Numerical Investigation into Propeller Cavitation Reduction and Performance Enhancement

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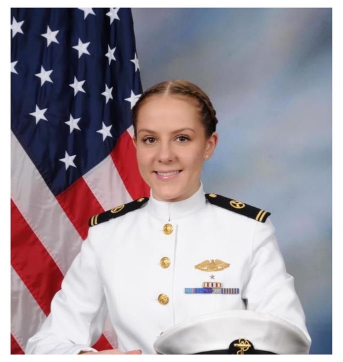
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Introduction

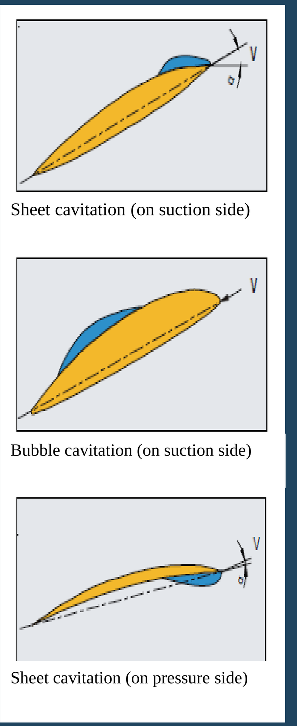
Drawing from research on propeller cavitation, our experiment focused on testing a novel propeller design created using Computational Fluid Dynamics (CFD) technology (EasyCFD). Our findings indicated that incorporating a nozzle at each center of the propeller blades effectively reduced propeller cavitation by displacing vapor bubbles formed on the blade's suction side.

Motivation

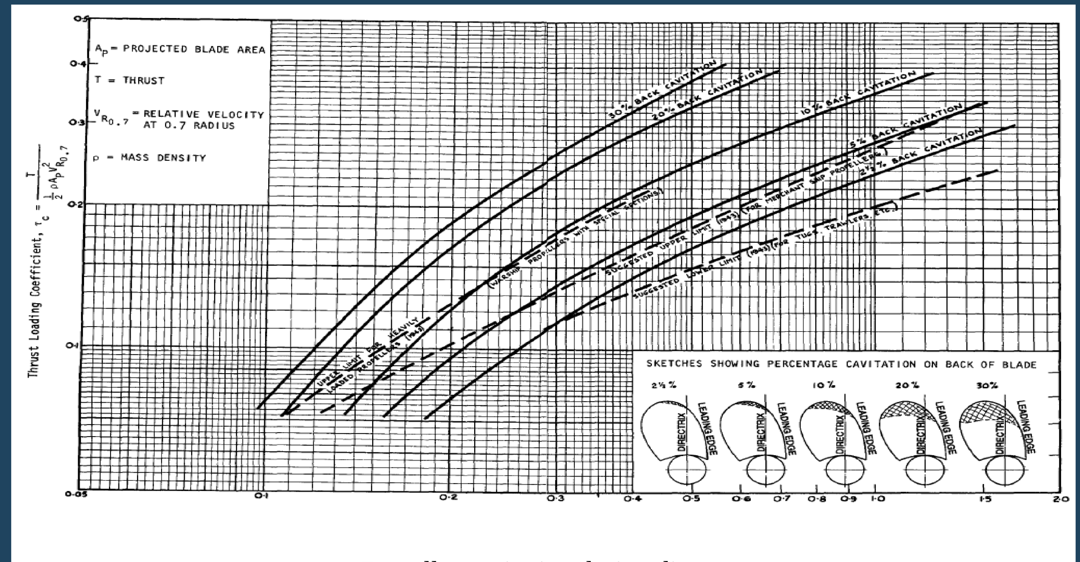
- Vaporous Cavitation poses common challenges in various fluid mechanics applications such as pumps, impellers, propellers, control valves, pipes etc.
- Environmental concerns and the need to explore green energy technology
- IMO's initiative to reduce GHG emissions
- Rising fuel costs
- Ships propellers play a crucial role in efficiency, reduction of noise/vibrations, and fuel costs

History and Background

- Layers of bubbles appear when local pressure drops below the fluid's vapor (saturation) pressure
- Migration of bubbles along the propeller blades leads to collapsing of bubbles on the propeller blades' surfaces causing noise and vibrations und ultimately erosion.
- Decreases life expectancy of propeller blades.
- Increases fuel consumption/operation costs.
- Three main types of cavitation (based on the type- and relative position on the blades surfaces: sheet suction side, sheet pressure side and bubble.
- Our project investigated bubble (vaporous) cavitation on the suction side of the propeller blades.



- Need to have low blade area for efficiency reasons (i.e., low drag, etc.)
- But blade must have sufficient area to prevent thrust breakdown
- Typical modern propellers tend to be highly loaded, hence, require large blade areas
- Experimental curves of optimal blade design is shown in the figure on the right
- Suggested criteria for various designs and amount of back cavitation as function of thrust loading coefficient (at the 0.7R) and advance coefficient, J = VA/(nd)



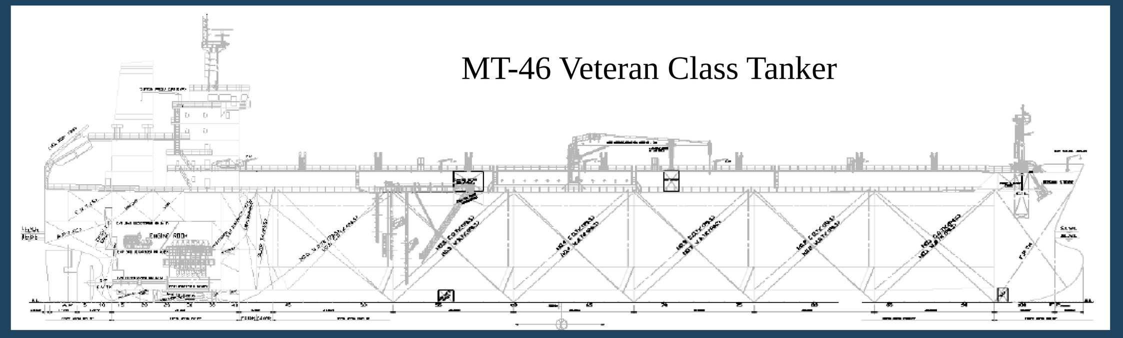
Propeller cavitation design diagram

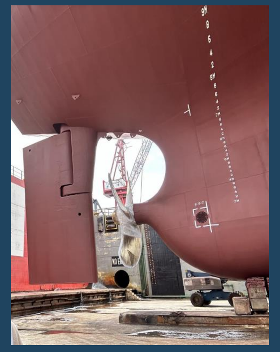
- The MT-46 Veteran Class Tanker is based on an Athenian-class 46,000 dwt (design by Hyundai Mipo Dockyard, HMD) Jones Act product tanker built by Aker Philadelphia shipyard, USA
- The MT-46 Veteran Class tanker has an overall length of 183.2 m, molded breadth of 32.2 m, and scantling draft of 12.2 m with a capacity of approx. 330,000 barrels.

Prototype Propeller (4-bladed FPP, pitch = 0.7R)
- Diameter = 5.82 m
- Normal Operation Speed: 100 RPM

3-D Model Propeller (4-bladed FPP, pitch = 0.7R)
- Diameter = 202.87 mm
- Blade length = 100 mm
- Blade height = 67.55 mm
- Simulated Operation Speed: 100 RPM

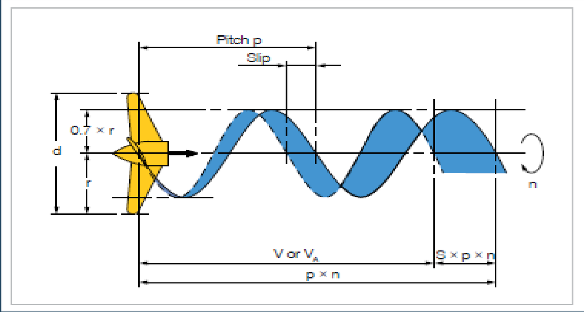
MT-46 Veteran Class Tanker



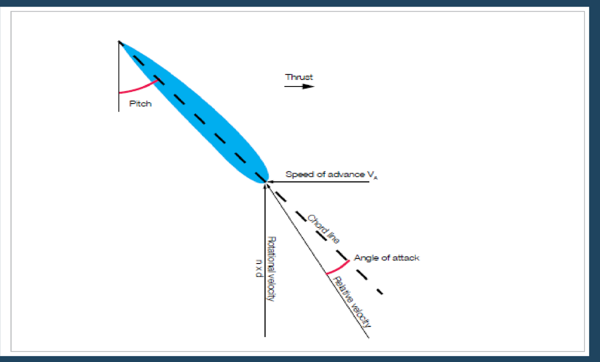


Propeller Basics

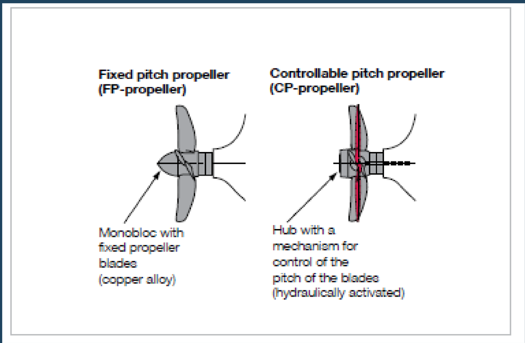
- Largest possible propeller diameter, *d*, is desirable for optimal efficiency and lowest fuel consumption of the ship propulsion
- Size limitations due to bottom/keel clearance, top clearance with hull, in all operations propeller must be fully submerged
- This is especially critical to tankers (whose operational draft varies significantly), $d/T = 0.65$
- Pitch diameter ratio, *p/d*, is measured between propeller pitch angle and diameter, d
- Typical $p/d = 0.7r$ (r = propeller radius = $d/2$) depending on propeller revolutions, *n* and propeller diameter, *d*
- Slip of propeller (like a screw) is difference in propeller forward speed drop (due to water "yielding" acceleration aft) and propeller speed in non-yielding medium
- This theoretical propeller forward speed is: $V = p * n$
- Typical propeller blade cross-section is similar to an airfoil (hydrofoil) shape with pressure and suction sides, and angle of attack



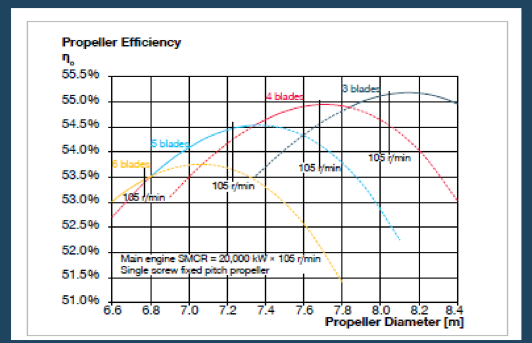
Typical propeller pitch and slip



Propeller hydrofoil design



FPP vs CPP

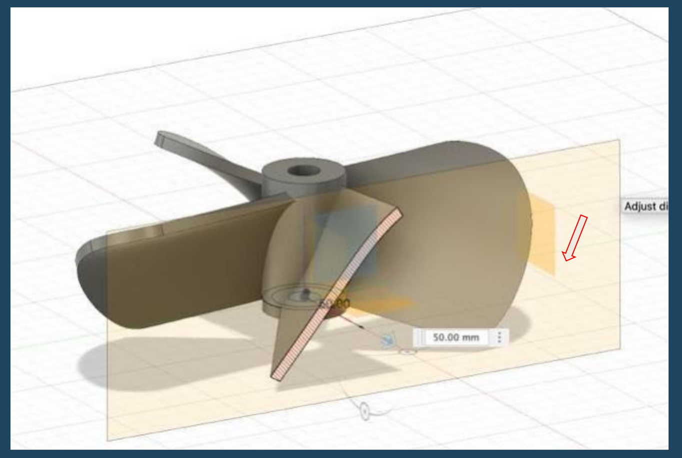


Propeller efficiency vs propeller blade number

- **Disk area coefficient** – ratio of swept surface area by propeller relative to the relative disk area
- Typically, this ratio is about 0.5 – 0.6 for most 4-bladed propellers with normal blade loading
- **Blade number** – typical propellers have 2 – 7 blades with higher number of blades leading to higher efficiency
- The higher the blade number, the lower the propeller optimal speed
- Certain specific blade numbers must be avoided to prevent natural frequency excitations with ship's hull and machinery
- Due to strength and vibration requirements, 4-bladed propellers tend to be most common in large merchant ships
- **Fixed Pitch Propellers (FPP)** – monolithic build (cast) with fixed number- and positions of blades (at a fixed pitch)
- Simpler design, highest number of blades and blade area ratio – our work investigated an FPP model
- **Controllable Pitch Propellers (CPP)** – relatively large hub area (containing all gearing mechanisms, etc.)
- CPP provide greater maneuverability (at a more complex construction)
- Slightly lower propeller efficiency compared to FPP

CFD Analysis: Conventional Propeller

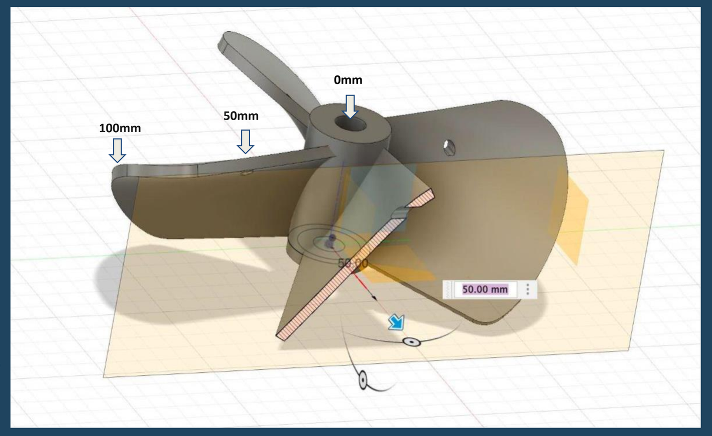
- 3D model by Fusion 360
- CFD simulation by EasyCFD
- Prototype Propeller: 4-bladed fixed pitch (0.7R)
- Prototype Propeller Dia. = approx. 5.8 m
- Model propeller Dia. = 202.87 mm
- Resulting scale = approx. 1:28.6
- Model Propeller Blade Length = 100 mm
- Blade Height = 67.55 mm



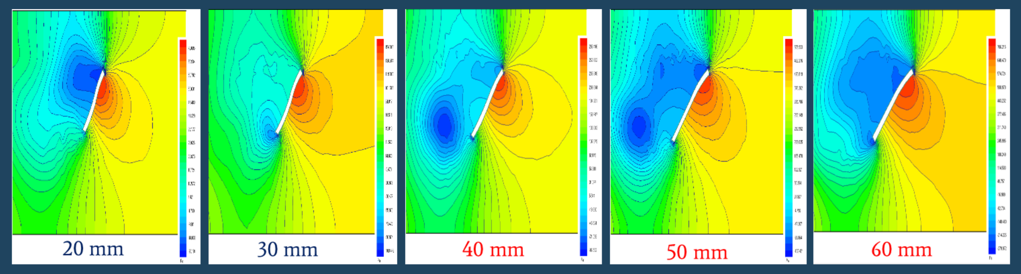
CFD Analysis: Nozzle Propeller

- Propeller with Nozzle at 50 mm from the hub
- Using a nozzle to divert the high pressure to the critical low pressure side of the propeller, will divert the low pressure.
- Three nozzle types tested:

- Straight - Direct Flow
- Convergent - Velocity Increases, Pressure Decreases
- Divergent - Velocity Decreases, Pressure Increases

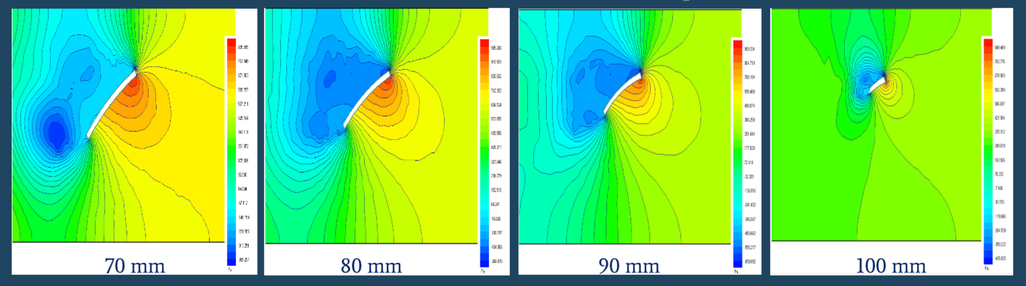


Easy CFD Constraints



- These cross-sectional images depict the high and low pressure zones for a conventional propeller.

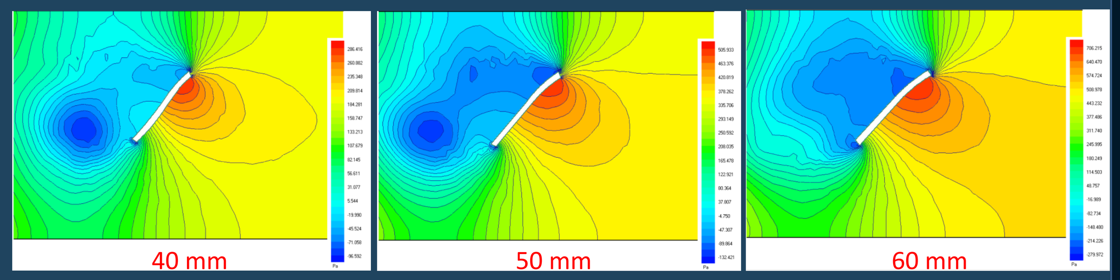
Cross Sectional Area of a Conventional Propeller

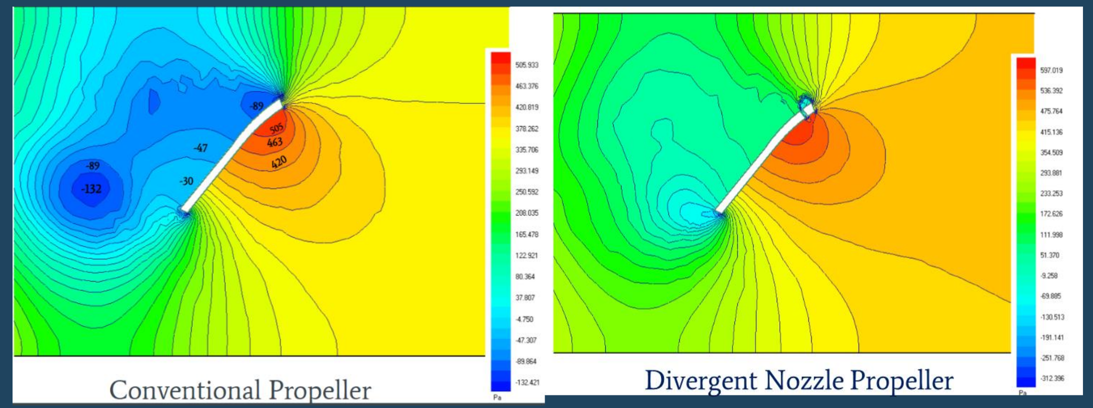


Critical Points Discussion
- Low pressure zones of interest
- These will cause a low enough pressure to form vapor bubbles

All pressure measurements are in pascals and are gauge pressure

Relative pressures are depicted through the color scheme



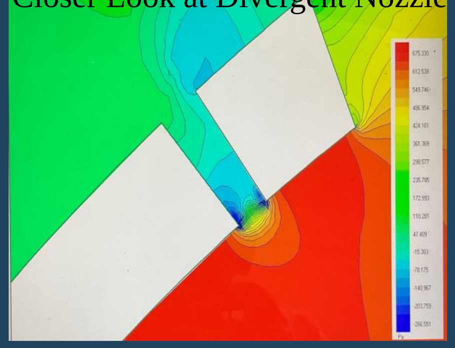


Conventional Propeller

Divergent Nozzle Propeller

- Low pressure zone located at nozzle entrance
- Cavitation will still occur, but there is a significant reduction

Closer Look at Divergent Nozzle



National Security Strategy (NSS) 2023

•The U.S. needs to outcompete China in 6 domains

•The second domain is economically

•NSS 2023 states that the American economy relies on the international economic system and global trade. 90% of this trade is done via the Merchant Marine.

•Regarding global trade, only 1.5% is done through the Merchant shipping on U.S. flagged vessels.

•The primary inhibitor of the U.S. Merchant fleet is high operational and maintenance costs.

•The proposed new propeller design aids in reducing the operational costs of the U.S. Merchant Marine through a reduction in fuel consumption through reduced propeller cavitation.

Conclusions

- The introduction of a divergent nozzle on the propeller blade with a nozzle reduces propeller cavitation by roughly 52% in comparison to the prototype conventional propeller.
- Cavitation that is seen in the propeller blade with a nozzle is isolated primarily to the region around the nozzle.
- With the use of a divergent nozzle, the low pressure zone is almost completely eliminated, decreasing cavitation.