New Fire Strategies in the Wake of Umoe Ventus

Concluding report

DBI FIRE AND SECURITY

OSK-ShipTech A/S

Content

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1 Preface

This document presents the project "New Fire Strategies in the Wake of Umoe Ventus" and gathers the main findings. Based on these findings, 5 fire scenarios are proposed as a basis for fire safety analysis of any new vessel project based on the High Speed Craft (HSC) Code and using composite materials for structural elements. A final section proposes a set of recommendations and guidelines aiming at increasing the level of safety on board HSC vessels built with composite materials.

The term "composite materials" as used in this report refers to Fibre Reinforced Polymers (FRP) also known as Fibre Reinforced Plastics. These materials are made from a given type of fibres (glass, carbon, basalt or aramid for the most common) which provide mechanical strength. The fibres are bound together by a polymer matrix (various types of thermosets or thermoplastics can be chosen). These materials present behaviour in fire much different from steel which is the traditional construction material in shipbuilding. Composite materials lose strength quickly when exposed to heat, and ultimately burn in releasing large amounts of heat and toxic smoke. As such they represent an increased risk compared to steel.

The full extent of the project work is detailed in a set of annexes presented at the end of this document. The reader is directed there for further information and details.

The project was led by the Danish Institute of Fire and Security Technology (DBI) and had OSK ShipTech A/S as project partner.

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2 Project introduction

2.1 Scope

The project "New Fire Strategies in the Wake of Umoe Ventus" has been triggered by the catastrophic fire which occurred on board the Crew Transfer Vessel (CTV) Umoe Ventus on December 23rd, 2015 near the Danish harbour of Bagenkop. Umoe Ventus was designed and built with composite materials and it complied with the International Maritime Organisation (IMO) High Speed Craft (HSC) Code [1]. When the HSC Code is followed for the design, it is assumed that the level of safety achieved, especially in the case of a fire, is acceptable and sufficient. However, the crew on board Umoe Ventus had to leave the ship in a chaotic way 15 min after the first observation of the fire, without time to attempt firefighting or follow any safety procedure. The fire developed quickly in a catastrophic manner and the ship sank. The event was deemed serious enough for the Danish Maritime Accident Investigation Board (DMAIB) to publish a marine accident report [2].

Based on the event and the report from DMAIB, it became obvious that following the safety principles of the HSC Code is not sufficient to achieve acceptable safety levels in case of fire when building with composite materials. IMO recently published the circular MSC.1/Circ. 1574 [3] proposing interim guidelines for fire safety design of elements made of fibre reinforced plastics (FRP). These guidelines have been translated into the Danish national system by the Danish Maritime Authority (DMA) under Circular no. 025 [4]. In this circular, a risk analysis is required for HSC composite vessels, inspired by the risk analysis required for SOLAS ships following the alternative design route opened by Chapter II-2 Regulation 17 [5]. According to the cases (see [4]), the risk analysis required by the DMA Circular no. 025 could be limited to the qualitative part. These requirements will nevertheless make new composite designs very expensive and more complicated to carry out even though they would follow the principles of the HSC Code.

Technical aspects are usually the ones used to explain accidents and failures, and the ones to be updated to higher technical and efficiency levels. However, human aspects were particularly important in the Umoe Ventus accident. Reading the DMAIB accident report, it became obvious that safety procedures were not adapted to the ship type, that the crew experienced very high stress levels and that the design of the technical systems and procedures made it difficult for the crew to react in a proper way, which led to a catastrophic accident. Taking into account the critical need for reaching acceptable levels of safety on board HSC composite vessels in case of fire, and the needs of the industry building such ships, this project proposes to look into both technical and human aspects of safety on board such ships to highlight their influence in fire situations, and particularly their interdependence. The overall aim is to then include socio-technical aspects of fire safety in design procedures. The project therefore contains tasks oriented towards technical topics and tasks oriented towards human factors.

The project encompasses:

- Gaining experience from real fires on board HSC composite ships to translate it into design for increased safety in case of fire
- Understanding how key stakeholders, including crew members, perceive fire safety on board composite vessels and how they prepare for fire incidents
- Understanding the reasons behind fires, their development, and the reasons why they develop in such a way in HSC composite vessels
- Highlighting important overlooked aspects of fire safety to translate them into design

2.2 Objectives

The objectives of the project are to:

- Promote a holistic approach to fire safety, by considering the ship in its totality and fire safety as a socio-technical problem
- Identify the human factors involved in handling a fire situation on board HSC composite vessels
- Propose realistic fire scenarios to be taken into account for the design of new HSC composite ships
- Make recommendations and suggest guidelines to increase fire safety levels in the design of HSC vessels built with composite materials

2.3 Limitations

The project is limited to composite vessels designed according to the principles of the IMO HSC Code. The research material includes only already-built vessels; one vessel at the design stage could be included.

The anthropologic part of the study is focussed on the crew of composite vessels. The behaviour of passengers has been left out of this study.

Due to the limited time and resources allocated to this study, it should be taken as a first step in putting forward improved ways of achieving acceptable levels of safety on board a HSC composite ship. Other studies are encouraged.

2.4 Structure

The project consists of three main parts.

The first part is focussed on technical issues. It consists of a background study and a workshop. The background study aims at exploring past fire accidents on board ships, mainly composite, to learn more about the accidents and their development. It is developed in Annex A. The workshop brought together the project group and external consultants from various actors of the industry in an attempt to identify fire scenarios. It is developed in Annex B.

The second part is focussed on human factors. It consists of an anthropology study based on desk research, expert study based on interviews from different and relevant actors, and an empirical case study. It aims at exploring the behaviour of the crew with respect to fire safety and is developed in Annex C.

The third part focusses on bringing together the findings of the previous two parts by looking at fire safety as a socio-technical problem. A technical analysis of active and passive fire protection on existing HSC composite ships is performed to refine the fire scenarios. This part is developed in Annex D. A new methodology is proposed to look at fire safety, refine fire scenarios, suggest new guidelines, and work as a design tool. This is developed in Annex E.

3 Summary of project findings

3.1 Background study

The objectives of the background study was to gather knowledge and facts about fires on board HSC composite vessels to increase understanding, and to highlight incompatibilities between the HSC Code and the used of composite materials.

Analysis of past fires
The analysis focused on accident reports from various international sources to highlight causes of fires and factors involved in the development of fire events on board ships of all types built with composite materials. A total of 45 fire accidents were analysed. The study found that fire incidents almost always go back to some sort of human error, and that maintenance is one of the most influential factors. In general, the study highlighted the important lack of knowledge on composite materials through the industry, particularly of their performance in fire.

Two findings are of major importance. Firstly, void and open spaces appeared as the third most frequent location of ignition for composite vessels. These areas are considered as areas of low or no fire risk in the HSC Code, due to the material properties of steel. Secondly, it was found that a hot surface or fluid in contact with composite material appears as the third most frequent cause of ignition for composite vessels. Most likely due to steel properties, the HSC Code does not provide for protection measures related to hot surfaces.

It was also highlighted that when a fire event occurred according to a foreseen scenario, the fire could be extinguished or evacuation performed. On the other hand, when the events did not follow a foreseen scenario, the fire ended in a catastrophe. This means that when a strategy is laid out to mitigate a risk scenario, this strategy is usually successful. In turns, this leads to the need to refine the fire scenarios used for vessels built with composite materials.

HSC Code and composite materials
This analysis focused on the compatibility of the HSC Code with the use of composite materials. It was found that in terms of material properties, fire safety strategy, classification of space use, and design procedure the use of composite materials is in conflict with the HSC Code.
Propositions have been put forward to address these discrepancies. It was suggested to account for the actual properties of composite materials when designing, rather than simply applying the code which heavily rely on the behaviour of steel. It was suggested that rules for passenger crafts should be used even for cargo crafts. It was also suggested to derive fire scenarios from redundant maintenance errors. An important suggestion concerned updating the classification of space use for open or void spaces, according to the type of penetrations passing through them.

3.2 Human factors

Human factors can be considered on three levels; strategic level (authorities, international regulations), tactical level (ship owners, ship management, ship yards, naval architects, maritime education institutions) and operational level (crew, students).

Analytical tensions
Muster lists training exercises are often too generic instead of being vessel and operation specific. They do not take the properties of the construction material into account.

When composite materials are used for construction instead of steel, more responsibility for fire safety is transferred to the technical systems (e.g. detectors and sprinklers) and to the crew.
Crew must be able to follow procedures to tackle foreseen fire scenarios in a safe manner. Though, they must also be able to adapt to the situation and be creative if the fire develops in an unforeseen manner. Both the procedural and adaptive approach can be difficult in a stressful situation where humans often act according to their previous experience.
Training of seafarers has not changed in the same pace as the technological development of ships.

Conclusions and recommendations
Human behaviour should be considered as an important part of a holistic vessel design. Moreover, it must be understood that fire safety is a socio-technical problem and should be treated as such.
Procedures on-board should be more vessel specific taking the properties of the construction material into account. Procedures should be updated over time to implement experience from daily operation and evaluated incidents. The improvement of procedures should be demanded by the strategic level.

The properties of composites should be taken into account when escape/evacuation routes, fire-fighting equipment and muster list is designed. Especially, the faster development of a fire must be considered.

Improving the adaptive and creative skills of the crew would prepare them to meet some of the unforeseen events in a safe and controlled way.

To build up more knowledge in a structured way the maritime educational institutions could be more active in producing new knowledge through research and collecting experience from the operational level. And the new knowledge can easily be transferred to the students as a supplement to the existing knowledge and support that the education stays updated.

Training of crew should not only be vessel specific but also material specific when composites are a substantial part of the vessel.

3.3 Technical analysis of active and passive fire protection on existing high speed crafts

The objective of the technical analysis was to evaluate how selected fire protection requirements in the HSC Code have been implemented in recent composite vessel designs and through that identify any gaps or inappropriate practices. Four composite vessels were selected as reference vessels for the analysis.

Cargo notation vs. Passenger notation
The Cargo notation was developed to allow for reduced safety level when the vessel is only carrying personnel trained in maritime operations including procedures related to fire. But, apparently, there is a practice for using the HSC Cargo notation for vessels that are intended for transport of passengers on a daily basis.

It is recommended to be more consequent regarding the Cargo/Passenger notation taking the actual use of the vessel into account. Cargo vessels should not be used for passenger transport.

Area classification
The investigation of the HSC Code and the reference vessels supported findings in the background study (appendix A) regarding risk classification of areas and systems. Currently, areas and systems are classified simply by consulting tables in the regulations. The risk assigned to various areas and systems is based on many years of experience, primarily with steel ships. Therefore, there are a lot of implied assumptions built into the risk classification scheme in the regulations.

For risk classification of areas and systems in composite vessels it is recommended to do a more holistic evaluation taking into account the factors that governs the actual risk; risk of ignition (e.g. hot surfaces, fuel load and fuel type in the respective area (will it promote a fast or a slow fire development) and the importance of the area (with respect to the safety of entire ship, the crew and the passengers).

Based on a holistic risk classification of areas and systems more appropriate fire safety measures can be chosen.

Passive fire protection measures
Passive fire protection is all the measures that are do not rely on any activation to fulfil their purpose. In maritime vessels it is primarily the fire insulation on bulkheads and decks. For composite vessels the fire insulation can potentially meet three objectives; protect the load-bearing structure, provide internal fire barriers between areas in the vessel and prevent combustible composite materials from contributing to the fire development.

It is recommended to use passive fire protection as the preferred fire safety measure in composite vessels. And instead of only applying it where it's required by the regulations, it should be used where it is needed based on the holistic risk classification of areas and systems. Fire safety should not be entirely dependent on activation of active fire protection systems.

Fixed firefighting systems
If an area or system is protected with a fixed firefighting system it should be considered to ensure that all technical equipment in the area can withstand exposure of the extinguishing agent. By reducing the risk of consequential damage the crew will be more inclined to activate the firefighting system at an early stage.

Water mist systems are preferred since they represent lesser risk to humans compared to gas systems.

Type rating of crew
The type rating is where the crew is trained in the operation of a specific vessel but it appears that training and procedures to a wide extend are based on a "steel vessel approach". This is supported by the findings in the study of human factors (appendix C).

It is recommended that the type rating of crew is much more tailor-made to account for the special properties of composites including training and procedures for maintenance, identifying signs of fire, firefighting and evacuation.

3.4 Failure Modes and Effects Analysis

Failure Modes and Effects Analysis (FMEA) is a well-known tool of reliability engineering used to investigate technical systems in terms of the failure of their constitutive elements, the causes of these failures, their effects, and lay out mitigation strategies to ensure reliable and redundant systems. FMEA is proposed in the HSC Code, Annex 4, as an "assessment of the failure characteristics of the craft and its component systems […] with the aim of defining and studying the important failure conditions that may exist". The FMEA tool is therefore an instrument of analysis accepted by IMO.

In the frame of the current project, it is proposed to consider *fire safety as a system*, in an untraditional sense since it is not a system in the technical sense of the term. When looking at fire safety as a system, it is then possible to apply to it the FMEA methodology. In this respect, it becomes possible to investigate in which ways the system "fire safety" can fail, what are the consequences of failures, and how they can be mitigated. It should naturally be kept in mind that the "fire safety" considered herein applies to HSC vessels built with composite materials.

Scope of the analysis
For maximum benefit, the findings of the background study, workshop, and technical analysis have been applied to the FMEA. The method is applied in general terms and specific terms. The purpose of the general application is to provide a framework of analysis for any HSC composite vessel project, and to highlight general issues with the state of knowledge, regulations, or design practices. The specific application is aimed at the Umoe Ventus design to illustrate detailed use of the FMEA method.

Results
The general application allowed highlighting the benefits of including fire safety early in the design phase when building with composite materials. The conclusions also reinforced the findings from the background study and the technical analysis on the need to increase the level of knowledge on composite materials through the industry, and to account for the properties of these materials in the design.

The consideration of the findings of the background study and technical analysis allowed highlighting additional failure modes for parts of the system "fire safety", with a particular look at the classification of spaces.

The specific application to the case of Umoe Ventus could highlight the cause of the actual accident. The FMEA also put forward other issues with the design which were not involved in the accident. In this respect, it is possible to say that the method did not only highlight what the analysis team was searching for, but also other issues, thus illustrating the value of such an approach.

4 Fire scenarios for composite ships following the HSC Code

The fire scenarios presented herein were developed using the findings from the background study (Appendix A) and the workshop (Appendix B). They have been further refined by the input from the anthropology study (Appendix C) and the technical analysis (Appendix D). The scenarios were developed based on the determination of the most critical areas of a ship, the most likely causes of ignition, and initial fuel sources. These scenarios are only relevant to ships built with composite materials. They are put forward as an illustration of which events are likely to happen on board a HSC composite vessel, and can serve as a basis to design protection adapted to HSC vessels built with composite materials.

The procedure for adequate fire protection design would be to consider which barrier could be placed at which stage of the scenario. The procedure could be assisted by a tool in the spirit of the FMEA proposed in Appendix E.

Development of a fire in a room can be illustrated in very general terms by the development of temperature as show in Figure 1. If sufficient oxygen and combustible material is available during the growth phase the fire will develop into a fully developed fire. When this phase is reached the fire is often impossible to suppress and extinguish. Therefore, the ignition phase and the growth phase are crucial for the fire safety to be successful. Appropriate measures must be implemented in the vessel design to ensure that a fire is detected, confirmed and extinguished before it reaches flashover and the fully developed phase.

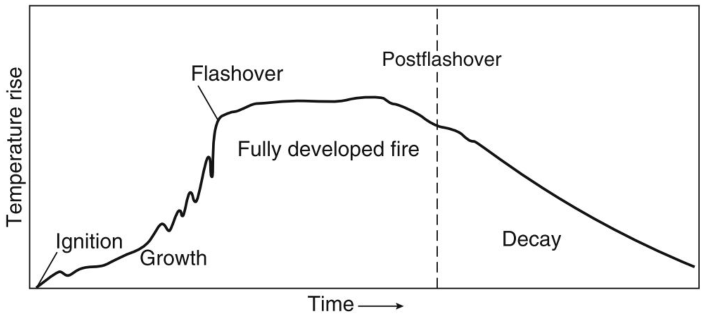

Figure 1 – Generic illustration of fire development in a room expressed by the temperature development [6]

The different phases of fire development important to keep in mind when likely fire scenarios are identified and the mitigating measures are designed. In the fire scenarios suggested below the fully developed fire phase is included to picture likely outcomes when fire protection measures are insufficient. Though, the important phases for a successful holistic fire safety design are the ignition and the growth phases.

4.1 Scenario 1, engine room

Ignition

In this scenario, fire starts in the engine room. A hot surface from e.g. a pipe of the engine is in contact with the combustible composite material because the insulation layer has not been replaced properly after a routine maintenance operation. This hot surface can be a pipe penetrating the bulkhead, or running close to it. Due to the source of high heat, the composite bulkhead ignites.

Growth
As the detectors are placed to monitor the engine, the fire is not discovered immediately and has time to develop unnoticed. The adjacent rooms start to be filled with smoke, which can be the way the fire is detected by crew members or passengers. The fire can also be detected by the detectors once it has spread to the engine or other equipment in the engine room. When the fire is detected, it is already well developed, beyond the capacity of the active systems, and too much smoke fills the room for intervention.

Fully developed fire
To confirm the detection, a member of the staff is sent to observe, opens a door and breathes large quantities of toxic smoke, leading to partial incapacitation. Stress level rises in the crew. The door to the engine room has been left partially open and fire starts spreading to the rest of the ship. The master is split between the decision to evacuate and the need to keep the ship. He considers the interest of the ship owner and his own job. External help is called and the firefighters use external boundary cooling to fight the fire, which is of no effect due to the insulating nature of composites. The ship is engulfed in flames before a smoke diving team can fight the fire. Evacuation is performed in a chaotic way with several intoxicated crew members. The crew members are in shock and the ship is lost.

4.2 Scenario 2, bridge

Ignition
In this scenario, fire starts in the bridge. Inside the casing an electrical fault or short circuit leads to a fire. No detector is fitted in the casing, and the inside of it is not accessible to fight the fire.

Growth
The fire is detected by the crew before the detectors, due to smells, smoke, and flames. The master takes portable VHF to keep communication with the shore. Fire spreads to the entire control panel, paralysing the ship and making it impossible to remain in the bridge. PPE is now inaccessible as most relevant equipment is located in the bridge.

Fully developed fire
Fire spread to the outside of the ship due to openings, and the superstructure is quickly engulfed in flames. The wind contributes to quick fire spread and directs the smoke, making a large portion of the ship inaccessible. Evacuation is the only option out, but one life raft already burnt. Fire has spread too fast for procedures to be followed, and stress levels in the crew are very high. In the end the whole ship is in flames so the remaining life raft is launched and the crew members have to jump in the water and swim towards it. They are in shock, some of them breathed too large quantities of smoke, and the ship is lost.

4.3 Scenario 3, void space

Ignition
In this scenario, fire starts in a void space located close to the evacuation station. The routing of the exhaust system makes it pass through a void space. The exhaust pipe is insulated, but the void space is not, in accordance with the HSC Code. Due to vibrations, the insulation layer slides and exposes part of the exhaust pipe near the composite material. After sufficient time, ignition occurs.

Growth
Since the void space is an area of Category F it is not fitted with fire detection or firefighting systems, and is inaccessible. Under these conditions, the fire can grow without being detected and spreads quickly to the next spaces, including the hull at the location of the evacuation station.

Fully developed fire
When the hull gets involved in the fire, the crew becomes aware of the situation which is already desperate. Following on-board procedures the master notifies the shore of the ongoing fire. Passengers are prepared for evacuation but the evacuation station is already in flames. Panic spreads quickly since the crew does not have procedures that suit this scenario, the fire is too big to be fought, and evacuation is made extremely difficult. Several people on board breathe toxic smoke to large extents. Only 15 min after the discovery of the fire the ship has to be abandoned. Evacuation is chaotic, life rafts are used as best as possible, and passengers have to jump in the water. Rescue cannot arrive in due time to the speed at which fire spreads. In the end, it is not guaranteed that every person on board is retrieved, many are intoxicated, all are in shock, and the ship is lost.

4.4 Scenario 4, switchboard

Ignition
In this scenario, fire starts in the electrical switchboard located in a room classified as an auxiliary machinery space. An electrical fault occurs in the switchboard, leading to ignition and quick fire spread to the uninsulated composite.

Growth
The fire is detected by the smoke detector and confirmation of the fire occurs a few minutes later by a crew member. The classification of spaces has not been performed properly and the auxiliary machinery space is not insulated. By the time the fire is confirmed, it could have spread to most of the composite and threatens adjacent rooms.

Fully developed fire
The amount of material involved makes firefighting difficult if not impossible. The master must consider the decision to evacuate, with the same considerations as expressed in Scenario 1. The limited time available is partially wasted in pondering the decisions and taking measures to mitigate the lack of procedure. The speed at which events unfold requires evacuating the ship. Most of the vessel is in flames at this moment, and is ultimately lost.

4.5 Scenario 5, galley

Ignition
In this scenario, fire starts in the galley by ignition of cooking oil.

Growth
The fire spreads to the greasy dust present in the ventilation. Fire detectors activate and alarm sounds.

Fully developed fire

Before the situation is confirmed, fire had time to spread to the furniture and to other spaces of the ship through the ventilation. At this point, fire dampers are activated. Sprinklers are activated and control the fire in the cooking area, but the flames spread to adjacent composite walls due to the inappropriate classification of spaces. Sprinklers should remain open to make sure crew members in their cabins located behind the galley can escape to a safe zone.

5 Recommendations

The findings and recommendations described previously in this report are summarised below. For further details the reader is referred to the previous chapters and the appendices.

- Vessels built with combustible composites are more vulnerable to inappropriate risk classification of areas and systems. The risk categories assigned by the HSC Code – and the way it is traditionally interpreted – does not always take all risks associated with composite vessels into account. Therefore, it is recommended to evaluate the risks associated to all areas and systems in the specific vessel design. The evaluation must include all spaces including voids and open spaces. The risk classification of a specific composite vessel design will most likely differ significantly from the risk classifications defined by the HSC Code.

- As part of identifying the risks associated with areas and systems, a series of fire scenarios should be defined. The scenarios suggested in this report can be used as inspiration. The fire scenarios are a valuable tool when passive and active fire protection measures are selected for each area and system in the vessel. Moreover, the fire scenarios should be used to design the procedures that describe how the crew is trained and how they should react in case of fire. All in all, the fire scenarios, the passive fire protection, the active fire protection systems and the crew procedures are part of a *holistic and vessel specific fire safety design*.

- A design team will never be able to identify all possible fire scenarios in a vessel in its entire lifetime. There is always a risk of unforeseen incidents that are not accounted for in the fire safety design. Therefore, fire safety strategy should be able to tackle both the identified risks and the unforeseen scenarios when they occur.

- The technical aspects of the fire safety design (passive and active protection) may be able to meet unforeseen scenarios but obviously they will never be able to adapt and be creative if the fire scenario is out if their range. Therefore, the technical measures should be designed with a level of robustness and redundancy to meet variations in the fire scenarios and failures in the individual system components. Thus, it is important that the fire safety design covers *a range* of fire scenarios and that a safety margin is added to account for extremes. Additionally, the fire safety design should be able to maintain an acceptable safety level if a subcomponent in the system is subject to failure.

- As opposed to the passive and active fire protection measures, the crew is actually capable of adapting to an unforeseen fire scenario. In theory at least. In a stressful event of a fire where fast response is crucial, a person is inclined to react according to experience. Therefore, it is recommended that training of crew include adaptability and creativity skills. Additionally, the training should be very "composite vessel specific", that is, the crew must be aware how a composite vessel differs from a steel ship in case of fire.

- As part of performing a holistic fire safety design it is recommended to consider all aspects of fire safety as part of one combined system. To do so it is suggested to use the tool Failure Modes and Effects Analysis (FMEA). This allows the design team to analyse the interdependencies of fire scenarios, technical fire safety measures and crew intervention, including the consequence when failures are introduced. It is suggested, that the FMEA tool is used actively in the design process – not just as a means to validate the final design.

6 List of annexes

The work performed in the project is available in full details in the following annexes.

Annex A: Background study

Annex B: Internal workshop

Annex C: Human factors

Annex D: Technical analysis

Annex E: Failure Mode and Effect Analysis for fire safety as a system

7 References

[1] IMO HSC Code

[2] DMAIB Marine accident report Umoe Ventus

[3] IMO MSC.1/Circ. 1574

[4] DMA RO Circular no. 025

[5] IMO SOLAS

[6] Estimating Temperatures in Compartment Fires, William D. Walton et al, SFPE Handbook 5th edition, chapter 30, Springer, 2016