Vard Marine Inc.

TECHNOLOGY MATRIX

545-000-03

Rev. 0

Date: 31 October 2023

Prepared for:
Transport Canada
TECHNOLOGY MATRIX

Report No.: 545-000-03  
Title: TECHNOLOGY MATRIX  
VARD Contact: Rienk Terweij  
Tel: +1 613 238 7979  
Email: Rienk.Terweij@vardmarineinc.com

SUMMARY OF REVISIONS

<table>
<thead>
<tr>
<th>Rev</th>
<th>Date</th>
<th>Description</th>
<th>Prepared By</th>
<th>Checked By</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>31 Oct 23</td>
<td>Initial Issue, based on below mentioned reference 1 and minor manual additions.</td>
<td>RTE</td>
<td>EMS</td>
</tr>
</tbody>
</table>

REFERENCES

<table>
<thead>
<tr>
<th>No.</th>
<th>Source</th>
</tr>
</thead>
</table>
## TERMINOLOGY

**Treatment/Description:**
Provides a summary of the mechanisms by which a mitigation measure operates. References are cited (as may be in subsequent columns to clarify specific points).

**Energy Efficiency (EE):**
% change (range). The change in energy required to transport a unit of cargo by a certain distance.

**GHG Reduction:**
% change (range). The change in CO$_2$ equivalent required to transport a unit of cargo by a certain distance.

**URN (Underwater Radiated Noise):**
dB Change - Expected Noise Reduction in Decibels (dB) for the specific treatment, and not (depending on the dominant noise source) necessarily the overall noise signature of the ship.

<table>
<thead>
<tr>
<th>B</th>
<th>N</th>
<th>Freq Rng</th>
<th>T</th>
<th>- Type:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>Broadband/Narrowband; Expected Frequency Range Affected in Hertz (Hz)</td>
<td>T</td>
<td>1 - Increase EE, decrease GHG and reduce URN</td>
</tr>
<tr>
<td>2</td>
<td>-</td>
<td></td>
<td></td>
<td>2 - Increase EE, decrease GHG but increase URN</td>
</tr>
<tr>
<td>3</td>
<td>-</td>
<td></td>
<td></td>
<td>3 - Reduce EE, increase GHG but reduce URN</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td></td>
<td></td>
<td>4 - Reduce EE, increase GHG and increase URN</td>
</tr>
</tbody>
</table>

| N/A | - | - | - | not available |

**Ship Impacts:**

<table>
<thead>
<tr>
<th>A/B</th>
<th>-</th>
<th>Advantages/Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>-</td>
<td>Enhanced crew/passenger Comfort</td>
</tr>
<tr>
<td>M</td>
<td>-</td>
<td>Reduced Maintenance</td>
</tr>
<tr>
<td>MA</td>
<td>-</td>
<td>Increased MANoeuvrability</td>
</tr>
<tr>
<td>S</td>
<td>-</td>
<td>Decreased Space Demand</td>
</tr>
<tr>
<td>W</td>
<td>-</td>
<td>Decrease in Weight</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C/D</th>
<th>-</th>
<th>Challenges/Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>-</td>
<td>Increased Design effort</td>
</tr>
<tr>
<td>M</td>
<td>-</td>
<td>Increased Maintenance</td>
</tr>
<tr>
<td>MA</td>
<td>-</td>
<td>Reduction in MANoeuvrability</td>
</tr>
<tr>
<td>P</td>
<td>-</td>
<td>Increased complexity</td>
</tr>
<tr>
<td>S</td>
<td>-</td>
<td>Increased Space demand</td>
</tr>
<tr>
<td>W</td>
<td>-</td>
<td>Increased Weight</td>
</tr>
</tbody>
</table>

(Impact on EE, GHG and URN is mentioned in the dedicated columns)

**TRL – Technology Readiness Level:**
TRL 1: Basic principles observed and reported.
TRL 2: Technology concept and/or application formulated.
TRL 3: Analytical and experimental critical function and/or characteristic proof of concept.
TRL 4: Product and/or process validation in laboratory environment.
TRL 5: Product and/or process validation in relevant environment.
TRL 6: Product and/or process prototype demonstration in a relevant environment.
TRL 7: Product and/or process prototype demonstration in an operational environment.
TRL 8: Actual product and/or process completed and qualified through test and demonstration.
TRL 9: Actual product and/or process proven successful.

**Cost Estimation:**

<table>
<thead>
<tr>
<th>Range</th>
<th>-</th>
<th>Range of expected cost:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>• Low – less than 1% of new ship cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Medium – 1 to 5% of new ship cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• High – greater than 5% of new ship cost</td>
</tr>
</tbody>
</table>

| Percentage | - | Percentage increase or decrease |
| Payback Period | - | Time in months/years to recover investment |
| Shorthand | - | Whether to expect an increase or decrease |
TERMINOLOGY

Applicability:
- RF
- NB

Ship Type: Only by quadrant from the below-presented figure, except where indicated.

General Notes:
- Many of the provided Energy Efficiency, Greenhouse Gas and Underwater Radiated Noise improvements as well as mentioned advantages/disadvantages of potential solutions are based on VARD’s ship design experience.
- VARD has aimed to provide realistic assessments of each treatment. Nonetheless, it needs to be recognized that in many cases, potential improvements will differ based on the ship type and operation. Individual stakeholders will need to undertake more detailed analysis of their specific applications.
- The effectiveness values of the URN reduction relate to the noise source being treated, and not (depending on the dominant noise source) necessarily to the overall noise signature of the ship. The URN frequency ranges treated are linked to the type of noise source and to the treatment approach (and not to the URN frequency distribution of the ship as a system).
- This matrix reflects the views of the authors and not necessarily those of the Innovation Centre of Transport Canada or the Canadian government.
- The Innovation Centre of Transport Canada does not endorse products or manufacturers. Trade or manufacturers’ names appear in this report only because they are essential to its objectives.
- This matrix does not attempt to provide a comprehensive description of any aspect of energy efficiency, GHG reduction, or URN.
- This current matrix does not focus on alternative fuels and combustion engines.
- This matrix is a snapshot of the current treatments available, and it is linked to reference data to the source with a number in square brackets (see Appendix B of the reference mentioned in the revisions table).

Comments:
Last column is reserved for remarks and statements that do not fit the earlier mentioned columns.
1.1 HULL APPENDAGE/DESIGN

All ships have coatings; however, there is potential to improve selection up to 10% RF / NB.

1.2 FRICTIONAL RESISTANCE

EE $ f ARD' .

1.2.1 EFFICIENT ABOVE WATER

Up to 5% 1

1.2.2 PARTIAL CAVITY DRAG REDUCTION

Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.2.3 UNDERWATER HULL SURFACE CLEANING AND MAINTENANCE

Up to 3% 1

1.2.4 AIR BUBBLER SYSTEM (MASKER)

High. > 10 dB

1.2.5 AIR LUBRICATION SYSTEMS (ALS)

May warrant more consideration for smaller and faster ships.

1.2.6 PARTIAL CAVITY DRAG

High. > 10 dB

1.3 HYDRODYNAMICS

Up to 10% 9

1.3.1 HYDRODYNAMIC PROPERTIES OF THE PROPELLER

May warrant more consideration for smaller and faster ships.

1.3.2 EFFICIENT HULL FORMS

High. > 10 dB

1.3.3 BULBOUS BOW

Up to 5% 1

1.3.4 ECONOMICAL HULL DESIGN

Efficient hull design takes into account the water flow around the hull and thus helps to save the fuel consumption. More increases the buoyancy in the front which helps in displacing the weight of the ship.

1.3.5 WAVEFOILS

Small extensions from the lower transom. Modifies the wave pattern produced by the ship and reduces powering requirements, reducing ship noise. 

1.3.6 BOW FOILS

Effective in forward speeds, active fins more accurately counteract the waves. Reduces pitch motions and losses in stern wave system, provides improved acceleration for the ship. Exemplar is Wavefoil. 

1.3.7 ECONOMICAL HULL DESIGN

Cleanliness reduces resistance and increases speed. Receives once and lasts throughout the life of the vessel. 

1.3.8 RETRACTABLE (ACTIVE) FIN

Reduces pitch motions and noise. Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.3.9 HYDRODYNAMIC PROPERTIES OF THE PROPELLER

High. > 10 dB

1.3.10 PARTIAL CAVITY DRAG REDUCTION

Can be effective for very specific ship types and operations. Efficiency and bird reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.3.11 UNDERWATER HULL SURFACE CLEANING AND MAINTENANCE

Up to 3% 1

1.3.12 AIR BUBBLER SYSTEM (MASKER)

High. > 10 dB

1.3.13 AIR LUBRICATION SYSTEMS (ALS)

May warrant more consideration for smaller and faster ships.

1.3.14 ECONOMICAL HULL DESIGN

High. > 10 dB

1.3.15 WAVEFOILS

Small extensions from the lower transom. Modifies the wave pattern produced by the ship and reduces powering requirements, reducing ship noise. 

1.3.16 BOW FOILS

Effective in forward speeds, active fins more accurately counteract the waves. Reduces pitch motions and losses in stern wave system, provides improved acceleration for the ship. Exemplar is Wavefoil. 

1.3.17 ECONOMICAL HULL DESIGN

Cleanliness reduces resistance and increases speed. Receives once and lasts throughout the life of the vessel. 

1.3.18 RETRACTABLE (ACTIVE) FIN

Reduces pitch motions and noise. Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.3.19 HYDRODYNAMIC PROPERTIES OF THE PROPELLER

High. > 10 dB

1.3.20 PARTIAL CAVITY DRAG REDUCTION

Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.3.21 UNDERWATER HULL SURFACE CLEANING AND MAINTENANCE

Up to 3% 1

1.3.22 AIR BUBBLER SYSTEM (MASKER)

High. > 10 dB

1.3.23 AIR LUBRICATION SYSTEMS (ALS)

May warrant more consideration for smaller and faster ships.

1.3.24 ECONOMICAL HULL DESIGN

High. > 10 dB

1.3.25 WAVEFOILS

Small extensions from the lower transom. Modifies the wave pattern produced by the ship and reduces powering requirements, reducing ship noise. 

1.3.26 BOW FOILS

Effective in forward speeds, active fins more accurately counteract the waves. Reduces pitch motions and losses in stern wave system, provides improved acceleration for the ship. Exemplar is Wavefoil. 

1.3.27 ECONOMICAL HULL DESIGN

Cleanliness reduces resistance and increases speed. Receives once and lasts throughout the life of the vessel. 

1.3.28 RETRACTABLE (ACTIVE) FIN

Reduces pitch motions and noise. Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.

1.3.29 HYDRODYNAMIC PROPERTIES OF THE PROPELLER

High. > 10 dB

1.3.30 PARTIAL CAVITY DRAG REDUCTION

Can be effective for very specific ship types and operations. Energy efficiency and birds reduction changes are application dependent and apply to high-speed ships with streamlined forms. In low speeds, additional losses may occur due to increased resistance and reduced performance.
2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1 PROPELLER/PROPULSOR DESIGN

2.1.10 TANDEM PROPELLER

Tandem propellers (Fig. 2) can be designed to operate by allowing one propeller to operate in a hubless system, the efficiency at design point is slightly lower because there is no hub, however, tandem propellers can increase the efficiency especially if an internal combustion engine is driving the propeller. Tandem propellers are also appropriate for highly variable load situations (1.0-0.5). Tandem propellers have the following advantages:

- Doubles the propeller efficiency.
- Higher capital cost.
- Modest additional cost.
- Increased load reduction on the tip of the propeller.
- The varying wake field is reduced in a more gradual manner, improving the propellers' performance.
- Can improve bollard pull performance by 40%.
- Can mitigate the early onset of cavitation on pressure and suction sides both at constant speeds and during acceleration.
- Can improve propeller efficiency in these conditions.
- Controllable pitch propeller simplifies reversing and most other manoeuvres.
- Hull propeller clearance needs to be sufficient to avoid high pressure pulses.
- Retrofitting a propeller after operational speed reduction (see 5.1.1) can give similar EE improvements.

Retrofitting a propeller after operational speed reduction (see 5.1.1) can give similar EE improvements. Propeller design should match the hub form.

2.1.9 CONTRACTED LOADED TIP PROPELLER

Contracted loaded tip propellers do not require a larger diameter of propeller or a higher gearbox ratio and reducing the speed of the flow at the tips of the blades. This reduces energy loss due to the pitching motion of the blades is unknown and not taken into account.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.

Increasing the shaft angle normally leads to an increase in cavitation and increased noise levels slightly more compared to fixed pitch propellers.
2.1 PROPELLER/PROPULSOR DESIGN

2.1.1 CONTRA-ROTATING PROPELLERS (ERT)
In most cases, propeller rotating in the opposite direction to each other, increases OS due to reduction in blade loading resulting in lower blade surface cavitation. [32][33][34]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Higher capital cost than conventional propeller, depending on the configuration
- Can be used with both shafted and azimuthing propulsion.

2.1.10 PROPELLERS WITH TIP MODIFICATIONS

2.1.10.1 PROPELLERS WITH TIP MODIFIED FORWARD

Propeller blades modified with tips curved towards the suction side (like Kappel Propellers): This reduces the strength of the tip vortices and thereby lessening tip vortex cavitation and increasing OS. [32][33][34]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Higher capital cost than conventional propellers
- Can be used with both shafted and azimuthing propulsion.

2.1.11 PROPELLERS WITH TIP MODIFIED REARWARD

Propeller blades modified with tips curved backwards towards the pressure side (opposite of Kappel Propellers): Blades have shown that there is an increase in efficiency and decrease in cavitation expected, however, there are few studies on the subject. [33][34]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Higher capital cost than conventional propellers
- Can be used with both shafted and azimuthing propulsion.

2.1.12 PROPELLERS WITH HOLES NARROWING THE TIP

- Increase in efficiency and reduction in tip vortices, the latter decreases noise and vibration and increasing CIS. [40][41]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Small increase in design and manufacturing costs
- Can be used with both shafted and azimuthing propulsion.

2.1.13 ADAPTABLE PROPELLERS

- Adapter propellers have motion in axial or reciprocating motion (rotate side to side) similar to the hull blade (significantly increases the inboard propellers);

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Components more expensive than shafted system
- Initial costs can be reduced

2.1.14 PODDED PROPELLERS

- Propeller mounted with an integrated duct in the gondola to achieve improved performance to the propeller reducing cavitation and OS. However, these electric motors and magnetic noise effects can increase medium high frequency noise, new systems are 3.5 to 5.5 paired with electric blade design.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Components more expensive than shafted system
- Initial costs can be reduced

2.1.15 WATER JETS

- Yard and ship designs with a jet nozzle located just forward of the upper half of the propeller, flow is redirected before entering the propeller, reducing cavitation and increasing EE and GHG.[39][82]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- High cost over conventional type
- Cost for several local inland ships

2.1.16 CONVENTIONAL PROPELLERS

2.1.16.1 2, 3, or 4 ALL

- Typical 1, 2, 3 or 4 propellers installed on the vessel create a small increase in efficiency and less cavitation, thus, reducing noise and vibration and increasing OS.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Typical Payback Horizon: 24 months

2.1.17 PROPELLER/PROPULSOR DESIGN

2.1.17.1 FORCED ROACH PROPELLERS

- Influence of blade loading on the blade load on the propeller reducing cavitation and increasing OS. [32][33][34]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- Typical Payback Horizon: 24 months

2.1.18 AZIMUTHING PROPELLERS

- Typically, this system allows the vessel to be steered with one propeller being driven by an electric motor and the other being driven by the ship's shafting; [21][37][38]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- The electric motor in the gondola can improve wake performance to the propeller reducing cavitation and increases CIS. However, the electric motor and magnetic noise effects can increase medium high frequency noise.

2.1.19 COMPOSITE PROPELLERS

- Propeller blades modified with tips curved towards the suction side (like Kappel propellers). This reduces the strength of the tip vortices and thereby lessening tip vortex cavitation and increasing OS. [33][34][91]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- High cost over conventional type
- Cost for several local inland ships

2.2 WAKE FLOW MODIFICATION

2.2.1 PRE-SWIRL STATORS

- Acoustic energy efficiency suffers when compared to conventional axial-flow turbines.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.2.2 SCHNEEKLUTH DUCT

- Flow redirected before entering the propeller, this improves flow performance, increasing EE, lowering the formation of cavitation of propeller blade tips and increasing CIS. [39][40][41]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.2.3 TROCHOIDAL DUCT

- An oval shaped duct located just forward of the upper half of the propeller, flow is redirected before entering the propeller, reducing cavitation and increases CIS. [39]

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.2.4 KARSTEN BOEING PROPELLER

- Consists of stator blades located on the stern boss in front of the propeller reducing cavitation and increases CIS. However, the electric motor and magnetic noise effects can increase medium high frequency noise.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.2.5 V.S. (HORIZONTAL) PROPELLER

- Variety of azimuthing propulsion with an integrated electrical drive to the propeller reducing cavitation and OS. However, these electric motors and magnetic noise effects can increase medium high frequency noise, new systems are 3.5 to 5.5 paired with electric blade design.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.3 NAVIGATION/SPECIAL PROPERTIES

2.3.1 PROPELLER/PROPULSOR DESIGN

2.3.1.1 PROPELLER MODIFIED FOR WAKE REDUCTION

- Propeller blades modified with tips curved towards the suction side (like Kappel propellers). This reduces the strength of the tip vortices and thereby lessening tip vortex cavitation and increasing OS.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- High cost over conventional type
- Cost for several local inland ships

2.3.1.1 COMPOSITE PROPELLERS

- Propeller blades modified with tips curved towards the suction side (like Kappel propellers). This reduces the strength of the tip vortices and thereby lessening tip vortex cavitation and increasing OS.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- High cost over conventional type
- Cost for several local inland ships

2.3.1.2 PROPELLER MODIFIED FOR WAKE REDUCTION

- Propeller blades modified with tips curved towards the suction side (like Kappel propellers). This reduces the strength of the tip vortices and thereby lessening tip vortex cavitation and increasing OS.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- High cost over conventional type
- Cost for several local inland ships

2.3.2 MODIFIED NOISE DUCT

- Flow redirected before entering the propeller, this improves flow performance, increasing EE, lowering the formation of cavitation of propeller blade tips and increasing CIS. However, the electric motor and magnetic noise effects can increase medium high frequency noise.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.3.3 TROCHOIDAL DUCT

- An oval shaped duct located just forward of the upper half of the propeller, flow is redirected before entering the propeller, reducing cavitation and increases CIS. However, the electric motor and magnetic noise effects can increase medium high frequency noise.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.3.4 KARSTEN BOEING PROPELLER

- Consists of stator blades located on the stern boss in front of the propeller reducing cavitation and increases CIS. However, the electric motor and magnetic noise effects can increase medium high frequency noise.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB

2.3.5 V.S. (HORIZONTAL) PROPELLER

- Variety of azimuthing propulsion with an integrated electrical drive to the propeller reducing cavitation and OS. However, these electric motors and magnetic noise effects can increase medium high frequency noise.

Payback Period: 6 to 10 months
ROI: 2000% ROI
Profit Margin: 8

- RF/ NB: 1 dB
2.2 WAKE FLOW MODIFICATION
2.2.1 PROFILER CAP TUNING (TCP)
Hydrofoil shaped blades integrated into the hull, cap, and also on PTP reducing hub vortex creation, and increasing CIS. The design also means less radiated energy, increasing efficiency. (12) [96]
9 % 3 % up to 30 dB 1200 Ns

2.2.2 PROFILER TUNING (TCP)
A series of canted fins attached to the hull, or even to the propeller, designed to improve flow to the propeller, reducing vibration, increasing CIS and improving raw efficiency. (24)
3 % 2 % 0.08 months

2.2.3 PROFILER MANDRELLS
A combination of brushing and propeller mandrels attached to the hull and/ or propeller, changing the vorticity to the propeller, avoiding propellers damages whereas increasing CIS. 

2.2.4 Mewis duct
A combination of canted fins integrated into the hull, cap, and also on PTP reducing hub vortex creation, and increasing CIS. The design also means less radiated energy, increasing efficiency. (12) [96]
15 % 5 % 0.08 months

2.2.5 DESIGN TWISTED LASER
Laser beams directed vertically through the propeller. This reduces acoustic scatter and increases efficiency. (28) [85]
up to 4 % 10 % 0.08 months

2.2.6 MEWIS DUCT
Propeller ducts of variable geometry integrated into the hull or cap or even to the propeller, changing the vorticity to the propeller, reducing propeller vibrations and lowering URN. (41) [44] [46]
1 % 1 % 0.08 months

2.2.7 PROFILER MANDRELLS
A series of canted fins integrated into the hull, cap, and also on PTP reducing hub vortex creation, and increasing CIS. The design also means less radiated energy, increasing efficiency. (12) [96]
9 % 8 % 0.08 months

2.2.8 ROODER THREAT FIN
Incision fins that are attached directly to the hull. Those fins capture energy and convert for kinetic. (16)
up to 4 % 2 % 0.08 months

2.2.9 PROFILER TPRINTED-PROPSYLLER ROODER
Integration of the propeller, reducing radius, reducing turbulence and one hydrodynamic efficient unit. Reduces propeller tip speed and reducing brake pressure pulses, thus, reducing vibration and noise. (20) [85] [106]
9 % 8 % 0.08 months

2.2.10 PROFILER MANDRELLS
A series of canted fins integrated into the hull, cap, and also on PTP reducing hub vortex creation, and increasing CIS. The design also means less radiated energy, increasing efficiency. (12) [96]
9 % 5 % 0.08 months

2.3 SUPPLEMENTARY TREATMENTS
2.3.1 COSTA PROFILATION-BLAZ 43N
The propeller is designed to reduce propeller noise lift of the propeller, improving performance caused by turbulence, reducing propeller vibrations and lowering URN. (41) [44]
9 % 9 % 0.08 months

2.3.2 PROPELLER DEFICIENTS 192
A series of canted fins integrated into the hull, cap, and also on PTP reducing hub vortex creation, and increasing CIS. The design also means less radiated energy, increasing efficiency. (12) [96]
9 % 3 % 0.08 months

2.3.3 PROPELLER MAINTENANCE
Specifically for faster vessels with finer hull forms. (24)

2.3.4 PROPELLER COATING
Hull Sludge reduction is only possible where propeller singling is a problem. (44)
9 % 4 % 0.08 months

3.1 MACHINERY SELECTION
3.1.0 PRIME MOVER SELECTION
Payback

3.1.1 GENERATOR SELECTION
Payback

3.1.3 CAPTURE SELECTION
Payback

3.1.4 LEAKAGE SELECTION
Payback

TECHNOLOGY MATRIX
3.1 MACHINERY SELECTION

3.1.1 (DIESEL) ELECTRIC

Long electric, rather than mechanical, feedback makes active noise suppression on land facilities easier. Many noise reduction approaches, from the use of machinery and enclosures to other passive solutions and modifications. A wider range of propulsion solutions are also available. Electrical transmission has superior efficiency compared to mechanical, and capital costs are lower, so it is generally used in places where other benefits outweigh these costs. [28]

3.1.2 VARIABLE SPEED POWER (STEAM ELECTRIC)

A reduced speed direct steam generation unit with variable input power. This reduces the need for larger power input, leading to increased efficiency, reduced heat production, and reduced fuel consumption. [54]

3.1.3 GAS/STEAM TURBINE

Natural gas turbines are ideal for generating power for relatively small ships. They have high efficiency, minimal emissions, and are suitable for ships with limited space. [52]

3.1.4 GAS/STEAM TURBINE

All of the above are suitable for ships with limited space. [29]

3.1.5 STRONGS ENGINE

A reciprocating engine is suitable for use in large vessels. The main advantage is its efficiency, which is higher than that of diesel engines. It is suitable for both new and existing vessels. [58]

3.1.6 PEM FUEL CELLS

PEM (Proton-Exchange Membrane) Fuel Cells produce electricity without combustion, making them ideal for submarines and naval ships. They have high efficiency, low emissions, and are suitable for ships with limited space. [53]

3.2 MACHINERY TREATMENTS

3.2.1 STAGE VIBRATION ISOLATION SYSTEM

Structures designed to enclose a specific piece of machinery, reducing noise transmission. Often used for engine/gearbox or generator; not applicable to 2-stroke diesels due to their lower weight. [57]

3.2.2 FLOATING FLOOR (DECK)

One or several pieces of machinery are mounted on an upper layer supported on the hull girder on a lower-level set of mounts. This reduces noise by creating an extra impedance barrier to the transmission of vibration energy. Often used for engine/gearbox or generator. [56]

3.2.3 METALLIC FOAM

A porous material designed to be used in the tanks of diesel or water ballast tanks, to reduce underwater radiated noise. The material has open enhanced acoustical properties when saturated with water. [62]

3.2.4 FLOATING BULKHEAD

Reduces radiated noise from diesel or water tanks. Also requires high quality materials to be used. [58]

3.2.5 ACTIVE CANCELLATION

Reduction of machinery excitation of the hull structure by means of secondary excitation to cancel the original excitation. Uses sensors to detect the original excitation and applies a secondary excitation to cancel it. This allows for the cancellation of noise at higher frequencies. [53]

3.2.6 SPUR/HELICAL GEAR NOISE

Gear design can be used to optimize number of teeth & profile shift to produce counter phase excitation. Capital cost is high. [59]

3.2.7 CONTROL OF FLOW EXHAUST

Exhaust flow component designed to reduce noise produced by sudden gas expansion during the combustion/exhaust stroke of a 2-stroke diesel engine. [61]

3.2.8 UNIFORM FLOW DUCTING

A ducting material designed to be used in the location of areas where noise is expected. This material has been enhanced acoustical properties when returned to its normal state. [28]

3.3 POWERING TO NOISE

3.3.1 DIESEL ELECTRIC

Electric propulsion provides significant fuel savings, reducing overall fuel consumption and emissions. [38]

3.3.2 GAS/STEAM TURBINE

Natural gas turbines are ideal for generating power for relatively small ships. They have high efficiency, minimal emissions, and are suitable for ships with limited space. [52]
3.2 MACHINERY TREATMENTS

- 2 to 3 %
- None
- 100 to
- None
- RF / NB

3.3 MACHINERY TREATMENTS

- Up to 4 %
- None
- Medium
- M
- M
- RF / NB

3.4 ALTERNATIVE FUEL

- From conventional and novel agricultural sources. The level of GHG
- Ammonia is a carbon free compound of nitrogen and hydrogen
- Hydrogen is a carbon free fuel. Hydrogen is an indirect greenhouse
- Methanol is the simplest alcohol with the lowest carbon content
- Liquified Natural Gas (LNG) has become popular as an alternative

3.3.7 MILLER CYCLE/TWO STAGE

- which reduces the NOx emission, however it results in reduced
- The Miller cycle reduces the in-cylinder combustion temperature

3.3.6 WASTE ENERGY RECOVERY

- Heat from engine exhaust and jacket water cooling systems can be
- load demand, these can function at higher load and combustion
- The application of damping tiles or other compounds on the
- The thickness of structural members is directly linked to URN

3.3.5 ENGINE CYLINDER DEACTIVATION/ SKIP FIRING

- The Miller cycle reduces the in-cylinder combustion temperature
- Electrically, controlled combustion engines have the potential
- These actuators control the main components of the engine

3.3.4 ENGINE CYLINDER (EEC)

- Electronic Engine Control (EEC) modifies the timing of the fuel injection
- Variable Frequency Drive (VFD) modifies the timing of the fuel injection
- Unknown

3.3.3 ELECTRONIC ENGINE CONTROL

- Variable Frequency Drive (VFD) modifies the timing of the fuel injection
- Unknown

3.3.2 VARIABLE VALVE TIMING (VVT)

- Variable Valve Timing (VVT) modifies the timing of the inlet/exhaust
- Unknown

3.3.1 VARIABLE FREQUENCY DRIVE (VFD)

- Layer of rubber foam or polyethylene foam applied to the exterior
- The application of ACOUSTIC DECOUPLING is particularly effective when used with resilient mounts; added
- The application of ACOUSTIC DECOUPLING is particularly effective when used with resilient mounts; added

3.2.11 ACOUSTIC DECOUPLING

- Acoustic damping has been applied to the exterior of the ships hull, designed to decrease underwater radiation from machinery vibration energy (most commonly applied to submarines). [24]

3.2.10 STRUCTURAL DAMPING

- Vibration is the oscillating motion of a dynamic system about a non-moving point (or axis or line) of reference. A system of either rotational or translational motion, which is described by a vector, where the magnitude of the vector is the vibration amplitude and the direction is the vibration direction.

3.2 MACHINERY TREATMENTS TO NOISE

- Use of resilient mounting bushings is effective at reducing the noise and vibration energy in machinery due to its ability to absorb vibrations, and it is particularly effective when used with resilient mounts; added
- The application of damping tiles or other compounds on the exterior of a ship, absorbing vibration energy, resulting in a reduction of URN. [24]

3.2 MACHINERY TREATMENTS TO NOISE

- Noise problems, 6-8 dB, can be reduced to 2-3 dB through the application of damping tiles or other compounds on the exterior of a ship, absorbing vibration energy, resulting in a reduction of URN. [24]

3.2 MACHINERY TREATMENTS

- Powering selection is an introductory treatment of means to improve efficiency and/or to reduce underwater radiated noise.
- This matrix is an introductory treatment of means to improve efficiency and/or to reduce underwater radiated noise. [24]

3.1 VARIABLE FREQUENCY DRIVE MECHANICAL PROPORTION

- This simplifies electric power production and alleviates the need of additional equipment and improves system efficiency and easy maintenance.

3.1.1 VARIABLE FREQUENCY DRIVE MECHANICAL PROPORTION

- 5 to 5 %
- None
- 100 to
- None
- RF / NB

3.1 VARIABLE VELOCITY TUBING (VVT) OR VARIABLE INJECTION TIMINGS (VIT)

- Electrically, controlled combustion engines have the potential to operate on fuel oils if required. Noise signatures similar to conventional diesels.
- Diesels.
- Operate on fuel oils if required. Noise signatures similar to conventional diesels.

3.1 FUEL CELL, HYDROGEN, AND ELECTRICITY

- For high-velocity vehicles, mixed fuel cells are a promising option. The source of the hydrogen determines the emission characteristics.
3.4 ALTERNATIVE FUEL

Increased operator skill/training required. See 4.1.1.

3.5 HOTEL LOAD

Suitable for short routes or highly weathered routes. EE could increase by a factor of 1.5 to 2 if weather routing could be applied.

3.5.1 LOAD SCHEDULING

High capital cost. Where batteries can provide full endurance, they can completely replace diesel, while used to improve the efficiency of an on-board plant will offer smaller gains. Battery operation is essentially silent for machinery noise.

3.5.2 REDUCED MANNING

8 to 10%.

3.5.3 VARIABLE FREQUENCY DRIVE (VFD) FOR AUXILIARY

No capital cost. See 4.1.1.

3.5.4 AUXILIARY BOILER

Where feasible, using boilers rather than electric heaters will increase energy efficiency.

3.5.5 POWER-TAKEN-OFF (PTO) FOR SHORT ROUTES (VFD)

Depend on number of machinery and type.

3.6 HOTEL LOAD

Maximum only need to be supplemented rather than to replace conventional plants.

3.6.1 LOAD SCHEDULING

Large improvement in EE and GHG is possible compared to equal load sharing. Depending on

3.6.2 REDUCED MANNING

Dependent on number of crew members (estimated).

3.7.1 SUCTION SAILS

Depend on number of machinery and type.

3.7.2 INVESTMENT

Dependent on number of low-mass members (estimated).

3.7.3 NOISE BENEFITS

Dependent on number of low-mass members (estimated).

4 OTHER MITIGATION TECHNOLOGIES

4.1 WIND ASSISTED SHIP PROPULSION (WASP)

Machinery noise may increase due to increased intervals for safe working of personnel.

4.1.1 LOAD SCHEDULING

Perceived (inherent) risks to the crew and public.

4.1.2 KITE SAILS

Installation cost may increase due to increased intervals for safe working of personnel.

4.1.3 FLETTNER/MAGNUS ROTORS

Where feasible, using boilers rather than electric heaters will increase energy efficiency.

4.1.4 RIGID AND SOFT WING SAILS

When operated as part of an integrated design. Where batteries can provide full endurance, they can completely replace diesel, while used to improve the efficiency of an on-board plant will offer smaller gains. Battery operation is essentially silent for machinery noise.

4.1.5 SUCTION SAILS

Where batteries can provide full endurance, they can completely replace diesel, while used to improve the efficiency of an on-board plant will offer smaller gains. Battery operation is essentially silent for machinery noise.

4.3.1 KITV

When operated as part of an integrated design. Where batteries can provide full endurance, they can completely replace diesel, while used to improve the efficiency of an on-board plant will offer smaller gains. Battery operation is essentially silent for machinery noise.

4.3.2 BIOPROCESSING

Where batteries can provide full endurance, they can completely replace diesel, while used to improve the efficiency of an on-board plant will offer smaller gains. Battery operation is essentially silent for machinery noise.

Vard Marine Inc.
31 October 2023

Matrix
Page 11

TECHNOLOGY MATRIX
Report F 586-000-03, Rev. 0
Depending on Low

5.1.2 WEATHER ROUTING AND

5.1.1 SPEED REDUCTION (STOW

5.1.4 TRIM/DRAFT OPTIMIZATION

5.1 OPERATIONAL PLANNING

5.1 OPERATIONAL PLANNING

5.1 OPERATIONAL PLANNING

5.1 OPERATIONAL PLANNING

5.1 OPERATIONAL PLANNING

5.2 SYSTEM MONITORING AND MANAGEMENT

5.2 SYSTEM MONITORING AND MANAGEMENT

5.2 SYSTEM MONITORING AND MANAGEMENT

4 OTHER ENERGY SOURCE

4 OTHER ENERGY SOURCE

4 OTHER ENERGY SOURCE
### 5 OPERATIONAL MEASURES

#### 5.2 SYSTEM MONITORING AND MANAGEMENT

**5.2.3 CONTINUOUS FUEL AND EMISSION MEASUREMENT**

Continuous fuel consumption and emission measurements will give insight in the ability of the ship to improve its fuel consumption and emissions before a certain threshold is reached and need to perform maintenance. This measure will not reduce URN or improve EE by itself, it needs to be followed up by Machinery Maintenance.

<table>
<thead>
<tr>
<th>Indirect</th>
<th>Salient</th>
<th>Neg.</th>
<th>Cost</th>
<th>Benefits</th>
<th>100k for fuel measurement system</th>
<th>Maintenance moving parts of machinery and maintaining resilient mounts (see 3.2.1) helps to keep the vibrations, noise and energy efficiency from degrading with time.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Indirect maintenance greater efficiency than time based or corrective.</td>
</tr>
</tbody>
</table>

#### 5.2 SYSTEM MONITORING AND MANAGEMENT

**5.2.4 MACHINERY MAINTENANCE**

Maintaining moving parts of machinery and maintaining resilient mounts (see 3.2.1) helps to keep the vibrations, noise and energy efficiency from degrading with time.

<table>
<thead>
<tr>
<th>Indirect</th>
<th>Salient</th>
<th>Neg.</th>
<th>Cost</th>
<th>Benefits</th>
<th>100k for fuel measurement system</th>
<th>Maintenance moving parts of machinery and maintaining resilient mounts (see 3.2.1) helps to keep the vibrations, noise and energy efficiency from degrading with time.</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Indirect maintenance greater efficiency than time based or corrective.</td>
</tr>
</tbody>
</table>

#### 5.3 SHIP ENERGY MANAGEMENT

**5.3.1 POWER/ENERGY MANAGEMENT SYSTEM (PEMS)**

Automated PEMS correlates the power plant generation with the ships machinery configuration to ensure efficient operation of the engines. See.

<table>
<thead>
<tr>
<th>Indirect</th>
<th>Salient</th>
<th>Neg.</th>
<th>Cost</th>
<th>Benefits</th>
<th>15% higher capital cost</th>
<th>15% + lower capital cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
</tbody>
</table>