the structure and the negative pressure on the upstream face. The result also shows that, for offshore structures and other elevated ocean structures, the drag coefficients increase drastically on the windward face of a wave.

OFE AREAS OF APPLICATION

1. Experimental techniques can be used for other offshore structures.
2. Provides drag coefficients for several basic structural elements mostly used in offshore structures.
3. Information on wave effect on wind loads can be applied to mooring system design.

IDENTIFICATION

Title : Conference on Wind Loads on Structures
Author : Edited by A. Roshko
Agency : National Science Foundation
Date : December, 1970
Miscellaneous: Summary Report of the Conference, held at Caltech, Pasadena, California

ABSTRACT

This publication summarizes the results of discussions in the conference on wind loads on structures covering the following areas: public safety and protection, tornadoes and hurricanes, meteorology and climatology, stochastic methods, structural analysis and design, aerodynamics and aeroelasticity, and wind tunnel and full-scale investigation. It also contains research of individual participants on wind loadings, including wind loads on ocean structures.

OFE AREAS OF APPLICATION

1. Many of the subjects discussed in the conference are applicable to ocean structural analysis.
2. The list of participants and their research interests provides a good reference on the state-of-the-art of wind loading research.

IDENTIFICATION

Title : Wind Forces in Engineering
Author : Peter Sachs
Agency : Pergammon Press, New York
Date : 1972

ABSTRACT

This book treats wind forces on structures in general and discusses wind data, basic shape factors of structures, wind tunnel test techniques, and their application to buildings, bridges, masts, towers, and cables. It provides a systematic approach to the calculation of wind forces in structural design applications. It also contains the codes of general practice in structural design.

OFE AREAS OF APPLICATION

1. The forcing formula and wind load shape factors can be used in the calculation of wind loads on offshore structures.
2. Introductory work on wind loads in engineering applications.

IDENTIFICATION

Title	: Measurement Over a Wide Range of Reynold's Number of the Wind Forces on Models of Lattice Framework with Tubular Members
Author	: R. W. Gould and W. G. Raymer
Agency	: National Physical Laboratory
Date	: May 1972
Miscellaneous	: 32 pages, N72-27996

ABSTRACT

Wind-tunnel tests were conducted to measure the wind loads on tubular frameworks to provide design data for tower construction. The models tested included plane frames consisting of two vertical tubes, small diagonal bracing tubes having three selected solidity ratios, and towers of triangular and square platforms constructed from these frames. The effects of joint gusset plates and a maintenance ladder on one-plane frames are examined.

OFE AREAS OF APPLICATION

1. Wind load data on models of lattice framework with tubular members.
2. Data can be used to calculate the wind load on offshore platforms.

IDENTIFICATION

Title : Estimation of Wind Forces on Offshore Drilling Platforms
Author : J. E. Aquirre and T. R. Boyce
Source : RINA Transaction
Date : 1974
Miscellaneous: 16 pages, 33 references, 15 figures

ABSTRACT

This is a survey of the effects of wind on structures such as ships, bridges, towers, and ratio telescopes. The authors give several examples of the application of the wind load data in estimating wind forces on offshore drilling platforms. The results are the drag and lift coefficients of many structural components used on offshore platforms. It is very well presented with the users in mind. The authors also discuss the characteristics of wind and of ice accretion on the wind loads.

OFE AREA OF APPLICATION

Wind loads calculation for offshore structures and superstructures of ships.

SUMMARY AND RECOMMENDATIONS

A survey was conducted on the wind loads on ocean facilities structures, namely, ships, moored systems, and offshore structures. Only experimental and analytical studies which are suitable for publication were included. Data item summary sheets were prepared for some of the representative works in each category of ocean structures. The literature related to wind loads on ocean structures. Because some publications about wind loads on onshore structures are useful to the ocean facilities engineer, a few examples of these from a large volume of materials are also listed.

The results of the survey can be summarized as follows:

1. There are extensive experimental data on wind loads for almost any kind of ship. These wind tunnel test data, however, have not been correlated with full-scale measurements of which there are very few. Attempts were made to predict the wind loads on ships by empirical models based on the past test data. Because of the disparity among the test facilities and measurement techniques, these empirical models can only give a qualitative estimate of the wind loads.

2. The wind loads data on moored ships exist only for most of the World War II Ships. As the ships become much larger, there is a need to update the existing wind loads data through a systematic experimental program. The wind loads on other moored systems such as buoys are mostly determined through analytical calculations on each of their components. Since their configurations are simple, this approach is deemed adequate for ocean facilities engineering applications.

3. Very few data on wind loads on offshore floating or fixed platforms are available for NAVFAC applications. It is possible to calculate these loads by adding the loads on each component of the platform and selecting a safety factor to cover the interference effects. Considering the cost of such structures, it is felt that a wind tunnel program for each structure should be conducted.

Thus, the following actions are recommended to provide more applicable wind loads data for ocean facilities engineers:

1. Revise the wind loads portion of the NAVFAC design manual DM-26 to include recent test results and modern naval ships. This effort should include a systematic experimental program to correlate model and full scale results.

2. A handbook of wind loads on ocean facilities structures should be prepared. Although there are textbooks and conference proceedings on wind loads, there is a need to compile the existing wind loads data on ocean structures for the use of designers. This handbook can be part of a handbook on environmental forces which could include wind, wave, and current loads on ocean structures.

3. A survey of the wind field above the ocean and its effect on the wind loads on ocean structures should be conducted. The wind field above the ocean has been a problem in both the experimental and analytical approaches. Different theories and data on wind field can change the results of the wind load calculation up to fifty percent. This survey will help the designer to select the proper wind formula.

4. A standard model for comparing results obtained in different wind tunnels may help designers in using these data.

5. A survey of existing special-purpose experimental facilities and modeling techniques will be valuable for future experimental work on wind loads.

6. The free and timely distribution of both model and full-scale data will help designers update their procedures for wind loads calculation.

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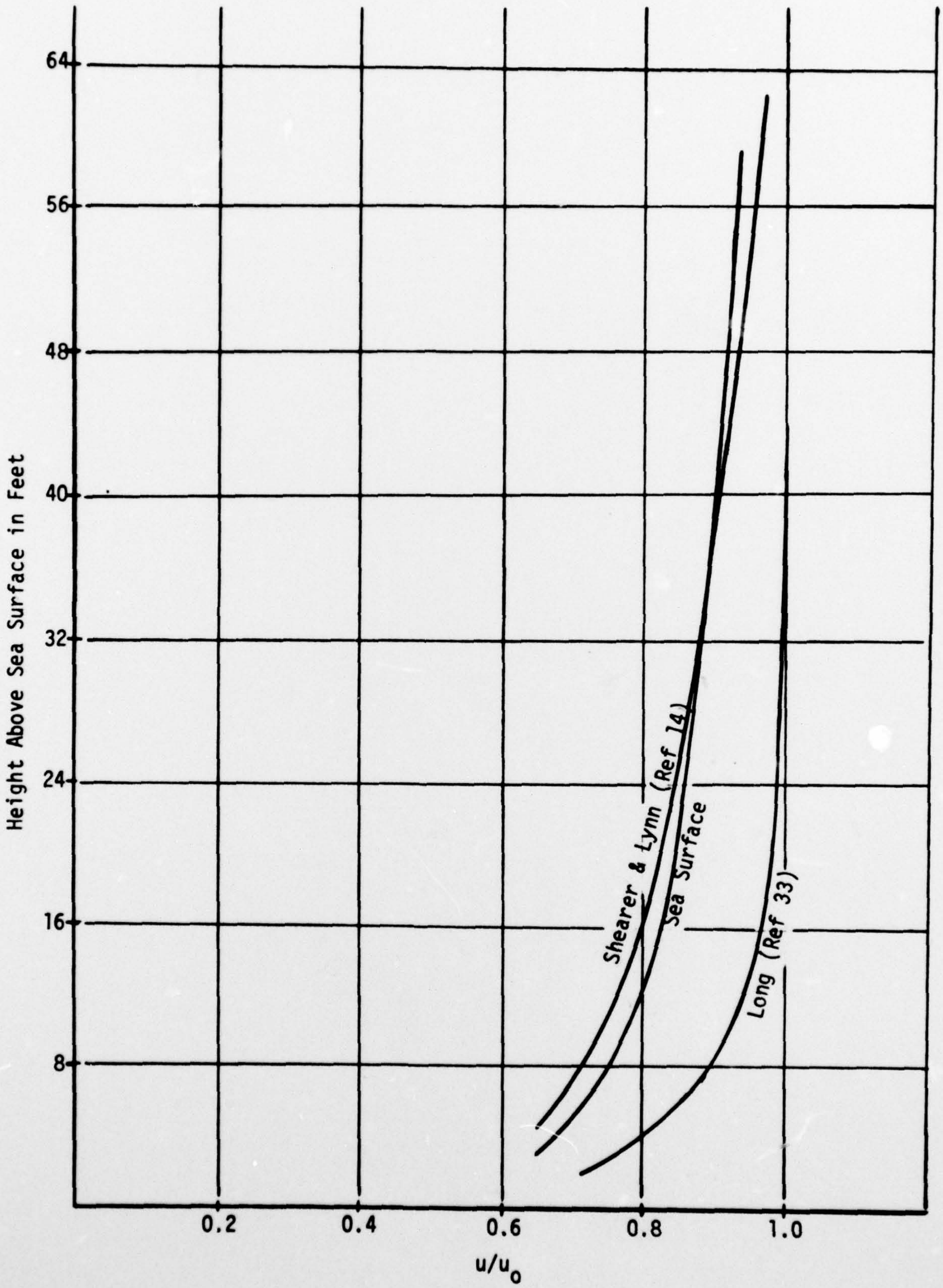


Figure 1 - Wind Velocity Profiles

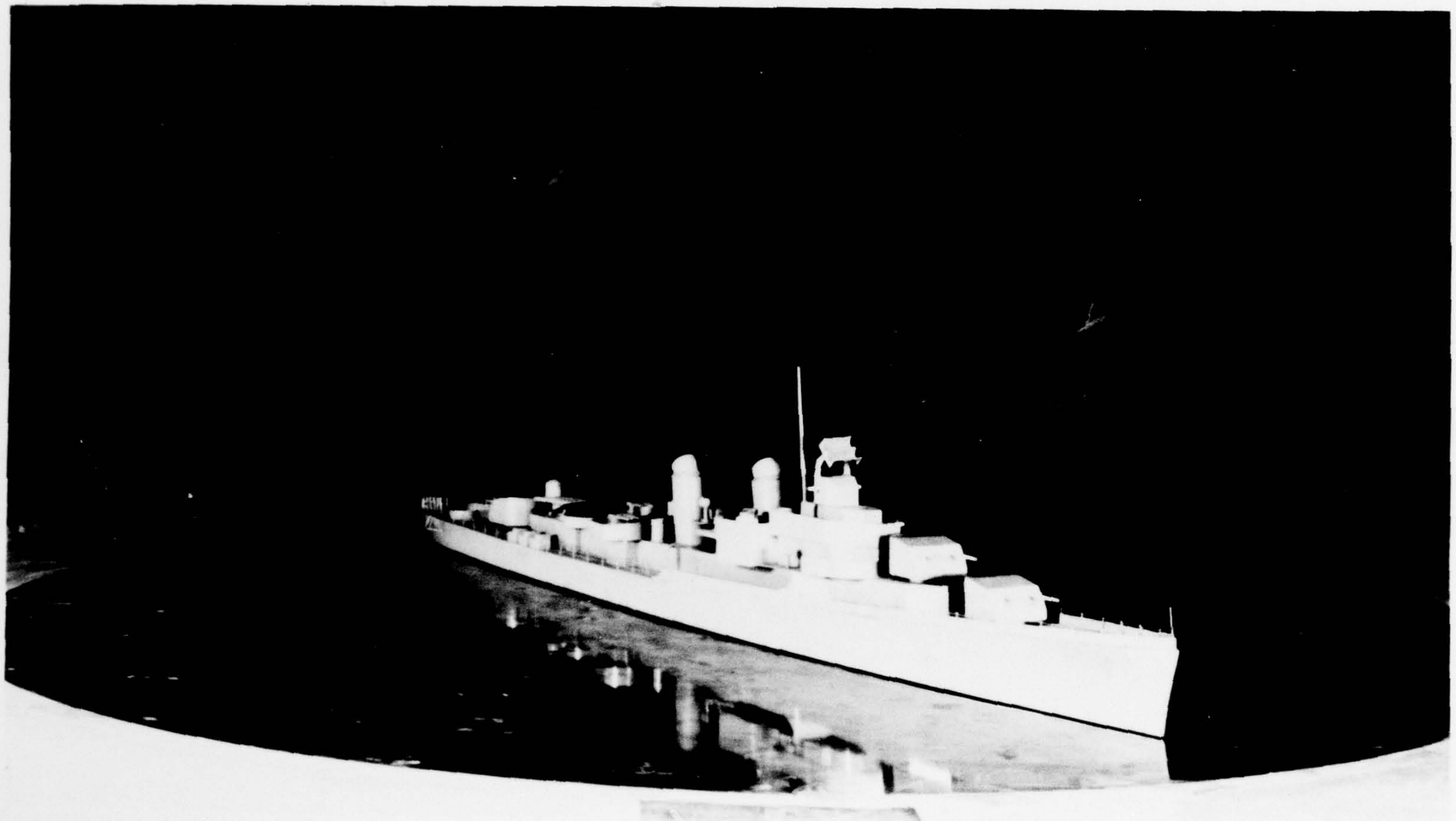


Figure 2 - One-Quarter Starboard View of a 1:73.8-Scale Model DD692-Class Destroyer Mounted on Ground Board in Wind Tunnel

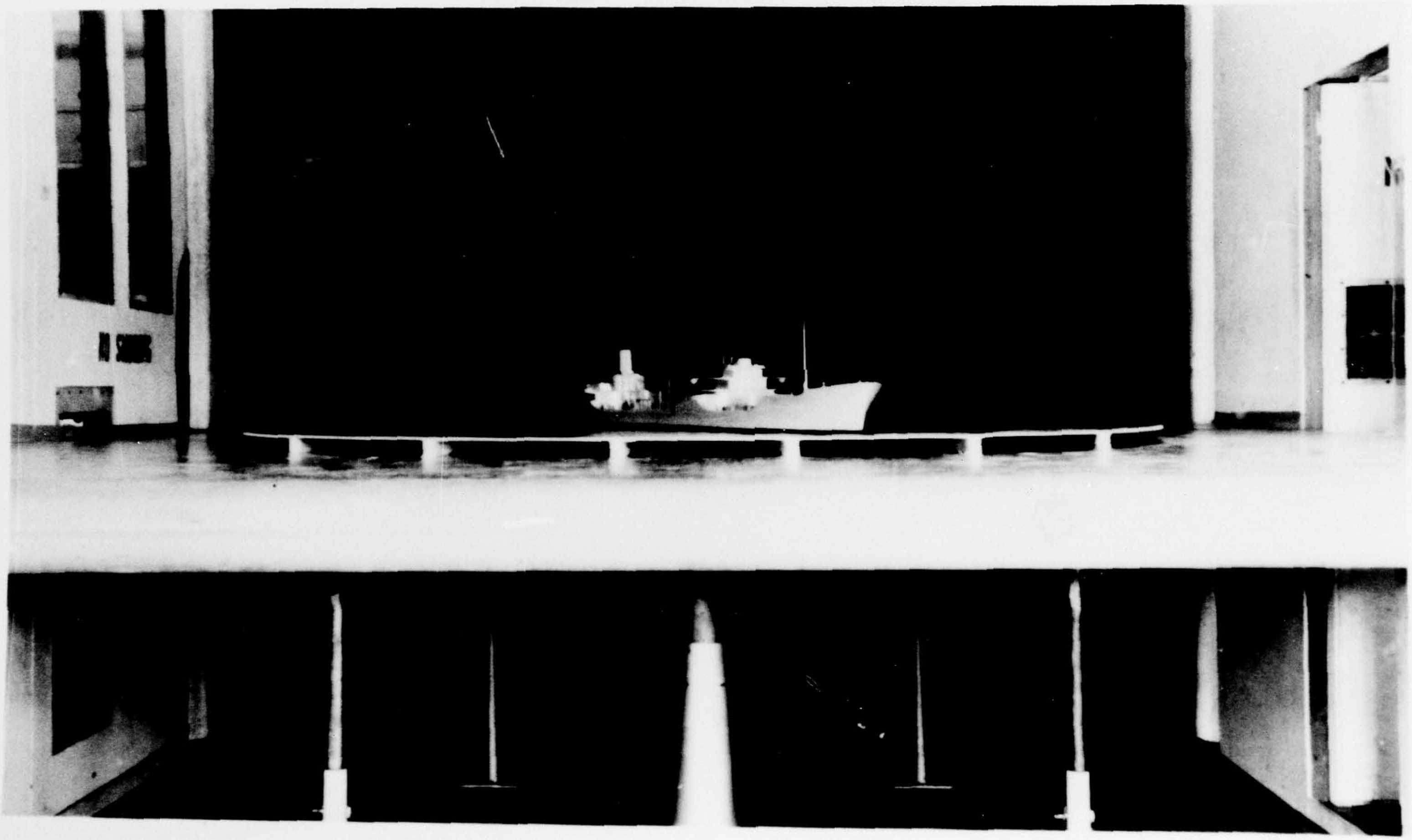


Figure 3 - One-Quarter Starboard View of a 1:120-Scale Model SS PENNSYLVANIA Showing Ground-Board and Fouling-Plate Installation in Wind Tunnel

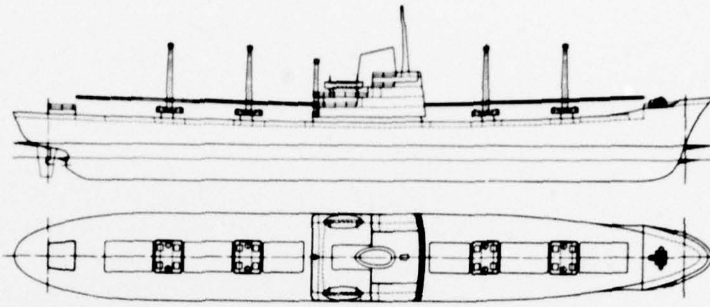


Figure 4a - Cargo Ship - Variation 1

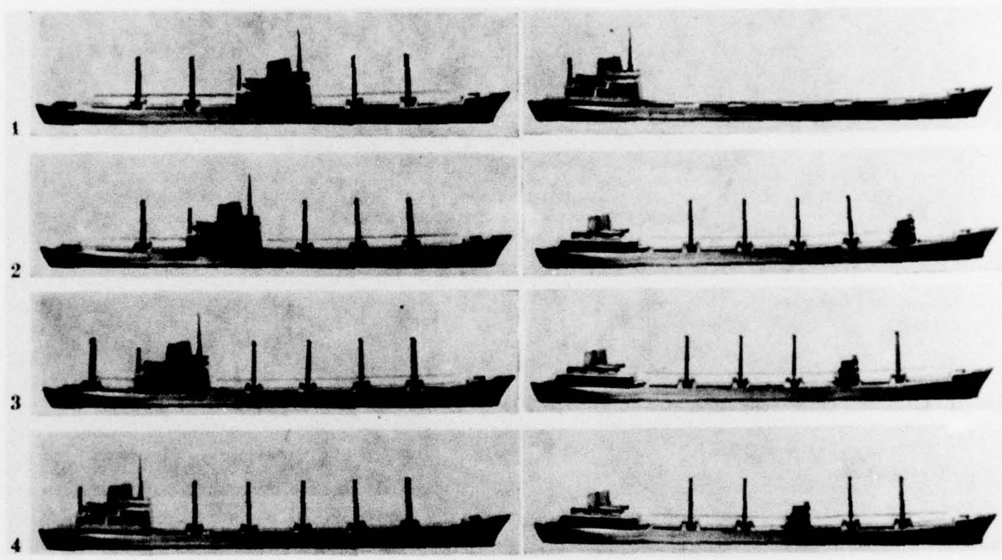


Figure 4b - Cargo Ship - Superstructure Variations

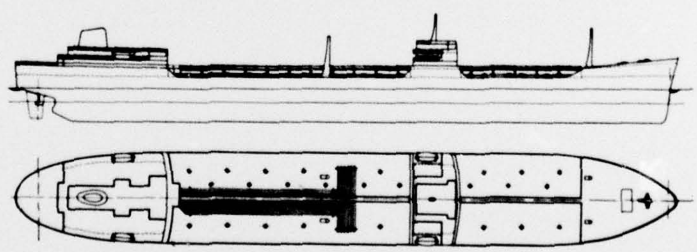


Figure 4c - Tanker - Variation 1

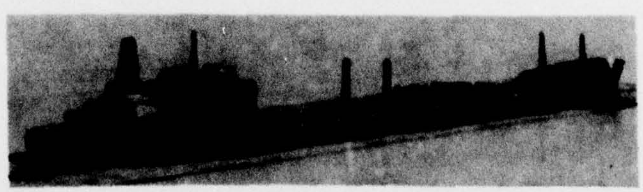


Figure 4d - Tanker - Variation 2

Figure 4 - Variations in the Superstructure Configuration of Two Models as Tested by Wagner

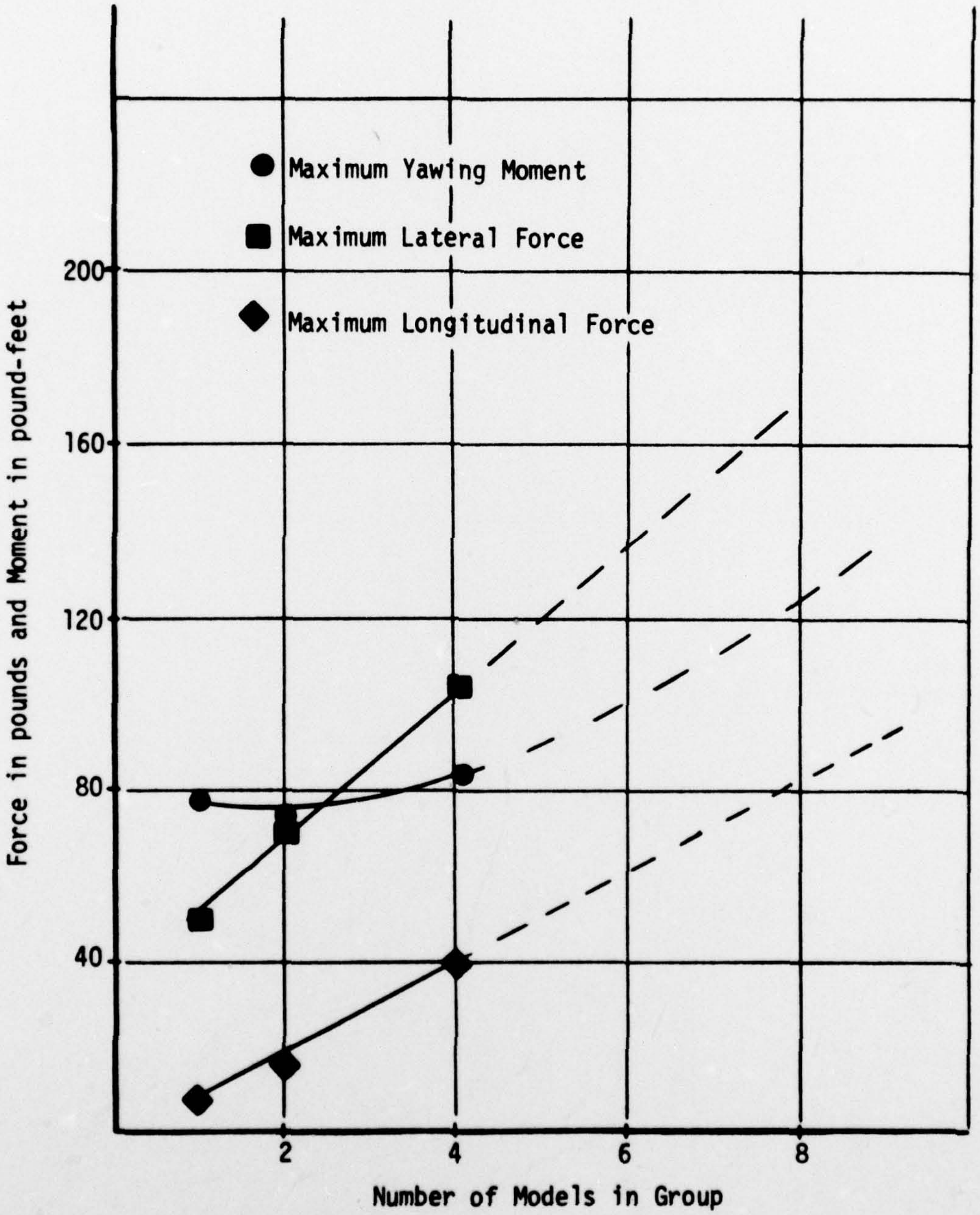


Figure 5 - Maximum Wind Loads for Different Groups of EC-2 Liberty Ships (Reference 18)

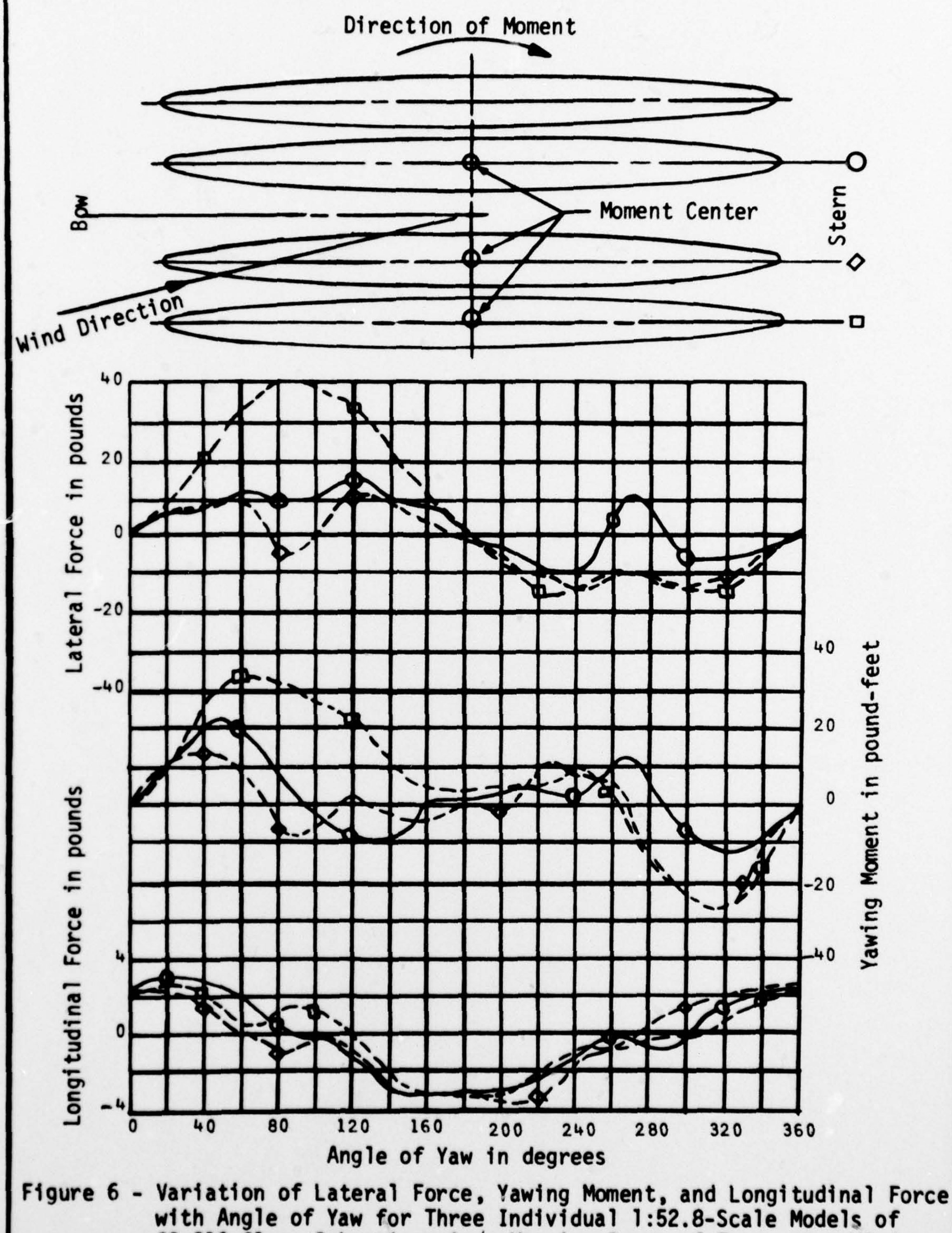


Figure 6 - Variation of Lateral Force, Yawing Moment, and Longitudinal Force with Angle of Yaw for Three Individual 1:52.8-Scale Models of SS-212 Class Submarines in a Mooring Group of Four, at a Wind Speed of 125 knots (Ref 52)

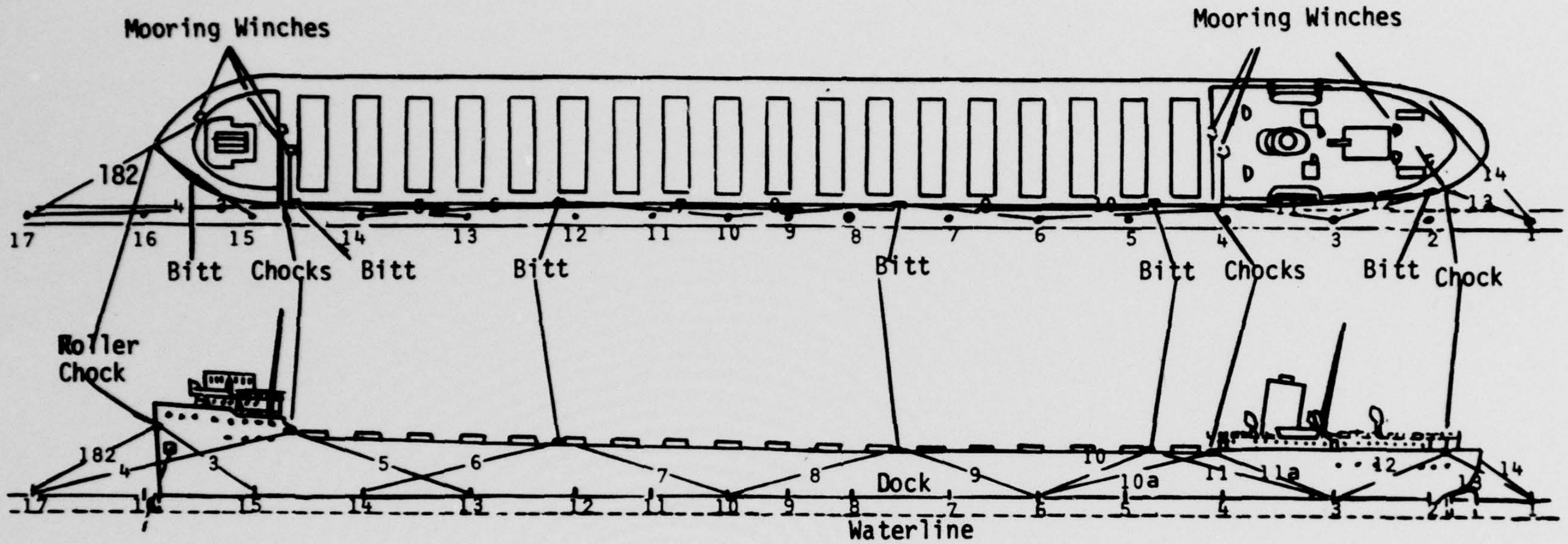


Figure Mooring Arrangement
(Reference 39)

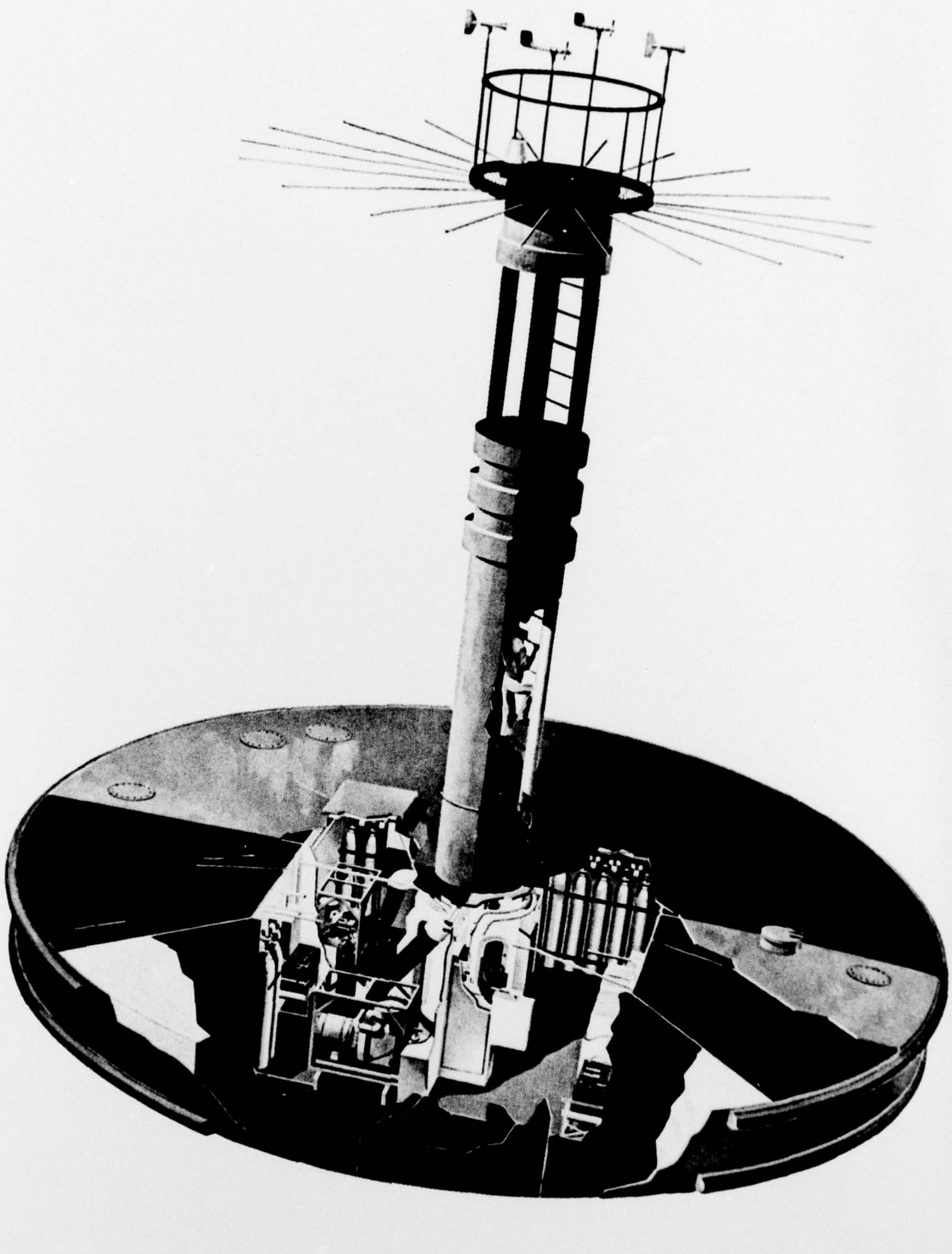
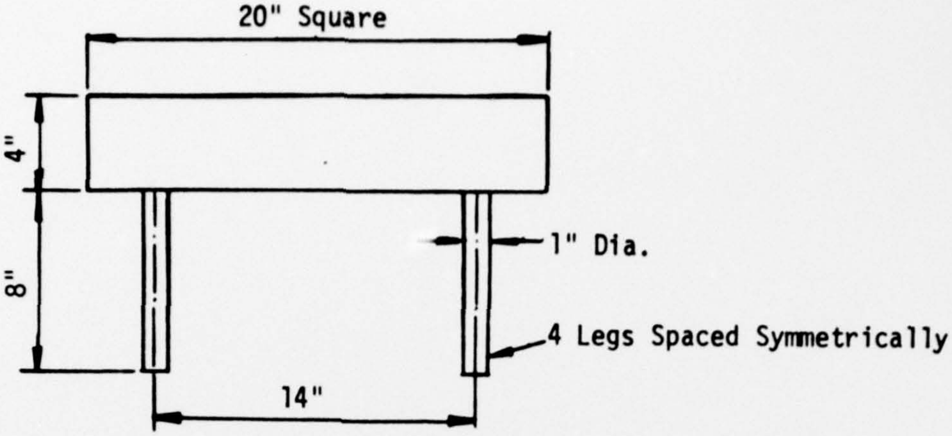
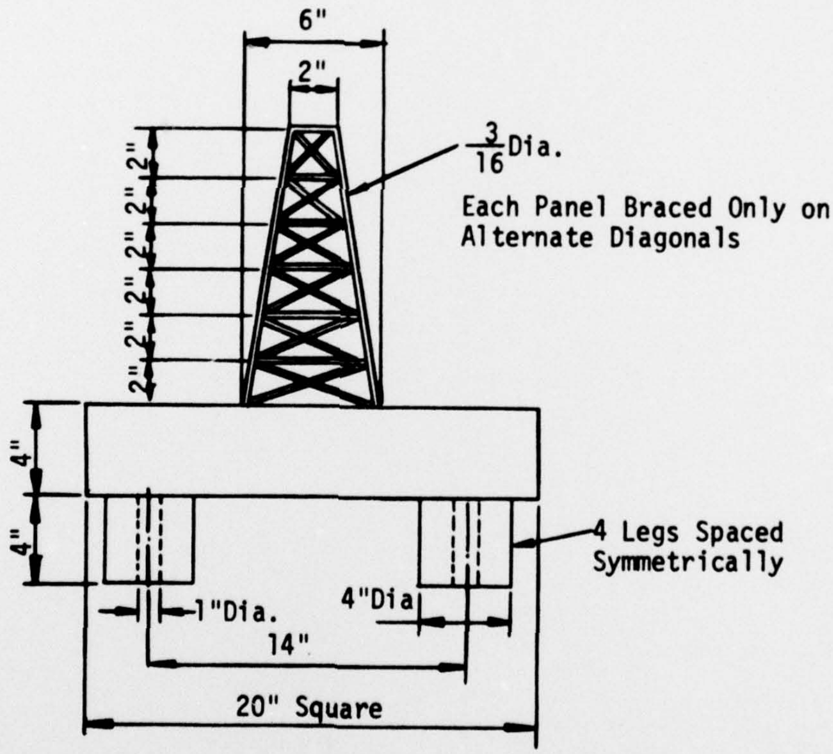


Figure 8 - ONR Oceanographic Buoy



Platform without Tower



Platform with Tower

Figure 9 - Models of Offshore Structures Tested

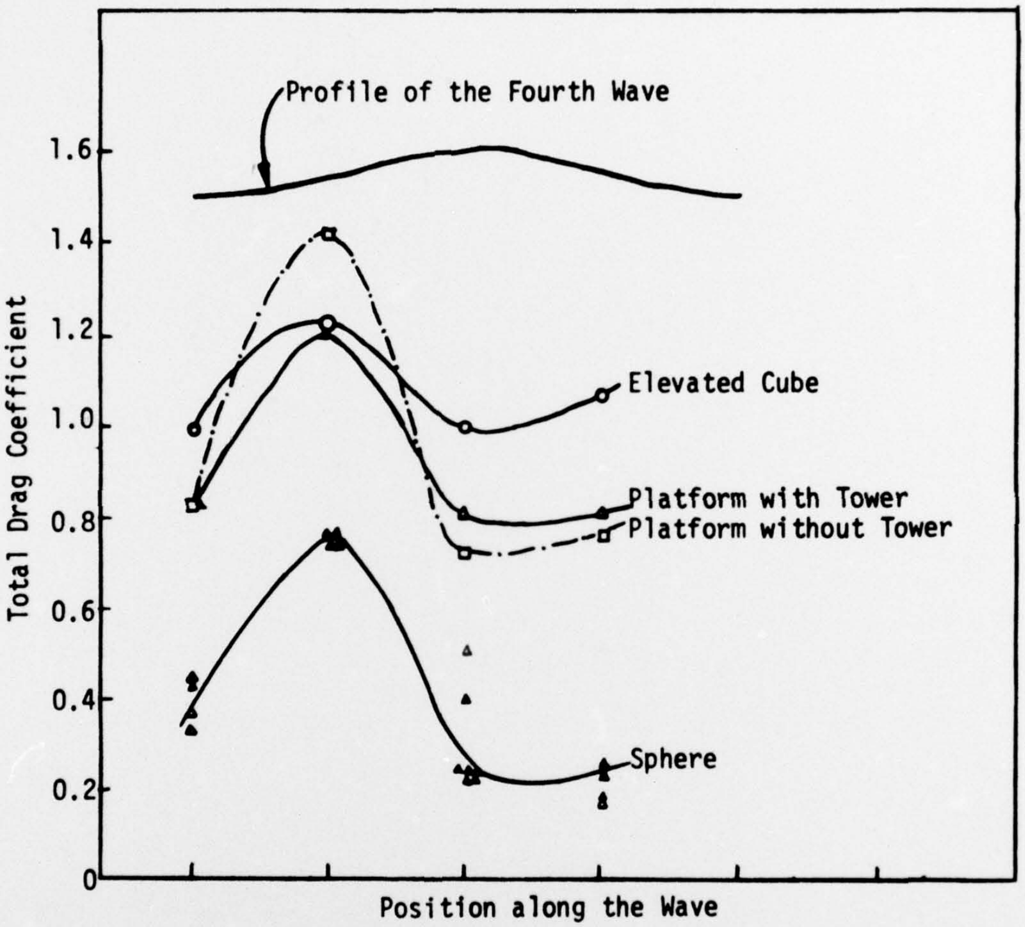


Figure 10 - Total Drag Coefficient vs. Position on the Wave for the Various Structural Models

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