E

INTERSESSIONAL MEETING OF THE WORKING GROUP ON ENERGY EFFICIENCY MEASURES FOR SHIPS
1st session
Agenda item 2

EE-WG 1/2/7
21 May 2010
ENGLISH ONLY

FURTHER IMPROVEMENT OF THE DRAFT TEXT FOR MANDATORY REQUIREMENTS OF EEDI AND SEEMP

Proposal for a Correction to EEDI Baseline Formula

Submitted by Greece

SUMMARY

Executive summary:	This document proposes a correction to the EEDI baseline formula that alleviates a key deficiency of the current EEDI baseline formula, namely, the effective imposition of a speed limit which would lead to underpowered ships
Strategic direction:	7.3
High-level action:	7.3.2
Planned output:	7.3.2.1
Action to be taken:	Paragraph 34
Related documents:	MEPC 60/4/7, MEPC 60/4/15, MEPC 60/4/16, MEPC 60/4/17, MEPC 60/WP.9 and MEPC 60/22

Introduction

1 MEPC 60 agreed to hold an Intersessional Meeting of the Working Group on Energy Efficiency Measures for Ships (EE-WG 1). Its terms of reference were approved by MEPC 60, as set out in annex 6 to MEPC 60/22, and the provisional agenda is set out in document EE-WG 1/1.

2 One of the terms of reference of the Intersessional Meeting is to develop guidelines for calculation of baselines for attained EEDI, based on documents MEPC 60/4/7 (Denmark and Japan) and annex 4 to MEPC 60/WP.9 and other documents submitted to MEPC 60 and previous sessions.

3 To assist in this process, Greece would like to propose an alternate and corrected formula for the calculation of the EEDI baseline. It is recalled that at MEPC 60, Greece, with documents MEPC 60/4/15, MEPC 60/4/16 and MEPC 60/4/17, put forward some concerns on the formula used to define EEDI and EEDI baseline.

4 In the present document, Greece proposes a way to alleviate one of the major deficiencies already identified and the effective imposition of speed limits. Alleviating this deficiency would require no change in the definition of EEDI, but a specific adjustment to the current formula for the EEDI baseline would be required. Regression analysis results for bulk carriers, tankers and containerships with one of the proposed EEDI baseline formulas are reported.

Speed limit deficiency

5 The current baseline formula for EEDI is as follows: **EEDI baseline = $aDWT^{-c}$** where DWT is the deadweight and a and c are positive coefficients determined by regression from the world fleet database, per major ship category. The regression is carried out between EEDI and DWT and outliers more than two standard deviations are removed.

6 In MEPC 60/4/15, Greece argued that there is a serious physical inconsistency between (a) the formula for EEDI and (b) the above formula for the EEDI baseline. In (a), making the common assumption that ship engine MCR grows like the cube of speed, EEDI grows like speed squared. In (b), speed does not enter the formula at all. It is straightforward to check that this combination is tantamount to imposing an upper bound on speed. This would translate to an upper bound on MCR and thus would essentially mandate the construction of underpowered ships, which, in their attempt to go faster or just maintain speed in bad weather, would emit disproportionately more CO_2. Furthermore, with the resulting trend for smaller engines, serious concerns are raised, especially for bulk carriers and tankers, about their power adequacy to safely navigate in bad weather.

7 Perhaps more important, this might also shift the focus of action from designing the best possible hull forms, engines or propellers, to just reducing service speed at the design level. With the current formulations, any bad or totally inefficient design can be made acceptable with the easy way out: a rather small reduction in "design speed" (and horsepower). This can hardly serve as an incentive for more efficient future ship designs. On the other hand, some simple "low tech" real design and hydrodynamic improvements can be immediately applied by any design office or shipyard resulting in serious reductions of the hydrodynamic resistance of the ship or the propelling efficiency. As examples, one could rethink the unrealistically very full bows featured in current bulk carrier designs[1], or the usual "one size fits all" off-the-shelf propeller selection mentality prevalent in tankers and bulk carriers, which leads to higher than efficient engine RPM and decreased propelling efficiency.

8 Last but not least, possible side-effects of reduced speeds include:

.1 adding more ships to match demand throughput;

.2 increasing cargo inventory costs due to delayed delivery;

.3 increasing freight rates due to a reduction in ton-mile capacity;

.4 reduced manoeuvrability and navigational safety; and

.5 inducing reverse modal shifts to land-based modes (mainly road), something that would increase overall GHG emissions.

---

[1] An actual example concerns a recent supramax design: With just a sacrifice of 0.5% in displacement (= 300 tonnes of DWT) for slightly refined lines forward over the standard design, fuel consumption was reduced by 3.5% at the same speed (1.2 tonnes/day MDO reduction at design draft, ISO conditions). In any conceivable future market scenario this is a gain for both the operator and the environment.

9 To alleviate the above deficiencies, in document MEPC 60/4/15, Greece proposed looking at various alternatives that would introduce speed to the current EEDI baseline formula, namely, functions of the form EEDI baseline = $a(DWT/V)^{-c}$, or $a(DWT/V^2)^c$, or $aDWT^{-c}V^{-d}$, where V is the reference speed that corresponds to 75% of MCR. The use of alternative formulations that incorporate speed in the baseline formula has also been proposed in other past IMO submissions, see for instance, documents GHG-WG 2/2/9, MEPC 59/4/20 (China) and GHG-WG 2/2/22 (CESA).

10 The above three alternatives were looked at, but none proved much better than the current formula. By contrast, a fourth alternative was tried and proved more promising, as will be explained below.

Alternate formula for EEDI baseline

11 Greece hereby proposes modifying the formula for EEDI baseline as follows.

Alternate formulae: **EEDI baseline = $aDWT^{-c}V^2$ or $aDWT^{-c}V^3$**

12 That is, one has to multiply the right-hand side of the current equation by the square or cube of the reference speed V. The formula for EEDI remains unchanged. As before, coefficients a and c are determined by regression. These coefficients will be different in the alternate formulae from what they are in the current one. Which of the two alternate formulae above is more appropriate depends on whether MCR grows as the cube of speed (which is the common assumption) or whether it actually grows as the 4th power of speed or even higher. Despite the common assumption, as will be elaborated below, the evidence from sea trial data of modern bulk carriers, tankers and containerships examined by Greece, suggest the latter to be true.

13 The rationale for such a proposal is as follows: if, based on the common assumption, the numerator of EEDI grows like V^3 and the denominator grows like V, EEDI will grow like V^2. If EEDI baseline is independent of speed, to obtain an EEDI below the baseline would mean that an upper bound should be placed on V, with all the repercussions stated earlier. One way to alleviate this problem is to try to redefine the EEDI baseline as being proportional to V^2. Similarly, if the numerator of EEDI actually grows like V^4, as the evidence suggests, then EEDI baseline should be redefined as being proportional to V^3.

14 Greece notes here that the idea to use the square of the speed to alleviate potential deficiencies in the EEDI is not new. Already, Germanischer Lloyd has suggested a function of the square of the ship's Froude number (which is proportional to speed) to be included in the denominator of the EEDI formula for high speed craft[2]. Here, Greece proposes something related, but the EEDI formula is kept intact, and V^2 (or V^3) is included in the baseline formula.

15 To test the alternate formulae, Greece has performed a set of regression analyses for dry bulk carriers, tankers and containerships, using the Lloyd's Register Fairplay Sea-web™ database. The regression analysis for the first option **EEDI baseline = $aDWT^{-c}V^2$** has been completed and is presented below. Regression analysis for **$aDWT^{-c}V^3$** is in progress and will be presented at EE-WG 1. The simplified formula for EEDI (as redefined in MEPC 60) was used, that is:

[2] See Köpke, M., P. Sames, "Energy Efficiency Design Index for High Speed Crafts", 10th International Conference on Fast Sea Transportation (FAST 2009), Athens, Greece, October 2009.

$$EEDI = 3.11(190P_{ME}+215P_{AE})/(DWT \cdot V)$$

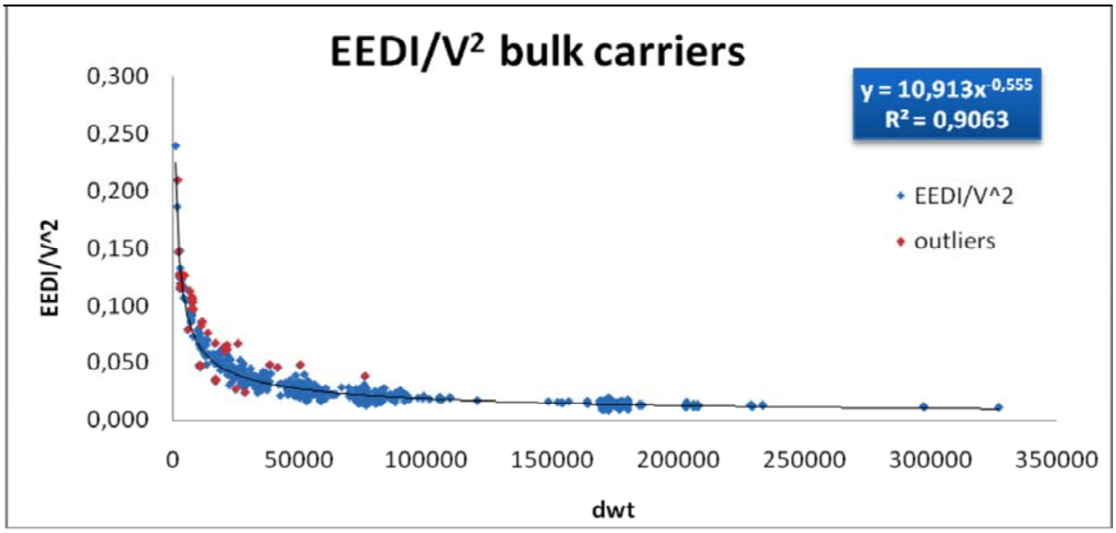
Where
$P_{ME} = 0.75MCR$
$P_{AE} = 0.025MCR + 250$ if $MCR \geq 10{,}000$ kW
$P_{AE} = 0.05MCR$ if $MCR < 10{,}000$ kW
V = service speed corresponding to 75% of MCR.

16 Note that the above formula has slightly different coefficients vis-à-vis the previously used formula, as agreed at MEPC 60, and thus new regressions for EEDI baseline would be required anyway. The differences concern the carbon coefficient (3.11 instead of 3.13) and the auxiliary power fuel consumption coefficient (215 instead of 210). All other coefficients remain the same. Another change versus previous runs is that for containerships, where the DWT used in the EEDI formula should be at the 65% of the ship's deadweight (MEPC.1/Circ.681).

Regression results

17 The results are shown in figures 1, 2 and 3 and in Table 1 below[3]. The curves shown in the figures depict the ratio EEDI/V^2 as a function of DWT. Outliers more than 2 standard deviations have been removed.

Figure 1 Bulk Carriers



3 The regressions were carried out by the National Technical University of Athens, Laboratory for Maritime Transport.

Figure 2 Tankers

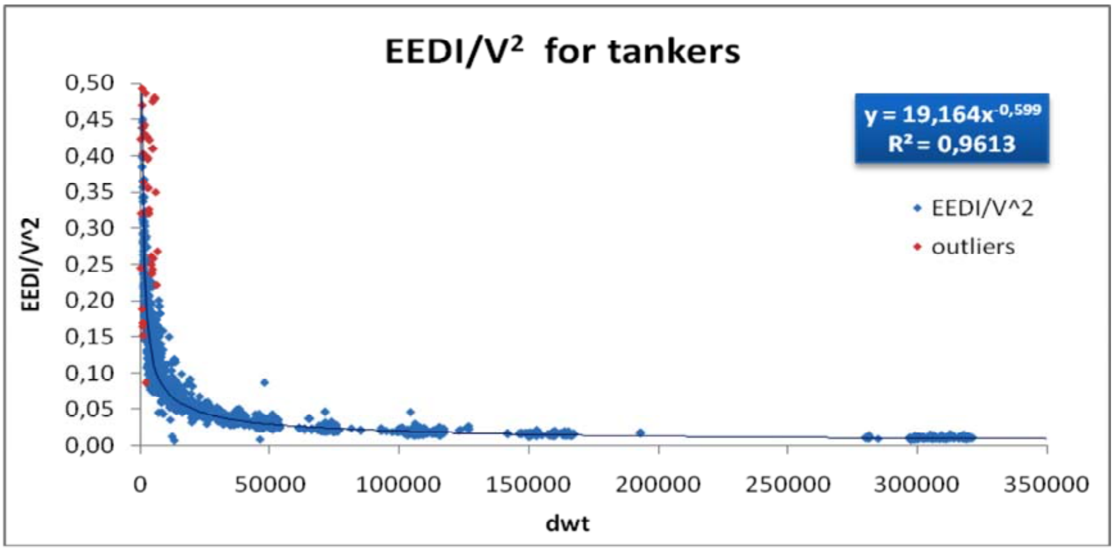


Figure 3 Containerships

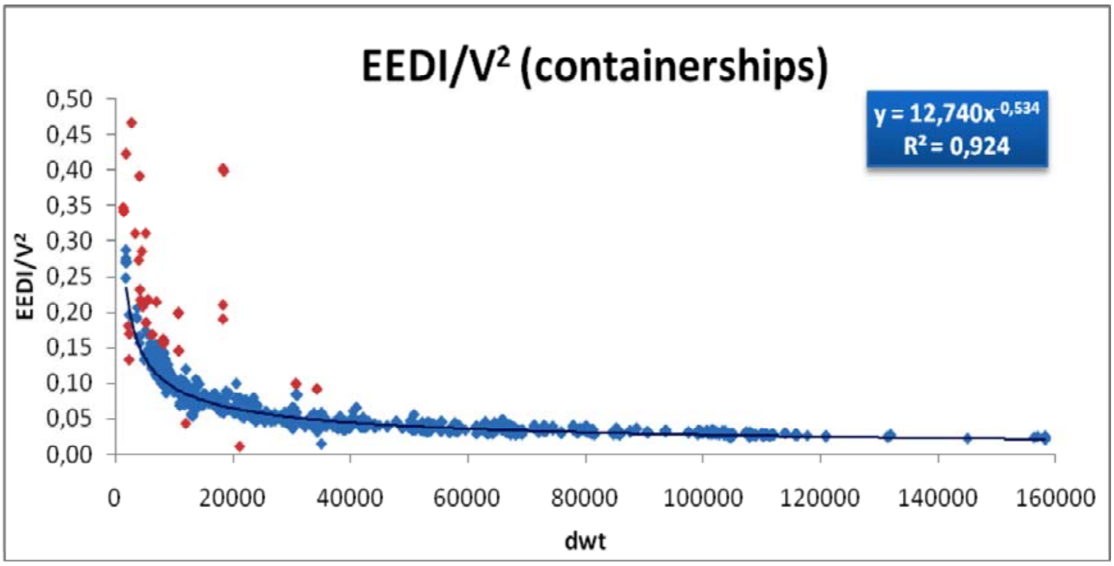


Table 1 REGRESSION RESULTS FOR EEDI BASELINE

	Dry bulk carriers	Tankers	Containerships
Denmark (GHG-WG 2/2/7)	$1,354DWT^{-0.512}$ ($R^2 = 0.93$)	$1,950.7DWT^{-0.534}$ ($R^2 = 0.97$)	$139.38DWT^{-0.217}$ ($R^2 = 0.66$)
Greece (MEPC 60/4/15)	$954.46DWT^{-0.478}$ ($R^2 = 0.93$)	$936.47DWT^{-0.468}$ ($R^2 = 0.96$)	$69.49DWT^{-0.151}$ ($R^2 = 0.42$)
Alternate formula Greece (this doc.)	$10.913DWT^{-0.555}V^2$ ($R^2 = 0.91$)	$19.164DWT^{-0.599}V^2$ ($R^2 = 0.96$)	$12.74DWT^{-0.534}V^2$ ($R^2 = 0.92$)

18 Perhaps the most interesting observation from table 1 is the very high correlation coefficient (R^2) for containerships, much higher than any previously obtained[4]. The correlation coefficients for the other two cases are of the same order of magnitude as those previously obtained.

19 Greece is of the opinion that the alternate formula's most important advantage over the current one lies not so much in its very good R^2, but in the significant alleviation (or even elimination) of the speed limit effect. The extent of this would depend on the exact functional dependency between MCR and V. If this is cubic, as is the common assumption, the speed limit effect will be essentially eliminated.

20 To obtain an actual indication of this relationship, Greece examined actual sea trial data from several modern ships of various types and sizes. Invariably, for all the examples examined, power grew higher than V^3, more like V^4 or even higher ($V^{4.5}$). This means that with **EEDI baseline = $aDWT^{-c}V^2$**, design speed reduction remains an alternative to make a design comply with EEDI (baseline), but not, of course, with the same ease or to the same extent as before. However, **great caution is required** in choosing the proper EEDI baseline alternative. If **EEDI baseline = $aDWT^{-c}V^2$** is chosen, based on the common assumption that power is proportional to V^3, when in fact it grows like V^4 or higher, the problem of underpowered designs may be exacerbated instead of improved. That is because while with the original (current) EEDI formulation a 1 knot design speed reduction may be sufficient to make a design compliant, with **EEDI baseline = $aDWT^{-c}V^2$** it may require 2 knots or more speed reduction if Power (MCR) is a function of V to a higher power. It is important, therefore, that the appropriate formulation is chosen between the 2 options (**$aDWT^{-c}V^2$** or **$aDWT^{-c}V^3$**) so that the speed effect is really alleviated or even eliminated. The intention should be that a marginal design may be "improved" this way but an unusually bad design will need an unrealistic design speed reduction to become acceptable and thus real design improvements will need to be applied. Greece will be in a position to offer a final proposal following completion of regression analysis for **$aDWT^{-c}V^3$**. Some examples are presented in the next section to illustrate this point.

21 It has to be stressed, however that, although with the above proposal, speed reduction will be a less easy alternative for **design** compliance, after delivery, speed reduction remains a primary **operational** measure for CO_2 emission reductions. In fact the CO_2 reduction, in real absolute values, will be much larger than that of an underpowered ship, for the same operational speed.

Discussion

22 As a further step in the analysis, Greece has compared the values produced by the alternate EEDI baseline formula **$aDWT^{-c}V^2$** with the values produced by the current EEDI baseline, as this was defined by Denmark in document GHG-WG 2/2/7. In all tables below, values are for the average ship in each size bracket, taken from the most recent update of the Lloyd's Register Fairplay Sea-web™ database. V is assumed to represent the speed corresponding to 75% of MCR.

23 In the tables, what is termed EEDI (old) is computed using the old simplified formula, and EEDI (new) is computed using the new simplified formula. The differences are minor and concern the new coefficients in the formula, as stated earlier. The results are as follows (an asterisk * denotes cases where EEDI is above the corresponding baseline, and therefore unacceptable).

[4] To Greece knowledge, the highest R^2 obtained thus far for containerships is around 0.7, by using (V/DWT) as the regression variable (see MEPC 59/4/20 by China).

Table 2 DRY BULK CARRIERS

SIZE	DWT	V (knots)	MCR (kW)	EEDI (old)	CURRENT BASELINE	EEDI (new)	ALT. BASELINE
Handysize 15-35	28,074	14.04	6,156	7.480	7.168*	7.445	7.309*
Handymax 35-60	51,484	14.46	8,539	5.493	5.256*	5.467	5.337*
Panamax 60-85	75,952	14.41	9,955	4.356	4.308*	4.335	4.432
Post Panamax 85-120	92,175	14.39	11,786	4.233	3.901*	4.213	3.969*
Capesize >120	181,376	14.71	17,164	3.037	2.759*	3.021	2.849*

Table 3 TANKERS

SIZE	DWT	V (knots)	MCR (kW)	EEDI (old)	CURRENT BASELINE	EEDI (new)	ALT. BASELINE
Small tanker (0-10)	5,279	12.56	2,557	18.469	20.112	18.381	17.809*
Handysize (10-60)	3,2574	14.45	7,744	7.879	7.615	7.841	7.925
Panamax (60-80)	7,2024	14.96	11,907	5.263	4.986*	5.237	5.281
Aframax (80-120)	10,7754	14.89	13,521	4.000	4.021	3.980	4.110
Suezmax (120-200)	156,643	15.21	18,093	3.581	3.294*	3.563	3.428*
VLCC/ULCC (>200)	305,815	15.76	27,187	2.643	2.305*	2.629	2.465*

Table 4 CONTAINERSHIPS

SIZE	DWT	V (knots)	MCR (kW)	EEDI (old)	CURRENT BASELINE	EEDI (new)	ALT. BASELINE
Handysize (1000-2000 TEU)	19,156	19.491	12,906	25.271	25.336*	25.146	25.006*
Sub-Panamax (2000-3000 TEU)	35,108	21.935	22,593	21.197	22.220	21.087	22.929
Panamax (3000-4400 TEU)	50,581	23.555	35,597	21.465	20.531*	21.350	21.756
Post Panamax (>4400 TEU)	82,542	24.987	57,673	20.015	18.464*	19.907	18.845*

24 In Table 4, and for comparison purposes, the EEDI (old) and current EEDI baselines have been recalculated assuming 65% of the DWT.

25 One can generally see that the alternate EEDI baseline proposed here is in most cases slightly above the current EEDI baseline. But this may be misleading, as the major difference between the two cases is that if a ship has an EEDI above the baseline, in case the current EEDI baseline formula is used, one easy way to fix this is by reducing V (and hence MCR). This becomes less of an option if the alternate EEDI baseline formula is used, and other ways to reduce EEDI must be sought.

26 An example can illustrate this point. Greece noticed in table 4 that the top tier containership class has an EEDI (old) equal to 20.015, above the current baseline of 18.464. A very easy way to drop to the baseline level would be to reduce its V approximately by one knot, from 24.99 to 23.99 knots. **Assuming a cubic relationship as being valid**, reducing V by one knot can be achieved by reducing MCR from 57,673 kW to 50,959 kW, that is, installing a smaller engine to the ship (power reduction 13%). The smaller engine would achieve the desirable EEDI, but could make the ship more prone to emitting more CO_2 just to maintain speed in bad weather.

27 None of this would happen with the alternate EEDI baseline formula. The same ship has an EEDI (new) equal to 19.907, above the alternate baseline proposed here (18.845). Reducing its V by one knot would reduce its EEDI to 18.345. But reducing V would also reduce the ship's EEDI baseline to 17.352, because the latter is proportional to V^2. So the ship with a reduced V (and hence a reduced MCR) would still have an attained EEDI above baseline. This means that one would have to find **actual design improvements**, rather than reducing speed (or MCR), to get below the EEDI baseline, which should be the main thrust of a ship design index. This example is valid if a cubic relationship of power – speed is valid. If it is higher, as the data suggests, then speed reduction will make the design acceptable, with renewed danger for seriously underpowered ships (especially bulkers and tankers).

28 In Greece's opinion, the reduction or elimination of sensitivity to speed is the biggest advantage of the proposed alternate formulae over the current one. In the quest for reduced emissions, it helps re-shifting the focus towards measures that would really improve the energy efficiency of the ship, such as improving the hull form, the propeller, the engine, or other parameters, rather than taking the easy solution of reducing speed (and hence MCR). Of course, in any case, speed reduction would still be an option in an operational setting. Furthermore, by not encouraging the fitting of a small engine at the design stage, any speed reduction at the operational phase will result in larger CO_2 reductions for the same design speed.

29 As explained above, due to the apparent actual power-speed relationship being higher than V^3, an EEDI baseline proportional to V^3 may be required to achieve the above goals. This is currently being analysed by Greece and will be reported at EE-WG 1. For instance, in the containership example above, assume that MCR grows like the 4th power of V. It is then straightforward to compute that in order for the attained EEDI to drop to the baseline level, V would have to be reduced from 24.99 knots to:

.1 24.33 knots, if the current baseline is used; and

.2 23.66 knots, if the alternate baseline is used.

30 One can see that speed reduction is greater for the alternate case, which can be explained by the fact that when V is reduced, the baseline is also reduced. But in this case, the reduction of the baseline is not sufficient enough as to alleviate speed reduction from being an enticing easy alternative. This is because the used EEDI baseline **= $aDWT^{-c}V^2$** was formulated assuming MCR grew like V^3, while, in reality, ship MCR grew like V^4. It follows that, in this case, a baseline of **$aDWT^{-c}V^3$** is more appropriate, otherwise the underpowering issue is exacerbated. It also follows that the actual relationship of MCR to speed must be reliably established and agreed in order to agree to the appropriate alternative EEDI baseline.

31 Based on Greece's ongoing work, indications are that for modern ships, power may actually grow higher than V^4, e.g., like $V^{4.5}$. In such case, a baseline proportional to V^3 (namely $\mathbf{aDWT^{-c}V^3}$) will still be appropriate, without total elimination of speed reduction as an alternative. For marginal designs, a small speed reduction may make them compliant, however, for very inefficient designs, V (and hence MCR) would have to be seriously or unrealistically reduced as a means to stay below the baseline. This would certainly increase the incentive of reducing the attained EEDI through better hulls, engines, propellers, etc. Reducing it via speed reduction alone would be less easy.

Conclusions

32 Greece has proposed an alternate way to compute the EEDI baseline, one that incorporates the square or cubic power of speed into the baseline formula. Although other deficiencies, as those were identified in documents MEPC 60/4/15, MEPC 60/4/16 and MEPC 60/4/17, still remain, the alternate baseline formulae are aimed to alleviate what is considered to be the main EEDI deficiency, the effective imposition of speed limits (which would lead to underpowered ships). As such, the alternate formulae encourage measures that would really improve the energy efficiency of the ship, such as improving the hull form, the propeller, the engine, or others, rather than taking the easy solution of reducing speed and MCR.

33 Whether a baseline incorporating the square of speed or one which incorporates the cubic power of speed is more appropriate depends on the actual dependency of MCR to speed. If MCR of modern ships grows as V^3, the former is appropriate. If it grows as V^4 or higher, the later is more appropriate. Greece endeavours to have finalized its analysis in time for EE-WG 1.

Action requested by the Intersessional Meeting

34 The Intersessional Meeting is invited to consider the information provided in this document and take action as appropriate.

___