as possibilities to identify and avoid potentially dangerous conditions.

The development of this booklet and first comments from ship operators on the draft version emphasize the need for such a general guidance for both: as a basis to understand the phenomena a ship might encounter in rough or severe conditions and for decision support on board. But of course, especially with respect to the latter – the decision support – there are phenomena which allow a generalization with sufficient accuracy while others will remain more difficult to judge for the crews on board. One example is the identification of dangerous speeds with respect to parametric excitation in following seas: Especially for vessels which experience a significant loss of stability in wave crest condition the roll period tends to elongate to the period of encounter over a large range of periods. Plus the changes in ship speed can be substancial in steep following seas and thus substancially change the period of encounter. For these situations it becomes very difficult to formulate general advice on how to identify the "dangerous zone of speeds".

4.2 Ship specific guidance

Based on numerical motion simulations these described gaps which are left by general guidelines can be closed. Many motion simulation programs which are able to predict parametric excitation and other phenomena leading to dangerously large angles of roll are internationally available. And based on the results comprehensive ship specific guidelines can be compiled. This also includes the chance to be proactive, as all problems which are identified via the numerical investigations can be included in the guidelines. No matter whether they are of general interest or "just" important for the design at hand.

But of course such guidelines can only be compiled on an appropriate basis – linear theory and/or studies in regular waves are not sufficient for the prediction of phenomena like stability losses, parametric excitation, etc.

And not only the ultimate safety of the ship is of interest. For many types of ships cargo safety is as important from an operational and safety point of view. As cargo shift does not only endanger the ship, but leads additionally to high economical losses for the operator. Plus cargo securing itself is time consuming and costly – thus operators have an interest to use sufficient but also efficient cargo securing.

Fig. 5 shows polar plots which are extracted from a ship performance manual of a RoRo-ship. Here the limiting criterion was not a capsize, or a large angle of roll, but the exceedance of a certain (reasonable low) value of horizontal accelerations in more than two percent of the time. Such diagrams are given for a number of significant wave length and roll periods of the ship. Here only the plots for three wave length (increasing from the top to the bottom diagram) and two roll periods are shown for comparison.

It can clearly be seen how the areas where resonance occurs shift with increasing wave length. In this case these are areas were 1:1 resonance occurs. Furthermore it can be seen, that the stiffer load case on the right hand side is more likely to encounter significant horizontal accelerations, due to the shorter period of roll. While the simulations showed, that the roll angles as such are slightly smaller for the stiffer load case.

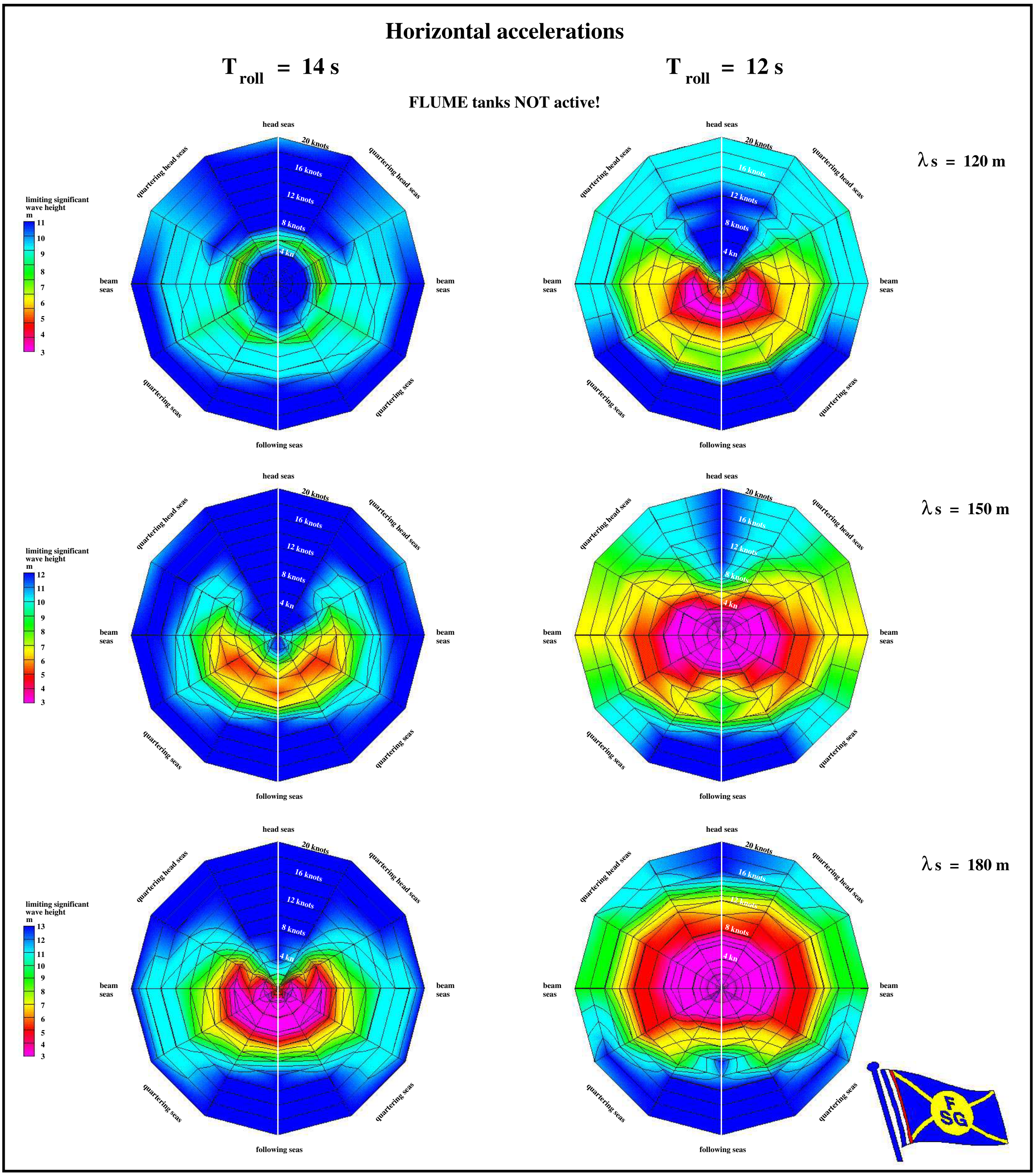

Figure 5: Polar plots with respect to horizontal accelerations for two different load cases extracted from a ship performance manual

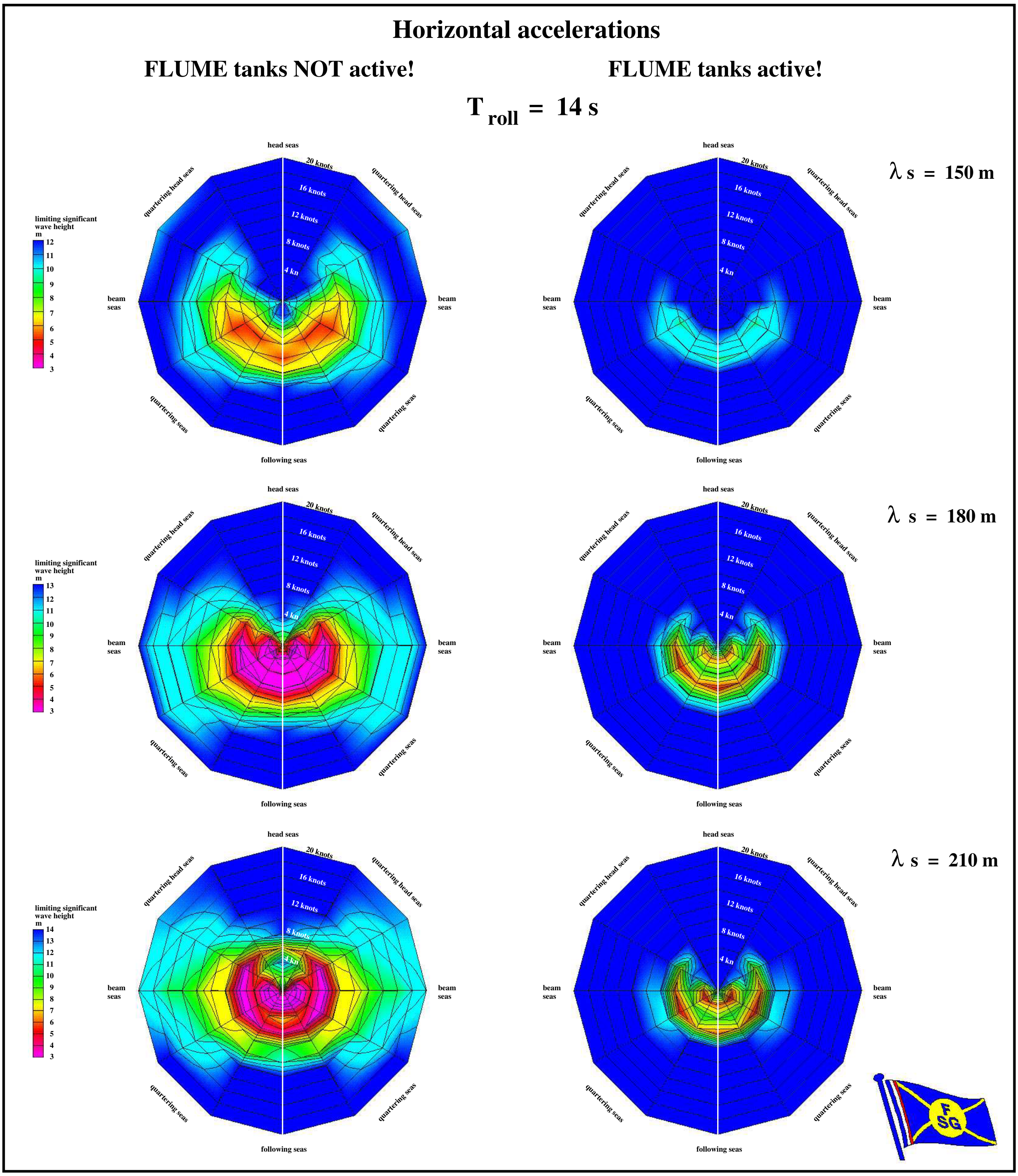

Figure 6: Polar plots with respect to horizontal accelerations illustrating the effectiveness of the FLUME-Tank arrangement extracted from a ship performance manual

Many of the modern ships (and especially Passenger and RoRo-Ships) have active or passive means of roll damping installed. Fig. 6 shows again polar plots which where extracted from a ship performance manual of a RoRo-ship. On the left hand side are polar plots for the unstabilized condition (as shown in Fig. 5 already), while on the right hand side results are shown for the same loading condition with activated FLUME-tanks. The efficiency of the tanks is well illustrated by these diagrams.

Both the compilation of these diagrams as well as the format of presentation are under further development, based on the experiences from both sides – the naval architecs running the simulations and the crews using the diagrams on board.

One difficulty is clearly the sufficiently accurate observation of seaway parameter (with respect to wave height and wave period in particular). The same problem is often causing difficulties in the interpretation of full-scale measurements of ship motions or loads on the ship's structure. Within the German research project SINSEE the WAMOS (Wave Monitoring System) will be futher developed and tested to enable reliable identifications of the relevant seaway parameter in the future.

5 REVISION OF INTACT STABILITY RELATED REGULATIONS

5.1 IMO's IS-Code

The IMO's IS-Code [10] is currently being revised. In order to bring the intended change towards a performance based formulation the following steps have to be performed in the revision process:

- Identification of safety related situations/mechanisms endangering the intact ship
- Collection of existing related knowledge and further research with respect to the physical phenomena endagering a ship and the assessment of ships performance in dangerous situations
- Development of a framework of performance based intact stability criteria
- Definition of criteria with appropriate standards

Besides analyzing designs, numerical simulations can be used to evaluate existing stability criteria and assist the development of revised regulations. In this respect, one of the aims of the German BMBF-funded research project SINSEE is to work out proposals for possible criteria taking into account the dynamic behaviour of the ship in rough seas. Several ships have already been analyzed and capsizing probabilities were determined following a.m. approach. All ships are simulated in conditions according to the existing intact stability limits and the following phenomena which may lead to a capsize are investigated:

- Insufficient stability on the wave crest, leading to a pure loss failure.
- Excessive heeling moments in heavy weather due to large roll exciting moments
- Parametric roll, and resonances in general, especially in combination with pure loss and/or excessive heeling moments

For most of the ships included in the study so far, the IMO Weather Criterion is the limiting criterion. And one result of this study is, that this criterion does not represent a unique safety level. Consequently, the ships analyzed have a large bandwith of capsizing probabilities, and for the development of new criteria it would be required that all ships have more or less an equivalent capsizing probability. Though the tolerable minimum capsizing probability might also depend on the type of ship (e.g. depending on the number of persons on board - passenger vessel vs. freighter or the like). Nevertheless, even on the basis of the data determined so far some trends can be observed as the following figures show:

Fig. 7 shows some interesting results for ships that tend to suffer from pure loss failures due to low stability on the wave crest. Here the idea was that there might be a connection between the alteration of the maximum righting lever between wave trough and wave crest condition and the capsizing probabilities. And the general trend shows clearly that the capsizing probability increases with higher maximum lever alterations, which suggests that the stability values for GZ_{max} to be attained in calm water should somehow depend on their alterations in waves.

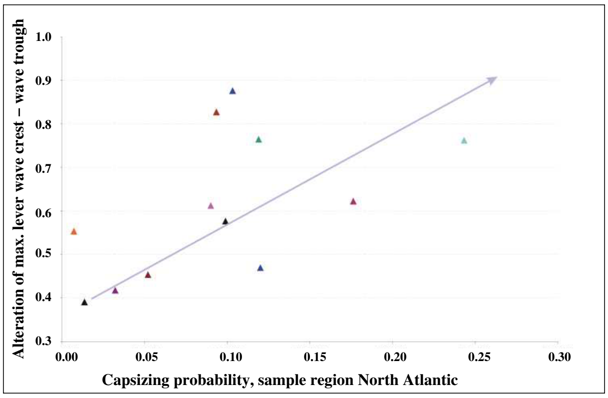

Figure 7: Capsizing probabilities versus alterations of the maximum righting lever between wave crest and wave trough condition for vessels suffering from pure loss of stability

Fig. 8 shows results for ships which are characterized by failures due to excessive heeling moments. This phenomenon seems to correlate with the roll energy in the system which could be expressed via the alteration of the area below the leverarm curve between wave crest and wave through conditions. As before, the trend is that the capsizing probability increases with larger area alterations, suggesting that the calm water area value to be attained should be a function of its alterations in waves.

The results show that it might be possible to generate criteria from such systematic simulations, but much more data is required.

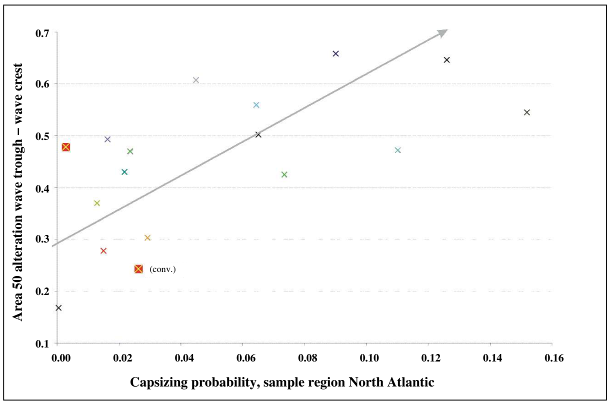

Figure 8: Capsizing probabilities versus alterations of the area 50 between wave crest and wave trough condition for vessels suffering from excessive heeling moments

5.2 IMO MSC/Circ. 707

While not yet included in the revision process at IMO-SLF the IMO MSC/Circ. 707 [9] urgently needs to be updated and extended. Numerical motion simulation tools can be used to support the revision process and also a lot of experience regarding many dangerous phenomena in rough and severe seaways is internationally available – from ship operation, model testing, numerical simulations, etc.

In Germany a joint effort of many members of the maritime community was undertaken to respond to the demand for more reliable guidance for the ship's crew in rough and severe conditions and the first draft version of a booklet called "Richtlinien für die Überwachung der Schiffsstabilität" was compiled, as already stated.

6 CONCLUSIONS

All three ship design, ship approval and ship operation determine the safety of a ship in rough conditions. Recent examples of (dynamic) intact stability problems show that the current rules and regulations are not able to represent todays vessels sufficiently well, and thus there is a strong demand from all three, design, approval and operation for more reliable and transparent regulations and guidance.

In this paper some examples are given on how numerical motion simulations and appropriate evaluation methodologies can support the design of safer ships and provide a basis for the compilation of ship specific guidance. Further examples show how these developments can also be used as a basis for rule development and the compilation of general "guidance to the master" applicable to all ships. Further developments are targeted in the ongoing research project SinSee in order to allow for quantitative safety assessments of a ships intact stability in the future.

At IMO-SLF the revision process of the IS-Code is ongoing and all three ship design, approval and operation will clearly benefit from the intended change towards transparent, perfomance based criteria – as will the ship's safety with respect to intact stability as such. And also the IMO MSC/circ. 707 needs to be included in the revision process, in order to provide more appropriate guidance for ship operation.

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