



EXECUTIVE SUMMARY

Marin Report No. 15416-2-TM

PODS IN SERVICE

Executive Summary

May 2004

PODS IN SERVICE

Executive Summary

MARIN order No. : 15416

Ordered by : Pods in Service JIP

Reference : EU Growth project G3RD-CT2000-00242

Reported by : Ir. H.J.J. van den Boom

TABLE OF CONTENTS	PAGE
REVIEW OF TABLES AND FIGURES	3
1 OBJECTIVE AND SCOPE	4
2 MONITORING CAMPAIGN.....	9
2.1 Overview	9
2.2 Data acquisition.....	10
2.3 The vessels	13
2.4 Data collection and analysis.....	17
3 MODELLING.....	18
3.1 Computational Methods	19
4 CONCLUSIONS.....	22
4.1 Conclusions from BOTNICA-team.....	22
4.2 Conclusions from RADIANCE-team	23
4.3 Conclusions from SUMMIT team.....	25
4.4 Conclusions from NILS HOLGERSSON team.....	26
4.5 Conclusions from Class Society Working Group.....	27
4.6 Overall conclusions from the Pods in Service JIP	29
5 REPORTS ISSUED	30

REVIEW OF TABLES AND FIGURES

Tables

Table 1 Participation Pods in Service JIP	7
Table 2 PSG Meetings	8
Table 3 Overview of the monitoring campaigns	9
Table 4 Review of the measurements	12

Figures

Figure 1 Podded Propulsor (Mermaid)	4
Figure 2 Data acquisition process on board SUMMIT	10
Figure 3 General lay-out of the measuring system installed on board MSV Botnica.....	11
Figure 4 MSV BOTNICA (2x 5MW Azipods)	13
Figure 5 RADIANCE OF THE SEAS (2 x 20 MW Azipods).....	14
Figure 6 GTS SUMMIT and her 20 MW Mermaid pods.....	15
Figure 7 NILS HOLGERSSON (2x 11 MW SSP drives).....	16
Figure 8 Mermaid Pod Body modes of motion studied with FEM model.	19
Figure 9 Comparison computed measured pod loads on BOTNICA	21
Figure 10 Steering angles on board Radiance of the Seas	24

1 OBJECTIVE AND SCOPE

The innovation of Podded Propulsors has developed fast both technically and in commercial acceptance in the shipping industry. The concept of an azimuthing submerged electrically driven pull propeller provides various economic, safety and comfort advantages. Vessel layout, assembly, propulsion efficiency increase, safer navigation in restricted waters and a significant increase in comfort on board due to vibration and noise reduction have all contributed to a swift acceptance of the podded propulsors by the maritime industry.

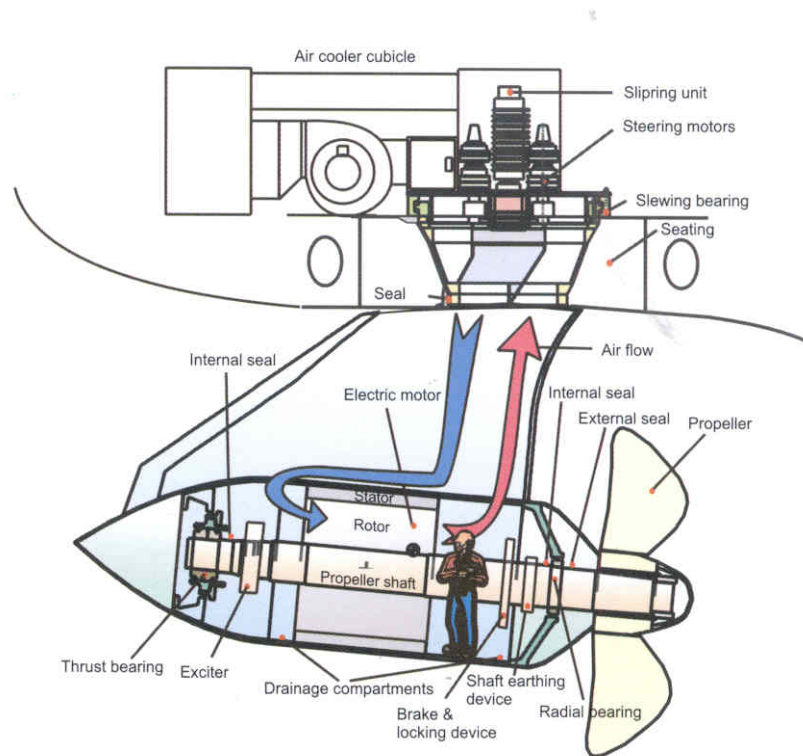


Figure 1 Podded Propulsor (Mermaid)

Developments in this field so far, are concentrated at European propulsion system manufacturers and European yards, which are the market leaders in the design, construction and operation of large cruise liners and ferries. Podded propulsors are considered as key technology for these ship types as well as various others. Further development is therefore important for a competitive maritime industry. Starting with cruise liners and ferries operating in fairly mild conditions, it is expected that podded propellers will be applied on various other ship types such as sea-river ships, coastal vessels and navy ships in the near future. To realize such applications and to incorporate this key technology in a competitive industry, the following developments are demanded:

1. Hydromechanic improvement of the podded propulsor and ship hull;
2. Improvement structural integrity and reliability of the podded propulsor and ship hull

Item 1 has been the subject of the OPTIPOD project conducted within the EU Growth program in 2000-2003. Research programmes in this field are also conducted in the CRS programme and for individual pod manufacturers and yards.

The Pods in Service Joint Industry Project (JIP) was initiated in 1999 to contribute to above item 2. The JIP concerned the structural loading and improvement of podded propulsors and aft ship structures. Specifically for design, engineering and classification detailed information as to the loads and response of podded propulsors under service conditions was required as these devices differ substantially from conventional propellers and rudders.

The objective of the JIP was to assess and evaluate the reliability and integrity of podded propulsors under operational conditions. The proposed project "Pods in Service" has been aiming at measuring the performance and the loads experienced by pods in service conditions. These loads comprise extreme loads during harsh conditions such as imposed by severe waves and manoeuvres, cumulative fatigue loads and "incident loads and responses" such as originating from emergency manoeuvres such as crash stops.

The objective was further to provide computational methods for determining these loads in the design and engineering stage. To achieve these objectives the following tasks were identified:

1. Concurrent Measurement Campaign on board four Pod Driven Ships;
2. Data Analysis;
3. Modelling;
4. Computational Methods;
5. Evaluation.

At the start of the JIP, the focus of the measurements was put on the global loads and on force interface between pod and ship hull. The instrumentation was aiming at the strains, vibration and dynamic pressures in the pod seating (hull part around the azimuthing bearing) and in the pod house it self. For obvious reason also the developed pod power (torque and RPM) the consumed power, as well as the steering angles and torque were monitored. Technical problems encountered with the new 21 MWatt pods coming into service during the course of this JIP and in some cases also on the vessels involved in this JIP, have learned that, the monitoring of components such as shaft bearing and seals would have been appropriate.

Both the navies and the cruise line operators involved in this JIP were interested in the underwater noise profile of pod driven ships. Although this was outside the scope of the EU-project, attempts have been made to plan under water acoustic measurement ranges, and cruise vessels with pods to be at the same location at the same time. Unfortunately these attempts were not successful, mainly due to the tight schedule of the ships and due to the limited availability in time and space of underwater noise measurement devices.

Organisation

As it was recognised from the start that the objectives of the project could only be realised in a close co-operation of all stakeholders i.e. manufacturers, yards, ship owners, class societies and research institutes a 4 year Joint Industry Project (JIP) was set-up in 1999.

This JIP actually encompassed two sub projects:

- The EU Growth Pods in Service project G3RD-CT-2000-00242 (1 July 2000-1 July 2003):
- The SSP Pods in Service project supported by Senter (1 July 2000- 31 December 2003).

The partners in conducting the work were:

- EU consortium: ABB, Alstom/Chantiers, RR/Kamewa, LR, Marin, Meyerwerft, RR/Kamewa and VTT;
- SSP consortium; Siemens, LR, GL, Marin;
- Vessel owners; FMA, RCI, Celebrity, TT-line;
- Class Societies; ABS, BV, DnV, GL, LR and RINA.

To ensure efficient work and industry confidentiality the work was performed by the following teams:

Vessel Teams:

- Botnica team; ABB, VTT, FMA, DnV;
- Radiance team; Meyerwerft, ABB, Marin, RCCL, DnV;
- Summit team; Alstom, RR, Marin, LR, RCCL;
- Nils Holgersson team; Siemens, GL, Marin, TT-line.

Class Society Working Group

- LR, DnV, GL, ABS, BV and RINA

Apart from the companies actively involved in the work, there were several companies that sponsored the project and played an active roll in the control and steering of the project in the Project Steering Group. A complete list of all participating companies is presented in Table 1

Sector	Participant	Representation in PSG
Ship owners	Carnival Corporation	StephenPayne(Chairman)
	Royal Caribbean International (RCCL)	Joseph Miorelli
	Celebrity Cruises (RCCL)	Joseph Miorelli
	TT-Line	Heinz Naujoks
	Finnish Maritime Administration	
	USCG	Martin Madiros
	DND	Nathalie Deszarzens
	RNN	Hans Hasen Flug
	DERA/Qinetiq	Christopher Richardsen
	Pod Manufacturers	ABB Azipod
	Kamewa Mermaid	M. Johansson/L.Holmstrom
	Siemens SSP	Peter Andersen
Ship yards	Meyerwerft	H.Luhmann/G. Untiedt
	Chantiers de l'Atlantique	R.Lepeix/C. Djeloyan/ M.Jourdan
	Fincantieri	Andrea Serra
	SS-werft	Diter Klug
	Kvaerner-Masa	Patrik Rautaheimo
Classification Societies	LR	Zabi Bazari
	GL	Andreas Junglewitz
	ABS	M. Mahmood
	BV	Pierre Bess
	DnV	Odvar Deinboll
	RINA	Angelo Tonelli
Research Institutes	VTT	H. Soininen/S. Kivimaa
	Marin	H.v.d.Boom/M.Kaminski P.Aalberts/J.Koning

Table 1 Participation Pods in Service JIP

As various competitors co-operated in the project and their commercial interests had to be safeguarded, the following confidentiality levels were agreed in the JIP

1. Vessel teams;
2. Class Societies working in the CSWG;
3. JIP-participants;
4. EU, Senter, Optipod consortium;
5. Outside world.

The issue of confidential information has been raised several times during the project. By working in Vessel Teams and the CSWG the project could proceed and deliver information to all partners on a need to know basis. In the Project Steering Group meeting in London (April 2003) it has been agreed, by the 3 pod manufacturers involved, that all measured data with the exception of the steering torques could be released to the JIP Participants.

Although the formal starting date of the EU project was July 1, 2000, the actual JIP started on January 1 because of the preparations required for the various ships and in particular the docking and measurements on BOTNICA conducted by VTT in the period April-October 2000. The formal closing date of the EU project was July 1, 2003.

Once the JIP was started and the EU project coming, the opportunity of incorporating a third pod type and a 4th ship to monitor materialized in a second sub project, the SSP project. It should be noted that work on the Nils Holgersson is part of the SSP project which will be completed by December 2003. The final report is due in February 2005. Therefore only provisional results and conclusions are available at the writing of this report.

MARIN was responsible for the JIP administration and management.

All participating organisations were represented in the Project Steering Group which was chaired by Mr. S. Payne of Carnival and that met every 6 months for progress reporting, planning and discussion of the results. The list of PSG meetings is presented in Table 2:

	Date	Host	Location
1	16 April 1999	MARIN	Wageningen
2	1 June 1999	MARIN	Wageningen
3	28 September 1999	MARIN	Wageningen
4	11 April 2000	Chantiers de l'Atlantique	St. Nazaire
5	9 & 10 November 2000	VTT	Helsinki
6	18 October 2001	Rolls-Royce	Kristinehamn
7	21 & 22 March 2002	Germanische Lloyd	Hamburg
8	10 October 2002	Chantiers de l'Atlantique	St. Nazaire
9	2 & 3 April 2003	Lloyd's Register	London
10	2 December 2003	Marin	Wageningen

Table 2 PSG Meetings

2 MONITORING CAMPAIGN

2.1 Overview

To quantify and model the loads experienced by the podded propulsor and the ship structure under actual service conditions, a full scale monitoring campaign was conducted. As these loads comprise extreme loads such as imposed by severe waves, incident loads such as originating from manoeuvres (e.g. crash stop), stochastic loads (equal in waves) and cumulative fatigue loads a long-term real world monitoring was considered essential.

To this end dedicated systems were developed to measure these loads in combination with the propulsor performance and general navigation data and wave conditions on board the following vessels:

1. **BOTNICA**; a supply vessel equipped with ABB Azipods operated by FMA in the North Sea (summer 2000).
2. **GTV 'RADIANCE OF THE SEAS'**; a new 300 m large cruise vessel equipped with Azipods and operated on the west coast of America incl. Alaska since spring 2001.
3. **GTS 'SUMMIT'**, a new 300m cruise vessel of the MILLENNIUM class, equipped with Mermaid pods and operated in the Mediterranean, Caribbean and Baltic since September 2001.
4. **'NILS HOLGERSSON'**, a new built Ropax ferry equipped with Siemens Schottel SSP pods and operated by TT-line on the Travemünde-Trelleborg service since August 2001.

On each of these vessels a dedicated monitoring system was installed to measure the selected parameters and variables automatically for a designated period starting with the sea trials of the vessel. During this period the system measured, recorded, processed and stored relevant data.

An overview of the monitoring campaigns on the 4 vessels is presented in Table 3

Vessel	contractor	PODS	Monitoring
Botnica	VTT	ABB/Azipod	Apr 2000 - Oct 2000
Radiance	MARIN T&M	ABB/Azipod	Feb 2001 – Apr 2003
Summit	MARIN T&M	RR/Mermaid	Mar 2002 – May 2003
Nils Holgersson	MARIN T&M	Siemens/SSP	Aug 2001 – Dec 2003

Table 3 Overview of the monitoring campaigns

2.2 Data acquisition

The measurements were aiming at extremes, operational profiles, long term statistics and incident events. To this end the monitoring systems utilised dedicated sensors, existing ship data e.g. coming from the ship network and an automated data acquisition system. The data acquisition process was configured in such way that both high frequency phenomena and typical wave frequency phenomena could be monitored.

As an example the acquisition process on board GTS Summit is presented in Figure 2.

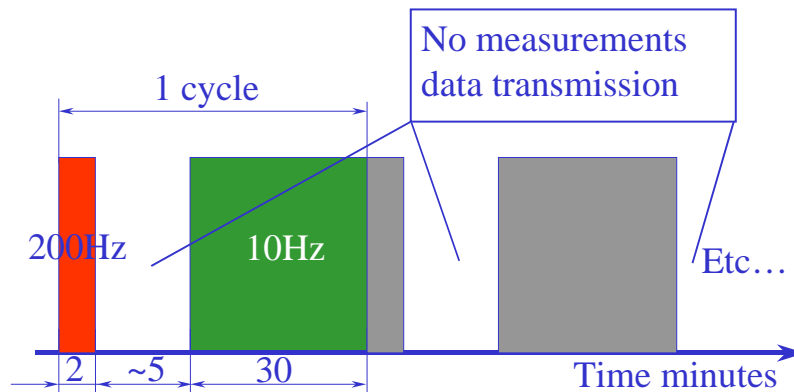


Figure 2 Data acquisition process on board SUMMIT

The measurements comprised the following areas:

Area	relevant aspects
1. engine and shaft	condition and efficiency monitoring
2. pod housing	loads, steering and vibrations
3. hull	construction, strength, vibrations
4. propeller	strength
5. environment	analyses and data interpretation

It should be noted that the JIP focussed on the global loads and force interface between pod and ship hull. Problems encountered by various ships with pod propulsions during this project were often related to specific pod components such as shaft bearings and seals. Unfortunately the monitoring of these components were not included in the scope of this JIP in the early stage of the project.

The monitoring system used in the Pods in Service campaigns was a dedicated system, designed and developed specifically for this project. Obviously, for the sensors, computer systems and data acquisition software, use was made of commercially available hardware and software. Specific areas of attention were the measuring of dynamic pressures and hull accelerations above the propeller, the strains in the pod support structure and obviously the strains, vibrations and drive

performance in the pods themselves. In particular, the high temperatures in the pods (up to 70 degr. C) required a special measurement computer in the pod. Data transmission from the pod to the hull was another hurdle to take. The monitoring systems were developed, assembled, installed and maintained by VTT (Botnica) and MARIN (other ships).

In Figure 3 an overview of the monitoring system on board BOTNICA is presented.

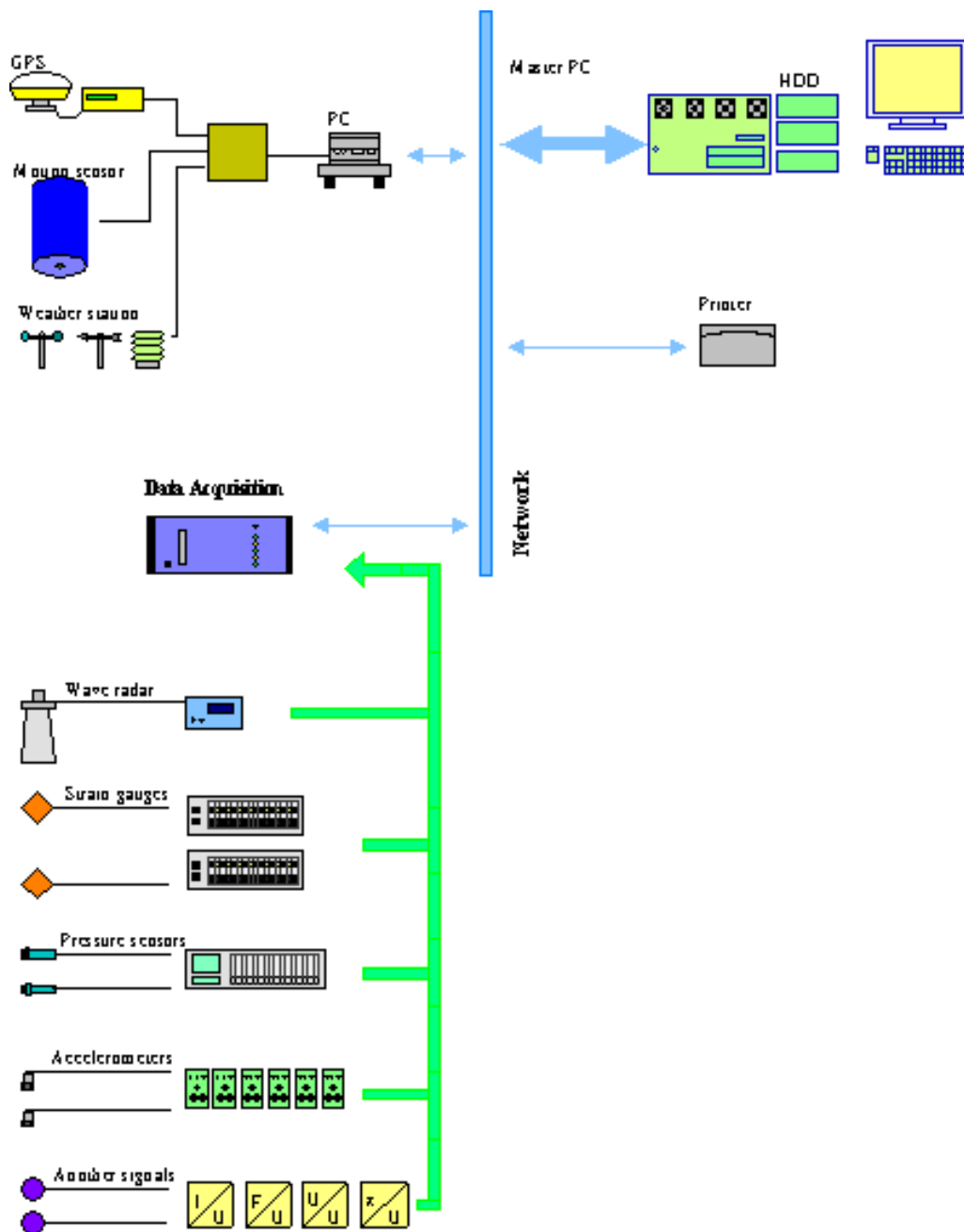


Figure 3 General lay-out of the measuring system installed on board MSV Botnica.

Relevant areas and aspects covered by the 4 measurement campaigns are indicated in Table 4

Area	variable	Botnica	Radiance	Summit	Nils Holgersson
Engine & Shaft	Torque	X	X	X	X
	RPM	X	X	X	X
	Electric power	X	X	X	X
	Temperatures		X	X	
Pod housing	House strains	X	X	X	X
	Steering moment and angle	X	-	X	
	Slewing ring loads	X	X	X	
	Vibrations& accel.	X	-	X	-
Hull & pod support	Hull press. & accel	X	X	X	X
	Strains	X	X	X	X
	Vibs & accel	X	X	X	X
Propeller	Blade strains in extreme conditions			attempt	
	Flow and cavobs		X	X	-
Ship	Draft	X	X	-	X
	Track	X	X	X	X
	Speed	X	X	X	X
	Motions (6 dof)	X	X	X	X
Environment	Wind	X	X	X	X
	Waves	X	X	X	X

Table 4 Review of the measurements

2.3 The vessels

The work on each vessel was conducted by separate teams and in all cases tailored instrumentation; data acquisition and analysis have taken place.

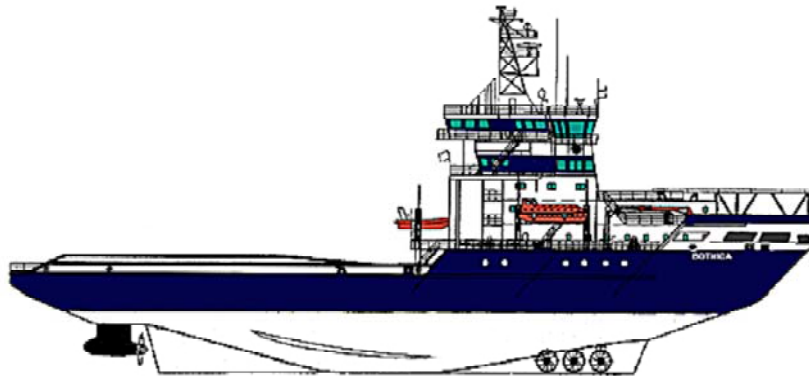


Figure 4 MSV BOTNICA (2x 5MW Azipods)

BOTNICA (Figure 4) has been instrumented by VTT prior to her summer service in the North Sea. To this end in March 2000 the vessel was docked in Helsinki and extensive static load-displacements test could be conducted.

In cooperation with her owners, operators and crew an extensive dedicated trial programme was conducted on her way from Finland to the North Sea in April 2000. In these trials systematic tests with various pod settings (azimuth angle and rpm) were conducted to provide valuable data on their effectiveness and on the pod and hull loading.

Although the period for monitoring was limited to 6 months, the vessel encountered extreme high seas in the northern North Sea in July 2000. This has resulted in important data sets for pod behaviour in extreme wave conditions.

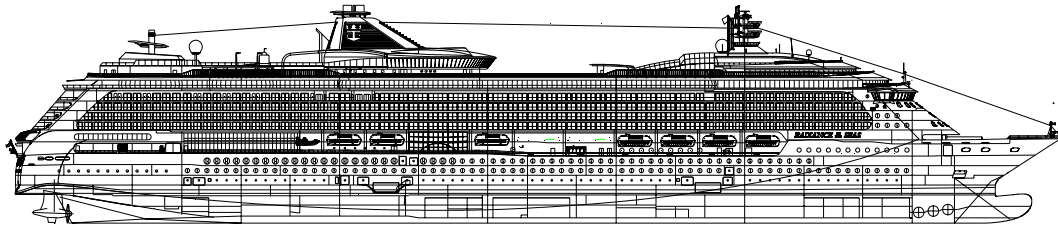


Figure 5 RADIANCE OF THE SEAS (2 x 20 MW Azipods)

RADIANCE OF THE SEAS (Figure 5) was equipped with the monitoring system during her construction at Meyerwerft in Papenburg. During her sea trials in February 2001, the monitoring system recorded all manoeuvres and the resulting loads such as the severe loads during the crash stop tests. When the vessel entered her service the monitoring system was set in automatic mode. After recovery from a few teething diseases the monitoring system has worked well until its dismantling in 2003.

In the mean time **RADIANCE** has been cruising in Caribbean, Alaskan and Hawaiian waters and this has resulted in a large data set for various operational conditions although extreme weather was not encountered.



Figure 6 GTS SUMMIT and her 20 MW Mermaid pods

GTS SUMMIT (Figure 6) is the third vessel of the MILLENNIUM series built by Chantiers de l'Atlantique for Celebrity/RCCL. The monitoring campaign on board this vessel was accompanied with an attempt to measure the propeller blade loads during the sea trials. To this end strain gauges were fitted on one of the blades and hard wired to a data logger was fitted in the hub cap. The data logger "slept" during the instrumentation and preparations in dock and was awake during the trials. Unfortunately the pod and propeller probably have been tested along side the quay and the wiring along the blade was damaged, therefore the blade loads could not be measured.

Observations of the propeller and the pod by means of video through observations windows in the hull during the sea trials were successful and resulted in recommendations to avoid cavitation on the pod house. After the sea trials the monitoring system suffered from several problems that were resolved in March 2002. Since that time the system has produced valuable data as Summit was cruising the Caribbean, Alaskan, US West coast and Hawaiian waters.



Figure 7 NILS HOLGERSSON (2x 11 MW SSP drives)

Ropax ferry **NILS HOLGERSSON** (Figure 7) was built by SSW in Bremerhaven in the year 2000. The vessel is equipped with 2 SSP pod units of 11 MWatt each. During the construction the ship was equipped with a monitoring system similar to RADIANCE and SUMMIT. Due to the construction schedule and the limited access to the SSP, it was not possible to instrument the pods themselves; however signals available from the Siemens instrumentation such as the strains in the pod house could be incorporated in the monitoring. The vessel was subjected to sea trials in July 2001 that were recorded by the monitoring system. After several months of commissioning work the NILS HOLGERSSON came in to the Travemünde-Trelleborg service operated by TT-Line. The vessel maintains a 24 hour service and leaves at 22.00 hours from Travemünde, which proved to be efficient for maintenance work on the monitoring system. Interesting for this project is of course that the NILS navigated all weather conditions experienced in the period in that area.

2.4 Data collection and analysis

Data sets from the vessels were mailed by crew members and vessel operator offices to Marin normally on a monthly basis. MARIN conducted the analysis of the data. Such analysis started with a quality check and the derivation of “long term statistics”. For a number of selected signals the statistics (i.e. mean, standard deviation and extreme values) over short periods (e.g. 20 minutes) were derived.

Subsequently these values were plotted as function of time over a long period of one month. Such a plot provides a good overview of the ship operations and from this data operational profiles of each vessel have been derived to distinguish the various modes of operation of the pods (e.g. speed range or manual/auto pilot), the weather encountered and the abnormalities in the signals. From these long term results shorter periods were identified for more detailed analysis such as spectral and statistical analysis.

In the operational profile of the cruise ships the following modes of operation were distinguished:

1. sea trials;
2. transit (auto pilot);
3. channelling (manual);
4. manoeuvring;
5. harbour (berthed);
6. anchorage;
7. DP;
8. docking/maintenance/repair.

3 MODELLING

3.1 Feed back from the monitoring campaigns.

In the original scope of the JIP it was foreseen that the full scale campaigns would result in a number of recorded phenomena that were outside the expected behaviour of the pods and ships and would require further investigation either by physical or by numerical modelling.

One of these phenomena was identified during the analysis of the BOTNICA data. During the severe storm (a “10 years” condition not normal for that period in the year) encountered by the vessel, the loads in the pod and pod support structure turned out to be extreme. Actually the measured strain levels were higher than those recorded during crash stops in the dedicated trials. Also pod motions and vibrations in those conditions were high. After a detailed analysis it was concluded by VTT that bow slamming had resulted in dynamic behaviour of the pod relative to the ship hull. As BOTNICA has been designed and constructed for ice breaking operation this was not considered a danger for the ship, in case of other ships with more elastic response and less over dimensioned pod houses and supports this behaviour can be a design issue. For that reason special investigations including a FEM mode analysis were conducted for the dynamic behaviour of pods due to ship motions, slamming and vibrations. These investigations were conducted for BOTNICA, RADIANCE and SUMMIT (see Figure 8). It was found that in case of BOTNICA the natural frequencies of pod motions are in the same region as the natural frequencies of the vessel in slamming/whipping. For the cruise vessels the pod frequencies are a factor higher than the slamming/whipping frequencies and therefore these vessels are not likely to experience the phenomena observed on board BOTNICA.

Another phenomenon for further investigation is the loading of the propeller in oblique flows. Although the incoming flow for a pod in neutral position on a straight course is better than for a conventional propeller, slew angles of the pod result in large angles of incidence and thus in abnormal loads on the propeller blades, hub and shaft. For this reason, in the JIP an attempt was made to measure the blade loads on the Summit. In dock prior to the launching, one of the blades was fitted with strain gauges that were hardwired to a sleeping data logger in the hub. During the sea trials the data logger was awake, however the connection with the sensors was lost probably because of unannounced testing of the propeller alongside the quay which damages the cabling. A second attempt was prepared but did not materialise as the vessel did not spend sufficient time in dry dock to enable this work.

For this reason a proposal for scale model testing of a pod unit under large angles of incidence was prepared. Unfortunately budget and time constraints did not allow the execution of this work within the JIP.

3.2 Computational Methods

The sea trial conditions and the resulting loads of the podded drives have been investigated by the Class Society Working Group (CSWG). The determination of those loads has been done using computational methods as well as evaluation of strain gauge measurements. The main aim was, to make sure that the calculation methods give reliable results in terms of maximum loads for scantling purposes. The reports issued represent the views and results of the Classification Societies Working Group (CSWG) of the “Pods in Service” project and additional data from the measurements campaign.

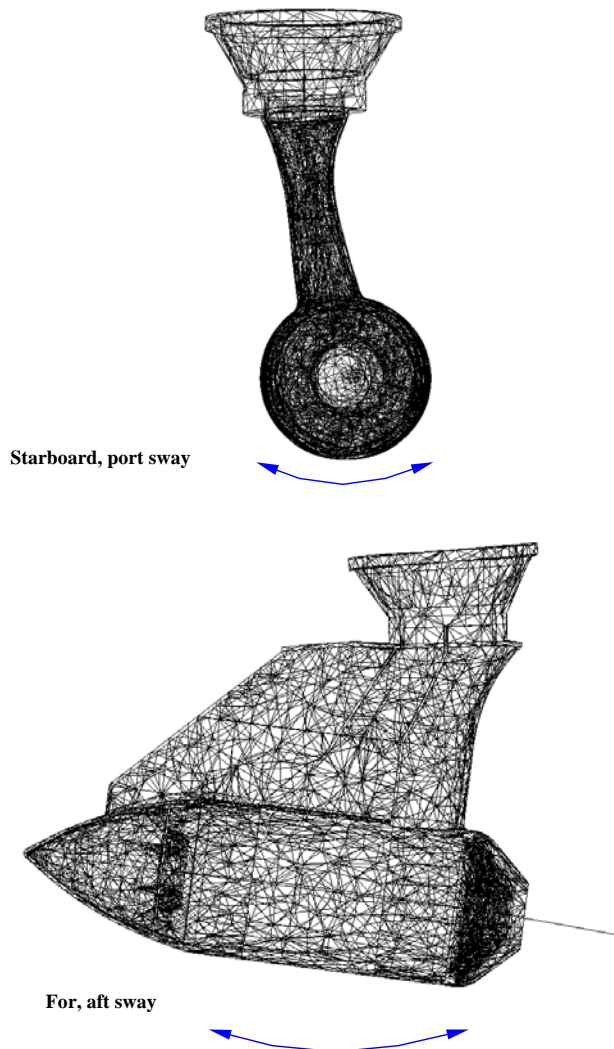
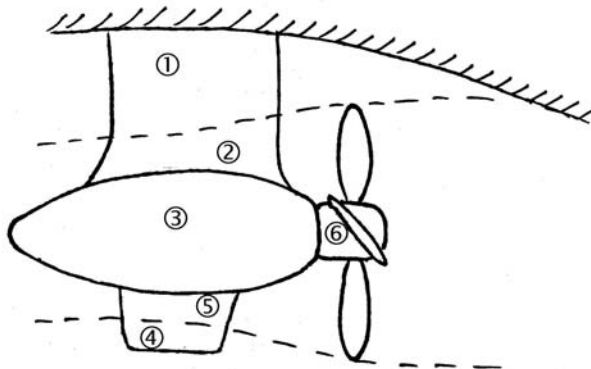
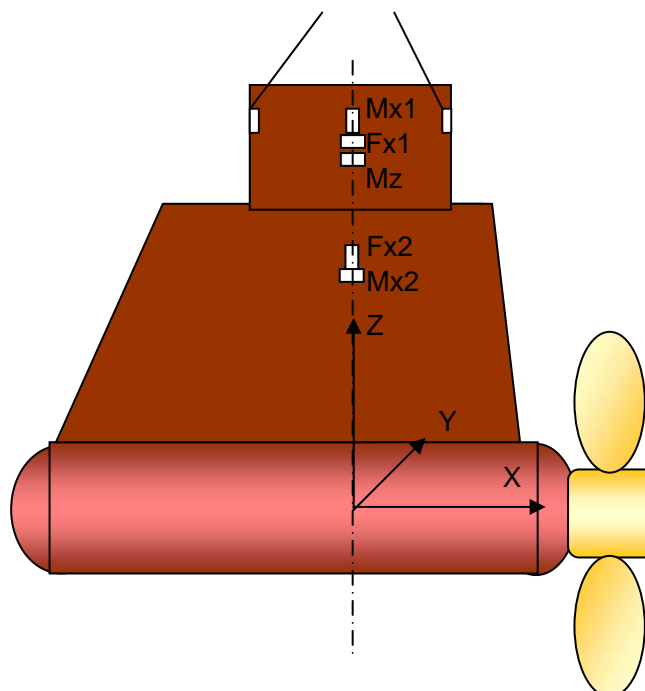


Figure 8 Mermaid Pod Body modes of motion studied with FEM model.



A pod load calculation model has been developed by the Class Society Working Group. This method distinguishes the main components of the pod and utilizes existing models, physical and empirical relationships to derive the force components and then sum the overall loads. This simplified method is described in report D17.

The report [D18] initially outlines the main ship and pod parameters and sea trial conditions under which the loads have been derived from strain measurements. Further on, methods have been applied to calculate loads under the predominated sea trial conditions. A validation of all used calculation methods in particular the simplified method and the capability of predicting pod loads with sufficient accuracy for classification purpose has been conducted and documented. The derived loads are applied on critical parts which have been identified and described in [D16]. This comprehensive overview is completed with results from very special investigations, described more detailed in the report DCSWG.



As an example in Figure 9 the comparison of the hydrodynamic loads as calculated with the simplified model are compared with the measurements for BOTNICA . Although the extreme loads found from calculation model show reasonable correspondence to measured results, the predicted values at a given steering angle may differ significantly from the measured value. If the calculation model is to be used as for dimensioning (extreme load) criteria for pods, the results reported here indicate that significant safety factors would have to be included. For high cycle fatigue calculations, the accuracy of the simplified calculations seems not to be good enough yet.

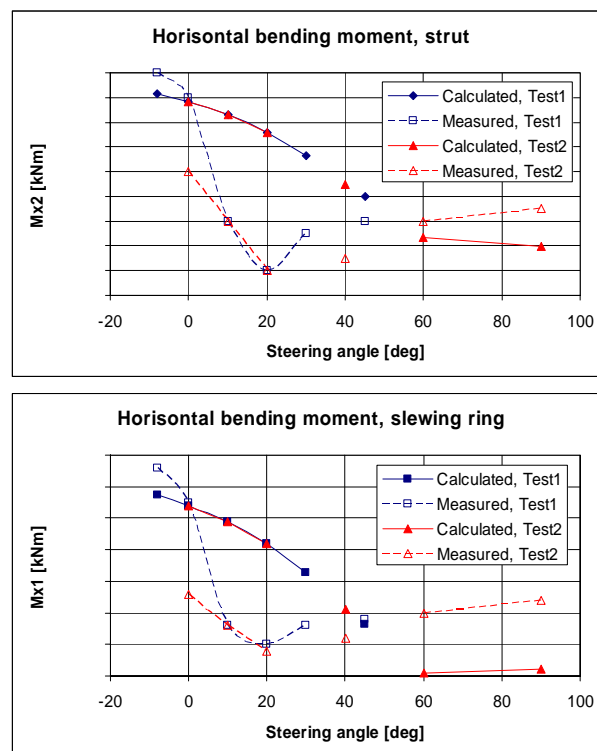


Figure 9 Comparison computed measured pod loads on BOTNICA

4 CONCLUSIONS

4.1 Conclusions from BOTNICA-team

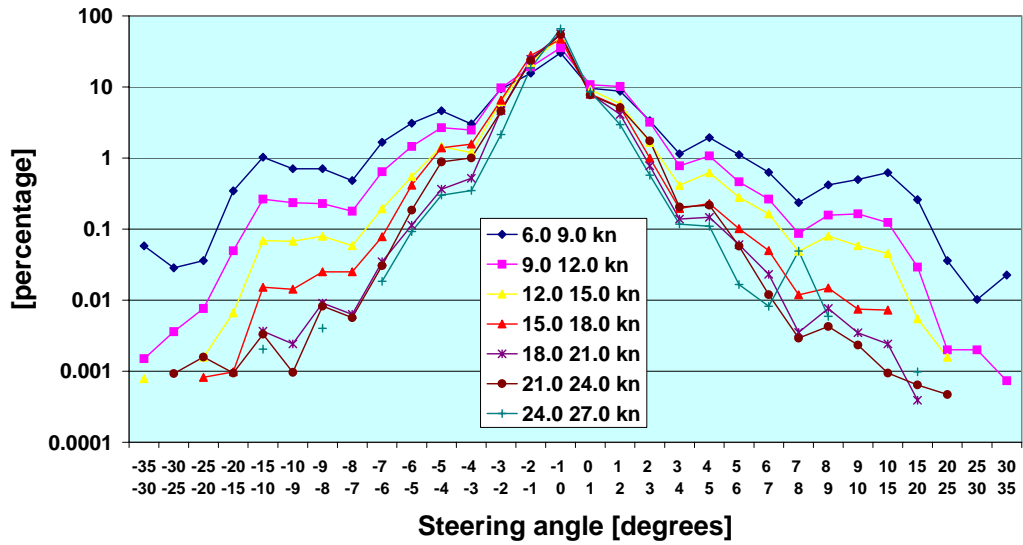
1. By extensive force calibrations at dry dock VTT built up a measurement system on board MSV Botnica that was able to define the acting global force components in pod housing close to the pod support, which represent the interacting forces between the pod and the ship hull.
2. The installed measurement instrumentation and data collection system for MSV Botnica operated successfully both in the dedicated sea trials and the long-term measurements. The automatic data collection system gathered data from the whole long-term measurement period of 6 months without any stops and no data packets were lost. The only difficulties were some disturbances caused by failures in telemetry transmission of the pod signals to the data collection computer on board. This complicated the analysis, but did not cause losing of data from interesting phenomena or operating conditions.
3. During the dedicated sea trials of MSV Botnica the highest pod forces were measured when the pod units were steered to large angles (45, 90 degrees). The maximum values were obtained both for longitudinal, transverse forces and bending moments at angles around 30 degr.
4. The most effective way to stop the vessel was turning both the pods outwards 180 degrees from ahead-position to astern position. This type of crash stop caused the highest loads but less vibratory behaviour in the ship aft body and pod structures than a crash stop by changing only the propeller revolution direction.
5. MSV Botnica encountered extreme high seas in the norther North Sea on July 13, 2000. During this severe storm the ship motions and the loads in the pod and pod support structure were extreme.
6. The long-term results showed that in severe wave conditions during offshore operations, the loads on the pods and the surrounding hull structures for a supply vessel like MSV Botnica are in the same order as the loads encountered during crash stops. Up till now both authorities and industry assumed that the crash stop provides the highest loads and should therefore be considered as design case. The stresses in severe wave conditions were related to the dynamic behaviour of the global pod structure.
7. Detailed analysis of the results have shown that in the severe wave condition the loads in the pod and support structure originated from dynamic bending of the pod/support relative to the global ship structure due to wave slamming on the ship body.

-
8. Pod loads and dynamic bending behaviour in extreme wave conditions should be considered as a design issue for the global strength of the pod units.

4.2 Conclusions from RADIANCE-team

1. A reliable set of measurements was obtained from the two year monitoring campaign on board the Radiance of the Seas
2. A comprehensive operational profile of the ship for different cruising areas was established.
3. The highest structural strain measured in service conditions were 73 per cent of the highest structural strain measured during the sea trials (35 degrees steering angle manoeuvre).
4. Reliable longitudinal loads, lateral loads and steering loads for the sea trials were obtained from dry-dock load tests, finite element calculations and strain measurements.
5. The maximum longitudinal load and lateral load found for the monitoring campaign was 161 tonf and 443 tonf respectively.
6. The maximum steering load found for the monitoring campaign was 3 ktonf*m.
7. Vibrations in the pod in transit conditions are higher than the vibrations in the pod during manoeuvring.

Actual steering angle PS Pod



Probability of exceedance (PS Pod) (15 - 18 knots)

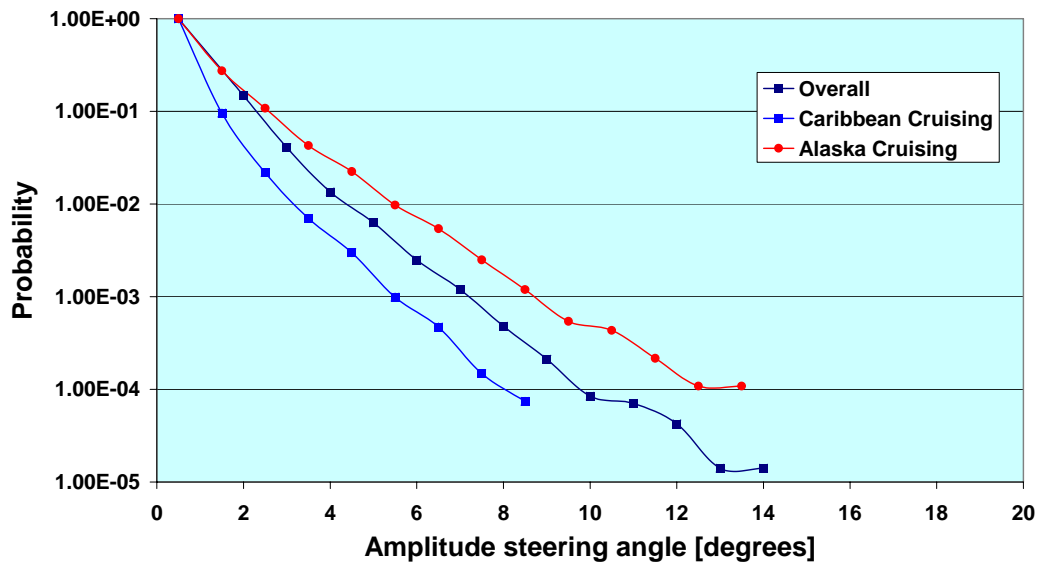


Figure 10 Steering angles on board Radiance of the Seas

4.3 Conclusions from SUMMIT team

Overall conclusions:

1. More than one-year data have been collected on ship and pod operational conditions and associated accelerations and stresses in pod, pod foundation and stern structure.
2. The data has been statistically analysed and the results are presented in several reports and presentations.
3. An attempt has been made to monitor propeller blade stresses. However, a dedicated monitoring sub-system was damaged shortly after installation.
4. The relationship between pod foundation strains and overall pod forces was attempted to be established by analysis of dry-dock tests. However, an insufficient number of loading cases was carried out due to a too short time window that was made available just before the ship delivery.
5. Consequently, the relation between ship and pod operational conditions and the forces acting on the pod structure has not been established.

Conclusions obtained from analysis of sea trials:

1. The highest normal stress variation in PS pod foundation was measured during 35-zig-zag manoeuvre when the ship was sailing 23 knots and the PS pod azimuthing angle of 32 degrees.
2. The amount of cavitation observed during normal operational conditions is small. The only type of observed cavitation is a small tip vortex starting at the blade tip. Finishing of details of the pod housing is important.

Conclusions obtained from analysis of operational data:

1. The pressure fluctuations are dominated by the first blade harmonic. The pressure levels are comparable with other podded propelled vessels and are lower than those for conventionally propelled vessels.
2. Maximum recorded azimuthing mean angle at full ship speed (about 24kn) and at medium speed (about 15kn) was +8 / -6 degrees and +12 / -8 degrees, respectively. Maximum turning angle at full ship speed (24kn) was 30 degrees.
3. No exceptional ship motion data were recorded. The maximum roll, pitch and heave ranges were not higher than about 7 degrees, 2.5 degrees, and 5.5 meters, respectively.
4. Pod vibration amplitudes did not exceed 4m/s^2 . Maximum pod accelerations appeared during transit condition.
5. Vibration amplitudes of stern structure during operation did not exceed 4.5m/s^2 . Maximum stern accelerations appeared during transit condition.
6. Comparable stress amplitudes were measured during normal operation, manoeuvring, channelling and transit conditions.

4.4 Conclusions from NILS HOLGERSSON team.

1. The Ropax ferry Nils Holgersson was instrumented with a measurement system aiming at the monitoring of the ship duty profile, the load conditions of the podded drives, the exerted loads on the pod foundation structure, and the propeller induced pressures on the hull plating. Wave and wind conditions were measured as well as the induced ship motions and acceleration levels.
2. Stress measurements were done with strain gauges in selected locations where high stress concentrations were expected. Pressure measurements were done above the forward and aft propeller discs of the starboard pod and for cross reference also at the port propeller. In order to monitor the vibration levels also the accelerations were monitored at the pressure gauge locations.
3. Measurements in more extreme conditions were done during the ship acceptance trials. Unattended long term measurements were performed from July 2001 to December 2003.
4. The measurements indicated that the measured strains in the pod foundation are generally quite low. The pod foundation structure apparently does not suffer greatly from the pod induced loads. Because the pod foundation is integrated relatively flexible in the global aftship structure, the pod can have some vibration and or deformation without high stress concentrations occurring in the foundation and aftship structure. Highest loads are found in the pod foundation close to the pod and inside the pod structure close to the slewing bearing.
5. From the ship acceptance trials it was found that high loads were found in the zig-zag manoeuvres and the crash stops. The most strenuous manoeuvre for the podded drives was however the full speed hard over manoeuvre where the pod was turned at full rpm over a range of plus and minus 35 degrees. Pressure levels and structure response never reached as high values as in this manoeuvre. Measured pressures showed wide band energy responses indicating cavitation effects. Measured structural responses showed both quasi static steering action effects and induced dynamic responses due to vibrations of the pod structure and foundation. Measured dynamic stress variations were however less than the quasi static variations due to the steering / manoeuvring forces.
6. Long term measurements indicated that the severe conditions as experienced during SAT trials are not encountered during regular operational service.
7. The duty profile of the ROPAX ferry clearly reflects the day and night time transit conditions in separate power setting regimes. Day time average power setting is at 7 MW doing 18 knots where night time transits are sailed at 3 MW and 14 knots speed. The ship generally operates at a power setting much less than the engine MCR even in daytime. The sea margin is useful when delays have to be made good or when bad weather is encountered. In the final stage of the

monitoring campaign the service regime of the vessel was changed to 3 crossings (1.5 trip) each 24 hours by means of higher power settings and speed.

8. Pod steering angles for course keeping remain inside 5 degrees for close to 99 percent of the time in transit conditions. Only in manoeuvring conditions in port at lower ship speeds, higher steering angles are observed. Relatively highest structural loads under port manoeuvring conditions are found in crabbing manoeuvres during berthing and leaving the dock. These loads are however less than these found in transit conditions under higher power regimes.
9. Structural loads in the pod foundation can be subdivided in:
 - quasi static loads due to thrust and steering forces
 - dynamic loads due to POD vibrations
 - dynamic loads due to wave induced motions
10. The highest loads are obviously caused by thrust and steering forces. Dynamic loads due to POD vibrations are only of significance in manoeuvring or acceleration conditions out of port. The vibrations in these cases are caused by propeller blade dynamics and cavitation induced pressures but reveal themselves mainly in the lower natural modes of the pod foundation. Most relevant mode is the pod vibration in sideways direction relative to the strut.
11. Wave induced motion dynamics have greater magnitude in structural response than Pod vibrations due to propeller induced excitations.

4.5 Conclusions from Class Society Working Group

Applicability of methods for podded propulsors

1. Podded drives are new types of propulsors but made of well known components. The applicability of calculation methods depend not only from the component itself, but also from their application in a system and interaction with other components;
2. The hydrodynamical loads can not all be calculated with conventional methods. A vortex lattice method has been applied for the propeller and the result is reliable depending on the load concentration and steering angle. Other parts, such as shaft and gondola, might be calculated with simple formulas but using adequate lift coefficients, which are not always known. The developed simplified method, incorporating simple formulas and assumptions for each component, has not been validated up to now and hence has not shown the necessary reliability. It could be assumed that a RANSE calculation would give the most complete and reliable result, but it has not been checked due to the enormous effort to be put in such a calculation;

3. Propeller induced pressure pulses are as low as expected, which has been shown during full scale measurements. A simple, but for conventional ships reliable calculation method, has totally failed in the prediction. Consequently, predictions have to be based on model tests, experience in a few full scale data, or other calculation methods have to be used, e.g. panel methods;
4. A shaft alignment calculation for pods can be performed using standard calculation tools. The difference to conventional shaft lines has to be regarded in respect of loads, e.g. mass and attracting and expelling forces of rotor, and requirements. The shaft is not dimensioned according to a certain stress but according to stiffness, which has to be determined according to the requirements of roller bearings and gap tolerances of the electric motor;
5. Other components, such as propeller, housings, roller bearings etc. can be analysed using conventional tools. The most interesting question is the generation of input data – the loads. As long as they are missing from sea trials and scheduled operation, no further analysis is possible;

Critical loads / conditions for critical parts

6. From sea trials it has been concluded, that the hard over test causes the highest loads. Except severe ice conditions, e.g. for an ice breaker, and difficult weather conditions the loads of normal operation are within the test scope of sea trials; Difficult weather conditions have been experienced by Botnica, but not made available so far;
7. The propeller shrink fit is not really critical but the decrease in safety margin is not always apparent. Therefore it needs to be regarded and included in the design, IACS and Classification Societies Rules, in which the thrust as a pulling force has to be taken into account.

4.6 Overall conclusions from the Pods in Service JIP

1. The Pods in Service JIP has produced valuable data sets of 3 different pod types in service conditions. The monitoring campaign on board 2 cruise vessels, 1 ferry and 1 offshore supplier/ice breaker comprises a large variety of operational and weather conditions. The campaign was focussed on the recording of global pod behaviour and the interface with the hull.
2. Pod components and measurement equipment experience extreme high temperatures in the pod house.
3. Sea trials with pod driven ships are conducted according to the IMO requirements for conventional propellers and rudders and in particular the steering trials such as zig-zag tests induce severe loads on pods whereas they are not considered as realistic or necessary for this ship type. Class Societies working in the CSWG have proposed better trials specific for podded driven ships for implementation by IMO.
4. Crash stops with pods can be conducted in various ways by reverse rpm, slewing of the pods and combinations of these. Effectiveness and loads can vary with these procedures. As considered in design, loads on pods and pod support during crash stop are extreme but not always the maximum load case.
5. Contrary to what has been stated in recent publications the steering angles of pods under normal sailing conditions (auto pilot) are not much larger than those of normal rudders. In case of manual steering even at high speed relation large steering angles (> 7 degrees) are observed which leads to vibration and efficiency degradation.
6. Pod vibrations can be associated with manoeuvring, channelling and transit mode of operation. In transit (full-speed) the severe vibrations are caused by large steering angles. In manoeuvring the vibrations are associated with reverse rpm or mutual pod flow interaction.
7. Slamming and whipping of the ships hull may induce pod body dynamics. This phenomena observed on BOTNICA in storm conditions produced the strains in pod and hull which were higher than during the crash stops.
8. Hydrodynamic loads on pods cannot be accurately computed with conventional methods. It is recommended to verify RANSE methods for this application.
9. Loads on pod propellers under large angles of incidence with the flow is to be investigated by means of full scale or small scale tests. The results are to be used to evaluate and improve propeller load calculation models.
10. Due to the more uniform inflow, cavitation on pod propellers is rare. Tip vortex cavitation has been observed and in one case also cavitation on the pod house due to imperfections in the shape and finish details of the pod house.
11. Podded propulsors induce low levels of pressure fluctuations on the hull which explains the superior comfort (noise and vibration) of pod driven ships.

5 REPORTS ISSUED

General reports

1. JIP Proposal Pods in Service; Marin report 15416-1-TM, April 1999;
2. 'Summary Report GTS SUMMIT', Marin, May 2004, 15416-S16-TM-032;
3. 'Summary Report Monitoring 'Radiance of the Seas', Marin, 15416-R15-TM
4. 'Summary Report BOTNICA, VTT, December 2003;
5. 'Summary Report Nils Holgersson', Marin, May 2004;
6. Technology Implementation Plan, January 2002, draft;
7. 'Pods in Service Executive Summary', Marin, 15416-2-TM.

Reports from Class Society Working Group

1. 'Specification of Method Development', Z. Bazari and M. McMahon, Lloyd's Register Report, 5 June 2001 (D16);
2. 'FEM analysis of Azipod thruster strain gauge calibration', Lars Bjornstad, DNV report 2002-0917, July 2002. (D15);
3. 'Method for Pod Load Calculation', Oddvar Deinboll, DNV, June 2002 (D17);
4. 'Validation of Pod Load Computational Method', A. Junglewitz, GL, June 2003 (D18).
5. Hydrodynamic Loads - Botnica / Calculated vs. Measured, Odvar Deinboll, DNV, June 06, 2003

Reports from BOTNICA Team

1. 'Instrumentation and calibration of the pod propulsion loads measurement system on board MSV BOTNICA'.S. Kivimaa, J. Vuorio, T. Teittinen, P. Tuononen, T. Lehti, J. Holopainen, S. Merinen, VTT Research report No. AVAL32-021139 (D2 + D8);
2. 'Dedicated sea trials for pod propulsion loads on board MSV BOTNICA', S. Kivimaa, J. Vuorio, T. Teittinen, P. Tuononen, VTT Report AVAL32-011076 (D8);
3. 'Long-term measurements of pod propulsion loads on board MSV BOTNICA'.S. Kivimaa, J. Vuorio, T. Teittinen, P. Tuononen, VTT Report AVAL-011077 (D8).

Reports from Radiance Team

1. 'Proposal Pods in Service measurement system on board 'Radiance of the Seas'', J. van Drie, Marin Report 15416-R01-TM, February 2000 (D1);
2. 'Measurement system on board 'Radiance of the Seas'', P.J. Aalberts, Marin Report 15416-R02-TM, March 2000 (D6);
3. 'Calibrations of strain gauges welded in 'Radiance of the Seas'', P.J. Aalberts, Marin Report 15416-R03-TM, October 2000 (D7).
4. Cavitation and hull pressure measurements on board 'Radiance of the Seas' P.J. Aalberts, Marin Report 15416-R04-TM, Rev. 1, December 2001.(D11).
5. 'Static strain measurements during manoeuvring trials on board 'Radiance of the Seas'', P.J. Aalberts, Marin Report 15416-R05-TM, Rev1, December 2001(D11).

6. 'Statistics measurements onboard Radiance of the Seas (February 2001 – Sept 2001)', P. Aalberts, Marin Report 15416-R06-TM, May 2002 (D11);
7. 'Statistics measurements onboard Radiance of the Seas (November 2001 – March 2002)', P. Aalberts, Marin report 15416-R07-TM, June 2002 (D11);
8. 'Statistics measurements onboard Radiance of the Seas (March 2002 – June 2002)', P. Aalberts, Marin report 15416-R07-TM, June 2002 (D11);
9. 'Statistics measurements onboard Radiance of the Seas (June 2002-September 2002)', P. Aalberts, Marin report 15416-R09-TM, November 2002 (D11);
10. 'Statistics measurements onboard Radiance of the Seas (October 2002 – December 2002)', P. Aalberts, Marin report 15416-R10-TM, February 2003 (D11);
11. "Statistics measurements on board 'Radiance of the Seas' (January 2003 - March 2003)", P.J. Aalberts, Marin report 15416-R11-TM, May 2003 (D11)
12. "Operational profile Radiance of the Seas", P.J. Aalberts, Marin report 15416-R12-TM, June 2003 (D11);
13. "Analyses of pod vibration measurements on board Radiance of the Seas", P.J. Aalberts, Marin report 15416-R13-TM, July 2003 (D11)
14. "Structural loads in pod foundation during manoeuvring trials on board Radiance of the Seas", P.J. Aalberts, Marin report 15416-R14-TM, July 2003 (D15);
15. "Summary Report Monitoring Radiance of the Seas", Marin 15416-R15-TM, September 2003, Draft.

Reports from Summit Team

1. "Static strain measurements during manoeuvring trials on board Summit', Marin, June 2002, 15416-S02-TM-02, final;
2. "Cavitation observation & hull pressures', Marin, Sep 2002, 15416-S03-TM-02, final;
3. "Measurement system on board GTS Summit", Marin, Sep 2002, 15416-S04-TM-04, final;
4. "Operational data GTS Summit March 14 2002 – May 22 2002", Marin, Sep 2002, 15416-S07-TM-02, final;
5. "Operational data GTS Summit May 22 2002 – July 7 2002", Marin, Oct 2002, 15416-S10-TM-02, final;
6. "Operational data GTS Summit, July 7 2002 – September 3 2002", Marin, Sep 2002, 15416-S11-TM-02, final;
7. "Operational data GTS Summit, September 3 2002 – October 24 2002", Marin, Dec 2002, 15416-S12-TM-01, final;
8. "Operational data GTS Summit January 24 2003 – April 21 2003", Marin Oct 2003, 15416-S13-TM-02, final;
9. "Operational data GTS Summit April 21 2003 – May 18 2003", Marin Oct 2003, 15416-S14-TM-01, final;
10. "Operational data GTS Summit Identification", Marin, Oct 2002, 15416-S15-TM-01, final;
11. "Summary report GTS Summit", Marin, Oct 2003, 15416-S17-TM, Team Internal;

Reports from Nils Holgersson Team

1. Pods In Service / Nils Holgersson, Instrumentation report
Marin report No. 15416 – N01 – TM;
2. Dry dock preloading calibrations Nils Holgersson
Marin report No. 15416 – N02 – TM;
3. Ship Acceptance Trials Nils Holgersson
Marin report No. 15416 – N03 – TM;
4. Long Term monitoring data reports
Marin report No. 15416-N04 through N09-TM;
5. Pods in Service Summary Report, Ropax extension/SSP Pods
Marin Report No. 15416-N10-TM, February 2004.