

AD 677044



CHESAPEAKE BAY INSTITUTE

The Johns Hopkins University

AN EXPLORATION OF THE ORIGIN
AND PERSISTENCE OF THE BEAUFORT
WIND FORCE SCALE

Blair Kinsman

Technical Report 39

This document has been approved
for public release and sale; its
distribution is unlimited.

D D C
RECEIVED
NOV 5 1968
RECEIVED

Reference 68-7

August 1968

Reproduced by the
CLEARINGHOUSE
for Federal Scientific & Technical
Information Springfield Va 22151



Admiral, Sir Francis Beaufort, K.C.B.
Courtesy of the National Maritime Museum, Greenwich, England.

CHESAPEAKE BAY INSTITUTE
THE JOHNS HOPKINS UNIVERSITY

TECHNICAL REPORT 39

AN EXPLORATION OF THE ORIGIN AND PERSISTANCE OF THE BEAUFORT WIND
FORCE SCALE

by

Blair Kinsman

This report contains results of work carried out for the
Office of Naval Research of the Department of the Navy
under research project NR 083-016, Contract Nonr 4010(11).

This report does not necessarily constitute
final publication of the material presented .

Reference 68-7

August 1968

D.W. Fritchard

Director

ABSTRACT

A discussion of the history and meaning of the original Beaufort wind force scale is presented and compared with a recent version. Some account of the accidents that have kept the Beaufort scale current after 160 years and the comedy of providing wind velocity equivalents is given. It is suggested that perhaps the time has come to return the Beaufort scale to the seamen from whom it was borrowed.

BLANK PAGE

An Exploration of the Origin and Persistence
of the Beaufort Wind Force Scale

The Beaufort wind force scale is one of those simple minded things that has always been around. There are numbers from 0 to 12 and when the wind reaches force 12 you stay ashore and batten down. The Beaufort numbers stand for wind velocities and you can look up the equivalent wind velocities somewhere if you need them. People describe the wind in Beaufort numbers when they want to sound salty and confuse land lubbers. It is all clear and straight forward with nothing about it worth much attention. At least so I thought until Dr. Krüger of the Deutsches Seewartamt sent me a set of wave photographs annotated with Beaufort numbers. For my students, I dug out a table of equivalents and converted the Beaufort numbers to wind velocity ranges. Some time later, one of the values was questioned and I again looked up the equivalents to see that no typographical errors had crept in. The reference I had used was not at hand so I went to another. I was taken aback to find that not only was the particular value of the wind velocity in question apparently wrong but that many of the others were off too. Even with the best of intentions typos do occur but this was a bit thick. A frantic search finally uncovered the first reference and inspection of the table showed that the equivalents had been reproduced exactly. However, the two references disagreed spectacularly. It was at this point that I began to wonder whether the Beaufort wind force scale was so simple after all and, more to

the point, whether I understood it.

What follows is an account of some of the things I discovered about the Beaufort scale. It is not a definitive account. I am not an historian nor have I been able to work with the original source material. Admiral Beaufrot and his activities deserve the attention of a qualified scholar. However, until his story is properly told, this sketch should be of some use to oceanographers.

Perhaps the best place--or at any rate the most interesting place--to begin is with Beaufort himself¹. Rear-Admiral, Sir Francis Beaufort, K.C.B. was born in Ireland--without the titles-- in 1774. His father was a protestant clergyman, a topographer, and one of the founders of the Royal Irish Academy. Beaufort entered the Royal Navy at the age of 13. He was a midshipman aboard the AQUILON, 32, Lord Howe's repeater for the rear squadron at the Glorious First of June² when the British thrashed the Brest Fleet under Villaret-Joyeuse. He made lieutenant in 1796 and was First of the PHAETON, 38, in 1800 when she chased His Most Catholic Majesty's polacre SAN JOSEF, 14, in under the 5 gun battery at Fangerola near Málaga, Spain. Two nights later Lt. Beaufort commanded a cutting out expedition of four of the PHAETON's boats. Unfortunately, the launch, which mounted a carronade, was unable to keep up and surprise was lost when the barge and two cutters were detected and fired upon by a French privateer schooner. In spite of this Lt. Beaufort laid his boats alongside the SAN JOSEF and,

¹ A Horatio Hornblower addict's delight!

² 1794

after having been thrown back twice, secured the deck and brought her out. During the action Beaufort accumulated three sword cuts and 16 musket shots in the head, arms, and body. As a result of his success Lt. Beaufort made the long step up to Commander and, as a result of his wounds, was given convalescent leave.

Commander Beaufort was on the beach until 1805 but hardly idle. In 1803-1804 he helped his brother-in-law, Mr. Edgeworth, father of the novelist Maria Edgeworth, to establish a line of telegraphs from Dublin to Galway over which messages and replies could be transmitted in 8 minutes.³

In the summer of 1805 Beaufort was appointed to the command of the WOOLWICH, ⁴⁴, Figs. 1 and 2, armed en flûte.⁴ It was at this time that Beaufort devised his wind force scale. At least that is what Admiral FitzRoy says in "The Weather Book, A Manual of Practical Meteorology" published in 1863 by Longman, Green, Longman, Roberts, and Green: London. On pages 30 and 31 one finds "... the practical, and now common, mode of estimating force of wind by arbitrary scale, ranging from 0 = a calm, to 12 = a hurricane, is found generally sufficient for descriptive purposes; and it is surprising how closely practised observers agree in such estimations. All honour to Beaufort, who used and introduced this succinct method of approximation by scale, expressed in numbers instead of vague words, about the beginning of this century. By

³ To us the word "telegraph" means Morse's gadget but in 1803 it meant a chain of semaphore stations.

⁴ A ship is "armed en flûte" when her guns have been removed leaving her gun ports only a row of empty holes.

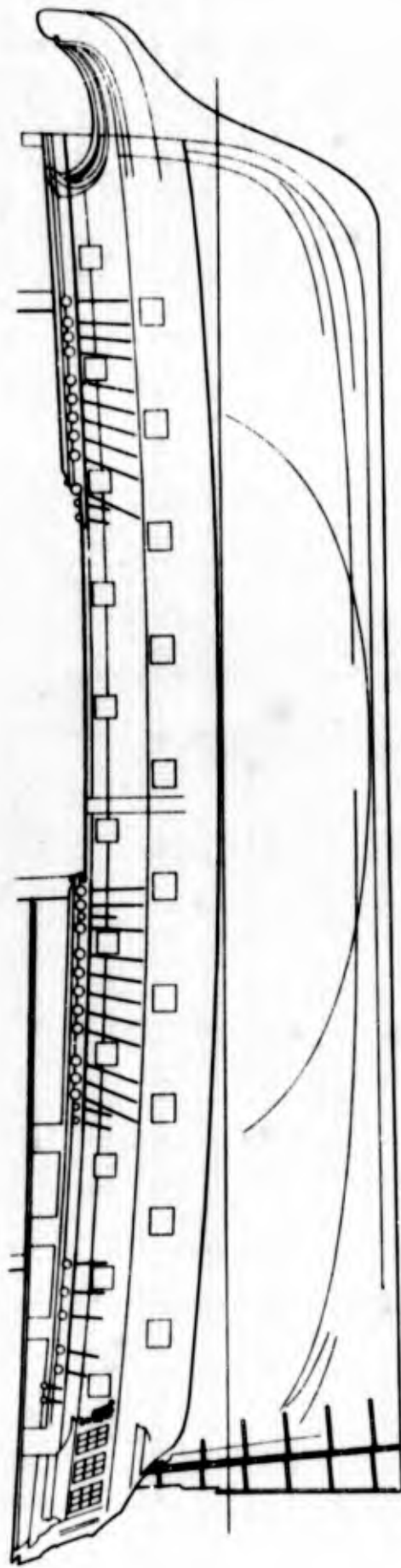


Figure 1. Lines of H.M.S. WOOLWICH, 44.

Courtesy of the National Maritime Museum, Greenwich, England.

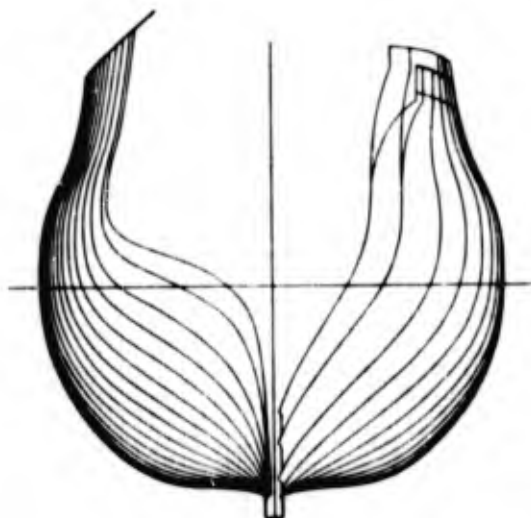


Fig. 2. Sections of H.M.S.
WOOLWICH, 44.
Courtesy of the National Maritime
Museum, Greenwich, England.

the kindness of his family, we have them now before us, in the log of H.M.S. 'Woolwich' in his own hand-writing dated 1805."⁵

Between 1805 and 1810 when he was promoted to post rank, Beaufort commanded a number of ships and saw service in the East Indies, the Rio de la Plata, the Cape of Good Hope, the Mediterranean, the north coast of Spain, Quebec, and on convoy duty. During this service, when not otherwise occupied, he engaged in hydrographic survey

work. For example, he provided the data for new and very accurate charts of the entrances to the Rio de la Plata.

During 1811-1812 Captain Beaufort commanded H.M.S. FREDERIKSSTEEN, 32, and was employed in the eastern Mediterranean on a hydrographic survey of the coasts of Asia Minor. With his left hand he suppressed the organized system of general and absolute piracy then prevalent there and also made astronomical observations.

⁵ The Keeper, Public Record Office, Chancery Lane, London, W.C. 2, England very kindly tried to find the original entry for me. He has both the captain's log (Adm. 51/1632) and the master's log (Adm. 52/3719) of H.M.S. WOOLWICH for 1805 but in neither is the Beaufort wind force scale recorded. Mr. R.F. Hunnisett of the Public Record Office speculates that the log referred to by Admiral FitzRoy in 1863 may have been Beaufort's private journal and that it may still be in the possession of one of Beaufort's descendents. (Personal communication.)

It was this last activity that led to an abrupt end to the survey. In June 1812, Beaufort had an astronomical party ashore when an armed skirmish between the local Pashas, who were thoroughly out of any control by the Porte, broke out. Captain Beaufort himself went in to take his shore party off and, as they were rowing back out of the harbor, a sniper, taking a long shot, put a ball through his groin breaking his hip. Beaufort was gotten safely back to Malta but he was many months in recovering. The survey had been interrupted and the FREDERIKSSTEEN through long service was in almost as bad shape as her captain. Both were ordered back to England at the end of 1812.

For the next several years Beaufort was busy working up the data from his survey and constructing a set of charts for the coast of Asia-Minor. Marshall (1835) comments, "From the weighty responsibility attached to such a work, he considered it necessary that the whole should be executed by his own hand;⁶ and we have reason to believe, ..., that previous to his doing so, no maritime surveyor ever lodged at the Admiralty, MSS. so drawn and arranged as to be fit for immediately placing on the copper, without first deriving aid either from the Hydrographer or some of his assistants."

In 1817 Beaufort published a book, "Karamania, or a brief description of the South Coast of Asia-Minor, and of the Remains of Antiquity." It was well written and well received. Quite characteristically, Beaufort refused to accept any payment for the book since "the materials ... were acquired in his Majesty's service in the execution of a public duty."

⁶ Modern oceanographers please emulate.

In 1829 Beaufort was appointed Hydrographer to the Admiralty, a post which he held for the next 26 years. In 1838 the Beaufort wind force scale was made mandatory for log entries in all ships of the Royal Navy. In 1846 Beaufort was made rear-admiral and, in 1848, K.C.B. in recognition of his civil services as hydrographer. He died in 1858 two years after his retirement.

One can not read much in the scientific literature of the 19th century without gaining the impression that Admiral Beaufort was regarded as a first rate scientist by scientists of substantial achievement. The Proceedings of the Royal Society for 1857-1859 gives him a three page obituary which, however, is vague about the specifics of his work. He is described in a general way as a marine surveyor, a classical scholar, and a geologist. He is credited with converting the office of Hydrographer to the Admiralty from an ineffective sinecure to a center of intense scientific activity in all things connected with the ocean. In particular, his freely given assistance to scientists, sometimes at the cost of overriding the regulations, is stressed.

I have found it suggested that Beaufort had a hand in the invention and development of the cup anemometer although Robinson (1855) in his paper which describes the invention of the cup anemometer does not mention Beaufort.⁷ In addition to his wind force scale

⁷ Robinson does mention Edgeworth, Beaufort's brother-in-law, as active in anemometry and the source of some of his ideas. Possibly that is the connection. I find his exposition of the problems of measuring wind velocity and the virtues and design problems of the cup anemometer far clearer than the discussions offered by most modern texts. Stephen (ed.) (1897) says that Robinson had devised the essential parts of the cup anemometer by 1843 and that he had

Beaufort devised a system for coding weather observations which was widely used. Some idea of the range of Beaufort's scientific interests can be gained from a memorandum he sent to Commander FitzRoy, captain of H.M.S. BEAGLE, on 11 November 1831.⁸ All 18 pages of it are reproduced in Volume II of "Narrative of the Surveying Voyages of His Majesty's Ships ADVENTURE and BEAGLE between the years 1826 and 1836, Describing their Examination of the Southern Shores of South America, and the BEAGLE's Circumnavigation of the Globe."⁹ In addition to outlining the hydrographic survey to be made and calling for a world girdling line of meridian positions--the exact longitude of even such long frequented ports as Rio de Janeiro was in doubt in 1831--Beaufort lists programs of observation in

- 1) Marine geology: deep sea soundings, sediment distributions and their relation to tidal currents, studies of coral reef formation;
- 2) Physical oceanography: tides in straits, open ocean tides, estuarine tides (set, force, duration, limits of salt intrusion, and variation with wind, current, and river flow all required), currents, and sea surface temperatures;

completed it by 1846. Considering that he read his paper in 1850 and that the date of volume XXII of the Transactions of the Royal Irish Academy is 1855, publication seems to have been an even more dilatory process a hundred years ago than it is today.

⁸ This is the FitzRoy of "The Weather Book." (He is also the FitzRoy who as governor of New Zealand from 1843 to 1845 championed equal rights for Maoris with such vigor that he got sacked--but that's another story.)

⁹ Volume III is still in print and is better known to you as "The Voyage of the Beagle." It was written by a bright, but usually seasick, young graduate student whose name appears on the ship's list as a supernumerary--Charles Darwin.

- 3) Meteorology: monsoon and trade wind limits and periods, barometric pressure, air temperature, winds, and weather;
- 4) Magnetism: variation, angle, dip, intensity, and diurnal variation;
- 5) Astronomical observations and, finally,
- 6) The Economic and Cultural Geography of each land visited.

Beaufort includes a liberal helping of advice for the 26 year old FitzRoy most of which would do no harm if taken seriously by modern oceanographers.¹⁰

Beaufort was a fellow of the Royal Society, London, vice-president and fellow of the Royal Astronomical Society, fellow of the Royal Irish Academy, and a corresponding member both of the Institute of France and of the U.S. Naval Lyceum.

As a victim of the modern publish-or-perish syndrome I expected that Beaufort had published extensively. The bibliography lists all I was able to find. He never appears as an author in the Philosophical Transactions of the Royal Society. The Royal Society Catalogue attributes to him only two very brief papers, one on an earthquake at sea and the other on longitude determination by means

¹⁰ As an example, "Trifling as it may appear, the love of giving a multiplicity of new and unmeaning names tends to confuse our geographical knowledge. The name stamped upon a place by the first discoverer should be held sacred by the common consent of all nations; and in new discoveries it would be far more beneficial to make the name convey some idea of the nature of the place; or if it be inhabited, to adopt the native appellation, than to exhaust the catalogue of public characters or private friends at home. The officers and crews, indeed, have some claim on such distinction, which, slight as it is, helps to excite an interest in the voyage." (Italics mine. Proponents of the "Cromwell" current please note.)

of a partial solar eclipse.¹¹

Pleasant as it is to linger with the Admiral, perhaps we should get along to his wind force scale. Here is the earliest version of it that I have been able to find. It dates from 1831 and is included with Beaufort's memorandum to FitzRoy.

F I G U R E S

TO DENOTE THE FORCE OF THE WIND

- | | | | |
|----|-----------------|---|---|
| 0 | Calm. | | |
| 1 | Light Air..... | Or just sufficient to give steerage way. | |
| 2 | Light Breeze... | Or that in which a man-of-war, with all sail set, and clean full, would go in smooth water from | 1 to 2 knots. |
| 3 | Gentle Breeze.. | | 3 to 4 knots. |
| 4 | Moderate Breeze | | 5 to 6 knots. |
| 5 | Fresh Breeze... | Or that to which a well-conditioned man-of-war could just carry in chase, full and by | Royals, & c. |
| 6 | Strong Breeze.. | | Single-reefed topsails and top-gall. sails. |
| 7 | Moderate Gale.. | | Double-reefed topsails, jib, & c. |
| 8 | Fresh Gale..... | | Treble-reefed topsails, & c. |
| 9 | Strong Gale.... | | Close-reefed topsails and courses. |
| 10 | Whole Gale..... | Or that with which she could scarcely bear close-reefed main-topsail and reefed fore-sail. | |
| 11 | Storm..... | Or that which would reduce her to storm stay-sails. | |
| 12 | Hurricane..... | Or that which no canvass could withstand. | |

I think we can take this version as a reasonably accurate statement of the original Beaufort scale. The same can not be said of many

¹¹ On form I suspect that Admiral Beaufort would agree with Norbert Wiener (1964) "... I say that one of the needs of science at the present is to keep the monkeys away from the typewriters."

of the versions which you may find in the "scientific literature." Meteorologists are not necessarily familiar with, or even interested in, the behavior of ships under sail. As a result they often misread Beaufort's intentions.

The first and most glaringly obvious thing one notices about Beaufort's scale is that it is a force scale. There is no mention of wind velocity. I think we must assume that the omission was deliberate. According to Robinson (1855), Edgeworth had built a refined instrument and used it to measure the velocity of air currents as early as 1783. Surely Beaufort in 1805 could have been ignorant neither of the concept of wind velocity nor of the work of his brother-in-law. I suggest that Beaufort, when he made his scale, felt that wind velocity was irrelevant to his purposes.

Beaufort's specification is essentially an association of lists of three different kinds of things. There is a list of 13 integers from 0 to 12, there is a list of common words for the strength of the wind, and there is a list describing the state and behavior of a "well-conditioned man-of-war." The choice of the list of numbers is quite arbitrary and is no different in principle from the choice of Celsius or Fahrenheit numbers for temperature. How many numbers you use depends on how many distinct levels of the phenomenon you think you can recognize. Beaufort obviously thought that there were 13 levels in the behavior of a man-of-war that he could recognize. He describes them in terms which may seem vague to a modern scientist but would certainly convey the idea with great precision to Nelson's captains. There is no need for fractional values. To say that one had a wind of Beaufort 6.5 would

be nonsense. Topsails are either single-reefed or they are double-reefed. There is nothing in between. Further, there is no use for Beaufort numbers higher than 12. When all you can do is drift off to leeward under bare poles it doesn't make much difference whether the wind is 70 or 170 mph.¹²

Beaufort's scale of numbers for the wind was not the only one in use during the 19th century. Scott (1874) lists the Continental scale, 0-4, the Land scale, 0-6, and the French scale for telegraphy, 0-9. Curtis (1897) on pages 51-53 tabulates equivalents for 20 scales of wind force other than Beaufort's. The ranges of those using numbers in the manner of Beaufort are, 0-4, 1-6, 0.0-6.0,¹³ 0-6, 0-10, 0-9, 0-7.

The list of common terms will refer to the same situation only if the users of them share a common experience. I have found that what Chesapeake Bay yachtsmen describe as a "heavy blow" will be called a "moderate breeze" by visiting yachtsmen from South Africa. The wind regimes in the Chesapeake Bay and in Table Bay and the yacht rigs characteristic of the two places are both so different that there is almost nothing "common" about the terms the two groups of yachtsmen use. Failure to associate the same common term with the same state of the wind often occurs when Beaufort numbers are used today. The numbers really belong to the seaman.

¹² Bowditch (1958) gives a version of the Beaufort scale extended to 17. Obviously in the last 150 years something has happened to the scale that bears Beaufort's name.

¹³ The scale from 0 to 6 in tenths was used by both Glaisher and Buchan. Apparently they feel that they can distinguish 61 states of the wind force but I am quite sure that they couldn't do it with a

Beaufort had no difficulty with this. He devised his scale for a group of men who had shared the same experience--years of unremitting blockade of Europe in sailing ships which were all quite similar in their characteristics. Their experience had been similar and their common terms were common.¹⁴

The third list, the phenomenon, is the meat of the matter. It describes the different things you may see and you are also told what number and common term to attach to each. And please note, what you are to look at is a ship--not the wind. It is true that the appearance of the ship depends on the wind but it does so in no simple way. I can not help but feel that Beaufort was intensely interested in the ship and but little in the wind. Let's look at this third list more closely.

The descriptions for numbers 0 through 4 are couched in terms of the speed of the ship, those for 5 through 9 jointly in terms of her mission and her sail carrying ability, and those for 10 through 12 in terms of her survival. To recover the meaning of the descriptions we must digress briefly.

No sailing vessel can move directly into the wind but some ships can work up closer to the wind than others, i.e., they are more "weatherly." According to Davidson (1956) a reasonable estimate of the weatherly ability for the ships of Nelson's (and

man-of-war as the probe.

¹⁴ Today the meteorologist seldom has the seaman's experience and has not had the advantage of being ridiculed for his greenhorn's compulsion to convert a moderate breeze into a full gale.

Beaufort's) day is 7 points off the wind, Fig. 3.¹⁵

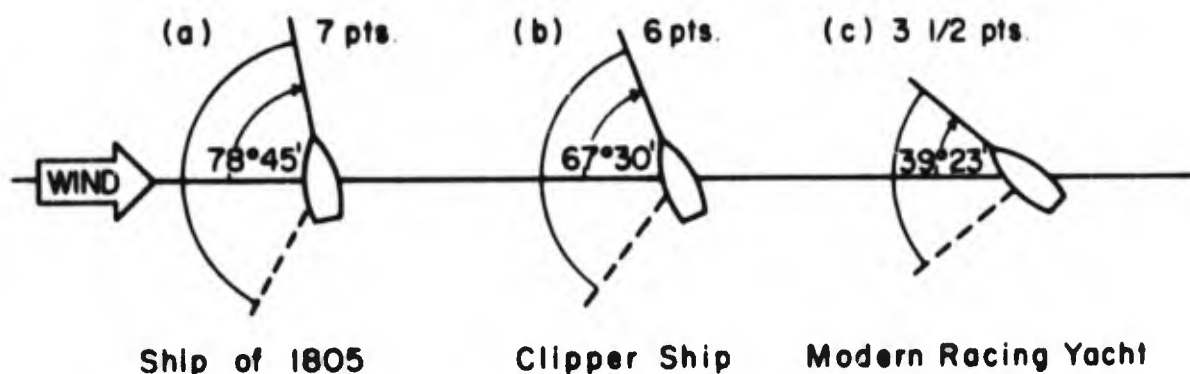


Fig. 3. Weatherly qualities for (a) a ship of Nelson's day, (b) a clipper ship, and (c) a modern racing yacht. The heavy arcs show directions relative to the wind in which the ships can not sail.

For comparison a clipper ship could work up to 6 pts off the wind and a good modern racing yacht can work up to 3 1/2 pts. For numbers 2-4 and 5-9 "clean full" and "full and by," respectively, describe the ship's angle to the wind. There is no difficulty with "full and by." It still appears in the dictionaries. Webster's gives "full and by. Naut. Sailing close-hauled (Fig. 4(b)) with all sails full, and lying as near the wind as possible." The meaning of "clean full" and its relation to "full and by" is more difficult. Lt. Cdr. A.H. Waite, R.N.V.R. of the National Maritime Museum, Greenwich, England says,

¹⁵ There are 32 points on the mariner's compass. Thus 8 points = 90° and 7 points = $78^\circ 45'$.

"Referring to your question about the Beaufort scale, the expression 'clean full' is quite correct and was much used in the last century. In Admiral Smythe's 'Sailors Work Book' of 1865 the entry 'clean

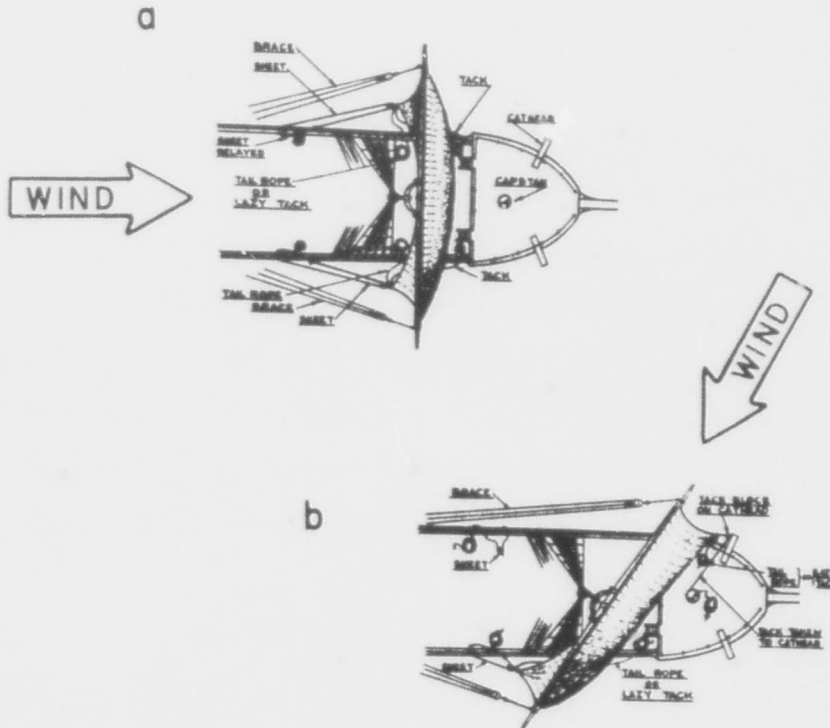


Fig. 4. View from above showing a square sail (a) squared away and (b) close hauled. From H.A. Underhill (1946).

full' is described as 'keeping the sail full, bellying off the wind,' and 'full and by' is 'sailing close hauled on a wind, when a ship is as close as she will be to the wind without suffering the sails to

shiver hence keep her full and by is the order to the helmsman not to incline too much to windward and thereby shake the sails which would retard the ship's velocity.'" (Personal communication.) FitzRoy (1863) in presenting a condensed version of the Beaufort scale says, "from 2 to 10 being supposed as felt in a good ship 'close-hauled.'" Mr. E.D. Stroup of the University of Hawaii comments, "It would seem that it would really have to be close hauled, after all, because if there were no restriction on the course with relation to the wind what would the speed ranges mean? 'Sailing off the wind' [The meaning I attributed to 'clean full' on first reading.--EK] could be in any direction. I begin to get the feeling that 'clean full' corresponds to 'a rap full;' that is, close hauled but holding her off just a shade to avoid any possibility of pinching. (I would guess that pinching would have a rather disastrous effect on speed in something like the WOOLWICH, especially in the lower wind-speed ranges, to which the admonition 'clean full' was applied.)" (Personal communication.) It seems that for all winds with Beaufort forces from 2 to 9 the ship is to be close-hauled, Figs. 3 and 4(b), but that for 2 to 4 the warning "Keep your sails full. Don't pinch." is added.

We have now to understand Beaufort's instructions about the sails. A full-rigged ship, Fig. 5, has 3 (or more) masts and carries a complete set of square-sails on each of them. The mast in the center,

which is usually the tallest, is the main-mast. The mast toward the bow, which is usually the next in height, is the fore mast. The mast toward the stern, usually the smallest, is the mizzen-mast.¹⁶ The mast, per se, is the unbroken spar which extends to the mast head, Fig. 5(a). Historically, everything else is an addition to the mast. The next section which extends above the mast is the topmast. Later a topgallant-mast was added to the topmast and later still a royal-mast to the topgallant-mast.¹⁷

The name for each square-sail is constructed by specifying, first, to which of the three masts it is attached and, second, to which section of the mast it is attached. For example, in Fig. 5(b) 6 is the fore-royal while 27 is the mizzen-topgallant. If more than one sail is carried on a section of a mast they are distinguished by including the words "upper" and "lower" before the mast-section name. For a bit of spice one needs exceptions and sails 10, 20, and 30 while they can properly be called the "fore," "main," and "mizzen" sails, are commonly called the "fore course," the "main course," and

¹⁶ The names used for the masts of modern yachts are assigned on the assumption that the yacht is a ship with pieces missing. For example, a schooner which has two masts with the taller one aft has a main-mast and a fore mast while a yawl, which also has two masts with the taller one forward has a mizzen-mast and a main-mast.

¹⁷ As cable and cordage were improved and more and more extreme clippers were designed in the search for speed, skysail-masts and sometimes even moonrakers were piled on top of these.

KEY FOR FIG. 5

Fore and Aft SailsSquare Sails

(Forward of the Fore-mast)

- *1. Flying-jib
- 2. Outer-jib
- 3. Inner-jib
- 4. Fore-topmast-staysail
- *5. Fore-staysail

(Between the main-mast and fore-mast)

- 11. Main-royal-staysail
- 12. Main-topgallant-staysail
- 13. Main-topmast-staysail
- *14. Main-staysail

(Between the mizzen-mast and main-mast)

- 21. Mizzen-royal-staysail
- 22. Mizzen-topgallant-staysail
- *23. Mizzen-middle-staysail
- *24. Main-spencer
- 25. Mizzen-topmast-staysail

(Aft of the mizzen-mast)

- 31. Spanker

* It is probable that these sails would not be carried in Beaufort's
sails.

** The division of topsails into upper and lower came toward the middle of the 19th century in response to the rising wages of seamen. Sails divided into smaller areas can be worked by smaller crews. With the manning rates common to the Royal Navy during the Napoleonic Wars this was not a consideration and topsails were single large sails as shown in Figs. 5(a) and 6(a).

(On the fore-mast)

- 6. Fore-royal
- 7. Fore-topgallant
- **8. Fore-upper-topsail
- **9. Fore-lower-topsail
- 10. Fore-course

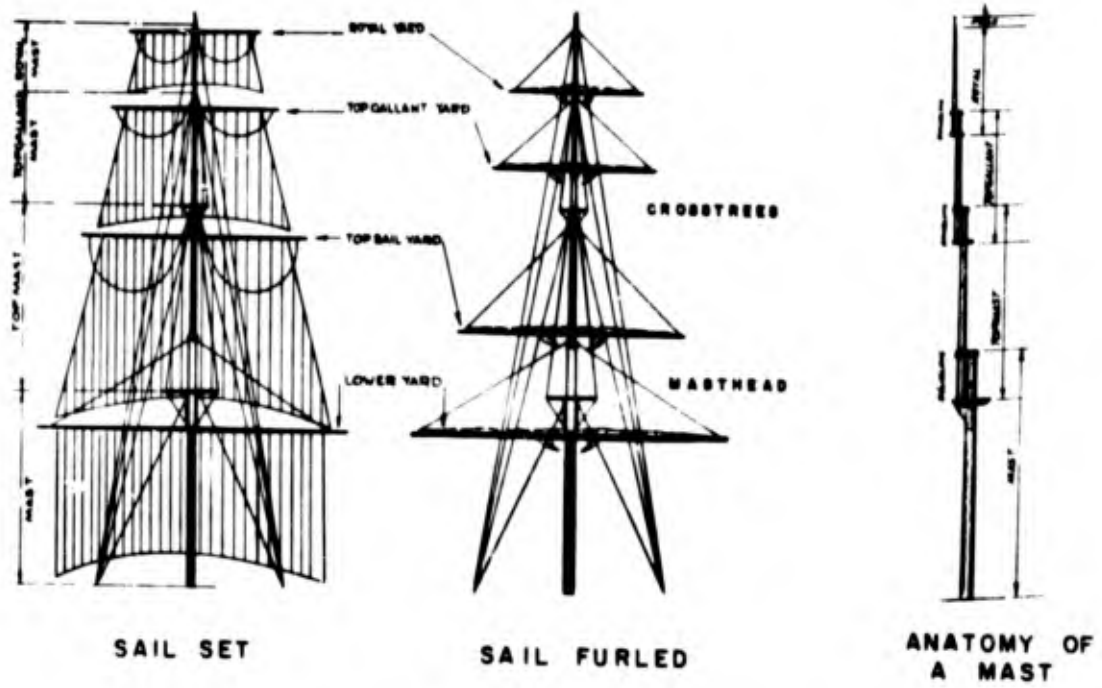
(On the main-mast)

- *15. Main-skysail
- 16. Main-royal
- 17. Main-topgallant
- **18. Main-upper-topsail
- **19. Main-lower-topsail
- 20. Main-course

(On the mizzen-mast)

- 26. Mizzen-royal
- 27. Mizzen-topgallant
- **28. Mizzen-upper-topsail
- **29. Mizzen-lower-topsail
- 30. Cro'jack

a



b

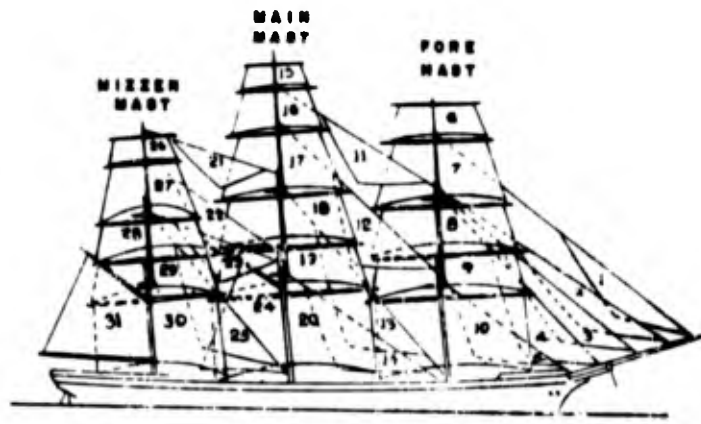


Fig. 5. Masts and Sails of a Full-Rigged Ship. From H.A. Underhill (1938, 1946).

(the exception to the exception) the "cro'jack" or collectively the "courses." The fore and aft sails are carried on the stays that run between masts. They are identified by giving the name of the mast which has the higher point of attachment for the stay followed by the name of the section within the mast to which the stay is attached. To prevent confusion with the square-sail carried on the same mast and section you add "staysail." Thus 22 is the "mizzen-topgallant-staysail."

When the wind breezes up the force it exerts on the sails increases and there always comes a time when you wish you had a little less--either of wind or of sail. Less sail is easier to arrange than less wind. You can always bunch the sail up against the yard and tie it there, i.e., furl it, Fig. 5(a). You can even take it entirely off the yard and send it below. However, the jump from sail set to sail furled is too big and provision is made for reducing sail in smaller increments. The device is the reef points shown in Fig. 6. Reef points are lengths of light line sewn to the sail in rows and extending on both sides of it. Fig. 6(c) shows perspective views of a sail with a single line of reef points. Fig. 6(a) shows a topsail with the three rows of reef points. In Beaufort's time four rows were customary. When it was desired to take a little sail off the ship the first line of reef points was drawn up to the yard, the reef points tied around the yard, and the part of the sail above gathered against it. When that is done, the sail is said to be "single-reefed." If you tie in the second row of reef points, you are "double-reefed," and if the third row, "treble-reefed." However, if you have a fourth row and you tie them in, you

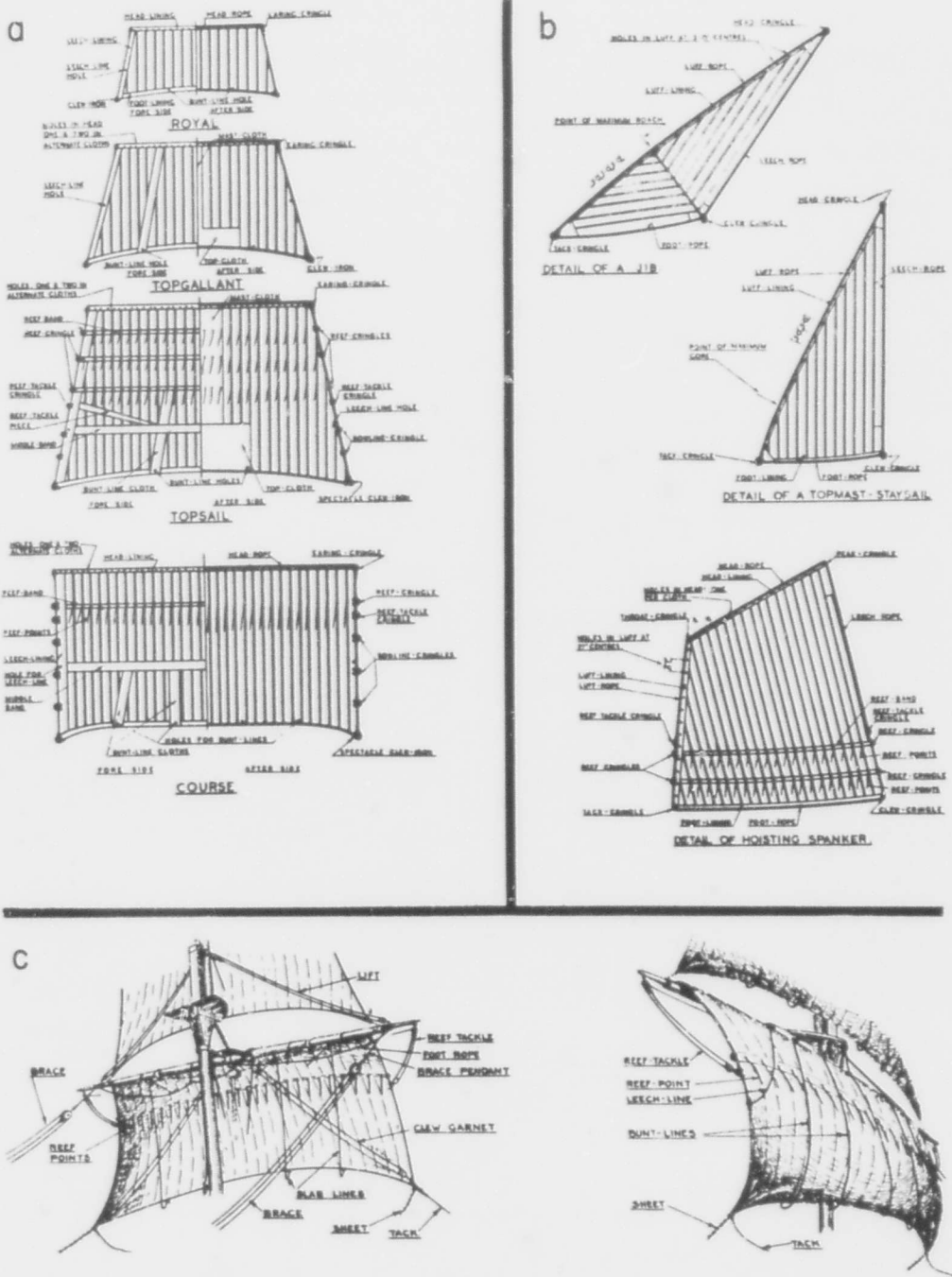


Fig. 6. (a) Square Sails (b) Fore and Aft Sails (c) Views from Aft and Forward of a Square Sail Showing Reef Points. From H.A. Underhill (1946).

are not "quadruple-reefed" but "close-reefed."¹⁸

With these terms in hand, consider some examples.

Beaufort Force 3: You are aboard a frigate like H.M.S. WOOLWICH.

Spread on the masts and stays are something like 25 great bellying expanses of canvas--all she has ("all sail set"). She is braced up hard on the wind but the helmsman has let her pay off just a little to get the best speed--although not the most distance to windward-- ("clean full"). The sea is covered with small waves and when the boatswain streams the log it shows that the ship is making 3 to 4 kncts through the water. That's Beaufort 3. There is no doubt about it. All you have to do is look at the state of the ship and how she goes. If you were to ask an old deck hand what the wind was he would most likely tell you that you had a gentle breeze.

Beaufort 7: The seas are considerably higher. You have the DROITS D'HOMME in sight to windward and the captain is straining everything to work up and engage her¹⁹ ("in chase"). You are really hard on the wind ("full and by") and the helmsman had better steer small and make every foot to windward that he can even at the cost of some speed-- he had better if he doesn't want his back flogged bloody. The captain has judged his sails to a hair's breadth. The courses are on her and so are her fore and aft sails. The topsails are set but they have

¹⁸ In a general way, when you have tied in the last row of reef points you are "close-reefed" whatever the number of rows the sail has.

¹⁹ Heretical as it may sound the French designed and built faster ships than the English during the Napoleonic period and your captain must get every last ounce out of his ship if he is to overcome the handicap.

been reefed down to the second row of reef points. The royals and top-gallants are furled. The captain knows that he can't show another square yard of sail without blowing the sticks right out of her. So you thrash along and perhaps you come up with the DROITS D'HOMME and perhaps you don't. Two things are sure. The captain is driving her for all she's worth and you have Beaufort 7. Your old deck hand calls it a moderate gale.

Beaufort 11: The DROITS D'HOMME may be in sight bu' you aren't paying her much attention. She isn't paying you much attention either. The seas are mountainous. The square-sails are all furled. If the job has not been well done the wind may pry into the wadded sail, rip it loose, and shred it to ribbons in seconds. The ordinary staysails have been unbent and you are now carrying a few small staysails of extremely heavy canvas--the storm staysails--in an attempt to give your ship just enough motion through the water to keep her under some sort of control with the rudder. The wind force is Beaufort 11 and your old deck hand, if he has the misfortune to be on watch, will tell you that it's quite a storm.

Two questions must be faced at this point. First, how reproducible is Beaufort's scale? Second, why should one want such a scale? The first question involves a number of subsidiary questions and, in attempting an answer, we will suggest an answer to the second. Perhaps we should begin by taking just a glance at the wind velocity. Wind velocity and force are associated through the $\rho \vec{v}^2$ terms in the equation of motion. Mean wind velocity varies with height and, for our five finger exercise, we might as well take the variation as logarithmic. As rough and ready values suppose that the roughness

length is 1 ft, that the crosstrees are 120 ft above the water while the quarter deck is 12 ft, and that the wind at anemometer height is 10 kts. Then the speed of the wind for the officer on the quarter deck is about 7.3 kts while that for the lookout on the crosstrees is about 14.1 kts, almost double. If each were equipped with an anemometer they would get quite different wind speeds and yet they would come up with the same Beaufort number for the wind force. They would get the same Beaufort number because both were looking at the ship which is the same for both and only incidently at the wind. What matters is the practical problem of how the ship behaves. Men who know a ship seldom disagree about that.

A reasonable description of Beaufort's scale would be that it is a set of index numbers for the quantized states of one of His Britanic Majesty's frigates of 1805. In some of the later versions of Beaufort's scale the "well-conditioned man-of-war" literally becomes a "frigate." Even if you are willing to concede the uniformity of judgement of men used to frigates you may well wonder if the judgement would remain uniform for a first-rate. Mr. Howard I. Chapelle, Curator, Division of Transportation, Smithsonian Institution says, "The 44 gun frigate would be less able to carry sail in strong winds than a 74 but would be comparable in moderate winds. A matter of hull and rig design in individual ships is involved, but a 44 gun frigate would be 'average' in sail carrying power." (Personal communication.) There was really no trouble about applying the Beaufort numbers to ships other than frigates like WOOLWICH. Almost every officer had served in, and often had commanded, frigates. Even though

he might be in a ship-of-the-line, or even in a grog shop ashore, he could still judge accurately what sail he would carry in chase if he were commanding a frigate.

The frigate in modern jargon was a "probe" for measuring wind force but putting it that way would seem to Beaufort getting the cart before the horse. The measuring system is one that averages over substantial intervals of space and time and which uses undefined and peculiar weighting functions. Wind velocity is a very local concept--ideally, an instantaneous point measure--but for Beaufort's scale the situation was not evaluated in terms of local or temporary gusts of wind. The judgement depends on the appearance of as much of the water surface as can be seen together with what is happening to other ships in sight, the behavior of birds, the appearance of clouds, and the feel of the ship. All these imply large space scales. Time scales are long too. You don't set or furl sail, or change from starboard tack to port tack in seconds. A French officer captured during the Glorious First of June expressed amazement that the British were able to tack ship in five minutes. The French could seldom do it in less than 15.²⁰

The clinching argument for the uniformity of application of the Beaufort scale lies in history and in the phrase "in chase." This is the fine adjust on the probe. In 1805 Britain had been at war with France, and indeed, more or less, with all Europe for 12 years. She was to be at war with France for another 10 with only

²⁰ For comparison, a modern racing dinghy can complete the same evolution in 3 to 5 seconds and if a modern ocean racer takes more than 20 she isn't winning any silver.

brief pauses. Her fleet was blockading a continent and was at sea almost continuously. The ships were supplied at sea and it was not unusual for even the great captains like Hood and Nelson to remain afloat without setting foot ashore for two or three years at a stretch. Obviously, these were experienced seamen. Further, for every captain with a ship there were a half-dozen qualified officers on the beach at half pay. The ships were always too few and they had to be fought at full efficiency if the blockade was to be maintained and England supplied. The real kicker in the Beaufort specification is the "in chase." I know personally that there is a vast difference between the way I will crack on sail when I race and what I am willing to carry when I cruise. "In chase" is a racing situation. A captain could fail to bring a chase to action in two ways. He could fail to carry every rag his ship could stand and let the enemy outsail him--and remember that the French ships were often inherently faster and handier--or he could carry too much and blow away spars and rigging so that the enemy escaped. The "in chase" really forces a very fine judgement. For encouragement, courts-martial were provided. Blow out your sticks, you lose your command to one of the qualified officers on the beach. Fail to press the chase, you are court-martialed and dismissed the service in disgrace. The log entries of wind force and weather were material evidence for the courts. A uniform scale such as Beaufort's made both log-keeping and courts-martial easier.

Simpson (1926) says, "The Beaufort scale defines the strength of the wind by the effect it has on a specified ship under specified

conditions of sailing. ...There is no ambiguity about this: force 8 is almost as definite a physical quantity as 8 kilograms. If necessary a well conditioned man-of-war can be used to check a Beaufort estimate in the same way as a standard weight can be used to check the weight of a body." The point is well taken. However, since Simpson appears to have misunderstood the significance of "in chase"--he omits it from his report of Beaufort's scale--we will have to do a bit more to re-establish Beaufort numbers than build a replica of H.M.S. WOOLWICH. We will have to build at least two replicas, arm them, and let them shoot it out. It would probably help to hang the captain of the losing ship should he survive.²¹

Many special scales have been proposed. Some have been used for a time. Most have vanished without a trace. It is a matter for wonder that such a museum piece as Beaufort's scale is a live subject 160 years later. Table I pages 30, 31 gives a recent version of the Beaufort scale given in Roll (1965) with wind velocity equivalents determined by Verploegh (1956). Beaufort's thirteen numbers are there. The "common" terms, somewhat altered, are there. The man-of-war of 1805 has disappeared but it has been replaced by another phenomenological specification in terms of the appearance of the sea surface.²²

²¹ Scientific determination of Beaufort force numbers might well become a new international sport with all the best features of an America's Cup defense, a Roman gladiatorial combat, and a lynching.

²² With the disappearance of the frigate of 1805 many attempts have been made to provide presently accessible phenomenological equivalents for the Beaufort numbers. Heaton (1949) gives one in terms of sailing trawlers (smacks), Bowditch (1958) one for the use of observers on land, and Marchaj (1964) an internal psychological scale for yacht crews. The divorce from the sailing ship was made official in

(Footnote 22 continued.)

1941--probably because of the necessity of making seamen out of plough boys in 90 days.

Beaufort Numbers	Specification for Coast use, based on Observations made at Scilly, Yarmouth and Holyhead	Effects observed on land	Psychological Scale
0	Calm .	Calm; smoke rises vertically .	
1	Fishing smack just has steerageway.	Smoke drift indicates wind direction; vanes do not move .	Boredom.
2	Wind fills the sails of smacks, which move at about 1-2 miles per hour.	Wind felt on face; leaves rustle; vanes begin to move .	Mild pleasure.
3	Smacks begin to careen and travel about 3-4 miles per hour.	Leaves, small twigs in constant motion; light flags extended .	Pleasure.
4	Good working breeze; smacks carry all canvas with good list .	Dust, leaves, and loose paper raised up; small branches move .	Great Pleasure.
5	Smacks shorten sail .	Small trees in leaf begin to sway .	Delight.
6	Smacks have double reef in mainsail; care required when fishing .	Larger branches of trees in motion; whistling heard in wires .	Delight tinged with anxiety.
7	Smacks remain in harbour, and those at sea lie to .	Whole trees in motion; resistance felt in walking against wind .	Anxiety tinged with fear.
8	All smacks make for harbour if practicable .	Twigs and small branches broken off; progress generally impeded .	Fear tinged with terror.
9		Slight structural damage occurs; slate blown from roofs.	Great terror.
10		Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.	Panic .

I think one may doubt both the reproducibility of the scale numbers based on this and other modern phenomenological descriptions and their equivalence with Beaufort's specification. Roll (1965) says on page 23, "Several disturbing effects have to be taken into account, e.g., the 'lag' between the wind increasing and the sea getting up, and the influences of fetch, depth, swell, heavy rain, and tidal currents on the appearance of the sea. ...the tidal effect, particularly in cases of low wind velocities, causes the estimation of an apparent wind force which corresponds to the air speed relative to that of water. Even the plankton count may influence wind estimates at sea since the foaming of the sea water depends on it. ...in sea areas rich in plankton the foaming (as taken from estimated wind forces greater than 3 Beaufort) observed with smaller wind speeds is the same as that with higher wind speeds in areas poor in plankton. Consequently, there is a certain tendency to overestimate wind speeds in regions with high plankton content.

"When the sea surface is invisible, e.g., at night, estimation becomes questionable." In brief, a quite precise set of phenomena has been replaced by one whose naked-eye observables are only loosely related in a way not yet really understood to the old force numbers.

(Footnote 22 continued.)			
Beaufort Numbers	Specification for Coast use, based on Observations made at Scilly, Yarmouth and Holyhead	Effects observed on land	Psychological Scale
11			
12	(Yacht crews decide to take up Golf.) (Heaton, 1949)	Very rarely experienced on land; usually accompanied by widespread damage. (Bowditch, 1958)	I want my Mummy. Yes, Mr. Jones. (Marchaj, 1964)

TABLE I
WIND SPEED EQUIVALENTS AND SPECIFICATIONS FOR THE BEAUFORT NUMBERS OF WIND FORCE

Beaufort number	Descriptive term	Wind speed equivalents				Specifications
		knots		meters/sec		
		Mean	Limits	Mean	Limits	
0	Calm	0	< 1	0	< 0.6	Sea like a mirror.
1	Light air	3	1-4	1.5	0.7-2.3	Ripples with the appearance of scales are formed, but without foam crests.
2	Light breeze	7	5-8	3.4	2.4-4.4	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break.
3	Gentle breeze	11	9-12	5.6	4.5-6.6	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses.
4	Moderate breeze	15	13-16	7.8	6.7-8.9	Small waves, becoming longer; fairly frequent white horses.
5	Fresh breeze	19	17-21	10.2	9.0-11.3	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).
6	Strong breeze	24	22-26	12.6	11.4-13.8	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).
7	Near gale	29	27-31	15.1	13.9-16.4	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind.

8	Cale	34	32-36	17.7	16.5-19.0	Moderately high waves of greater length; edges of crests begin to break into the spin-drift; the foam is blown in well marked streaks along the direction of the wind.
9	Strong gale	39	37-42	20.4	19.1-21.8	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble, and roll over; spray may affect visibility.
10	Storm	45	43-48	23.3	21.9-24.8	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; on the whole, the surface of the sea takes a white appearance; the tumbling of the sea becomes heavy and shock-like; visibility affected.
11	Violent storm	52	49-55	26.5	24.9-28.2	Exceptionally high waves (small- and medium-size ships might for a time be lost to view behind the waves) the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected.
12	Hurricane	> 55	> 28.2	> 28.2	> 28.2	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected.

To my knowledge, no serious attempt has ever been made to demonstrate the equivalence of any of the newer phenomenological descriptions with that given by Beaufort.

Estimating Beaufort wind force numbers is, at root, a matter of experience. Simpson (1926) says, "The sailor's estimate of the strength of the wind as used in his ordinary conversation is based on its effect on his surroundings: on the waves formed on the surface of the sea, on the amount of broken water, on the sound produced as it blows through the rigging and on the way his ship can stand up to it. ...

"The rig of ships has changed, sail has been replaced by steam, but the effect of the wind on the sea has remained, and will always remain the same. The sailor's description of the strength of the wind being based on effects independent of the rig of his ship has survived all the changes in marine transport and an air, a breeze, a gale and a hurricane mean just the same to a sailor now as they did in Beaufort's time.

"Thus the Beaufort Scale of wind force, being anchored to the everyday language of such a conservative class as seamen, has served through a hundred years and is just as useful now, when there is not 'a well-conditioned man-of-war' on the sea, as it was when the majority of sailors had sailed and handled such ships." Simpson states his position with poetry and force but I doubt that he could establish it. In the discussion recorded in Curtis (1896) Capt. A. Carpenter commented, "Created as [Admiral Beaufort's scale] was some 90 years ago, and based both on the speed and sail-carrying power of a well-found frigate of those days, its basis is now quite obsolete.

Even in his early days, which were spent in men-of-war chiefly under sail, they never based their estimation of the force of the wind on the speed that they travelled, so much had vessels already altered in build from those of 1805. And now in these days when steamers monopolize the sea-carrying power, and men-of-war are fast abolishing masts altogether, he doubted if many officers of watches would have the faintest conception what force of wind would necessitate taking in the first reef in the topsails, or what would enable a ship to just carry her royals. ...The fact is, that the younger officers learn from the older experienced officers what amount of wind ... may be noted as a particular force on Beaufort's scale. ... The scale is thus learned arbitrarily, ..." Apparently at least one experienced seaman did not believe in the efficacy of the apostolic laying on of hands from master to midshipman which seems so certain to Simpson.²³ However, if one wants to use the Beaufort scale, there is no substitute for learning it at sea under the guidance of an experienced observer who already knows how to use it. It is not something that can be learned from a textbook. Bowditch (1958) on pages 774, 775 tries to alleviate one's ignorance by printing 13 pictures of the sea surface and identifying each with one of the 13 Beaufort numbers. The intention is good but the pictures have been so much reduced and have suffered so much in reproduction that they are not very informative. The Seewetteramt (1964) gives a similar set of photographs

²³ Capt. Carpenter also grumped, "At force 12 it is noted in the Beaufort scale that no canvas can be shown, and under that notation an officer of a modern torpedo-catcher would not be far wrong in always noting it at 12, for certainly they could show no canvas!"

for the guidance of shipborne weather observers which is much better. Still, no amount of reading will effectively replace guided experience. However, it is not in the substitution of one phenomenological specification for another that the version given by Roll (1965) differs most drastically from that included in FitzRoy (1839). It is in the inclusion of extra columns of wind speed equivalents.

We really must ask ourselves in what sense wind speeds can be equivalent to wind forces at all. Roll (1965) says, "The values published by Verploegh (1956) are based on the results of all comparative studies so far available from the sea and may, therefore, be considered as the most suitable ones at present. ... It should be noted that these wind speed equivalents are valid for a height of 10 meters above sea level under indifferent atmospheric stability. Marked deviations from these equivalents may occur with other thermal stabilities ..., winds colder than the sea producing higher and steeper waves than warm winds." Curtis (1897) gives no less than 29 different sets of wind speed equivalents the earliest being that of Snow Harris (1857). Köppen (1898) lists another dozen. Simpson (1926) dismisses the lot with, "Many attempts have been made to [provide wind speed equivalents for the Beaufort force scale], but it is unnecessary to refer to them all here, it is sufficient to say that they showed very large differences, divergencies of more than 100 per cent between velocity equivalents for the same Beaufort force being frequent. ...most of the old determinations of the velocity [have] been superseded by two determinations made by the Deutsche Seewarte [Köppen (1898)] and the London Meteorological

Office, Simpson (1906)." Fig. 7 shows them together with Verploegh's equivalents.

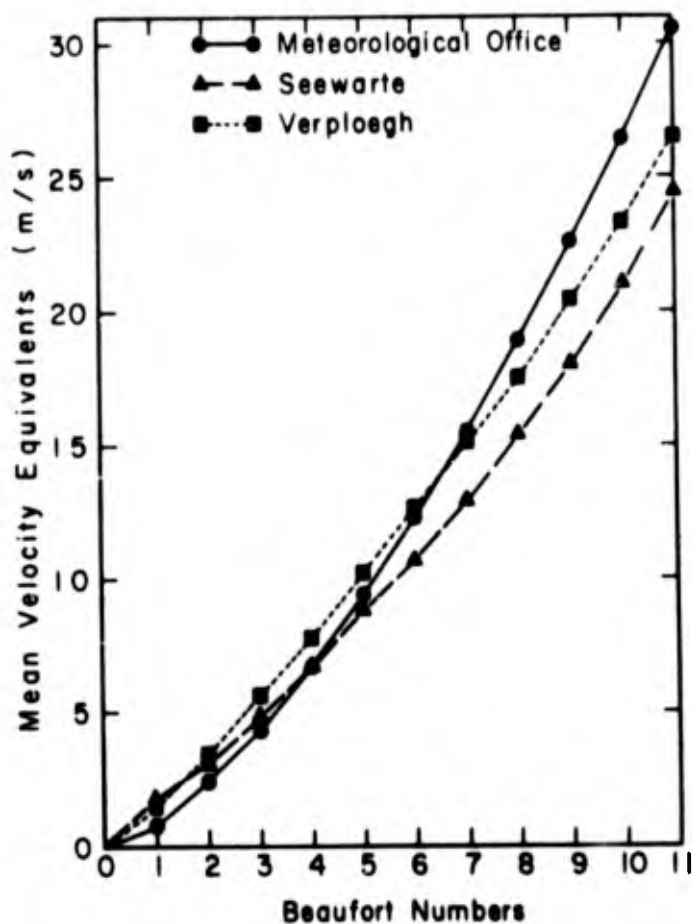


Fig. 7. Three Sets of Equivalents for the Beaufort Force Numbers

The Seewarte equivalents are the means of four independent sets of measurements, one "oceanic" and one each from the coasts of Germany, Norway, and England. The oceanic group comprises four sets of data: 1) those made aboard GAZELLE from 1874-1876, 2) those from ELIZABETH in 1877 during four heavy storms--two at anchor in Yokohama and two at sea--, 3) a short set by Waldo in 1882 while crossing the North Atlantic in the OHIO, and 4) a short set made from the NATIONAL in 1889. Köppen weights the GAZELLE data by 4 in computing the means for the oceanic group. Simpson (1926) likes the

GAZELLE data too. "By far the most important series of observations used by the Seewarte was that made on the 'Gazelle.' The 'Gazelle' was a large sailing ship of the type specified by Beaufort. In the years 1874 to 1876 she made a cruise for scientific purposes which took her into all oceans. An anemometer was carried and regular Beaufort estimates and simultaneous measurements of the velocity were made. As the ship was of the type specified by Beaufort the estimates were of particular value, for the conditions described by Beaufort could be controlled by the ship itself. In the reduction of the observations, only those estimates were used which were made when the ship was sailing as described by Beaufort in his specification." Considering that 1874 is much later than the period of the extreme clippers one may suspect that GAZELLE's hull was radically different from WOOLWICH's. Then too there is the question of rig. "Die Forschungsreise S.M.S. "Gazelle" (1888-1889) is remarkably uninformative. One is told that GAZELLE was launched in 1850, a few brief facts about her service are given, and some gross statistics follow. It is interesting that she was dragging a two-bladed screw through the water which under her 1300 horsepower engines could drive her at 9 to 10 knots. Under sail alone at Beaufort 7-8 she could make, sailing free, 13.3 knots and she could work to within 5 to 5 1/2 points of the wind. The brief passage ends with, "Die Takelage (vollgetakelt) und die sonstigen Einrichtungen des schiffes entsprechen den für jene Schiffsklasse allgemein gebräuchlichen und bedürfen daher keiner weitem Besprechung."²⁴ Dr. F. Krüger very

²⁴ Free translation: Any dope knows what a ship like GAZELLE looks like.

kindly undertook a search of the archives of the Seewartamt for information on the lines and rigging of GAZELLE. Unfortunately,²⁵ the only thing left is Fig. 8 which shows GAZELLE and a sister ship at anchor in the Straits of Magellan. The picture doesn't tell us too much. It is not known which ship is GAZELLE and the critical underwater hull form can not be seen. The rigging shows main, top-sail,²⁶ and topgallant yards but no royals.²⁷

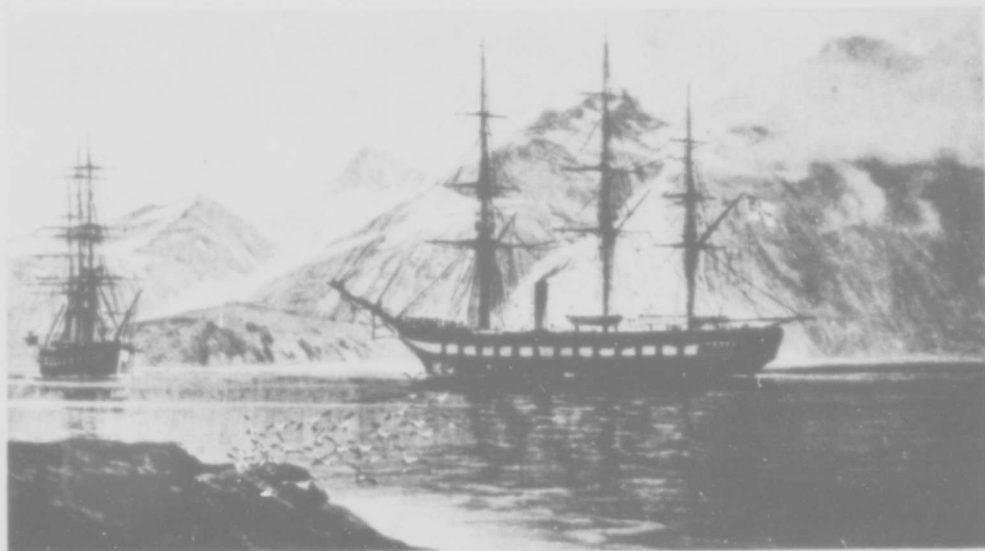


Fig. 8. 1874: Corvettes GAZELLE and VINETA in the Straits of Magellan. Courtesy of Dr. F. Krügler.

²⁵ Apparently the Allied bombers over Hamburg did their job too thoroughly for the well being of scholars.

²⁶ Single Topsails--not the divided topsails common in the merchant ships of the 1870's.

²⁷ This does not necessarily mean that GAZELLE was normally without royals as ships rounding the Horn habitually sent down their tophamper.

To give you some idea of how radically hulls could change in 50 years Figs. 9 and 10 showing the lines of CUTTY SARK are given for comparison with the lines of WOOLWICH, Figs. 1 and 2.²⁸ Since GAZELLE was armed she would probably have been intermediate between WOOLWICH and CUTTY SARK. Her primary function matches the former and her time of building matches the latter. Fig. 8 shows that she had very little tumble home. Chappelle says, "I do not think GAZELLE was comparable to a sailing frigate of 1800-40. Was not GAZELLE an auxiliary? If so, the drag of her wheel and the usual reduced sail area would make her quite different in qualities." (Personal communication.)

If the "Forschungsreise" gives scant information about GAZELLE, it is unexpectedly candid about the anemometer used to get equivalent wind speeds. I translate from page 156 of "V. Theil. Meteorologie," "Anemometer measurements aboard the S.M. Corvette GAZELLE were made with considerable care using a Kraft's hand-held anemometer. At the time of sailing as well as upon the return of the

²⁸ The comparison between a man-of-war and a cargo carrier is not entirely fair. The man-of-war carried the greatest weight in her guns, which were of necessity above the water line. The marked tumble home shown by WOOLWICH is an effort to bring her guns in toward the centerline and thus improve her stability. A commercial carrier could get much more of the weight below the waterline and more vertical topsides were feasible. Another difference arising from the uses intended for the two designs is that WOOLWICH is much more slack bilged--the curvatures of the arcs connecting bottom and topsides are much more gentle. This gave a much slower natural roll, an important consideration when guns were fired by igniting fuses and the instant of detonation could not be closely controlled.

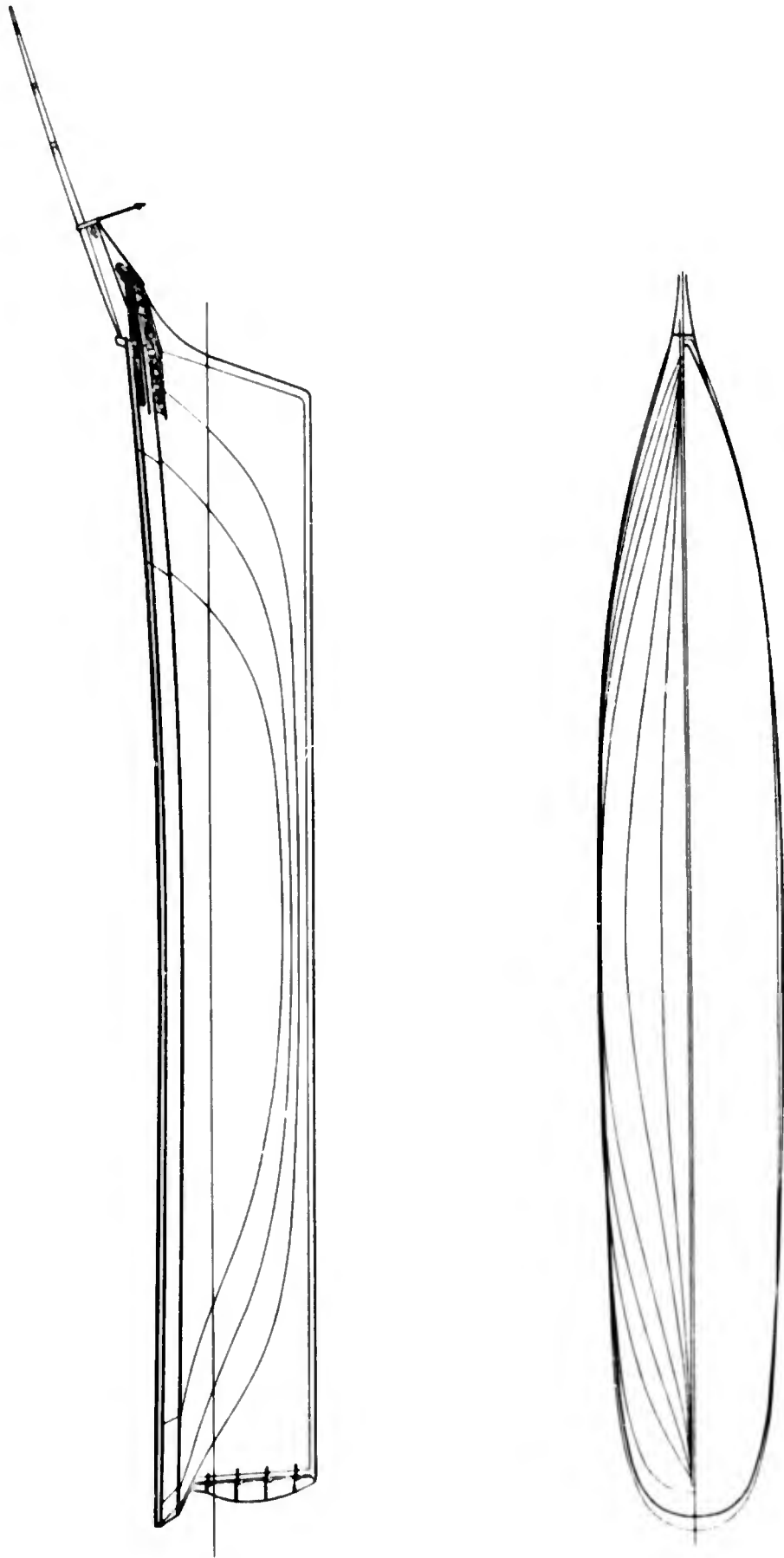


Fig. 9. Lines of the Clipper Ship CUTTY SARK.

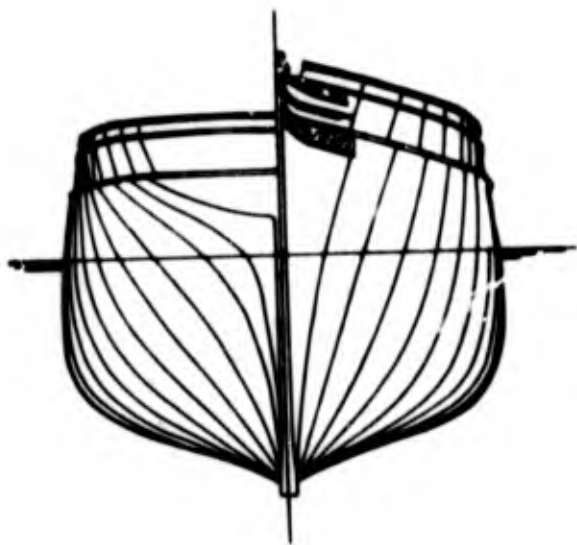


Fig. 10. Sections of the Clipper Ship CUTTY SARK.

ship there was no means of calibrating the anemometer available in Germany. Thus, for the present, the formulae given in the ship's log must be used to reduce the data. Since the instrument is no longer available and its constant is uncalibrated nothing remains but to assume that the values recorded here are correct. (Italics mine.)

So much for what Simpson calls "By far the most important series of observations used by the Seewarte... ." The ship from which

they were made was very probably not the equivalent of Beaufort's "man-of-war." She may have been sailing close hauled when the Beaufort estimates and anemometer measurements were made but she most certainly was not "sailing as described by Beaufort in his specification" since she could not have been "in chase." The anemometer used for the measurements was uncalibrated when GAZELLE set out. It was uncalibrated when she returned. By the time there was anything with which to calibrate it the instrument was long gone. Nothing has been said about the exposure of the hand-held anemometer. To anyone who has ever struggled with the problem of getting an anemometer away from disturbances Fig. 11 should speak for itself. If this is the best of the lot I think we are entitled to be a little skeptical of the rest.

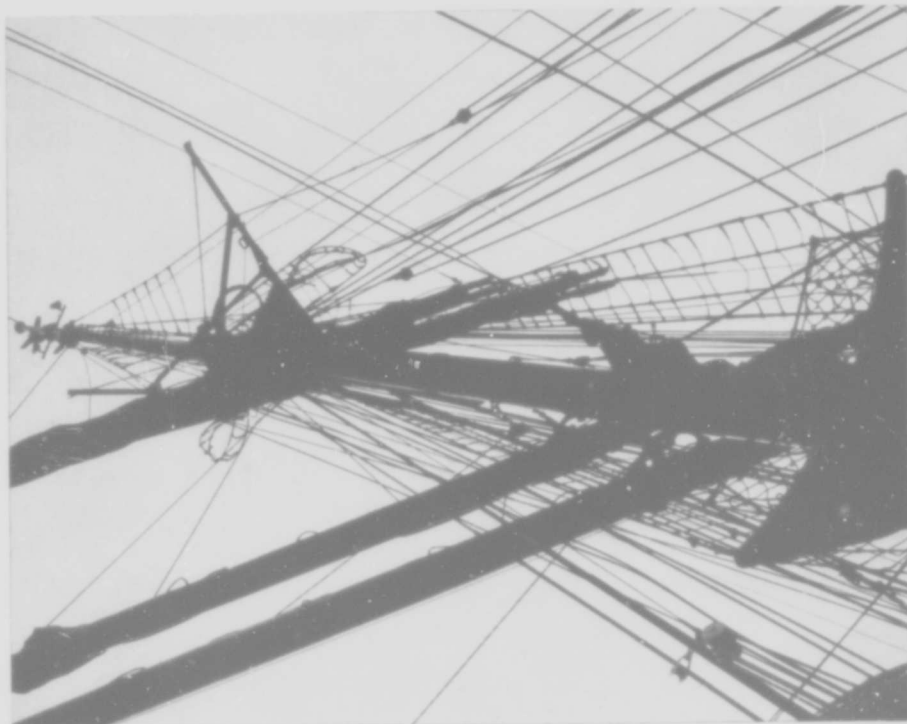


Fig. 11. Rigging of the U.S.C.G. Barque EAGLE.
U.S. Coast Guard Photo. Courtesy of the U.S. Coast Guard Academy, New London, Conn.

The equivalents given by Verploegh (1956) are something else again. If you must have equivalents and if you want ones with as much physical meaning as possible, then Verploegh's are the ones to use. His own data taken every three hours from L.V. Terschellingerbank ($53^{\circ}31'N$ $05^{\circ}08'E$) from 11 Sept 1950 through 1 Sept 1951--2321 observations--and from L.V. Texel ($53^{\circ}07'N$ $04^{\circ}30'E$) from 16 Nov 1950 through 1 Sept 1951--1996 observations--are impressive. With this he includes all previous observations made at sea whose quality is known and good. Most commendably, he faces the difficulties inherent in establishing velocity equivalents for Beaufort force numbers squarely and sweeps nothing under the rug. At least part of the confusion today over Beaufort numbers and equivalents arises, as Verploegh points out, from the fact that they have been used in two opposite ways. For anemometer readings taken at land based stations the Beaufort numbers are used as a code--the input is a velocity, the output a Beaufort number. For evaluation of the wind at sea the use is reversed--the input is an estimated Beaufort number, the output a wind velocity in knots. It would be a hopeless task to attempt to improve on Verploegh's presentation by summarizing it here. You should read his paper. Let's turn instead to the intervening years.

What happened between 1838 when the use of the Beaufort scale was made mandatory in the Royal Navy and 1956 when Verploegh published his table of equivalents? In one sense the story is a tale of the triumph of technology over rational thought. It begins with the invention of a couple of gadgets. In 1837 Morse demonstrated the first practical electromagnetic telegraph and in 1846 Robinson invented the cup anemometer. However, neither of these exercises in

engineering would probably have had much effect on the decent super-annuation of the Beaufort force scale without the intervention of catastrophe. In 1854 the French and British armies were besieging Sevastopole. Their supply port was Balaclava and, as luck would have it, the fleet carrying almost all their winter supplies was at anchor in the harbor on 14 November. In Kinglake (1875-1888) one finds an account of what happened. "In the evening of the 13th November, after wild storms of wind and rain, there set in a calm which lasted until an hour before sunrise on the following day; but then, over the open downs on Chersonese, and the neighboring coasts, harbors, and roadsteads, there swept on the 14th of November a violent hurricane, accompanied by thunder and lightning, by heavy rain, hail, and sleet, and followed, before the day ended, by driving snow. The storm, it appears, was a cyclone revolving upon a center which passed from south to north at a rate of no more than some twenty miles an hour, but on this moving axis the whirlwind flew around with a velocity said to have reached to nearly a mile in the minute. Of the French shipping, one man-of-war, the 'Henri IV.,' one dispatch-boat, and several supply-vessels and transports were lost; but it was upon the English supply-ships and the English camp that the disasters most heavily fell. Of the vessels freighted with munitions and stores for our army no fewer than twenty-one were dashed to pieces and totally wrecked, with grievous loss of life, whilst eight besides were dismasted. The 'Retribution'...had her rudder unshipped, lost two of her anchors, and was long in extreme peril. Indeed, it was at the cost of throwing overboard his upper-deck guns that Captain Drummond

proved able to save her. Even in the little land-locked pool of Balaklava, the shipping there huddled was grasped, as it were, and confounded and rudely battered together, by the whirling tornado; whilst, moreover, the captains of vessels which had been lying outside, seized the one hope of saving their crafts which seemed to be left to them, and lawlessly drove their way in, carrying yet more confusion and havoc into a crashing thicket of bulwarks, and masts, and spars." In 12 hours the French and English navies had sustained a disaster whose losses exceeded the most savage fleet action that had ever been fought.

Ships cost money and governments don't like to spend it. In particular, Napoleon III had always had the reputation of being a hard man with a sou and he didn't like the prospect of paying for more ships which might be lost in the same way. He called in the astronomer Leverrier, then fresh from his triumphant discovery of Neptune and president of the Academy of Sciences at Paris and said, in summary, "Don't just stand there. Do something." Leverrier put together a research team. For years Leverrier, as an astronomer, had been in correspondence with observatories all over Europe. One of their mutual concerns was "seeing conditions" and among the data exchanged on that subject were records of barometric pressure. Within a year the team returned to Napoleon III with the proposition that fluctuations in the barometric pressure associated with storms appeared to travel like waves and that, if the pressure information could be assembled fast enough, something might well be done in the way of forecasts and storm warnings. Twenty years earlier the idea would

have died right there except for a few scientists laboriously gathering pressure data and grinding out hindcasts for deposit in the archives. Instead, it just happened to coincide with the birth of the first reasonably complete electromagnetic telegraph system spanning much of Europe.

The English government didn't like its losses one wit better than did Napoleon III so the British Admiralty and the French Marine decided to sponsor a weather net²⁹ to provide storm warnings. And here is where Beaufort's wind force scale instead of fading away began its protean growth. All of us who have done contract research know how it goes. We may do our work in meters but if the agency that pays the bills likes fathoms, fathoms is what they get in the final report. The scientists might have liked meters per second but Beaufort force numbers were what the Royal Navy used. Further, the uses to which the forecasts of the weather net were to be put were maritime. The Royal Navy was the training ground for the British merchant marine. The British merchant marine was the training ground for the rest of Europe. Beaufort numbers were adopted--at any rate they made a reasonable telegraphic code.

In 1863 FitzRoy wrote the first good meteorological text and the methods of meteorology began to stabilize. The meteorologists were in a ferment over the possibilities of the new weather net and as fast as stations were established they were equipped with cup

²⁹ This is the start of what time has transformed into the World Meteorological Organization.

anemometers for measuring wind speeds.³⁰ The wind speeds were, of course, still coded in Beaufort for telegraphic transmission. One has the picture of a peasant in the Ukraine who had never seen the ocean let alone a frigate of 1805, going out to the shack, reading 37 rpm and then, after looking up the equivalent on the tattered mimeographed table Scotch-taped to the wall, transmitting Beaufort 7. To go with the first picture you have a second. There is his confrere up in Karalia who has never seen the ocean or a frigate of 1805, reading his mimeographed table and coding 37 rpm as Beaufort 5. Pictures of this sort can ruin a meteorologist's whole day.

In fact, the number of men who had seen the ocean and who were also competent to judge what the behavior of one of the few surviving frigates of 1805 would be if they had to chase somebody with it was becoming vanishingly small. In 1874 a committee revised Beaufort's specification in terms of the commercial ships and rigs common at the time.³¹

The confusion continued to increase until by the early 20th century it was well nigh intolerable. In 1912 at its London meeting the International Commission for Weather Telegraphy was asked to get some agreement on the velocity equivalents. A subcommission including

³⁰ Meteorologists of the time seem to have been having a love affair with Robinson's anemometer just the way we all do with a new instrument--at least until we begin to find out from experience what its problems are.

³¹ This was really love's labor lost with steam already challenging sail.

Professors Köppen and Palazzo and Mr. Lempfert was appointed and instructed to report at the 1913 meeting in Rome. The subcommission quickly identified the Seewarte and Meteorological equivalents as the only ones to be seriously considered. Their report with its adjustment, however, was not accepted, mainly because they proposed overlapping equivalent velocity ranges at the higher Beaufort numbers, and they were told to get back to the drawing board. Before they could report again everyone was fully occupied with World War I.

In 1921 Dr. Simpson was asked to try his hand at the problem and his proposal, Simpson (1926), was accepted without change by the International Meteorological Committee at its 1926 meeting in Vienna. Verploegh (1956) comments, "To understand the significance of the resolution for the further development of the Beaufort equivalents, it must be realized that in those days the problem had a somewhat different nature than it has today. Though originally the scale of Admiral Beaufort was a measure for the estimated wind force at sea, the Beaufort numbers were gradually being used as a general indication for the wind forces on land too. Some agreement therefore had to be made in order to match the 'terrestrial' scale to its 'marine' counterpart. Especially so, after the Beaufort indication for the wind was prescribed in coded telegrams, a measure, which implied the necessity for an equal interpretation of the respective Beaufort numbers in all countries and also between land and sea observations.

"By the time that the Meteorological Office and the Seewarte series came into use, at most land stations the wind velocity was

being measured with anemometers. For the coded telegrams the velocities had to be converted into numbers of the general Beaufort scale and for this purpose it did not really matter, whether the exact equivalent wind force, which would have been estimated at sea under the same circumstances, was obtained. The general scale for the wind force is an abstraction and for that matter it need not relate to a specific case, in the same way as the original marine scale. For practical purposes, however, a close relationship between both scales is highly recommendable, though it should be remembered that it will never be possible to make the scales wholly identical because of the different nature of the wind at sea and on land.

"In constructing the Seewarte series Köppen tried to obtain the best equivalents for estimates at sea, while the Meteorological Office series had a more intermediate character, being derived from both land and sea observations. With the derivation of the international equivalents in 1926 Simpson had the abstracted Beaufort scale in mind.

"Concluding that the difference between the Meteorological Office and Seewarte series was mainly to be ascribed to a difference in the exposure of the anemometers, Simpson recommended in 1926 a mean series, which he obtained by averaging his and Köppen's series in a rather special way and which would be generally acceptable for conversion of the anemometer readings, at an exposure of 6m, into Beaufort numbers.

"His final conclusion is worthwhile being cited here, since it is still of significance nowadays.

'In conclusion, it should be emphasized that the suggested code is not an attempt to determine the true velocity equivalents of the Beaufort scale. The latter cannot be done without taking into account the exposure of the anemometer. The way is, therefore, still open for further work in finding a better relationship between Beaufort estimates and anemometer readings than that yet reached by the Meteorological Office and the Seewarte.'

"In 1946 the IMC accepted a resolution at Paris, by which, on the suggestion of the Meteorological Office in London, the former Meteorological Office series were to replace the equivalents agreed upon in 1926. The background of this resolution was the recommendation that the standard height, for which the surface wind speed is given in coded reports, should be increased from 6m to 10m.

"This resolution did not change the situation essentially. Being merely a consequence of Simpson's conclusions it meant another evaluation of the abstracted Beaufort scale.

"In maritime meteorology the shortcomings of both the international equivalents of 1926 and 1946 were felt in connection with theoretical work and several new estimations have been made on board ship, mainly by German investigators. Some of these resulted in the Seeskala, published by H. Seilkopf in 1939. Most countries, however, used the international scales when converting the estimates at sea into wind velocities, mainly because a satisfactory solution to this problem had not yet been found.

"In 1949 the situation in respect to the general usage of the

Beaufort equivalents, was changed radically. According to a resolution, adopted at the Directors Conference at Washington in 1947, the Beaufort numbers were abandoned in coded reports and replaced by wind velocities in knots. As a result of this the estimates at sea were generally to be converted into wind velocities in knots. The problem of finding the best equivalents for the estimates of the wind force at sea become relevant also in synoptic meteorology. In connection with the altered situation another resolution was adopted by which further research into the true equivalent velocities at sea was recommended."

With Verploegh's work I think any useful outcome of the recommendation of the Directors Conference has been realized. The Beaufort force scale belongs to the seamen. It was devised by a sailor for sailors and to meet a very explicit situation. It did so and handsomely. If Beaufort estimates continue to serve today's seamen in their day to day work so much the better.

All the trouble over finding a set of wind velocity equivalents for the Beaufort force numbers is the fault of the scientists. That the Beaufort numbers were ever used as a telegraphic code for anemometer readings is one of those irrelevant accidents of history. If one hundred years ago there had been a reasonable way to extend the land based weather net to the ocean I suspect the exercise would never have been suggested. In their desperate efforts to extend their observations the scientists snatched at what they could get. However, even if we had "perfect" equivalents the data would, for meteorological purposes, be of intolerably low quality. With our

present ability to sense, record, store, and transmit data and with the untended telemetering ocean buoy-instrument system on the verge of operational reality, I suggest that it is high time scientists gave Beaufort a decent burial--preferably at sea.

BIBLIOGRAPHY

- Beaufort, F.
1817 Karamania, or a brief description of the South Coast of Asia Minor, and of the Remains of Antiquity. London: R. Hunter. 299 pp.
-
- 1826 Account of an earthquake at sea. Edin. Jour. of Sci. Vol V, pp. 232-234.
-
- 1853-1854 Determination of the longitude of Papeete, from observations of a partial eclipse of the sun. Mon. Roy. Astrn. Soc. Vol XIV, pp. 48-49.
- Bowditch, N.
1958 American Practical Navigator, an Epitome of Navigation. U.S. Navy Hydrographic Office, H.O. Pub. No. 9, U.S. Gov't Printing Office, Washington, D.C. 1524 pp.
- Curtis, R.H.
1897 An attempt to determine the velocity equivalents of wind forces estimated by Beaufort's scale. Quart. Jour. Roy. Met. Soc. Vol XXIII, No. 101, pp. 24-61.
- Davidson, K.S.M.
1956 The mechanics of sailing ships and yachts, in Surveys in Mechanics. G.K. Batchelor and R.M. Davis (eds.). London: Cambridge University Press. pp. 431-475.
- FitzRoy, R.
1839 Narrative of the Surveying Voyages of His Majesty's Ships ADVENTURE and BEAGLE. Vol II. London: Henry Colburn. 694 pp.
-
- 1863 The Weather Book, a Manual of Practical Meteorology. London: Longman, Green, Longman, Roberts, and Green. 464 pp.
- Germany, Marineleitung. Nautischeabteilung
1888-1890 Die Forschungsreise S.M.S. "Gazelle" in den Jahren 1874 bis 1876 herausgegeben vom Hydrographischen Amt des Reichs-Marine-Amtes. 5 Bände, Berlin.
- Heaton, P.
1949 Sailing. Penguin Books. Harmondsworth, Middlesex. 224 pp.

Kinglake, A.W.

1875-1888 The Invasion of the Crimea: its origin, and an account of its progress down to the death of Lord Raglan. (4th ed.) New York: Harper and Bros. 6 volumes.

Köppen, W.

1898 Neuere Bestimmungen über das Verhältniss zwischen der Windgeschwindigkeit und Beaufort's Stärkeskala. Aus dem Archiv der Deutschen Seewarte, Hamburg. Vol XXI, No. 5, 21 pp.

Marchaj, C.A.

1964 Sailing Theory and Practise. Dodd, Mead and Company, New York. 450 pp.

Marshall, J.

1828 Royal Naval Biography. Supplement Part II. London: Longman, Rees, Orme, Brown and Green. pp. 82-94.

1835

Royal Naval Biography. Vol IV, Part II. London: Longman, Rees, Orme, Brown, Green, and Longman. p. 452.

Proceedings of the Royal Society

1857-1859 Beaufort obituary. Proc. Roy. Soc., London. Vol IX, pp. 524-527.

Robinson, T.R.

1855 Description of an improved anemometer for registering the direction of the wind, and the space which it traverses in given intervals of time. Trans. Roy. Irish Acad. Vol XXII, Pt. 1-Science. pp. 155-178.

Roll, H.U.

1965 Physics of the Marine Atmosphere. Academic Press, New York. pp. 24, 25.

Scott, R.H.

1874 An attempt to establish a relation between the velocity of the wind and its force (Beaufort's scale), with some remarks on anemometrical observations in general. Quart. Jour. Met. Soc., new series, Vol II, No. 11, pp. 109-123.

Seewetteramt

1964 Seegangsbilder zur Schätzung der Beaufort-Windstärke nach dem Aussehen der Windsee. Deutscher Wetterdienst, Seewetteramt, Hamburg.

Seilkopf, H.

1938 in Handbuch d. Fliegerwetterkunde. Bd. II. (Maritime Meteorologie), S. 44.

- Simpson, G.C.
1906 London, Meteorological Office Publication No. 180.
-
- 1926 The velocity equivalents of the Beaufort scale. Air Ministry, Meteorological Office, London, Professional Notes, No. 44, 24 pp.
- Snow Harris, W.
1857 Pamphlet on a new form of anemometer. London: Lilley and Son.
- Stephen, L. (ed.)
1885 Dictionary of National Biography, Vol IV. New York: Macmillan and Co. pp. 39-41.
-
- 1885 Dictionary of National Biography, Vol XIX. New York: Macmillan and Co. pp. 207-209.
-
- 1897 Dictionary of National Biography, Vol XLIX. New York: Macmillan and Co. pp. 53-55.
- Underhill, H.A.
1938 Sailing Ship Rigs and Rigging. Glasgow: Brown, Son & Ferguson, Ltd., Nautical Publishers, 52 to 58 Darnley Street. 128 pp.
-
- 1946 Mastng and Rigging the Clipper Ship and Ocean Carrier. Glasgow: Brown, Son & Ferguson, Ltd., Nautical Publishers, 52-58 Darnley Street. 304 pp.
- Verploegh, G.
1956 The equivalent velocities of the Beaufort estimates of the wind force at sea. Koninkl. Ned. Meteor. Inst. Mededel. Verhandl. No. 66.
- Warner, O.
1961 The Glorious First of June. London: B.T. Batsford, Ltd. 184 pp.
- Wiener, N.
1964 Monkeys at the typewriters--too much theory, not enough practice. International Science and Technology, June 1964. pp. 106-107.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author) Chesapeake Bay Institute The Johns Hopkins University		20. REPORT SECURITY CLASSIFICATION Unclassified
		20. GROUP
3. REPORT TITLE AN EXPLORATION OF THE ORIGIN AND PERSISTENCE OF THE BEAUFORT WIND FORCE SCALE		
4. DESCRIPTIVE NOTES (Type of report and, inclusive dates) Technical Report		
5. AUTHOR(S) (First name, middle initial, last name) Blair (none) Kinsmen		
6. REPORT DATE August 1968	70. TOTAL NO. OF PAGES 55	70. NO. OF REFS 32
8a. CONTRACT OR GRANT NO. Nonr 4010(11)	90. ORIGINATOR'S REPORT NUMBER(S) Technical Report 39 Reference 68-7	
b. PROJECT NO. NR 083-016		
c.	90. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT Distribution of this document is unlimited		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Office of Naval Research
13. ABSTRACT A discussion of the history and meaning of the original Beaufort wind force scale is presented and compared with a recent version. Some account of the accidents that have kept the Beaufort scale current after 160 years and the comedy of providing wind velocity equivalents is given. It is suggested that perhaps the time has come to return the Beaufort force scale to the seamen from whom it was borrowed.		

DD FORM 1473 (PAGE 1)
1 NOV 65
S/N 0101-807-6811

UNCLASSIFIED

Security Classification

A-31400

UNCLASSIFIED

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Beaufort equivalent wind speed wind force wind speed						

DD FORM 1473 (BACK)
1 NOV 68

S/N 0101-007-0021

UNCLASSIFIED

Security Classification

A-31409