HISTORICAL TRAILS OF SHIP BROACHING-TO

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SUMMARY

The article intends to bring back to light old perceptions about the "broaching-to" behaviour of ships. The signature of broaching-to is the sudden loss of controllability. The phenomenon sometimes ends with vessel capsize. The findings of an investigation into old bibliographical sources are reported, spanning more than 300 years of use of the term. Several citations have been identified in texts of nautical or related content, including voyagers' records, nautical journals, training manuals, old encyclopaedias and even literary sources and leisure magazines. At a time when broaching-to is considered in the currently formulated new ship stability criteria at IMO, this paper provides a historical perspective on a problem that has maintained relevance despite the changes in ship technology and design.

1. INTRODUCTION

"Broaching-to" is an unstable type of ship behaviour, occasioned by steep following/quartering seas. Loosely described, it is the loss of heading of an actively steered ship, often manifested as a tight turn despite the "hard-over" setting of the rudder. A resonant-type build-up of heading deviation from the desired course is another possible manifestation of broaching-to. Capsize on a wave down-slope is a likely consequence as the ship is brought broadside to the weather. Whilst the subject has been alive in the nautical bibliography for centuries, essential advances in the understanding of the dynamical origins of this behaviour have been realised only after the 1950s [1-6]. Reflective of the notable scientific progress achieved is the current consideration of broaching-to prediction methodologies within the framework of the so called "new generation intact stability criteria" which are currently being discussed at IMO [7].

Since modern ships usually carry no sails, research has targeted the physics of broaching-to as exhibited by modern motor ships operating under the effect of waves, with no concern for wind. In the era of boats with sails however, wind represented a key source of excitation and subsequently, it should have played a major role in shaping the perception of what broaching-to is. The arrangement of sails and the incurred significant destabilising wind forces should have been very influential for turning suddenly, despite all efforts, a ship broadside to the weather. It must be a fair conjecture that, the combination of wind and waves should have placed more heavy demands upon the Master of the old days. It should be interesting therefore to learn how broaching-to was described and dealt with in the past; an era that in fact still survives to some extent, through the modern sailing boats. Whilst for modern ships one finds some, often vivid, descriptions of broaching-to behaviour [8]; the community of ship designers maintains limited recollection of the deep past of the subject. A glimpse into that, long-gone, world when navigation was, in its own capacity, an adventure reveals that, the prevention of broaching-to represented a great concern for the seamen. Several book excerpts and other texts from the 19th, 18th and even 17th century authenticate explicit use of the term "broaching-to" by the old seamen for characterising what they apparently believed to be one of the most dreadful conditions that ships could encounter during their operation. Such a feeling is distilled in an old sailor's pocket book where one reads that [9]:

"The one great danger, when running before a broken sea, is that of broaching-to."

According to the Oxford and the Merriam-Webster dictionaries of the English language, the first documented use of the term "broaching-to" is traced to the year 1705 (referring to a book however which, as will be discussed later, had firstly appeared in 1699). Their definitions of the phenomenon appear quite alike: according to the Oxford English Dictionary, *broach to* is [10]; "to veer suddenly so as to turn the side to windward, or to meet the sea"; whereas in the Merriam-Webster it is defined as [11]: "to veer or yaw dangerously so as to lie broadside to the waves".

The literature (nautical and beyond) was found to offer some captivating descriptions of real occurrences of broaching-to along with deliberations on how to avoid it; attempts of defining the phenomenon formally; rowing and steering practices; and improvised gear devised specifically for dealing with it in the critical hour. From our investigation comes out that, broaching-to was mostly feared when a vessel was heading towards the shore; especially when lying very near to a steep shore. Moreover, it was often discussed within a scenario of the ship sailing at a high speed, rushing before the weather (this is the condition identified as "scudding" and discussed more thoroughly later). The experience has apparently survived in the description of broach-to in the Oxford Companion to Ships and the Sea [12]. In there, all emphasis is placed on the effect of wind and the occurrence of the phenomenon is associated with some skippers' habit of running their ships too fast; further suggesting that, it is dangerous to sail with spinnaker.

The purpose of the current paper is twofold: firstly, to provide a historical perspective and inform about how

Figure 1 The Shipwreck by Nicholas Pocock, 1810 (© National Maritime Museum, Greenwich, London).

broaching-to was perceived, and dealt with, in the past. Secondly, to trace any seeds of scientific thinking, let pre-mature, about the nature and dynamics of this intricate phenomenon. Our historical research runs up to about the year 1860 when the Royal Institution of Naval Architects was established, that opened up the era of more scientifically rigorous investigations of ship dynamics.

2. THE FIRST RECORD

Captain William Dampier is identified as buccaneer and scientific observer [13]. His claim to fame was that he was the first Englishman to explore certain parts of Australia and New Guinea. At the dusk of 17th century he describes in his book with title *"A New Voyage Round the World"* [1] his experiences from navigating around the globe (he was the first to go around it three times) and offers the first known citation of the term broaching-to [14]:

"; and besides, often very violent and fierce, so that a Ship with her sails loose, would be in danger to be over-set by them, or at least lose Masts or Yards, or have the Sails split, besides the Consternation that all Men must needs be in at such a time, especially if the Ship, by any unforeseen accident, should prove unruly, as by the mistake of the Man at Helm, or he that Conns, or by her broaching to[2] against all endeavours, which often happens when a fierce gust comes; which though it does not last long, yet would do much damage in a short time, and tho' all things should fall out well, yet the benefit of it would not compensate the danger:"

3. THE 18TH CENTURY

3.1 A SAILOR TURNED FAMED POET - FALCONER'S "THE SHIPWRECK"

A celebrated poem written by a sailor, William Falconer, that was published in 1762 under the title "The shipwreck" describes the poet's tragic experiences in 1749, on board the foundered ship Britannia [15]. The drama unfolded near to the shore of Attica, off Cape Sounion (known as Cape Colonne or Collona in those days).[3] The true story and proceedings surrounding his poem come out from the following extract [17]:

"… he served on board the Britannia, a merchantman, bound from Alexandria to Venice, which touched at the Island of Candia[4], whence, proceeding on her voyage, she met with a violent storm, that drove her on the coast of Greece, where she suffered shipwreck near Cape Colonne, three only of the crew being left alive."

The following passage conveys the anxiety as the final moment is approached: the ship is nearing to the shore at high speed while any attempt to change course is feared to lead to broaching-to [18]:

[1] This book is in fact the one referred-to in the introduction.

[2] In the original text it appears as "too"; but it is later corrected in an Errata Table included in the book.

[3] Contributory to the eminence of the geographical spot was Lord Byron's remark that "In all Attica, if we except Athens itself and Marathon, there is no scene more interesting than Cape Colonna."; continued by, "for an Englishman Colonna has yet an additional interest as the actual spot of Falconer's shipwreck." [16].

[4] This is today's island of Crete.

"While shoreward now the bounding vessel flies,
Full in her van St. George's cliffs arise;
High o'er the rest a pointed crag is seen,
That hung projecting o'er a mossy green.
Nearer and nearer now the danger grows,
And all their skill relentless fates oppose.
For, while more eastward they direct the prow,
Enormous waves the quiv'ring deck o'erflow.
While, as she wheels, unable to subdue
Her sallies, still they dread her broaching-to:
Alarming thought! For now no more a-lee
Her riven side could bear th' invading sea
And if the following surge she scuds before,
Headlong she runs upon the frightful shore;"

A painting of 1810 by Nicholas Pocock depicts the final moment, with the Cape Colonne on sight (Figure 1). A footnote in Anderson's edition of the poem offers the following remarkable definition [15]:

"Broaching-to is a sudden and involuntary movement in navigation, wherein a ship, whilst scudding or sailing before the wind, unexpectedly turns her side to windward. It is generally occasioned by the difficulty of steering her, or by some disaster happening to the machinery of the helm."

Broaching (without *-to*) is mentioned also earlier in the poem referring to the placing of the ship obliquely to the weather and seemingly alluding to a voluntary change of heading. As for the condition of "scudding" referred-to in the above definition, this is well explained in another of Falconer's publications:

3.2 FALCONER'S MARINE DICTIONARY

Falconer's name is better known to mariners from his "Dictionary of the Marine" firstly published in 1769, the year of his bereavement.[5] In there he describes "broach-to" as follows [19]:

"*To* BROACH-TO, in navigation, to incline suddenly to windward of the ship's course when she sails with a large wind; or, when she sails directly before the wind, to deviate from the line of her course, either to the right or lest, with such rapidity as to bring the ship's side unexpectedly to windward, and expose her to the danger of oversetting.

It is easy to conceive that a ship will carry much more sail before the wind than when she makes a progress with her side to it's direction; because when the current of wind as nearly endways on her hull, the pressure of it on the masts must be considerably diminished as she yields to it's impulse and flies before it; and that if she carries a great sail at this time, it can only press her fore-part lower down in the water. But if, when she carries a great extension of sail, her side is suddenly brought to the wind, it may be attended with the most fatal consequences, as the whole force of it then pours like a torrent into the cavities of the sails. The masts therefore unavoidably yield to this strong impression, acting like levers on the ship sideways, so as nearly to overturn her, unless she is relieved by some other event, which may be also extremely pernicious, such as the sails rending to pieces, or the masts being carried away.

It is generally occasioned by the difficulty of steering the ship; by the negligence or incapacity of the helmsman; or by some disaster happening to the helm or its machinery, which renders it incapable of governing the ship's course."

At this point he explains the difference between "broaching-to" and "bringing by the lee" (this clarification is often cited in later publications [20]):

"Suppose a ship with a great sail set is steering south, having the wind N.N.W. then is west the weather, and east the lee-side. If by some deficiency in the steerage her head turns round to the westward, so as that her sails are all taken aback on the weather-side before she can be made to return to the course from which she has deviated, she is said to broach-to. If otherwise her head, from the same cause, has declined so far eastward as to lay her sails aback on that side which was the lee-side, it is called bringing her by the lee."

One can thus deduce that, broaching-to is attributed to the unfavourable placement of the ship to the wind as regards the arrangement of her sails, with the effect of waves neglected (possibly considered as secondary). In Falconer's dictionary we find also the following definition for "scudding":

"Scudding, the movement by which a ship is carried precipitately before a tempest. ... A ship either scuds with a sail extended on her fore-mast, or, if the storm is excessive, without any sail, which in the sea phrase is called scudding under *bare poles*. In sloops and schooners, and other small vessels, the sail employed for this purpose is called the square-sail. In large ships, it is either the foresail, at large, *reefed*, or with its *goose-wings* extended, according to the degree of the tempest; or it is the fore-top-sail close reefed, and lowered on the *cap*: which last is particularly used when the sea runs so high as to *becalm* the foresail occasionally; a circumstance which exposes the ship to the danger of *broaching-to*. The principal hazards incident to scudding are generally, a *pooping* sea; the difficulty of steering, which exposes the vessel perpetually to the risk of broaching-to;"

[5] Unable to steer clear off his destiny, William Falconer disappeared, possibly in the Mozambique Chanel, with the frigate Aurora in the winter of 1769.

Figure 2 "A Dutch ship scudding before a storm", by Willem van de Welde, circa 1690.
(© National Maritime Museum – Greenwich, London).

3.3 JOHN HAMILTON MOORE'S "THE PRACTICAL NAVIGATOR" [21]

A concise definition of "broach-to" appeared in this 18th century book, with the author portraying himself as "Teacher of Navigation, Hydrographer and Chart Seller":

"Broach to: Is when a Ship, on a sudden, lays her Broadside to the Sea, and is dangerous in bad Weather."

3.4 HUTCHINSON AND THE SOCIETY FOR THE IMPROVEMENT OF NAVAL ARCHITECTURE

With the opportunity of the establishment in London of the "Society for the Improvement of Naval Architecture" (forerunner of the Royal Institution of Naval Architects), Hutchinson advises in 1791 that [22]:

"… and if the waves run high, when carrying a pressing sail, large, by such bad steering there is great danger of broaching the ship to; therefore none but the best helmsman should be permitted to steer at such times."

Later on, Hutchinson advises how to avoid broaching-to even when the foremast is lost. He recommends that, when other means fail, to veer out a tow-line or hawser from the stern, in order to slow down the vessel and keep her before the wind. His discussion of broaching-to develops also in connection to scudding.

A 17th century painting by the Dutch Willem van de Welde (shown in Figure 2) indicates how old this operational practice must have been.

3.5 NAVAL COURTS

Captain's Ayscough, Master of his Majesty's Ship Blanche which had run ashore, testifies in Court [it appears in the first (1799) issue of "The Naval Chronicle"[6]][23]:

"...but at 11 o'clock I cut away my main mast – and a little after, the ship broaching-to, I cut away my mizzen mast and rigged two boat-sails on the poop, to endeavour to steer her, having previously to this lost my rudder, and nothing left to steer the ship in case she drifted over the shoal."

4. BROACHING -TO IN THE 19TH CENTURY

4.1 MORE DEFINITIONS

A definition of broaching-to had appeared in the "Naval History of Great Britain" of James & Chamier (1860). The wording implied that it should be equally expected from the effect of wind and from quartering waves [24]:

"Broach to, is when, by the violence of the wind, or a heavy sea upon the quarter, the ship is forced up to windward of her course or proper direction, in defiance of the helm."

4.2 OPERATIONAL PRACTICES

An article entitled "Management of ships in a surf and

[6] This was a well-known journal which reported news about the British Navy including the period of Napoleonic Wars.

broken water"[7] published in October 1855 in the Journal "The Life-boat" leaves no doubt about the fear for broaching-to and the dexterity required for avoiding it [25]:

"On the second point, running before a broken sea, an equal variety of management is observable, as practised on the coast, yet all alike intended to meet the one great risk of "broaching-to", which nearly all agree in considering to be the greatest danger to which a boat can be exposed, and to be that which calls for the most skill and management to obviate it."

The magnitude of the problem on the English coast is then stated:

"We have been rather prolix in our account of the phenomenon of broaching-to, because it is a very interesting one, which it is important should be understood in order to arrive at the proper management and to obviate its disastrous effects, which have been more fatal to the lives and property of boatmen on our coasts than those proceeding from any other cause whatever."

A detailed discussion follows about operational practices for avoiding broaching-to and also some remarkable thoughts about its cause. The extract below is particularly noteworthy because it describes a practice exercised by oarsmen for mitigating the wave effect: by increasing the drag as the boat was experiencing extra thrust owed to the longitudinal component of wave's down-slope pressure; and, by speeding up while on the up-slope (this helps to avoid being caught in the types of behaviour that we would characterise today as "nonlinear surging" and "surf-riding"[8] [26]):

"As before observed, the greater number of skilful boatmen on the coast are in the habit of checking a boat's way through the water or of backing her against a heavy sea on its approach. Their practice is to stop the boat's way by backing their oars until the crest of the wave has struck the boat's stem and passed her midship part, then to give way again, running in on the back of that wave, as far as they may be able to, then watching for the approach of the next, and repeating the same operation until they arrive at the beach, being careful, by steering with oars at the quarter or stern to keep the boat as far as possible, end on to the direction in which the sea is running. It must be here observed, that this management is so far varied according to the character of the boat; that in cobles, and other square sterned boats which have their bows better formed for meeting a sea than their sterns are, their position is reversed before entering the broken water, and they are taken in stern foremost and bow outwards, but the same principle being acted on rowing back to meet each heavy wave instead of running from it. In a sailing boat this principle can only be so far acted on as to diminish the boat's speed through water by taking her in under a very educed amount of sail, which is commonly one and by towing weights or instruments lade for the purpose."

Another use of the oars, for maintaining the course, is also considered:

"The steering with an oar on each quarter is another expedient, employed to prevent broaching-to, as when running, a boat will not answer her helm on being overtaken by a sea."

Then we are introduced to the practice of using "drogues", apparently the evolved technology of hawsers or ropes that we had found to be discussed in 18th century's literature. Drogues were (and still are) valuable aids for keeping the course and for avoiding broaching-to (as well as for avoiding "bow diving"[9]; as comes out later, bow diving was seen by some as connected with broaching-to):

"Another expedient is to tow a pig of ballast, or a basket, or other instrument, which by its weight or hold on the water has the effect of a drag on the rear end of the boat, and prevents its being beat to leeward by the sea, thus keeping her end on to it. On the coast of Norfolk the following ingenious plan is commonly practised. The boatmen there employ an instrument for the above purpose called a "drogue"; it is a conical shaped canvas bag, of the form of a common candle extinguisher, about 2 feet diameter at the base or mouth of the bag, and 6 feet long, having a small opening at the other end or apex of the cone. When running before a heavy sea in broken water, the drogue is thrown over from the stern, and towed by a stout rope with the large end foremost, when it instantly fills, and from the resistance it opposes to the water, holds the stern back and prevents the boat's broaching-to: as soon as the danger is past the large tow rope is let go, and the drogue then towed with the smaller end foremost by a small line attached to that end, it then immediately collapses is emptied of water and offers but little resistance."

[7] According to the Merriam-Webster Dictionary: "surf – date 1685 - is the swell of the sea which breaks upon the shore; and the foam, splash, and sound of breaking waves."

[8] Surf-riding is a peculiar condition of ship operation corresponding to her capturing between two wave crests in following/quartering seas; i.e. the ship is forced to travel with speed equal to wave's celerity. Nonlinear surging on the other hand is, the asymmetric oscillation of a ship in her longitudinal direction, where she spends more time near wave crests and passes quickly for the troughs – it represents forerunner of surf-riding.

[9] Bow diving is a phenomenon where a ship, while running somehow faster than the waves, nails her bow into a steep wave's up-slope. Ships with fine lines, and thus low buoyancy, in the bow area are prone to this. The large increase of resistance to forward motion, experienced by a bow diving ship, causes her slowing down and her possible capsize under the effect of the next wave.

An alternative practice of speeding up before the waves is also described, and also the trimming of the boat by the stern in order to minimise the area acted upon by wind and waves:

"Proceeding then to the opposite practice of giving a boat speed, in fact running away from the sea, which constitutes the other important distinction in practice. The principle then acted on is to escape from the danger as fast as possible and other expedients are then resorted to prevent the risk of broaching-to. The most common of these is to trim the boat by the stern, by bringing all moveable weights aft (this supposes her stern to be outwards; if she were being taken in stern foremost, she would then be trimmed by the head). The force of the sea or wind on either quarter has then less power to beat it off, and cause the boat to broach-to, than it would have if the stern were light."

A question as to the causes of broaching-to, leads to a detailed account of the authors' understanding of broaching-to (interestingly, the question about the criticality of rudder's emergence for realising broaching-to continued to be raised till our days [4]):

"In reply to another question as to the cause of a boat's broaching-to, the almost invariable answer is, "because the stern is thrown out of the water and the rudder therefore ceases to act". From our own observation we have formed the opinion that this is not the case, although it is quite true that, at the moment of broaching-to, a boat will not answer her helm.

The phenomenon of broaching-to, we believe, may be correctly accounted for as follows: - on a boat encountering a heavy broken sea or roller end on, if she be stationary or is being profiled in a contrary direction to the wave, she will receive its blow, and it will quickly pass by her, her own inertia preventing her being carried away by it. If however she is being propelled in the same direction as the waves, and running rapidly through the water with her stern towards them, on a wave overtaking her, its first effect is to throw her stern up and to depress her bow, but so far from her rudder being out of water, both it and her stern are buried in the crest of the wave; in consequence, however, of her previous motion being in the same direction as that of the wave, she now offers so slight resistance to it, that instead of its passing her, she is hurried along with it at a rapid rate over the ground, her stem high up still immersed in the crest of the sea, and her bow low down at its base; as the wave approaches shoaler water, its inshore surface approaches more end more nearly to a perpendicular, and the tendency of the boat to run down this steep inclination added to the momentum she has already from her previous motion, causes her to run her bow under water, when her buoyancy at that end being destroyed her stern still light is pressed onward by the summit of the wave, and the undercurrent from the last receding wave at the same time acting on her bow, she is instantly, if a short boat, turned "end over end," or if a long one, capsized quarter wise If she have so high a bow that it does not become altogether immersed, or if, as in a life-boat, the end of the boat is occupied by a water-tight air-case to the height of the gunwale, so as to prevent the admission of the water over the bow, the effect then is that the boat is instantaneously turned round broadside to the sea, when again, unless she be a life boat of a superior description, she is almost certain to be upset. In the circumstances thus described, the sole cause of a boat's running herself under water or broaching-to is that of running from a sea instead of awaiting it, and suffering it to pass by; and the cause of the rudder being useless to keep the boat end on to the wave, is not that it is thrown out of the water, (although at other times it doubtless is so), for it is actually buried in it as is also the stern of the boat up to her gunwale, but it is because it is stationary in it the crest of the wave having acquired an actually progressive motion equal to that of the boat. If on the other hand the wave passes the boat, as its crest advances from the stern to the fore part, the rudder and stern are thrown out of the water; steering oars are therefore a most valuable auxiliary aid when running before a sea, but we would recommend the use of a rudder as well."

Reference to broaching-to exists also in later issues of the same journal. The following piece, from the January 1856 issue, is particularly noteworthy, referring to the frequent occurrence of broaching-to near to the English coast town Deal to the North-East of Dover [25]:

"…nevertheless, we are positively informed that boats have been lost by broaching-to when running for the shore at Deal; and we have known a Suffolk yawl of 18 or 20 tons burden, broach-to, upset, and drown the greater part of her crew, when running under sail for the shore on as steep a beach as that at Deal."

J.R. Ward, Commander of the Royal Navy, writes to the Times and advises on the occasion of a capsized life-boat [27]:

"It is a well known thing to the seamen on the most exposed parts of our coasts that the chief danger to a boat does not occur when going off against a heavy sea, but on returning before it, at which time the greatest skill and carefulness are necessary, even under oars, to prevent a boat from broaching to and turning broadside on to the sea. Their experience has taught them that, when seeing a heavy breaker following their boat up from astern, instead of yielding to the natural impulse of giving her all possible speed away from it, and so, as might be expected to lessen the violence of the shock, their only safety lies in checking the boat's way through the water, and keeping her end on to the sea until it has passed them to effect which they back their oars, or even face a portion of the crew round the reverse way, who row backwards with all their force against the heaviest of the seas as they approach. If this precaution be neglected it is

almost a matter of certainty that the boat will broach to broadside to the sea and be capsized."

In Folkard's "The Sailing Boat", and under the rather unsurprising heading "Causes of ship capsizing" is given another view of broaching-to [28]:

"The action of the sea upon a boat running into a heavy surf, may be thus described: - when on the top of a heavy wave or roller, the bows are lifted high out of the water; then, as the sea recedes, the boat is hurled forward, and the bows are buried under water; when the sea acting powerfully on her head and fore gripe, twists her round, broadside to the waves, called "broaching to;" and the sea then runs over the gunwale into the boat; the next motion that inevitably follows, is a heavy lurch on the other side and another sea breaks completely over, and fills or capsizes the boat. This may happen either under sail or oars. There is considerable difficulty in preventing a boat from broaching to, when stem and stern are alternately lifted out of the water by the waves; and should the boat broach to and meet a very heavy roller, broadside on, the chances are fifty to one that she will be swamped."

Enlightening for the modern reader is the ensuing passage from Folkard about the widespread use of drogues in the English coasts at the middle of the 19th century. He considers them to be somehow shorter (about 4 ft 6 inches) in comparison to our earlier description.

"Drogues are now a good deal used on the Eastern Coast, in both sailing and rowing boats; they serve to check the boat's way, and keep her end on to the waves; and are, therefore, of great assistance to the crew, in preventing the boat from broaching to. Experience teaches, that when a heavy breaker follows the boat up astern, it is useless to attempt running away from it: then a question naturally arises, what must be done on the impulse of the moment. "For your lives men! back her astern; hard at it every one of you! and let the man in the stern-sheets creep forward a moment, to lighten the boat's stern!" By this effort the wave strikes the boat kindly, and passes on; but if allowed to follow her up astern, so surely as such an experiment is tried, the sea will either curl over the stern, or the boat will broach-to and take it over the gunwale.

Multiple ("series") drogues are present as drag devices on sailing boats even in our days. They are intended for use when heavy weather is encountered [29].

In a manual for naval cadets (1860), drawing possibly upon his experiences from the Royal Navy, Mc-Neill-Boyd advises the young cadets of the time about broaching-to and the proper tactics for avoiding it [30]. We are informed also that drogues were commonly used by boatmen at the Norfolk coast. It is remarkable that in the paragraph below he is alluding firstly to the condition of surf-riding and then to the condition of bow diving:

" But if a boat on being overtaken by a heavy surf, has not sufficient inertia to allow it to pass her, ..., - her stern is raised high in the air and the wave carries the boat before it, on its front, or unsafe side, sometimes with frightful velocity, the bow all the time deeply immersed in the hollow of the sea, where the water, being stationary or comparatively so, offers a resistance, whilst the crest of the sea, having the actual motion which causes it to break, forces onward the stern, or rear end of the boat. A boat will in this position sometimes, aided by careful oar steerage, run a considerable distance until the wave has broken and expended itself. But it will often happen that, if the bow be low it will be driven under water, when the buoyancy being lost forward, whilst the sea presses on the stern, the boat will be thrown (as it is termed) end over end; or if the bow be high, or it be protected, as in some life-boats, by a bow air chamber, so that it does not become submerged, that the resistance forward acting on one bow will slightly turn the boat's head, and the force of the surf, being transferred to the opposite quarter, she will in a moment be turned round broadside by the sea and be thrown by it on her beam-ends, or altogether capsized. It is in this manner that most boats are upset in a surf, especially on flat coasts, and in this way many lives are annually lost amongst merchant seamen when attempting to land after being compelled to desert their vessels."

Informative is his advice for managing a situation where broaching-to is imminent, for a boat operating with oars near to a shore. He proposes to follow one of three distinctive operational practices:

1st. By turning a boat's head to the sea before entering the broken water, and then backing in stern foremost, pulling a few strokes ahead to meet each heavy sea and then again backing astern. If a sea be really heavy and a boat small, this plan will be generally the safest, as a boat can be kept more under command when the full force of the oars can be used against a heavy surf than by backing them only.

2nd. If rowing to shore with the stern to seaward, by backing all the oars on the approach of a heavy sea, and rowing ahead again as soon as it has passed to the bow of the boat, thus ,rowing in on the back of the wave; or, as is practised in some lifeboats, placing the after-oarsmen, with their faces forward, and making them row back at each sea on its approach.

3rd. If rowed in bow foremost, by towing astern a pig of ballast or large stone, or a large basket, or a canvass bag termed a "drogue" or drag, made for the purpose, the object of each being to hold the boat's stern back and prevent her being turned broadside to the sea or broaching-to."

4.3 SHIP DESIGN

In the 1816 edition of the Encyclopaedia Perthensis there

is a section offering advice for selecting the proper shape of a life-boat, with specific reference to the avoidance of broaching-to [31]:

"The curvature of the keel has however been demonstrated to be the principal or only error in the construction of the vessel and we would recommend to those who in future may construct such vessels to preserve the spheroidal form of the body of the boat, yet, so as to leave a straight keel and a sufficient quantity of gripe to hinder the boat from broaching to, on receiving the stroke of the waves on her ends."

In his 1826 guide for the shipbuilders of the time, Partington recommends the use of sliding keels as a means for avoiding broaching-to [32]:

"… no misfortune, similar to that of broaching to, can ever befall a vessel furnished with sliding keels."
We learn more about these keels from another passage referring to a 66 ft vessel:

"She has three sliding keels inclosed in a case or well; they are each 14 ft in length; the fore and the after keels are 3 ft broad each, and the middle keel is 6 feet broad. The keels are movable by means of a winch, and may be let down 7 feet below the real keel; and they work equally well in a storm as in still water."

In a discussion at the Institution of Civil Engineers, Captain Hosken replies to the Society's President that he doesn't believe the steam ship "Great Britain" to be more liable to broaching-to than other ships when scudding [33]:

"His opinion was founded upon experience in the Great Western. The same question had been put to him by old seamen, before the first voyage of that vessel, when, from that ship's great length, it was thought there would be more than usual difficulty in steering her:".
In his lectures of 1846 on naval architecture, Gardiner Fishbourne argues for selecting a less fine stern compared to the bow (as known today, shifting the centre of hydrodynamic reaction towards the stern improves directional stability) [34]:

"The reason why short vessels do not run well.- It is notorious that vessels with fine after bodies, particularly if they be short, run badly. It is because there is so little action in the after body in such case, for the water cannot turn in upon it, there is even a danger in such vessels of their broaching to against their helm. The after body then should be greater than the fore body, in some ratio inverse of this action of the water."

Notwithstanding these deliberations, in another article of the Journal "The Life-Boat" (published in 1855) no clue could be offered for ship design [25]:

"In reply to the question, as to whether any particular kinds of boats are more liable than others to broach-to, the answers given are so conflicting and contradictory as to afford no information on the point."

4.4 MORE LITERARY SOURCES

Besides Falconer's poem, reference to broaching-to has appeared also in several other literary texts:

In "Arthur Gordon Pym", a nautical story written in the early literary life of Edgar Alan Poe, one comes across the following passage [35]:

"The boat was going through the water at a terrible rate-full before the wind-no reef in either jib or mainsail-running her bows completely under foam. It was thousand wonders she did not broach to".

In Charles Reade's novel "Love me Little, Love Me Long" Jack easies down Lucy's worries while on board [36]:

"No I tell you miss; all we have got to mind is two things: we must not let her broach-to, and we must not get pooped."..."But I mean, what could be the consequence of-broaching-to?" Jack opened his eyes in astonishment. "Why, the sea will run over her quarter, and swamp her."

And later:

"But oh! Mr. Dodd, there is another danger. We may broach-to."
"How can she broach-to when I am at the helm? Here is the arm that won't let her broach-to".

4.5 NARRATIVES

In his memoirs, Lieut. John Harriott writes in 1808 with reference to a trip from St. John's (Newfoundland) to Gibraltar [37]:

"For several days we continued thus, depending on the man at the helm to guard against the ship's broaching-to."

Telling his experience of travel by sea from New Brunswick to Quebec, Moses Guest provides a dramatic account of feelings on board as his ship has broached-to [38]:

"… finding we could not, with any degree of safety, lay to any longer, we commenced scudding, under a close reefed foresail but soon found we could only scud under our bare poles, which we continued to do until 6 A.M.. The vessel then broached to, and lay with her broad side to the wind, in the trough of the sea (which is the most dangerous situation that a vessel can be in:) a most tremendous sea was rolling down upon us, which we expected would soon swallow us up. I shall never forget

the frightful looks and behaviour of the man who was at the helm when the vessel broached to. Although he was a very experienced seaman, he exclaimed calling on his God and Saviour -we are gone! we are gone! nothing can save us!"

The broaching-to amidst squall of a corvette that was earlier firing against his ship is described by an unknown author in the magazine "The Casket" [39]:

"The corvette, moreover, was a wreck, stripped of every thing, and broaching to, with the waters rolling like a cataract over the weather side, and her horror struck-crew hanging in affright in the shrouds, and whenever they could clutch a rope."

In a similar magazine about literature, philosophy and religion ("The dial") we find the following sentence, referring to the travel of a brig from Boston to Jamaica [40]:

"...ten hours since the commencement of the gale, and the winds and the sea were still increasing in violence. Directly there came over us a sea so very heavy as to cause the brig to "broach to" (fall into the wind) and throw her down on her side. But her cargo being solid did not shift, she therefore righted immediately."

A life-boat's (under sail) capsize is discussed in the earlier mentioned letter to the Times by Ward [27]. Written in defence of having sails on the life-boats of the time, in the letter is argued that the accident should be attributed to the action of the sea alone:

"She had been to a wreck at a distance of six or eight miles from the land, and was on her return in the night time, running before the wind and sea, when, on nearing the shore and getting within the broken water, a heavy breaker threw her stern up, and buried her lee gunwale under water; she then broached to, broadside on to the sea, and was turned over by the following wave. The wind had previously fallen light, so that the accident was occasioned by the action of the sea alone."

It should be noted finally that, short references expressing the fear of broaching-to have appeared in several narratives of legendary expeditions as for example:

- In the search for a North-West passage from the Atlantic to the Pacific [41].
- In the tales of the voyages of the ship H.M.S. Samarang in the islands of the Eastern Archipelago [42].

5. CONCLUDING REMARKS

The motive behind the research presented in this paper was to find out whether there is anything to be learnt from what was empirically perceived in the past about the erratic type of ship behaviour known since many years as "broaching-to".

It came out that, phenomena such as bow diving and surf-riding have been regarded, for at least two centuries, to be closely connected with the occurrence of broaching-to. Thus, their relevance is not a recent discovery. The scientific basis of these phenomena and their dynamical contribution to broaching-to are matters considered nowadays as resolved. Yet there account in ship design is still very limited.

Broaching-to was mostly feared when approaching a steep shore. Nevertheless, several records of broaching-to incidents away from shore have also been identified.

Whilst wind was initially considered to be responsible for broaching-to, gradually a more balanced view was developed as regards the effect of wind and of waves. It seems that the controversy about the use of sails on lifeboats contributed to the better understanding of the effect of waves, at least for boats of small size. It is worthy to note however that, whilst nowadays we have a solid grasp about the role of waves, our scientific understanding about the role of wind in the occurrence of broaching-to of a sailing boat is not on a similar footing.

The recommended strategies for avoiding broaching-to were mainly: either to try to go ahead of the weather, or, adopt an action cycle where, by use of the oars, the boat is slowed down at waves' down-slope and is speeded up at the up-slope. In today's language, this would mean to work against the development of nonlinear surging behaviour; where the ship is accelerated as it passes from the wave crests and becomes prone to being captured into surf-riding at a nearby wave trough.

Ropes, and later on drogues, were used in order to increase resistance and slow-down the boat so that to avoid, what we would call in modern IMO vocabulary, the dangerous speed zone [43]. Technology and scientific knowledge have advanced; yet the essence of the recommended practice has remained.

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