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POSSIBILITIES TO DECREASE THE ATTAINED EEDI OF THE FINNISH MERCHANT SHIPS

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FOREWORD

In its report no 78, the Winter Navigation Research Board presents the outcome of the project on possibilities to decrease the attained Energy Efficiency Design Index of the Finnish merchant ships.

A study about the impact of the proposed energy efficiency regulation on Baltic bulkers and tankers was carried out in April – May 2011. The results showed a clear conflict between energy efficiency requirements and ice performance requirements. The present report details the results from analyzing the Finnish merchant ship fleet. The methods to decrease the attained EEDI of all existing Finnish flag ships under the EEDI legislation were checked. The changes were made keeping the deadweight constant and the propulsion power at least the minimum required by the ice class.

The Winter Navigation Research Board warmly thanks Mr. Harri Eronen and Professor Kaj Riska for this report.

Helsinki and Norrköping

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POSSIBILITIES TO DECREASE THE ATTAINED *EEDI* OF THE FINNISH MERCHANT SHIPS

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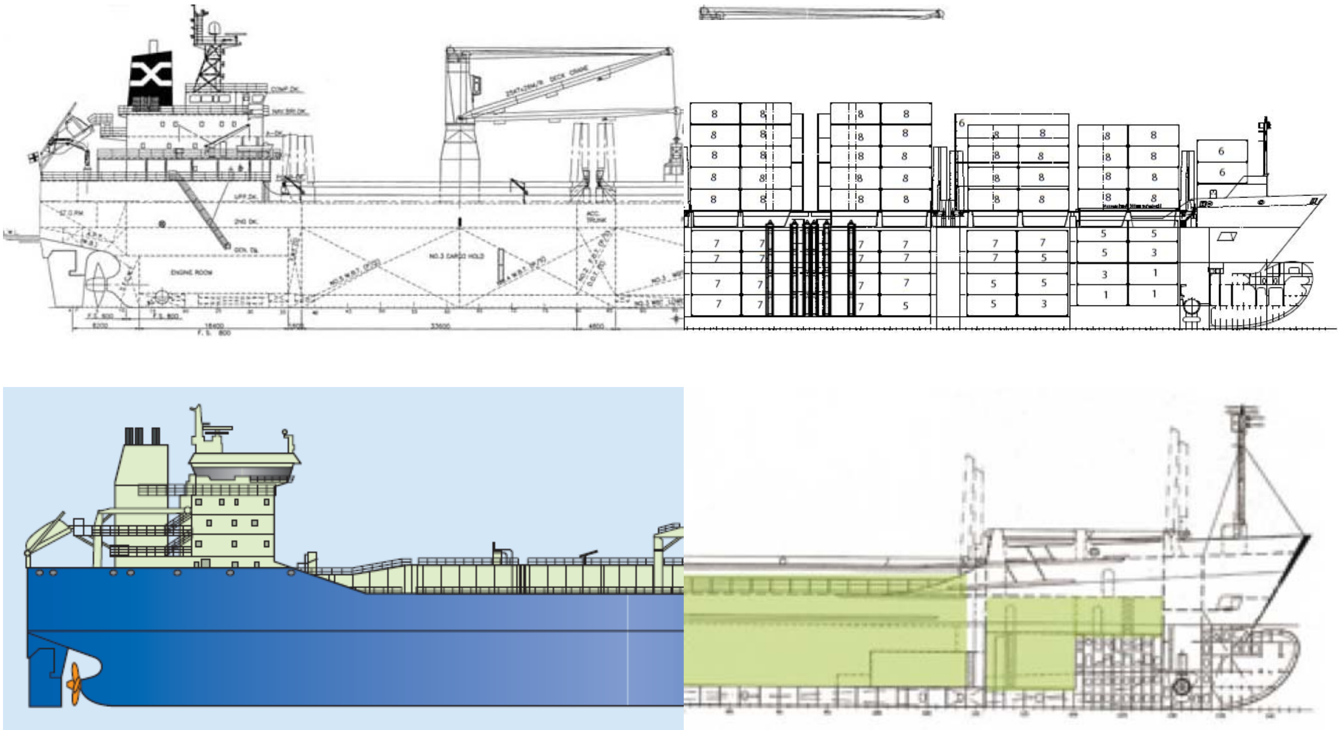

12.5.2011 / Harri Eronen & Kaj Riska

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Cover figures clockwise from top left: MS Eira, ESL Shipping; MS Linda, Oy Langh Ship Ab; MS Klenoden, Bore Oy and MT Jurmo, Neste Shipping.

1. INTRODUCTION

A study about the impact of the proposed energy efficiency regulation at IMO on the Baltic bulkers and tankers was carried out in April – May 2011. The study focused on the attained *EEDI* (Energy Efficiency Design Index) and the means to decrease it, preferably below the reference lines developed by the IMO secretariat. The study concentrated on two example ships, MS Eira and MT Jurmo, and ships derived from these. The results of the study suggested that it is very difficult to achieve the required *EEDI*, especially taking into account the new reference lines. Before deciding about any action to make the future legislation more suitable for ice class tonnage, it was decided to check the impact on all the ships flying the Finnish flag of the required *EEDI*. The present report details the results from analyzing the Finnish merchant ship fleet.

The study was carried out by first calculating the attained *EEDI* and the required *EEDI* for each ship (including the requirements in the future phases, Phase 1 to Phase 3). After this some design changes were introduced to the ships and the resulting *EEDI* was calculated. The changes included improvement of the ship hull (reduction of beam and introduction of an ice breaking bow, keeping the deadweight (DW) constant), improvement of the propulsion efficiency (larger propeller diameter which improves the ice capability or introduction of a nozzle) or use of gas diesel using LNG as fuel. The decrease of the attained *EEDI* stemming from each design change for each ship is calculated and finally it is checked what changes must be done (taking into account the interaction with the changes) to get below the required *EEDI* at each phase.

The present report contains a summary of the analysis; this report is accompanied by data sheets detailing the calculations. The nomenclature of the quantities used in the EEDI-analysis is explained in the former report; this report is a direct continuation of it.

2. THE STARTING POINT

2.1 Analyzed Ships

Altogether 29 Finnish flag ships fall under the EEDI legislation; other ships are either smaller than the lower limit or of different ship types. The main, and larger, Finnish ships that at this stage are excluded are the RORO and ROPAX ships. The ships analyzed are shown in the Table 1.

The analysis of the design changes requires some ship data to be available. These data comprise of the data required to calculate the required ship power according to the Finnish-Swedish ice class rules. These data was collected from the in-house files available, data available at the various home pages and some data were obtained from the ship owners. In many cases the data must be estimated from a deck plan, side view or the like. Thus there is likely to be some values which are incorrect; all the data has been checked so that no gross deviations should exist. The ship data used are given in Table 2.

2.2 The Design Changes

The means to decrease the attained *EEDI* of the ships follow similar lines as in the previous analysis. The aim is to change an existing ship so that the attained *EEDI* decreases while keeping the deadweight constant and the propulsion power at least above the minimum given by the ice class. The means to decrease the attained *EEDI* can be divided into four categories (changes in the hull, improved propulsion, improved machinery efficiency and use of LNG as fuel. Only the means in the third category, methods related to machinery efficiency, require some comments here as the others have been described well in the previous report. All the ships are considered to have a CP propeller (or diesel-electric machinery); only the AFRAMAX tankers have a FPP (Tempera, Mastera have a FPP and also diesel-electric machinery, Stena Arctica has a FPP). The use of CPP (or diesel-electric machinery) reduces the power required in ice because diesel-electric machinery or machinery systems with a CPP have a far better torque capability than a direct shaft with a FPP. This better torque capability especially at lower RPM's leads to a better performance in ice. The design means available for a designer are listed in the table below.

The advantage of using shaft generators stems from the fact that the power of any PTO's can be deduced from the main engine power but the total engine power may be used in ice class calculations and in reality also when proceeding in ice.

The use of LNG as fuel instead of MDO changes just the multiplicative factor in the attained *EEDI* equation representing the amount of CO_2 emission per a ton of fuel used. Using LNG reduces the value of the attained *EEDI* about 13%, but the use of gas diesels may cause problems in operations where the used power varies much. This large variation of used power is typical in ice breaking operations.

Each design change is analyzed individually but when more than one method to decrease the attained *EEDI* is used, the interaction between these means is checked (the decreases from each method cannot be summed directly).

Method (related to reducing the resistance)	Description
Bow shape optimization	An ice breaking bow reduces much the power needed.
Main dimensions	The ship beam influences much the ice resistance, reducing the beam while keeping the dwt constant, reduces the power needed.
Method (related to enhancing propulsion)	**Description**
Propeller optimization	Larger propeller diameter increases the delivered thrust at low ice breaking speeds, and also improves somewhat the propulsive efficiency in open water speeds (larger propeller diameter is made possible especially when moving from single to twin screw solution).
Special propulsion	Nozzles and CRP's increase the delivered thrust. CPP is more efficient in ice thus reducing the required power.
Method (related to machinery efficiency)	**Description**
Diesel-electric machinery	Better efficiency in ice thus reducing the required power.
Use of shaft generators	If shaft generators are used, the power of these is deduced from the main engine power. Required ice power is, however, the maximum power available at the propeller.
Method (other)	**Description**
Use of two powers	The ship could have a high power in ice which is exempt from attained *EEDI* calculation and the power required in open water could thus be much lower. A dual mode ship utilizes this principle.
Use of LNG	Using gas as fuel reduces the CO_2 emissions.

Table 1. The Finnish merchant ships falling under the EEDI legislation.

	Name	Ice class	DWT	P_{ME} [kW]	L_{pp} [m]	*EEDI*	f_{j0}	f_{jMIN}	f_j	f_{i0}	f_{iMAX}	f_i
Bulk carriers	Eira	IA Super	19625	7860	148.00	11.9408	0.7346	0.8651	0.8651	0.9902	1.2120	1.0000
	Hesperia, Pasila, Tali	IA Super	13518	6050	130.56	13.2208	0.7828	0.8564	0.8564	0.9339	1.2290	1.0000
Container ships	Aila, Linda	IA Super	11300	8400	132.26	27.6216	1.0000	-	1.0000	1.1165	1.1686	1.1165
	Containership	IA	13900	12600	149.26	31.6099	1.0000	-	1.0000	1.1972	1.0720	1.0720
General cargo ships	Jollas	IA Super	14505	7282	152.38	11.8466	0.9215	0.8289	0.9215	1.5056	1.2500	1.2500
	Laura, Hjördis, Marjatta	IA	6535	5850	111.58	19.6286	0.5481	0.8653	0.8653	1.1439	1.1200	1.1200
	Fingard, Swegard	IA	4956	2760	90.05	18.9970	0.6989	0.8469	0.8469	0.7215	1.1200	1.0000
	Aura	IA	4600	4440	96.50	30.5865	0.5119	0.8528	0.8528	0.9862	1.1200	1.0000
	Klenoden	IA	4450	3330	97.34	18.9512	0.6967	0.8535	0.8535	1.0503	1.1200	1.0503
	Najaden, Trenden	IA	4402	2960	97.60	17.6648	0.7945	0.8540	0.8540	1.0829	1.1200	1.0829
	Alholmen	IA	3150	2729	80.57	24.6339	0.5431	0.8376	0.8376	0.7742	1.2500	1.0000
Tank ships	Mastera, Tempera	IA Super	106200	16000	237.59	4.3836	0.8940	0.7712	0.8940	1.0408	1.1505	1.0408
	Stena Arctica	IA Super	117099	15806	240.96	4.2390	0.9291	0.7725	0.9291	0.9896	1.1487	1.0000
	Jurmo, Futura, Neste, Purha	IA Super	25049	7950	159.12	7.8800	0.7152	0.7350	0.7350	1.1474	1.2023	1.1474
	Kiisla, Suula	IA Super	14750	8400	130.92	13.2140	0.5587	0.7180	0.7180	1.0117	1.2284	1.0117
	Stena Poseidon, Palva	IA	74940	13560	221.02	4.4736	0.9215	0.8579	0.9215	1.1568	1.1073	1.1073

Table 2. The ship data used in the analysis. The data points marked with bold font are estimated from the information available.

	Name	Ice class	DWT	P_{ME} [kW]	L_{pp} [m]	L_{oa} [m]	L_{bow} [m]	L_{par} [m]	B [m]	T [m]	A_{wf} [m^2]	α [°]	φ_1 [°]	φ_2 [°]	ψ [°]	D_p [m]
Bulk carriers	Eira	IA Super	19625	7860	148.00	157	**27.0**	**93.0**	24.6	9.0	418	**25**	**40**	**40**	**63.3**	5.0
	Hesperia, Pasila, Tali	IA Super	13518	6050	130.56	137.2	**26.5**	**85.0**	21.6	8.2	365	**32**	**41**	**41**	**58.6**	5.0
Container ships	Aila	IA Super	11300	8400	132.26	141.2	**20.0**	**91.8**	21.3	8.6	250	**37**	90	**50**	**44.5**	4.7
	Containership	IA	13900	12600	149.26	158.1	**45.0**	**77.0**	21.75	8.94	525	**20**	90	**60**	**78.8**	5.5
General cargo ships	Jollas	IA Super	14505	7282	152.38	159.2	**31.0**	**89.5**	18.2	9.13	375	**21**	**35**	**35**	**62.9**	4.4
	Laura, Hjördis, Marjatta	IA	6535	5850	111.58	120.0	**17.6**	**73.5**	18.2	6.8	160	**27**	90	**40**	**61.6**	4.1
	Fingard, Swegard	IA	4956	2760	90.05	95.0	**13.2**	**64.5**	13.2	6.2	102	**37**	90	**55**	**67.1**	3.4
	Aura	IA	4600	4440	96.50	101.8	**10.8**	**91.8**	18.8	4.9	150	**42**	**18**	**46**	**57.1**	2.9
	Klenoden	IA	4450	3330	97.34	103.5	**21.2**	**62.8**	16.2	6.1	240	**28**	90	**65**	**77.7**	3.5
	Najaden, Trenden	IA	4402	2960	97.60	104.8	**21.3**	**62.3**	16.0	5.8	195	**25**	90	**60**	**76.3**	3.4
	Alholmen	IA	3150	2729	80.57	87	**14.0**	**50.7**	13.17	5.91	100	**30**	90	**50**	**67.2**	3.3
Tank ships	Mastera, Tempera	IA Super	106200	16000	237.59	252.0	**49.2**	**124.2**	44.0	15.3	1370	**41**	90	**90**	**89.3**	7.5
	Stena Arctica	IA Super	117099	15806	240.96	249.8	**49.2**	**140.0**	44.0	15.4	1460	**30**	90	**70**	**79.7**	7.0
	Jurmo, Futura, Neste, Purha	IA Super	25049	7950	159.12	169.5	**31.0**	**100**	23.8	10.9	460	**25**	90	**55**	**70.5**	8.0
	Kiisla, Suula	IA Super	14750	8400	130.92	139.8	**29.40**	**65.10**	21.7	9.0	470	**30**	90	**50**	**67.2**	5.1
	Stena Poseidon, Palva	IA	74940	13560	221.02	228.5	**32.2**	**126**	32.2	17.2	640	**36**	90	**90**	**89.4**	7.0

3. RESULTS OF THE ANALYSIS

3.1 Effect of the Design Changes

Each design change was analyzed for each ship; these results for each ship are given in a separate data sheet collection. Here all results are collected in Table 3 where the new reference lines (MEPC 62/6/4) and old reference lines calculated by Denmark (MEPC 58/4/8) are used. The table is made so that it was considered what collection of changes must be made to get under the required *EEDI* at each phase.

The use of a nozzle increases the thrust at lower speeds used in ice but at higher open water speeds the effect of a nozzle may be detrimental. Further, the nozzle may lead to problems in heavy brash ice channels or in ridged ice fields due to clogging. Thus it may in practice be necessary to install, instead of a nozzle, higher power LNG machinery. If the nozzle starts clogging, this leads to worsened performance in ice and consequently more icebreaker assistance is needed.

Table 3. The design changes required to achieve an attained *EEDI* that is below the reference lines in different phases.

FINNISH BULK CARRIERS

		New reference line				**Old reference line**			
Vessel	**DWT**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**
EIRA IA Super Stem angle 40˚	19625	(Bow Bred Nozzle)	LNG Bred Nozzle	LNG Bow Bred Nozzle	Not achieved	(Bred)	Bred Bow Nozzle	LNG Bred	LNG Bow Bred Nozzle
Hesperia IA Super Stem angle 40˚	13518	(Bow Bred nozzle)	Bow Bred Nozzle	Bow Bred Nozzle	LNG Bow Bred	(Bred Nozzle)	Bred Bow	Bred Bow Dprop	Bred Bow Dprop

FINNISH CONTAINER SHIPS

		New reference line				**Old reference line**			
Vessel	**DWT**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**
Aila IA Super Bulbous bow	11300	(As built)	As built	Drop	Dprop				
Containership IA [1)] Bulbous bow	13900	(Power reduced)	Power reduced	Power reduced	Power reduced				

REM!

[1)] Main engine power well over min required by ice class rules. (Vessel has better performance in ice originally and high open water speed).
- Old reference not calculated because system how DWT is calculated has changed

FINNISH GENERAL CARGO SHIPS

Vessel	DWT	New reference line BL Phase 0	Phase 1	Phase 2	Phase 3	Old reference line BL Phase 0	Phase 1	Phase 2	Phase 3
Jollas IA Super[1)] Stem angle 35˚	14505	(As built)	Power reduced	Power reduced	Power reduced	(As built)	As built	As built	As built
Laura IA[1)] Bulbous bow	6535	(Dprop)	Power reduced Dprop	Power reduced Dprop	Power reduced Dprop	(As built)	As built	As built	Dprop
Fingard IA Bulbous bow	4956	(Nozzle)	Nozzle	Nozzle	Bow Nozzle	(As built)	As built	As built	As built
Aura IA[1)] Stem angle 16˚	4600	(LNG Power reduced)	LNG Power reduced	LNG Power reduced	LNG Power reduced Nozzle	(Power reduced Nozzle)	Power reduced Nozzle	Power reduced Nozzle	Power reduced Nozzle
Klenoden IA Bulbous bow	4450	(Bow)	Nozzle	Nozzle	Nozzle	(As built)	As built	As built	As built
Najaden IA Bulbous bow	4402	(As built)	As built	As built	As built	(As built)	As built	As built	As built
Alholmen IA Bulbous bow	3150	(Bow Nozzle)	Bow Nozzle	Bow Nozzle	Bow Nozzle	(Dprop)	Dprop	Dprop	Dprop

REM!

[1)] Main engine power well over minimum required by ice class rules. (Vessel has better performance in ice originally).
- Shaft generator power has been reduced from the ME power

FINNISH TANKERS

		New reference line				Old reference line			
Vessel	**DWT**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**BL** Phase 0	**Phase 1**	**Phase 2**	**Phase 3**
Mastera IA Super DAT Bulbous bow	106200	Bred	LNG	LNG Bred	Not achieved	As built	Bred Dprop	LNG	LNG Bred Dprop
Stena Arctica IA Super Bulbous bow	117099	Bred	Bred Dprop	Bred Bow Nozzle	LNG Bred Dprop	As built	Bred	Bred Dprop	LNG bow
Jurmo IA Super Bulbous bow	25049	As built	As built	Bred Bow Nozzle	LNG Nozzle	As built	As built	As built	Bred Bow Nozzle
Kiisla IA Super Bulbous bow	14750	(Bred)	Bred	Bow	LNG Bred	(As built)	As built	Dprop	Bred
Stena Poseidon IA Bulbous bow	74940	As built	As built	Nozzle	Bow Nozzle	As built	As built	As built	Bow Nozzle

REM !

- Shaft generator power has been reduced from the ME power
- Mastera propulsion power has been used as ME power

3.2 Comments on the Design Changes

New Reference Lines

New reference lines tighten the EEDI requirements e.g. of Finnish flag ice class ships as follows:

General cargo ships (7 ship types)

Between 10.1% (Jollas 14 505 dwt) and
21.6% (Alholmen 3150dw t)

Tankers (5 ship types)

Between 7.3% (Mastera 106 200 dwt) and
16.4% (Kiisla 14 750 dwt)

Bulk Carriers (2 ship types)

Between 12.6% (Eira 19 625 dwt) and
15.3% (Hesperia 13 518 dwt)

Container ships (2 ship types)

Rem.! New way is to take only 65% of DWT with new reference line, not directly comparable.

Between 30.1% (Containership 13 900 dwt) and
30.8% (Aila 11 300 dwt)

Conclusion is that the ice factors which are based on old reference lines are not any more valid. Simple correction of ice factors is not possible; because the difference between the reference lines is getting higher when DWT gets lower i.e. ice factors should be recalculated. The influence of the tightened EEDI requirements on ice class vessels is dramatic, as Table 3 shows.

Influence of EEDI requirements on Finnish flag ice class ships

General

Only limited number of vessels with ice classes of IA and IA Super are under Finnish flag. Thus no ice class IB or IC ships are calculated

The accuracy of the calculations varies because only public data was available. So individual ships have to be treated with care due to assumptions made.

The influence of the tightened EEDI requirements on ice class ship design and performance is dramatic, see enclosed tables. As mentioned old ice factors cannot be used with new reference lines, thus this general summary has been made based on the old reference lines. The influence of tightened new reference lines, see different ship type analysis below and enclosed tables.

The influence of the EEDI requirements on Finnish flag ice class ships varies a lot between ship types.

Also ice factors lead in certain cases (mainly due to Baltic ship small sizes and main dimension proportions) to contra dictionary results e.g:

- Lengthening of the ship reduces *EEDI* dramatically although emissions go down only little
- Adding propulsion efficiency/thrust sometimes has no influence on *EEDI* although emissions go down much

This may lead to non optimal vessel designs.

If old reference lines are used:

- Typical small general cargo ships fulfill the requirements quite well
- Tankers have difficulties to fulfill Phase 2 and 3 and large tankers even Phase 1 requirements even if DAT principle is used. LNG machinery is needed in case of larger tankers at phases 2 and 3 in excess of other changes.
- Bulk carriers need changes even from phase 0 (B reduced/nozzle) and in other case also LNG is needed from phase 2.
- Container vessels, due to high open water power/speed, could cope with power reduction and still have power well over ice class requirements.

This would mean that certain ship types would become expensive and have ice bows/low beam/nozzle/LNG use resulting in high costs and low ice power, nozzle blocking etc. meaning need of more icebreaker assistance (power reduced typically 20-40%). Also open water resistance would rise when ice bow is used to minimize required ice class power adding emissions.

LNG bunkering would be also a problem if ice class ships are required to use LNG machinery when open water ships could still manage with lower speed.

On the other hand in case of pure open water ships the reference lines are determined so that the speed drop etc. would be similar for different ship types, thus certain ice class ships would be expensive to use in open water market and cargoes would probably be carried more on e.g container ships which have high power due to high speed of open water ships.

Also ships which have higher power than ice class requires would often be impossible.

<u>General Cargo Ships (See Table 3)</u>

Ships are quite small (DWT between 3150-14 505 t) and many have on purpose extra power over ice class requirements.

Due to small size the difference on EEDI requirements between Phases is small.

Old reference lines:

- Most of the vessels could reach even phase 3 “as built”
- Problematic is special ships like Aura. It should reduce power down to iceclas minimum and use nozzle to cope with requirements.

New reference lines:

- Most of the ships don't fulfill phase 0 without changes
- Phases 1-3 mean practically same changes needed i.e power reduction down to minimum ice class power/use of nozzle/larger propeller/change to ice bow and in case of special ships like Aura also LNG use.

On special ships with variable routes use of LNG machinery is very difficult (bunkering)
Use of nozzle may lead to problems in heavy channels. Also reduction of power in many cases about 30-35% means that more icebreaker assistance would be needed, even if theoretically ice class power requirement would be fulfilled.

<u>Tankers</u>

Old reference lines:

- All ships would fulfill phase 0 "as built"
- At phases 1-3 building ships narrower and longer would mean lower ice class power and even extra advantage on EEDI due ice factor benefits of longer vessels. Also use of larger diameter propeller/nozzle/ice bow is utilized. LNG is needed in two vessels of five.

Use of nozzle may lead to problems in heavy channels. Also reduction of power in many cases about 30-40% at phase 3 means that more icebreaker assistance would be needed even if theoretically ice class power requirement would be fulfilled.

New reference lines:

- At phase 0 two of five types would need changes (more narrow and longer vessel)
- DAT vessel Mastera, even if propulsion motor power is taken as the main engine power P_{ME}, needs LNG machinery already at Phase 1 and cannot achieve phase 3 at all. Due to DAT type the power is low. This means that large tankers would have big difficulties to reach required ice performance.
- At Phase 3 also all other ships (except one which could manage with ice bow and nozzle) would need LNG machinery

Use of nozzle may lead to problems in heavy channels. Also reduction of power in many cases about 30-40% at phases 2-3 means that more icebreaker assistance would be needed, even if theoretically ice class power requirement would be fulfilled.

<u>Bulk Carriers</u>

Only two vessels of about same size included.

Old reference lines:

- Even at phase 0 vessels should be built narrower and longer and Hesperia should have even nozzle.
- At phases 2 and 3 B reduction/ice bow/larger propeller and in case of Eira even LNG machinery would be needed

Use of nozzle may lead to problems in heavy channels. Also reduction of power in many cases about 20-35% at phases 0-3 means that more icebreaker assistance would be needed, even if theoretically ice class power requirement would be fulfilled.

New reference lines

- Even at phase 0 ice bow, B reduction and nozzle would be needed on both ships
- MS Eira would need in excess of other changes also LNG machinery at Phase 1 and 2 and phase 3 cannot be reached.
- MS Hesperia would need LNG use at phase 3 with ice bow and reduced beam.

Use of nozzle may lead to problems in heavy channels. Also reduction of power in many cases about 20-35% at phase 0-3 means that more icebreaker assistance would be needed, even if theoretically ice class power requirement would be fulfilled.

Container ships

Only two container ships included in the Finnish merchant ship fleet.

Container ships, due to high open water power/speed, could cope with power reduction / adding propeller diameter because their power is typically well over ice class requirements

3.3 General Analysis of the Design Changes

Many of the present ships have an attained *EEDI* which is above the present reference lines. The thrust of the EEDI regulation is to force ships to be more environmentally friendly in way of less CO_2 emissions per ton mile. This lower attained *EEDI* is to be reached by designing ships better, using more efficient equipment and using sustainable energy (solar cells, sails etc.). Here a short analysis of the design means to decrease the attained *EEDI* in ice class ships is carried out. Two main means to decrease the attained *EEDI* exist; improving the propulsion and changing the ship hull.

The attained *EEDI* can be decreased by improving the propulsion (larger propeller diameter, optimum propeller or nozzle) while keeping the ship length, dwt and speed constant. The definition of the attained *EEDI* is

$$EEDI \propto \frac{f_j \cdot P}{f_i \cdot DWT \cdot v}$$

where the ice class factors are

$$f_j = MAX[\frac{\overline{P}_{ow}}{P}, f_{jMIN}]$$
$$f_i = MIN[\frac{\overline{DWT}_{ow}}{DWT}, f_{iMAX}]$$

where bar refers to average value and subscript ‘ow’ refers to open water. The average values are defined based on ship length for each ship type as well the limits for ice factors. The value for the limiting ice factor depends also on ship ice class. The limits for the ice factors are in essence of form

$$f_{jMIN} = \frac{\overline{P}_{ice}}{P}$$
$$f_{iMAX} = \frac{\overline{DWT}_{ice}}{DWT}.$$

Thus if the ship needs less power due to improved propulsion, and the ice factor f_j is above the limit, then the nominator in the attained *EEDI* expression is constant and no change in the attained *EEDI* results. Thus the attained *EEDI* will decrease only, if the ship power P is larger than the average power of ships in the ice class considered $\overline{P}_{ice}$, i.e. $P > \overline{P}_{ice}$. This is a consequence of the fact that if $P > \overline{P}_{ice}$ then $f_j = f_{jMIN}$. Note that if $P < \overline{P}_{ice}$ then in the expression for the attained *EEDI* the power term is just $\overline{P}_{ow}$ as $f_j \cdot P = \overline{P}_{ow}$, this being a consequence of the definition of the ice class factor $f_{j0} = \frac{\overline{P}_{ow}}{P}$. This effect is illustrated below.

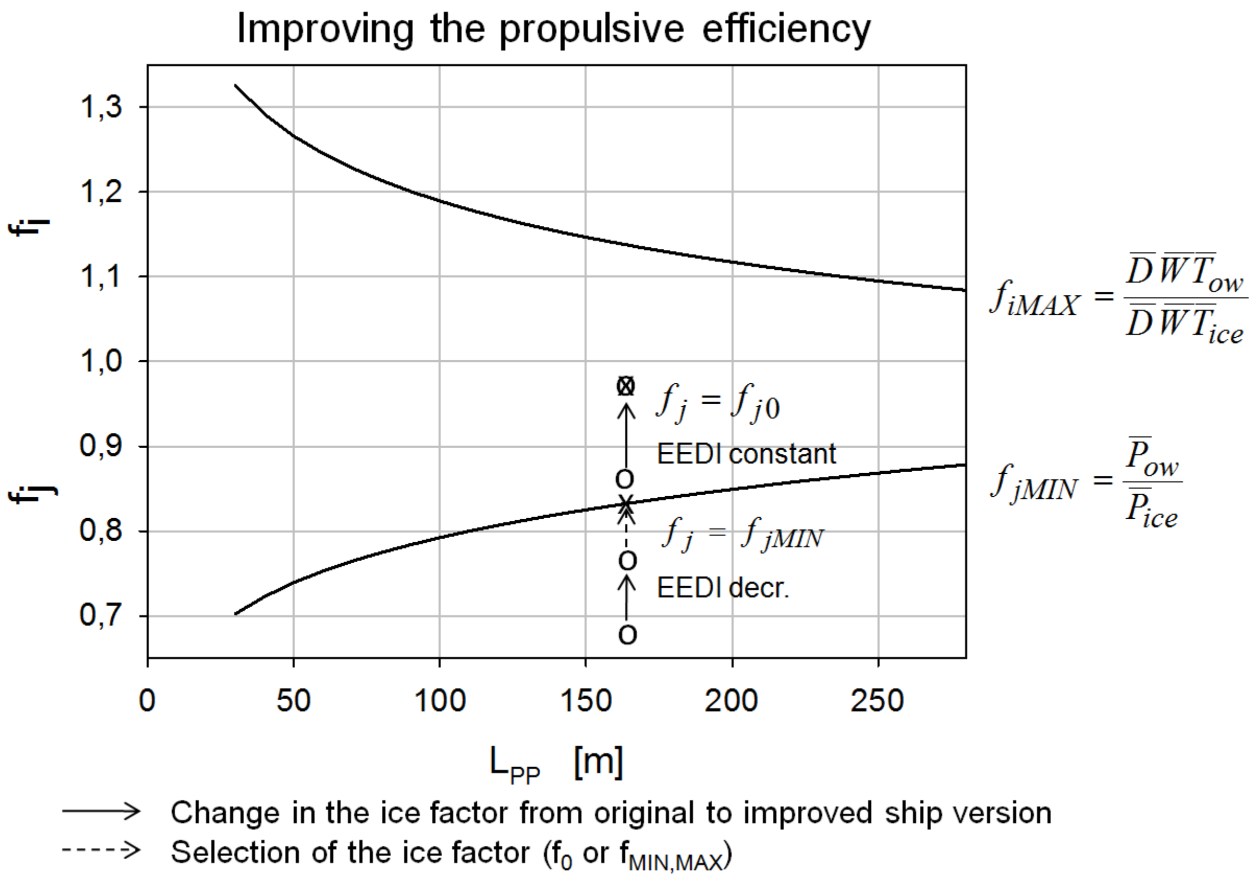

Fig. 1. The effect of the improved propulsion on the power correction factor.

The conclusion of this analysis is that the limits for the ice class factor f_j should be determined so that the minimum should correspond as closely as possible the minimum power given by the ice class. Additionally it can be concluded that only the ships that have larger power than the bare minimum, get some advantage from the ice class factor.

The attained *EEDI* can also be decreased by changing the main dimensions, mainly by decreasing the beam. A similar way to decrease the attained *EEDI* is to change the bow to a more ice breaking form. These changes decrease the required propulsion power. If this change is done by keeping the dwt constant, then the length of the ship increases and the speed may decrease slightly. These effects on the attained *EEDI* are illustrated in the figure below.

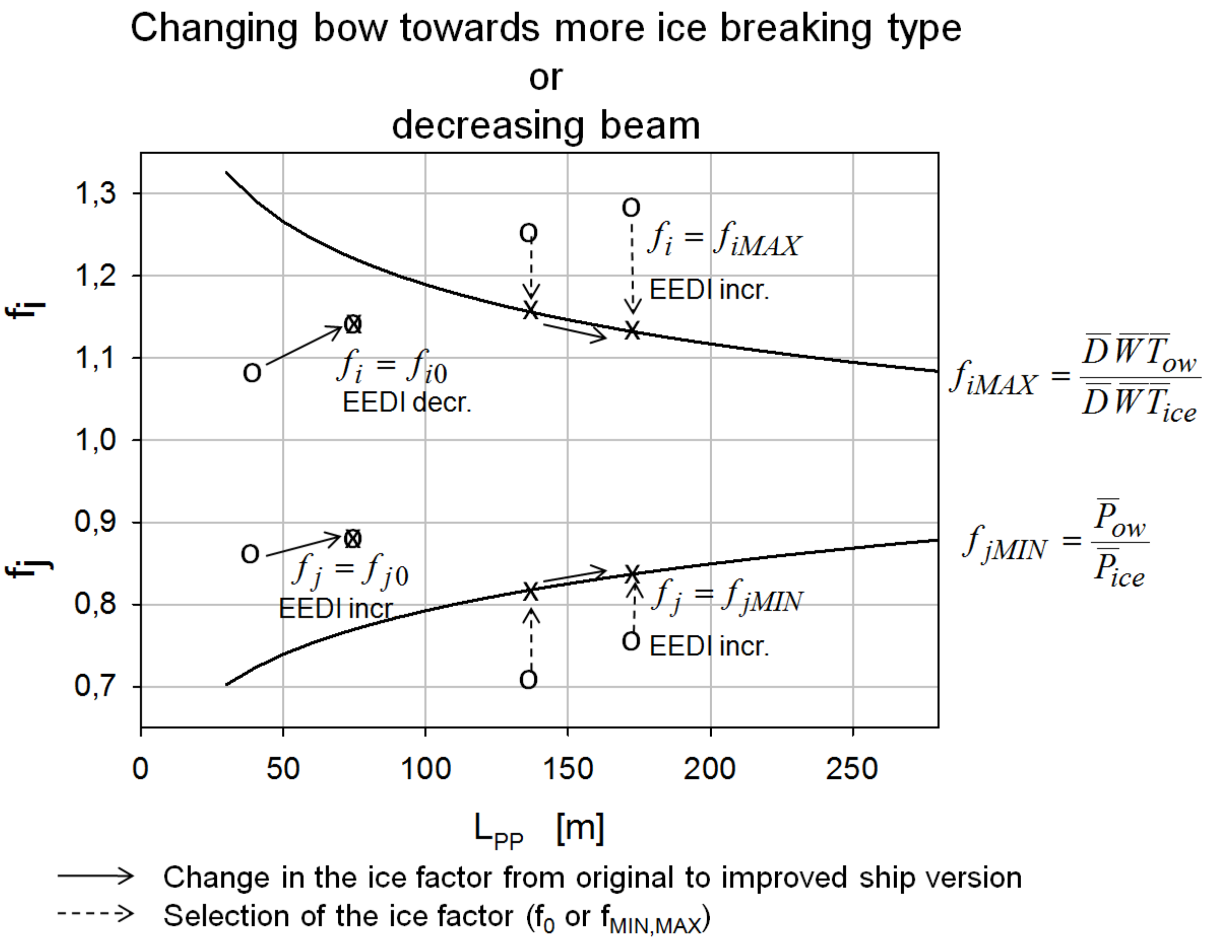

Fig. 2. The effect of the changes in the ship hull on the power and capacity correction factor.

Both the regression for the average power $\overline{P}_{ow}$ and dwt $\overline{DWT}_{ow}$ for open water ships are of form $a \cdot L_{pp}{}^{b_{ow}}$. This is also the form of the limiting curves for the ice class factors. If the original ship is marked with subscript '1' and the improved with '2', then the change in the attained *EEDI* value, when the ice class factors are within the limit curves, is

$$\frac{EEDI_2}{EEDI_1} = \left(\frac{L_2}{L_1}\right)^{b_{P,ow} - b_{dwt,ow}} \cdot \frac{v_1}{v_2}.$$

As generally $b_{dwt,ow} > b_{P,ow}$ and $v_2 \approx v_1$, the attained *EEDI* value generally decreases.

Similarly, if the both ice class factors are in the area outside the limits, the change in the attained *EEDI* is

$$\frac{EEDI_2}{EEDI_1} = \left(\frac{L_2}{L_1}\right)^{b_{P,ow} - b_{dwt,\lim it}} \cdot \frac{v_1}{v_2}$$

showing an increasing trend for the attained *EEDI*.

The most common situation for the Finnish merchant ships is that the dwt factor is within the limits but the power factor is outside the limits. In this case the change in the attained *EEDI* is the same as if both factors would be within limits.

The above analysis shows that it is important where the limits for the ice class factors are drawn. The plot below shows that many power ice class factors f_{j0} are outside the limits whereas most of the dwt factors are within limits.

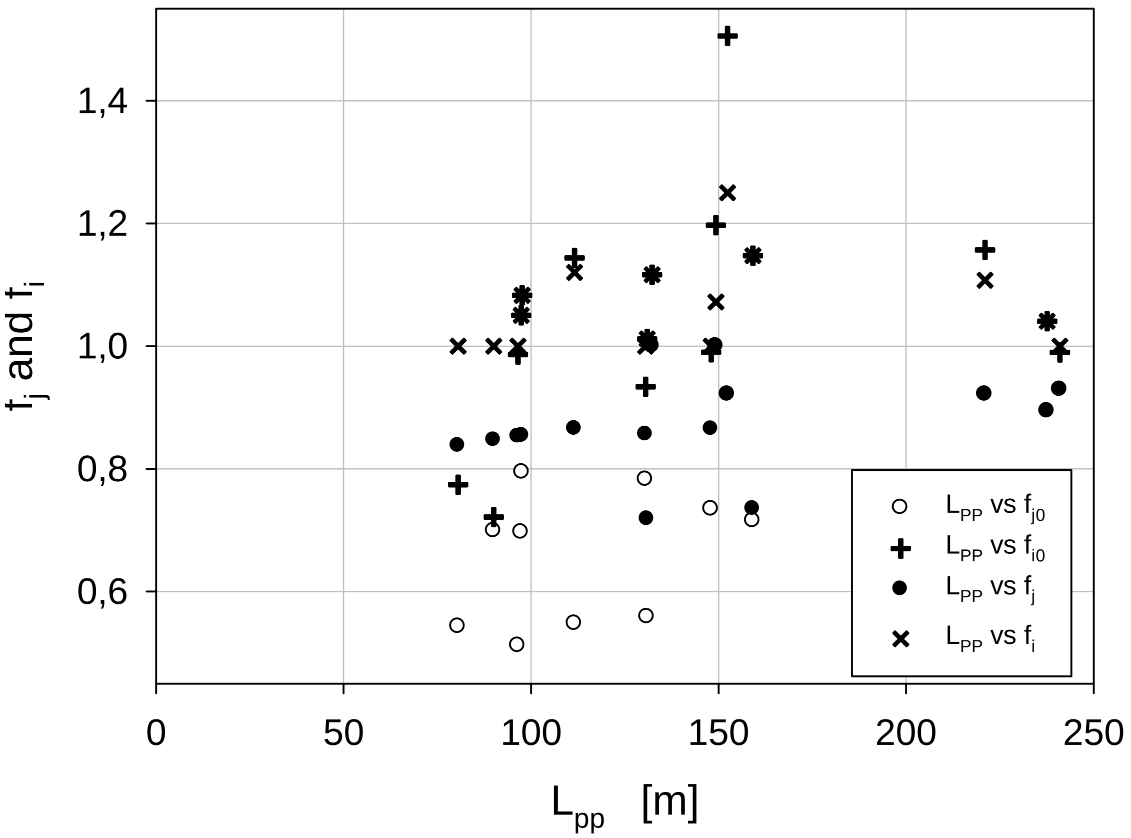

Fig. 3. The actual ice class correction factors f_i and f_j compared with the ship specific factors f_{i0} and f_{j0} (i.e. without correction due to the limits).

There are some ships for which the dwt factor is below one, two of these are MS Fingard and MS Alholmen. These ships have a large dwt when the length is taken into account. The ratios L/B and B/T are for Fingard and Alholmen 6.838 and 2.124 as well as 6.118 and 2.228 respectively. These lead to L/T ratios of 14.52 and 13.63 whereas the average value for merchant ships is about 16.4 (Alanko 2007). Thus the open water ships would have the average draughts of 5.50 m and 4.90 m, respectively. These ships have thus about 700 t and 900 t more displacement than an average ship of similar length. This displacement correction explains the dwt of Alholmen but not completely that of Fingard.

4. CONCLUSION

The methods to decrease the attained *EEDI* of all existing Finnish flag ships falling under the EEDI legislation were checked. The changes were made keeping the deadweight constant and the propulsion power at least the minimum required by the ice class. The results varied from ship type to ship type; the results are collected for each ship type as follows:

<u>Bulk carriers</u> cannot fulfil the Phase 3 requirement at all or only by using LNG.

<u>Container ships</u> can best meet the required *EEDI* by improving the propulsion of by reducing speed by reducing power.

<u>General cargo ships</u> can meet the required *EEDI* as built (one out of seven ships meets the requirement as built) or by improving only the propulsion (1/7). Some general cargo ships have a high power (in excess of the minimum required by the ice class) in order to improve the performance in ice; this results also in higher open water speed and thus the speed may be reduced by reducing the power.

<u>Tankers</u> generally must start using LNG to meet the Phase 3 required *EEDI*; for one tanker introduction of a nozzle and change in the bow is enough and for one (out of five) not any investigated means is enough to meet the Phase 3 requirement.

In general it is noted that even using the old reference lines many changes are required and in many cases only use of LNG makes the ship fulfil the EEDI requirement. This is especially the case for larger, AFRAMAX-size tankers. The use of LNG is not straightforward in ice going ships where the power used varies a lot in ice operations. Gas diesels may not be that efficient in working this kind of environment.

Many of the design changes (ice breaking bow, nozzles) may be detrimental for the overall energy efficiency as the open water efficiency suffers even if the ice performance is improved. This is important as general Baltic ships sail in ice for at most four months per year and during the rest of the year sail in open water. The overall aim to reduce the emissions per a carried ton should be kept in mind. Use of nozzles may reduce the power required in ice due to larger thrust but nozzles may also bring in its train problems in ice.

The introduction of the new reference lines for the required *EEDI* changed the situation for smaller ships as the change from the proposed reference lines is larger for these ships. This conclusion stresses the importance to use the same database in calculating various factors for attained *EEDI* calculation; thus also the ice class correction factors should be recalculated using the same data as is used to calculate the reference lines.

Finally it can be concluded that ships which have power in excess of the required minimum power given by the ice class rules must reduce this power to meet the required *EEDI*. This power reduction results in more extensive need for icebreaker assistance with the result of increasing the emissions per a carried ton of cargo. This is a point that requires somewhat more extensive study.

REFERENCE

Alanko, Jussi 2007: Conceptual design of ships [in Finnish; Laivan yleissuunnittelu], Turku.