University of Padua – Department of Industrial Engineering

Bachelor Degree in Aerospace Engineering

Report for final examination
Toroidal propellers for marine propulsion: working principles and applications

University tutor: Prof. Ernesto Benini

Student: Lorenzo Lupia

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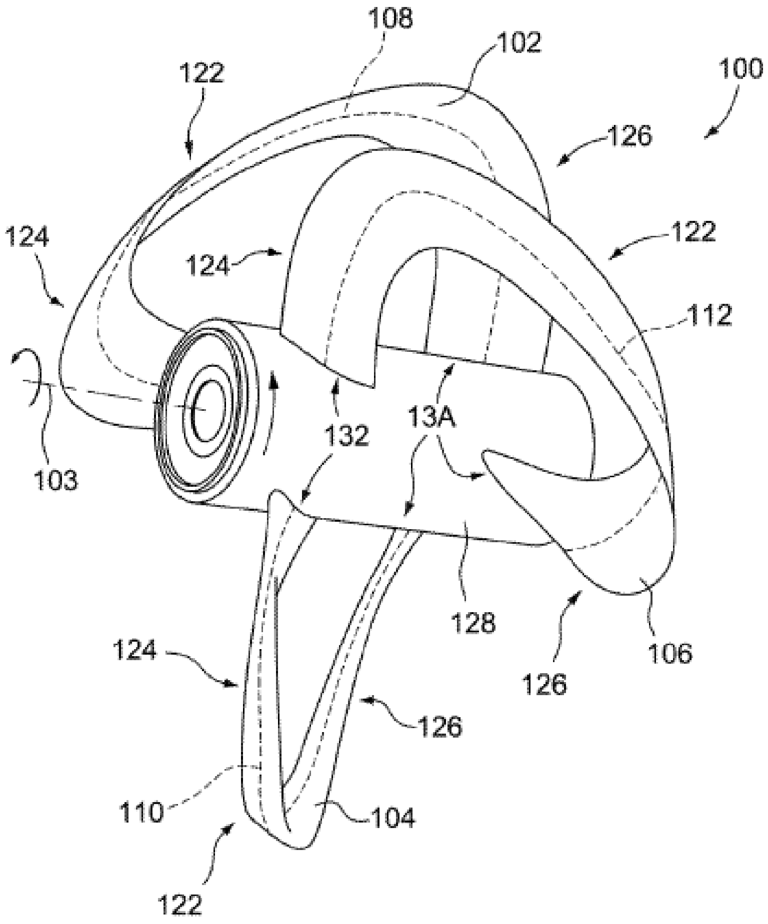
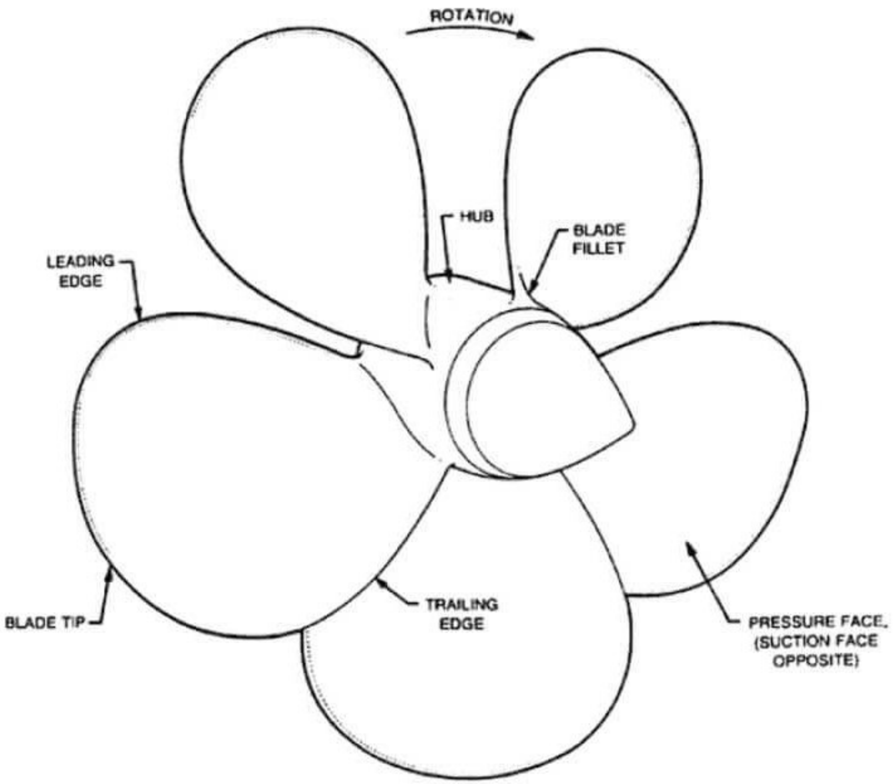
INTRODUCTION



Toroidal propeller [1]



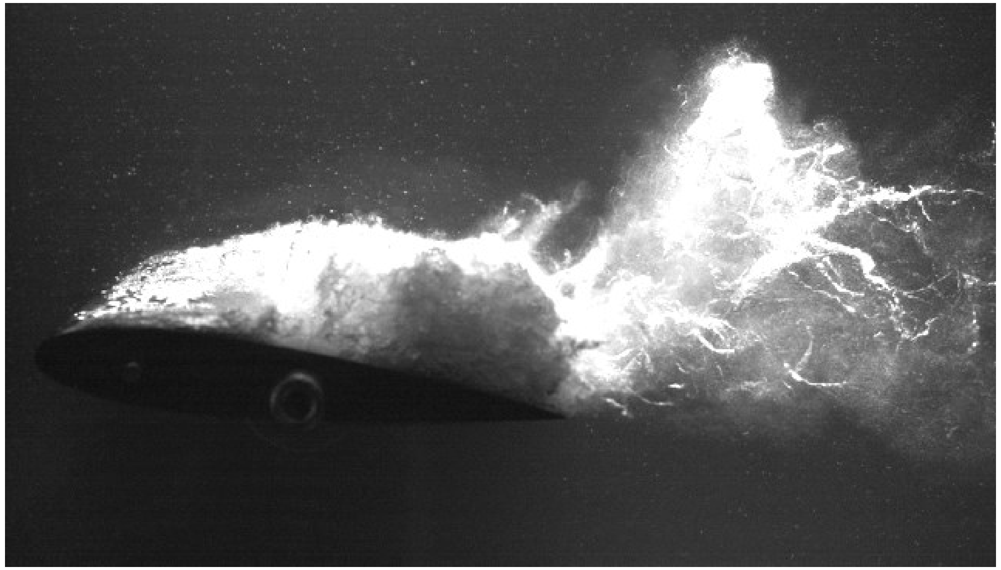
Ordinary propeller [2]

Bernoulli's equation for inviscid free-flow

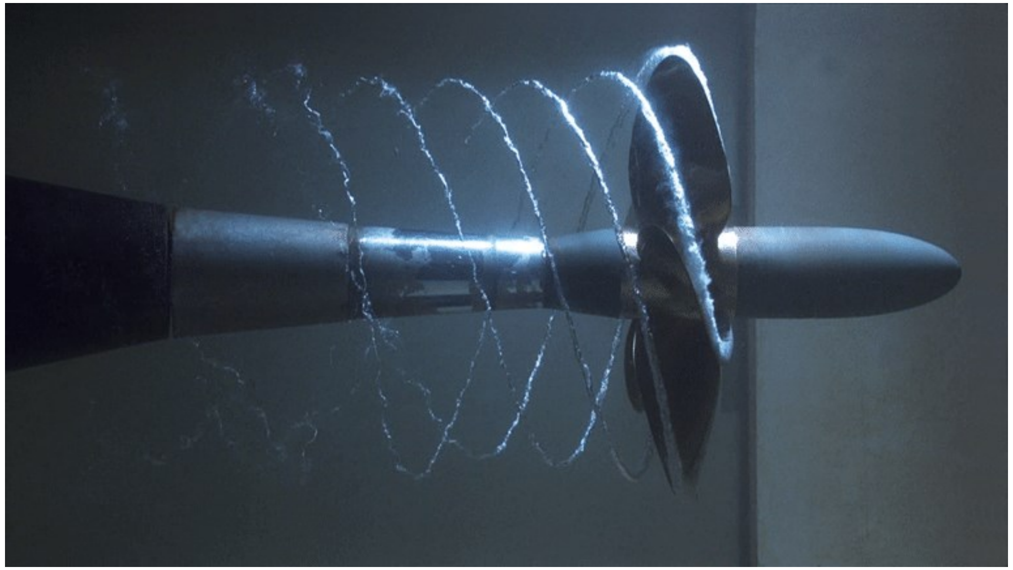
$$\frac{1}{2}\rho\, u^2 + P = P_0$$

- ρ: Fluid density
- u: Fluid local speed
- P: Fluid local pressure
- P_0: Fluid resting local pressure

CAVITATION



Fixed cavitation [3]



Tip-vortex cavitation [4]

CAVITATION

$$SPL = C + 10 \ \log \left(\frac{N}{N_i} \left[\frac{N}{N_i} - 1 \right]^2 \right) \quad [5]$$

- C: constant dependant on propeller geometry
- N: propeller rotational speed (rpm)
- N_i: propeller rotational speed at cavitation incipiency (rpm)
- SPL: sound pressure level (dB)

$$\left[\frac{A_e}{A_0} \right] \geq \frac{(1.3 + 0.3\, Z)s}{(P_0 - P_v)\, D^2} + K \quad [6]$$

- A_e: expanded area
- A_0: Propeller circumference area
- Z: number of propeller blades
- s: propeller thrust
- P_0: liquid's static pressure
- P_v: liquid's vapor pressure
- D: propeller diameter
- K: constant dependant on propulsion setup (single or twin screw)

Influence of propeller's parameters on cavitation

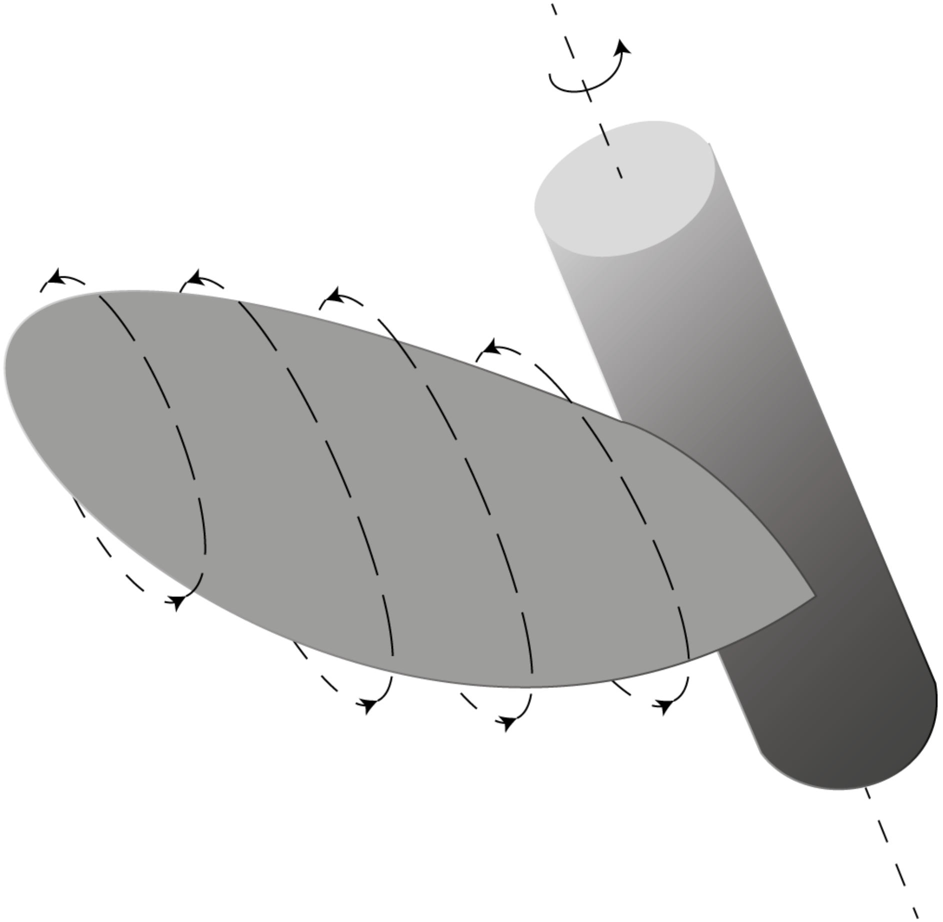
- Expanded area ratio reduces cavitation [6].
- Propeller diameter reduces cavitation [6].
- Propeller rotational speed and thrust promote cavitation [5] [6].
- Hydrofoil's shape influence the blade's stall behaviour and, as a consequence, fixed cavitation.
- The number of blades influences cavitation [7].
- Blade skew can reduce cavitation [7].
- Twists and different tip geometries can reduce cavitation [7].

Screw propulsion

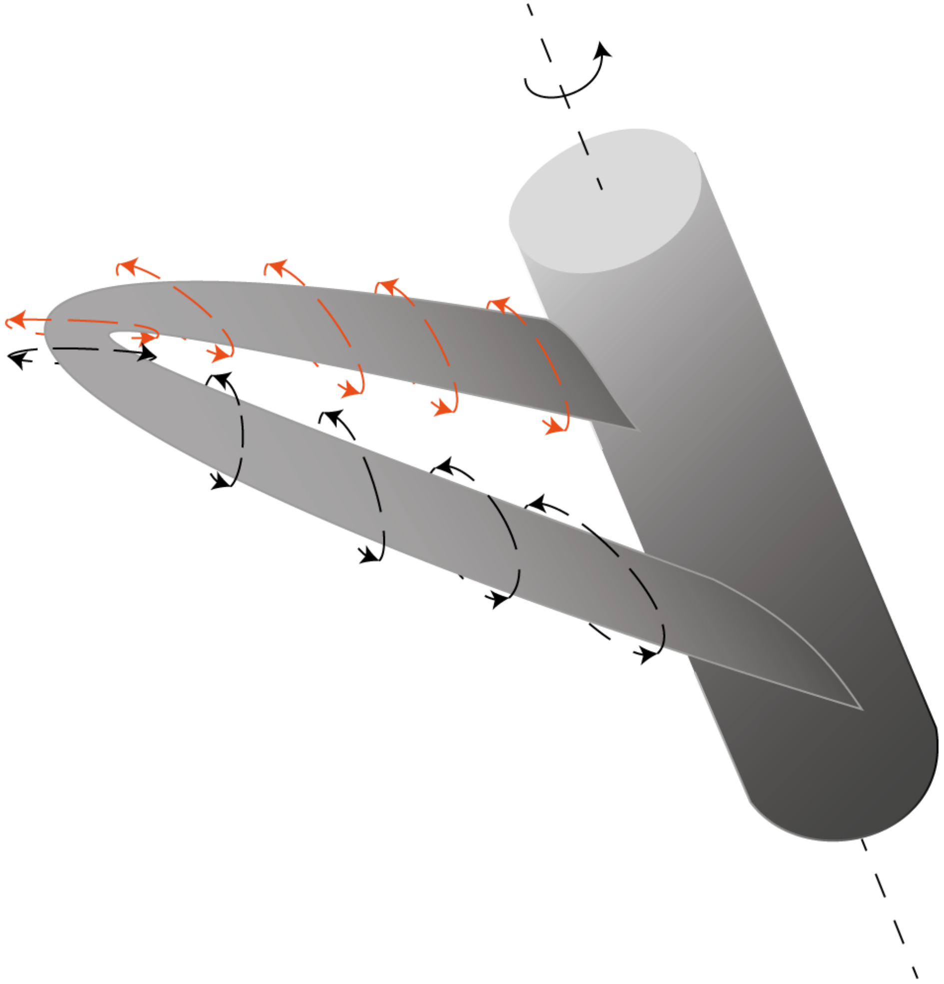
The propeller behaves like a screw, generating thrust by the acceleration of a certain liquid mass flow. Thrust increases with slip, defined as the difference between the distance traveled by the vessel in a real setting and the distance the vessel would have traveled if the propeller behaved like a screw in a solid medium . Propeller efficiency decreases with the increase of flow acceleration, since the energy aquired by the accelerating mass flow is lost.

Hydrofoil propulsion

The propeller behaves like a series of wings, deflecting flow and generating hydrodynamic lift and drag. Due to this behavious, hydrofoil propulsion could ideally attain perfect efficiency.

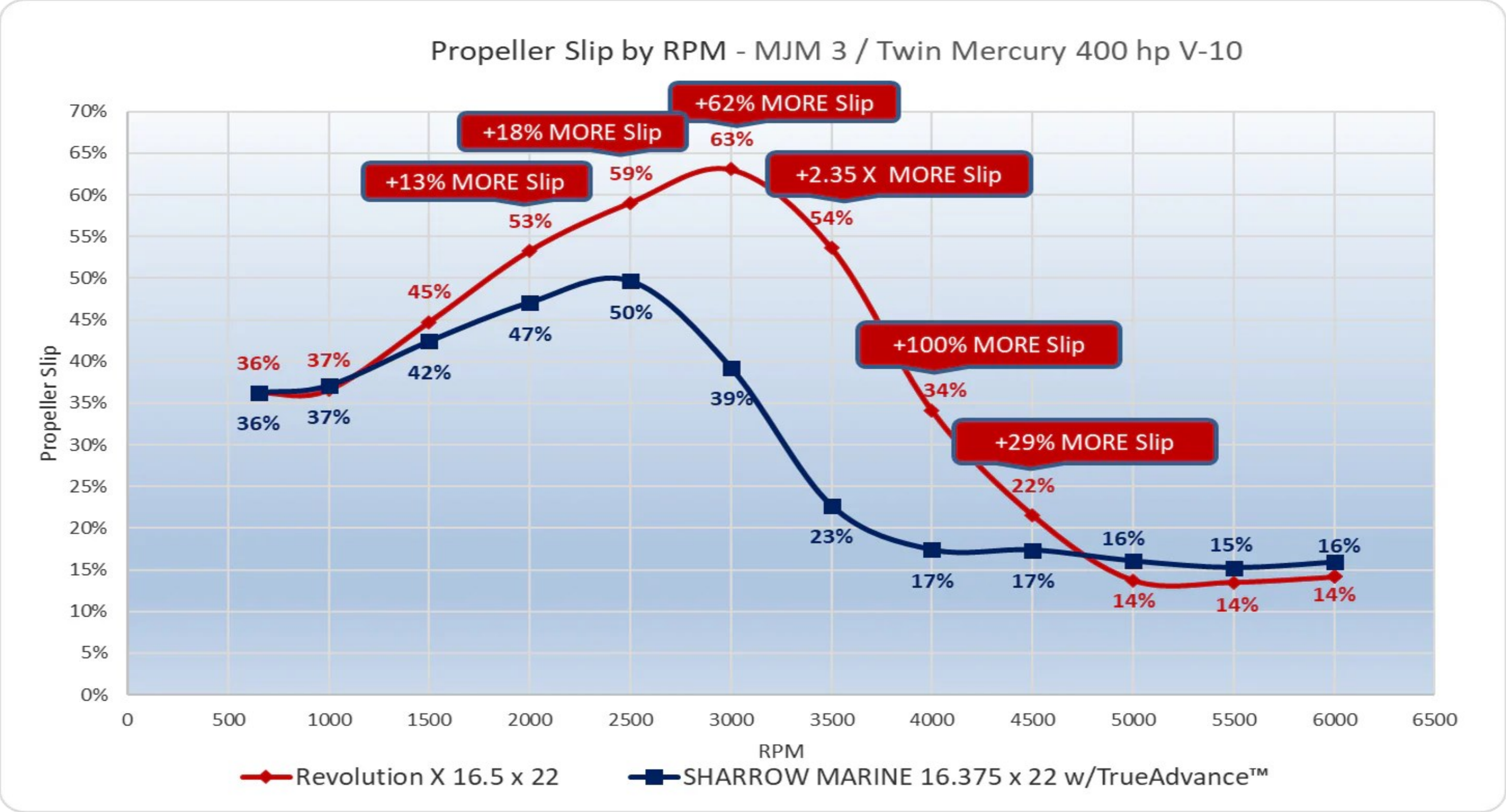


Vortex distribution on an ordinary propeller's blade



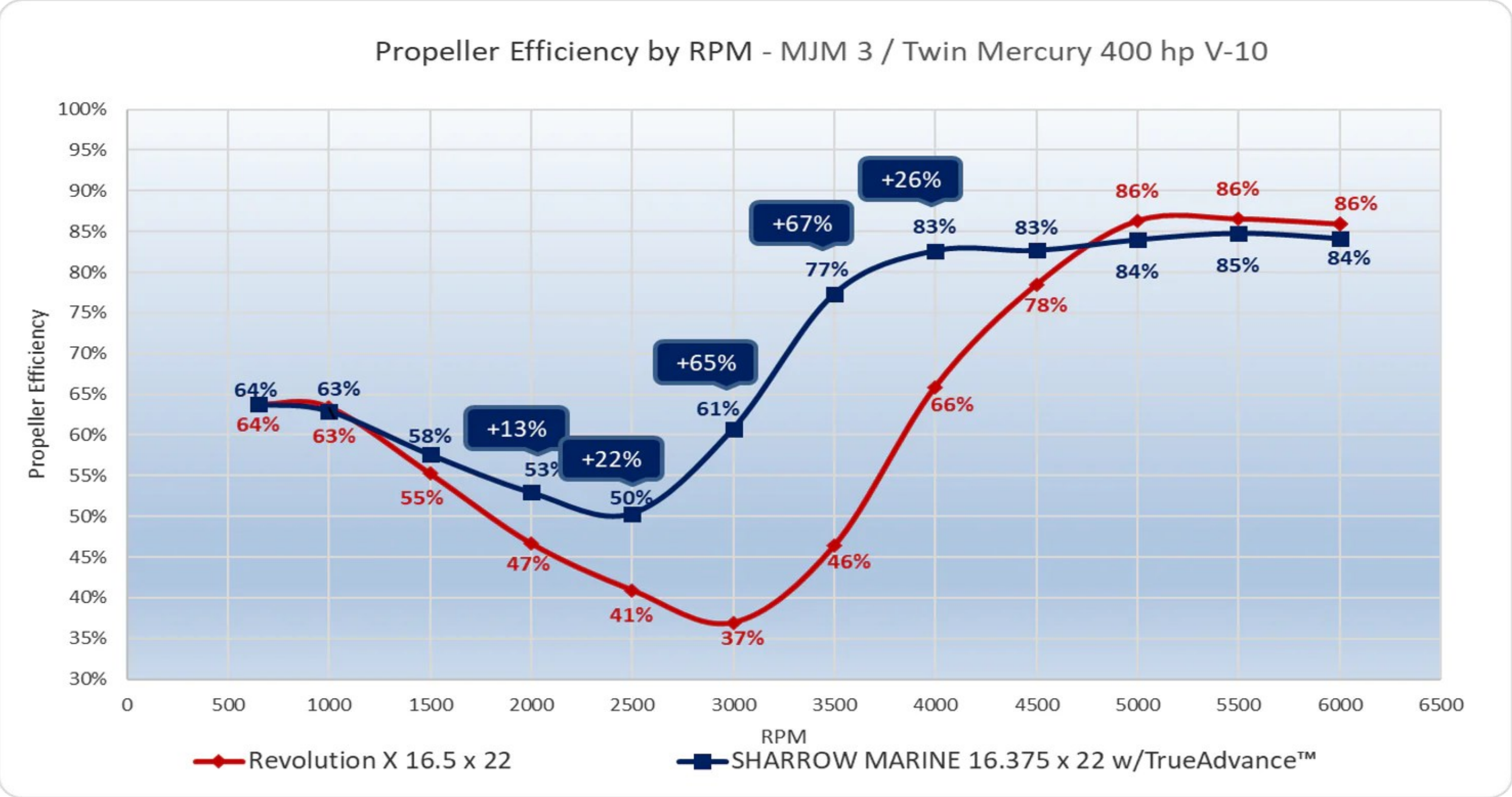
Vortex distribution on a toroidal propeller's blade

CONSIDERATIONS



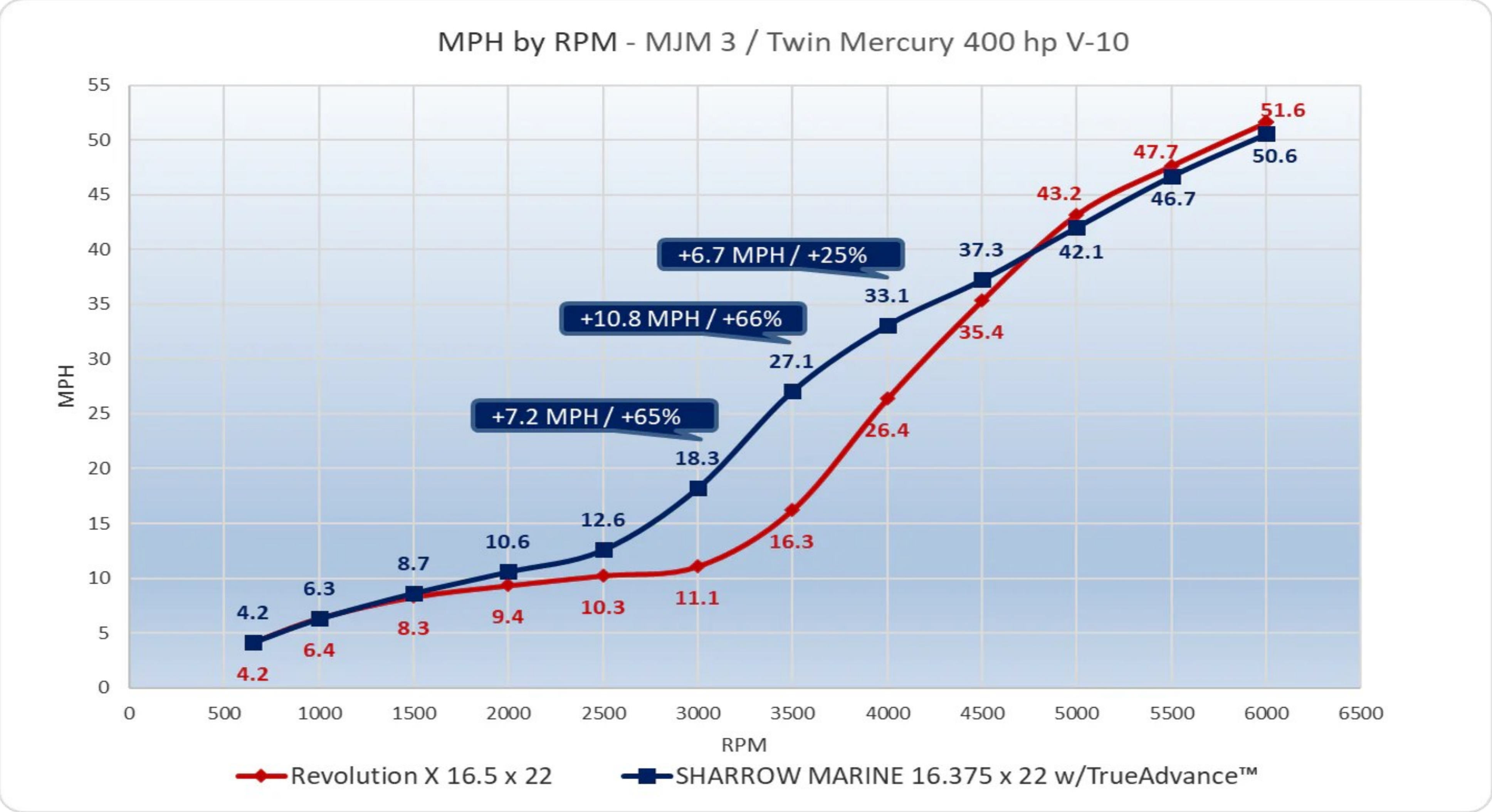
Slip comparison between an ordinary propeller and a toroidal one by RPM [8]

CONSIDERATIONS



Propeller efficiency of ordinary and toroidal propellers by RPM [8]

CONSIDERATIONS



Travel speed of ordinary and toroidal propellers by RPM [8]

CONSIDERATIONS

- Toroidal propellers tend to be more efficient than ordinary ones in a specific rpm range, allowing vessels to reach planing conditions sooner and improving top speed and fuel efficiency.
- Toroidal propellers tend to be more quiet due to reduced tip-vortex cavitation.
- Ordinary propellers can be more efficient than toroidal ones at low and high rpms, probably due to the tendency of examined toroidal propellers to be overfitted.
- Due to high production costs, relatively low structural resistance and high required rpm ranges, it's likely that toroidal propellers will keep on being employed only on small, frequently used vessels.

CITATIONS

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[3] R. Arndt, G. Balas, and M. Wosnik, "Control of cavitating flows: A perspective," Jsme International Journal Series B-fluids and Thermal Engineering - JSME INT J SER B, vol. 48, pp. 334–341, May 2005. DOI: 10.1299/jsmeb.48.334.

[4] J. Bosschers, "Propeller tip-vortex cavitation and its broadband noise," Ph.D. dissertation, Sep. 2018. DOI: 10.13140/RG.2.2.17691.92966

[5] R. F. Young, Cavitation, eng. Longon : McGraw-Hill Book Company, 1989, ISBN: 0077070941

[6] M. Gaafary, H. El-Kilani, and M. Moustafa, "Optimum design of b-series marine propellers," Alexandria Engineering Journal, vol. 50, no. 1, pp. 13–18, 2011, ISSN: 1110- 0168. DOI: https://doi.org/10.1016/j.aej.2011.01.001. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1110016811000093.

[7] Z. Zhang, "Research on ship propeller noise reduction: Advanced materials and innovative geometric design," Applied and Computational Engineering, vol. 61, pp. 222–230, May 2024. DOI: 10.54254/2755-2721/61/20240964.

[8] S. Marine, Sharrow x10 propellers outperform standard props on mjm 3 with mercury 400hp v10s, https://sharrowmarine.com/blogs/performance-reports/, 2021.