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Investigation of a series of accidents involving yachts for diving vacations

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Abkürzungsverzeichnis

ADTO Association of Dive Tour Operators

AIS Automatic Identification System

BG Verkehr Berufsgenossenschaft Verkehrswirtschaft Post-Logistik Telekommunikation

BV Bureau Veritas

CDWS Chamber of Diving and Watersports

DNV Det Norske Veritas

EAMS Egyptian Authority for Maritime Safety

EMSA European Maritime Safety Agency

EU European Union

IMO International Maritime Organization

IATA International Air Transport Association

IOSA IATA Operational Safety Audit

IS-Code International Code on Intact Stability

ISM-Code International Safety Management Code

ISPS-Code International Ship and Port Facility Security Code

LAS-Code Lifsaving Appliences Code

MAIB Marine Accident Investigation Branch

NTSB National Transportation Safety Board

SCV-Code Code of Safety for Small Commercial Vessels operating in the Caribbean

SOLAS-Konvention Safety of Life at Sea Convention

STCW-Übereinkommen International Convention on Standards of Training, Certification and Watchkeeping for Seafarers

UN united Nations

USA United States of America

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1. Introduction

The paper analyzes accidents on yachts for diving vacations, as according to observations by German dive reporters, more serious accidents have occurred since 2022. These ships offer longer so-called diving safaris, where the guests live on board and go diving from the ship. The ship travels from one dive spot to the next.

For this analysis, the known accidents are first briefly described and a statistical evaluation of the accidents is carried out with regard to the distribution over time, the causes and consequences of the accidents, the number of victims and the locations of the accidents. The data collected in this way is then compared with data from the global shipping industry. Researched accidents from the years 2006 to 2023 (August) are taken into account. The regulations on the most common causes of accidents are then presented and compared with guidelines from local organizations such as the Egyptian Chamber of Diving and Watersports (CDWS). Inspections by local organizations are also described and analyzed.

Subsequently, the accident involving the „Conception“ is dealt with, as it claimed the most victims with 34 fatalities. The official marine casualty investigation report of the National Transportation Safety Board (NTSB) is used to describe the accident and the identified causes and recommendations are presented. In addition, the marine casualty of the „Carlton Queen“ on April 25, 2023, for which no official investigation report is available, is examined in more detail. When the „Carlton Queen“ capsized in the Red Sea, several people fell from the ship, but all were rescued. The ship capsized after several strong rolling movements and sank shortly afterwards. These accidents are also used to show how similar accidents can be avoided in the future. Finally, suggestions for changes in the supervision of ships during construction and later operation as well as in the training of crews are presented.

The data available on the accidents is imprecise, as official accident investigation reports such as those for the „Conception“ are only available for a few accidents. Instead, it was usually necessary to rely on statements from those affected and media reports. In some cases, there are video recordings of the accidents, which could also be used for support. In addition, the willingness of local authorities to cooperate in providing further information is often very limited, as they do not want these accidents to be publicly noticed. Every accident of this kind damages the local tourism industry. As it is not possible to access the actual ships or wrecks, this analysis can only be based on the above-mentioned sources. This lack of data also means that only serious accidents could be taken into account, as these were reported in the media.

In view of the high number of accidents, it is reasonable to assume that the existing regulations are not being adequately enforced. However, it is also possible that the regulations are not sufficient. Unfortunately, it is often the case that only a serious accident leads to changes and improvements in the regulations. The accidents considered in this analysis are presented in the following section.

2. Summary of accidents

First, basic information on the accidents found is summarized. 31 accidents from the years 2006 to 2023 (August) were taken into account for the analysis. In almost all incidents, the ship involved in the accident sank. This does not mean that the ship was not salvaged and resumed operations after repairs. It was not determined which liveaboard vessels were recovered after sinking. In order to understand which accidents were analyzed here, a short list of the ship names, the date of the accident, the reason for the sinking and the number of casualties follows. Unfortunately, there are no clear identification numbers for the ships involved in the accident, such as a International Maritime Organization (IMO) number or a Maritime Mobile Service Identity (MMSI). A IMO number must be assigned to all passenger ships if they are not smaller than 100 GT, with exceptions for leisure yachts, warships, wooden ships and other [1]. Liveaboard vessels are normally in the range below 50 GT and therefore do not need to be assigned a number. With a length between 30 and 45 m [2] + [3].

The earliest accident considered in the analysis occurred on September 20, 2006, when the „Dolce Vita“ hit the Shaab Sharm reef in the Red Sea at night and sank due to the subsequent water ingress. There were no significant injuries during the evacuation to another liveaboard vessel [4].

On September 30, 2008, the „Heaven Diamond“ sank after a fire on board. After the rescue, a woman was taken to hospital due to burn injuries [5].

Six months later, the „Choke Somboon“ sank on March 8, 2009 after capsizing due to wind and swell. Of the thirty people on board, seven died [6].

Later that year, the „Coral Princess“ sank in Egypt. After capsizing on November 19, 2009, two Spaniards went missing and were declared dead shortly afterwards [7].

Just under a month later, the „Emperor Fraser“ sank after being pushed onto a reef by a change in wind direction on December 16. All guests and crew were rescued without injury [8].

After several years without any accidents attracting media attention, the „Mandarin Siren“ sank on December 29, 2011 due to a fire on board. All those on board were rescued without serious injury [9].

A short time later, on June 07. 2012, the second ship of the Siren fleet sank. The „Oriental Siren“ was evacuated after taking on water without any injuries [10].

On April 16, 2013, the ship „Little Princess“ capsized in a storm, presumably due to a lack of stability. Everyone on board was rescued and evacuated from the storm area together with everyone on a nearby island [11, p. 3].

Less than a year later, a series of accidents rocked Thailand's diving tourism industry when three ships sank within two weeks. First, the „Aladdin“ sank on January 29, 2014 due to a water ingress of unknown origin [12, p. 3]. Three days later, the „Bunmee I“ sank due to a fire on board [13, p. 1f]. On February 9, 2014, the „MV Blue Star“ was the third to sink while burning down[13, p. 2]. There were no fatalities or serious injuries in any of the three accidents[12, p. 3] [13, S. 1f].

On July 28, 2014, a fire broke out in the engine room of the „Blue Melody“ but it was extinguished. Although the boat did not sink, the guests were evacuated to another ship. Three crew members were treated in hospital for smoke inhalation [14].

On September 12 of the same year, another fire broke out on board a liveaboard vessel in the port of Phuket. As the „Choke Somboon 15“ was not carrying any guests at the time, there was only one person on board. This person saved himself by jumping into the water [15].

In April of the following year, the „Wind Dancer“ ran aground on a reef on the Cocos

Islands. The leak was repaired overnight and the following day the ship sailed slowly to the next port. There were no casualties [16].

On August 03, 2015, strong winds pushed the „Palau Siren“ onto a reef. All occupants were evacuated without any injuries [17].

Another fire broke out in the galley of the „Overseas“ on May 13, 2017. All 32 people on board were evacuated and picked up by a fishing boat. No injuries were mentioned, however, according to the description, smoke poisoning is possible [18].

A few months later, the „Chok Thara 2“ sank in a storm on July 26, 2017. After the rescue of 11 people, 5 missing persons have still not been found [19].

Later that year, the „Fiji Siren“ sank on November 15 due to a leak in the engine room. Everyone on board was successfully brought ashore in the dinghies [20].

At the beginning of the next year, the „WAOW“ sank during a crossing without guests. After a fire broke out in the engine room, the attempts to extinguish it failed and the crew abandoned the ship without any casualties [21].

The „Majestic Explorer“ ran aground on May 31, 2019. The resulting leak caused the ship to capsize and sink. All those on board were evacuated with the help of the local navy without any injuries [22].

The deadliest fire in this list occurred on September 2, 2019 on the „Conception“. Almost everyone on board died in this fire. Of a total of 39 people, 34 died and another person was seriously injured. Only 3 crew members got off the ship unharmed. Due to the poor escape routes from the lower deck to the main deck, which were possibly unknown to the guests, this high number of fatalities occurred [23, p. vi + p. 19 and 74].

Just two months later, another person died in a fire on board the „Red Sea Aggressor I“. On November 1, a fire broke out in the saloon and only 30 of the 31 people on board were able to leave the ship [24].

Another year later, on April 19, 2022, an additional fire broke out. This time, the „Scuba Scene“ was affected and sank. All guests and crew members were evacuated [25].

Just one month later, on May 9, 2022, the „Socorro Vortex“ ran aground on the coast of Socorro Island in Mexico. All 14 guests and 11 crew members evacuated the ship and came ashore without injury [26].

On October 30, 2022, the „Seawolf Felo“ ran aground on a reef and sank due to the resulting water ingress. Again, there were only minor injuries [27].

In the spring of 2023, the „Carlton Queen“ capsized on 24 April. The ship began the journey heeling, which presumably led to the capsize due to a further loss of stability. The guests and crew abandoned the ship. There were only minor injuries [28]. This marked the beginning of a series of accidents in 2023.

Just five days after the „Carlton Queen“ the „Dream Keeper“ capsized in a squall on 30 April. Despite an intensive search, 4 missing persons were not found [29]. After a week, the missing persons were declared dead, but the search for them continued [30].

Next, the „Sea Flower“ ran aground on a reef in the fog on May 17. Everyone on board abandoned the ship after unsuccessful attempts were made to free it from the reef using the dinghies and their own power
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Shortly afterwards, the „Omneia Soul“ came into contact with a reef at night on May 29 after an anchor line broke. All passengers were evacuated to another ship. The ship did not sink [31].

A month later, on June 7, the „New Dream“ ran into a reef during the night and sank. The crew and guests were picked up by another nearby liveaboard ship [32].

Most recently, the „Hurricane“ burned down completely on June 11. Only 12 of the 15 guests were able to escape. Only 27 of the 30 people survived, and three British guests died [33]. The Marine Accident Investigation Branch (MAIB) has been informed about this accident and the British state has been registered as a state of special interest for the investigation by the Egyptian authorities.

For clarity, the characteristics are summarized again in table 1. These accidents are statistically analyzed in the following section.

name	date	possible reason	location	fatalities
Dolce Vita	20.09.2006	ground contact	Shaab Sharm, Egypt	0
Heaven Diamond	30.09.2008	fire	Hurghada, Egypt	0
Choke Somboon	08.03.2009	lack of stability	Patong Beach, Thailand	7
Coral Princess	19.11.2009	lack of stability	Naama Bay, Egypt	2
Emperor Fraser	13.12.2009	ground contact	SS Dunraven wreck, Egypt	0
Mandarin Siren	29.11.2011	fire	Raja Ampat, Indonesia	0
Oriental Siren	07.06.2012	leak	Layang Layang/ shallow reef	0
Little Princess	16.04.2013	lack of stability	Tachai Island, Thailand	0
Aladdin	29.01.2014	lack of stability	Tachai Island, Thailand	0
Bunmee I	01.02.2014	fire	Hin Daeng, Thailand	0
Blue Star	09.02.2014	fire	Nyaung Oo Phee Island, Myanmar	0
Blue Melody	28.07.2014	fire	Thistlegorm wreck, Egypt	0
Choke Somboon 15	12.09.2014	fire	Phuket, Thailand	0
Wind Dancer	29.04.2015	ground contact	Chatham Bay, Costa Rica	0
Palau Siren	03.08.2015	ground contact	Palau	0
Overseas	13.05.2017	fire	Hurghada, Egypt	0
Chok Thara 2	26.07.2017	lack of stability	Ko Kalok, Thailand	5
Fiji Siren	15.11.2017	leak	Namena, Fiji	0
WAOW	31.01.2018	fire	Cenderawasih Bay, Indonesien	0
Majestic Explorer	31.05.2019	ground contact	Santiago Island, Ecuador	0
Conception	02.09.2019	fire	Channel Island, Kalifornien	34
Red Sea Agressor I	01.11.2019	fire	Marsa Alam, Egypt	1
Scuba Scene	19.04.2022	fire	Hurghada, Egypt	0
Socorro Vortex	09.05.2022	ground contact	Socorro, Mexico	0
Seawolf Felo	30.10.2022	ground contact	Abu Nuhas, Egypt	0
Carlton Queen	25.04.2023	lack of stability	Abu Nuhas, Egypt	0
Dream Keeper	30.04.2023	lack of stability	Tubbataha-Riff, Philippines	4
Sea Flower	17.05.2023	ground contact	Red Sea, Egypt	0
Omneia Soul	29.05.2023	ground contact	Red Sea, Egypt	0
New Dream	07.06.2023	ground contact	Marsa Alam, Egypt	0
Hurricane	11.06.2023	fire	Marsa Alam, Egypt	3

Table 1: Overview of the accidents taken into account

On October 28, 2023, another ship was severely damaged in Egypt after the mooring lines broke in a thunderstorm. All persons on board the „Emperor Echo“ were able to leave the ship [34]. This accident is no longer included in the analysis as it occurred after the statistics were compiled. Nevertheless, it should be mentioned here.

3. Statistical analysis

Excel was used to analyze these 31 accidents. The aim was to identify the most dangerous causes in order to find out which regulations may be inadequate or insufficiently enforced.

This is only a small proportion of the actual accidents. Unfortunately, the countries' databases are only available in the respective national language, such as that of the Thai Marine Department[35], which was not found as the website was only partially translated, or is not public, as is the case with the Egyptian Authority for Maritime Safety [36]. Unfortunately, there has been no response to inquiries in this direction so far [37] [38]. Not publishing such reports is permitted for accidents that are not particularly serious. [39, Chapter 14.1]. Particularly serious accidents include all accidents in which the ship is lost, a person dies or the environment suffers serious damage [39, Chapter 2.22]. In the event of such serious accidents, the official accident investigation reports must be forwarded to the IMO. In general, the investigation of particularly serious marine casualties is mandatory for all member states of the IMO [39, Chapter 6]. However, the preparation of such reports can take some time, which is why no reports need to be available for accidents from later years. Due to these difficult circumstances in obtaining official information, a large number of accidents were probably not found. Therefore, the data that was found is not completely reliable.

Due to the fire of the „Conception“ the NTSB has conducted an analysis of small passenger ships sailing in the United States of America (USA). According to this analysis, liveaboard vessels account for 7.5% of accidents in this vehicle category in the USA (see table 2). Fatal accidents on liveaboard vessels for diving account for 9% of total casualties. It should be noted here that in the overall statistics, 24% of victims are not related to ship accidents and a full 47.8% of victims on diving vessels are not related to ship accidents [23, p. 84+85]. This means that these people did not die as a result of a ship accident, but as a result of another accident. For example, a large proportion of deaths on submersibles cannot be attributed to an accident involving the boat but to a diving accident. General statements about the danger on American submersibles were not made by the NTSB, as no breakdown of the number of vessels by type is possible due to missing figures. In addition to the missing figures, the data on small passenger vessels is incomplete and inconsistent [23, p. 86].

Table 5. Number of small passenger vessels by initial event type based on the NTSB classification's ten most common vessel types

NTSB Classification of Initial Event Types	General	Ferry	Excursion/Tour Vessel	Diving Vessel (Recreational)	Charter Fishing Vessel	Amphibious Vessel	Sailing Vessel	Crew Boat	Offshore Supply Vessel	Water Taxi	All others	Total	Percent
Hull/ Machinery/ Equipment Damage	3,593	710	421	65	157	291	85	92	266	92	266	5,837	67.0
Contact/ Grounding/ Stranding	1,204	16	157	20	39	21	70	76	40	29	108	1,900	21.8
Collision	202	20	26	4	8	2	4	19	16	16	11	328	3.8
Fire/ Explosion	108	10	14	1	6	1	4	10	4	2	12	172	2.0
Others[41]	109	7	8	4	3	0	1	9	8	2	10	161	1.8
Vessel Maneuver[42]	98	5	16	2	2	1	5	1	4	2	7	143	1.6
Flooding	88	7	10	1	7	4	3	4	4	1	8	137	1.6
Capsizing/ Listing	20	0	5	0	2	0	1	1	0	1	4	34	0.4
Total	5,422	985	657	97	224	320	173	212	141	145	426	8,712	100
Percent of Total	62.2	10.3	7.5	1.1	2.6	3.7	2	2.4	1.6	1.7	4.9	100	

Table 2: Number of small passenger ships by cause based on the 10 most common types [23, p. 86]

The statistical analysis for this work must be carried out in part with two different data sets, as the fire at „Conception" in 2019 represents an outlier in the data. This point causes deviations in the mean values and can therefore reduce the comparability of the results to other statistics with such a small data set. For this reason, a data set without this accident is used for some of the subsequent comparisons. However, the fire must be included in the statistics as it caused more fatalities than all other accidents combined and is therefore highly relevant. If the data set was used without this accident, this is indicated in the diagrams and calculations by a „NoCon".

Due to the small number of data points, which also differ greatly in the number of people, guests and victims, there are high standard deviations from the arithmetic means, which makes it difficult to draw clear conclusions.

If the number of crew members is missing in the available data, it is assumed to be at least 4 if this supplements the remaining data on persons on board. It is assumed that there is one person as helmsman and captain, one engineer, one dive guide and one person to look after the guests. If there are at least 20 guests, a second person to look after the guests is added to the assumption, which increases this to 5 crew members. This is only used in places where information on the number of guests or all persons is already available. In the following section, the accidents are analyzed by year.

3.1. Analysis by year

Accidents from 2006 to 2023 are divided into classes by year and the absolute frequencies are listed (Fig. 1). It quickly becomes apparent that most of the ships were involved in

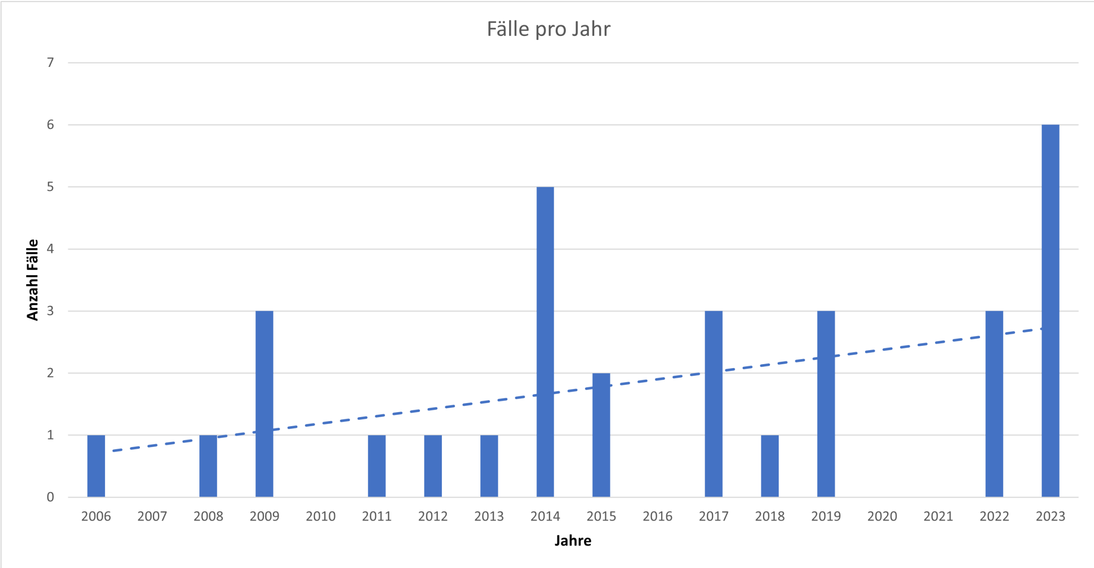

Figure 1: Cases per year

accidents in 2014 and 2023, which had not yet been completed by the time of the report. In 2014, there was probably no investigation of the overall picture, as no fatalities were reported and one of the ships only burned down in port. The gap in accidents in 2020 and 2021 can probably be attributed in part to the coronavirus pandemic, which has brought global tourism to a standstill [40]. Nevertheless, it is possible that in these years, as in 2007, 2010 and 2016, no accidents with media relevance occurred. However, despite the slump, an increase in accident frequency can be seen over the years.

To identify a clear trend, a regression line is determined[41, p.43]. This results in a linear equation of $y = 0.119x - 237.36$ for this data, which is shown in Fig. 1 is shown as a dashed line. This means that, on average, one more accident occurs every 8.4 years. However, this increase can also be explained by the fact that victims can now generate attention more easily through social media. Another way to explain the increase in recent years could be the lack of revenue in the years of the pandemic. These financial problems could have led to inadequacies in maintenance, training and management.

The annual accident frequency of 1.72 cases per year is above the expected value. The standard deviation is high at 1.78, as there is little data available and the data points in 2014 and 2023 therefore contribute extreme values to the statistics. The following section analyzes the accidents under consideration according to their type.

3.2. Analysis by category of accident

Accidents are categorized into four categories for evaluation purposes.
These causes are

- Fire: Fire has broken out on board (most frequently in the engine room)
- Lack of stability: Ship has insufficient stability and capsizes (in a storm or calm)
- Water ingress: Water ingress of unknown origin, but not due to grounding.
- Grounding: Grounding on a rock or reef, usually associated with water ingress.

The absolute and relative frequency is then determined for these categories (Table 3).

Cause	**amount of this type**	**% of all accidents**
Fire	12	38,7%
ground contact	10	32,3%
lack of stability	7	22,6%
leak	2	6,5%
total	**31**	

Table 3: amount by cause

Water ingress due to grounding probably occurs frequently, as these vessels operate very close to reefs and shallow waters, which are good places to dive. With ten accidents, this is the second most common cause. This represents a proportion of 32%. Fires could be explained by the additional equipment for diving, but the places where the fires break out are usually the engine room or the saloon, which argues against this thesis. This category is the most common cause with 12 accidents (39%). Lack of stability is another common reason for the sinking of liveaboard vessels. Ships are normally designed for wind pressures up to $504Pa$ [42, Chapter 3.2.2.2], which corresponds to a wind speed of 31 m/s [43]. However, it must not happen that a ship capsizes without strong winds or other clear reasons such as water ingress, even if this rarely occurs with 6% of accidents. In the case of water ingress without grounding, there are several possibilities, for example a hull weakness that gives way or waves that push water onto the deck and through leaking openings.

The consequences of accidents can be deduced quite simply from the causes. Only a few ships are not completely lost.

consequence	**amount by consequence**	**% of all accidents**
cancellation of tour	1	3,2%
burnt	11	35,5%
stuck on reef	1	3,2%
fire put out	1	3,2%
capsized	7	22,6%
sunk due to water ingress	10	32,3%
total	**31**	

Table 4: frequency by consequence

This shows that only 3 ships did not sink (table 4). The fire on „blue Melody“ was extinguished by the crew. The „Wind Dancer“ had to abandon the voyage after running aground and returned to the next port. In contrast, the „Sea Flower“ only did not sink because it was stuck on the reef against which it had run and was unable to free itself. Some of the ships were subsequently salvaged and repaired. For example, the „Omneia Soul“ is once again regularly taking guests on board [44]. After evaluating the causes and consequences for the vehicles, the next section is dedicated to the accident victims.

3.3. Analysis by the number of victims

In the arithmetic mean, 3.39 people are seriously injured or die on liveaboard vessels per year, but due to the „Conception“ as an outlier, a large standard deviation of 8.59 deaths and serious injuries per year is obtained here. This casts doubt on the significance of the mean value. For this reason, a mean value without the „Conception“ is also given for the comparison of the mean values. This results in 1.44 deaths and serious injuries with a standard deviation of 2.75 deaths and serious injuries per year. This value is also still high, but significantly lower in comparison. The mean value with the „Conception“ describes the current situation somewhat better, as this data set represents the actual data total. However, the value without „Conception“ is much more useful for predictions, but the standard deviation is also too high here for precise statements. For a more precise analysis of the reliability of the data, an analysis of variance with a t-test would have to be carried out, which would be too far-reaching for this work. For passenger ships in Europe, the mean number of deaths per year is 5.5, but this is not easily comparable due to the significantly larger number of passengers, which amounts to several hundred million per year [45].

The same applies to the evaluation of the number of fatalities and serious injuries per accident. This gives a mean of 1.97 fatalities and serious injuries per accident and a standard deviation of 6.37 fatalities and serious injuries per accident if the „Conception“ is included. If this accident is not taken into account, the mean value is 0.87 fatalities and serious injuries per year with a standard deviation of 1.78 fatalities and serious injuries per year.

When assessing the number of deaths as a percentage of the number of people on board, the „Conception“ gives an average value of 5.8% and a standard deviation of 16.8%. Here, too, only an uncertain statement can be made due to the high variance. Excluding the accident of „Conception“ the mean value is 3.1% and the standard deviation is 7.6%.

The assumption that a smaller crew in relation to the number of guests leads to more fatalities is made and subsequently verified. For this purpose, a ratio between the number of guests and the number of crew members on board is first established. This is then shown in Fig. 2 with the fatalities as a percentage of all persons on board. Only accidents for which the ratio between guests and crew is known are used for this purpose.

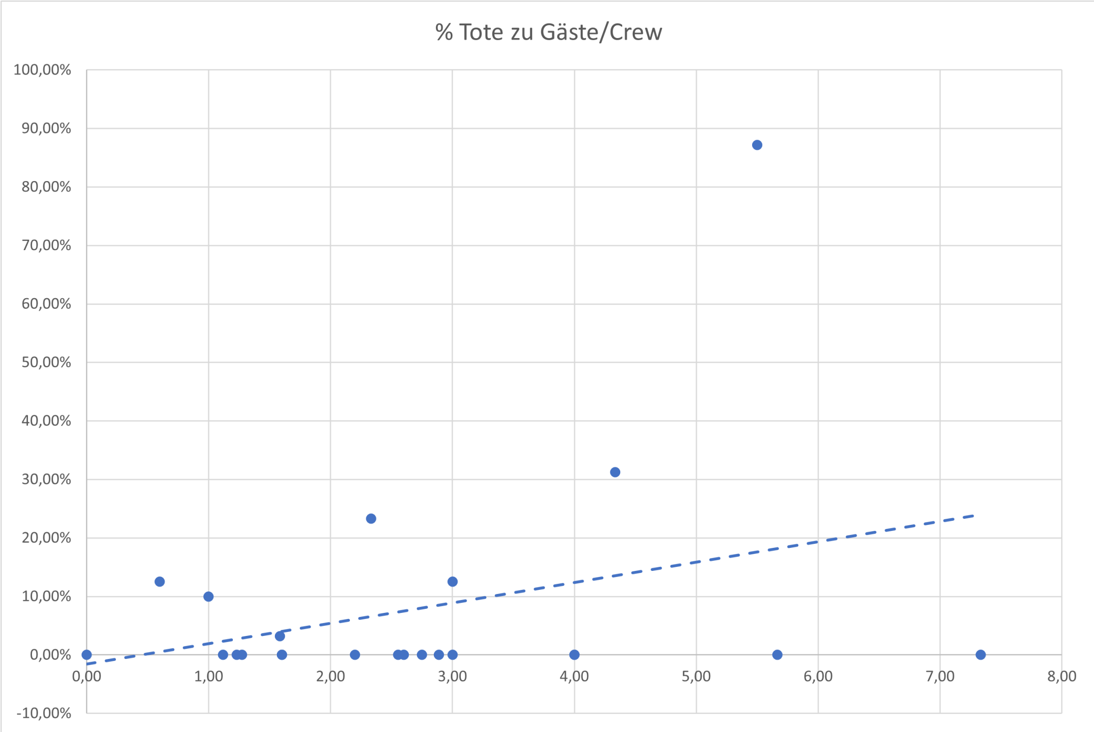

Figure 2: Fatalities in proportion to the amount guests per crew member

Here, the trend line suggests a proportionality. To check this assumption, the Pearson correlation coefficient is calculated [41, p.36]:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{3.1}$$

This provides a value of 0.322 with the „Conception“ which indicates an existing but low correlation. However, if this accident is removed from the data, a correlation coefficient of 0.09 is obtained, which would mean no correlation. Accordingly, the influence that the ratio of crew to guests has on the number of fatalities in relation to all persons on board is only very small, insofar as there is an influence at all, although this would be obvious. It is assumed that good crew training is significantly more important for the chances of survival.

The breakdown of deaths and injuries by type of accident is also an interesting analysis. Most people die in fires on board. However, this figure is dominated by the „Conception“ tragedy. Of the total of 43 deaths and serious injuries, 35 were caused by the „Conception“accident. In contrast, over half of all fires ended without casualties. In fig. 3 the numbers of victims are further divided into categories.

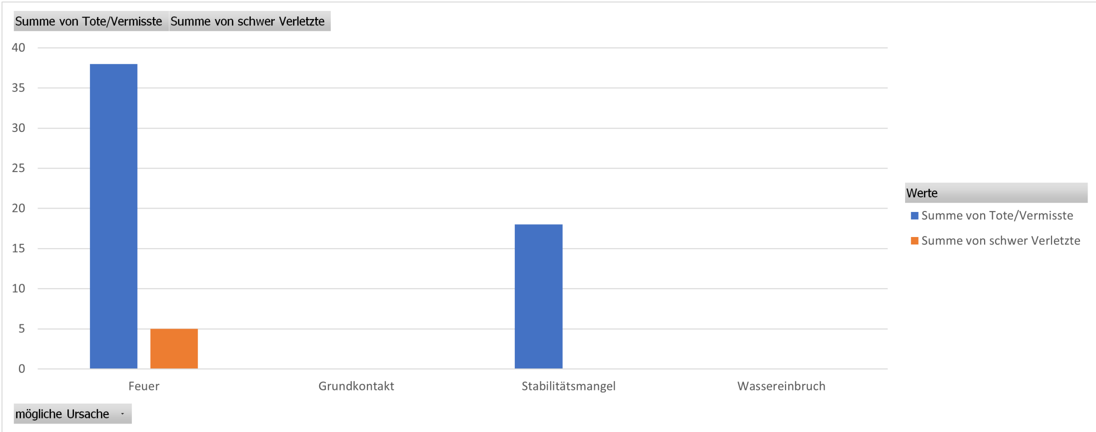

Figure 3: fatalities by type of accident

Lack of stability is the second most dangerous cause with 18 fatalities. It should be noted that a large proportion of accidents in this category also resulted in fatalities (see Fig. 4).

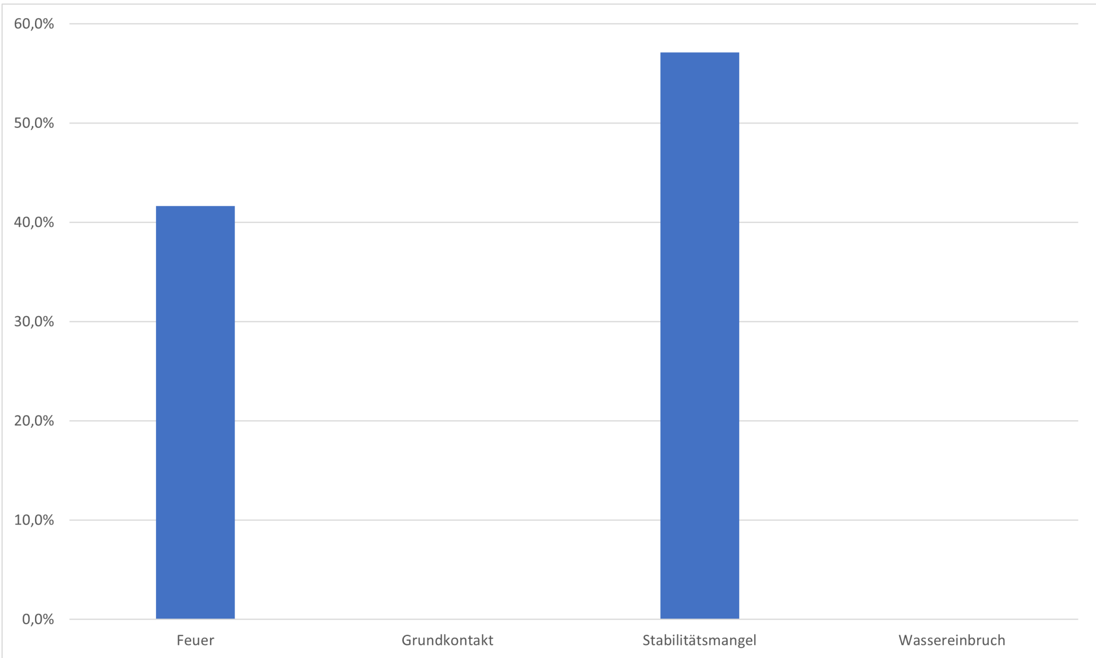

Figure 4: Accidents with fatalities by type

In contrast to fires, where there are fatalities in 41.7% of accidents, there are fatalities in 57.1% of cases of lack of stability. This is particularly fatal in storms. This accident category can therefore be considered similarly dangerous. Excluding the „Conception“ accident, this category is also the one with the most fatalities.

The location of the accident is also interesting in the context of this analysis, as this could allow conclusions to be drawn about regional problems. This aspect is considered in the following chapter.

3.4. Analysis by accident location

Two regions stand out in terms of accident locations: the Egyptian Red Sea on the one hand and the Southeast Asian island states on the other. In fig. 5 blue markers stand for one

Figure 5: MapsData: Google 2023, Accident map worldwide

accident, yellow for two and red for three accidents at the marked location. The locations that are closest to the last known position or in the vicinity of the accident location have been marked.

It is very easy to establish a link between the accident locations and the most popular diving areas. All accident locations are close to the most popular liveaboard destinations [46]. Most liveaboard vessels are also operated at these locations. It therefore stands to reason that most accidents occur here. However, there are also very popular regions where there are no or only a few accidents. It is reasonable to assume that stricter regulations apply there or that the applicable regulations are better observed. These places include the Caribbean and the Great Barrier Reef in Australia, for example. The Red Sea off Egypt has the highest accident density with 13 accidents considered (see Fig. 6). Here, the great popularity alone cannot explain the number of accidents, as these account for 42% of all accidents found, although only about one fifth of the world's liveaboard vessels operate there [47] [48]. Therefore, the further analysis focuses mainly on Egypt and the islands of Southeast Asia.

Figure 6: MapsData: Google 2023, Accident map Egypt

For further classification, the statistics determined so far are compared with global shipping in the following section.

3.5. Comparisons with global shipping

For comparison with worldwide data, statistics from Allianz Versicherung are used first. In order to compare the number of accidents involving liveaboard vessels per year with global shipping, the number of accidents per year can be set in relation to the number of vessels currently in service. In shipping, there are currently over 100,000 ships with a gross tonnage of over 100 [cf. 49, p.33] and this with around 3000 accidents per year [cf. 50, p.18] and only 38 ship losses in 2022 [cf. 50, p.14]. This means that 1 ship out of 37 reports an accident every year and 1 ship out of 1275 is completely lost. Data on the number of liveaboard vessels ranges from 255 worldwide for the largest provider of liveaboard trips PADI [47] to 866 - 1096 according to an estimate by experts. The maximum number of the estimate is not used for the calculation, as not all liveaboard ships also operate [48]. This does not allow a clear statement about the number of ships, as a tour operator probably does not offer all ships and the estimate also contains a large variance. Nevertheless, a minimum value can be obtained from the estimate with which a comparison can be made. With 866 ships worldwide, one ship out of 503 sinks every year. This is significantly more than in worldwide shipping, even with a rough estimate, which is nevertheless high compared to the liveaboard ships offered online, especially since a number of liveaboard accidents that cannot be ignored cannot be taken into account in this analysis.

Looking at the causes of accidents in global shipping in detail, fires on board are only the third most common cause of ship losses between 2013 and 2022, accounting for 14.4% of 807 total losses. The main reason for ships to sink is sinking after taking on water, accounting for 53.8% [50, p. 15+18]. This can happen due to insufficient stability or leaking hatches, among other things. Subsequently, grounding is responsible for slightly more losses. At 17%, this cause ranks in the same place in the frequency of causes of accidents as for liveaboard vessels. This is surprising given the proximity to reefs in the cruising areas of liveaboard vessels. It should be noted that the number of casualties is decreasing from year to year. Almost all causes of accidents in global shipping are on the decline. However, the absolute numbers of losses due to fire and explosions have remained relatively constant (see Fig. 7). In contrast, the frequency of accidents on liveaboard vessels is increasing.

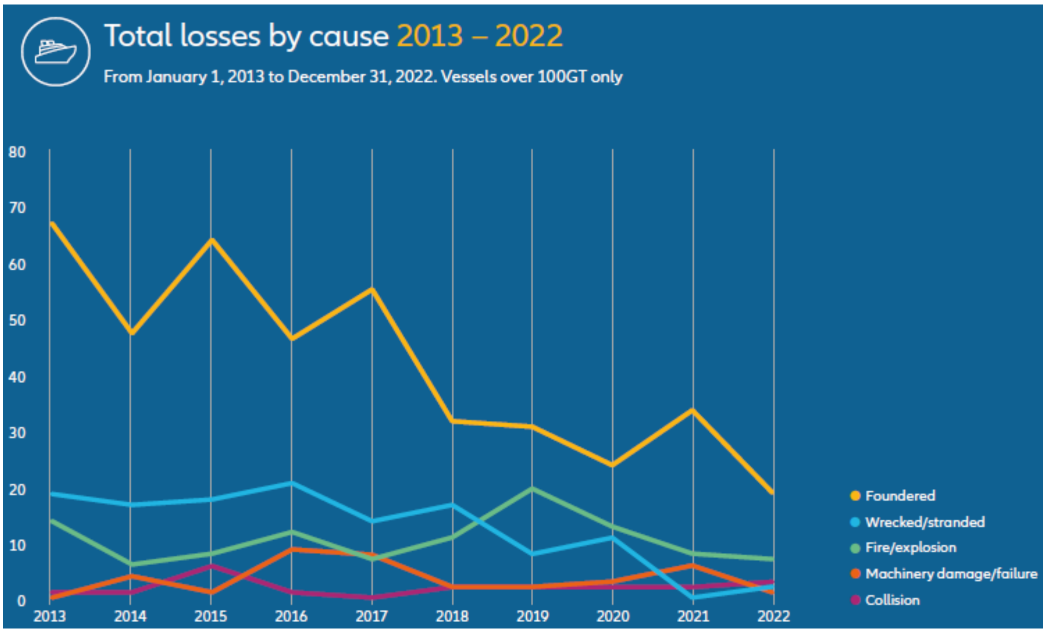

Figure 7: Vessel losses by cause [50, p.15]

These values can be compared very well with the values available for liveaboard ships, as most liveaboard accidents involve sunken ships. Even if some of these were recovered, it makes more sense to compare accidents involving liveaboard ships with ship losses than to compare them with the total number of reported accidents in international shipping. According to the European Maritime Safety Agency (EMSA), the reports are characterized by minor and non-critical accidents [51, p. 12]. These minor accidents are missing from the statistics on accidents involving liveaboard vessels. According to diving forums such as ScubaBoard, there are occasionally minor accidents that do not make it into the media [52]. It would be best to combine ship casualties with other serious accidents, but there are no separate statistics for this. This can be worked out from the statistics of EMSA, for example, but these are not valid worldwide.

Sinking after water intake includes the categories of lack of stability and water ingress in the analysis of the accident data, but if you add these together, you only get a total value of

29%. This value is also significantly lower than the proportion that water intake is assumed to be the cause for large ships (53.7%). When comparing the data on fires, it is noticeable that these occur almost three times more frequently on liveaboard vessels (38.7%) than on other vessels (14.4%). In both statistics, stranded ships rank second in relative frequency with 32% for liveaboard ships and 17% for large ships[50, p. 15]. It should be noted that collisions, hull damage and some other reasons are also listed in the Allianz statistics, which are not broken down or listed in the statistics for liveaboard vessels.

The „Annual Overview of Marine Casualties and Incidents 2022“ of EMSA was used to classify casualties, as the Alliance does not deal with fatalities and injuries. This refers to ships flying the flag of a European Union (EU)-state, accidents within the waters of EU-states or waters assigned to EU-states under the United Nations Convention on the Law of the Sea, or accidents in which EU-states have a high interest [51, p. 11]. This shows that an average of 70 people per year died in shipping accidents in the years 2014 - 2022[51, p. 26]. With 2,647 accidents per year [51, p. 12], that is 1 death every 37.8 accidents. If the same calculations are made for liveaboard vessels, the result is 2 fatalities per accident if the „Conception“ is added. If this accident is not taken into account, the result is one death every 1.2 accidents. This indicates a considerable safety gap in liveaboard vessels.

The high proportion of trained personnel with a low proportion of passengers on large ships [51, p. 26] means that most fatalities are also crew members. The large number of trained persons also leads to a reduction in fatalities overall.

On large ships, almost half of all fatalities are caused by slips and falls [51, p.27]. This is not a separate category in the accidents investigated on board liveaboard vessels. Although it may happen that people die as a result of the accident, there is no way of checking how often this occurs. Together with other categories, this category forms a group which is summarized here as accidents during normal ship operation. If this group is disregarded, only at least 84 people died in the entire period. There could also be more, as the other causes of death can generally occur in major accidents. Deaths caused by fire and explosions in particular are very rare. In the overall period from 2014-2022, only 10 people died from fire in merchant shipping [51, p. 27], or 1.1 deaths per year. In contrast, 2.1 people per year died due to fire on liveaboard vessels. The fact that even the absolute number of deaths caused by fire on liveaboard ships is higher than on large ships indicates significant safety gaps, as all large ships worldwide employ many more people than liveaboard ships.

The most fatal category without the „Conception“accident, lack of stability, is difficult to compare as the possible causes of death have been split into different categories in the EMSA statistics. If only the category overflow, capsizing, leaks, water flow, evaporation, emission of liquids is taken into account, 31 people die. This category describes all deaths caused by leaking liquids and gases. This includes all deaths caused by drowning during capsizing, but also many other cases that have nothing to do with capsizing. In contrast, there were a total of 18 deaths due to lack of stability. It should be noted that the absolute figures relate to different periods. The observation period over which this analysis took place is twice as long as the period of the EMSA report. If you take this into account, you get 1 death due to capsizing on liveaboard vessels and 3.4 on larger vessels per year, from which no conclusions can yet be drawn due to the large difference in incidents. If you divide this by the number of accidents each year, you get 0.58 deaths per year per accident for liveaboard vessels and 0.001 for large vessels.

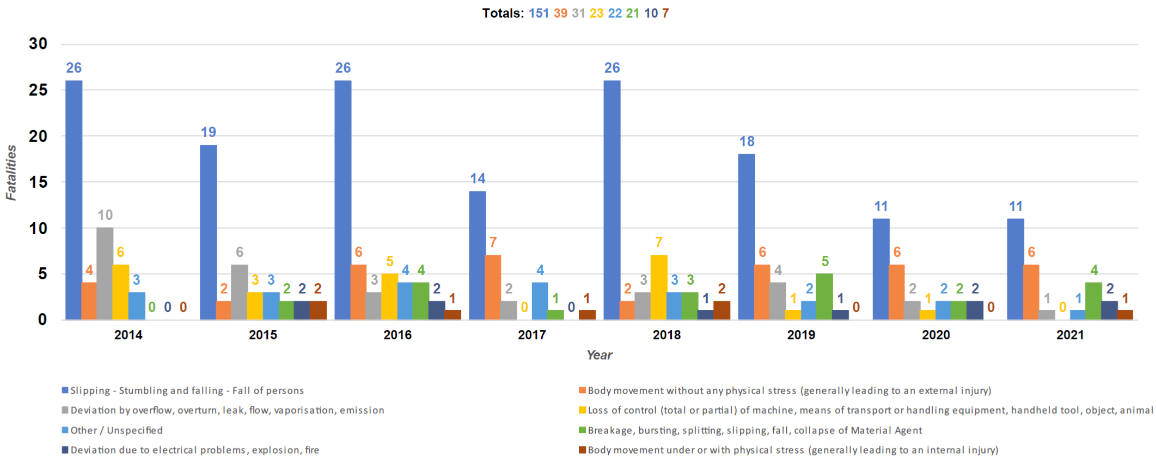

Figure 8: Deaths by cause of death [51, p. 27]

In view of these significant differences in the accident figures, the underlying regulations are considered in the following section.

4. Regulations

There are a large number of regulations worldwide, which are drawn up by various organizations and countries and compliance with which is monitored. In this chapter, some of the relevant regulations relating to the most common causes of accidents will be outlined. Due to the frequency of accidents in connection with fire safety and stability, regulations on these topics will be discussed. In addition, the extent to which these regulations apply to liveaboard vessels or can be reasonably applied will be classified. The regulations according to which a ship is built are normally composed of various other regulations. The IMO establishes international regulations that are valid everywhere. There are also other national regulations. From these regulations, classification societies draw up their own regulations that fulfill all the necessary requirements. These regulations are checked and comply with all international regulations and the regulations of the flag state that commissions the classification society.

4.1. Regulations of the IMO

The International Maritime Organization (IMO) is an organ of the united Nations (UN) and regulates maritime shipping worldwide. All member states have ratified the IMO conventions and implement them in their country. These regulations apply to all ships that are registered with the IMO or come into contact with international shipping. The topic of ship safety at the IMO is anchored in the SOLAS-Konvention, among other things.

4.1.1. SOLAS

The SOLAS-Konvention is a UN convention for the protection of people at sea. The SOLAS-Konvention was created in response to the sinking of the Titanic in 1912. The current version of this regulation was ratified in 1974 and has been expanded and improved ever since. All areas of ship safety are covered in 14 chapters. It is generally valid for all ships that sail on international voyages [53, Chapter I Part A Regulation 1]. The convention thus forms the minimum standard for all larger merchant ships with a gross tonnage of over 500 [53, Chapter I Part A Regulation 3]. All other ships can implement the regulations on a voluntary basis. Further restrictions are made individually for each chapter [53, Chapter I Part A Regulation 1]. Many liveaboard vessels do not sail internationally, but remain in the territorial waters of their home country, which means that the convention is not binding. Furthermore, the SOLAS-Konvention does not apply to leisure yachts that do not engage in trade [53, Chapter I Part A Regulation 3]. This also applies to liveaboard vessels. However, vessels with 12 guests or more are considered passenger vessels, which applies to almost all liveaboard vessels considered in this statistical analysis. It is therefore expected that other liveaboard vessels will also largely fall into this category. Unlike commercial vessels, there is no minimum size requirement for passenger vessels. The following section covers the regulations that apply to passenger vessels of the size of typical liveaboard vessels.

Fire protection is simplified according to the age of the ship, in that individual parts do not apply to old ships [53, Chapter II-2 Regulation 1.2]. At the beginning, the SOLAS--Konvention deals with the consideration of ignition probabilities and the propagation by draught and flammable materials [53, Chapter II-2 Regulation 4-5]. This topic is not discussed in detail here, as liveaboard vessels are partly built of wood. Wood is not considered, as the SOLAS-Konvention assumes steel ships. In addition, such considerations only make sense if the structure and materials used on liveaboard ships are known, which is usually not the case. Fire detection systems are then worked out. Fire detectors are required in engine rooms that are not continuously manned [53, Chapter II-2 Regulation 7.4]. When accommodating guests, a distinction is made between ships with more than 36 guests and ships with fewer guests. Only the regulations for fewer than 36 guests are described here. These require fire alarms in every room except empty rooms or sanitary rooms and similar spaces [53, Chapter II-2 Regulation 7.5]. To prevent the spread of smoke, appropriate ventilation systems must be installed to remove the smoke [53, Chapter II-2 Regulation 8]. In order to prevent the spread of fire, the division into individual fire protection zones is required. These may be a maximum of 48 m long or wide [53, Chapter II-2 Regulation 9.2.2.1]. For the delimitation of these zones, bulkheads with certain building regulations are required [53, Chapter II-2 Regulation 9.2.2.4]. This stipulates methods for extinguishing fires. The SOLAS-Konvention requires two fire pumps, one of which can be started automatically or from the bridge[53, Chapter II-2 Regulation 10.2.1.2 + 10.2.2.2]. The design of these pumps is based on the pressure at the hydrants and the diameter of the pipes [53, Chapter II-2 Regulation 10.2.1]. There must be several hydrants for these fire pumps, which must be distributed in such a way that the water jet from a hydrant with a hose can reach every part of the ship that a person can reach [53, Chapter II-2 Regulation 10.3.2]. In addition, fire extinguishers are required in all accommodation spaces [53, Chapter II-2 Regulation 9.2.2.4]. A fire extinguishing system with gas, foam or water must be installed in engine rooms [53, Chapter II-2 Regulation 10.4 + 10.5]. A sprinkler system can be installed in addition to the fire alarms in guest areas. Escape routes should be specially protected and lead all the way to the lifeboats or life rafts [53, Chapter II-2 Regulation 13.3.2.4]. In addition, it is specified that there must be several emergency exits for most spaces such as atriums[53, Chapter II-2 Regulation 13.2.1 + 13.3.2]. Certain spaces may also have only one emergency exit [53, Chapter II-2 Regulation 13.3.1.2]. For fire emergencies, a manual with information on the distribution of tasks and instructions for firefighting must also be on board [53, Chapter II-2 Regulation 16.2].

These regulations are generally also useful on liveaboard vessels. However, as soon as the sailing area is extended to international voyages, the provisions of the SOLAS-Konvention are mandatory. However, separate ventilation or smoke extraction systems cannot always be installed on such ships due to the small size and type of superstructure. A sprinkler system would also only make limited sense, as this would require a large amount of additional tanks and equipment, such as pumps and pipes. As this is therefore not a sensible control method, more fire extinguishers or other control methods should be installed. This could, for example, be a permanently installed hydrant with redundant pumps. Retrofitting permanently installed fire protection equipment requires reconsideration of the ship's stability due to the additional equipment.

In terms of stability, the old version of SOLAS Chapter II-1 applies to ships built before 2020 and ships operating more than 20 nautical miles from the coast. Ships that sail less than 20 miles from the shore during the entire voyage can be exempted from parts of the regulation by national organizations [53, Chapter II-1 Regulation 1]. Both may apply to liveaboard vessels depending on the route. Initially, the current status of the regulations is applied, as the difference is primarily reflected in leak stability. The stability in undamaged condition is mainly regulated by the International Code on Intact Stability (IS-Code), which applies to all ships over 24 meters in length. This IS-Code is also referred to in the SOLAS-Konvention [53, Chapter II-1 Regulation 5.1]. Among other regulations, this also contains the weather criterion [42, Part A Chapter 2.3]. This defines requirements that make a ship safe against heeling due to wind. A constant heeling moment for the wind is applied depending on the ship type, size and other factors. A lever arm curve must be calculated for the IS-Code and a complete stability book must be created [42, Part A Chapter 2.1]. The required lever arms according to Chapter 2 must be fulfilled in all loading conditions [42, Part A Chapter 2.1].

Accordingly, there should also be stability calculations for liveaboard vessels. For all yachts that have been registered at some point, a stability calculation should be carried out in accordance with the IS-Code. This is relevant in the event of yachts being converted to liveaboard vessels. The effort for such a calculation is very low if the ship also exists in digital form at the shipyard, as it can be carried out with all common ship design programs. However, if the ship does not exist in digital form, the pantocarenes must be calculated using integral calculations, which involves a great deal of effort. You have to calculate pantocarenes for different draughts using integrals from a frame crack. A possible alternative is an experimental stability test. This is less accurate but also involves significantly less effort and can be carried out for existing ships.

The compartment index R to be achieved is relevant for leak stability. For liveaboard vessels, this is 0.722 [53, Chapter II-1 Regulation 6.3]. The achieved department status is calculated from three shares, whereby each of the shares must not be less than $0.9 * R$[53, Chapter II-1 Regulation 7].

$$A = 0.4A_s + 0.4A_p + 0.2A_l \tag{4.1}$$

For three different draughts: d_s is the deepest draught reached in normal operation, the so-called summer load line. d_l is the draught for the lightest load case with passengers on board. d_p is calculated as $d_p = d_l + 0.6 * (d_s - d_l)$ [53, Chapter II-1 Regulation 2]. Each of the individual proportions is formed by a sum of the probability of survival s_i and the probability of occurrence p_i of all leakage cases [53, Chapter II-1 Regulation 7].

$$A = \sum p_i s_i \tag{4.2}$$

The calculation usually requires many cases, which is why the calculation is normally carried out using a computer program.

Leak stability in particular is very important on liveaboard vessels, as water ingress due to ground contact can easily occur due to the cruising areas and proximity to reefs. However, the effort required for a probabilistic leakage calculation is very high, as a specific computer program is needed for this. Therefore, older methods may be more appropriate.

A non-probabilistic method was used for older ships. First of all, a double bottom and bulkheads in the bow and for the engine room are required [54, Chapter II-1 Regulation 9-12]. In addition, the ships must survive a predefined leakage block [54, Chapter II-1 Regulation 9]. This involves monitoring how many compartments this leak block can flood and whether the ship survives this. This also requires a description of the stability via pantocarenes or lever arms. To implement the SOLAS-Konvention, a management system was introduced in 1998, which is defined in Chapter IX of the SOLAS-Konvention as the International Safety Management Code (ISM-Code).

4.1.2. ISM code

The ISM-Code is a guideline for creating a safety structure on board ships and on land. It applies to all ships that must also comply with the SOLAS-Konvention [55, Part A, 1]. This includes regulations for the safe operation of ships, risk assessment, responsibility and other aspects. There shall be a person ashore who has direct access to the management and is responsible for safety [55, Part A, 4]. The company shall ensure that the crew on the ship is adequately trained and certified [55, Part A, 6]. In addition, a plan with emergency procedures should be drawn up for each probable emergency. These procedures must also be trained [55, Part A, 8].

The IMO also draws up general regulations for sea areas where national regulations would lead to confusion due to the large number of different nations. One example in the Caribbean is the Code of Safety for Small Commercial Vessels operating in the Caribbean (SCV-Code), which is described below.

4.1.3. SCV code

The SCV-Code is an example of a special regulation for small vessels used mainly for tourist purposes. The SCV Code was developed in cooperation with the IMO and introduced as mandatory in 2001. It is based on US Coast Guard regulations for vessels of this size. However, this regulation only applies to ships up to a length of 24 m and even here mainly to ships carrying 12 or more guests [56, Chapter I Part A Regulation 1]. In addition, this only applies to ships operating in the Caribbean, as the name suggests. These regulations are not as strict as those of the SOLAS-Konvention. In addition, these rules apply to all ships regardless of their age.

For fire protection, these regulations require that for ships over 15 meters in length, at least one fire pump with a hose of 7.5m to 15m in length must be installed on board in such a way that the entire ship can be covered[56, Chapter V Part B Regulation 7-9]. Furthermore, fixed fire extinguishing systems must be installed in engine rooms and all other rooms with an increased fire risk. In addition, all unmanned rooms with an increased fire risk as well as guest rooms must be equipped with fire alarms [56, Chapter V Part B Regulation 10]. In addition to the permanently installed fire extinguishing systems, portable fire extinguishers must be on board. The engine room, bridge room, galley and pantry must have a fire extinguisher and one fire extinguisher must be provided for every 232.3 m^2 of guest rooms. The capacity and type of fire extinguisher are also specified [56, Chapter V Part B Regulation 11].

These regulations are much more detailed and therefore easier to apply than those of the SOLAS-Konvention. In addition, the guidelines for fire alarms appear easy to implement. A fire pump is unlikely to be retrofitted. However, manually operated pumps are also permitted[56, Chapter V Part B Regulation 7.1], which are easier to install as no engines or additional generators need to be installed on board. The number of prescribed fire extinguishers in guest rooms is lower than in accordance with the SOLAS-Konvention.

Simplified stability tests are required for stability. These are intended to show with little effort whether the stability of the ship is sufficient [56, Chapter III Part B Regulation 6]. An operating situation is simulated using weights that generate a trim and center of gravity typical for operation. Weights are then used for heeling, which represent the greater of the passenger moment and the wind moment. The load mark should not be submerged by more than 50%. For vessels without a fully watertight deck above the waterline, the load mark shall not be submerged more than 25% [56, Chapter III Part B Regulation 8]. If this test is not passed, it should be carried out again with a reduced heeling moment, as the draining water from weather decks reduces the heeling moment [56, Chapter III Part C Regulation 12]. If this test is also not passed, stability must be verified by other methods, such as detailed calculations[56, Chapter III Part B Regulation 6].

Such proof of stability can also be provided quite easily for existing ships. Therefore, the obligation to carry out such a test is a suitable measure to check the stability of liveaboard vessels. The exact values for heeling moments may have to be adjusted for this, as the heeling moments in the SCV-Code are greatly simplified and therefore not necessarily transferable to liveaboard vessels.

Leak stability is only considered through the placement of bulkheads and is not treated separately. A collision bulkhead is provided for this purpose [56, Chapter III Part D Regulation 16 and 17]. The distance between further bulkheads d is defined by a factor for the floodable length F, the freeboard f, the length of the deck above the bulkheads L and the draught D [56, Chapter III Part D Regulation 21].

$$d = \frac{FfL}{D} \tag{4.3}$$

This leads to several additional bulkheads.

For liveaboard vessels, the leak stability should be considered more closely, as the probability of a leak is significantly increased due to the proximity to reefs. Nevertheless, such a consideration is also sufficient for small ships.

The construction and conversion of ships is normally monitored by classification societies. The following section deals with the guidelines they use.

4.2. Classification

Classification societies work with their own guidelines, which are based on international regulations. Compliance with these regulations is regularly checked during construction and also during operation of the ship. Classification societies therefore make an important contribution to safety on the water. Classification societies have specialized so that the individual regulations deal with different types of ships and special features. In addition, this closes gaps in the general regulations of the IMO and defines much more specific rules. At this point, we will mainly deal with regulations for yachts and small ships. The latest versions of the guidelines only apply to newly built vessels. Older ships must normally continue to comply with the regulations according to which they were built. It should be noted that, with the exception of the „Royal Evolution“ none of the liveaboard vessels considered in this work have a class according to a classification society. Bureau Veritas is one such classification society that has also certified a liveaboard vessel and is presented in the next section.

4.2.1. Bureau Veritas

The Bureau Veritas (BV) has a complete set of rules for yachts with NR500. This is applicable to yachts that are shorter than 90 m and carry no more than 36 guests. For liveaboard vessels, yachts over 24 m in length and under 500 GT are considered, as this best represents the average liveaboard vessel.

For firefighting, various materials are listed with specific certificates for fire resistance that can be used [57, Part C Ch4 Sec 2]. In addition, fire alarms must be installed in all machinery spaces and in all spaces that do not have a particularly low fire risk, such as bathrooms. Smoke and fire detection systems must also be present in escape routes [57, Part C Ch4 Sec 3]. To make it more difficult for fires to spread, fireproof and partially gas-tight bulkheads must be used for engine rooms. In addition, the regulation requires partitions to prevent the spread of heat [57, Part C Ch4 Sec 4.2.2]. Less extreme fire barriers must be used in guest rooms [57, Part C Ch4 Sec 4.2.3]. Furthermore, several independent ventilation systems are required for the galley, engine rooms and guest rooms, most of which must not lead through the areas of the others [57, Part C Ch4 Sec 4.5]. Fire-fighting pumps are also required here. These should be portable or independent pumps. However, flow rates, designs and drive methods are also described here [57, Part C Ch4 Sec 5.2]. In addition, permanently installed fire extinguishing systems are to be installed in engine rooms [57, Part C Ch4 Sec 5.3.2]. At least three fire extinguishers must be on board to protect guest rooms, which may be a maximum of 10 m from each room [57, Part C Ch4 Sec 5.4.2]. Finally, special regulations on emergency exits are mentioned. There must be no dead ends and, where possible, emergency exits must not lead through engine rooms or the galley. This must apply to two independent escape routes [57, Part C Ch4 Sec 6].

Compared to SOLAS-Konvention in particular, these rules are easier to apply and also more clearly structured, making it much easier to work with the regulations. They also deal with topics that are given little attention in the SOLAS-Konvention, such as heat transfer.

In addition, the values are much clearer, which simplifies the design process. The number of fire extinguishers for guest compartments is low at three, but this number is significantly increased by the maximum clearance requirement, especially for larger ships. It is also difficult or impossible to retrofit the required equipment. For example, fire barriers in the form of walls can only be retrofitted at great expense. Retrofitting several independent ventilation systems also involves considerable effort.

The stability requirements are divided according to the area of travel and the length of the vehicle. Here, the widest sailing area of unrestricted travel far from the coast is used, as the liveaboard vessels operate far from the coast, particularly in South East Asia, but also in Egypt. A stability book and test are required for control purposes [57, Part B Ch3 Sec 1]. The intact stability is based very closely on the IS-Code, as this forms the basis for the stability of all ships. However, the heeling levers for the weather criterion are approximated to real conditions with a quadratic cosine [57, Part B Ch3 Sec 2.3]. In contrast, the weather criterion uses a heeling lever (see chapter 4.1.1), which is not variable according to the heeling angle. [42, Ch 3.2]. In addition, the criterion is extended by a part for sailing yachts [57, Part B Ch3 Sec 2.3.2]. Large sailing yachts are also used as liveaboard vessels, particularly in Southeast Asia. In addition, a chapter for ice on decks is added [57, Part B Ch3 Sec 2.5], which was not considered in detail, as liveaboard vessels rarely sail in weather that allows ice.

According to these rules, both a stability test and a calculation must be carried out. Since most liveaboard vessels are not built at modern shipyards that use digital methods, calculations involve a great deal of effort. Therefore, tests are probably the only sensible inspection method. These tests can also be carried out on ships that have already been built.

The calculation of leak stability is based on a compartmentalized approach. A watertight compartment is assumed to be flooded and certain criteria must be met in the final floating position [57, Part B Ch3 Sec 3.1]. The requirements for the survival of the ship are clearly defined [57, Part B Ch3 Sec 3.2.5].

The „Royal Evoultion“ is a liveaboard vessel operating in Egypt and Sudan. Unlike most liveaboard vessels, this one was built according to the SOLAS-Konvention and building regulations of the BV. This ship demonstrates that it is possible to build liveaboard vessels in accordance with international regulations and still operate them profitably. This ship has extensive stability calculations, as well as plans and protocols for safety [58]. Det Norske Veritas is another classification society whose regulations are briefly presented here.

4.2.2. Det Norske Veritas

Det Norske Veritas (DNV) also has rules for yachts. However, here the ships are divided according to the number of passengers and not according to length.

Yachts with 13 to 36 guests are accepted for firefighting purposes [59, Part 4 Ch 11 Section 4]. For this, reference is made to the Yacht Code Part B of the Red Ensign Group [59, Part 4 Ch 11 Section 4]. This also initially deals with materials and fire risks of rooms and materials [60, Chapter 6.2 + 6.3]. The installation of fire alarms is required in machine rooms if they are not permanently manned. In guest areas, smoke alarms are sufficient in all cabins, stairwells and escape routes. Only rooms with a particularly low fire risk do not require smoke alarms to be installed [60, Chapter 6.5]. Ventilation systems must be used to prevent the spread of smoke and the cutting off of escape routes by smoke [60, Chapter 6.6]. Fire protection zones are also defined here for fire-resistant walls and bulkheads. The exact requirements depend on the respective fire risk. [60, Chapter 6.7]. Similar to other regulations, the ship needs at least one extinguishing water pump, which is dimensioned here not only by the flow rate but also by the water pressure. The hoses and hydrants must be able to reach every part of the ship [60, Chapter 6.8 2-29]. For the number and type of fire extinguishers, reference is made to the administration, which means that the regulations of the flag state must be applied [60, Chapter 6.8 31]. Reference is then also made to escape routes. Very detailed regulations on the nature of escape routes in terms of width, height and the like are described. It is also made clear that there must be several emergency exits for certain rooms such as atriums [60, Chapter 6.11].

There is no clear regulation here on some things like fire extinguishers, but this is left to the flag state. This is a problem, as it leads to cheaper flags, which, however, do not require sufficient safety standards. Under these conditions, the regulation is very similar to the SOLAS-Konvention, so that no great added value is created by this set of rules.

In terms of stability, this regulation is also close to the IS-Code, as this forms a good basis [59, Part 3 Ch 10 Section 2.2.1]. However, there is no reference to the weather criterion. Here, too, this basis is extended by a regulation for sailing ships [59, Part 3 Ch 10 Section 2.2.2]. The DNV also requires an additional test [59, Part 3 Ch 10 Section 2.4].

The same applies here as for the regulations of BV. The great effort of a stability calculation does not necessarily have to be carried out, but a test is considered a good alternative.

In the event of a leak, yachts of a certain length should be able to lose up to two compartments without sinking. Ships from a length of 48 m should be able to lose one compartment, whereas from a length of 85 m two leaking compartments must be survived [59, Part 3 Ch 10 Section 2.2.2]. The extent of the leak is clearly defined [59, Part 3 Ch 10 Section 3.2.1]. Likewise, clear minimum criteria must be met for a leak to be considered survived [59, Part 3 Ch 10 Section 3.3]. From this, a plan must be drawn up that shows watertight compartments [59, Part 3 Ch 10 Section 3.5].

Such leakage regulations are very useful, but again involve a great deal of effort due to prior calculation of the pantocarenes. However, such a calculation is the only way to make a reliable prediction of the ship's stability behavior in the event of a leak. Functioning simple tests for the leakage case are not known. Simulations are another possibility, but these are considerably more complex. The majority of liveaboard vessels operate without any classification.

In addition to international rules and classification societies, which implement local and international rules in regulations and monitor compliance with them, there are also local regulations from various bodies. These are discussed in the following section.

4.3. Local regulations

Flag states have their own additional regulations. There are also various rules on sailing areas, such as local environmental protection areas in which you may only sail using certain methods [61]. In addition to environmental protection, there are also rules on personal safety and other topics. These local rules for sailing areas are examined in this chapter for their applicability and other useful regulations.

4.3.1. European standards

The EU has drawn up a guideline on recreational craft that may be sold and used on the European market. According to Dipl.-Ing. Hans-Josef Braun from the Berufsgenossenschaft Verkehrswirtschaft Post-Logistik Telekommunikation (BG Verkehr), this guideline can be used as a guide [62]. However, only boats with a maximum length of 24 m and other smaller vessels are covered by these regulations [63, Art. 2]. Liveaboard vessels can be divided into categories A or B due to their area of operation far from the coast, as a storm must always be taken into account due to the distance from the coast and the wave height can also increase significantly. These categories are waves from a height of 4 m and wind forces up to force 8 [63, Annex I A 1.]. The wave height is less relevant for liveaboard vessels. However, the basic requirements only refer to sufficient stability in relation to the maximum load and category [63, Annex I 3.2].

The regulations on fire protection are somewhat more extensive. Here too, however, there are no clear rules for the most part, but only sufficient fire-fighting methods are required. Here, consideration must be given to „open [...] flames [...], hot surfaces or machines and auxiliary machines, leaking oil and fuel, uncovered oil and fuel lines and that electrical lines do not run close to heat sources and hot surfaces“ [63, Annex I 5.6.1]. Engine compartments must be unopened in case of fire. In addition, extinguishing devices appropriate to the fire hazard“ [63, Annex I 5.6.2] must be on board. A type examination is required. Among other things, this requires „designs, production drawings and plans“ [64, Module B 3.] for submission to an inspection body. A decision is then to be made here on compliance with the applicable regulations of the[...] standards and technical specifications“ [64, Module B 4.2]. In addition, the manufacturer is obliged to carry out quality assurance measures and individual tests [64, Module G + H]. Separate standards are responsible for all individual topics.

EN ISO 9094:2022 is used for fire protection. All aspects of fire protection are initially covered here, from materials to distances between fuel tanks and engines to insulation material [65, Chapter 4]. Reference is made to a large extent to other European standards. The standard then deals with the detection of fires. Detection systems, such as smoke or heat detectors, must be installed for this purpose. These must cover the entire living area(s) and the engine compartment“ [65, Chapter 5]. It can also be operated by on-board power, so it does not have to be independent [65, Chapter 5]. There must be at least one fire extinguisher on board if there are sleeping areas [65, Chapter 7.3]. However, the requirements for the arrangement of fire extinguishers can quickly lead to mandatory equipment with more fire extinguishers. An extinguisher must be located at a maximum distance of 2 m from the steering position or the galley, as well as closer than 5 m from a berth [65, Chapter 7.5.4.1]. One fire extinguisher is also required per 20 m^2 of living space [65, Chapter 7.5.4.2]. Diesel and petrol engines of a size relevant for liveaboard vessels must be equipped with a permanently installed extinguishing system [65, Chapter 7.4]. These may have a manual release and do not have to be automatic. Furthermore, these systems must be able to switch off diesel engines [65, Chapter 7.6].

Only a brief overview of the very detailed rules is shown here. The requirements for fire extinguishers are stricter compared to the previously tested guidelines. This ensures additional safety, although the installation of fire extinguishers is not very complicated.

In terms of stability, there are several standards that deal with different types of boats.

EN ISO 12271-1:2021 is used for this because it is applicable to boats with a length of 6m to 24m without sails [66, Chapter 1]. Categories A and B are also used here, as these are the most suitable for liveaboard vessels due to the sailing area and the possibility of being surprised by a storm. In the standard, a constant wind moment is assumed for intact stability, which is based on a different wind speed depending on the design category [66, Chapter 6.3.2].

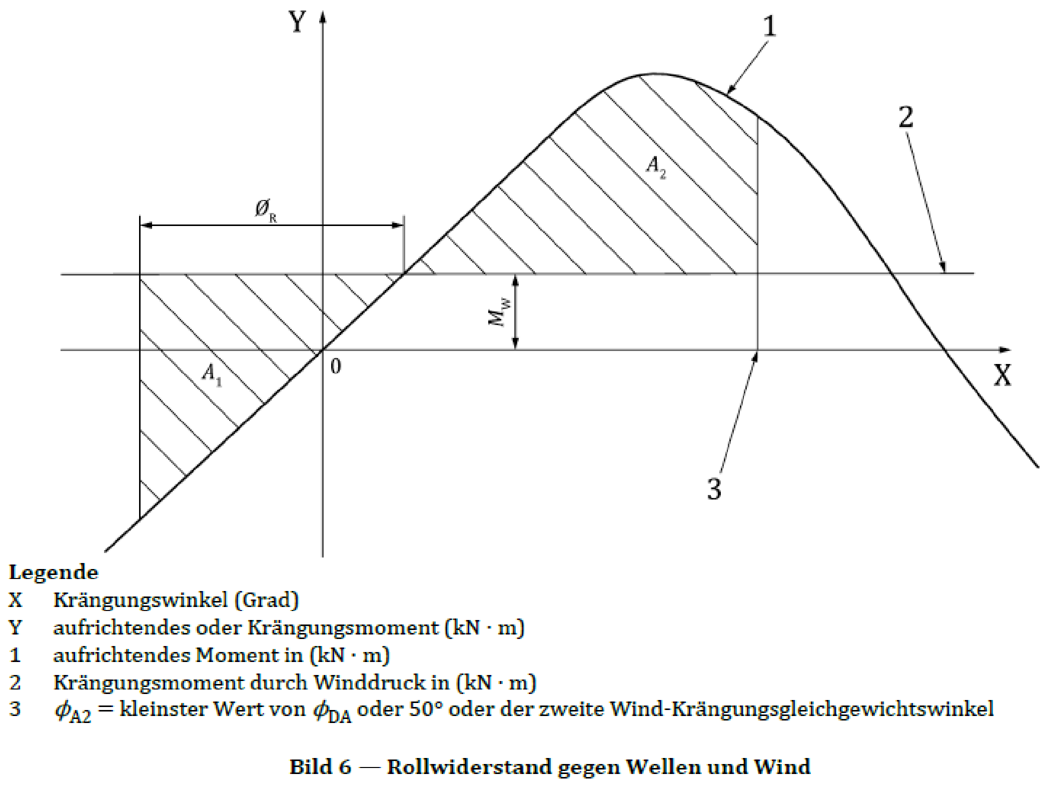

Figure 9: Weather criterion according to ISO 12271-1 [66, Chapter 6.3.2]

To meet the criterion, the area A_2 must be greater than A_1 [66, Chapter 6.3.2]. For small angles below 30°, a minimum and maximum of the righting moment and lever is required [66, Chapter 6.3.3]. This is shown in Figure 9. There are also regulations for checking eccentric loads [66, Chapter 6.2].

The provision on wind is also similar to the weather criterion from the IS-Code, but the calculation method is adapted and not all parts are used. The guidelines for small angles provide a clear benchmark for both too high and too low stability. Too high stability can also lead to damage and injury.

Leak stability is mainly controlled by flooding guidelines. A freeboard reserve is defined for a calculated flooding height [66, Chapter 6.1.].

Such a stability assessment should be further elaborated if it is to be used for liveaboard vessels. This is due to the increased risk.

After considering these European regulations, the following section deals with their national implementation in Germany in the form of the BG Verkehr.

4.3.2. BG Transport

The work of the BG Verkehr is based on international regulations such as the SOLAS--Konvention or the Convention on Load Lines and adds its own rules and German laws to these. There is no clear guideline for liveaboard vessels here either. However, Mr. Braun is working on a checklist for these, although this is not on behalf of the BG Verkehr [62]. It should be noted that no liveaboard vessels are currently sailing under the German flag, but that this checklist is being developed to protect passengers.

Directive 2009/45/EC on passenger ships is dealt with first, as it specifies fire safety measures. The use of this directive is designed for large passenger ships such as ferries. According to this directive, liveaboard vessels should be classified in category A or B of passenger ships, as they regularly sail more than 20 nautical miles from the coast [67, Article 4]. Fire pumps with a certain volume flow of extinguishing water are required here [67, Annex 1 Chap. II-2 3.]. The hoses used for this purpose must be able to reach any part of the ship with water [67, Annex 1 Part A Chap. II-2 3.]. Portable fire extinguishers must not be installed in cabins [67, Annex 1 Chapter II-2 Part A 5.4]. There must be enough fire extinguishers on board so that the maximum distance to the nearest fire extinguisher is 10 m. In addition, a fire extinguisher must be available on the bridge and at every location particularly at risk of fire [67, Annex 1 Chapter II-2 Part A 5.13]. A fixed extinguishing system and a portable foam extinguisher are required in engine rooms [67, Annex 1, Chapter II-2, Part A 6.1 - 2]. If oil is used or processed in the respective engine room, additional requirements are made [67, Annex 1 Chapter II-2 Part A 6.3 - 8]. For fire detection, it is required that an overview of the monitored rooms and the fires there is provided on each fire indicator [67, Annex 1 Chapter II-2 Part A 8.7]. In addition, sprinklers are required for all passenger ships except those staying closer to shore than 15 nautical miles and less than 40 m in length [67, Annex 1, Chapter II-2, Part A 8.22 - 23]. Automatic smoke detectors must be fitted every 11 m and in all corridors and escape routes [67, Annex 1 Ch. II-2 Part A 9.2]. Part B specifies structural measures. These include bulkheads, escape routes, shelters and ventilation systems [67, Annex 1 Chap. II-2 Part B].

These are very comprehensive rules that can only be implemented to a limited extent on liveaboard vessels, as they were designed for much larger ships. However, parts can also be applied very well to smaller ships, as the relevant requirements are easily scalable. One example of this is the fire extinguishers, as the distances can also be maintained on small ships, meaning that fewer fire extinguishers are required. In contrast, it is difficult to retrofit indicators and a sprinkler system and these are also more difficult to scale, as the corresponding equipment such as an additional pump, piping, etc. is always required.

With regard to stability, the BG Verkehr ship safety manual is used, as it presents many individual regulations for different types of ships. Reference is made here to the IS-Code, which was already dealt with in Chapter 4.1.1 [68, Chapter 2a.1]. Reference is then made to additional guidelines. First of all, the general rules require a consideration of free surfaces with used fuel, provided that none of the specified loading conditions occur and no operating heeling test or rolling time test can be carried out [68, Chapter 2a.2.1.2]. In this regulation, the heeling lever after wind is approximated to real conditions with a cosine [68, Chapter 2a.2.1.5]. Frequent reasons for deviations between calculations and reality are also given.

These are other actual cargo weights and centers of gravity, closure condition, free surfaces, original floating positions, rudder position, swell and wind pressure [68, Chapter 2a.2.2]. For passenger ships, the heel must not exceed an angle of 12° [68, Chapter 2a.2.3.2.4.1]. In addition, these ships must also observe passenger moments where the guests are assumed to be gathered as a group on one side of the ship [68, Chapter 2a.2.3.2.4.2]. Heeling during a turning circle must also be considered separately [68, Chapter 2a.2.3.2.4.2].

These requirements are also high compared to most other regulations. However, all important aspects are taken into account. Nevertheless, the additional requirements for passenger ships are very high. With regard to liveaboard vessels, even a low requirement is already a major improvement. This can be seen in comparison with other national regulations, which are considered in the following section.

4.3.3. Egyptian regulations

The Egyptian Authority for Maritime Safety (EAMS) requires ships flying the Egyptian flag to comply with certain parts of the SOLAS-Konvention and other regulations. These include the fire defense systems, firefighting drills and also plans for fire protection zones [69, p. 2]. They should also adhere to the complete International Ship and Port Facility Security Code (ISPS-Code) [69, p. 2]. In addition, there are the requirements for lifejackets from the SOLAS-Konvention [69, p. 2].

These regulations probably only apply in this form to merchant ships and other ships registered with the IMO, although the majority of Egyptian liveaboard ships currently in operation do not appear to comply with these regulations. Nevertheless, the „Carlton Queen“ sailed under the Egyptian flag and was also registered there [70]. Further regulations are currently only available in Arabic.

The CDWS issues further regulations for liveaboard vessels. However, these only require communication equipment, diving equipment and some rooms for the crew as well as a generator [71]. With regard to safety, only regulations for first aid equipment are mentioned [72]. In addition, a blacklist of illegally operating companies is maintained [73].

The regulations of the EAMS and CDWS for liveaboard vessels therefore result in a safety standard that is far below that of the aforementioned international regulations and supervisory bodies and does not correspond to the state of the art.

4.3.4. Southeast Asian regulations

Access to Indonesian and Thai construction and operating regulations failed due to the language barrier, as the websites of the respective responsible organizations are only accessible in the local language. The Marine Department of Thailand has not yet responded to inquiries [74]. The Indonesian Maritime Safety Agency requires a detailed request for scientific cooperation for access, which cannot be pursued further in the context of this work [75].

4.4. ADTO

Since some providers of diving trips have also realized that there are not sufficient safety measures on all liveaboard ships, a group of tour operators check some safety features themselves. The Association of Dive Tour Operators (ADTO) is „a group of 19 dive tour operators“ [76] from several European countries. They want to guarantee a minimum level of safety. To this end, they are working on an independent quality seal. This requires fire extinguishers and smoke detectors on board ships, as well as an annual inspection in a dock [77]. Further criteria are currently being developed by experts.

In aviation, too, international regulations are interpreted and monitored with varying degrees of strictness by different countries. This leads to national regulations that do not offer a uniform level of safety. For codeshare flights, however, airlines must guarantee at least the same level of safety as on their own aircraft. As a result, airlines had to audit each other regularly in order to provide evidence of the actual safety level of codeshare partners. To replace these mutual audits with a universal audit and save resources, the International Air Transport Association (IATA) developed the IATA Operational Safety Audit (IOSA) [78]. This is a globally standardized test procedure that can be used to demonstrate a good level of safety. Every IATA member airline must now pass regular IOSA audits in order to maintain IATA membership and be able to offer codeshare flights. A similar model could also be considered for liveaboards to address the problem of differing national regulations and enforcement of these regulations. At present, however, the principle according to which shipping regulations are structured is very different. National regulations are based on international ones, resulting in a network of different directives.

In addition to guidelines for the construction of ships, a well-trained crew is also necessary to prevent accidents. Therefore, some training standards are considered next.

4.5. Training standards

The IMO has created theInternational Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW-Übereinkommen) a generally recognized principle for the training of officers and seafarers. This requires all seafarers to be familiar with personal safety equipment and to be able to use it. This includes life jackets, survival suits, life rafts, fire extinguishers and first aid measures. Furthermore, familiarity with emergency procedures and emergency communication is required [79, Section A-VI/1]. For passenger ships, the ability to communicate with passengers in an emergency, to give them reassuring orders and to bring order to groups of guests is also required. In addition, they must be able to search the cabins correctly [79, Section A-V/2]. For firefighting, each crew member must be familiar with the escape routes, causes of fire and flammable materials. In addition, each seafarer must also demonstrate knowledge of firefighting equipment and methods [79, Section A-VI/1]. There is additional evidence of advanced firefighting for crew members who are to be specifically assigned to firefighting on board [79, Section A-VI/3]. The training normally lasts a total of 12 months in addition to the deployment at sea or 4 months for special training on land or on board a ship. This training only forms the basis. For extended tasks, such as launching lifeboats, mooring the ship or maintenance work, extended training of 12 -30 months is required[79, Section A-VII/2]. Training to this standard is possible in many countries. For example, there are [80] in Egypt, [81] in Thailand and [82] in the Philippines. training centers.

The CDWS is striving to achieve a better standard of training for liveaboard crews in Egypt by offering training courses. The initiative for the qualification of liveaboard crews and the training for technical supervisors for liveaboard vessels are discussed here. The liveaboard crew qualification initiative does not offer a single training course. Instead, crew members are facilitated in achieving an official qualification through the [83]. It is unclear what standards are used for testing and there has been no response to an inquiry so far [84]. However, the STCW-Übereinkommen requires significantly longer training, which means that it is not tested according to this standard. The training to become a technical manager for liveaboard vessels is intended to improve their knowledge of possible dangers and rules for diving [85].

Rescue equipment also contributes greatly to the probability of survival. Therefore, the requirements for these are considered next.

4.6. Safety equipment and rescue equipment

Rescue equipment ranges from lifejackets to lifeboats and life rafts for abandoning ship. The number and position of the various life-saving appliances is regulated by the SOLAS--Konvention. The regulations on the design and construction of life-saving appliances are set out in the Lifsaving Appliences Code (LAS-Code).

There must be 8 lifebuoys on board a passenger ship, at least 6 of which must be fitted with automatic lights [53, Chapter III Part B Regulation 22.1]. All lifebuoys must be fitted in such a way that they can be released quickly and are not permanently attached [53, Chapter III Part B Regulation 7.1]. The buoyancy must be above 14.5 kg and lifebuoys must withstand fire for 2 seconds without catching fire themselves [86, Chapter 2.1.1].

The design and properties of lifebuoys are difficult to assess from the outside. However, there are often too few on board liveaboard vessels. In addition, the buoyancy aids are sometimes incorrectly fitted. For example, on board the „Emperor Elite“, where the lifebuoys are attached with cable ties (Fig. 17), so that their rapid deployment is hindered.

Lifejackets must also be kept on board for 5% more people than there are on board. These additional 5% must be stored outside cabins on deck. [53, Chapter III Part B Regulation 7.2 + 22.2]. In addition, 10% of the number of lifejackets must be available as children's lifejackets and lifejackets must also be on board for all babies [53, Chapter III Part B Regulation 7.2]. All lifejackets must be designed for a body weight of 140 kg and should keep the head above water even if the person is unconscious [86, Chapter 2.2.1].

These guidelines are not always adhered to on liveaboard vessels either. For example, the lifejackets on the „Emperor Elite“ are very simple and do not comply with the regulations, e.g. they do not have a collar (Fig. 18). This is not an isolated case. The lifejackets on the „Carlton Queen“ are also said to have had no collar [87]. Correct lifejackets have collars and can usually be stacked (Fig. 19).

Only two life rafts must be on board, which can accommodate all persons. There must be one island on each side of the ship [53, Chapter III Part B Regulation 21.1.4]. These must be equipped with paddles, first aid equipment, smoke and light signals, food, water and more [86, Chapter 4.1.5]. It must be possible to access the islands via a ramp or ladder [86, Chapter 4.2.4]. In addition, the liferafts must be marked with the manufacturer, serial number, date of manufacture, competent authority, maintenance record and capacity [86, Chapter 4.2.7].

These markings are also not filled in for the „Emperor Elite“ (Fig 20) and therefore no statement can be made about the functionality of the liferaft.

In addition, a lifeboat must be on board [53, Chapter III Part B Regulation 21.2]. This must be able to tow a life raft [86, Chapter 5.1.1.7]. Lifeboats must be equipped with more signaling equipment than life rafts. In addition, boat hooks and navigation equipment should be on board [86, Chapter 5.1.2]. Lifeboats are usually not available on liveaboard vessels. There are usually only dinghies intended for diving, which consist of a partially fixed and partially inflatable hull.

Most ships also use Automatic Identification System (AIS) for positioning and collision avoidance. This is completely absent on liveaboard vessels, which can be seen by the fact that these vessels are not found on vessel tracking websites such as Vesseltracker or MarineTraffic. The use of AIS is mandatory in the SOLAS-Konvention for passenger ships [53, Chapter V Regulation 19.2.4]

The basic safety equipment of a ship also includes anchoring equipment. This is laid down in the regulations of classification societies. The BV has defined a calculation for yachts based on the forces acting on the yacht. This takes into account forces caused by current and wind on various parts of the ship. These shares are added together with factors to form a comparative force [57, Part B Ch7 Sec 1.2.2]. For an exact calculation of this force, data on liveaboard vessels is unfortunately missing. The anchors and chains are then dimensioned using the comparative force [57, Part B Ch7 Sec 1.3]. Due to the complexity of this calculation, it is not possible to make any meaningful assumptions about values for liveaboard vessels in general, as the shape and size of the deck superstructures are discussed in detail and these can vary greatly from vessel to vessel. For this reason, the comparatively simpler design for steel ships is used. Here, an equipment coefficient is calculated from the displacement lateral area, height, width and funnel dimensions [88, Part B Ch12 Sec 4.1.2]. As an example, an equipment coefficient of approx. 191 is calculated for a liveaboard vessel with an above-water lateral area of 300 m^2, a height of 10 m above the water, a width of 7 m, a displacement of 110 t and no significant funnel. The number and weight of anchors and the dimensions for the chain are determined from this equipment coefficient from a table [88, Part B Ch12 Sec 4]. The equipment rating calculated for the example ship results in a weight of 570 kg for two anchors, which must be used on board. Chains with a length of 302.5 m and a diameter of 20.5 to 24 mm must also be used.

Many liveaboard vessels do not have large anchor systems. There are only cleats in the foredeck for the mooring lines in the reefs [89]. Small anchors are sometimes used for the reefs, such as on the „Ghazala Explorer“ (Fig. 26). Anchors are needed to be able to hold position in an emergency if the engine fails, even if they are not regularly used for anchoring. For example, the accident involving the „Omneia Soul“ or the „Emperor Echon“ could possibly have been prevented by deploying additional anchors.

5. Interaction of the regulations

These regulations form a tangle of different organizations and states that have a vested interest in the safety of ships. Flag states are obliged to check compliance with international regulations for ships flying their flag and have an interest in enforcing their own regulations. Classification societies are usually commissioned to carry out these inspections. They use the national and international regulations to draw up their own sets of rules according to which a ship can be built. These usually already contain the most relevant regulations. Additional requirements must be checked separately.

Together with the other regulations on training, life-saving appliances and regulations such as the ISM-Code, these building regulations form a safety net consisting of several layers. The Swiss cheese model is just such a net. The first layer consists of design and ship management decisions, both of which can prevent accidents such as fires. A further layer is formed by fire detectors, which prevent the fire from spreading by giving early warning and fighting it quickly. Only if both layers fail must an evacuation be considered at all. This is where crew training helps, which creates further layers. Only when several layers can be penetrated due to gaps such as poor training or malfunctions in the equipment does an actual emergency arise [90, p. 4]. Since a failure of one or more layers is always possible because it is never possible to establish seamless safety, as many layers as possible that contribute to safety must be established. In this way, the overlapping of all layers can be prevented.

What happens if there are only a few layers with a few gaps can be seen in the fire at „Conception “ in 2019, in which 34 people died. The report on this accident is discussed below.

6. Investigation into the fire at „Conception“

There is a detailed investigation report by NTSB on the fire on the „Conception“ on September 02, 2019. At the time of the accident, the ship was already 38 years old [23, p. 1] and therefore designed according to old regulations and standards. The „Conception“ caught fire while anchored off Santa Cruz Island (California, USA) at night and sank as a result.

6.1. Background information

The „Conception“ was 23m long and 8m wide. It had room for 46 overnight guests and a crew of 6 people [23, p. 3]. Compared to the Carlton Queen, this is a lot of people on a comparatively small ship. This was made possible by the fact that the guests slept in bunk beds on the lower deck [23, p. 4f] and there was only one shared shower. The layout and location of all the rooms are shown in a deck plan (Fig. 10). However, there is no plan for the tank deck. However, in contrast to the „Carlton Queen“ this is not so relevant for the course of the accident and the investigation.

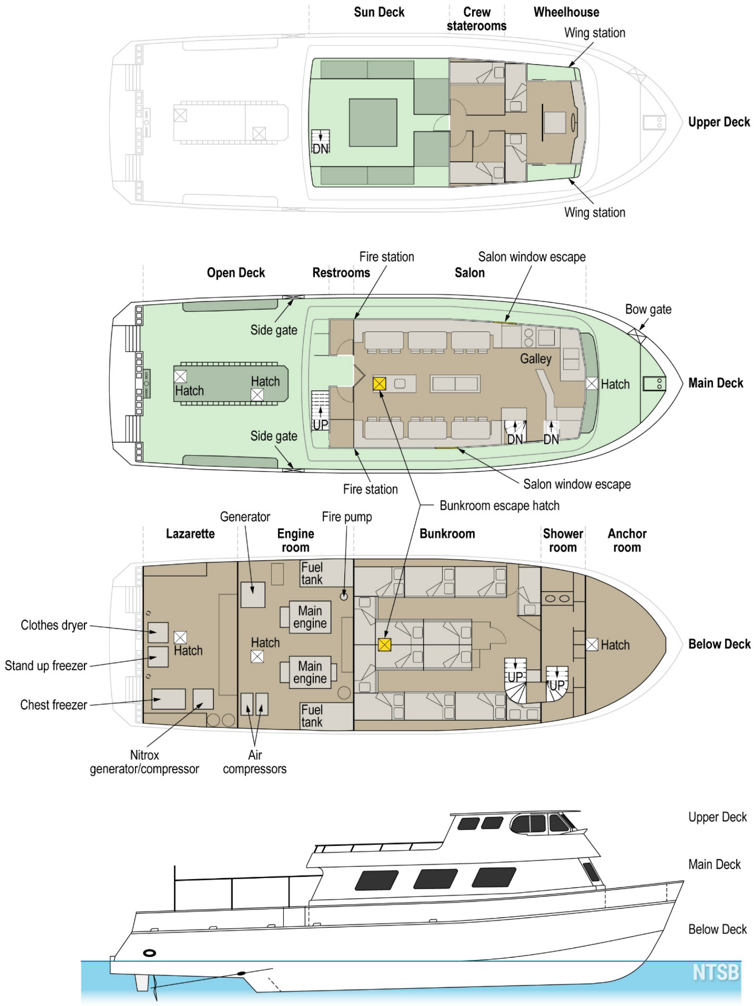

Figure 10: Deckplan Conception [23, p. 3]

6.2. course of the accident

The voyage began on August 31, 2019 with 33 guests, i.e. not with full occupancy [23, p. 7]. The crew was full at the start of the voyage. This allows the ship to depart on time at 4 a.m. A safety briefing is then given on safety equipment, escape routes from the saloon and dormitory, the assembly point in an emergency and diving safety. However, this was cut short after a guest fell unconscious. When the guest regained consciousness, the briefing was continued. However, some relevant topics were not covered.

The next two days went as planned and several dive sites on Santa Cruz Island were visited for diving. On the evening of September 1, after the last dive, some equipment was connected in the salon for recharging. Afterwards, both the guests and all crew members went to sleep. A night watch was not planned, although this is mandatory. [23, p. 9].

Shortly after half past two in the night, a crew member woke up and recognized the fire after becoming aware of it through noises. This crew member alerted the rest of the crew. At this point, the stairs from the upper deck to the main deck were already on fire and could no longer be used. The saloon was also already so engulfed in flames that it was impossible to escape through the emergency exits provided. One crew member and the second captain climbed down over the railing onto the main deck. Another crew member tried to jump and broke his leg [23, p. 10f]. On the main deck, two crew members tried to help the guests trapped in the lower deck escape from the burning saloon by opening a window at the bow. This failed due to the catches on the inside of the window.

In the meantime, the captain made an emergency call, which was received by the coastguard. However, the smoke forced him to leave the bridge while still talking and he jumped off the ship into the sea. This meant that not all the necessary information could be transmitted. The distress call was therefore misinterpreted as a medical emergency, as the captain said he could not breathe. As a result, the coastguard was initially unaware that the entire ship was on fire. The second captain and a crew member saw the apparently burning captain jump into the water. The second captain then jumped in after him to provide assistance [23, p. 11].

Further attempts to provide an escape route for the passengers failed due to the fire and the limited possibilities. The three remaining crew members also jumped off the ship after being ordered to do so by the captain. The second captain climbed back onto the stern of the ship and tried once again to rescue passengers via the access to the engine room. However, the smoke prevented him from doing so. He then launched a dinghy with the help of another crew member, who had also climbed back on deck. The crew member then tried to activate a fire pump, but failed due to the fire and smoke blocking the way [23, p. 12].

While the crew member tried to switch on the fire pump, the second captain picked up the captain with the dinghy. They then returned to the ship to pick up the crew member on the „Conception“ and the other two crew members. These five then sought refuge on a nearby pleasure craft, where they woke everyone on board. From there, the captain contacted the coastguard again and the other crew members were taken care of [23, p. 12].

Due to the hectic and unclear radio traffic between the „Conception“ and the Coast Guard, the latter initially only sent out vessels for a medical emergency. It was only when someone from the pleasure craft called again that it became clear that the „Conception“ was on fire and 34 people were still trapped in the hull [23, p. 13f].

The second captain and a crew member went back into the dinghy to search for more survivors. However, they gave up after a while and returned to the pleasure craft. An hour after the radio message went out from the pleasure craft, the first Coast Guard boat arrived, but it was not designed for firefighting. Other Coast Guard vessels gradually arrived and took part in the search for survivors and firefighting efforts [23, p. 16f]. The following mission lasts another nine days. Of the 39 people on board the „Conception“ at the time of the accident, 34 people died; the victims were all 33 guests and 1 crew member.

6.3. Possible causes of the fire

The NTSB initially investigated various possible locations where the fire could have started. The galley, the entire lower deck including the engine room, as well as the upper deck were ruled out as probable locations for the outbreak of the fire for various reasons. The reasons range from equipment such as ovens, engines and generators being switched off to statements made by the survivors about the spread of smoke and fire [23, p. 58f].

According to the crew, most of the saloon was already on fire when the fire was discovered, blocking the stairs to the upper deck. From the spread of the fire at this time and the possible objects that could have started the fire, the NTSB concludes that the fire originated in the aft part of the saloon [23, p. 59]. The lack of a night watch was contrary to regulations. However, compliance with this regulation was not monitored by the Coast Guard. The NTSB has therefore urged the Coast Guard to monitor this better [91].

The probable causes of the fire are then worked out. Attention is drawn to the electrical equipment charging in the rear of the saloon and also to the possibility of cigarette waste not being disposed of correctly. Some of the electrical equipment has been installed by the crew. Therefore, the NTSB assumes a spark due to faults in the electrical connections is possible. Charging batteries can also lead to fires if there is a fault [23, p. 60].

There are other possible causes of fire outside the saloon. The most likely causes there are the cigarette waste mentioned. The plastic waste garbage cans in this location can quickly cause a fire when combined with such waste. A report from other authorities claims that the fire started here [91]. However, the NTSB cannot rule out other causes of the fire [23, p. 61].

6.4. Problems with evacuation and rescue

A major problem at the „Conception“ was the escape routes. Both escape routes from the dormitory led into the lounge. This meant that the fire in the saloon could quickly block all escape routes from the lower deck and the saloon, thus trapping everyone sleeping on the lower deck [23, p. 67f]. The prescribed emergency drills were not carried out either [23, p. 48].

The rescue was made more difficult by the initially unclear situation for the coastguard. Initially, only a medical emergency was assumed and therefore no boats equipped for fire-fighting were sent out. Fire engines were only alerted after contact was made from the pleasure craft [23, p. 69].

6.5. Recommendations of the NTSB

The NTSB has made recommendations to both the Coast Guard and other organizations. The Coast Guard should require the installation of smoke alarms in all sleeping quarters on old and new passenger vessels. The smoke detectors should be interconnected so that all are activated when one is triggered. Furthermore, a crew member should carry out regular inspections. In addition, there should be two independent escape routes from guest rooms, which must not lead into the same room and cannot be blocked by a fire at the same time [23, p. 76].

Until this is adopted by the Coast Guard in its regulations, the NTSB recommends the voluntary installation of the described smoke detection systems and escape routes [23, p. 76f].

A recent accident, for which there is not yet an official investigation report, will now be analyzed. Possible causes and problems are worked out.

7. Analysis of the capsizing of the „Carlton Queen“

The „Carlton Queen“ capsized and sank on April 24, 2023. For a more detailed investigation, we spoke to those affected and contacted various authorities in Egypt. The Maritime Transport Sector of the Egyptian Ministry of Transport and the [92] have not responded to inquiries.

The „Carlton Queen“ was a newly refurbished and extended vessel that took guests on board for the first time this season. The construction was based on an existing hull.

7.1. Background information

With a length of 42 m and a width of 8.5 m, the „Carlton Queen“ was one of the larger liveaboard ships. To determine the height, the total height in pixels was measured from an image from the construction phase and compared with the known length in pixels (Fig.

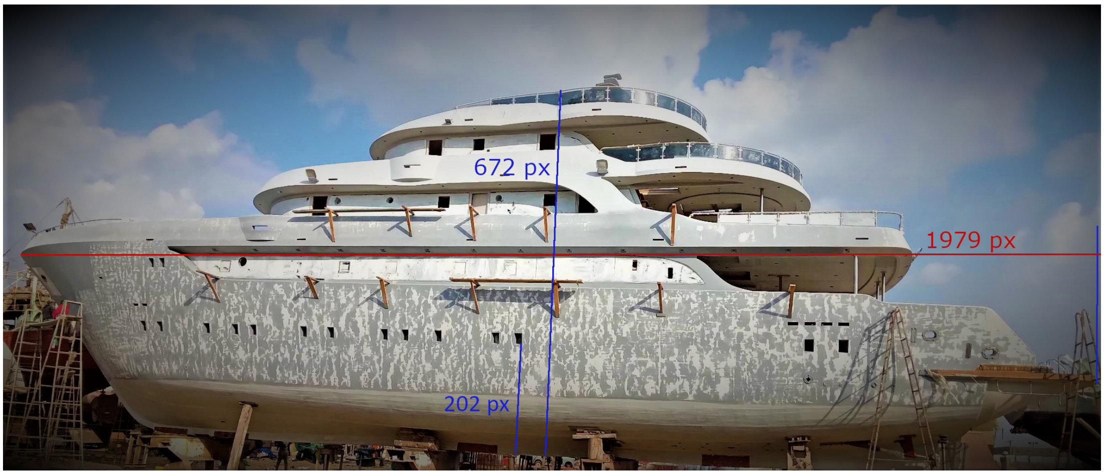

Figure 11: Measurement of the height of the Carlton Queen

A height of 14.3 m is obtained from the known length using a rule of three, ignoring both the perspective distortion of the image and the curvature of the bow. The calculated height should therefore only be regarded as an estimate. The ship was designed for 28 guests and a crew of 9.

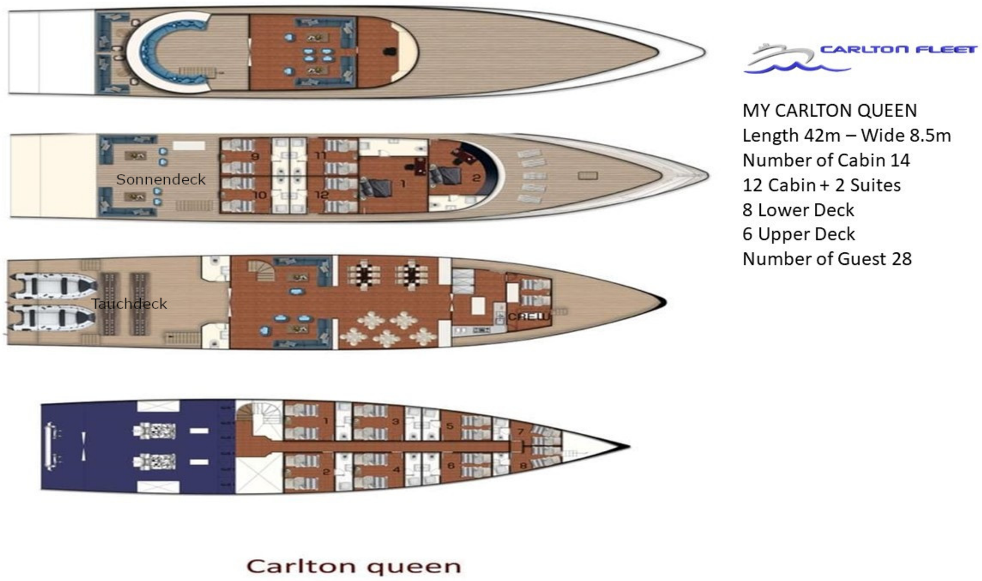

Figure 12: deck overview „Carlton Queen“ [93]

In fig. 12 there is no representation of the top deck, to which guests have no access, as only the bridge can be found there. There is also no plan of the tank deck.

The weather for the relevant sea area on the day of the accident shows sunshine and winds of around 20 km/h or 4 Beaufort from the west-northwest [94].

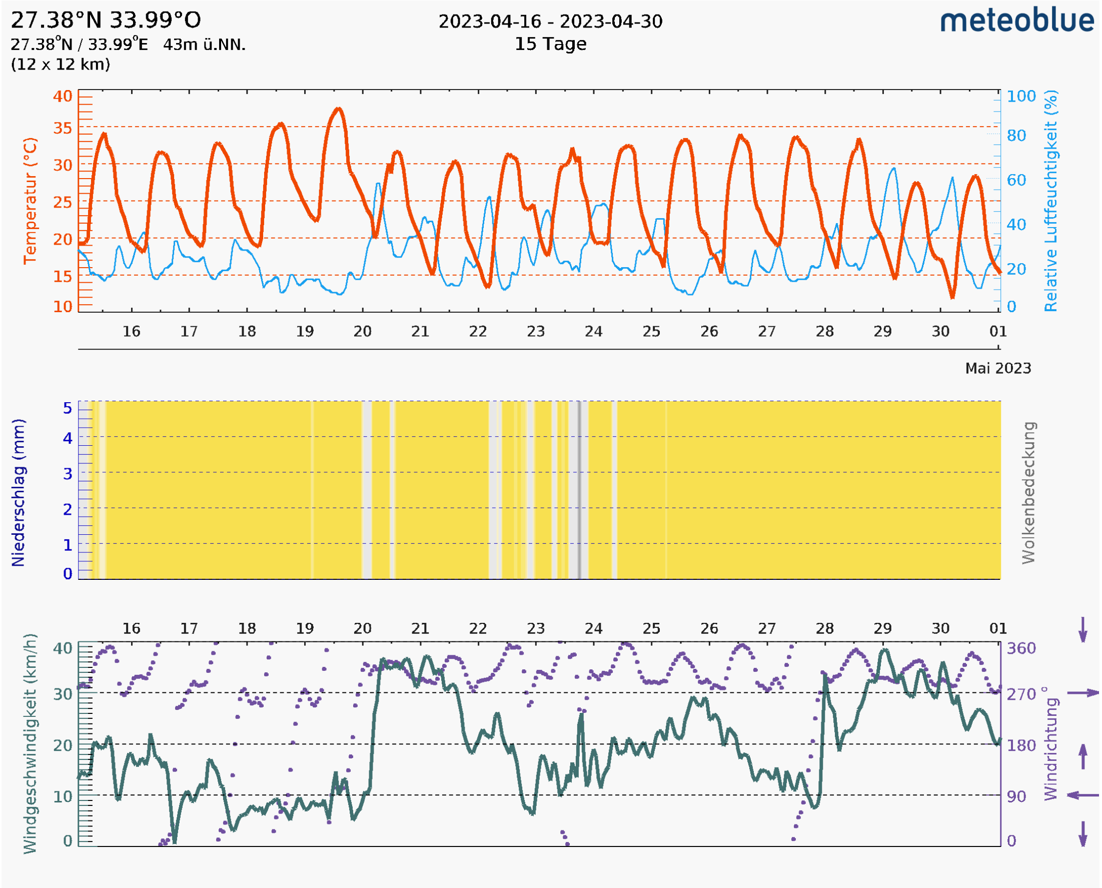

Figure 13: Weather at the scene of the accident at the end of April [94]

It should be noted that the values in Fig. 13 are not actual measured values, but simulation data. However, the aforementioned values can be considered sufficiently reliable and accurate. The course of the accident is described in the following section.

7.2. Course of the accident

This section is based on statements from guests who were on board the Carlton Queen at the time of the accident [87]. The guests boarded for the first time on 22.04.2023. At this time, a clearly visible heeling was already observed by the guests, which the crew attributed to the bunkering process. In the very brief safety briefing, life jackets under the beds and a hatch as an emergency exit in the foremost cabin for people below deck were pointed out. There was no emergency drill on this or any of the following days where the boat was evacuated for practice or at least evacuation plans were discussed.

The next day, the „Carlton Queen“ cast off for the first time for this voyage. At this point, there was no noticeable heeling on board. A so-called check dive to check the equipment and diving facilities as well as two planned dives were carried out without incident.

The morning of April 25, 2023 again brought a strong heel to port, which was first noticed by the surveyed guests at about 04:00. At this time, the ship was still moored to the reef with mooring lines. The crew used the lack of experience with mooring the new ship as a reason for the slanting position. After a morning meeting and breakfast, during which plates and glasses slipped due to the heeling, a long crossing began. This was to last most of the day. At the beginning of the crossing, the heeling became less pronounced again, so that the guests' anxiety subsided somewhat, as the guests had already completed the same tour the previous year and the ship had also made some strong rolling movements the previous year. After a short time, the „Carlton Queen“ began to roll. The roll shifted more and more to starboard by an angle of heel.

The heeling of the „Carton Queen“ then took on extreme angles within three rolling periods. The ship remained in the heavily heeled floating position for 30 seconds to over a minute. This was the beginning of the capsize. At this point, there were 10-12 people on the sun deck above the diving deck, 3 in the saloon and 3 more below deck. The majority of the crew were in their cabins forward. There were 3-5 people on the top deck. Some guests were in their cabins on the upper deck. Other people were spread out over the entire ship. When the first extreme angle was reached, the compressors were presumably torn from their moorings, although this has not been confirmed. Due to this strong heel, some people fell from the ship. There were no lifebuoys or other buoyancy aids to help them.

After the last rolling period, the ship did not recover and remained on its starboard side. The port side of the ship was now protruding almost horizontally out of the water and some people were standing on this side of the ship. As a result, some guests tried to get rescue equipment ready. There were no instructions from the captain or the crew at any time. The life raft on the port side of the ship was lowered into the water. When it was released with a ripcord, it floated in the water on the roof and could not be turned over. Only one of the two dinghies could be freed from the diving deck. The other was too heavily wedged. But even this dinghy was not fully operational, as one of the hoses was losing a lot of air. This boat was manned by a dive guide and another crew member in order to rescue the people in the water. The second life raft was now also lowered into the water. This was fully deployable, but quickly drifted off as it was not connected to the ship. A slow evacuation now began.

At this point, there were still three people below deck. There was neither emergency power nor self-luminous signage. These three people checked each of the cabins below deck for other people. They then tried to get out via the forward emergency exit towards the bow. The door of the emergency exit could not be opened even with three people. When all three arrived back at the aft stairs, the water was already slowly rising and only two people could be lifted up to the saloon via the stairs that were now on the ceiling. This left one person on the lower deck. The others were able to leave the ship via the saloon and the diving deck.

The majority of the people on board escaped into the one functioning life raft, which was significantly overloaded as a result. There was no manifest to check the presence of guests and crew. As a result, it only became clear late on that one person was still trapped in the ship. At this point, the life raft had already drifted too far to swim back to the ship. Three signal rockets were found in the life raft. The people in the island fired two of them. However, these only left a trail of smoke and no flare. The crew of a nearby freighter nevertheless saw the signal and turned around. The capsizing was also observed by another liveaboard vessel, which immediately launched a dinghy for assistance.

The last person on the „Carlton Queen“ took advantage of the rising water to reach the stairs after all. This person then had to dive through the saloon, which still had just enough air for two breaths, and the diving deck. This person was then able to leave the ship and climbed to the highest point of the capsized ship to attract attention.

All persons were rescued by the dinghy of the second liveaboard and transferred to it. On the available footage, none of the rescued persons is wearing a lifejacket, which illustrates the lack of coordination during the rescue. The second liveaboard initially brought everyone back to the dive spot where the journey had started in the morning, as there were other liveaboard vessels there. One of these ships had a well-equipped doctor on board who took care of the injured. Shortly afterwards, the guests were brought ashore. The events on land are not part of this work.

In the following section, possible causes for the capsizing are discussed.

7.3. Possible causes of the capsize

The heeling already during bunkering indicates a very low basic stability and shows that no standard procedures were used for bunkering. However, it appears that the vessel was sufficiently stable at the time of departure. The heeling that occurred due to the mooring of the vessel is very unlikely.

Since the wind tended to die down in the course of the voyage, this is also unlikely to be the cause. However, a strong gust cannot be ruled out, although none of the interviewees mentioned anything that would suggest a gust [87]. In general, the wind speed was around 20 km/h or 4 bft (Fig. 13).

However, the roll that built up during the crossing on the day of the accident suggests that the wave period was a multiple of the ship's own roll period. This similarity in frequency results in steadily increasing roll angles. Due to this resonance, the rolling motion increases with each wave [95, p. 222]. However, the wave period that the ship experiences can be influenced by changing course or speed [95, p. 235-237]. In this way, a capsize can be prevented by this rolling motion by good ship handling. Waves in or against the direction of travel can also have a negative impact on stability by partially lifting the ship out of the water. Waves with a wavelength equal to the length of the ship reduce stability the most [95, p. 224]. Videos show that the waves are not particularly high [96]. The wave height is estimated at a maximum of 2 m, 1 m is more likely, but without an actual scale this can only be roughly assessed from videos. Therefore, a higher wave is assumed to assess maximum stability. 2 m high waves are very rare in the north of the Red Sea [97, p. 4522]. The waves usually have a period of 3 to 6 s [97, p. 4524].

The stability is calculated using a series of distances between the points relevant for the stability (Fig. 27). The roll period of the ship depends on the $\overline{GM}$, the width and a factor c, which is between 0.8 and 0.9 for yachts [95, p. 141].

$$T_0 = \frac{\pi c B}{\sqrt{g\overline{GM}}} \tag{7.1}$$

Assuming an $\overline{GM}$ of 0.3 m and a c of 0.85, this results in a roll period of 13 s for the „Carlton Queen“Ȧccordingly, it is unlikely that resonance has occurred, although resonance can also be generated by multiples of the roll period. In addition, the frequency of the waves may have been influenced by unfavorable ship routing [95, p.237].

Furthermore, the windows in the showers on the lower deck could be opened [87]. If the state of closure of these windows is not sufficiently controlled, water can very easily penetrate through such an open window, even if it is weather or watertight when closed.

Figure 14: height of the windows

If the length of the ship is taken as known and measured with 2910 pixels in length in the image, an estimate of the height of the windows above the water surface can be made. This does not take into account the perspective distortion of the image or the curvature of the bow. This is therefore only a rough estimate. A rule of three with these measurement results gives a height of the windows above the water surface of only 2.1 m. Similarly, from Fig. 11 that these windows are 4.3 m above the keel. This low height leads to possible water absorption even with small rolling movements or high waves if the windows are open or not completely sealed. Water absorption rapidly reduces stability, as the windows represent a leak in such a case. However, water is only reported in the lower deck after capsizing. As the windows were small and you couldn't stick your head through them [87], they are treated as portholes here, although it is not possible to measure their exact size. According to the Convention on Load Lines, portholes are a maximum of 0.16 m^2 in size and may not be installed below 0.5 m above the summer load line. In addition, they may only be opened if the result of the leak stability calculation shows that the porthole does not submerge even in the event of a leak [98, Annex I Regulation 23]. Since a corresponding leakage calculation is not available, it is not possible to assess the extent to which this regulation was complied with.

The heeling during bunkering and while the vessel was moored indicates low initial stability and possible errors in the ballast distribution. Incorrect use of off-center tanks or errors when filling ballast water tanks can also reduce stability. However, there is no information about the tank deck and the use of ballast. Therefore, no further analysis is possible in this regard.

Due to the low stability from the beginning, the distance $\overline{GM}$, which is a good measure of the initial stability, is assumed to be 0.3 m. For an analysis of the center of gravity $\overline{KG}$, an $\overline{KB}$ is determined from images of the stern and an $\overline{BM}$ from the lowest deck from the deck plan (Fig. 12), since the $\overline{GM}$ can be calculated according to Meyer-Bohe [99, p. 14-16]:

$$\overline{GM} = \overline{KM} - \overline{KG} \tag{7.2}$$

$$\overline{KG} = \overline{KB} + \overline{BM} \tag{7.3}$$

$$\overline{BM} = \frac{I_T}{V} \tag{7.4}$$

The $\overline{KB}$ is determined from a stern view, as the center of the submerged surface (Fig. 24). For the position of the waterline, i.e. the upper edge of the polyline, which forms the submerged surface, the height of the platform at the stern above the water was determined from the side view (Fig. 14) at approximately one meter and this distance was selected for the waterline. The calculated $\overline{KB}$ from this frame is only 1.5 m with a draught of 2.5 m.

The displaced volume must first be calculated for the $\overline{BM}$. A block coefficient is calculated from two comparable liveaboard vessels in order to estimate the displaced volume of the „Carlton Queen“

$$c_B = \frac{V}{L * B * T} \tag{7.5}$$

The comparison ships for this are the „Caribbean Explorer II“ with a block coefficient of $c_B = 0.136$ [2] and the „Seahorse“ with a block coefficient of $c_B = 0.176$ [3]. It should be noted that these ships both have a greater draught than the „Carlton Queen“ and for the block coefficients the length and width over all is used instead of the length and width of the waterline, as this corresponds to the values known for the „Carlton Queen“The mean value is 0.156. This means that the volume of the „Carlton Queen“ is 139 m^3.

The waterline of the lower deck is used to determine the waterline moment of inertia. As the deck plan has been distorted and does not match the length and width of the ship, it is transformed back so that the length and width of the outline for the top deck match the actual values of the ship. The waterline is used from this plan and measured with a surface moment of inertia of 1244 m^4 (Fig. 23). From this and the displaced volume, an $\overline{BM}$ of 8.9 m is calculated. The resulting $\overline{KG}$ is 10.4m. This results in an $\overline{KG}$, i.e. the height of the center of gravity of 10.1 m. This is very high for a total height of 14.3 m. The center of gravity is approximately at the height of the railing of the first upper deck. Such a high center of gravity is unlikely, as most of the equipment for diving and operating the ship and the tenders are located on the lower two decks. However, the center of gravity may also be shifted upwards due to the use of fuel in the tank deck. However, the $\overline{GM}$ must be significantly greater to reduce heeling, as an analysis of the heeling moment due to the wind shows.

To estimate the heeling moment due to wind, the lateral area was determined from a lateral image of the „Carlton Queen“ (Fig. 15).

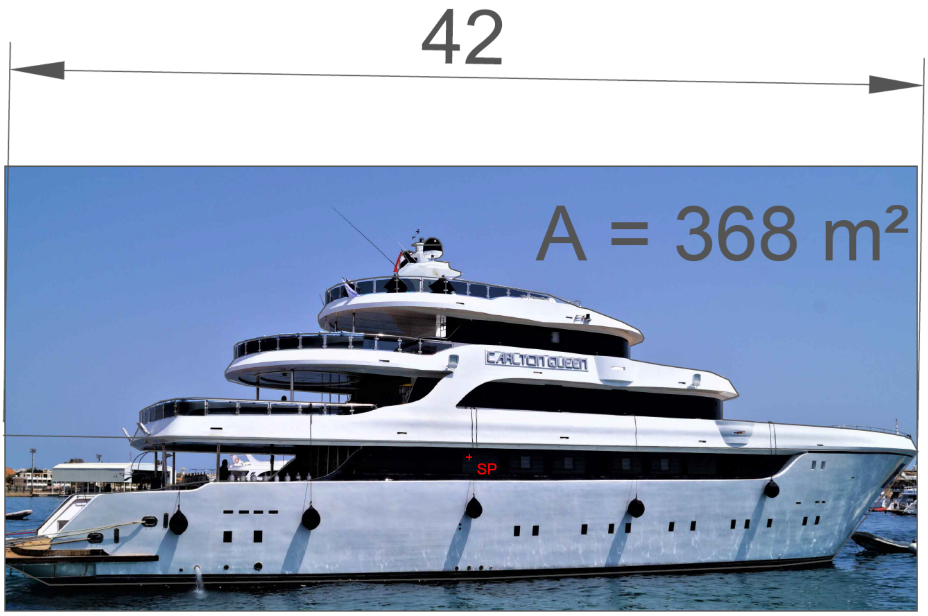

Figure 15: Page lateral surface determined from AutoCAD

The determined area can only be roughly compared with the actual area, as the perspective makes it much more difficult to determine. The shooting angle from aft visually shortens the ship and reduces the size of the bow by adding depth. In addition, the upper decks cannot be depicted well, as the covered deck areas are shown larger when viewed from below. These were depicted with a larger area, as this reduces the effect of image depth. The center of gravity marked in red is at a height of 5.8 m. This position is not exact due to the aforementioned problem. However, the distortion has a much greater influence on the position along the length of the ship. Therefore, an estimated value for the wind moment is calculated using this area and center of gravity position. A wind pressure of 115 Pa or 38 Pa is calculated, which corresponds to a wind force of 6 bft or 4 bft [100]. These wind forces were chosen because 4 bft corresponds to the average wind speed on the day of the accident and 6 bft in a gust is still realistic for that day. This results in a heeling moment of 81 kN for the average wind and 245 kN for gusts. With the previously calculated displacement, this corresponds to heeling levers of 0.569 m and 1.72 m according to Meyer-Bohe [99, p. 39]. With the assumed $\overline{GM}$ of 0.3 m, these lead to angles at which the small angle approximation [99, p. 13] is no longer applicable.

$$h = \overline{GM} \sin \varphi \tag{7.6}$$

A lever arm curve would therefore be necessary. However, this cannot be calculated from the limited data. To reduce the heel angle to 16°, as required by the IS-Code [42, Chapter 2.3.1.2], the $\overline{GM}$ must be 2 m or 6.2 m in the small angle approximation (7.6). These values are definitely not met, even if the estimated $\overline{GM}$ is too low by a factor of 6.

From the stern view with the frame for the $\overline{KB}$ (Fig. 24), a minimum angle can also be calculated at which the windows come to water, whereby waves are not taken into account. A curved frame is drawn for this. This has the same area as the frame without heeling and has the height on the starboard side up to the lower edge of the windows (4.3 m), as shown in Fig. 11 can be determined by pixel measurement. The area must remain the same so that the displacement does not change. Changes due to the shape of the ship are ignored, which can also result in trim angles or a slightly different angle. In order to determine these changes, pantocarenes and a more extensive stability calculation would be necessary, for which the data is missing. The angle resulting from this analysis is 27° (Fig. 16). This can be significantly reduced by waves, as they partially overcome the height above the water. This is low for windows that are to be opened given the low initial stability of the„Carlton Queen“.

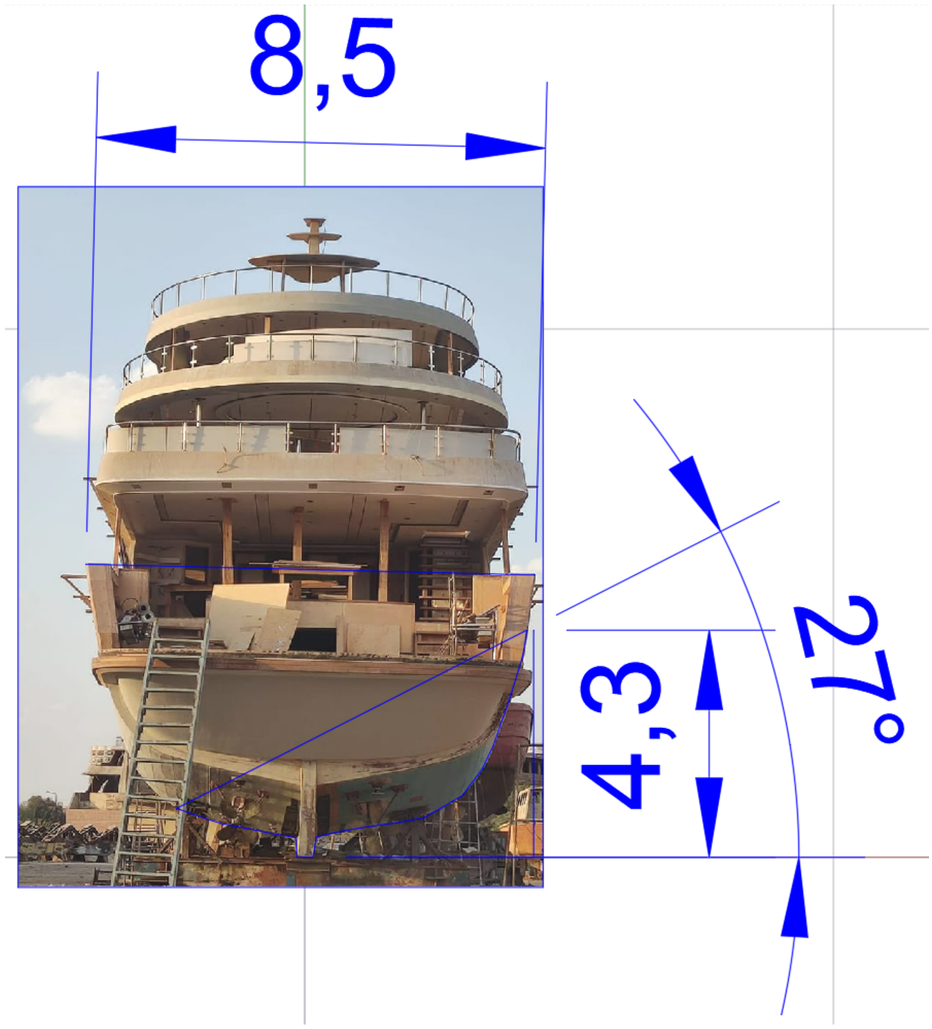

Figure 16: Angle at which windows reach water determined from AutoCAD

The extreme inclination quickly made the staircase difficult to access. These and other problems are now considered.

7.4. Problems during evacuation and rescue

The lack of instructions from the crew meant that some of the rescue equipment was probably used incorrectly. As the liferafts were not equipped with an automatic system for inflating to a certain depth [86, Chapter 4.1.6], the liferaft containers were thrown into the water without anyone being informed about how to open them and that the lifeline had to be attached on board. This lack of information delayed the inflation of the life rafts. In addition, the life rafts were not attached to the ship with a line that would be released if the ship actually sank. The life rafts could therefore drift away unhindered. Normally, instructions are displayed as pictograms on the containers. However, untrained people can easily overlook such instructions in an emergency situation or not implement them sufficiently.

According to the LAS-Code, life rafts must be able to be turned from the upside down position to the correct position by just one person in calm seas [86, Chapter 4.2.5]. Accordingly, it should have been possible for two people to turn the life raft that was deployed first, even if the weather was not calm. It should at least have been possible to ensure the usability of this life raft with the help of the inflatable boat. However, only two untrained people attempted to turn the rafts over and they gave up after a short time. The damaged dinghy was not used for support. If you are not trained in the correct technique, raising a life raft could be difficult. It is therefore likely that the liferaft could have been raised if this had been attempted by trained persons.

From a capacity perspective, the existing liferafts were sufficient according to SOLAS-Konvention if the tenders can be launched as lifeboats [53, Chapter III Part B Regulation 21]. However, since there was no equipment on the dinghies, such as signaling devices, a searchlight, first aid equipment, equipment to prevent hypothermia and safety knives, they cannot be used as lifeboats, which means that there is not enough capacity here either.

The crew would have had to search all cabins, as must be practiced in training according to the
STCW-Übereinkommen. It was also reported that some of the crew were unable to swim, meaning that they could not contribute to the rescue without hindrance [87].

The inadequate safety briefing for the guests contributed to the fact that they did not know any assembly points. In addition, the use of the available rescue equipment was not explained. It is possible that the crew did not have this knowledge either, as otherwise they would have known how to turn over a life raft floating on the roof. This lack of expertise indicates a considerable lack of training on the part of the crew.

The ship's furnishings were only partially secured properly, so that some pieces of furniture in the saloon slipped through the room when the ship capsized (Fig. 21). This led to injuries and made it difficult to move through the ship. The deck plan (Fig. 12) shows that capsizing to starboard makes the stairs to the lower deck very difficult to access, as they are not located amidships. In addition, there is no handrail installed on the stairs and only the steps are covered with mats to prevent slipping (Fig.22). There are also no handrails on the sides of the gangway to make it easier to move around the ship in the event of strong ship movements. Such handrails are common on other seagoing vessels.

Three people were unable to open the emergency exit in the bow with joint effort [87]. One possible explanation for this is that the hatch was already under water at the time of the opening attempts and was thus closed by the water pressure. However, it could also be that the hatch was blocked by something else. The hatch was not specially marked on the foredeck, as otherwise it would probably have been noticed by the guests. It is therefore also conceivable that someone had placed something on it. Escape routes on board liveaboard vessels are often poorly designed. On the „Emperor Elite“ the transom above the washbasin in the bow cabin was the emergency exit (Fig. 25). This contradicts the requirement that there should be no obstacles in the way [53, Chapter II Part D Regulation 13], as you have to climb over the sink to use the exit.

The following chapter summarizes the findings from this work.

8. Summary

For a statistical analysis, 31 accidents from the years 2009 to August 2023 were analyzed. This analysis has a high variance and relatively low significance. The poor data situation due to a lack of accident reports and thus almost only media articles as sources did not allow a reliable analysis. For this reason, the analysis focuses on the serious accidents that generated media coverage.

Fire, grounding and lack of stability were identified as the main causes of accidents. The high proportion of groundings can be partly explained by the sailing area near reefs. The majority of ships sink after the accident.

Every year there is an arithmetic average of 1.7 accidents with an upward trend. On average, 1.8 people die per accident. If the accident involving the „Conception“ is not taken into account as an outlier, the figures are significantly lower. Despite the high number of accidents caused by grounding, there were no fatalities in the accidents considered. All fatalities in this analysis occurred in fires or capsizing. At least one person died in more than half of the accidents, particularly in the case of lack of stability.

When analyzing the accident locations, two concentration points quickly emerged: the Red Sea off Egypt and the islands of Southeast Asia. Accidents are particularly frequent in Egypt.

A comparison with merchant shipping shows that there are more than twice as many accidents per ship in liveaboard shipping. When analyzing the causes of accidents, there is also a clear difference in the frequency of fires, which result in 2.6 times as many shipwrecks on liveaboard vessels. On the other hand, capsizing is responsible for more ship losses in global shipping. In merchant shipping, only a few people die in fires. In comparison, far fewer people die on large ships when they capsize. However, it is not possible to make precise comparisons due to the lack of clear data on people on ships and the different periods covered by the statistics.

The analysis of two accidents also revealed clear deficiencies in the safety equipment. Some of the life rafts were not properly maintained. Lifeboats were replaced on board by dinghies that were not correctly equipped, so that the capacity according to SOLAS--Konvention was not reached. As this is not mandatory for liveaboard vessels, this is a problem of missing regulations. Other equipment such as lifebuoys are often not on board in sufficient numbers, are not fitted correctly or do not meet the usual standards, such as lifejackets. The two required escape routes from the rooms are usually maintained on board. However, these are not always usable, so that in emergency situations there is often only one exit available. In some cases, this is also difficult to reach. The accidents also show a lack of training and errors in ship management. For example, correct evacuation or night watches are apparently not carried out.

Subsequently, regulations from international and regional organizations are examined with regard to fire protection and stability. This serves to identify possible solutions to prevent such accidents in the future. The possible applicability and validity in relation to liveaboard vessels is assessed. These regulations are summarized here in two tables (Table 5 and 6). It was recognized that almost no regulations are mandatory for liveaboard vessels.

Regulation	fire alarms	fixed extinguishing devices	movable extinguishing devices
SOLAS	every room except empty rooms, sanitary rooms, etc.	two extinguishing water pumps and hydrants, hose must be able to reach entire ship; extinguishing system in engine rooms	fire extinguishers for each room for guests
SCV-Code	all unmanned rooms and guest rooms	one extinguishing water pump, hose must be able to reach the entire ship; extinguishing systems in engine rooms	one fire extinguisher per 232.3 m^2, one per bridge, engine room, galley, pantry
BV	all rooms that do not have a particularly low fire risk, escape routes	extinguishing water pumps according to flow rate, etc.; extinguishing system in engine rooms	min. 3 fire extinguishers every 10m one
DNV	all rooms that do not have a particularly low fire risk	one extinguishing water pump and hydrant + hose must be able to reach the entire ship	fire extinguishers according to national regulations
EU EN ISO 9094:2022	all engine rooms and living areas	extinguishing system for each engine	one extinguisher per 20 m^2 maximum 5 m away from sleeping areas
BG Verkehr 2009/45/EC	all corridors and escape routes as well as a maximum distance of 11 m	extinguishing water pumps according to volume flow, hose must be able to reach the entire ship, sprinkler system throughout the ship	one fire extinguisher per 10 m, one fire extinguisher on the bridge, and in other endangered places

Table 5: Summary of fire safety regulations

Regulation	intact stability	leak stability
SOLAS	IS-Code	probabilistic leakage calculation for new ships, consideration of bulkheads in old regulations
SCV-Code	stability test	collision bulkhead + further bulkheads according to calculated distance
BV	IS-Code with $\cos^2$ for wind moment	flooding of any compartment + assessment of the floating position
DNV	close to the IS-Code + stability test	flooding of any compartment through a defined leak, assessment of the floating position
EU EN ISO 12271-1:2021	constant wind moment similar to weather criterion	freeboard and buoyancy reserve with calculated flooding height
BG Verkehr	IS-Code + free surfaces/ operating heeling test	reference to SOLAS-Konvention

Table 6: Summary of the regulations on stability

Regulations from the relevant countries could not be examined as they did not provide any information despite repeated requests. In order to counter this unsatisfactory safety supervision, the diving tourism industry is attempting to regulate itself. For example, the ADTO is currently creating a quality seal that provides for an annual review.

The training standards of the IMO were then summarized and the STCW--Übereinkommen defines training standards for dealing with guests and behavior in emergencies. The most important parts include knowledge of escape routes and communication. Familiarity with the equipment on board, personal survival equipment and knowledge about the development of fires are also required.

The regulations on rescue equipment were dealt with next. There must be 8 lifebuoys and 5% more lifejackets than people on board on passenger ships of a relevant size. In addition, there must be two life rafts for all persons on board. The one lifeboat required by the SOLAS-Konvention is usually missing on liveaboard vessels. The anchoring equipment is also considered.

When investigating the fire on the „Conception" the NTSB considers a fire caused by charging battery-powered devices and batteries in the saloon or a fire in a garbage can to be the most likely places where the fire broke out. The NTSB then called for stricter guidelines on fire safety and escape routes, especially for old ships, which the US Coast Guard has since implemented.

The capsizing of the „Carlton Queen" was then analyzed. The course of the capsize indicates that the ship was very unstable. At the time of the accident, the wind was not strong enough to cause a correctly designed ship to capsize. Waves in conjunction with the opening windows on the lower deck are considered to be the probable cause. The waves caused the vessel to roll and water may have entered the vessel through a leaking window, further reducing stability. The wind probably also contributed to significant heeling, as the ship had a very large windage area.

The capacity of the life-saving equipment was insufficient as there was no lifeboat. The lifejackets and life rafts were correctly equipped on board. The evacuation was not planned. Only one escape route from the lower deck was usable and access to it was considerably more difficult.

Based on this summary, short and long-term safety recommendations are made below. These are also summarized in table 7.

9. Recommendations

Since the SOLAS-Konvention is voluntary for liveaboard vessels due to the national sailing areas and size and cooperation with classification societies is only sporadic, clear mandatory regulations must be introduced at national level or by the industry itself. The beginnings are currently being made by the ADTO.

There is a consensus in the international and national guidelines on firefighting regulations that fire alarms must be installed in all areas for guests as a minimum. This includes the engine rooms, where a detection system should also be installed. Attention should be paid to fire alarms in all guest areas at short notice. The fire cannot spread as far before it is discovered, making it even easier to extinguish and blocking fewer paths on board. In this way, such regulations can mitigate or prevent accidents such as that of „Conception“ through early fire detection. In addition to the fire alarm systems, the extinguishing equipment must also be clearly defined. The installation of fire extinguishers is required in the short term. The number and position of these can be designed according to area as in the SCV-Code or via distances as in BV. It makes sense to adopt the rule from the EU standard for passenger ships that fire extinguishers must not be installed in cabins, as access to them is not always possible. These fire extinguishers allow smaller fires such as incipient fires to be extinguished quickly before they become dangerous. In the longer term, a permanently installed extinguishing system is a useful extension to be able to extinguish larger fires. Permanently installed extinguishing water pumps or sprinkler systems are expensive to retrofit and would cause a significant change in stability due to the additional weight. Such systems are therefore probably only applicable to new ships and should therefore be planned for the long term. However, almost all regulations insist on fire pumps that can cover the entire ship with hoses. These regulations should also become mandatory for new liveaboard vessels.

Similarly, there are also some regulations on stability that make sense. The regulations are largely based on the IS-Code. This is a very good basis for ships of all sizes without sails. A consideration of the heeling moment due to wind with more precise methods such as a cosine or quadratic cosine should be used (table 6), as this better reflects reality and the conservative reserves from the IS-Code become smaller. The biggest problem in creating a stability manual is the lack of digital models for liveaboard vessels. A calculation based on other applicable regulations is the best solution. A calculation of the stability from drawings costs roughly 35,000 euros at a German shipyard [101]. If the documents for a ship are not sufficient for a calculation, it is also possible to take measurements using a 3D scan. This can also be used to perform a calculation [102]. A stability test is another way of estimating the stability of a ship. This would cost around 20,000 euros at a German shipyard [101]. Both are required by DNV, but one of the two methods is sufficient to make a statement about stability. Therefore, the stability of each ship should be verified either by calculation or by a test. This can prevent many accidents for stability reasons.

Due to the proximity to reefs on liveaboards, sufficient precautions must be taken to avoid grounding and sinking after water ingress. A probabilistic view of the leakage calculation is clearly too complex to establish an initial improvement, as this requires a digital model. Therefore, a consideration of the subdivision and placement of bulkheads is sufficient for the first. However, retrofitting bulkheads is very expensive, depending on what needs to be converted. The costs here can also exceed 200,000 euros. However, the prices are highly dependent on the ship and the work required [101]. The regulations of the BV are recommended, as it has already certified the liveaboard ship „Royal Evolution"Ḣowever, this is probably not feasible for existing liveaboard vessels due to the high costs. An echo sounder that looks ahead can also be used to avert groundings. However, due to the limited range, these can only provide enough time to prevent grounding at very slow speeds [103]. A final examination of all documents by a classification society costs around 15,000 euros [101].

The training standards of the IMO are difficult to meet in the short term, as training takes at least 12 months. However, the training of the crew in Egypt is apparently not sufficient or the level of training is not sufficiently monitored. This cannot be verified without further information on the ongoing training in Egypt. However, training in accordance with STCW-Übereinkommen is necessary in the long term in order to improve the execution of evacuations and the handling of emergencies.

The quantity and quality of the existing life-saving equipment on board liveaboard vessels is insufficient in some cases. Attention must be paid to correct certification and sufficient maintenance. This can easily be ensured by regular inspections. Attachment is often inadequate. Attention must be paid to the ease of deployment of life rafts and other equipment. For example, the heavy containers of life rafts should be attached to racks from which they only need to be rolled down or can be lowered into the water via davits. The position and design must be carefully considered, which is why it is not possible to implement this measure on every liveaboard. However, the handling of this equipment must be mastered by the crew and discussed or practiced with the guests. The safety briefings must include at least one tour in which assembly points, escape routes and the equipment are shown. The use of life jackets must be demonstrated and preferably practiced with the guests. Safety equipment also includes anchoring equipment. The regulations of the BV are recommended. In these, the regulations for yachts should be used in order to use a better interpretation than the rough estimate of commercial vessels.

Although there are often several emergency exits, as required by most regulations, these cannot always be used. The usability of escape routes must also be ensured in emergency situations. This must be checked regularly and ensured by means of suitable markings. The equipment on the ships must also be secured in such a way that it cannot become a hazard as long as this is possible. Handrails are also necessary for free movement in the ship in heavy seas. The most relevant points are summarized once again in a conclusion.

These recommendations can also be found in Table 7. In the long term, certification by classification societies should be sought. This would give liveaboard vessels the same level of safety as large international vessels.

10. Conclusion

There are almost no mandatory regulations that liveaboard vessels must comply with. However, existing regulations can be used to create their own sensible regulations for liveaboard vessels. Due to the current poor level of safety and often ineffective national safety supervision, action by the diving industry for self-regulation is urgently required. If the current series of accidents continues, guests are likely to stay away. The ADTO's initiative to improve safety on liveaboard vessels sends an important signal in this regard. Further regulations include fire alarms and fire extinguishers in all guest rooms for fire protection and stability tests or stability calculations with minimum requirements in accordance with the IS-Code for increased stability. In the medium term, fixed fire extinguishing equipment such as extinguishing water pumps and bulkheads for leaks should be installed in new ships. In the long term, official certification of liveaboard vessels by classification societies should be sought.

In a longer investigation with access to some ships and inspection of their documents, it would also be possible to assess the design and make more precise statements on improvements. Due to the poor data situation and lack of access to relevant design documents, only rough recommendations could be made in this study. In further work, these recommendations must be further elaborated so that they can also be applied directly. This requires discourse with more operators and owners of liveaboard vessels as well as people with more experience in shipbuilding. Such activities should result in clear guidelines for the stability tests and calculations, as well as a timeframe for meeting short and long-term safety improvements. In addition, it must be clarified how the implementation of the recommendations can be incorporated into normal maintenance cycles and shipyard visits.

This work provides an initial starting point for this further work. The necessary safety measures will require extensive further work in order to implement these improvements across the board.

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A. Annex

BIBLIOGRAPGHY ——————————————————————

scources

[1] International maritime Organization. *IMO identification number schemes.* 2023. URL: https://www.imo.org/en/ourwork/msas/pages/imo-identification-number-scheme.aspx (visited on 10/04/2023).

[2] Explorer Ventures Fleet®. *Caribbean Explorer II | OFFICIAL | Saba & St. Kitts Liveaboard Diving.* 3.02.2023. URL: https://www.explorerventures.com/saba-st-kitts/caribbean-explorer-vessel-layout/ (visited on 10/17/2023).

[3] Wallacea Dive Cruises. *MSY Seahorse luxury Liveaboard - Wallacea Dive Cruise.* 2023. URL: https://www.wallacea-divecruise.com/liveaboard/msy-seahorse (visited on 10/17/2023).

[4] taucher.net. *M/Y Dolce Vita - Bericht von wirbelwind bei Taucher.Net.* 2006. URL: https://taucher.net/liveaboard-m_y_dolce_vita-bericht-blz30290 (visited on 08/02/2023).

[5] taucher.net. *Eilmeldung: Heaven Diamond abgebrannt! - Diveinside News.* 2008. URL: https://taucher.net/diveinside-eilmeldung__heaven_diamond_abgebrannt_-kaz3525 (visited on 08/02/2023).

[6] N-TV. "Boot in Thailand gesunken: Europäerin tot geborgen". In: *n-tv NACHRICHTEN* (2009-03-10). URL: https://www.n-tv.de/panorama/Europaeerin-tot-geborgen-article59932.html (visited on 08/03/2023).

[7] CDWS. *Update: liveaboard incident in Sharm el Sheikh.* 2009. URL: https://cdws.travel/news/update-liveaboard-incident-in-sharm-el-sheikh (visited on 08/03/2023).

[8] CDWS. *Red Sea liveaboard Emperor Fraser sinks.* 2009. URL: https://cdws.travel/news/red-sea-liveaboard-emperor-fraser-sinks (visited on 08/03/2023).

[9] Matt J. Weiss. *Siren Fleet Tragically Loses Mandarin Siren To Fire – Nobody Injured.* 2012. URL: https://www.divephotoguide.com/underwater-photography-scuba-ocean-news/siren-fleet-loses-mandarin-siren-fire-nobody-injured/ (visited on 08/03/2023).

[10] Vanessa Richardson. *Problems with the Siren Fleet: Undercurrent 07/2012.* 2012. URL: https://www.undercurrent.org/UCnow/dive_magazine/2012/ProblemsSirenFleet201207.html (visited on 08/03/2023).

[11] Tanyaluk Sakoot. "Phuket dive boat drama". In: *The Phuket News* III.No 15 (2013-04-19), p. 2. URL: https://www.thephuketnews.com/archive-view.php?listing_archive_id=19-04-2013&Page=02#p2 (visited on 08/03/2023).

[12] The Phuket News. "All safe after dive boat sinks near Koh Tachai". In: *The Phuket News* IV.No 6 (2014-02-07), p. 3. URL: https://www.thephuketnews.com/archive-view.php?listing_archive_id=07-02-2014&Page=01#p1 (visited on 08/03/2023).

[13] Alasdair Forbes and Claire Connel. "Third Dive Boat Sinks". In: *The Phuket News* IV.No 7 (2014-02-14), pp. 1–2. URL: https://www.thephuketnews.com/archive-view.php?listing_archive_id=14-02-2014&Page=01#p1 (visited on 07/31/2023).

[14] John Bantin. *Fire Aboard!: Undercurrent 08/2014*. 2014. URL: https://undercurrent.org/UCnow/dive_magazine/2014/FireAboard201408.html (visited on 08/03/2023).

[15] Bangkok Post Public Company Limited. *Dive boat burns, sinks in Phuket*. 2014. URL: https://www.bangkokpost.com/thailand/politics/431878/dive-boat-burns-sinks-in-phuket (visited on 08/03/2023).

[16] Under Current. *A Bad Night on the Wind Dancer: Undercurrent 06/2015*. 2015. URL: https://www.undercurrent.org/UCnow/dive_magazine/2015/WindDancer201506.html (visited on 08/07/2023).

[17] Ben Davidson. *Palau Siren Grounds and Floods: Undercurrent 09/2015*. 2015. URL: https://www.undercurrent.org/UCnow/dive_magazine/2015/PalauSiren201509.html (visited on 08/03/2023).

[18] Divernet. "Red Sea liveaboard fire left divers stranded". In: *Divernet* (2017-05-23). URL: https://divernet.com/scuba-diving/red-sea-liveaboard-fire-left-divers-stranded/ (visited on 08/03/2023).

[19] Bangkok Post Public Company Limited. *Five die when snorkelling boat sinks in storm*. 2017. URL: https://www.bangkokpost.com/thailand/general/1294935/five-die-when-snorkelling-boat-sinks-in-storm (visited on 08/03/2023).

[20] Maika Bolatiki Suva. *Fiji Siren Not To Be Salvaged*. 2017. URL: http://fijisun.com.fj/2017/11/18/fiji-siren-not-to-be-salvaged/ (visited on 08/03/2023).

[21] Rebecca Strauss. *Waow Liveaboard in Indonesia Lost to a Fire • Scuba Diver Life*. 2018. URL: https://scubadiverlife.com/waow-liveaboard-indonesia-lost-fire/ (visited on 08/03/2023).

[22] Marc Patry. *Luxury ship Majestic Explorer Runs Aground – and Sinks*. 2019. URL: https://www.cnhtours.com/news/2019/6/1/luxury-ship-majestic-explorer-runs-aground-and-sinks/ (visited on 08/07/2023).

[23] National Transportation Safety Board. *Marine Accident Report*. 2020.

[24] Michael Houben. *Ägypten - Feuer auf Safarischiff: Der Untergang der Red Sea Aggressor 1 - Diveinside News*. 2019. URL: https://taucher.net/diveinside-aegypten_-_feuer_auf_safarischiff__der_untergang_der_red_sea_aggressor_1_-kaz8118 (visited on 08/03/2023).

[25] The Scuba News Press Team. "Red Sea Liveaboard Destroyed By Fire". In: *The Scuba News* (2022-04-20). URL: https://www.thescubanews.com/2022/04/20/red-sea-liveaboard-destroyed-by-fire/ (visited on 08/03/2023).

[26] Ian Bongso-Seldrup. *Socorro Vortex Runs Aground Near Socorro Island*. 2022. URL: https://www.divephotoguide.com/underwater-photography-scuba-ocean-news/breaking-news-socorro-vortex-runs-aground-near-socorro-island-mexico (visited on 08/03/2023).

[27] taucher.net. *Rotes Meer: Unfall Seawolf Felo - Diveinside News*. 2022. URL: https://taucher.net/diveinside-rotes_meer__unfall_seawolf_felo-kaz8898 (visited on 08/03/2023).

[28] taucher.net. *Kurzanalyse zur Kenterung des Tauchsafaribootes M/Y Carlton Queen - Diveinside News*. 2023. URL: https://taucher.net/diveinside-kurzanalyse_zur_kenterung_des_tauchsafaribootes_m_y_carlton_queen-kaz8984 (visited on 08/03/2023).

[29] John Eric Mendoza. "Two Edca sites used during rescue efforts to find divers in Tubbataha Reef — AFP". In: *INQUIRER.net* (2023-05-02). URL: https://globalnation.inquirer.net/214196/two-edca-sites-used-during-rescue-effort-to-find-divers-in-tubbataha-reef-afp (visited on 08/03/2023).

[30] Martin Sandongdong. *What is a squall, the cause of Dream Keeper's sinking in Palawan?* 2023. URL: https://mb.com.ph/2023/5/2/what-is-a-squall-the-cause-of-dream-keeper-s-sinking-in-palawan (visited on 08/03/2023).

[31] taucher.net. *Taucher.Net - Ui. Der ging völlig an uns vorbei. Vor 10 Tagen:... / Facebook*. 2023. URL: https://www.facebook.com/Taucher.Net/posts/682990113839049 (visited on 08/03/2023).

[32] taucher.net. *Taucher.Net - Infos zum Unfall mit der Omneia Soul: Am 29.5.... / Facebook*. 2023. URL: https://www.facebook.com/Taucher.Net/posts/pfbid02gEU5QGTR89pCZ42TC5fKWzx5KiAGz88PtcpdA9tSP78nx7YSLTduz6qfLpU4SDvhl (visited on 08/03/2023).

[33] taucher.net. *Update und Interview zur Kenterung der M/Y Carlton Queen - Diveinside News*. 2023. URL: https://taucher.net/diveinside-update_und_interview_zur_kenterung_der_m_y_carlton_queen-kaz8994 (visited on 08/03/2023).

[34] Emperor Divers. *Emperor Divers - In the late hours of Saturday, October 28th;... / Facebook*. 2023. URL: https://www.facebook.com/emperordiversofficial/posts/pfbid0nAKfjCxAV1bqFy7A5arkxArFZwJBF993iUXr4tCkzW1QPnDU6fSYewPA9dNGqxYXl (visited on 10/30/2023).

[35] Marine Department. *Marine Department*. o.J. URL: https://md.go.th/en/ (visited on 08/17/2023).

[36] Egyptian Authority for Mariteme Safety. *Home page - EGYPTIAN AUTHORITY FOR MARITIME SAFETY*. 2023. URL: https://eams.gov.eg/IndexEN (visited on 08/25/2023).

[37] Justus Schiszler. *Anfrage EAMS*. 2023-10-31.

[38] Justus Schiszler. *Anfrage Unfallregister MDT*. 2023-10-31.

[39] International maritime Organization. *Casualty investigation code*. 2008 ed. IMO publication. London: IMO, 2008. ISBN: 978-9280114980.

[40] Statista. *International tourism receipts worldwide from 2006 to 2022*. 2023. (Visited on 08/17/2023).

[41] Günter Bamberg et al. *Statistik*. 14., korrigierte Aufl. Oldenbourgs Lehr- und Handbücher der Wirtschafts- und Sozialwissenschaften. München and Wien: Oldenbourg, 2008. ISBN: 978-3-486-58565-0.

[42] International maritime Organization. *International code on intact stability, 2008*. 2009 ed., 3rd. ed. IMO publication. London: IMO, 2009. ISBN: 9280115065. DOI: Sales.

[43] Gunter Heim. *Winddruckformel*. 24.09.2023. URL: https://www.rhetos.de/html/lex/winddruckformel.htm (visited on 10/07/2023).

[44] Omneia. *Safarischiff Soul of Omneia - Ägypten, Rotes Meer*. 2023. URL: https://www.omneia.de/tauchsafaris/safarischiffe/soul-of-omneia--ss109.php (visited on 09/08/2023).

[45] Eurostat. *Maritime passenger statistics*. 2022. URL: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_passenger_statistics (visited on 10/07/2023).

[46] Julius. "Die 10 besten Tauchsafari Reiseziele 2023 - Social Diving". In: *Social Diving* (2022-06-09). URL: https://www.social-diving.com/de/beste-tauchsafari-reiseziele/ (visited on 08/25/2023).

[47] PADI Travel. *Ghazala Explorer | Tauchsafari | PADI Travel*. 2023. URL: https://travel.padi.com/de/tauchsafari/egypt/ghazala-explorer/ (visited on 11/02/2023).

[48] Maik Solf. *Anzahl Tauchsafarischiffe*. 2023-09-06.

[49] Shamika N. Sirimanne. *Review of Maritime Transport*. Erscheinungsort nicht ermittelbar: United Nations, 2022. ISBN: 978-92-1-002147-0. URL: https://www.un-ilibrary.org/content/books/9789210021470.

[50] Allianz Global Corporate & Specialty. *Safety and Shipping Review 2023*. München, 2023.

[51] European Maritime Safety Agency. *ANNUAL OVERVIEW OF MARINE CASUALTIES AND INCIDENTS 2022*. Lissabon: European Maritime Safety Agency, 2022. URL: https://www.emsa.europa.eu/newsroom/latest-news/item/4867-annual-overview-of-marine-casualties-and-incidents-2021.html.

[52] ScubaBoard. *Accidents & Incidents*. 2023. URL: https://scubaboard.com/community/forums/accidents-incidents.286/ (visited on 09/01/2023).

[53] *SOLAS*. Consolidated edition 2020, seventh edition. London: IMO International Maritime Organization, 2020. ISBN: 9789280116908.

[54] International maritime Organization. *SOLAS, Consolidated Version 2012*. 2012. URL: http://www.merle-arbeitsmedizin.de/wp-content/uploads/2018/01/app7_290115.pdf.

[55] International maritime Organization. *ISM code*. 4th. ed. IMO publication. London: International Maritime Organization, 2014. ISBN: 9789280115901.

[56] Peter Moth, ed. *SCV code*. Hayling Island, Hants: Foreshore, 2005. ISBN: 1901630048.

[57] Bureau Veritas Marine & Offshore. *Rules for the classification and the certification of yacht*. Paris, 2022.

[58] Royal Evolution. *Liveaboard - Enjoy your Diving trip with Royal Evolution*. 2023. URL: https://royalevolution.com/liveaboard/#specifications-l1 (visited on 10/17/2023).

[59] DNV. *DV-RU-YACHT*. Det Norske Veritas, 2021.

[60] Red Ensign Group. *Yacht Code*. 2019.

[61] Kristin Omholt-Jensen. *Global Sulphur regulations / ECA / SECA Zones*. Ed. by Shipintel. 2021. URL: https://www.maritimeoptima.com/blog/global-sulphur-regulations-eca-seca-zones (visited on 09/20/2023).

[62] Hans-Josef Braun. *Vorschriften zu Tauchsafarischiffen*. 2023-09-20.

[63] European Union. *DIRECTIVE 2013/53/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 November 2013*. 2013-11-20. URL: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02013L0053-20131228 (visited on 09/20/2023).

[64] European Union. *BESCHLUSS Nr. 768/2008/EG DES EUROPÄISCHEN PARLAMENTS UND DES RATES*. 2008. URL: https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=celex%3A32008D0768 (visited on 09/21/2023).

[65] Europäisches Komitee für Normung. *Kleine Wasserfahrzeuge - Brandschutz*. Berlin, 2022-12-02. URL: https://www.iso.org/standard/78242.html.

[66] Europäisches Komitee für Normung. *Kleine Wasserfahrzeuge - Stabilitäts- und Auftriebsbewertung und Kategorisierung*. Berlin, 2021-01-08. URL: https://www.iso.org/standard/79072.html (visited on 09/21/2023).

[67] European Union. *EG Fahrgastschiffrichtlinie, Richtlinie 2009/45/EG*. 2009. (Visited on 09/22/2023).

[68] BG-Verkehr. *Schiffssicherheitshandbuch*. Dienststelle Schiffssicherheit BG Verkehr, 2010.

[69] Egyptian Authority for Mariteme Safety. *Flag state requirements*. 2023.

[70] Liveaboard.com. *83 Egypt liveaboards available*. 2023. URL: https://www.liveaboard.com/search/egypt (visited on 11/02/2023).

[71] CDWS. *CDWS Blacklist*. 2023. URL: https://www.cdws.travel/blacklist (visited on 09/25/2023).

[72] CDWS. *First Aid for Safari Boats*. 2018.

[73] CDWS. *Safari Boats Standards*. 2023.

[74] Justus Schiszler. *Anfrage MDT 1*. 2023-10-04.

[75] Justus Schiszler. *Anfrage Bakamla*. 2023-10-08.

[76] Association of Dive Tour Operators. *start*. 2018. URL: https://adto.de/ (visited on 09/25/2023).

[77] Association of Dive Tour Operators. *Qualitätssiegel*. 2019. URL: https://adto.de/qualitaetssiegel/ (visited on 09/25/2023).

[78] International Air Transport Association. *IATA Operational Safety Audit (IOSA)*. 2023. URL: https://www.iata.org/en/programs/safety/audit/iosa/ (visited on 09/25/2023).

[79] International maritime Organization. *STCW Code - Seafarers' Training, Certification and Watchkeeping*. 2021.

[80] Center Arab Academy for Science Technology and Maritime Transport. *Maritime Education & Training-Alexandria | AASTMT*. 2023. URL: https://aast.edu/en/maritime/contenttemp.php?page_id=51900039 (visited on 10/30/2023).

[81] Galileo Maritime Academy |. *STCW Courses | Galileo Maritime Academy*. 2023. URL: https://galileomaritimeacademy.com/stcw-courses/#stcw (visited on 10/30/2023).

[82] The Maritime Training Center of the Philippines. *The Maritime Training Center of the Philippines, Inc. (TMTCP) - Course Types Basic Safety Courses*. 2023. URL: http://tmtcp.org/course-type/basic-safety-courses/ (visited on 10/30/2023).

[83] CDWS. *https://cdws.travel/info/1training/technical-manager-diving*. 7.10.2023. URL: https://cdws.travel/info/1training/technical-manager-diving (visited on 10/07/2023).

[84] Justus Schiszler. *Anfrage Vorschriften MDT*. 2023-10-08.

[85] CDWS. *https://cdws.travel/info/1training/training-safari-daily-crew*. 7.10.2023. URL: https://cdws.travel/info/1training/training-safari-daily-crew (visited on 10/07/2023).

[86] International maritime Organization. *Life-saving appliances*. 2017 edition. IMO publication. London: IMO, 2017. ISBN: 9789280116540.

[87] taucher.net. *Taucher.Net Talk Nr. 4 - Kenterung der Carlton Queen*. 2023. URL: https://www.youtube.com/watch?v=nUONBmC0yAg (visited on 09/27/2023).

[88] Bureau Veritas Marine & Offshore. *Rules for the classification of steel ships*. Paris, 2023.

[89] Liveaboard.com. *Carlton Queen*. 2023. URL: https://www.liveaboard.com/de/diving/egypt/carlton-queen (visited on 09/25/2023).

[90] Tapiwa Shabani et al. "A comprehensive review of the Swiss cheese model in risk management". In: *Safety in Extreme Environments* (2023). ISSN: 2524-8170. DOI: 10.1007/s42797-023-00091-7.

[91] Stefanie Dazio. *Four years after fire engulfed California scuba dive boat killing 34 people, captain's trial begins*. 2023. URL: https://www.columbian.com/news/2023/oct/24/four-years-after-fire-engulfed-california-scuba-dive-boat-killing-34-people-captains-trial-begins/ (visited on 10/25/2023).

[92] Justus Schiszler. *Anfragen zur Carlton Queen*. 2023.

[93] Tauchsport Leeb-Lange. *Von 21. bis 28. Oktober 23 sind wir auf Tauchsafari in Ägypten - Tauchsport Leeb-Lange*. 2023. URL: https://www.tauchsport-leeb-lange.de/tauchsafari-aegypten-oktober-2023.html (visited on 09/28/2023).

[94] meteoblue. *Wetterarchiv 27.38°N 33.99°O - meteoblue.* 2023. URL: https://www.meteoblue.com/de/wetter/historyclimate/weatherarchive/27.380N33.990E?fcstlength=15&year=2023&month=4 (visited on 09/28/2023).

[95] Adrian B. Biran and Rubén López-Pulido. *Ship hydrostatics and stability.* Second edition. Amsterdam et al.: Butterworth-Heinemann an imprint of Elsevier, 2014. ISBN: 9780080982878.

[96] Storyful News & Weather. *Carlton Queen Passengers 'Thrown Over Board' and Left 'Clinging to Debris' as Yacht Capsizes.* 2023. URL: https://www.youtube.com/watch?v=FS3A_r87C1M (visited on 10/12/2023).

[97] Sabique Langodan et al. "The climatology of the Red Sea – part 2: the waves". In: *International Journal of Climatology* 37.13 (2017), pp. 4518–4528. ISSN: 0899-8418. DOI: 10.1002/joc.5101.

[98] International maritime Organization. *Load lines convention 1966.* 2021 Edition. IMO-publication. London: International Maritime Organization, 2021. ISBN: 9789280117325.

[99] Andreas Meyer-Bohe. *Schwimmfähigkeit & Stabilität von Schiffen.* 1. Aufl. Schiffbau. Göttingen: Cuvillier, 2011. ISBN: 9783869556888.

[100] Gunter Heim. *Winddruck-Tabelle (N/m^2).* 2023. URL: https://www.rhetos.de/html/lex/winddruck-tabelle.htm (visited on 10/16/2023).

[101] Martin Conrad. *Preise Umbau.* 2023-11-02.

[102] Otto Heunecke. "Ermittlung von Stabilitätshebelarmkurven aus 3D-Punktwolken". In: *zfv – Zeitschrift für Geodäsie, Geoinformation und Landmanagement* 2/2017 (2017), pp. 88–97. ISSN: 1618-9050. DOI: 10.12902/zfv-0157-2016.

[103] Sönke Roever. "Erfahrungsbericht: Vorausschauendes Echolot von GARMIN (Panoptix)". In: *BLAUWASSER.DE* (2022-05-30). URL: https://www.blauwasser.de/erfahrungsbericht-vorausschauendes-echolot-garmin-panoptix (visited on 11/13/2023).

[116] PADI Travel. *all Trips in the World | PADI Travel.* 2023. URL: https://travel.padi.com/s/liveaboards/all/?crid=619285875&page=5&utm_campaign=ww-en-travel-pros-search-travel2021&utm_medium=cpc&utm_source=google.com&utm_term=ww-en-travel-pros-search-listings-diving (visited on 10/07/2023).

[120] Orangemarine. *Feststoff-Rettungsweste SOLAS für Erwachsene von Lalizas.* 2023. URL: https://www.orange-marine.de/rettungswesten-erwachsene/4871-rettungsweste-solas-erwachsene.html#technical-informations (visited on 11/11/2023).

not cited scources

[104] Aftonbladet TV. *Svenskar i drama när turistbåt sjönk i Thailand - Aftonbladet TV.* 2014. URL: https://tv.aftonbladet.se/video/32350/svenskar-i-drama-nar-turistbaat-sjonk-i-thailand (visited on 08/03/2023).

[105] Martin Sandongdong. *PCG turns to retrieval of 4 missing passengers of sunken M/Y Dream Keeper.* 2023. URL: https://mb.com.ph/2023/5/7/pcg-turns-to-retrieval-of-4-missing-passengers-of-sunken-m-y-dream-keeper (visited on 08/03/2023).

[106] Karolin Schäfer and Helmi Krappitz. *Touristen-Yacht geht vor Ägypten in Flammen auf – drei Urlauber tot.* 2023. URL: https://www.merkur.de/welt/vermisst-urlaub-reisen-grossbritannien-news-brand-yacht-aegypten-boot-touristen-92335098.html (visited on 08/03/2023).

[107] Justus Schiszler. *Anfrage Anzahl Tauchsafarischiffe CDWS.* 2023-10-07.

[108] Mark 'Crowley' Russell. "Conception liveaboard fire victims were trying to escape when they died – report". In: *Dive Magazine* (2023-01-05). URL: https://divemagazine.com/scuba-diving-news/conception-fire-victims-were-trying-to-escape (visited on 08/03/2023).

[109] Dominic Schmitt and Zoe Josephine Schmitt. *Schiffsunglück - Taucher brauchen eure Hilfe [GER], organisiert von Dominic Schmitt.* 2023. URL: https://www.gofundme.com/f/3180vhrtko (visited on 08/03/2023).

[110] ScubaBoard. *Vortex sank in Socorro?* 2022. URL: https://scubaboard.com/community/threads/vortex-sank-in-socorro.620739/ (visited on 08/03/2023).

[111] ScubaBoard. *Liveaboard Sinks Off Tubbataha Reef.* 2023. URL: https://scubaboard.com/community/threads/liveaboard-sinks-off-tubbataha-reef.632881/ (visited on 08/03/2023).

[112] Justus Schiszler. *Anfrage Trainingstandards CDWS.* 2023-10-08.

[113] Seawolf Safari. *Seawolf Felo Boat.* o.J. URL: https://www.seawolf-safari.de/boat/seawolf-felo (visited on 08/03/2023).

[114] news.com.au. "Terrifying moment tourists jumped for their lives". In: *news.com.au — Australia's leading news site* (2014-01-31). URL: https://www.news.com.au/travel/travel-updates/dramatic-video-footage-as-an-illegally-operating-boat-sinks-in-thailand/news-story/8e2b72ce59ff0105555e4f3b27f09e03 (visited on 08/11/2023).

[115] N-TV. "Deutscher unter Vermissten: Boot in Thailand gesunken". In: *n-tv NACHRICHTEN* (2009-03-09). URL: https://www.n-tv.de/panorama/Boot-in-Thailand-gesunken-article59764.html (visited on 08/03/2023).

[117] Chris Pechmann. "Feuer auf Touristenboot: Drei Tauchgäste kommen ums Leben". In: *TAG24 NEWS Deutschland GmbH* (2023-06-12). URL: https://www.tag24.de/thema/unglueck/feuer-auf-touristenboot-drei-tauchgaeste-kommen-ums-leben-2862062 (visited on 08/03/2023).

[118] Pedder. "Marine-Behörden sprechen bei dem gesunkenen Tauchboot Aladdin von einem „Unfall“". In: *ThailandTIP* (2014-01-31). URL: https://thailandtip.info/2014/01/31/marine-behoerden-sprechen-bei-dem-gesunkenen-tauchboot-aladdin-von-einem-unfall/ (visited on 08/16/2023).

[119] Red Sea DTA Team. “M/Y Scuba Scene: Official Statement”. In: *Red Sea Dive Adventures* (2022-04-25). URL: https://redseadiveadventures.com/m-y-scuba-scene-official-statement/ (visited on 08/11/2023).

[121] taucher.net. *Video | Facebook Hurricane*. 2023. URL: https://www.facebook.com/watch/?v=644429177545061 (visited on 08/03/2023).

[122] The Bali Times. “Two Injured as Tourist Dive Boat Sinks off Komodo”. In: *The Bali Times* (2010-09-16). URL: https://www.thebalitimes.com/arts-entertainment/bali-diveboat-sinking/ (visited on 08/03/2023).

[123] Travel The World. *Red Sea Emperor Fraser Sinks - Everyone Safe*. 2009. URL: https://www.dive-the-world.com/blog/red-sea-emperor-fraser-sinks-everyone-safe/ (visited on 08/03/2023).

[124] Under Current. *Flotsam & Jetsam: Undercurrent 06/2019*. 2019. URL: https://www.undercurrent.org/UCnow/dive_magazine/2019/FlotsamJetsam201906.html (visited on 08/07/2023).

[125] United Nations. *Navigating stormy waters*. Vol. 2022. Review of maritime transport / United Nations Conference on Trade and Development, Geneva. Geneva: United Nations, 2022. ISBN: 978-92-1-113073-7.

[126] Steve Weinman. “Divers escape Red Sea liveaboard blaze”. In: *Divernet* (2022-04-20). URL: https://divernet.com/scuba-news/divers-escape-red-sea-liveaboard-blaze/ (visited on 08/03/2023).

[127] Steve Weinman. “4 missing as Philippines dive liveaboard sinks”. In: *Divernet* (2023-04-30). URL: https://divernet.com/scuba-news/4-missing-as-philippines-dive-liveaboard-sinks/ (visited on 08/03/2023).

[128] Under Current. *Raja Ampat Liveaboard Goes Down in Flames: Undercurrent 02/2012*. 2012. URL: https://www.undercurrent.org/UCnow/dive_magazine/2012/RajaAmpatLiveaboard201202.html (visited on 08/13/2023).

[129] taucher.net. *Taucher.Net - Heute morgen ist die M/Y New Dream in der Nähe... | Facebook*. 2023. URL: https://www.facebook.com/Taucher.Net/posts/pfbid02oGobi3QkJDqRFVovjzWaJ6fmK9w1gBiGBfj8BBFksLpCcjrM8iN9m1HBuqXiPrCil (visited on 08/03/2023).

[130] Rebecca Strauss. *Breaking News: Socorro Vortex Runs Aground • Scuba Diver Life*. 2022. URL: https://scubadiverlife.com/breaking-news-socorro-vortex-runs-aground/ (visited on 08/03/2023).

[131] Kamal Tabikha. “36 passengers rescued after speed boat capsizes in Egypt’s Red Sea”. In: *The National* (2023-06-07). URL: https://www.thenationalnews.com/mena/egypt/2023/06/07/36-passengers-rescued-after-speed-boat-capsizes-in-egypts-red-sea/ (visited on 08/03/2023).

[132] TAUCHEN.de. *Heaven Diamond nach Brand gesunken*. 2008. URL: https://www.tauchen.de/archiv/heaven-diamond-nach-brand-gesunken/ (visited on 08/02/2023).

[133] taucher.net. *Palau Siren gesunken - Diveinside News*. 2015. URL: https://taucher.net/diveinside-palau_siren_gesunken-kaz5800 (visited on 08/03/2023).

[134] taucher.net. *Thailand: Fünf Taucher sterben bei Schiffsunglück - Diveinside News.* 2017. URL: https://taucher.net/diveinside-thailand__fuenf_taucher_sterben_bei_schiffsunglueck__-kaz7075 (visited on 08/03/2023).

[135] taucher.net. *Malé, Malediven: Safarischiff „Nautilus One“ sinkt nach Feuer an Bord - Diveinside News.* 2021. URL: https://taucher.net/diveinside-mal____malediven__safarischiff____nautilus_one____sinkt_nach_feuer_an_bord_-kaz8448 (visited on 08/03/2023).

[136] taucher.net. *Katastrophe auf Safarischiff im Rooten Meer: Feuer auf der M/Y Hurricane - Diveinside News.* 2023. URL: https://taucher.net/diveinside-katastrophe_auf_safarischiff_im_rooten_meer__feuer_auf_der_m_y_hurricane-kaz9034 (visited on 08/03/2023).

[137] taucher.net. *M/Y New Dream: Safari Schiff im Roten Meer gesunken - Diveinside News.* 2023. URL: https://taucher.net/diveinside-m_y_new_dream__safari_schiff_im_roten_meer_gesunken-kaz9030 (visited on 08/03/2023).

[138] taucher.net. *Taucher.Net - Gestern ist der ausgebrannte Rumpf im Hafen von... | Facebook.* 2023. URL: https://www.facebook.com/Taucher.Net/posts/pfbid02aLrjzKePBZHjBrsafZm3nqcwjcvwSNWrXX9QQkFLurzkj9oQPiHR2i9sibdNifRzl (visited on 08/03/2023).

[139] Welt. “Noch sechs Vermisste: Tote Touristin nach Bootsunfall in Phuket geborgen”. In: *WELT* (2009-03-10). URL: https://www.welt.de/vermischtes/article3348826/Tote-Touristin-nach-Bootsunfall-in-Phuket-geborgen.html (visited on 08/03/2023).

[140] Der Spiegel. “Touristen vermisst: Ägyptisches Tauchboot sinkt im Roten Meer”. In: *DER SPIEGEL* (2009-11-19). URL: https://www.spiegel.de/reise/aktuell/touristen-vermisst-aegyptisches-tauchboot-sinkt-im-roten-meer-a-662235.html (visited on 08/03/2023).

[141] DivePhotoGuide. *Red Sea Aggressor I Sinks After Fire, Killing One Diver.* 2019. URL: https://www.divephotoguide.com/underwater-photography-scuba-ocean-news/red-sea-aggressor-sinks-after-fire-killing-one-diver (visited on 08/03/2023).

[142] CDWS. *Breaking news: Boat sinks in Naama Bay, 2 missing divers.* 2009. URL: https://cdws.travel/news/breaking-news-boat-sinks-in-naama-bay-2-missing-divers (visited on 08/03/2023).

[143] Blue O. TWO. “Electrical fire on board M/Y blue Melody...”. In: *The Scuba News* (2014-08-08). URL: https://www.thescubanews.com/2014/08/08/electrical-fire-on-board-my-blue-melody/ (visited on 08/03/2023).

[144] Michael Bode. “Tauchschiff brennt ab”. In: *Bodeweb* (2011-12-29). URL: https://bodeweb.de/blog/tauchschiff-brennt-ab/ (visited on 08/03/2023).

[145] Michael Bode. “Mandarin Siren gesunken”. In: *Bodeweb* (2012-01-03). URL: https://bodeweb.de/blog/mandarin-siren-gesunken/ (visited on 08/03/2023).

[146] Michael Bode. “Ein bisschen Notfall”. In: *Bodeweb* (2012-07-09). URL: https://bodeweb.de/blog/ein-bisschen-notfall/ (visited on 08/03/2023).

[147] Kroftman. *Windgeschwindigkeit und daraus resultierende horizontale Windlast (Druck) auf Bauwerke.*

[148] Kühlmeyer and Kottusch. *Statistische Auswertungsmethoden für Ingenieure.* [Place of publication not identified]: Springer Berlin Heidelberg, 2001. ISBN: 3-540-41097-x.

[149] John Liang. "Scuba Scene Liveaboard Destroyed By Fire - DeeperBlue". In: *DeeperBlue.com* (2022-04-20). URL: https://www.deeperblue.com/scuba-scene-liveaboard-destroyed-by-fire/ (visited on 08/03/2023).

[150] Liveaboard.com. *All Star Scuba Scene.* o.J. URL: https://www.liveaboard.com/de/diving/egypt/all-star-scuba-scene (visited on 08/03/2023).

[151] Liveaboard.com. *Die zehn besten Tauchsafari-Ziele für Anfänger.* 2018. URL: https://www.tauchen.de/reise/reiseberichte/die-zehn-besten-tauchsafari-ziele-fuer-anfaenger/ (visited on 08/25/2023).

[152] Liveaboard.com. *WAOW Sinks.* 2018. URL: https://www.liveaboard.com/news/waow-sinks (visited on 08/03/2023).

[153] Marine Accident Inverstigation Branch. *Anfrage zu Hurricane.* 2023-10-16.

[154] European Union. *European statistics on accidents at work (ESAW).* Theme: Population and social conditions. Luxembourg: Publications Office of the European Union, 2013. ISBN: 978-92-79-28419-9.

[155] Mark Evans. "Luxury liveaboard lost in Fiji, guests and crew safe and well". In: *Scuba Diver Mag* (2017-11-15). URL: https://www.scubadivermag.com/luxury-liveaboard-lost-in-fiji-guests-and-crew-safe-and-well/ (visited on 08/03/2023).

[156] Mark Evans. "Egyptian dayboat runs aground". In: *Scuba Diver Mag* (2023-05-18). URL: https://www.scubadivermag.com/egyptian-dayboat-runs-aground/ (visited on 08/03/2023).

[157] Joachim Hahne. *Handbuch Schiffssicherheit.* Hamburg: Seehafen Verlag, 2006. ISBN: 3-87743-815-6.

[158] Sam Helmy. "Fiji Siren Lost At Sea - DeeperBlue". In: *DeeperBlue.com* (2017-11-15). URL: https://www.deeperblue.com/fiji-siren-lost-sea/ (visited on 08/03/2023).

[159] ICS-shipping. *Shipping and World Trade: Global Supply and Demand for Seafarers.* 2021. URL: https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-global-supply-and-demand-for-seafarers/ (visited on 08/16/2023).

[160] Master Liveaboards. *Palau Siren liveaboard.* o.J. URL: https://masterliveaboards.com/boats/palau-siren/ (visited on 08/03/2023).

[161] Fathmath Zunaam. *Nautilus One safari sinks after catching on fire.* 2021. URL: https://timesofaddu.com/2021/01/25/nautilus-one-safari-sinks-after-catching-on-fire/ (visited on 08/03/2023).

Bilder

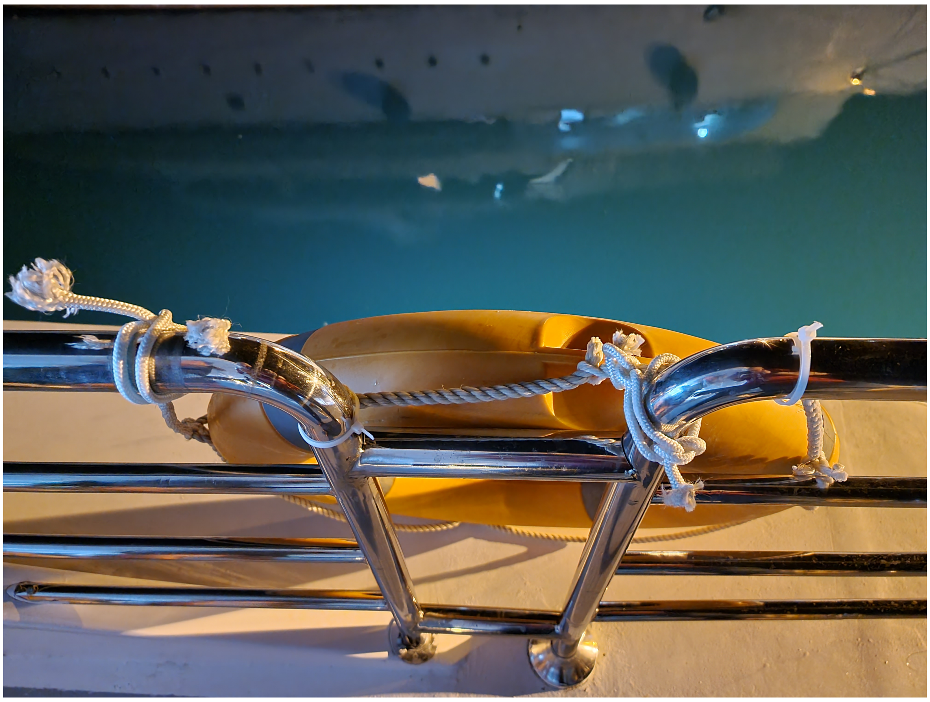

Figure 17: Lifebuoy attached to the „Emperor Elite“with cable ties

Figure 18: Lifejacket on the „Emperor Elite“

Figure 19: Example of a lifejacket according to SOLAS-Konvention [120]

Figure 20: Plaque of a life raft on the „Emperor Elite“

Figure 21: mess room of the „Carlton Queen“

Figure 22: Staircase from the lower deck on the „Carlton Queen“

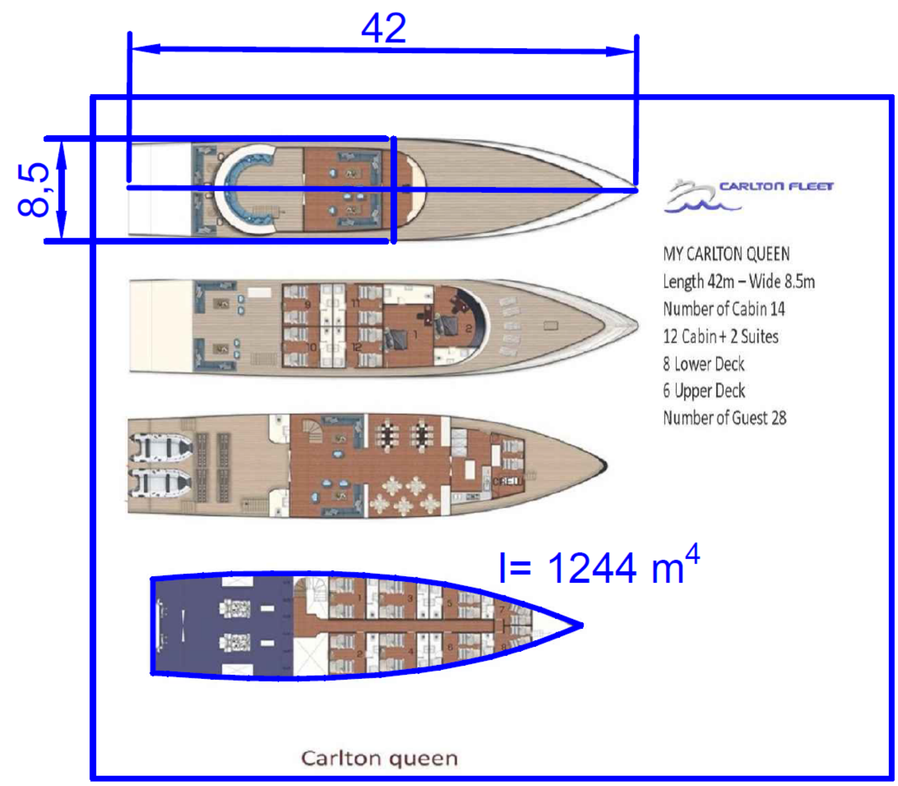

Figure 23: Waterline determined from AutoCAD

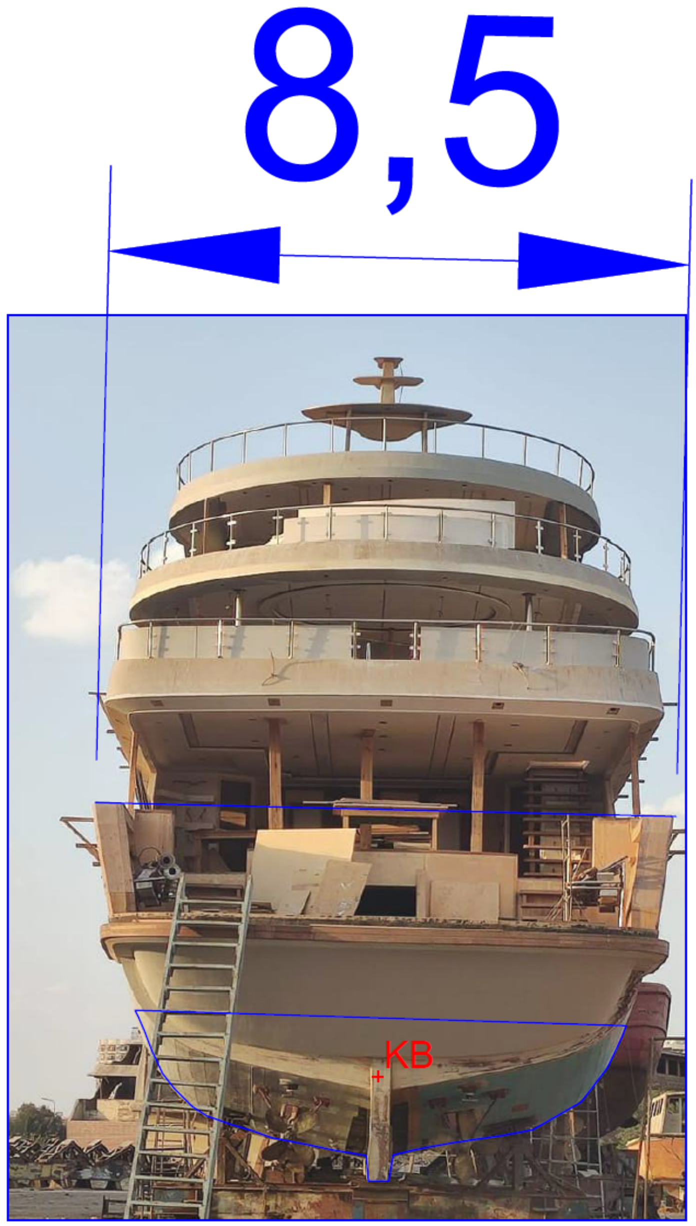

Figure 24: KB determined from AutoCAD

Figure 25: Mirror as emergency exit on the „Emperor Elite“

Figure 26: Anchor on the „Ghazala Explorer“ (Cropped from an image by [116])

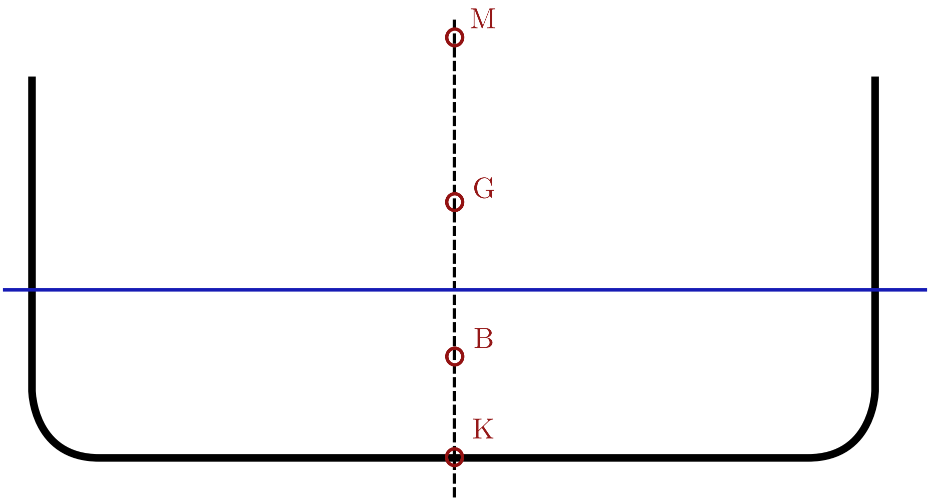

Figure 27: Representation of the points relevant for stability (K: lowest point in the middle of the ship; B: center of buoyancy; G: center of gravity; M: metacenter)

Topic	Short-term	long-term
Fire protection	fire alarms in guest areas and engine rooms; portable fire extinguishers according to BV or SCV-Code outside cabins	permanently installed extinguishing equipment; extinguishing pumps according to any regulation
Stability	verification via stability tests or calculation close to the IS-Code with cosine^2	assessment of leak stability via bulkheads according toBV
Training	safety briefings with tours and practice	training according to STCW-Übereinkommen
Equipment	correct certificates on the equipment & regular maintenance	installation of racks for liferafts; design of anchors according to BV
Ensure escape routes	usability of existing escape routes	handrails in all corridors

Table 7: Recommendations summarized

Errata for Investigation of a series of accidents involving yachts for diving vacations

Justus Schiszler

February 5, 2024

Contents

1 Fehler in 7. Analyse zur Kenterung der „Carlton Queen“ 2

1.1 Fehler in 7.3. Mögliche Ursachen für die Kenterung 2

1 Error in cap. 6 analysis of the capsizing of the „Carlton Queen“

1.1 Error in 6.3 Possible causes of capsizing

Equation 7.3 on page 44 must be correct: $\overline{KG} = \overline{KB} + \overline{BM} - \overline{GM}$
The calculated $\overline{KG}$ of 10.1 has been calculated correctly using the formula. The following analysis remains the same.

The gravitational acceleration was not correctly taken into account in the calculation for the calculated lever. Therefore, the calculated results are incorrect. The correct heeling moments are 95 kNm at 4 bft. wind force and 288 kNm at 6 bft. wind force. This results in heeling levers of 0.068 m and 0.206 m respectively. The necessary $\overline{GM}$ to fulfill the IS code is therefore 0.25 m or 0.747 m. This means that a $\overline{GM}$ of less than 0.3 m would possibly have to be assumed, as the „Carlton Queen“ already capsized at a wind force of 4 bft. However, as discussed in the paper, the capsizing can also be caused by other factors.