APPLICATION OF THE TRIPOD METHOD FOR HUMAN FACTOR ANALYSIS ON THE EXAMPLE OF M/F JAN HEWELIUSZ CAPSIZING

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ABSTRACT

The SLF Sub-Committee commenced the work on a new approach to intact ships stability assessment. This may require human factor analysis if risk based approach is considered. Application of the TRIPOD method is one possible way of identification and gathering data on ships' capsize scenarios and human factor deficiencies in this respect. The paper shortly describes details of m/f Jan Heweliusz capsizing basing on survived crew reports, stability calculations and available documents. The diagram containing a number of triple blocks (hazard, target and event) identified during the investigation of the capsizing is shown. The blocks present in the form of pictograms the most possible capsizing scenario. The examination of the scenario identified a number of different "barriers" which should stop the sequence of events leading to capsize of the ferry provided the operation was free of human errors. A table of 14 broken barriers: 8 existing and 6 missing is presented. An example of the activity of Polish delegation to SLF Sub-Committee leading to fill the gap consisting in missing regulations is presented.

Keywords: *ship capsizing, human factor, TRIPOD method*

1. INTRODUCTION

The Sub-Committee on Stability and Load Lines and Fishing Vessels Safety (SLF) commenced the work on a new approach to intact ship stability assessment. Critical opinions regarding present intact ship stability criteria are well recognised and justified (Belenky, de Kat, Umeda, 2008, Kobyliński, 2005). A new item of the Sub-Committee work program defined during the 51st Session in 2008 is named „*Development of new generation intact stability criteria*" (IMO, 2008). Deferent ways to complete this difficult tusk are possible. One of them is risk-based approach – risk analysis exemplifying an alternative to prescriptive criteria used at present in regulatory work (both for design and operation purposes) (Kobyliński, 2006, IMO, 2008 a).

Risk based methods have been introduced by IMO under the name of Formal Safety Assessment (FSA) (Hermann, 2008). The proposed methodology for FSA consists of the following main steps:

1. Hazard identification.
2. Risk assessment.
3. Risk control options.
4. Cost benefit assessment.
5. Recommendations for decision making.

An analysis of intact ship stability failures, both total and partial, that happened in the past, could be helpful for elaboration of the set of data for hazard identification - the first (preparatory) step of the FSA procedure. A very useful tool for such an analysis and for recording of stability failures are fault trees and event trees. The fault tree is a diagrammatic tool representing sequence of events that might lead to failure in a "top-down" structure.

2. THE PRINCIPLES OF THE TRIPOD METHOD

TRIPOD is an approach to the analysis of accidents using the Tripod Theory of Accident Causation. The theory is in line with the statement that accidents are usually multi-causal events and that the immediate causes are in most cases set up by the effect of latent failures that may have been present in a system or organisation for many months or years before the accident occurred (Gower-Jones, van der Graaf, 1998).

The TRIPOD tool is so called "trio": a HAZARD, TARGET and EVENT. The hazard is an agent of harm, the target is the object of harm and the event is the occurrence where the hazard and the target get together, resulting in harm or the potential for harm. In this context harm should be seen as an undesirable change of state. Different barriers and controls are usually established in a properly planned industrial operation serving as hazard management measures in order to protect potential targets from harm. The basic elements of the diagram modelling the sequence of events – the TRIPOD path – is shown in the figure 1.

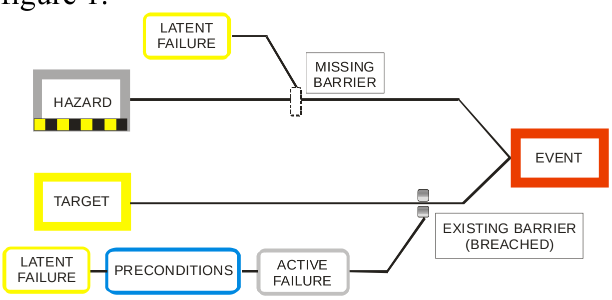

Figure 1. Hazard, Target and Event trio.

The purpose of this diagram is to identify the hazard trajectories – the conceptual pathways joining hazards and targets with events. Identification of failed and missing barriers completes the picture of what happened and what failed. The diagram simplifies identification of the failed barriers and controls. The TRIPOD path shows links between latent failures, active failures and specific failed barriers.

The TRIPOD method provides thorough accident investigation with clear, concise and consistent reporting. Normally a few "trios" are needed to fully describe an accident. The approach allows to model the events sequences leading to the accident, immediate and latent causes, as well as corrective actions to be targeted at the most effective areas (www.tripodsolutions.net}.

3. CAPSIZE OF M/F JAN HEWELIUSZ

M/f Jan Heweliusz was a ro-ro passenger ferry operated on the route between Świnoujście (Poland) and Ystad (Sweden). She capsized on 14th January 1993 between 4:25 and 5:12 in the morning and sank probably on 15th January 1993. The position of the wrack is about 20 nautical miles from Kolifer Ort (Germany). The weather conditions during the capsizing: mean wind speed about 59 knots, increasing to 85 knots in gusts; visual wave height about 4 meters; water temperature 3°C. The cargo onboard: 10 rail wagons and 28 lorries. There were 35 passengers and 29 crew members on board. Only 9 crew members survived the disaster.

A short description of the sequence of events and decisions leading to capsize of m/f Jan Heweliusz is given below.

A. Events which took place long time before the capsizing but had strong impact on the disaster:
   1. The inclining test (in the shipyard) was performed not reliable.
   2. Faulty construction of 3 DB BT allowing the ballast water to outflow the ship. When the ship was heeled more than 17 degrees the water run gravitationally from the upper tank

through the pipe, lower tank and the air pipe out the ship. It was not possible to control this outflow. This construction is shown in the figure 2 and is recognised as a latent failure.

3. Faulty construction of 10 HT allowing the water to shift gravitationally from upper tank to lower tank when the angle of heel exceeded 42 degrees. It was not possible to control this shift. This construction is recognised as a latent failure.
4. The inclining test was not executed after the fire onboard the ship and the renovation of the superstructure despite appropriate regulations. As a result the light ship weight and the centre of gravity co-ordinates were not known and actual stability of the ship was worse than described in the *Information*

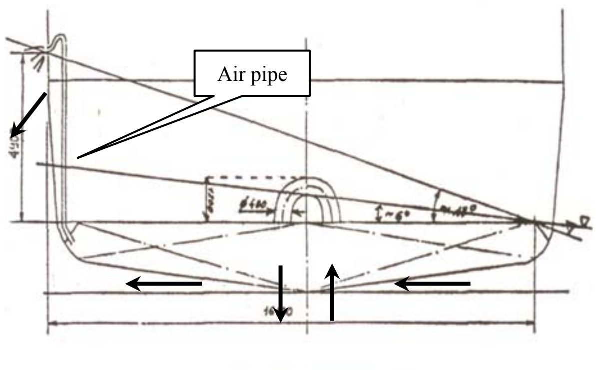

Figure 2. Construction of No 3 Double Bottom Ballast Tanks. The latent failure.

B. Events (decisions) which took place just before and during the last voyage of the ship.

5. Lack of the actual weather forecast.
6. Departure in load condition not satisfying stability requirements (damage).
7. Departure with a crack in the aft door. The ship contacted a quay with aft door 4 days before capsize.
8. The cargo (lorries) not lashed.
9. Severe wind and waves.
10. The heel due to wind pressure compensated with shifting of the water in 10 HT (partly) and filling of AP PS (unsymmetrical mass distribution).
11. Low speed of the ship.
12. Unintended change of the ship course in relation to wind direction.
13. The change of the ship course in relation to the wind direction with low speed in unsymmetrical loading condition resulted with the angle of heel about 30 degrees. It was impossible to change the course by bow (barrier No 5). There was no attempt at change the course by aft. The angle of heel caused increasing unsymmetrical mass distribution in 3 DB BT (ballast water outflow) and 10 HT (shift of the water). It was possible cargo shift to Port Side caused by increasing angle of heel. The crack in the aft door could cause flooding of the train deck (bulkhead deck) including the ladder way to the engine room. All mentioned events caused increase of the angle of heel and finally capsize of the ship in quasi static way in about half an hour from changing the course.

The change of the ship course and its effect on the angle of heel is shown in figures 3 and 4. Unintended change of the course could be a result of lower wind speed at the moment when the crew steered the ship to the head wind.

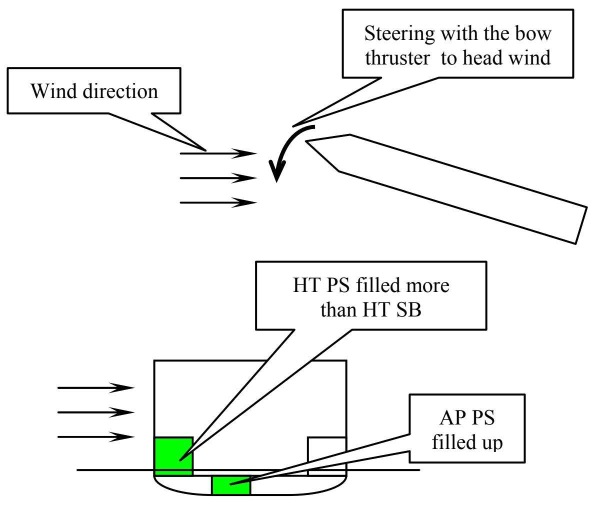

Figure 3. The situation before changing the course. The angle of the heel ~ 0 degrees.

It is recognised that after occurrence of this event the process leading to capsize was not possible to be stopped by the crew using the measures available on board in these conditions.

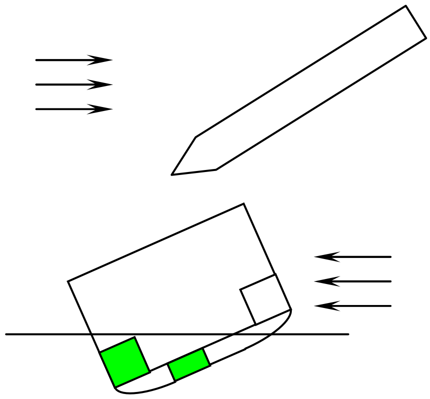

Figure 4. The situation after changing the course. The angle of the heel ~ 30 degrees.

Sequence of events described above is based on survived crew reports, stability calculations and available documents gathered by Polish marine chambers. The investigation of the marine chambers in Szczecin and Gdynia lasted almost 6 years (PiOM, 1999, Szozda, 1998).

Figure 6 shows increasing heel (quasi static) versus time and successive events causing increase of the heel when activated.

Percentage of heeling moments capsizing the ship is shown in the figure 5. It is clear that measured wind (mean speed 59 knots) could not capsize the ship with calculated stability characteristics.

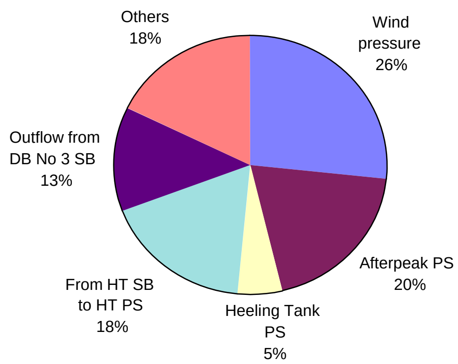

Figure 5. Percentage of heeling moments capsizing the ship.

- 100 % in the figure 5 means a static external heeling moment necessary to capsize the ship.
- "Afterpeak PS and Heeling Tank PS" are the result of the event number 10.
- "Outflow from DB No 3 SB" and "From HT SB to HT PS" are the result of events number 2 and 3.
- "Others" might contain such events like shifting of the cargo to PS or flooding of the main deck. It is not possible to calculate these values separately.

4. TRIPOD PATH AND BREACHED BERRIERS

The diagram containing a number of triple blocks (Hazard, Target and Event) identified during the investigation of the capsize is shown in the figure 7. This figure exemplifies the TRIPOD path of this accident and present in the form of "trios" the most possible capsizing scenario. The examination of the scenario identified a number of different barriers which should stop the sequence of events leading to capsize of the ship provided the design and operation were free of human errors. The Table 1 contains 14 breached barriers: 8 existing and 6 missing. The nature of all barriers is classified as human factor. The barriers are divided into 3 groups: lack of regulations, design and operation.

Table 1. Breached barriers classified as human factor.

No	Type of a barrier	Description of a barrier	Factor breaking the barrier
1	Existing	Ignorance of the weather forecast onboard before departure in spite of knowledge on severe weather in other countries in Western Europe. Lack of good seamanship.	Human factor - Operation.
2	Missing	Lack of regulations	Human

		prohibiting the compensation of the angle of heel caused by the wind pressure by the mean of unsymmetrical mass distribution.	factor - Missing rules.
3	Missing	Lack of the shipowner procedures to analyse the accidents taking place in the past within the managed fleet and application the results of the analysis in the operation.	Human factor - Missing rules.
4	Existing	The inclining test after the renovation caused by fire onboard was not executed (a few years before the capsizing). The rules were not applied.	Human factor - Operation.
5	Existing	The power (designed) of the bow thruster was too low in order to make possible crossing the wind line in particular weather condition (as intended by the Master).	Human factor - Design.
6	Missing	The air release pipe in 3 DB BT was too short. The possibility of outflow of the water occurred in case of large heel (enlargement of the angle of heel).	Human factor - Design.
7	Existing	Starting 10 HT was impossible in particular conditions during the sequence of events. The power of the pump was too low in order to shift the water from lower to upper tank. Lack of the remote control of the valve.	Human factor - Design.
8	Missing	Lack of shut-off valve in 3 DB BT.	Human factor - Design.
9	Existing	The cargo (lorries) was not lashed before departure. The rules were not applied. Lack of good seamanship.	Human factor - Operation.
10	Missing	The air release pipe in 10 HT was too short. The possibility of shifting the water (gravitational) from upper to lower tank occurred in case of large heel (increase of the angle of heel).	Human factor - Design.
11	Missing	Lack of shut-off valve in 10 HT (on the air release pipe).	Human factor - Design.
12	Existing	The ladder way from the Train Deck to engine room was opened. The rules were not applied. There was a possibility of flooding the hull.	Human factor - Operation.
13	Existing	There was a crack in the aft door on the departure. The rules were not applied. There was a possibility of flooding the ro-ro space (bulkhead deck).	Human factor - Operation.
14	Existing	The watertight doors in the watertight bulkheads were opened. There was a possibility of flooding the watertight spaces in the hull.	Human factor - Operation.

5. INITIATIVE OF POLISH DELEGATION TO IMO – EXAMPLE OF ACTIVITY TO BUILD A MISSING BARRIER

The sequence of events leading directly to the capsize of m/f Jan Heweliusz was started with the use of 10 HT (partly) and AP PS in order to compensate the heel caused by the wind pressure. Use of anti-heeling devices resulting in unsymmetrical mass distribution weaken ship's stability on the windward side significantly. At the time of capsizing there were nor requirements or recommendations prohibiting such procedure. It was recognised as a missing barrier in TRIPOD nomenclature – lack of regulations. For this reasons Polish delegation to SLF presented at the 46th Session the paper proposing a new paragraph in the IS

Code containing statement "... *heeling caused by the wind should not be compensated with anti-heeling measures*." (IMO, 2003). There was not full consensus with Polish proposition but after discussions within the working group and plenary the final decision of SLF Sub-Committee was to include Polish proposition after modifications into:

Part B of IS Code –
Recommendations for certain types of ships and additional guidelines;
Chapter 5. –
Operational provisions against capsizing;
Paragraph 5.3. –
Ship handling in heavy weather.

The final text reads as follows:

> *"In severe weather, the lateral wind pressure may cause a considerable angle of heel. If anti-heeling measures (e.g. ballasting, use of anti-heeling devices, etc.) are used to compensate for heeling due to wind, changes of the ship's course relative to the wind direction may lead to dangerous angles of heel or capsizing. Therefore, heeling caused by the wind should not be compensated with anti-heeling measures, unless, subject to the approval by the Administration, the vessel has been proven by calculation to have sufficient stability in worst case conditions (i.e. improper or incorrect use, mechanism failure, unintended course change, etc). Guidance on the use of anti-heeling measures should be provided in the stability booklet."*

In the opinion of the Author this new paragraph in the IS Code 2008 exemplifies building of missing barrier (the second item in Table 1).

6. CONCLUSIONS

Most of accidents at sea, especially stability failures, are caused by a sequence of a number of events. In majority of cases one event acting separately can not cause the accident. Proper identification of particular events, their sequence and connections are the most important in the analysis of the accident. Basing on the analysis of the capsizing presented in this paper one can say TRIPOD method is very convenient for this purpose. This method possesses a lot of advantages, for example:

1. Is helpful in elaboration of a clear identification of particular events leading to an accident and their sequence in the form of concise diagram.
2. Offers a possibility of defining barriers and controls. Breaching of the barriers makes a path to next events and bring a ship closer the accident.
3. Offers possibility of defining not existing barriers. Potential existence of such barriers could cut off the sequence of events and did not let the accident to happen.
4. Allows to identify latent failures. Latent failures have been existing in the construction or organisation for many years and are not dangerous if the operation is kept within some limits. But when special operational conditions appear such latent failures become active failures and might cause events leading to the accident.
5. Application of the method makes the time necessary for investigation much shorter and may be helpful for the investigation team in achieving proper conclusions.
6. Offers a measure for elaboration of the set of data in the form of diagrams. Such data may be useful for hazard identification when the risk based approach is considered for stability assessment.
7. A software for facilitation of the building of the TRIPOD paths is available on the market.

Application of the TRIPOD method require some experience. Proper identification and decision weather a given object should be a Target or a Hazards well as the answer how describe and place in the diagram barriers or controls is not easy. Different experts may on the first step build TRIPOD paths for the same accident in different ways. It may be concluded with the statement that the first step of building TRIPOD path should be a team work.

7. REFERENCES

Belenky V., de Kat J.O., Umeda N., 2008, "Toward Performance-Based Criteria for Intact Stability", Marine Technology and SNAME News, Volume 45, Number 2, April 2008.

Gower-Jones, A.D.,. van der Graaf G.C., 1998, "Experience with Tripod Beta Incident Analysis", SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Caracas, Venezuela, June 1998.

Hermann, R., 2008, "Goal-Based Standards for all ship types", 2nd International Workshop on Risk-Based Approaches in the Maritime Industry, Glasgow, 2008.

IMO 2003, International Maritime Organization, Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety, Review of the Intact Stability Code, doc. SLF 46/6/3; London 2003.

IMO 2008, International Maritime Organization, Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety, doc. SLF 51/17; Report to the Maritime Safety Committee, London 2008.

IMO 2008 a – International Maritime Organization, Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety, Revision of the Intact Stability Code, doc. SLF 51/4/5; London 2008.

Kobyliński L., 2005, "Appraisal of risk assessment approach to stability of ships", 8th International Stability Workshop, Istanbul, 2005.

Kobyliński L., 2006, "Alternative stability requirements based on system and risk approach", Proceedings of the 9th International Conference on Stability of Ships and Ocean Vehicles, Rio de Janeiro, 2006.

PiOM 1999, Prawo i Orzecznictwo Morskie nr 41 (92), Odwoławcza Izba Morska przy Sądzie Okręgowym w Gdańsku z siedzibą w Gdyni, Gdynia, 1999 (in Polish).

Szozda Z., Wypadek promu m/f Jan Heweliusz, Materiały IV Konferencji Okrętownictwo i Oceanotechnika, Politechnika Szczecińska, Międzyzdroje, 1998 (in Polish).

www.tripodsolutions.net – home page of Tripod Solution.

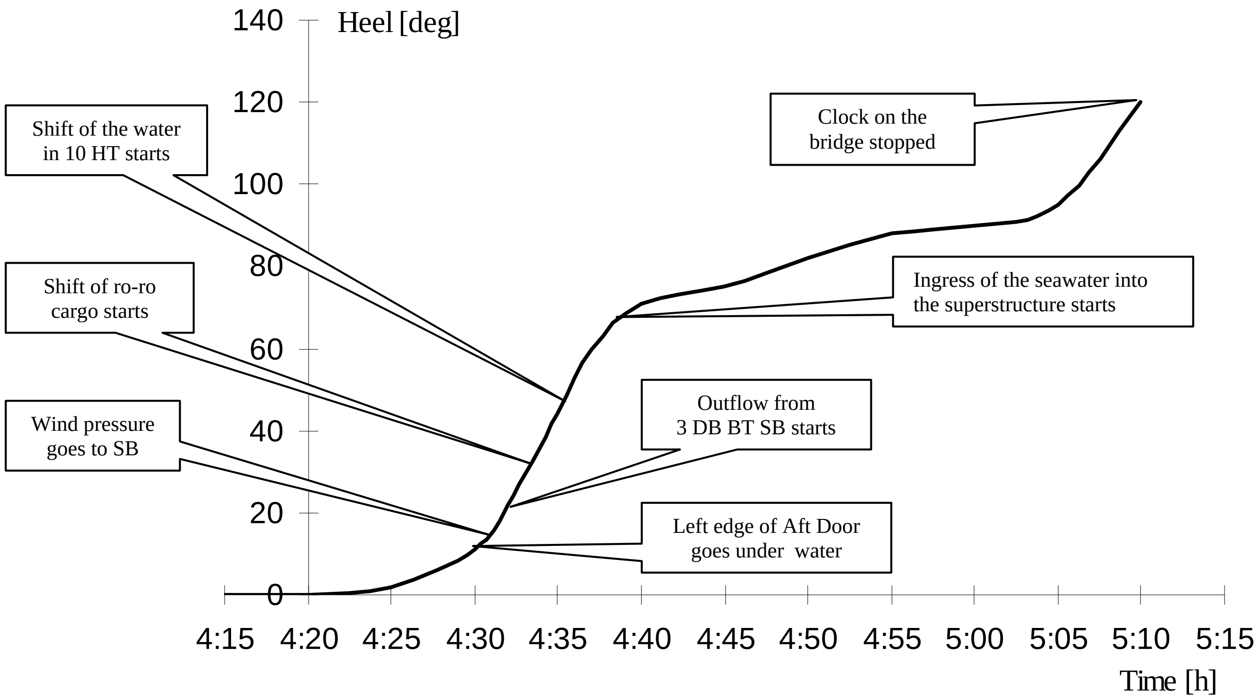

Figure 6. Quasi static heel of the ship versus time

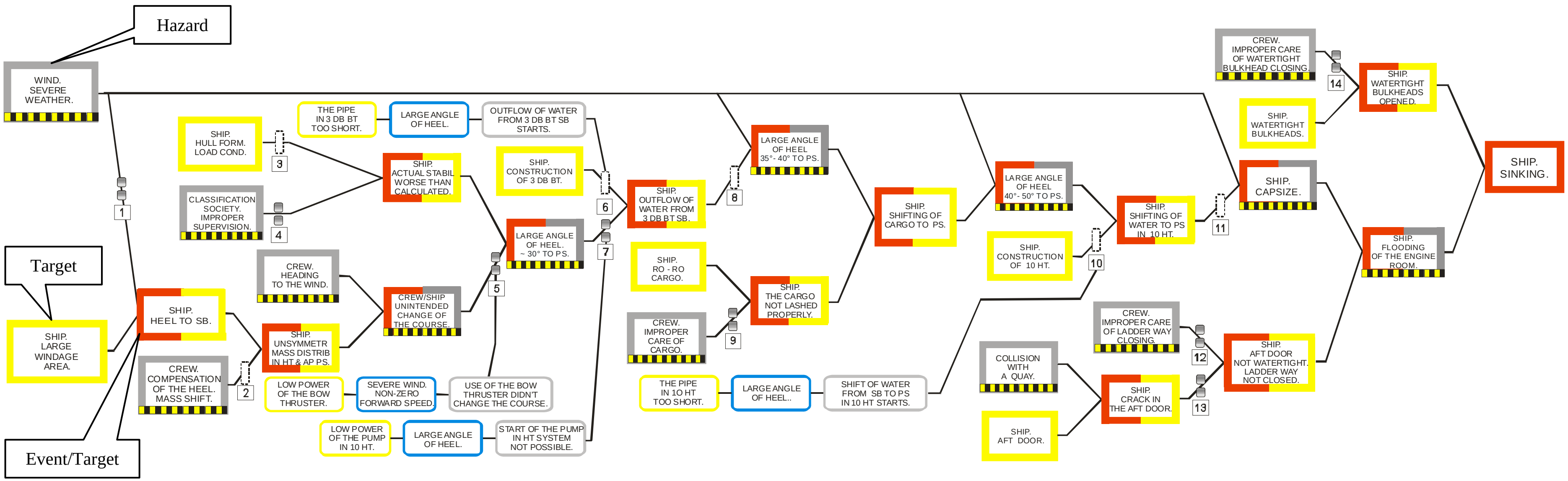

Figure 7. TRIPOD path of m/f Jan Heweliusz capsizing.