CENTRUM TECHNIKI OKRĘTOWEJ S.A.

Ship Design and Research Centre S.A.

SELECTED ASPECTS OF RESEARCH & DESIGN OF INNOVATIVE SHIPS AND OFF-SHORE CONSTRUCTIONS

PIOTR CZABAJ

DESIGN & TECHNOLOGY DEPARTMENT

CTO S.A.

CTO S.A.

- DESIGN: COMBINATION OF CURRENT RULES & FUTURE DEMANDS AND EXPECTATIONS

- COMPROMISE BETWEEN REQUIRED FUNCTIONS, AVAILABLE SOLUTIONS AND COSTS OF CONSTRUCTION

- INNOVATIVE DESIGN: HOW SHIP OR OFF-SHORE CONSTRUCTION WILL PERFORM DESIGNED FUNCTIONS IN COMPARISION TO FAMILAR VESSELS

- INNOVATIVE MEASUREMENTS: FUEL CONSUMPTION, DEADWEIGHT, ENDURANCE, ENVIRONMENT IMPACT, SAFETY OF CREW AND CARGO

- INNOVATIVE DESIGN BASED ON R&D RESULTS

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SELECTED ISSUES OF RESEARCH AND DESIGN OF INNOVATIVE SHIPS AND OFF+SHORE STRUCTURES

- ENERGY EFFICIENCY DESIGN INDEX
- EMISSIONS TO ENVIRONMENT
- FUELS AND INNOVATIVE PROPULSION SYSTEMS
- CREW COMFORT
- NOISE AND VIBRATION INFLUENCE ON ENVIRONMENT

ENERGY EFFICIENCY DESIGN INDEX

- LEGAL REGULATION IMO RESOLUTION A.963(23) CONCERNING REDUCTION OF GREENHOUSE GAS EMISSION
- VALID FROM JANUARY 1th, 2013
- REQUIRED FROM ALL SHIPS AND OFF-SHORE VESSELS OPERATING FROM JULY 1th, 2015
- EEOI AND SEEMP SHOULD BE IMPLEMENTED (DEMONSTARTORS HOW IS IMPLEMENTED ENERGY EFFICIENCY PLAN)
- MBI AND MBM SHOULD BE IMPLEMENTED (EMISSION TRADING INSTRUMENTS)

ENERGY EFFICIENCY DESIGN INDEX

Started with Resolution A.963(23): IMO Policies and Practices Related to the Reduction of Greenhouse Gas Emissions from Ships, adopted by Assembly 23 in 2003

IMO's GHG Work involves 3 distinct measures:

Technical Measures

EEDI – a design index

Applies only to NEW ships from 2013

Operational Measures

EEOI and SEEMP

(Ship Energy Efficiency Management Plan)

Applies to all ships in operation

Market Based Instruments (MBI – MBM)

Carbon Price on shipping

ETS (Emission trading)

Tax on bunkers

author: Panos Zachariadis, Technical Director, ABCML

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WHAT MEANS EEDI ? IT'S SIMPLY DESCRIBED BY FOLLOWING FORMULA:

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w} +$$

$$\frac{\left\{\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right\} - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

TRANSLATED INTO POLISH / ENGLISH:

EEDI (ENERGY EFFICIENCY DESIGN INDEX) IT'S A MEASURE OF CO_2 EMISSION IN REFERENCE TO WORK PERFORMED BY THE SHIP, I.E.:

$$EEDI = \frac{\text{AMOUNT OF EMISSED } CO_2}{\text{TRANSPORT CAPACITY}}$$

ENERGY EFFICIENCY DESIGN INDEX

PURPOSE OF EEDI INTRODUCTION:

- TO DEFINE MINIMUM EFFICIENCY FROM NEW BUILDED SHIPS
- PROMOTION OF ECO-FIRENDLY SOLUTIONS
- REDUCTION OF CO_2 EMISSIONS
- COMPARISION OF SHIPS (EQUAL BY THE TYPE)

SCOPE OF USE:

- MERCHANT SHIPS
- PASSENGER VESSELS
- CONVENTIONAL DIESEL PROPULSION SYSTEM

METHODOLOGY OF COMPUTATION:

- IMO MEPC.1/CIRC.681, INTERIM GUIDELINES ON THE METHOD OF CALCULATION OF THE ENERGY EFFICIENCY DESIGN INDEX FOR NEW SHIPS

- IMO MEPC.1/CIRC.682 INTERIM GUIDELINES FOR VOLUNTARY VERIFICATION OF THE ENERGY EFFICIENCY DESIGN INDEX

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ENERGY EFFICIENCY DESIGN INDEX

EEDI formula

Main Engine

Generators

Power take in

Aux power reduction

Mechanical power reduction

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

$$+ \frac{\left\{\left(\prod_{j=1}^{M} f_j \cdot \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} \cdot P_{AEeff(i)}\right) C_{FAE} \cdot SFC_{AE}\right\} - \left(\sum_{i=1}^{neff} f_{eff(i)} \cdot P_{eff(i)} \cdot C_{FME} \cdot SFC_{ME}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w}$$

Speed

Deadweight

$$EXAMPLE = \frac{1 \times (11000 \times 3.1144 \times 168.0) + (600 \times 3.1144 \times 220.0) + 0 - 0}{1 \times 100{,}000 \times 14.5 \times 1.0} = 4.405 \quad (g - CO_2/ton \cdot mile)$$

DETERMINATION OF THE CO_2 EMISSION IS AN EXPOTENTIAL FUNCTION OF THE CARGO AMOUNT AND DEPENDS FROM EFFICIENCY OF MAIN PROPULSION SYSTEM (INCLUDING GENERATORS) INCLUDING REAL SPEED OF THE VESSEL.

ENERGY EFFICIENCY DESIGN INDEX

Effects of EEDI formula

Want the smallest possible EEDI, thus…small numerator and large denominator

power

about constant

$$EEDI = \frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC_{ME(i)}\right) + \left(P_{AE} \cdot C_{FAE} \cdot SFC_{AE}\right)}{f_i \cdot Capacity \cdot V_{ref} \cdot f_w} + \ldots$$

Dwt

Minimize installed power, Minimize lightweight (in order to increase Dwt)

ENERGY EFFICIENCY DESIGN INDEX

Effects of EEDI formula

$$P_{ME} \sim V^{3+}$$

$$EEDI = \frac{\left(\sum_{i=1}^{nME} P_{ME(i)} \cdot C_{FME(i)} \cdot SFC\right)}{f_i \cdot Cap \cdot V_{ref} \cdot f_w} = \frac{\left(\sum_{i=1}^{nME} V^3 \cdot C_{FME(i)} \cdot SFC\right)}{f_i \cdot Cap \cdot V \cdot f_w} = \frac{\left(\sum_{i=1}^{nME} V^2 \cdot C_{FME(i)} \cdot SFC\right)}{f_i \cdot Cap \cdot f_w}$$

Easiest way to reduce EEDI -> Reduce Design speed

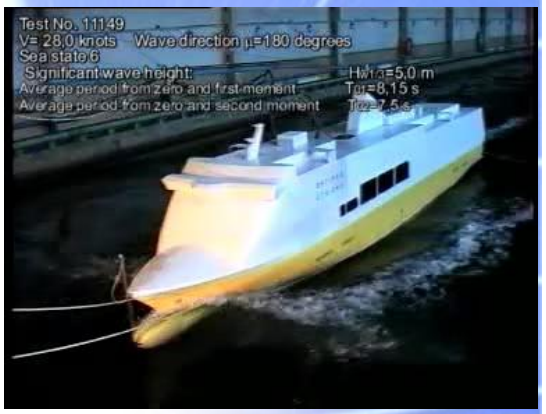
ENERGY EFFICIENCY DESIGN INDEX – IMPACT ON DESIGN ISSUES

DURING DESIGN EXECUTION, DESIGNER MUST TAKE INTO ACCOUNT INNOVATIVE PROPULSION SYSTEMS

- **REDUCTION OF MAIN ENGINES POWER**
- **REDUCTION OF ELECTRIC GENERATOR POWER**

SCOPE OF RESEARCH WORKS PERFORMED BY CTO S.A. IN DETERMIANTION OF EEDI INDEX:

- **HULL OPTIMISATION (RESISTANCE AND POWERING) ACCORDING TO EEDI**
- **NUMERICAL SIMULATIONS**
- **MODEL TESTS**



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R&D DEPARTMENT - SHIP HYDROMECHANICS DIVISION

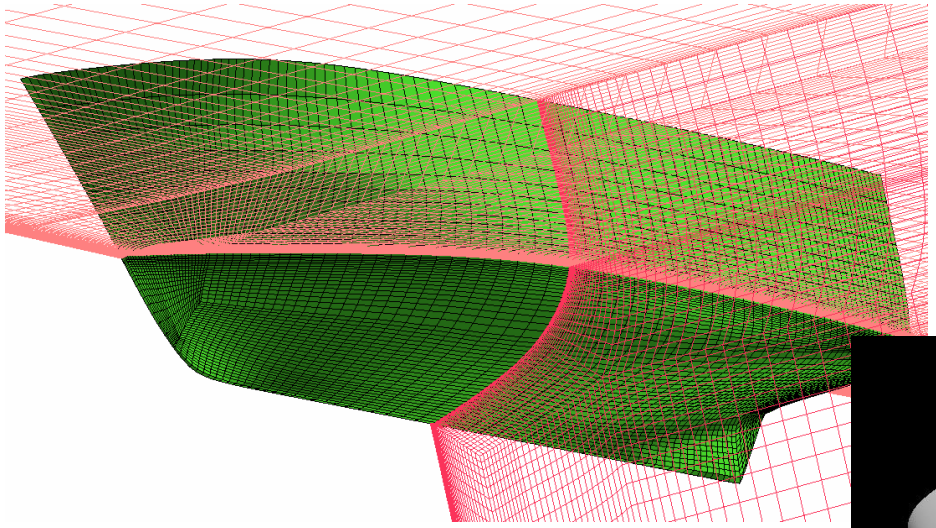
LARGE TOWING TANK

size: 260 m x 12 m x 5,8 m fitted out with a towing carriage of a maximum speed of 12 m/s and a wave generator

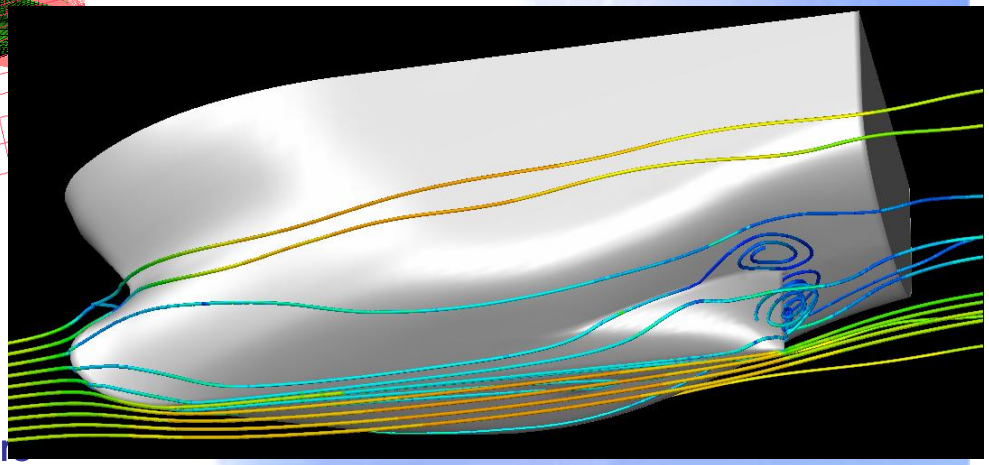
CTO S.A.

R&D Department - Ship Hydromechanics Division

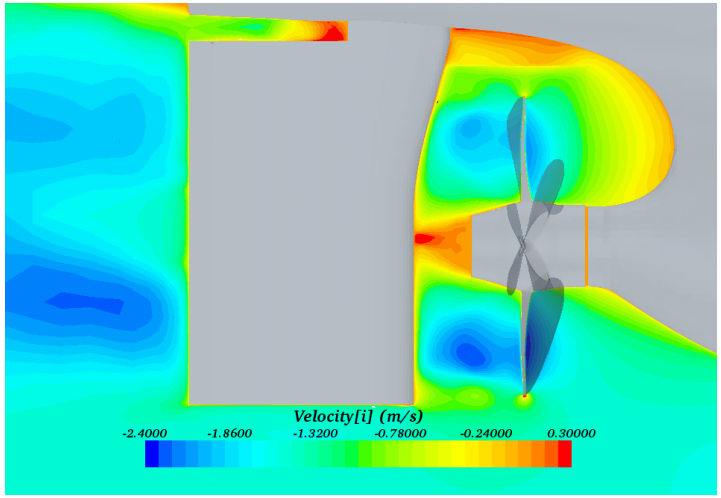
CFD tools

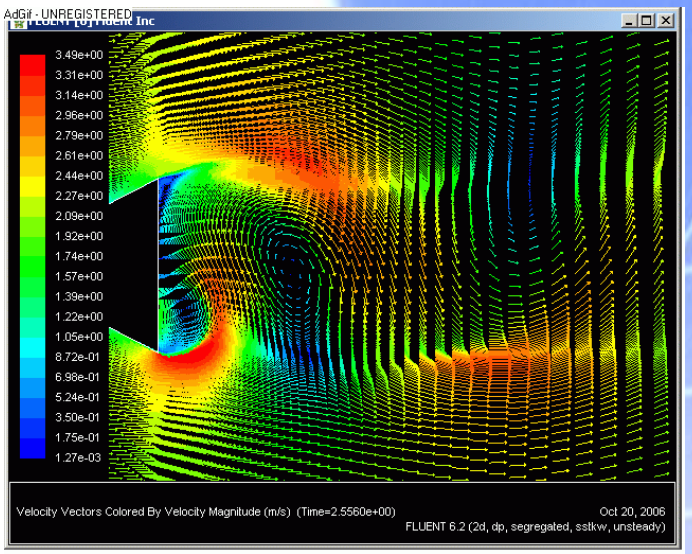


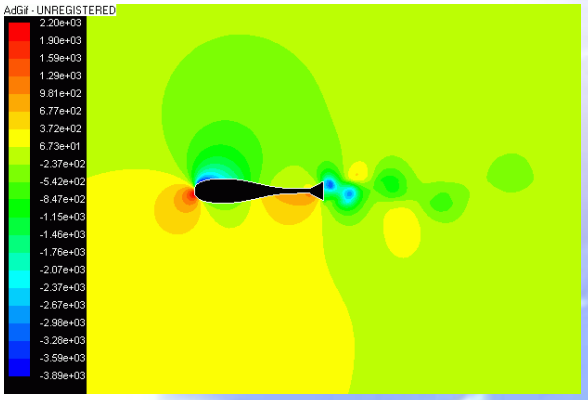
ICEM preprocessing
modeling of numerical mesh for calculations



FLUENT and STAR CCM+ commercial solvers
viscous flow computations with free surface and dynamic trim







NUMERICAL SIMULATIONS

EMISSIONS TO ENVIRONMENT

SEVERAL IMO RESOLUTIONS AND EU DIRECTIVES TO PREVENT FROM GREENHAUSE GAS EMISSION FROM THE SHIPS.

- **IMO RESOLUTION 176(58), OCTOBER 2008 „CONTROL EMISSION FROM THE SHIPS”**

- **IMO RESOLUTION NO. 14 TO MARPOL – DEFINITION OF AREAS WITH LIMITED EMISSION (BALTIC SEA, NORTH SEA INCLUDING CHANNEL LA MANCHE), MAY 19th 2006 WITH MODIFICATION FROM NOVEMBER 21th, 2007**

- **DIRECTIVE 1999/32/WE INCLUDING AMENDMENT 2005/33/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL RELATING TO A REDUCTION IN THE SULPHUR CONTENT OF CERTAIN LIQUID FUELS LAYS DOWN THE MAXIMUM PERMITTED SULPHUR CONTENT OF HEAVY FUEL OIL, GAS OIL AND MARINE GAS OIL USED IN THE COMMUNITY, VALID FROM JANUARY 01th, 2010**

EMISSIONS TO ENVIRONMENT

Legislations and Regulations

- emission control areas (ECA)

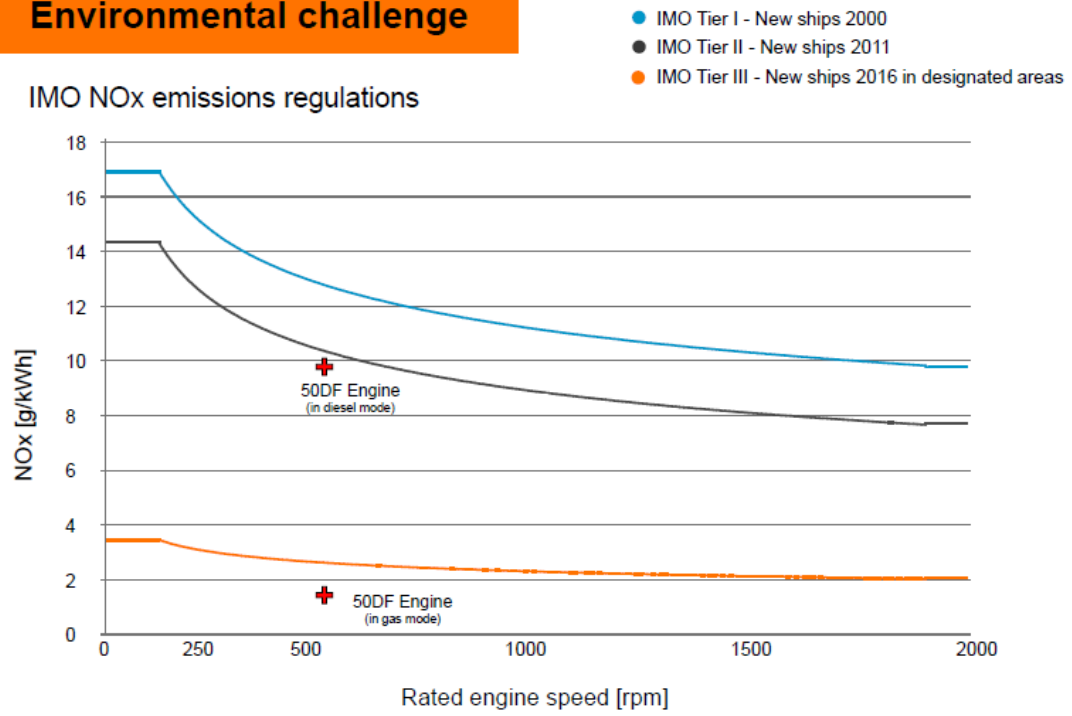
USA and Canada, EPA / IMO regulated area

Baltic sea, North sea and English channel, IMO regulated area

EMISSIONS TO ENVIRONMENT

ROADMAP TO ACHIEVE THE GOAL IN THE FUTURE

Environmental challenge



Source: WARTSILA

FUELS AND INNOVATIVE PROPULSION SYSTEMS

BECAUSE OF IMO REGULATION, IN CURRENT MOMENT FOR SHIPS OPERATING ON NORTH SEA AND ON BALTIC SEA, FOLLOWING FUELS ARE USED:

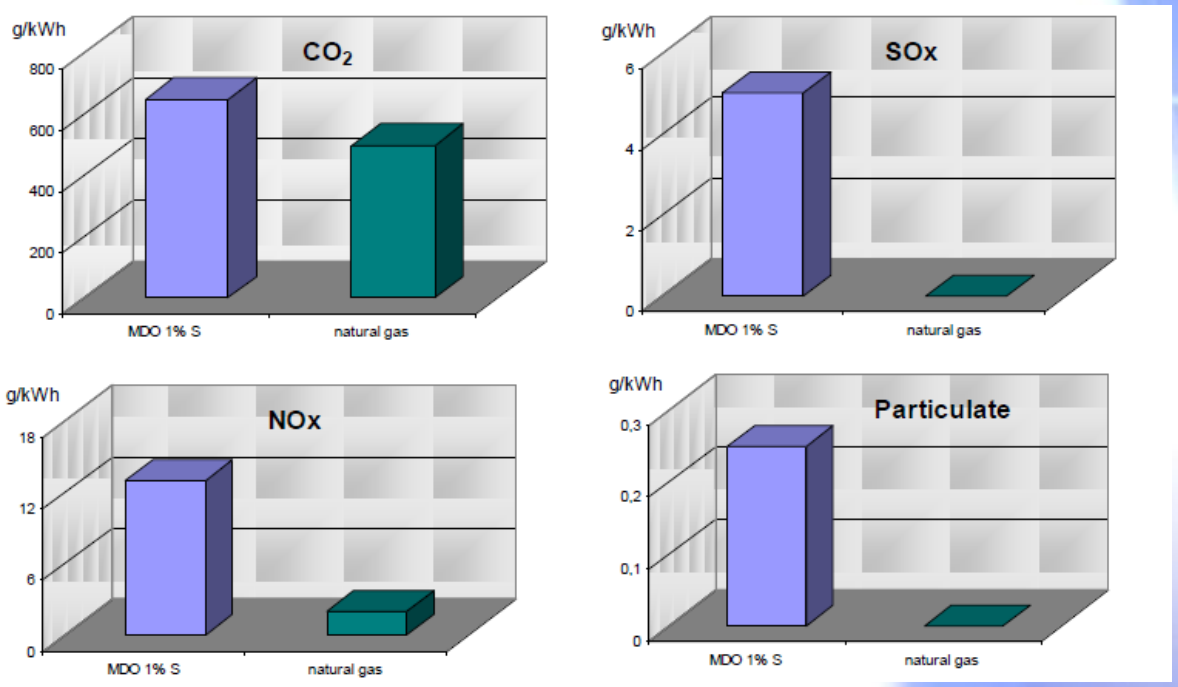
- **LSDO (LOW SULPHUR DISTILATE OIL)**
- **LSHFO (LOW SULPHUR HEAVY FUEL OIL)**
- **LNG**

STARTING FROM 2015 WE EXPECT FOLLOWING GREEN FUELS WILL BE USED ON BOARD OF THE SHIPS:

- **BIODIESEL**
- **HYDROGEN**
- **SYNTHETIC FUELS**
- **LNG (IN LARGE SCALE)**

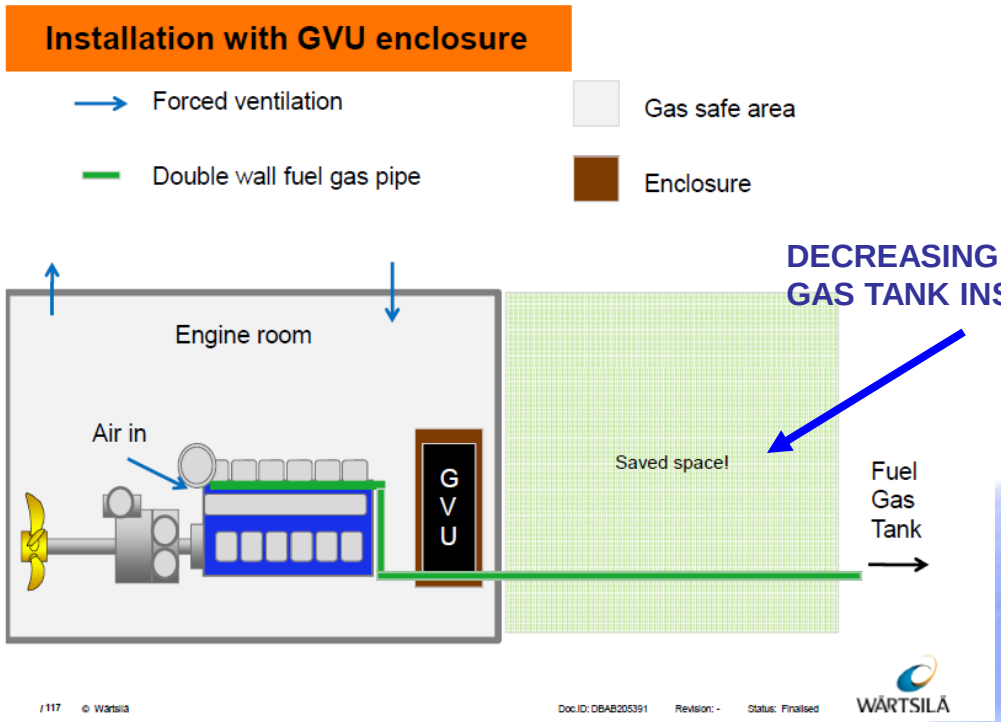
FUELS AND INNOVATIVE PROPULSION SYSTEMS

BENEFITS FROM LNG AGAINST LSMDO



Source: WARTSILA, ROLLS-ROYCE

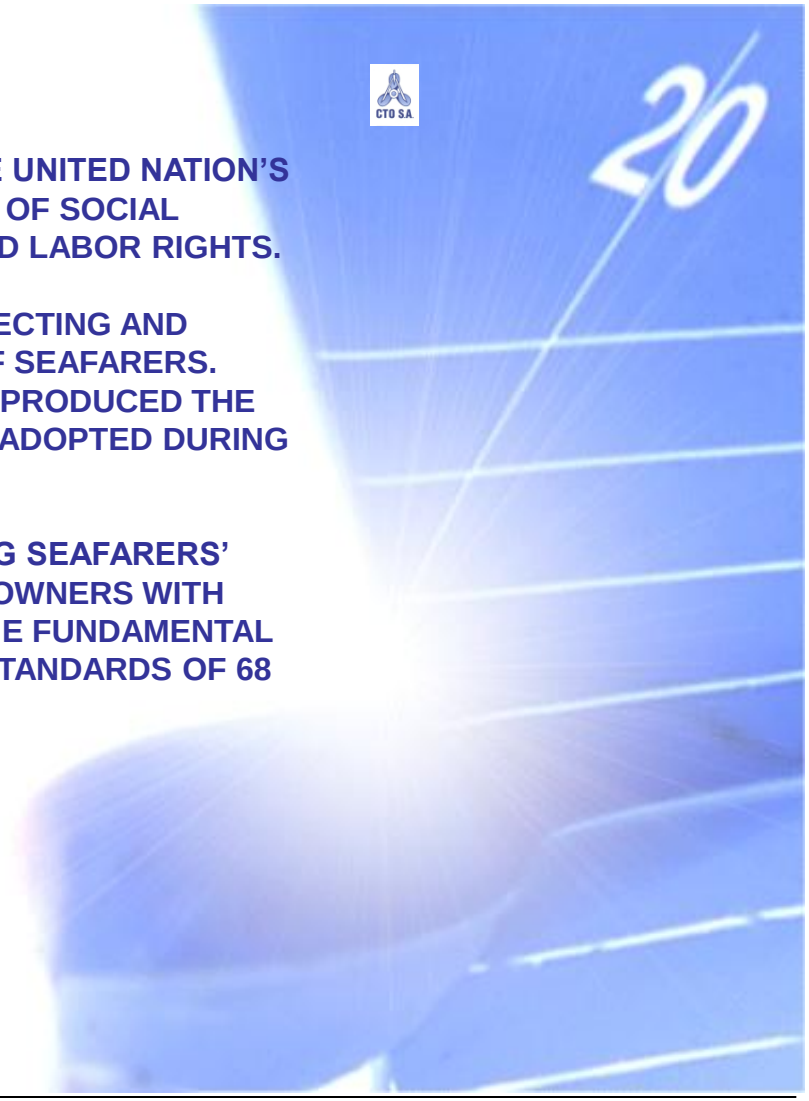
EXAMPLES OF INNOVATIVE MAIN PROPULSION SYSTEM, FUEL – LNG, SYSTEM DEVELOPED BY WARTSILA. SUCH SOLUTION MET REQUIREMENT OF INTERNATIONAL GAS CARRIED CODE AND INTERNATIONAL GUIDELINES LNG AS SHIP FUEL.



DECREASING OF ENGINE ROOM SIZE, ALLOW TO USE GAS TANK INSIDE HULL OR ONBOARD OF THE SHIP

Source: WARTSILA

CREW COMFORT



THE INTERNATIONAL LABOUR ORGANIZATION (ILO) IS THE UNITED NATION'S (UN) SPECIALIZED AGENCY THAT SEEKS THE PROMOTION OF SOCIAL JUSTICE AND INTERNATIONALLY RECOGNIZED HUMAN AND LABOR RIGHTS.

THE ILO PROVIDES LEGAL INSTRUMENTS AIMED AT PROTECTING AND IMPROVING WORKING CONDITIONS, INCLUDING THOSE OF SEAFARERS. RECENTLY, THE INTERNATIONAL LABOUR ORGANIZATION PRODUCED THE MARITIME LABOUR CONVENTION, 2006 (MLC) WHICH WAS ADOPTED DURING THE 94TH SESSION OF THE ILO ON FEBRUARY 23, 2006.

THE MLC PROVIDES A COMPREHENSIVE CODE REGARDING SEAFARERS' RIGHTS, AND THE OBLIGATIONS OF STATES AND VESSEL OWNERS WITH RESPECT TO THESE RIGHTS. THE MLC INCORPORATES THE FUNDAMENTAL PRINCIPLES OF MANY ILO CONVENTIONS AND UPDATES STANDARDS OF 68 EXISTING ILO CONVENTIONS INTO ONE DOCUMENT.

KEY ISSUES:

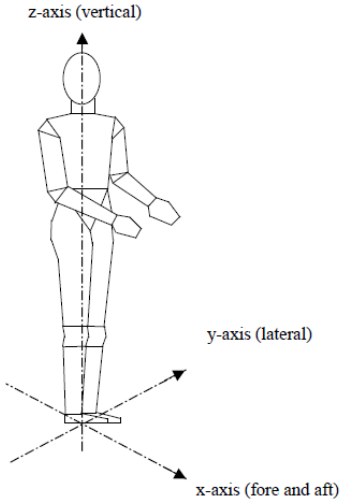
- WHOLE-BODY VIBRATION
- NOISE
- INDOOR CLIMATE
- LIGHTNING

CREW COMFORT – SPECIFIC REQUIREMENTS

TABLE 1
Maximum Weighted Root-Mean-Square Vibration Level *(15 October 2010)*

Notation	*Frequency Range*	*Acceleration Measurement*	*Maximum RMS Level*	
			Transit Conditions	*Thruster Conditions*
	1.0 - 80 Hz	a_w	214 mm/s^2 (6 mm/s)	286 mm/s^2 (8 mm/s)

Measurement Axes



CREW COMFORT – SPECIFIC REQUIREMENTS

Noise Criteria*

Space	*Noise Limit dB(A) Maximum*
Accommodation Spaces	
Cabins and hospitals	60
Mess rooms	65
Recreation room	65
Open recreation areas	75
Offices	65
Service Spaces	
Galleys, without food processing equipment operating	75
Serveries and pantries	75

* In any manned space with noise levels above 85 dB(A), hearing protection should be worn in accordance with appropriate IMO regulations.

CREW COMFORT – SPECIFIC REQUIREMENTS

Summary of Indoor Climate Requirements

Item	*Requirement or Criterion*
Air Temperature	Non-adjustable air temperature between Winter or Summer: 22 to 25°C (71.5 to 77°F)
Relative Humidity	A range from 30% minimum to 70% maximum
Air Exchange Rate	The rate of air change for enclosed spaces shall be at least six (6) complete changes-per-hour.

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CREW COMFORT – SPECIFIC REQUIREMENTS

Lighting Criteria for Seafarer Accommodations Spaces

Space	*Illuminance Level in Lux*	*Space*	*Illuminance Level in Lux*
Entrances and Passageways			
Interior Walkways, Passageways, Stairways and Access Ways	110	Exterior Walkways, Passageways, Stairways and Access Ways (night)	110
Cabins, Staterooms, Berthing and Sanitary Spaces			
General Lighting	150	Bath/Showers (General Lighting)	325
Reading and Writing (Desk or Bunk Light)	540	All other Areas within Sanitary Space (e.g., Toilets, Change Room)	150
Mirrors (Personal Grooming)	540		
Dining Spaces			
Mess Room and Cafeteria	300	Snack and Coffee Bar	500
Vending Machine Area	75		
Recreation Spaces			
Lounges	300	Gymnasiums	300
Library	540	Bulletin Boards/Display Areas	150
Multimedia Resource Center	300	All other Recreation Spaces (e.g., Game Rooms)	300
TV Room	150	Training/Transit Room	540
Medical, Dental and First Aid Center			
Dispensary	540	Wards - General Lighting - Critical Examination - Reading - Toilets	 100 810 540 150
Medical and Dental Treatment/Examination Room	810		
Medical Waiting Areas	540		
Laboratories	810	Other Medical & Dental Spaces	325

CREW COMFORT – SPECIFIC REQUIREMENTS

SCOPE OF RESEARCH AND DESIGN WORKS PERFORMED BY CTO S.A. RELATED TO CREW COMFORT ISSUES:

- **DESIGN OF COMPARTMENTS AND ACCOMODATION INCLUDING LIGHTNING / HEATING AND VENTILATION SYSTEMS**
- **NUMERICAL ANALYSES OF NOISE AND VIBRATION**
- **HEATING AND VENTILATION ANALYSES**

NOISE AND VIBRATION INFLUENCE ON ENVIRONMENT

304 *Airborne noise standards*

IMO Resolution A.468(XII), "Code on noise levels onboard ships".

ISO 2923 "Acoustics – Measurement of noise on board vessels".

ISO 31/VII, "Quantities and units of acoustics".

ISO 717-1, "Acoustics – Rating of sound insulation in buildings and of building elements – Part 1: Airborne sound insulation".

ISO 140-4, "Acoustics – Measurements of sound insulation in buildings and of building elements – Part 4: Field measurements of airborne sound insulation between rooms".

IEC Publication 651, "Sound level meters".

IEC Publication 225, "Octave, half octave and third-octave band filters intended for the analysis of sound and vibration".

IEC Publication 942, "Sound calibrators".

305 *Vibration standards*

ISO 6954, "Mechanical vibration and shock – Guidelines for the overall evaluation of vibration in merchant ships".

ISO 2041, "Vibration and Shock – Vocabulary".

ISO 4867, "Code for the measurement and reporting of shipboard vibration data".

ISO 4868, "Code for the measurement and reporting of local vibration data of ship structures and equipment".

ISO 2631, "Guide for the evaluation of human exposure to whole-body vibration".

Source: DNV

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NOISE AND VIBRATION INFLUENCE ON ENVIRONMENT

Table B1 Maximum allowable noise levels

Area designation	*Noise limits in dB(A)*	
	Harbour and normal service	*Maximum speed*
Machinery spaces (continuously manned) [1)]	90	
Machinery spaces (not continuously manned) [1), 2)]	110/120	
Machinery control rooms	75	75
Workshops	85	
Stores [1)]	90	
Navigation bridge and chart rooms	65	65
Listening posts, including navigation bridge wings and windows	70	70
Radio rooms (radio equipment in operation but not producing audio signals)	60	60
Radar rooms	65	65
Cabins and hospitals [3)]	60	
Mess rooms [3)]	65	
Recreation rooms [3)]	65	
Offices [3)]	65	
Open recreation areas	75	
Gymnasiums and laundries	80	
Galleys (without food processing equipment in operation)	75	
Serveries and pantries	75	
Ammunition rooms	75	
Signal distribution offices	70	70
Fire control rooms, combat information centres, damage control rooms	65	65
Sonar control rooms, electronic countermeasure rooms	60	60

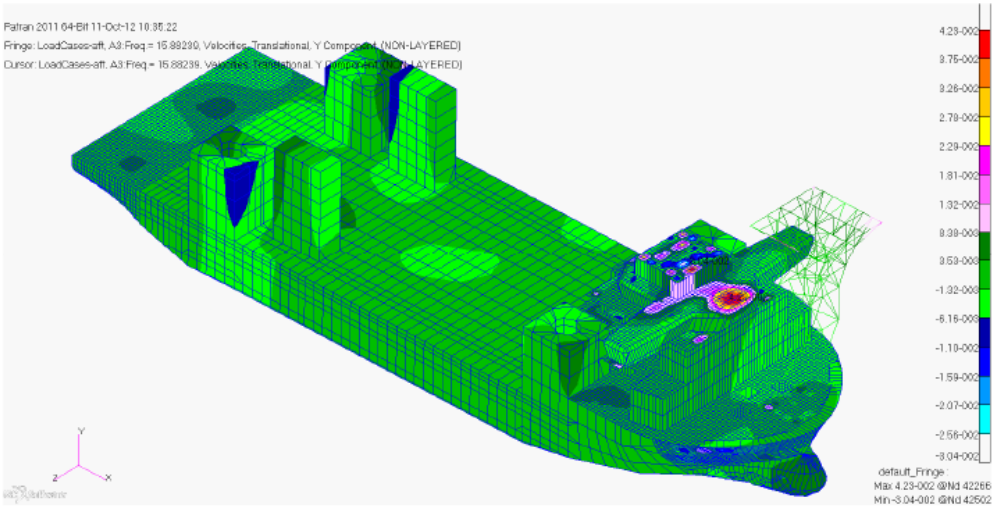
1) Warning signs should be posted at all entrances and ear protectors should be worn when the noise exceeds 85 dB(A).

2) It is recommended that the noise levels in unmanned machinery spaces are kept below or as close to 110 dB(A) as practically possible. The maximum level of 120 dB(A) should not be exceeded. Warning signs should be posted at all entrances and earmuffs should be used in combination with earplugs when the noise level exceeds 110 dB(A).

3) For "high speed craft" see definition in Pt.0 Ch.6 Sec.1 and "light craft" see definition in Pt.1 Ch.1 Sec.2, these limits only apply for harbour conditions without propulsion machinery in operation, but with auxiliary machinery, ventilation and all systems that normally are running in harbour, in operation. However, the limits mentioned in Pt.3 Ch.7 Sec.1 E100 apply for all operating conditions.

Source: DNV

VIBRATION INFLUENCE ON ENVIRONMENT – DESIGN REQUIREMENT ISO 6954:200



Please find below a table with vibration levels for given localizations at f = 15,88 [Hz] for **LC04**.

no	Node no.	Vibration velocity level [mm/s]	ISO 6954:2000 [mm/s] Area classification B	Notes
		Y Component (Vertical)		
3	38559	4,04	6	A Deck
4	21349	4,25	6	B Deck
5	24291	4,58	6	C Deck
6	27213	5,71	6	D Deck
7	28953	5,55	6	Bridge Deck

*Area classification B - Crew Accommodations

NOISE AND VIBRATION INFLUENCE ON ENVIRONMENT

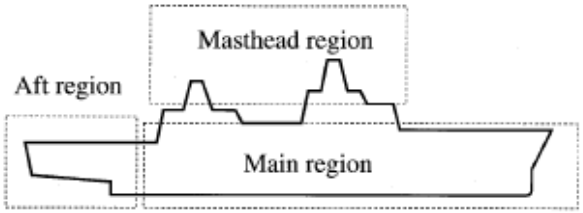


Fig. 1
Division of a craft with length larger than 35 m

202 The structural vibration levels should not exceed the following values in the frequency range between 5 and 100 Hz:

Main region, decks normally accessible to personnel and structure for mounting of equipment	5 mm/s
Aft region, decks normally accessible to personnel and structure for mounting of equipment	7 mm/s

For frequencies between 1 Hz and 5 Hz the vibration should be restricted to the acceleration level at 5 Hz corresponding to the relevant velocity level at 5 Hz.

Mast head region	15 mm/s

Other structure where personnel comfort or proficiency is not affected and critical equipment is not to be mounted, e.g. tanks and void spaces:

Steel craft	30 mm/s
Aluminium craft	10 mm/s

For frequencies between 1 Hz and 5 Hz the vibration should be restricted to the displacement level at 5 Hz corresponding to the relevant velocity level at 5 Hz.

All vibration levels refer to single frequency components.

Source: DNV

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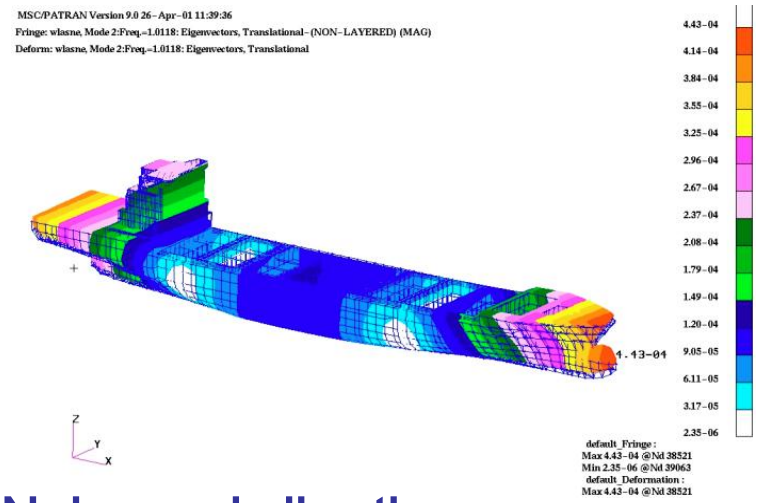
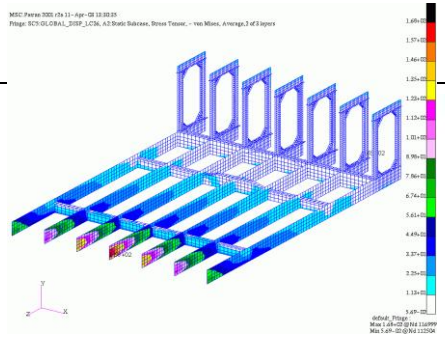
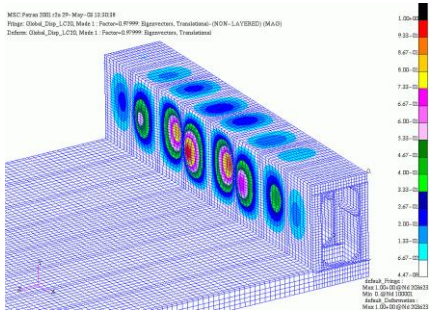
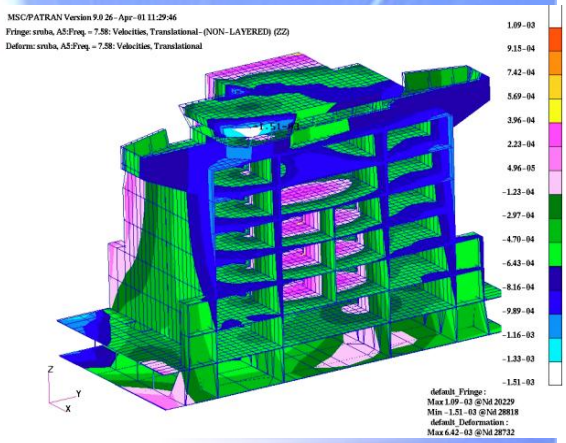
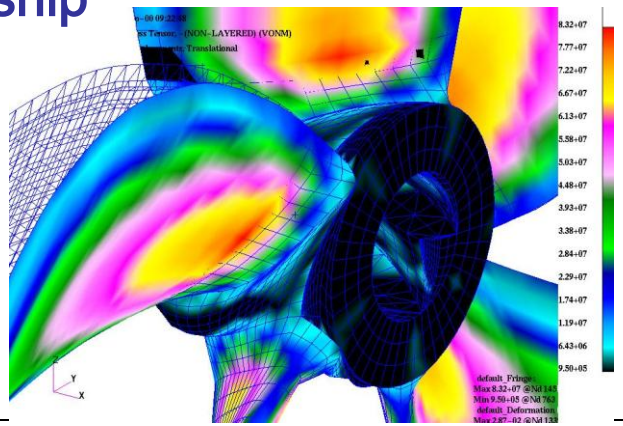


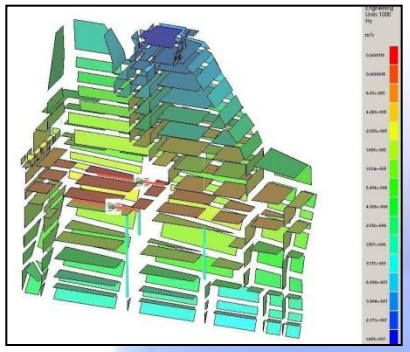


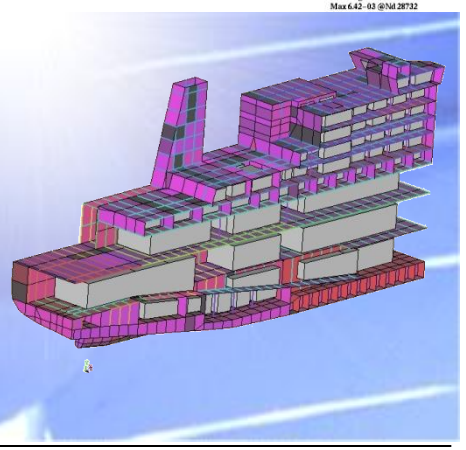




Noise and vibration predictions onboard a ship







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