Captain's Response to the Canada Transportation Safety Board's
Marine Investigation Report M10F0003
Regarding the Loss of the Sail Training Vessel *Concordia*

Capt. Bill Curry, December, 2011

Safety Issues as per the TSB Report

Nineteen months after the sinking of the SV *Concordia*, the Canada Transportation Safety Board released Marine Investigation Report M10F0003 (the TSB Report) on the loss of the SV *Concordia.*

Canada Transportation Safety Board Report M10F0003 identifies two underlying safety deficiencies brought to light by this casualty, which I quote below:

> "Many flag states do not require sail training vessels to have guidance information, such as squall curves, that indicates safe stability margins in various environmental conditions.
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> Flag states do not require officers to be knowledgeable in the use of stability guidance information, such as squall curves."

With matching recommendations to the Canadian government:

> "-The Department of Transport ensure those officers to whom it issues sailing vessel endorsements are trained to use the stability guidance information that it requires to be on board sailing vessels.
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> -The Department of Transport undertake initiatives leading to the adoption of international standards for sail training vessels on the provision of stability guidance to assist officers in assessing the risk of a knockdown and capsize, and for the training of officers in the use of this information."

SECTION I: Summary of Captain's Response

"If tall ship safety is to evolve constructively and rationally, the link between casualty and policy must be faithful to the facts."[1]

While my testimony is of course part of the TSB record, interested parties will want to hear directly from me, as the captain of the *Concordia*. I was responsible for the training and instruction of the officers and crew, the preparation of the vessel to meet emergency situations and the minute-to-minute conduct of the voyage.

This paper is a specific response to the findings, conclusions and omissions of M10F0003, and is best read with a copy of said Report at hand. It is organized into five sections: an initial summary, a discussion of the specific omissions and errors of the Report, a point by point address of the Report's conclusions, a section outlining the safety deficiencies I've identified along with my safety recommendations and an appendix containing supplemental information. In this response, I assume readers are familiar with the chronological narrative of the events leading up to and through the knockdown, abandon ship and rescue and are referred to the "Captain's Report" which I prepared in March 2010. Both the Captain's Report and M10F003 provide similar narratives of the events.

This response is based on written and oral testimony provided to me by members of the crew, faculty and students of the *Concordia* soon after the accident and in the interim since. It relies on the work, statements and comments made by meteorologists and naval architects, none of whom were paid by me or in my behalf to so comment. It focuses primarily on events with which I have direct experience either shipboard, in the rafts or during the rescue. I am solely responsible for the accuracy of my statements and for the interpretations and conclusions I draw. Interested parties may contact me at captbcurry@gmail.com.

The TSB Report has erroneously discounted the central role of the most likely cause of the knockdown: a microburst squall. Because of this, the Report does not accurately identify the proper context of the accident, has not identified the primary risks to the safety of sail training vessels brought to light by this casualty and hence does not recommend follow-up action comprehensive enough to assist stakeholders to fully benefit from the lessons to be learned.

Summary of Additional Safety Concerns

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[1] Capt. Dan Parrott, Tall Ships Down

I fully endorse the goals articulated in the Canada Transportation Safety Board Report of promoting stability information and related training for sailing vessel operators. However, this accident was not due primarily to insufficient stability training; rather it was the coincidence of two central factors: a partially open ship encountering the damaging effects of a microburst's vertical winds. I find that this accident has highlighted several urgent and important safety deficiencies that have not been identified by the TSB Report and yet are applicable to the vast majority of sail training vessels afloat. In order of priority they are:

A) The nature and presentation of extraordinary weather events at sea such as microbursts and downbursts are poorly understood by many mariners because very little information on such events exists. Such events can and do occur and may be more common than supposed.

B) The effect of wind heeling arms developed by inclined winds on sailing vessels' righting arms has not been seriously investigated. The effect may be such that even vessels with the highest stability standards can be easily overwhelmed by winds with strong vertical components.

C) The current design of some sail training vessels may draw a poor balance between providing for ventilation and deck access with a vessel's ability to better withstand sudden knockdown and subsequent down flooding.

D) Up-to-date instrumentation to assist masters and watch officers to monitor and assess their stability picture is not readily available. Graphical solutions that do not recognize the effect of inclined wind vectors may be limited in this respect.

Summary of Omissions and Errors of the TSB Report

Specifically, the TSB Report:

1. Has misinterpreted the indicators that the *Concordia* most likely encountered a microburst in its early contact phase and has failed to provide the public with the key meteorological analyses.
2. Has produced misleading wind speed/heel calculations based on assumptions not representative of the *Concordia's* rig, sail trim, and point of sail during the occurrence.
3. Does not adequately or completely describe the mechanics of the knockdown.
4. Fails to emphasize the hazard that vertically inclined winds typical of stage of microbursts pose to the stability of sailing vessels.
5. Does not address crew actions in the context of this weather phenomenon: specifically the difficulty deck officers experience when assessing wind strength in some types of squalls, including microbursts and downbursts.
6. Miscategorises crew actions and decisions as resulting primarily from a lack of stability knowledge rather than from a lack of awareness of microburst indicators.
7. Has not stressed the risks inherent in the vulnerability of many sail training vessels to loss of deckhouse-enabled stability following knockdown from unexpected or unrecognized dangers.

And, finally:

8. Has missed the opportunity to recommend important follow-up safety action such as:
    a. Research of microbursts and downbursts and related weather events at sea.
    b. Research into the effect of inclined winds emanating from such squalls on sailing vessels.
    c. Review of design standards to protect vessels against sudden post-knockdown loss of buoyancy and stability.
    d. Adoption of modernized stability related instrumentation and information for large sailing vessels.

As Canada Transportation Safety Board Marine Investigation Report M10F0003 demonstrates, those qualified to investigate sailing vessel casualties for the benefit of the public would benefit themselves from a comprehensive understanding of the operation of such vessels. In order to have this understanding, however, researchers and board members must first be provided with the pertinent information and then must be competent in its interpretation and application. In the absence of such knowledge, the public may be misinformed.

SECTION II: Omissions and Errors of the TSB Report

Point 1) Meteorological Analysis: *Concordia* Most Likely Encountered a Microburst

The description of the weather event likely experienced by the *Concordia* is a microburst of moderate power encountered in its early contact stage. Independent professional meteorologists associated with both the National Oceanic and Atmospheric Administration [2] and Environment Canada[3] have studied satellite imagery as well as the testimony of the crew and have come to this conclusion.

Analysis of satellite imagery by NOAA meteorologist Ken Pryor of the United States, a recognized expert currently conducting research of microbursts, has shown that conditions at the place and time of the knockdown were conducive to microburst formation. These included appropriate conditions for evaporation cooling, negative buoyancy generation, and subsequent acceleration of storm downdrafts, the driving factors for such small scale downbursts.[4]

The TSB Report apparently relies on an Environment Canada (EC) analysis of the weather conditions at the knockdown site. The EC and Pryor analyses share common assessments of the driving factors for microbursts directly over the *Concordia*. However, this key EC analysis is not listed as one of the "available reports" offered on page 36 of the Report. The TSB Report selectively quotes the EC analysis and a critical conclusion of the EC analysis was not included in M10F0003:

> "Although the occurrence of a strong microburst can neither be confirmed nor denied by this meteorological analysis (due to a lack of information), a weaker downburst occurrence is much more likely in this case because the intensity of the convection was weaker than many other cases have shown, when strong microbursts were evident." And "Downburst winds with speeds from the west to southwest in excess of 80km/hr following the initial gust front passage likely did occur between the hours of 1709 UTC and 1739 UTC on February 17 in the location where the *Concordia* capsized."[5]

As proven in the TSB Report, and as will be discussed elsewhere in this response, winds in excess of 80km/hr winds with a strong downward component would have been capable of knocking the *Concordia* down (to an angle of approximately 90 degrees) while 80 km/hr horizontal winds would not.

Regarding wind speeds and microbursts, the TSB Report, Section 2.1.3, says:

> "…the wind speeds attained during the occurrence were lower than those typically required for classification as a microburst, which, for terrestrial events, is in the range of 50 to 150

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[2] (see Soundings article at http://www.soundingsonline.com/news/coastwise/255772-expert-a-microburst-sank-*Concordia*)

[3] Brazil Coast Incident 17 February 2010 1722Z Meteorological Analysis, NSOD MSC-NCR/Environment Canada

[4] MICROBURST APPLICATIONS OF BRIGHTNESS TEMPERATURE DIFFERENCE BETWEEN GOES IMAGER CHANNELS 3 AND 4 Kenneth L. Pryor Center for Satellite Applications and Research (NOAA/NESDIS) Camp Springs, MD

[5] From the analysis prepared by Environment Canada

> knots. The maximum wind speed during the occurrence is unlikely to have been in excess of 50 knots.
> The precise intensity of the downburst experienced during the occurrence is difficult to quantify due to the lack of Doppler radar imagery. However, another tool that is used to establish wind speeds in a downburst is the post-hoc analysis of the damage patterns caused by the winds in the area of the suspected downburst. In this occurrence, the only available evidence of damage was the vessel's knockdown and 2 sails torn."

From this, one can surmise that the TSB has defined a microburst as having a minimum wind speed of 50 knots. However, experts indicate that the majority of events described as being microbursts have wind speeds less than 50 knots, with the range of wind speeds starting at 20 knots. According to Mr. Pryor (in private email correspondence with the author regarding the TSB Report):

> "The report uses a threshold for microburst occurrence as a measured wind speed of 50 knots. This is not consistent with published literature that sets the minimum peak wind speed for microburst occurrence at 10 m/s (~20 knots). Ted Fujita and Roger Wakimoto (microburst experts), in their analysis of microbursts during the Joint Airport Weather Studies (JAWS) project, used the 20-knot threshold for microburst occurrence.
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> In my study of downbursts that occurred over the Mid-Atlantic coastal region during the summers of 2010 and 2011, only 9 out of 44 (~20%) events were associated with peak winds greater than 50 knots. I have found that the majority of measured downburst wind speeds were between 35 and 49 knots with an average speed of 46 knots, well below the 50 knot threshold. In U.S. coastal waters, convective storm winds of 34 knots or greater meet the threshold for a 'Special Marine Warning'. Thus, the TSB's use of the 50-knot threshold excludes the majority of downburst/microburst events that could be documented."

Regarding the Report's post-hoc analysis of damage patterns it must be remembered that the *Concordia* was built to withstand not only extremely high winds but the much more damaging effects of boarding seas. One would not expect to find the coach roofs blown off by wind. The blown out topsail and rent mizzen are telling signs of significant winds. Both of these sails had been inspected, reinforced and overstitched just months prior by professionals in a respected Lunenburg sail loft. While the sails were not new I would never-the-less have placed damaging sustained wind speeds for the topsail at 50 to 60 knots and over 60 for the deep reefed mizzen. Gusts and bursts of lower wind speeds are well known to blow out sails. However, despite the confusion offered by the TSB Report ("…the investigation was unable to determine if the sail damage was caused by the wind or the knockdown…" page 40) the damage was most probably caused by the wind as the starboard side (damaged side) of the upper topsail and the luff of the deep reefed mizzen were both out of the water throughout the knockdown.

The actual peak wind speed experienced briefly during the knockdown cannot be definitively stated, as there were no reliable measurements made or recorded during the event. The limitation of the cup-style anemometer to record vertical winds is a one significant source of error.

To those aboard, the sensible clues to the nature of the wind event included the sudden burst-like action of the wind, the arrival of the squall in relatively high ceiling, benign-appearing conditions,[6] the absence of early wind indicators on the surface of the sea and the very quick passing of the squall. (I include microbursts, macrobursts, downbursts and significant down drafts etc. within the broader term squall. However, when rain patches occur without significant increases of wind, I would label such events rain showers.)

In this case, we have the crew observing both weather and vessel kinetics which support the microburst/downburst explanation, we have the research of professional microburst experts and meteorologists also supporting the possibility, we have, perhaps for the first time, satellite gathered data over the oceanic knockdown site of a major sail training vessel and we have the Canada TSB Stability Report itself proving that only vertically inclined winds could have resulted in the type of knockdown observed.

Inexplicably and contradictorily the TSB Report states that "There is no evidence that a microburst occurred." and, "The precise intensity of the downburst experienced during the occurrence is difficult to quantify…" The Report seems to agree that a wind event sharing the highly specific and unique characteristics and dynamics common to both microbursts and downbursts (and thus sharing common dangers) regardless of how either are defined, did indeed occur. In order to remove confusion about the terms as used in this paper, I consider microburst and downburst synonymous expressions for the same type of event since the fluid dynamics, if not the scale, are essentially the same.

On page 18 of the Report the TSB provides a graphical illustration of a typical thunderstorm cell instead of a microburst/downburst cell. There was no testimony provided to the TSB by eyewitnesses that anything looking like this illustration occurred. It is misleading to include un-related illustrations in the context of the TSB Report.

This obfuscation in an investigative report of such scope is unfortunate. The legalistically phrased denial and the semantic avoidance of the term "microburst" may protect the TSB from future criticism on this point, or it may not. Never-the-less, the TSB Report should have included the possibility of a microburst, using that specific term, in its discussion. Further, the TSB Report should have urged the experts—the mariners, meteorologists, naval architects, administrators and safety managers, from both the private and government sectors—to conduct further research into this very real and critical safety hazard.

Point 2) TSB Calculated Wind Speeds Not Representative of *Concordia's* Condition

Concerning the wind speeds calculated throughout the Report, former crew of the *Concordia* will have a hard time reconciling the minimum wind speeds proposed by the TSB with the associated events. We know, for instance, that far more than 25 knots of wind would have been needed to

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[6] WW2010 University of Illinois. The scariest looking squalls and storms get all the air time, but what we are discussing here is a microburst in its early stage coming out of an apparently non-threatening environment. Photos of microbursts in this stage are rare. http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/svr/comp/out/micro/home.rxml

knock the ship down configured as she was.   The TSB has let calculations based on questionable assumptions lead it to inaccurate statements.

One such assumption is found in the values (1.00 and 2.00) selected as representative of the occurrence for the sail heel force coefficients (Cs) used to produce Table 3: "Apparent wind speed versus wind heel angle." When questioned, TSB researchers offered no rationale for assuming the value Cs=2. The source material suggests this value is not applicable.[7]

The TSB Report cites research conducted by Barry Deakin[8] as its source for the sail heeling force coefficients used to calculate the wind force required to heel the *Concordia* to various angles. As a close inspection of Mr. Deakin's work will demonstrate however the actual coefficient value for this situation—that is for a barkentine under short sail with fore and aft sails sheeted out, square sails braced up one or two points and the wind broad on the quarter--would have been closer to 1 than 2.[9]   Mr. Deakin reports finding wind heeling arm coefficients (sail heel force coefficients) of as low as 0.86 for a barque under short sail to 1.42 for a fore and aft schooner, both values for vessels close hauled with the wind on the beam.[10] (He further notes that the coefficient is extremely variable, even for a given vessel and difficult to calculate or estimate.)

However, Cs values varying from 0.85 to 1.15 are undoubtedly more representative of the *Concordia's* condition during the knockdown. Readers need to appreciate that the range of wind values quoted in the TSB Report are based on hypothetical Cs values and that the lower wind speeds thus calculated are not logically representative of this case.

Point 3: Downflooding and the Mechanics of the Knockdown

The TSB Report states that the horizontal wind speeds experienced by the vessel at the time of the knockdown were most likely in the range of 25 to 50 knots.[11] It is important to note however that (horizontal) wind speeds of even 50 to 60 knots could not have been responsible for the full knockdown. According to the Report a 50 knot wind could produce a heel of around 70 degrees. Further, on page 15 of the Stability Report the TSB states:

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[7] (From a standpoint of looking at a hypothetical worst case scenario, the Cs=2 coefficient has value even for square riggers, for instance when wanting a conservative estimate of the wind it would take to knock you down if you were lying becalmed with all your fore and aft sail set and sheeted tight to minimize rolling and you were struck by a squall on the beam.)

[8] Deakin, B., "Stability Regulation of Very Large Sailing Yachts", 10th International Conference on Stability of Ships and Ocean Vehicles, St. Petersburg, June 2009. See figure 8, page 176.

[9] B. Deakin private correspondence

[10] 1990 The Royal Institute of Naval Architects. *The Development of Stability Standards for UK Sailing Vessels*, by B. Deakin.

[11] TSB Report page 52, Other Findings.

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> "It can also be seen in Figure 4 that to induce wind heel angles beyond 70 degrees or so, the necessary apparent wind speeds increase significantly to the point where winds in excess of 100 knots would be required to knock the vessel down to an angle in the range of 90 degrees."

In its explanation of the cause of the knockdown the TSB Report does not satisfactorily account for the forces involved for the heel between 70 degrees and 90 degrees.

Given that100 knots of wind did not occur, what did knock the *Concordia* down to her beam ends? Please go to Figure 8, page 38 of the TSB Report, referring to "25 to 50 knot" winds:

> "As Figure 8 indicates, although the vessel would theoretically take up a steady heel angle of almost 70° in such winds, water would have begun entering at various critical points before that angle was reached—first, via the open doors in the forward deckhouse (56.5°), then shortly thereafter via the sanitary exhaust vent, which was just aft of that (65°). With all of the doors on the port or lee side, as well as the ventilators and engine room skylight in the open position at the time of the knockdown, there was nothing to prevent or mitigate the downflooding that followed, progressing until the vessel ultimately lost all stability, rolled over, and capsized."

This paragraph is a description of the mechanics of the knockdown, yet there are a number of critical problems here. The essential problem is that this explanation does not take into account the suddenness of the knockdown, which, between the angles of 23 degrees and 90 plus degrees happened in less than 10 seconds. During these 10 seconds, significant down flooding *to the hull* is unlikely to have occurred because of the limited cross sectional areas and depths of immersion of the ventilation ducting leading into the hull. TSB researchers have confirmed they did not calculate the rate of the downflooding cited in their analysis. The shapes of the occurrence righting and heeling arm curves presented in figure 8 of the Report take into account the complete loss of buoyancy of the two deckhouses at the angles their respective doors to the weather deck went under.[12]

According to figure 8, the vessel should have heeled to 70 degrees and steadied. But she did not steady at 70 degrees; she was pushed onto her beam ends in one quick motion. The TSB analysis in order to get beyond the 70 degree knockdown point, to in effect erase the residual bump in the righting arm curve, says water would then have "begun entering at various critical points" with resultant loss of stability. However the graph has *already* factored in the loss of buoyancy of the deckhouses, therefore it has already accounted for flooding through doors, windows and vents into the deckhouses. The primary conduits for downflooding to the hull, i.e. the companionways, did not immerse until much later. The engine room skylight would not have gone under until about 110 degrees, according to the Report's calculations, so no effect from it, yet. What's left are the port side off-center vents leading below into the hull (sanitary, etc.) Given enough time after the knockdown,

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[12] Page 8 TSB Stability Report. "Note that the effect of water entering the deckhouses via the open doors (for details of these, see section on downflooding points below) was modeled by eliminating the buoyancy contribution of the relevant space at angles beyond that which immersed their door – the forward deckhouse was neglected after about 58 degrees and the aft deckhouse after about 88 degrees - thereby reducing the righting arms beyond those angles."

these immersed vents did lead to downflooding of the hull, settling the vessel gradually and eventually immersing the companionways. Over a period of nearly 18 minutes or more, *Concordia* lay on her side settling, gradually inclining but without capsizing (with this term I refer to the arc from 90 to 180 degrees) until the final few seconds.

The ship passed through the critical 20 degrees from the "theoretical steady angle of heel" of 70 degrees to her beam ends in, literally, several seconds. Downflooding to the hull through suddenly immersed ventilation ducting could not have erased that residual rise of the righting arm curve during a period of 5-7 seconds; rather, vertically inclined winds suddenly overcame it.

Given that: a) the full knockdown happened in less than 15 seconds, b) 100 knot winds were not experienced, and c) the residual rise of the occurrence righting arm curve was not erased by downflooding to the hull in a few seconds, it follows that *only* vertically inclined winds could have knocked the *Concordia* down to her beam ends.

The TSB Report hedges and uses an ambiguous statement "...while there was *probably* a vertical component to the wind..." (italics are mine) as if reluctant to address this conclusion.

Point 4) Vertically Inclined Winds and Stability

Because of the extraordinary vulnerability of most sailing vessels to full 90 degree knockdowns from inclined or vertical winds, this subject should have been given more attention and emphasis than the brief recognition found in the final TSB Report. In fact, vertically inclined winds were not considered at all in the initial draft of the report, an oversight I protested at the time.

The principle is intuitively simple. When your vessel heels to a horizontal wind, the more you heel the less your sails are exposed. Equilibrium may be reached. If it is reached before you heel to the angle at which your righting arm curve steeply declines, you may have time to fall off, let fly sheets, cast off halyards, start the engine, etc. If it is reached toward the bottom of that curve, you will have difficulty doing any of the above due to the great angle of heel. If major downflooding thresholds have not been reached, you will have some time to attempt them and some large vessels have recovered from deep knockdowns.[13] But if, as you lay over to the first of the squall, the wind inclines toward the vertical, your vessel will be losing righting arm quickly even as heeling arm increases. You will, most likely, wind up on your beam ends.

On pages 16 and 17 the TSB Stability Report includes two paragraphs and one graph (Figure 6) regarding wind heeling arm curves and inclined winds based on arguments I forwarded to the TSB in response to its draft report. Compare this minimal discussion with several pages devoted to an assessment of the existing stability training regulations worldwide. And yet, this graph represents one of the two most important points to come out of this casualty*: inclined winds have a disastrous effect on the stability of sailing vessels.*

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[13] *Windeward Bound*, ATSB TRANSPORT SAFETY INVESTIGATION REPORT Marine Occurrence Investigation No. 204

I recommend that all tall ship operators engage a naval architect to look at the effect of vertically inclined winds on their vessel's stability picture. It is easily and inexpensively done. The revelations will be shocking.

Points 5) Crew Actions in Microburst Context

The productive way to investigate this accident is to study the reactions of the crew and vessel within the context of a range of most probable weather occurrences. The TSB Report does not do this. Unless this omission is corrected, the sail training fleet finds itself today in the same position the airline industry was in decades ago, as illustrated by the following excerpt from Air Line Pilot Magazine[14]:

> "Too many windshear accidents have been analyzed wih (sic) emphasis on pilot error without attempting to understand why the errors were made. In most cases, the analyses were flawed, and no substantial pilot error existed. This has caused considerable misunderstanding of serious aspects of windshear hazards that still exist in pilot training literature. These misunderstandings pose human factor problems for pilots when they have to deal with windshear. Many pilots have been trained to avoid large supercell-type thunderstorms in the belief that this will prevent encounters with microbursts. Yet no evidence exists that any of the known microburst encounters have occurred in supercell storms. Dr. Ted Fujita and Dr. Fernando Caracena recognized authorities in this field~ have repeatedly emphasized that microbursts are frequently generated from benign-appearing cells. Many "experts" who disagree with Drs. Fujita and Caracena have emphasized the supercell storms with warnings of dangers of gust fronts. These so-called experts are leading pilots down the primrose path for microburst encounters."

Disturbing reports of atypical squalls have been provided by mariners for centuries. The media and Hollywood have piled on to exploit people's fears and to create myths surrounding and obscuring the real life phenomena. The white squall and the Devil's Triangle are examples. Mariners who report what they believe to have been a downburst are often ridiculed or worse.

Subsequent to the release of their report, Canada Transportation Safety Board members issued public statements that, besides being inaccurate, are both sarcastic ("Many of you will have heard that *Concordia* was overcome by a vicious microburst associated with a tropical storm.") and belittling ("Certainly the conditions were no worse than those this vessel must have encountered many times before during its 20-year history.") The implication behind these statements is clear.

Equally disturbing are both the lack of nuanced understanding shown by board members of the pertinent weather phenomena being discussed here and the dampening effect such public

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[14] "Windshear Revisited" by Capt. William W. Melvin (from Air Line Pilot Magazine, Nov. 1994, excerpted from SAE Paper 901995)

comments could have on the willingness of sailors to candidly report on and surmise about the weather they have experienced, particularly if that weather should include a microburst.

Lack of timely action by the crew and a paucity of stability knowledge are cited by the TSB Report as having directly contributed to the knockdown, capsize and sinking of the *Concordia*. It goes without saying that if different decisions had been made, a different outcome might have been experienced. Unfortunately, the TSB Report has failed to thoroughly examine the nature of the weather event that contributed to crew perceptions of the level of risk the vessel was facing.

Point 6) Role of Stability Knowledge

According to the TSB Report, a lack of stability training was the central cause of this accident and stability training for officers is one of only two safety recommendations issued by M10F0003. I think that stability training keyed to the challenges of tall ship sailing is certainly critical for all licensed officers and I agree fully with the TSB Report that most flag states do not adequately examine candidates for license in this subject matter. Sail training will be safer for everyone involved if the Report's training recommendation is adopted internationally.

However, the TSB Report, by placing too much emphasis on the role of stability training and misrepresenting the role played by the weather, has not produced a balanced analysis of the human factors involved. The Report states on page 54 and 55:

> "The squall curves contained in the *Concordia's* stability booklet indicated that the vessel would be safe in wind speeds approximately twice those experienced in the hour leading up to the occurrence. Although a squall was approaching, the 2/O, who was not aware of this guidance, did not change the sail plan or heading despite the fact that squalls are unpredictable and could involve wind speeds several times greater than those being experienced. Had the squall curves been consulted and acted upon by either the master or the 2/O, the sail plan would likely have been reduced and the heading changed significantly, thereby reducing the risk of a knockdown."

This statement demonstrates that the TSB has not properly interpreted the circumstances of the case.

Firstly, the rain being tracked by the mate was judged to be associated with no significant increase in wind, as wind signs were mostly absent. This was clearly not to be the case, but the point that needs to be made is that it is extremely difficult to detect wind if it is still only a potential within the weather system. Had signs of wind been evident, if the approaching rain had been judged to be a squall, if the mate was in any doubt about the situation , he was required to call me as per the standing orders and I am confident he would have done so.

Secondly, why then does the TSB expect the mate to have unilaterally taken additional squall tactics after consulting the squall curves? The squall curves are a guide indicating what wind speeds one's vessel might withstand. They cannot tell you what wind speeds may actually be approaching. Instead, they advise the master of his/her current condition and imprecisely quantify what additional wind speed would lead to downflood angles of heel. This was all the architect of the squall curves intended for the tables. It would be highly unrealistic to expect that sail reductions would be made on the observation that the wind speed in squalls can be up to 10 times the speeds being experienced, just in case. Masters must have weather cues to act on and this is the central point: if those cues are either not detected or misinterpreted no amount of stability knowledge will avail.

Thirdly, the *Concordia's* position on the squall curves indicated that the ship had been prudently shortened down for wind speeds up to around 45 knots. Therefore, had I been on deck to do so, or had the mate been trained to do so, consulting the squall curves during the hour before the event would not have led to either changing course--the vessel was already broad reaching--or reducing sail--sail had already been reduced to a conservative level based on my reasonable judgement of wind speeds likely to be encountered.

On page 65 of the Report, the TSB provides a copy of *Concordia's* squall curves with two points plotted: the mate's estimation of heel angle and wind speeds during the hour before the event and immediately before the knockdown. The TSB did not include a plot based on the testimony I provided for the period one hour before the event, which placed us squarely on the 45 knot squall line. Using either the mate's observations or my own, the squall curves indicated the *Concordia* was being managed for 40 to 45 knot squalls: my estimation of possible peak wind speeds.

Nor can anyone be expected to retire to a chart room to plot estimated positions on the squall curve table while dealing with a sudden and unexpected increase in wind and its demand on heads-up attention to the situation developing on deck

The TSB Report repeatedly suggests that the 2nd mate's unfamiliarity with the squall curves was the deciding factor leading to the knockdown, but this is simply not accurate for this instance.

Point 7) Vulnerability of Sailing Vessels to Loss of Deckhouse-enabled Stability

I applaud the work the TSB Report has done regarding weathertight integrity. The lessons regarding this are critical for sail trainers to consider while assessing their own vulnerabilities. However, this consequential subject should have been highlighted and the Report should have included specific weathertight integrity safety recommendations.

Like many other sailing vessels engaged in passenger and sail training activities, the *Concordia* had large deckhouses. To some eyes, large superstructures detract from the visual appearance, but in many cases the enclosed areas above the main deck provide for essential aspects of the ship's mission, such as mess halls, classrooms, pilothouses and laboratories. Superstructures also change the stability picture for any given hull, raising the center of gravity but also generally acting to extend the vessel's range of stability. Barry Deakin points out that deckhouses are routinely included in stability calculations as watertight spaces:

> "To obtain such large ranges of stability, watertight integrity is assumed at all angles of heel. Some of the very large yachts have substantial superstructures and, if they are of

> adequate strength and watertight integrity, their inclusion in the stability calculations is acceptable."[15]

The TSB Report exhibits graphs comparing the righting arm curve of the *Concordia* in her open and closed conditions[16]. Although the occurrence righting arm curve may not be accurately drawn at very large angles of heel[17] these are never-the-less very telling graphs. The *Concordia's* range of intact stability was greatly extended courtesy of her superstructures. But because she was in an open condition and the deckhouses partially flooded her full range of stability was denied her. The results are incontrovertible: a powerful righting arm, accepted in the design stability calculations, was not available and once on her side she could not recover. Subsequent downflooding of the hull through primarily the ventilation system caused the *Concordia* to lose buoyancy and settle. Once the vessel had settled—more or less still at an inclination of 100 degrees or so—to the point where the level of the sea reached the companionways that led below into the hull, downflooding accelerated.

Many existing sail training vessels will recognize their vulnerability to loss of deckhouse buoyancy. Every master of a sailing vessel that has deckhouses that have been included in the stability calculations should pull out their stability booklets and have a look at the consequences of losing deckhouse buoyancy in the event of a deep knockdown. If you don't have a stability booklet that includes such a graph, and you probably do not, insist that your naval architects and vessel owners provide one ASAP. Then you must decide what you are going to do about your situation: I'd suggest firstly you try to manage it aboard by reviewing your weathertight door policies and secondly you enlist the aid of naval architects and your fund raisers and you make the modifications needed to fully protect that deckhouse.

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[15] STABILITY REGULATION OF VERY LARGE SAILING YACHTS
Barry Deakin, Wolfson Unit MTIA, University of Southampton b.deakin@soton.ac.uk

[16] TSB Stability Report, page 9, figure 2

[17] See Appendix B

SECTION III: Response to TSB Report Conclusions

Interpreting Causal and Contributing Factors

The TSB Report (pages 51and 52) lists six contributing factors citing crew actions and an additional 13 findings regarding risk. My interpretation differs in some significant respects; I will try to present the facts clearly where these differences occur and will address the TSB's findings individually and specifically.

On some important points, I concur with the findings of M10F0003**; most importantly, had the watertight integrity of the deckhouses not been lost the vessel's chance of recovery would have been significantly improved.**

My direct response to conclusions drawn by the TSB, in the order presented in their Report, may be the best way of organizing this section:

TSB: *When the master handed over the watch to the second officer, he did not provide instructions that would have allowed the 2/O to react to changing weather conditions appropriately and maintain the stability of the vessel.*

I am of course fully responsible for the success or failure of any and all communications between me and my crew. I consider standing orders to be an important part of my guidance for watch officers along with verbal instructions during the day and written night orders in the evening.

Standing Orders: Prior to our departure from Recife I reviewed my standing orders that had been in place for our earlier trans-Atlantic leg from Lunenburg, Canada to Dublin, Ireland. After consulting with the mates, I edited the orders with the goals of updating them for our current route and making them as succinct and clear as possible. As part of my crew orientation at Recife, the 1st and 2nd mates and I met to discuss the standing orders to ensure understanding. The standing orders covered watch keeping instructions (as per SOLAS), navigational orders, sail handling and vessel handling procedures, weather parameters, and safety issues with guidelines on when I should be called. The standing orders required the mates to call me any time they thought it prudent to strike or douse sail but the orders also explicitly authorized them to do so without waiting for my presence on deck. This was to guard against occasions when I might be difficult to locate (in the shower, engine room, bosun's locker, etc.) Conversely, the officers could only set sail after consulting with me. During this pre-voyage meeting, I drew the mates' attentions to the Stability Information Booklet (SIB). During the voyage, the SIB was kept on the bridge with other instructional documents such as the standing orders and the night order book.

The standing orders included requirements that I be called for any significant deterioration of the weather including squalls, if wind speeds increased to 25 knots or higher or in any situation that caused the watch officer to be concerned about the safety of the vessel. The orders did not require that I be called for all rain unless it looked threatening or included signs of wind. My standing orders have always been custom prepared for the specific vessel, route, season, crew, mission and other factors. This last provision regarding rain was specific to our route between Brazil and Uruguay, as this section of the coast sees a frequent sweep of rain showers.

The safest way to handle a squall is before it reaches the ship. The intention of my standing orders was to get me on deck early enough to have time to assess and react to heightened risk conditions.

Watch Orders: Two hours before the knockdown, during the hand-over of the watch, I briefed the 2nd mate on our situation and went over the plan for the afternoon. The 2nd mate, as always, was focused fully on his upcoming watch and asked pertinent questions. The rationale for our sail plan was discussed. In response to the 2nd mate's questions about what sails might be struck next and in mind of my plan for the evening, I explained that the mainsail might be reefed, but that to do so would take time and careful work. Therefore I instructed him to bear away should he be caught in an unexpected gust or squall, as this would be the quickest move to increase safety and the sail plan had been prepared to facilitate such an emergency manoeuvre.

None of my change-of-watch instructions superseded the requirement that I be called for any significant change in the weather, including squalls or for any situation that appeared threatening. The final admonition of the orders was "If in any doubt, call me."

In this case the 2nd mate did not consider the change in conditions to be significant enough to call me and did not perceive the 20-plus degree heel as threatening. Likewise the 25 knot limit had not been reached. As the TSB Report suggests, additional explicit instructions might have been useful. If they do not already do so, masters should include a maximum angle of heel well below the stability booklet's "maximum safe angle of heel" (which for the Concordia was 24 degrees) as a trigger to be called.

TSB: *Despite the changes in the wind conditions in the 60 to 75 minutes preceding the occurrence and the fact that several squalls were being tracked, both visually and on the radar, the 2/O did not perceive any threat to the vessel.*

During the hour before the occurrence there *were* no significant changes in the wind conditions (see pages 69-70 TSB Report.) In the 10 or 15 minutes prior to the knockdown, the mate noticed rain cells on the radar, and tracked them as per standing orders. Since the rain cells he was observing included no signs of increased wind, the 2/0 did not consider them threatening. Rain showers from moderate convection cells are common in the tropics and we had experienced isolated rain showers with very little associated wind for several days. The nature of the developing squall, a microburst in its early contact stage forming from benign-looking clouds and producing no noticeable wind print, hid the severity of the situation from the 2nd officer. He had not been trained to recognize a developing microburst because no such training is available and in fact very little information exists about what smaller, but still catastrophic, microbursts/downbursts look like in the marine environment.

This is a critical safety deficiency affecting the broader sail training community as many vessels may be vulnerable to microbursts and downbursts. Research into the nature and presentation of severe and sudden downdraft cells in the marine environment, such as microbursts and downbursts, and follow-up training would greatly serve mariners. While most sailing ship crews will be adept at detecting squalls due to their typical cloud formations and signs of wind, microbursts are less common and dissipate more rapidly, hence are encountered infrequently.

TSB: *As the apparent wind speed increased with the onset of the squall, the vessel's heel angle reached roughly 23 degrees for approximately 2 to 3 minutes without mitigating action being taken.*

Although there was very little time to react, the 2/O should have called me immediately as per standing orders because he was, albeit suddenly and unexpectedly, involved with a significant change in the weather. However, it is doubtful this would have made much difference; as soon as I felt the vessel heel and without waiting for a call I got up and started collecting my gear to go on deck. The event unfolded so quickly that I was not even out of my cabin before she came to rest on her beam ends. Once the vessel started experiencing the outflow winds associated with the still descending core of vertical winds and heeled to 23 degrees, the 2nd mate had little time to react.

Consider the choices and probable outcomes in this case. A microburst with crippling vertically inclined winds was shortly to strike the vessel. Although the video clearly shows the vessel was already well off the wind, as these winds inclined, the horizontal wind angle would become less relevant. With the wind well abaft the beam, the mainsail would not have struck easily; scandalizing would have been the only option. The topsail sheets could have been cast off. However, had the bosun's day watch (suiting up in the mess) been called out on deck they would have been exposed to falling overboard during the coming knockdown.

Without the typical visual cues associated with most squalls the 2nd officer would have had little warning that descending air would shortly strike the vessel. It must be borne in mind that significant squall preparations were already in place: the mate knew the vessel had been shortened down for winds to 40 knots and that he was steering off the wind with sails trimmed for a breeze on the quarter.

The single most effective mitigating action any watch officer can take is to call the master early. In this case because early cues to the nature of the event suggested little wind, by the time the wind was experienced it was already too late.

TSB: In response to a further, modest increase in wind speed, probably including a vertical component, the vessel began to heel beyond 23 degrees. At this point, the action taken to steer downwind was too late to prevent the vessel from heeling to angles sufficient to immerse the lee-side doors and ventilators.

As shown elsewhere in this response, only a vertically inclined wind of the approximate force experienced could have knocked the *Concordia* down to her beam ends. The greater the inclination of the wind, the less effective any steering would have been as it is apparent that a vertical wind will affect a vessel on any heading the same: there is no longer a "down" wind direction in which to turn. (The TSB Report alleges the auto pilot was set to limit helm to 5 degrees of rudder angle, but neither I nor the mates re-adjusted the auto pilot during this leg and the auto pilot had been adjusted to aggressively steer in down wind conditions. I believe the auto pilot limit setting was somewhere between 10 and 15 degrees.)

TSB: The forward and aft deckhouses had not been fully secured weathertight and, therefore, the vessel's righting ability at large angles was reduced and protection against the ingress of water was compromised. As a result, downflooding progressed until the vessel lost all stability and capsized.

In my opinion, this is the single most important subject to be discussed relating to the loss of the vessel. Again, context will help the mariner assess the choices made so I will go to some detail.

Before turning over the watch to the 2/O I considered our state of closure. We were sailing in easy conditions with a 1.5 meter sea under a greatly reduced sail plan. The frontal system was not due for 10-15 hours. The air temperature was over 80 degrees F. The sky was mostly clear with no sign of the system developing to our south. There were no thunder cells and no rain cells at the time. We were in what I judged to be a low risk level environment for downflooding and I expected that level to persist over the next few hours. I intended to be back on deck within two or three hours to reassess our condition before making preparations for the night.

Classes were being held in both the aft classroom and the mess hall forward. The bosun's deck watch was mustering for their afternoon watch. All hatches (lazarette, mizzen house emergency exit, mess hall emergency exit and bosun's locker) were closed; of these only the bosun's locker would be routinely opened as crew went in and out throughout the afternoon. Ventilation ports, located along the upper edges of both deckhouses, were open and active as were engine room vents for generator aspiration and engine space ventilation. The engine room skylight/vent was open about one inch on the port side. The windows in the aft classroom were closed (this room was air conditioned); some in the forward mess hall were open.

Most significantly, the port side weather deck doors to the forward deckhouse were open, as was the port side door to the pilothouse. In good weather while in the tropics, the doors to the forward deckhouse were usually kept open throughout the afternoons to facilitate the transit of students, faculty and crew coming and going from classes, deck maintenance duties, navigation watches and free time on deck. The door to the galley provided important ventilation in hot weather.

The process I adopted for preparing for heavy weather was staged:

1. First, the ship's complement was advised as soon as the high seas forecast indicated upcoming events. This allowed everyone, cook, engineers, mates, bosun, and faculty to consider preparations in their departments and to secure equipment.
2. Next, sail reductions were carried out well in advance of the onset of the threat.

3. Then lifelines would be broken out and rigged; these could take up to an hour to set up, depending on how hard the bosun needed to push the work.
4. Finally, the commonly used weather deck closures would be addressed.

There were three basic door closure modes aboard: open, during which free passage was allowed, closed except for use, and closed, during which no use of the weather deck doors was allowed except under the direction of a deck officer. In these later cases, which usually only occurred in heavy weather (approximately 30 plus knots and seas 4m or higher) or in rough weather at night, students and watch groups traversed fore and aft through the vessel on the level of the accommodation deck. In such conditions students might be barred from the deck entirely and a team of faculty and crew would be assembled to handle sail.

The responsibility for ordering weathertight doors to be secured lies squarely with the master. On my ships, mates and other crew members were permitted to secure such openings at any time without first finding me, but my standing orders would require that I be called immediately as this would indicate that the weather had changed or the mate had detected a heighten threat level.

On recent voyages I have subsequently imposed the policy that all lee side weather-deck doors are to be closed and not opened any time the vessel is underway under sail. However, this policy does not always work well for the traffic or work patterns necessary to the mission of some vessels (educational, research, etc.) and even a highly motivated captain will face very good arguments for why some doors need to be open or at least in use during fine weather. The danger to personnel when handling these doors in a seaway is a factor. When threat levels are clearly elevated everyone is eager to cooperate but if such doors are kept closed or off limits in benign-appearing low-threat environments use conflicts can occur.

The best development regarding this critical question would be if new vessels were built with the conflict designed out (and existing vessels were reconfigured to minimize the conflict.) There are arrangements of deckhouse doors and interior vestibules that allow both unrestricted deck access and enhanced protection of deckhouse buoyancy.[18]

TSB: Concordia's shore-based management did not provide direction on the need for squall tactics and stability booklet familiarization, which would have provided an additional defence against a knockdown and capsize.

I think it rather farfetched to suggest that Concordians were not familiar with squall tactics and that such basic seamanship would have to be provided by shore-based management. This statement reflects the TSB's lack of contextual awareness in this occurrence, in that it seems to suggest that if only the office had told the captain about squalls...However, familiarization with squall tactics and advice offered by the stability booklet are subjects every master should thoroughly cover with the mates and it would be prudent for shore-based management to so direct.

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[18] See appendix

TSB: In the absence of guidance information that addresses a sailing vessel's stability in terms of the sail plan and environmental conditions under which it is operating, officers may lack key information with which to assess the corresponding risk to safety.

Firstly, let's see how this statement bears up for the master. Context and background will help.

Being fully conversant with the guidance provided by the *Concordia's* Stability Information Booklet as well as knowing the capabilities of the vessel through experience, I took early and substantial action to assess and manage our risk. During my forenoon watch (0800-1200 on the 17th) rather than add sail area for the day as would have been typical for the conditions, I decided to prepare early for stronger winds for the following reasons:

1) Although the front was ostensibly many hours away, forecasts over oceanic regions can be several hours in error.
2) We were only in the second week of our cruise and many of our students were new to the vessel; sail handling orders needed time for execution. During the relatively calm morning with an easy motion to the ship, students could safely lay aloft to furl the square sails we would not need. Reefing the mizzen and mainsails was a somewhat time-consuming and laborious job requiring that students and crew climb onto the mizzen deckhouse and main catwalk where they were exposed to falling. By personally directing the reefing of the mizzen, (which had been struck rather than reefed at 0400 that morning) I could show both the crew and the students how I wanted this done.
3) I would be officially off watch from 1200 to 2000. While I would be immediately accessible, the 2nd and 1st officers would have the watches during this period. Shortening sail as a weather tactic during my watch would increase the margin of safety during their watches.

The sail plan I chose for the afternoon was based on several principles:

1) It should have enough area to drive the vessel with good steerage way throughout the afternoon in moderate breezes.
2) It should be sufficiently reduced so that it could safely handle forecasted conditions as well as any surprises. I reduced sail to what our stability book designated "short" sail, about 43% of our total sail area. With this reduction of sail and our resultant average heel angle, we were located safely on the squall curves for winds of up to approximately 45 knots.
3) We were sailing large (off the wind) and were expected to be doing so until the front passed so the plan needed to balance the vessel well for downwind work. This meant that the center of effort needed to be kept well forward so the vessel steered easily, i.e. to avoid excessive weather helm. The topsails were selected because they could be quickly clewed up and temporarily left in their gear, while the course was more dangerous to douse and required immediate furling.
4) The plan, with its center of effort forward, was designed to assist the vessel to run off quickly should this need arise.

5) The plan needed to facilitate the next steps to be taken before dark, the most complicated of which would have been reefing the mainsail. For this reason, I elected to deep reef the mizzen rather than douse it entirely so that it would be available to provide balance and at least some drive if and when the mainsail was struck and either reefed or stowed.

I would expect sailing vessel captains and crews to recognize the thought process described above, for they will have employed similar logic many times. I would categorize the actions I've described as prudent, timely and conservative while dealing with the "*vessel's stability in terms of the sail plan and environmental conditions under which it is operating.*"

However, the TSB Report does not seem to make the connection between this planning and pre-execution and later events. Non-mariner researchers are not expected to appreciate the full context of events and actions aboard a square rigger but this is never-the-less a straight forward connection.

Secondly, regarding the 2/O, guidance concerning the vessel's condition was provided by me through specific instructions during the change of the watch. The issue here is not one of stability knowledge but of the difficulty of assessing the wind strength in microbursts during their formative pre-contact stage.

TSB: In the absence of training, sailing vessel masters and officers may not be able to interpret and make effective use of the critical guidance information provided by stability booklets.

The TSB places great emphasis on stability guidance in the form of Curves of Maximum Steady Heel Angle to Prevent Downflooding in Gusts and Squalls (squall curves) first introduced by Barry Deakin in 1990. However, it is unclear that the TSB is aware of their limitations. As indicated, the *Concordia's* Stability Information Book included a squall curve table and the table remains one of the most effective guides I've found. But because the TSB Report specifically faults the crew regarding their level of knowledge of the curves, I would like to make a number of observations:

1.) As Mr. Deakin points out, squall curves cannot tell a master or mate what wind speed will be encountered in any given squall (wind gusts are more reliably predicted). Hence a plot on the table must be further interpreted by the master's forecast of probable peak wind speeds in hypothetical wind events that may still be over the horizon.
2.) The squall curves are based entirely on the effect of horizontal winds. A plot on the squall curves based on horizontal inputs will tell you nothing about your exposure to the less favorable effects of inclined or vertical winds on your heeling angle.
3.) The squall curves are intended to be a tool used by the master to set up his or her vessel for future anticipated conditions, using averaged inputs of heel angle and apparent wind speed, not as a tool to be used by a watch officer conning a vessel through an unexpected squall. As in many other situations where additional help is needed for navigation, radar plotting, communications and steering, a watch officer must call the master to assume the con so that such heads-down work can be safely attended.

The Canada TSB Report hinges around the role that stability knowledge and training played in this casualty, implying in several statements that a lack of same on my part and on the part of the 2nd officer led directly to the knockdown:

> *"As this occurrence demonstrates, those qualified to be a master or officer of a sailing vessel would benefit from a comprehensive understanding of the stability characteristics of their vessel and its limits with respect to combinations of apparent wind speed and heel angle." And "Even in cases where this guidance information has been provided it may not be fully understood."*

Neither of these statements is demonstrated by this occurrence. In fact:

1) I have had college level education in the stability characteristics of vessels and as a professional mariner have continued over the past 40 years to study sailing vessel design and stability.
2) I had previously studied the *Concordia* Stability Information Book (SIB) and I was fully conversant with the specific guidance presented regarding wind speed/heel angle constraints and downflood angles.
3) The "guidance for the master"[19] in the SIB is clearly written and is easy to understand. It is, in fact, basic, well-understood seamanship the precepts of which are constantly employed by the vast majority of captains around the world, whether or not they have a stability booklet to articulate such general principles.
4) Aboard the *Concordia* I routinely used the squall curves to help me quantify our level of protection for wind speeds I judged we would encounter.
5) As plotted for us by the TSB (see Appendix F of the TSB Report), up until the last minute or two prior to her knockdown, *Concordia's* position on the squall curves indicated she was being prudently and conservatively managed for expected wind conditions.
6) Despite the TSB Report's assertion that squall curves are "complex to interpret" quite the opposite is the case: anyone who can plot a fix on a chart and tell you where you are could easily use the squall curves.

TSB: The complement of a sailing vessel is placed at increased risk when emergency preparedness and response to knockdown scenarios are not given specific consideration.

This statement does not apply to the *Concordia* as both emergency preparedness and responses to knockdown scenarios were given specific consideration, as the facts of the case demonstrate. The *Concordia* enjoyed the benefits of a strong safety culture. In several important ways, the constant drilling and emphasis on safety helped prepare the ship's complement for their difficult evacuation and abandonment. I clearly understood that the potential of a knockdown was real, if remote, and

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[19] Section 1.19, page 22 of M10F0003

my crew and I (as well as previous masters and mates) made specific provisions for such an event in our safety preparations:

1) Lifejackets were located on deck in lockers with hydrostatically released lids.
2) Supplemental emergency water was stowed in the on-deck safety equipment lockers.
3) Liferafts were positioned both fore and aft and on either side of the vessel to ensure the survival of several rafts should a section of the vessel be underwater or otherwise unavailable.
4) Evacuation arrows and signs were plentifully located throughout the accommodations to direct evacuees to the deck during difficult situations.
5) The emergency lighting system was regularly inspected and operationally tested.
6) Emergency flares, medical equipment, line throwing apparatus, SARTs and communications equipment was stowed in the bridge. (One of the lessons of this accident is that such equipment should be evenly divided and stowed to survive a knockdown to either side.)
7) During abandon ship drills, the automatic function of the liferafts and lifejacket boxes was explained as a safety preparation for sudden knockdown, collision or sinking.
8) Students were drilled and practiced in the techniques of donning lifejackets and immersion suits.
9) All professional crewmembers were trained in STCW mandated abandon ship procedures including the launching, deployment and use of liferafts and their equipment.

If the TSB statement also refers to knockdown drills, this is certainly a recommendation masters should consider adopting. It would be useful for crews to imagine their vessel on its beam ends and to then step by step walk through all the ramifications.

TSB: In the absence of requirements for effective safety management systems, there is an increased possibility that individuals at all levels of an organization may not have the appropriate knowledge and tools to effectively manage risk or the necessary information to make sound decisions in any operating condition.

In this case, risk management was alive and well within the culture of the organization and the ship. However, the extensive documentation of shipboard safety equipment inspections, drills, safety procedures, etc. that was kept aboard the vessel was not formulated into a formal, shore-administered safety management system. This would be a productive step for all ships and organizations.

TSB: The wind speeds experienced by the vessel at the time of the knockdown were most likely in the range of 25 to 50 knots. While there was probably a vertical component to the wind, there is no evidence that a microburst occurred at the time of the knockdown.

This statement contains several inaccuracies with which I hope I have dealt: wind speed calculations used throughout the report are in error due to assumptions not representative of the *Concordia*'s condition; only a wind with a strong vertical component could have knocked the *Concordia* down, and; there is ample evidence that a microburst, encountered in its early contact stage was the responsible wind event.

TSB: Some large sailing vessels may have a combination of sail plan and stability characteristics that can make them vulnerable to wind speeds below 30 knots.

This statement is borrowed from Barry Deakin's research already extensively cited in this paper. I do not believe the TSB's work has demonstrated this to be the case for the *Concordia*, unless vertically inclined winds are specified. However, this statement, in light of potential encounters with microbursts, should get the attention of all ship owners and operators.

It may also be the case that some large sailing vessels, especially if under full sail in an arrival condition, could be vulnerable to knockdown in 30 knots of wind, especially in worst case scenarios where a vessel may be fully canvassed, trimmed for closehauled and struck by a squall on the beam.

The statement correctly draws attention to the circumstance where the slopes of the GZ curve and a wind heeling arm curve closely match: in such a situation, as pointed out by the TSB Report and as applicable to the *Concordia*, such a vessel may reach a point where a very small increase in apparent wind speed will result in a dramatic increase in heeling. However, the TSB Report's wind speed calculations are not representative of her occurrence condition and so give a misleading picture of her occurrence stability.

In the case of the *Concordia*, vertically inclined winds were required to get past the residual increase in GZ even considering her flooded deckhouses.

SECTION IV: Safety Deficiencies and Recommendations

Deficiency: The nature and presentation of extraordinary weather events at sea such as microbursts and downbursts are poorly understood by many mariners because very little information on such events exists. Such events can and do occur and may be more common than supposed.

Recommendation: Sail training associations and other trade groups should provide funding to pursue the study of microbursts/downbursts in the marine environment. Mariners have surely been bedevilled by the phenomenon of microbursts for hundreds of years. Because the events are relatively rare however, the risks have been considered acceptable. Now, with only yachts and sail training vessels on the firing line, there is little economic rationale for studying them, unlike the situation ashore where the protection of the commercial airline industry has brought the funding needed to improve safety. Perhaps the sail training world can piggy-back on some of the research underway to protect airports, as certainly many coastal airports share territory with coastal sail trainers.

Some questions for meteorologists:

> -Are there specific regions and seasons where coastal and oceanic microbursts occur? If so, can maps be prepared that delineate regions and the relative frequency of such events? (One parallel example is seasonal ice limit products.)
>
> *Response by Ken Pryor: "This research is currently in progress. In the process of validation the GOES sounder and imager microburst products, downburst events have been documented over the U.S. Atlantic coast region. Validation has also commenced over the eastern Caribbean Sea region. This effort entails comparing product output with surface downburst wind measurements by weather data buoys and coastal weather observing tower-mounted stations (i.e. C-MAN, PORTS). Radar reflectivity data is also employed to verify downburst occurrence."*
>
> -Can satellite images alone provide reliable indications of potential microburst zones? If so, it should be possible to create forecasting methodologies for oceanic regions. Perhaps forecasts of microburst conditions could become a feature of coastal and oceanic weather reports. While this would not provide hard and fast information for individual boats, at least regions prone to risk might be identified in a timely manner.[20]
>
> -Can observers be trained to detect by eye the early warning signs of impending microbursts? Well formed systems packing all the signs of wind and danger are easy to detect whether such systems include downbursts or not. It is the subtle storm that has the greatest chance of penetrating a ship's defences.

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[20] NOAA experimental product is available at http://www.star.nesdis.noaa.gov/smcd/opdb/kpryor/mburst/mwpi.html

-Are there any indicators of wind that could be detected by X-band radar within precipitation cells? Are there patterns that are particular to microbursts?

Deficiency: The effect of wind heeling arms developed by inclined winds on sailing vessels' righting arms has not been seriously investigated. The effect may be such that even vessels with the highest stability standards can be overwhelmed by moderate winds with strong vertical components.

Recommendations: While the gross effects of inclined winds on a vessel's righting arm are intuitively understood, research into the extent of the problem is needed to fully identify the risks involved, especially for existing vessels. I would assume that wind tunnel research on models using microburst wind patterns would be required to thoroughly understand the dynamics.

Questions for naval architects:

-What point of sail and sail trim combinations are most susceptible to inclined winds?

-What sailing rigs are most vulnerable? Square riggers, fore-and-afters, multi-masted?

-What hull forms (and GZ curves) are better able to withstand inclined winds?

-What does a survey of existing sail training vessels' stability pictures reveal about current levels of safety?

-How might naval architects alter an existing vessel's configuration to improve survivability?

-What recommendations might be proposed for international design standards?

Deficiency: The current design of some sail training vessels may draw a poor balance between providing for ventilation and deck access with a vessel's ability to better withstand sudden knockdown and subsequent down flooding.

Recommendations: The practice of including the contribution of deckhouses to a vessel's compliance with stability regulations should be reviewed for special classes of vessels, such as sail training vessels, where deck access needs are often in conflict with the need to protect watertight integrity.

Questions for naval architects:

-Can deckhouses be designed to simultaneously provide both unrestricted access to the deck and complete protection against downflooding? (See Appendices C and D)

-Can ventilation requirements be met with centerline or automatically closing ventilator cowls or intakes?

-How might companionways below be protected from downflooding at all times?

-How might other water tight or subdivision provisions be re-thought to bridge the gap between regulatory assumption (doors will be closed in time because it's always easy to see disaster coming) and reality (threats unrecognized may not be guarded against in time.)

Deficiency: Up-to-date instrumentation to assist masters and watch officers to monitor and assess their stability picture is not readily available. Graphical solutions that do not recognize the effect of inclined wind vectors may be limited in this respect.

Recommendations: Develop a computerized version of Mr. Deakin's squall curves that provide a real time assessment of a vessel's vulnerability to future conditions based on constant input from wind and vessel motion sensors. Whether we traditionalists like it or not, the sail training bridge has become more digital and computerized. Just as having an electronic chart program aboard should not prevent navigators from pricking the chart, so more sophisticated weather and vessel attitude sensors and software should not impede the master or mate from staring over the rail just as hard as ever.

Questions for engineers/designers:

-Is it feasible to measure, smooth and present apparent, true and inclined wind angles and speeds?

-Is it feasible to measure vessel motion and attitude in a similar fashion?

-What are the difficulties in assembling existing components into a hardware/software package that can run on the ship's navigational computers?

- Is it possible to package this into units that sail training organizations can afford?

CONCLUSION

The phenomenon of microbursts at sea, a double-edged sword pairing elusive detection with the power of inclined winds, will continue to overwhelm well found ships and experienced crews. Besides improving the standards for stability training for officers, regulatory bodies should look closely at raising the accepted level of design standards for vessels in order to withstand loss of buoyancy and downflooding in the event of catastrophic knockdown, as it can be demonstrated that most sailing vessels that meet today's stability standards are never-the-less vulnerable to downbursts. The study of these damaging wind systems should be prioritized and methods of detection and avoidance developed for mariners. Instruments to display real time assessment of a sailing vessel's level of risk of knockdown based on omni-directional inputs of wind and heel would assist ship officers.

SECTION V: Appendices

Appendix A

Positive Survival Factors

It is also useful to note what contributed importantly and specifically in this casualty to the survival of all hands. Although there are many factors not mentioned here, some that stand out for me include:

1) The ship and program enjoyed a strong safety culture personally promoted and overseen by the owner.
2) *Concordia* was manned by experienced, licensed crewmembers who fully cooperated with and contributed to the shipboard safety and emergency protocols.
3) My crew and I had a clear understanding of the mission with regards to shipboard operations: sail the vessel conservatively to provide a safe environment for young, inexperienced students in an academic program at sea.
4) The vessel, her manning and her emergency equipment met or exceeded all regulatory requirements for her class.
5) The vessel and her equipment were well maintained with particular attention paid over many years by the ship's crews to the condition of the emergency equipment.
6) Officers were up to date and fully compliant with all internationally mandated (STCW and GMDSS) training, including training the in use of liferafts and associated safety equipment.
7) Evacuation and abandon ship drills were conducted regularly, with an emphasis on watch groups accounting for all their members. (Individuals were occasionally instructed not to show up for a muster to test and drive home this point.)
8) All hands regularly practiced distributing and donning lifejackets, immersion suits and safety equipment.
9) A ship's officer was designated Safety Officer and conducted and logged regular safety equipment inspections, maintenance and service as per the shipboard safety plan.
10) Lifejackets were located in on-deck, float-free boxes and were readily at hand.
11) Immersion suits and abandon ship equipment and supplies were stowed in lockers on deck accessed from both sides of the vessel.
12) Evacuation routes from all spaces below deck were clearly and generously marked with directions, symbols and arrows.
13) Emergency lighting was regularly spaced and tested routinely.
14) Equipment and supplies throughout the accommodations were carefully stowed and secured and no major dislocations occurred.
15) During an evacuation conducted in terrifying conditions, crew, faculty and students put themselves at risk by delaying their own egress to assist others around them.
16) Many students, faculty and crew acted bravely and calmly and comforted and assisted each other.

17) While some individuals were visibly distressed, no panic of any kind occurred.
18) The highest priority was put on launching as many rafts as could be accessed and disembarking the complement in the shortest possible time.
19) The vessel carried liferafts for twice the number of persons on board, evenly distributed to port and starboard. This provision provided enough raft capacity for the complement even though three of the six 20-man rafts were not deployed.
20) The sides of the deckhouses functioned as horizontal platforms on which the complement donned immersion suits and lifejackets.
21) The cook and faculty members took an especially active role in assisting students to don safety equipment and board the rafts.
22) The bosun was instrumental in assisting with the deployment of lifejackets and liferafts and was responsible for recovering the EPIRB as it floated free from the sinking vessel.
23) The chief mate and second mates worked forcefully and quickly to get students and faculty into the rafts. This focus resulted in everyone being in a raft before the vessel sank.
24) The vessel floated for about 18 minutes, providing an important platform from which to board the rafts.
25) Emergency water supplies had been renewed by the cook in Recife, Brazil and were readily at hand to the rafts.
26) Although the ship's GMDSS suite was destroyed during the knockdown, the EPIRB was recovered and its automatic functions performed properly.
27) Despite the four intact rafts getting free of the vessel at different times, three of the four managed to reunite.
28) Only one member of the ship's complement, the medical officer, was injured. First aid training acquired both ashore and aboard allowed crew and students to attend the injured officer.
29) The advantages of being rafted together allowed survivors to be evacuated from the partially deflated raft, lessening the burden in that damaged raft.
30) The rescue vessels, *Hokuetsu Delight* and *Crystal Pioneer* were expertly handled by their masters to come alongside the drifting rafts.
31) The rescue vessel crews managed the raft evacuations well and no further injuries were sustained by the survivors.

Appendix B

Concordia's Aft Deckhouse and Her Occurrence Range of Stability

The TSB Report notes that the stability consequence of water downflooding into the hull of the vessel was not accounted for in computer modeling used to create the GZ curves, and such flooding would certainly have further reduced stability. The righting arm curve, as drawn in the Report, assumes that the buoyancy of the deckhouses was lost as their port side doors were immersed at around 58 degrees for the forward house and 88 for the after house.[21] This certainly occurred for the forward house.

However, there are strong reasons to believe the classroom section of the after deckhouse retained nearly full buoyancy until the last few seconds before the final capsize occurred:

1) According to the written and verbal testimony of the students and faculty who were in the classroom, the room did not flood after the knockdown. There is direct testimony from a reliable student who had been aboard for over 30,000 miles that he not only closed the windows himself, but noted that they withheld the water after the knockdown. This is consistent with my own observations as I was briefly in the reception area just forward of the classroom helping students through the classroom door and then out onto the deck. In contrast, all reports agree the forward deckhouse flooded immediately (albeit to a level below the lip of the companionway leading to the accommodation deck thus saving that means of escape.)

2) Unlike the situation in the forward deckhouse, in the after superstructure the port side door led from the deck into the pilothouse which was in turn separated from the classroom by an interior steel bulkhead fitted with a fire door. This door was located in the starboard side of the deckhouse, well to the starboard side of the centerline of the vessel. In effect, this bulkhead, although the door was opened to allow students to escape, acted as a dam; the sill of the door was well above the waterline as the vessel lay on her beam ends. The buoyancy of the classroom was thus protected by the geometry of the interior bulkheads.

3) The vessel lay on her beam ends, at an angle of around 100 degrees, for 18 minutes before capsizing. It is hard to see how she could have done this if her damaged righting arm curve was as drawn in the TSB Report. Instead, she was in equilibrium and must have had some minimal positive righting arm at angles greater than 100 degrees. This shift in the center of buoyancy could have come from the mostly intact classroom.

4) Prior to her final roll to port, the vessel trimmed down by the head, indicating that there was more buoyancy aft than forward. The final burst of air came out of the hull through the

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[21] Stability Report, page 8, figure 1

> watertight door from the reception room, just forward of the classroom. This door was the primary point of egress for people located in the after sections of the vessel and was closed (but not dogged) after escape from the classroom was affected to keep people from falling into the open doorway.

I believe it was the intact buoyancy of the classroom that held the vessel at the angle at which she came to rest after the knockdown. It was this protected buoyancy that prevented the ship from rolling over while she was slowly downflooding through her ventilation system.

Although I advocate for more, such minimal inviolable protection should be designed into every sail training vessel. If we did not have our precious 18 minutes in which to launch and board our rafts, our story may have ended differently.

Appendix C

Design Recommendations

The *Concordia* was a modern, purpose-designed sail training vessel with a proven record at sea. Over her nearly 20 years of operation she had logged several hundred thousand miles of sailing on all the major oceans of the world. At the time of her loss, she was fully current with all legal and statutory requirements of her owners, insurers, flag state and international authorities and had been maintained so since her commissioning. Under my direction, she had recently completed her annual safety inspection by a Lloyds approved, flag-state inspector (Barbados Maritime) in Lunenburg, Nova Scotia and was fully up to date and compliant with all safety regulations. [22] It should also be noted that, had the *Concordia* been inspected under Canadian rules and regulations for sail training vessels, that is under TP13313E "Standard Relating to Design, Construction and Operational Safety of Sail Training Vessels" she would have met, exceeded or provided equivalent protection to those standards.

Deckhouses

Deckhouses aboard sail training vessels should provide simultaneously for the fine-weather free passage of the ship's numerous crew with absolute protection of critical buoyancy. The geometry of the *Concordia*`s layout in her after deckhouse might point toward a simple solution for protecting deckhouses from accidental flooding.

Imagine a rectangular box-shaped deckhouse located fore and aft along the centerline and protecting a centerline companionway leading down into the hull. This deckhouse has only two doors to the main deck through the longitudinal house sides, one right forward, and one right aft but on opposite sides. Each door opens into a hallway, or transverse vestibule, protected with a watertight partial bulkhead which leads athwartship to the opposite side before opening to allow passage into the working center of the deckhouse. While these exterior doors would be typical weathertight doors, should they for any reason be open during a knockdown, the integrity of the deckhouse would not be lost. The partial bulkheads would act as dams or sills. Only the buoyant contribution of one of the hallways could be lost and the all important companionway below would be protected. (See Appendix C)

Evacuation from the deckhouse, if required, could be via the top side weathertight door or via a dedicated escape hatch through the weather side of the deckhouse. Due to the obvious dangers of having students on deck at extreme angles of heel, evacuation from the deckhouses might be delayed to give the vessel the time and opportunity to overcome the heeling forces should they abate as might be expected for wind and wave heeling forces.

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[22] With the exception that the phone number registered to the ship's EPIRB was subsequently shown to be incorrect.

In my recently acquired opinion, superstructures that are considered essential components of a vessel`s stability picture should not be capable of being compromised. This will not happen until designers come up with ways to simultaneously allow for the unencumbered passage of many people while maintaining strict watertight integrity. The *Concordia* met all applicable design standards for ocean-going vessels of her class but events conspired to cause the loss of her deckhouse integrity. I believe most captains and crews are diligent about closing weatherdeck doors when danger is perceived, but they will recognize that in ostensibly fine weather the doors may be open.

Although perhaps not as important a factor in the case of knockdowns, the watertight doors through transverse watertight bulkheads meant to provide compartmentalization are another issue the sail training community needs to review. Often the free flow of people along the accommodation deck results in these doors being open more often than closed. Few sail training vessels will be able to afford remotely controlled watertight doors.

Windows, Portholes and Ventilators

Windows and portholes in superstructures protecting critical buoyancy should be non-opening. Ventilation should be provided by other means. This is often a challenge for sailing vessels visiting the tropics, especially for vessels with a limited source of electrical power. Ventilator cowls should either be located on the centerline and designed to close automatically at extreme angles of heel or incorporate water-trap designs similar in concept to the above described deckhouse. One can imagine systems designed to shut down fans automatically via one inclinometer.

The more off-center openings there are aboard sailing vessels, the greater the chance that they cannot be accessed quickly to provide the needed watertight integrity after a knockdown. People will naturally flee a quickly flooding area or an area perceived to be flooding rather than risk being trapped below.

Skylights, Hatches, Companionways and Exit Routes

All hatches used for accommodation ingress or egress should ideally be protected by an un-floodable deckhouses. Hatches to working areas, such as areas forward of the collision bulkhead or to the lazarette, should be located on the centerline. Emergency-only escape hatches for the deckhouses could be located to either side. Skylights with opening panels or skylights fitted as emergency escape hatches should be self-closing at large angles of heel. However, such escape routes will only be effective if the vessel can be counted on to float with her centerline out of the water. Of course, all escape routes when opened may be vulnerable to boarding seas.

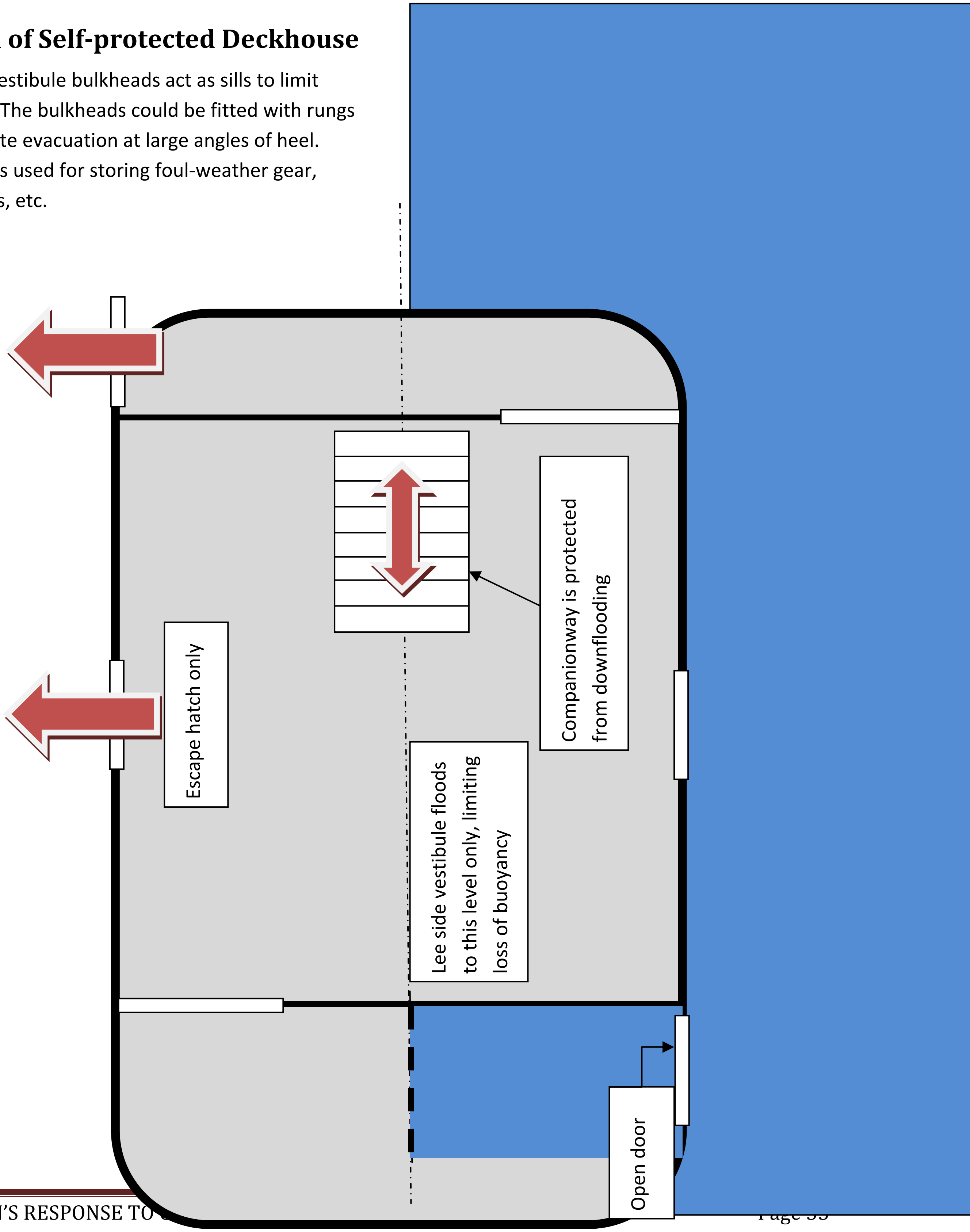
Companionways that lead below into the hull should be protected either by deckhouses that cannot be flooded, in the sense I've mentioned above, or should be on the centerline, or both. If you study the drawings of the *Concordia*, you will see that both of her companionways were offset to the starboard side of the centerline. Had the *Concordia* suffered a knockdown to starboard (assuming leeward doors open) these companionways would have necessarily flooded much sooner, and the vessel would not have had those precious 18 minutes. Obviously, flooding of a companionway will greatly impede the evacuation from down below.

Sail training vessels should be well signed below with exit signs, directional arrows along designated exit routes, signs denoting the companionways and signs noting the location of emergency and firefighting equipment. *Concordia's* signs proved very useful to people evacuating the accommodations deck. One student told me that she was completely lost after the vessel was knocked down, so she simply followed the directional arrows and the exit signs to the deck. The emergency lighting in the accommodations functioned as designed and provided the necessary light after the generators went dead.

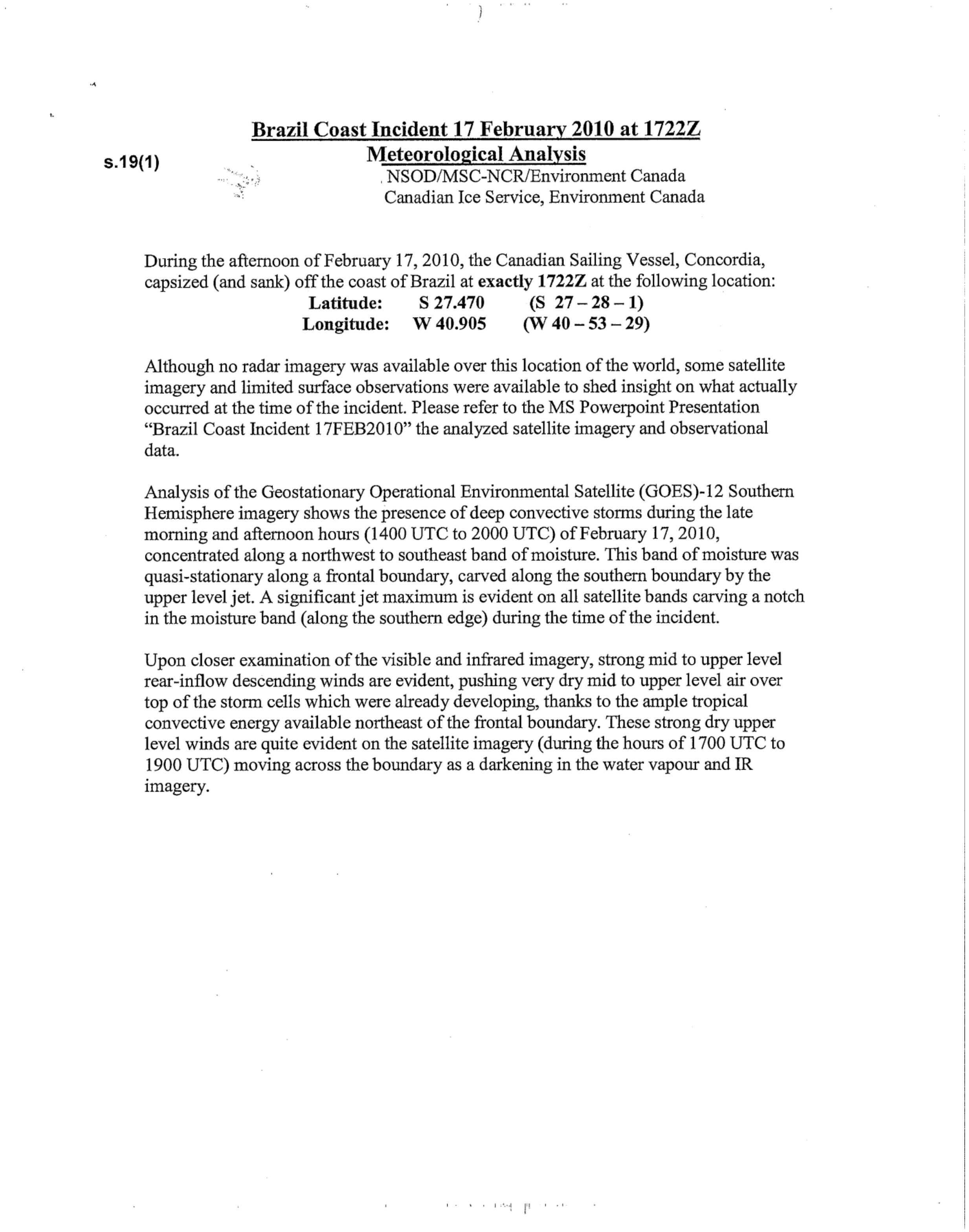
Appendix D

Sketch of Self-protected Deckhouse

Notes: Vestibule bulkheads act as sills to limit flooding. The bulkheads could be fitted with rungs to facilitate evacuation at large angles of heel. Vestibules used for storing foul-weather gear, harnesses, etc.



APPENDIX E: Environment Canada Weather Analysis



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Brazil Coast Incident 17 February 2010 at 1722Z

Meteorological Analysis

NSOD/MSC-NCR/Environment Canada
Canadian Ice Service, Environment Canada

During the afternoon of February 17, 2010, the Canadian Sailing Vessel, Concordia, capsized (and sank) off the coast of Brazil at **exactly 1722Z** at the following location:

Latitude:	**S 27.470**	**(S 27 – 28 – 1)**
Longitude:	**W 40.905**	**(W 40 – 53 – 29)**

Although no radar imagery was available over this location of the world, some satellite imagery and limited surface observations were available to shed insight on what actually occurred at the time of the incident. Please refer to the MS Powerpoint Presentation "Brazil Coast Incident 17FEB2010" the analyzed satellite imagery and observational data.

Analysis of the Geostationary Operational Environmental Satellite (GOES)-12 Southern Hemisphere imagery shows the presence of deep convective storms during the late morning and afternoon hours (1400 UTC to 2000 UTC) of February 17, 2010, concentrated along a northwest to southeast band of moisture. This band of moisture was quasi-stationary along a frontal boundary, carved along the southern boundary by the upper level jet. A significant jet maximum is evident on all satellite bands carving a notch in the moisture band (along the southern edge) during the time of the incident.

Upon closer examination of the visible and infrared imagery, strong mid to upper level rear-inflow descending winds are evident, pushing very dry mid to upper level air over top of the storm cells which were already developing, thanks to the ample tropical convective energy available northeast of the frontal boundary. These strong dry upper level winds are quite evident on the satellite imagery (during the hours of 1700 UTC to 1900 UTC) moving across the boundary as a darkening in the water vapour and IR imagery.

It is well understood that warm moist air is much lighter than colder drier air. When relatively colder drier air is pushed over top of very moist, convectively unstable air, any convection already occurring can become explosive with very strong updrafts. In response to these powerful updrafts, strong downdrafts will also develop (what goes up must come down). As the storm system matures and becomes more organized, the downdraft may become equally if not more intense than the updraft. Depending on the storm structure and longevity of the storm complex, strong downdrafts from the same convective complex may become more prevalent, and more likely.

All thunderstorms produce downdrafts of varying intensities, which may or may not reach the Earth's surface. Downdrafts develop as part of the life cycle of a thunderstorm but the strength of a downdraft is dependent on the structure of the thunderstorm, the intensity of the main updraft (what goes up must come down) and some other factors. A downburst is a strong downdraft which produces an outburst of damaging winds at or near the surface. Some severe thunderstorms produce very strong downbursts which cause severe wind shear, and rarely, some severe thunderstorms will produce downdrafts that are so localized and intense, they are classified as microbursts.

A microburst is a rare, localized, very intense downdraft that descends to the surface resulting in a strong divergent wind. As the powerful downdraft plunges towards the surface, it generates radially divergent outflow winds. These high-intensity outflow winds tend to be less than 4 km in horizontal extent but can cause severe wind shear over localized areas. In spite of its small horizontal scale, an intense microburst can generate damaging winds as high as 150 knots. Most microbursts are rather short-lived (2 – 5 minutes), but have been rarely known to last longer than 5 minutes. Microbursts can also be generated from benign-looking convective storm cells, if atmospheric conditions are conducive to supporting strong downdrafts.

In contrast, a macroburst is a large downburst, with its outburst winds extending over 4 km in horizontal extent, which normally develops from an organized thunderstorm complex. An intense macroburst often causes widespread, tornado-like damage. Damaging winds, lasting much longer than a microburst (5 to 30 minutes), can be as high as 120 knots.

Downdrafts are caused by factors such as the drag from heavy rain and hail (precipitation loading), and by the fact that falling precipitation evaporates and cools the air, making it heavier than its environment, therefore resulting in an accelerated descent . In order for further downdraft intensification, for downburst or microburst production, the presence of an additional forcing mechanism, such as an intrusion of drier, colder air at mid levels is usually required.

Conclusions

1. The meteorological conditions on February 17, 2010 from 1600 UTC to 2000 UTC were conducive to the development of strong convective storms over the area in question.
2. Satellite imagery from both the GOES satellite and MODIS imagery clearly show:
    a. A significant upper level jet maximum carving a notch in the moisture band (along the southern edge) during the time of the incident, which provided an intensification of the fluid dynamics required to increase the production of strong updrafts and downdrafts over the area in question.
    b. A band of strong convective storms which exhibited significant precipitation loading and strong updrafts (overshooting tops) over the area in question.
    c. A strong band of westerly dry mid level winds, just ahead of the upper level jet max, overspreading the convection which had previously developed thanks to pre-existing favourable convective initiation conditions.
    d. An obvious dry notch (especially on the IR and water vapour imagery) which indicates the possibility of a rear inflow jet (RIJ) pointing directly towards the Concordia at the exact time and location the vessel capsized. Other weaker dry notches were also evident northwest of the area in question.
    e. A fairly rapid decay of all of the storms over the area in question during the 1 hour period following the possible downbursts (as evident from the collapsing storm tops and strong mid to high level drying as the anvils were pushed rapidly northeastward).
3. Although the occurrence of a strong microburst can neither be confirmed nor denied from this meteorological analysis (due to a lack of information), a weaker downburst occurrence is much more likely in this case, because the intensity of the convection was weaker than many other cases have shown, when strong microbursts were evident.
4. Downburst winds with speeds from the west to southwest in excess of 80 km/h following the initial gust front passage likely did occur between the hours of 1709 UTC and 1739 UTC on February 17 in the location where the SV Concordia capsized.