The great challenge of propeller cavitation in Shipbuilding.

Continuous control with the innovative Non-Intrusive Cavitation Detection System (Ni-CDS)

Autores: D. Publio Beltrán / D. Richard García / D. Luis Piqueras

Cartagena de Indias. 8-10 Marzo 2023

Introduction (I)

Since its identification, and given its direct relationship with:

- The propulsion performance,
- consumption (fuel prices),
- the comfort of the passengers, endowments and crews,
- the strategic value of “stealthy” for military vessels,
- the “acoustic signature” of ships.

the phenomenon of cavitation of the propellers of ships has meant, and is, one of the great challenges of Naval Engineering and the Shipbuilding Industry.

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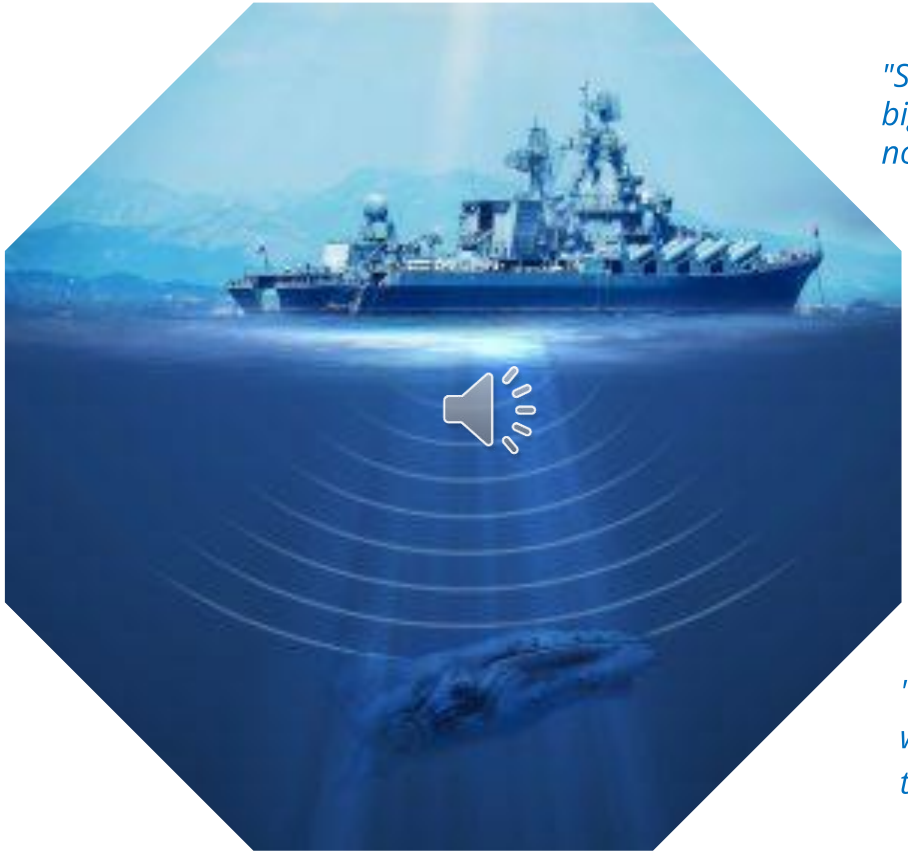
Introduction (II). The environmental reality

With increasing focus on noise pollution in the oceans,

“Measurements of ambient noise levels in the 25–50 Hz frequency band show an increase of approximately 19 dB over the period 1950–2007, which corresponds to a rate of increase of 3.3 dB per decade.”

“Maritime traffic on the world’s oceans has increased 300 per cent over the past 20 years”, according to a new study by the American Geophysical Union (AGU) aimed at quantifying global ship traffic.



"Shipping traffic is probably the biggest source of anthropogenic noise at sea."

GOBIERNO DE ESPAÑA | MINISTERIO DE AGRICULTURA, ALIMENTACIÓN Y MEDIO AMBIENTE

Between 1965 and 2004 the number of merchant ships sailing the world's oceans has doubled and their gross tonnage has quadrupled" ((McDonald et al., op.cit.).

"Shipping is also a major source of noise pollution, which is increasingly considered potentially harmful to marine mammals. (Jean Tournadre. Ifremer).

Continuing to deny this reality is pointless

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Introduction (III). Dedicated projects. The Regulatory Context

At present, and with the focus on the environmental impact of ships,

SEVENTH FRAMEWORK PROGRAMME

BESST Breakthrough in European Ship and Shipbuilding Technologies

SILENV

Achieve QUieter Oceans

HORIZON 2020

Saturn Developing Solutions for Underwater Radiated Noise

SEA DEFENCE

PYME INNOVADORA
Válido hasta el 10 de diciembre de 2023

European Commission

Directive 2008/56/EC
MSFD 2010/Descriptor 11

GENERAL PROVISIONS. Article 1
1.- This Directive established a framework within which Member States shall take measures to achieve or maintain good environmental status in the marine environment by year 2020 at the latest.

IMO INTERNATIONAL MARITIME ORGANIZATION

MEPC.1/Circ.833, 7 April 2014
GUIDELINES FOR THE REDUCTION OF UNDERWATER NOISE FROM COMMERCIAL SHIPPING TO ADDRESS ADVERSE IMPACTS ON MARINE LIFE

The relevance of cavitation propellers has only grown!

Introduction (IV). The Regulatory Context

With increasing focus on noise pollution in the oceans,

INTERNATIONAL MARITIME ORGANIZATION

MEPC.1/Circ.833, 7 April 2014
GUIDELINES FOR THE REDUCTION OF UNDERWATER NOISE FROM COMMERCIAL SHIPPING TO ADDRESS ADVERSE IMPACTS ON MARINE LIFE

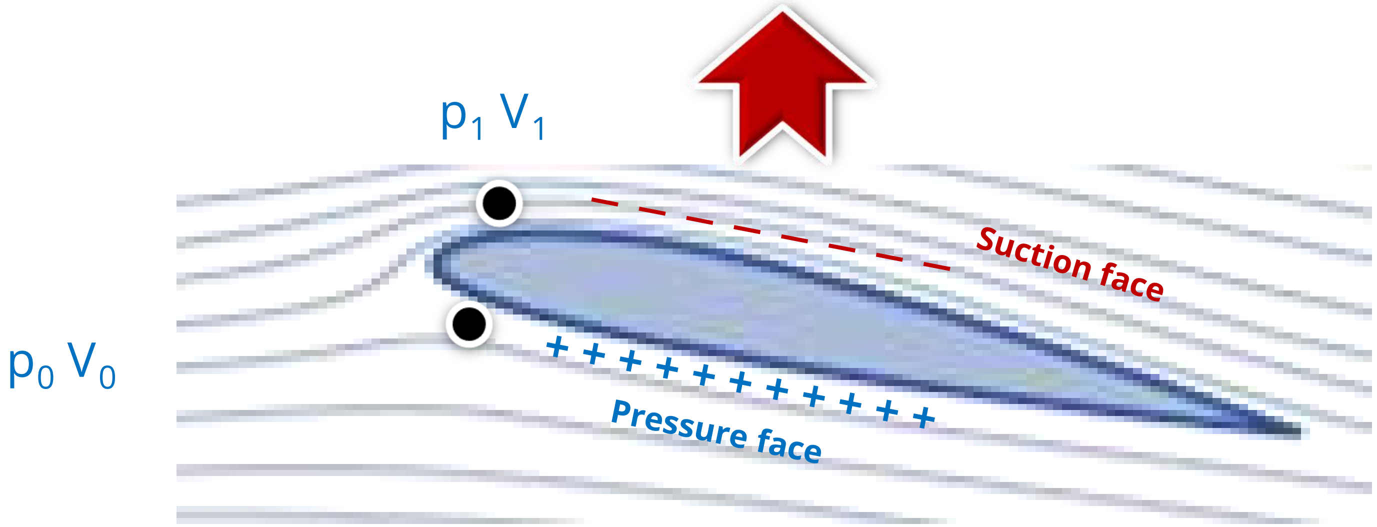
7.2.1 Propellers should be designed and selected to reduce cavitation. Cavitation will be the dominant source of radiated noise and can significantly increase underwater noise.

Cavitation can be reduced under normal operating conditions through good design, such as optimizing propeller loading, ensuring as even water flow across the propellers as possible (which can be affected by hull design), and a careful selection of the characteristics of the propeller, such as: diameter, blade number, pitch, skew and sections.

It is well known that design principles to reduce cavitation (ie, reduce pitch at blade tips) can cause decreased efficiency.

Cavitation. Basic Principles & Formulation

The basic function of the propeller is to propel the ship by transforming the power: torque/revolution generated in the main propulsion engines into thrust in the proper direction and direction.



Bernoulli´s Equations

$$p_1 + \frac{1}{2}\rho V_1^2 = p_0 + \frac{1}{2}\rho V_0^2$$

$$p_0 - p_1 = \frac{1}{2}\rho (V_0^2 - V_1^2)$$

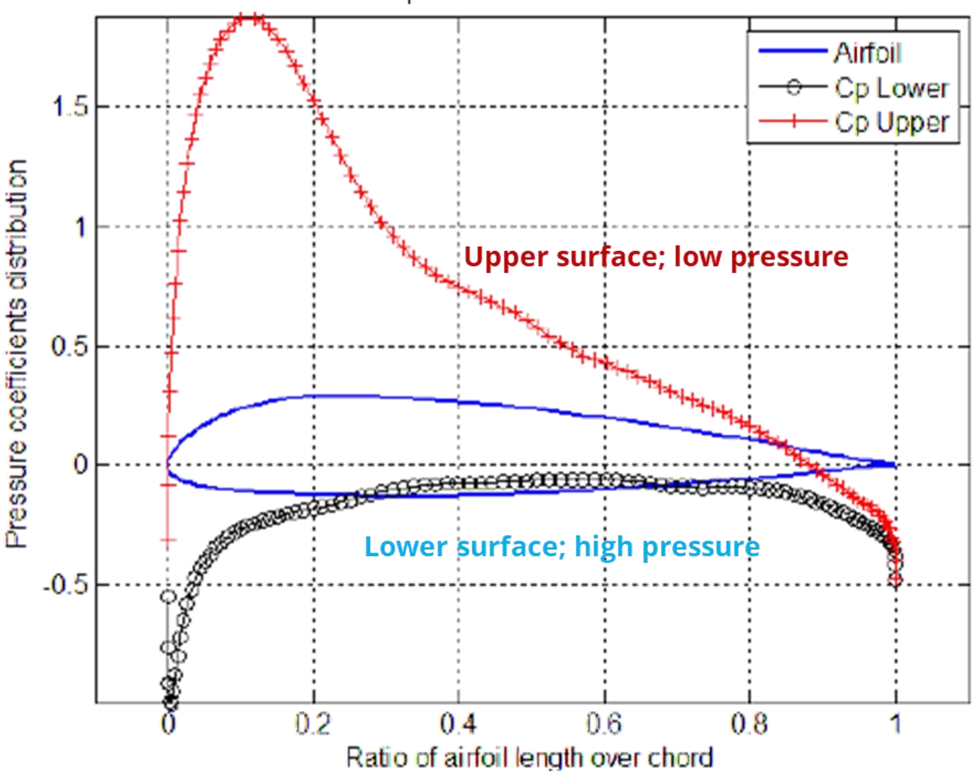
$$\Delta p < 0 \rightarrow p_1 < p_0$$

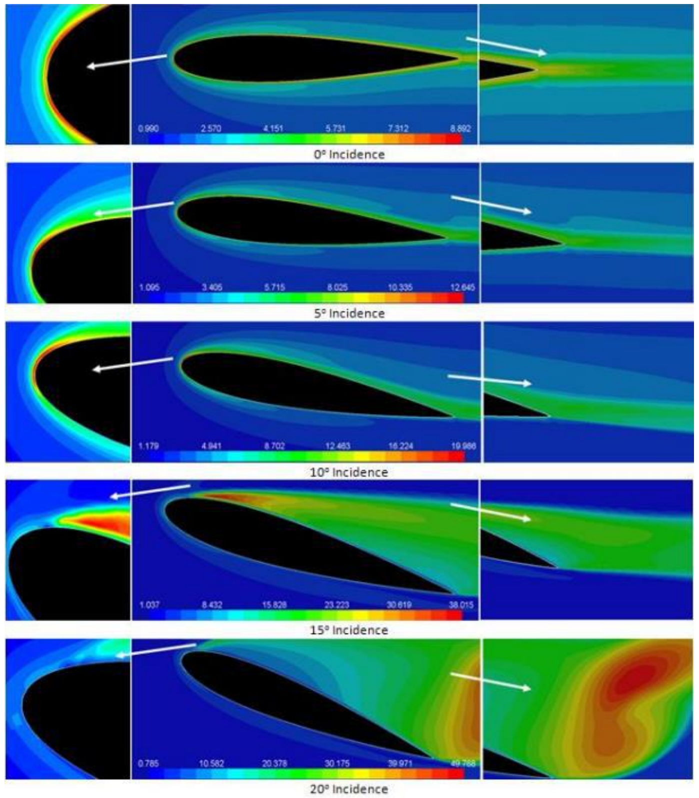
Local Pressure Coefficient: $C_p = \frac{p_1 - p_0}{\frac{1}{2}\rho V_0^2} = 1 - \left(\frac{V_1}{V_2}\right)^2$

To achieve this effect, the propellers, when rotating due to the effect of the engine torque, produce a pressure front on the faces of their blades. While on the back side (pressure side) there is a rise in pressure, on the opposite side, the front side (suction side), there is a remarkable drop in pressure.

Cavitation. Basic Principles & Formulation

Local Pressure Coefficient: $C_p = \frac{p_1 - p_0}{\frac{1}{2}\rho V_0^{2}} = 1 - \left(\frac{V_1}{V_2}\right)^2$





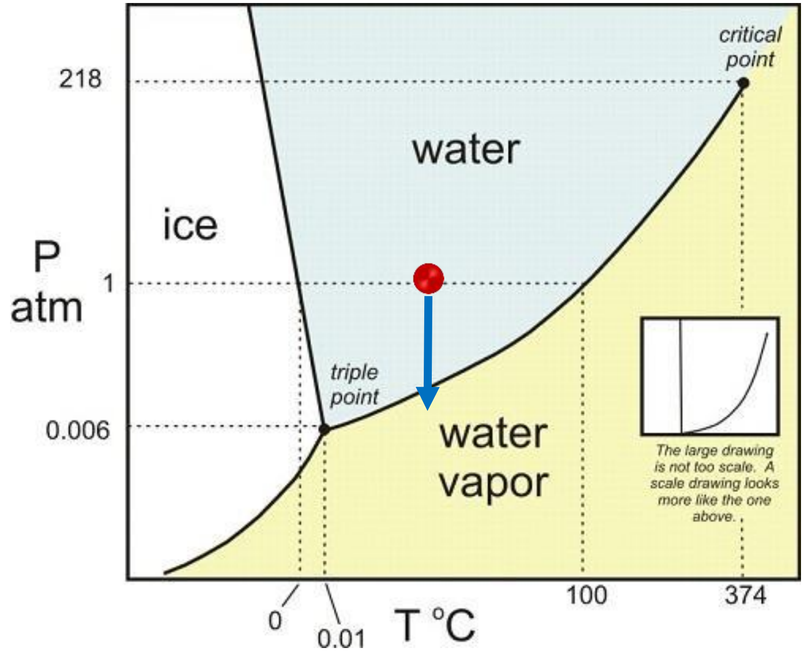
The pressure coefficient depends on the angle of incidence of the flow in the profile.

Cavitation. Cavitation Conditions

Being p_v the vapor pressure of water at a given temperature, the cavitation number is defined as the relation:

$$\sigma = \frac{p_o - pv}{\frac{1}{2}\rho V_0^2}$$

The cavitation phenomenon occurs when the local pressure p_1 at a point in the fluid is below the vapor pressure p_v at that temperature.



No Cavitación

$p_1 > p_v$

$\sigma > -C_p$

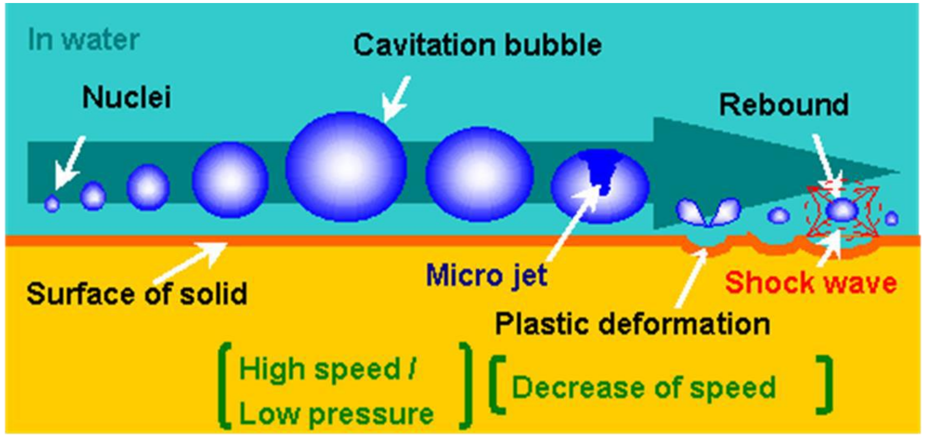
Cavitación

$p_1 \leq p_v$

$\sigma \leq -C_p$

Cavitation. Mechanism of generation

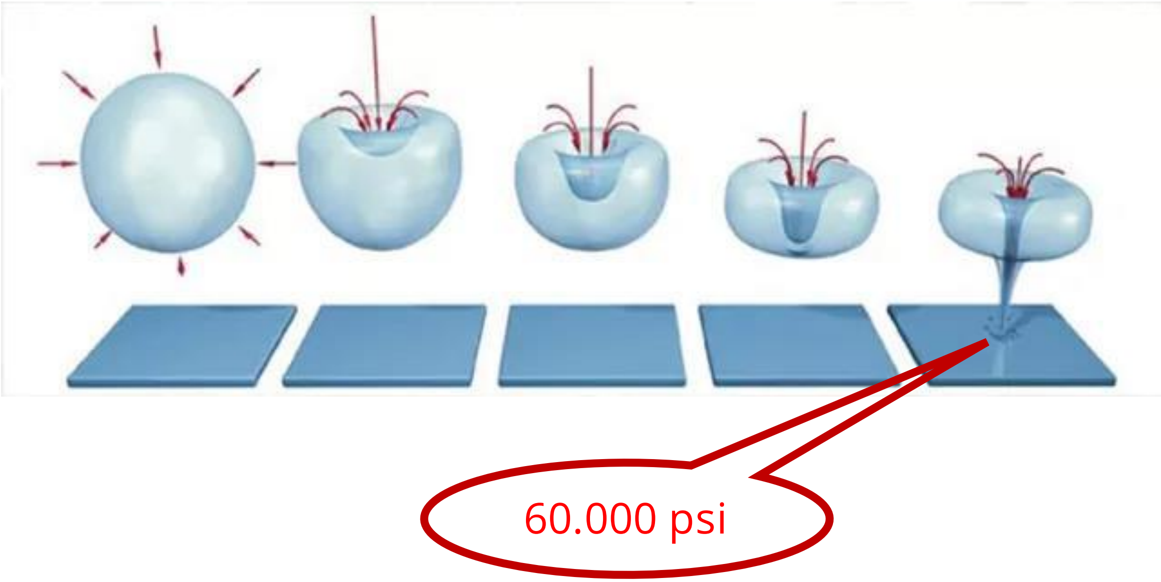
In a propeller blade profile, high local velocities can occur giving rise to low pressures that, in some cases, can reach the vapor pressure corresponding to the temperature of the water. If this happens, the water vaporizes, forming steam bubbles that are carried away by the flow.

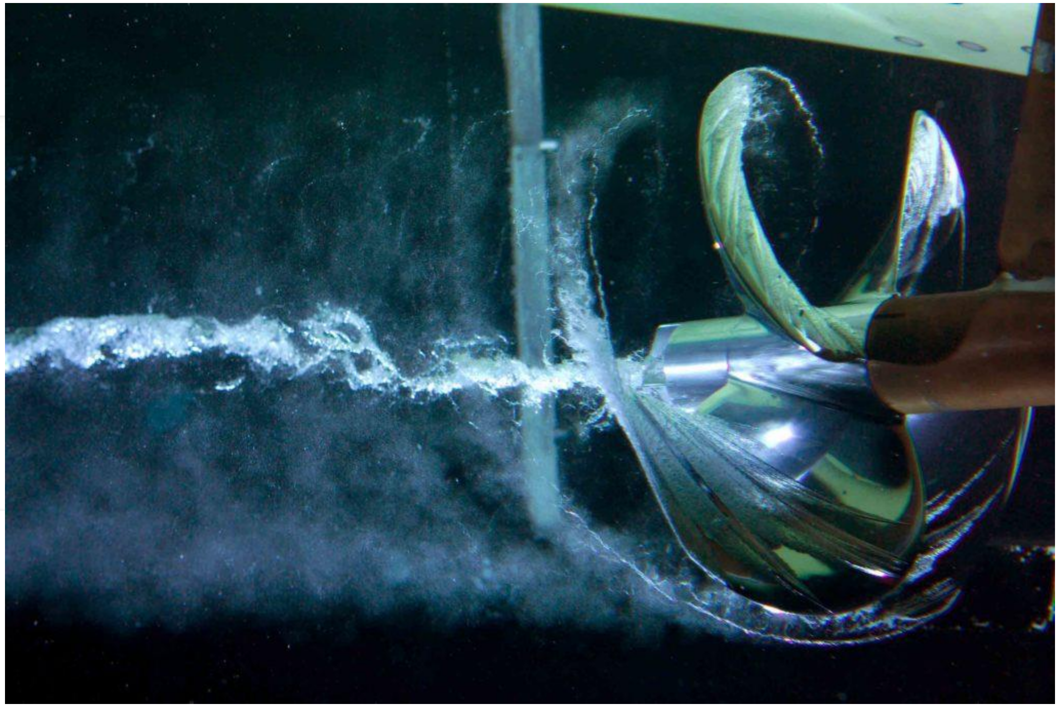


The process is reversed when reaching higher pressure zones and the bubbles collapse when they change phase again. As the vapor has a much greater specific volume than the liquid phase, an empty zone is produced that is filled with water again. In this process of collapse, high speed pressure waves are generated, resulting in noise, vibrations and deterioration of the blades.

Cavitation. Definition

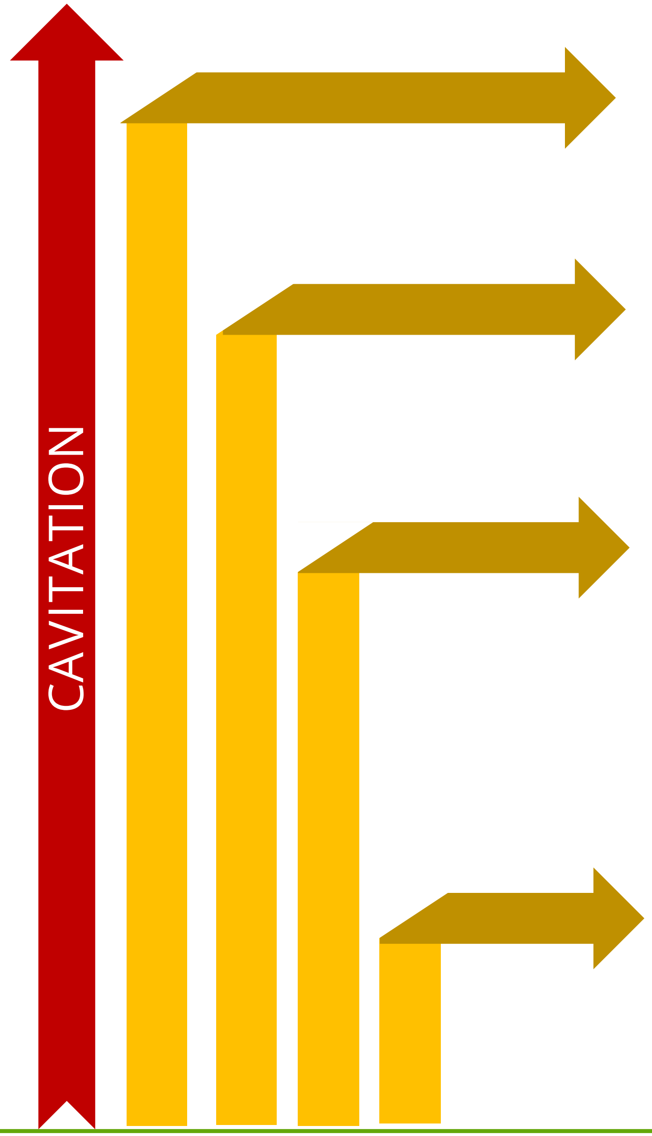
Propeller cavitation is the formation and implosion of water vapor cavities caused by the decrease and increase in pressure as water moves across the blade of a propeller.





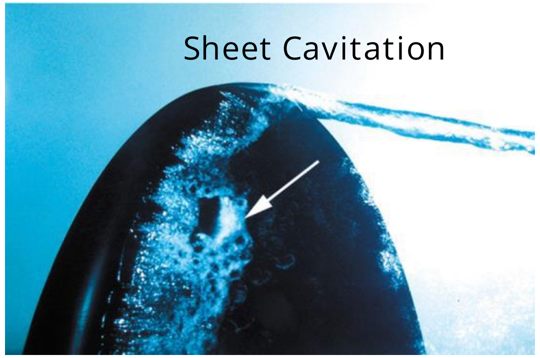
The cavitation initiation velocity (cavitation inception speed) is the lowest speed of the ship at which cavitation occurs.

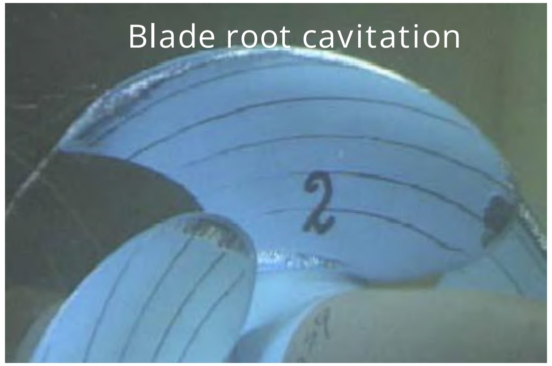
Cavitation. Effects and direct consequences of Cavitation

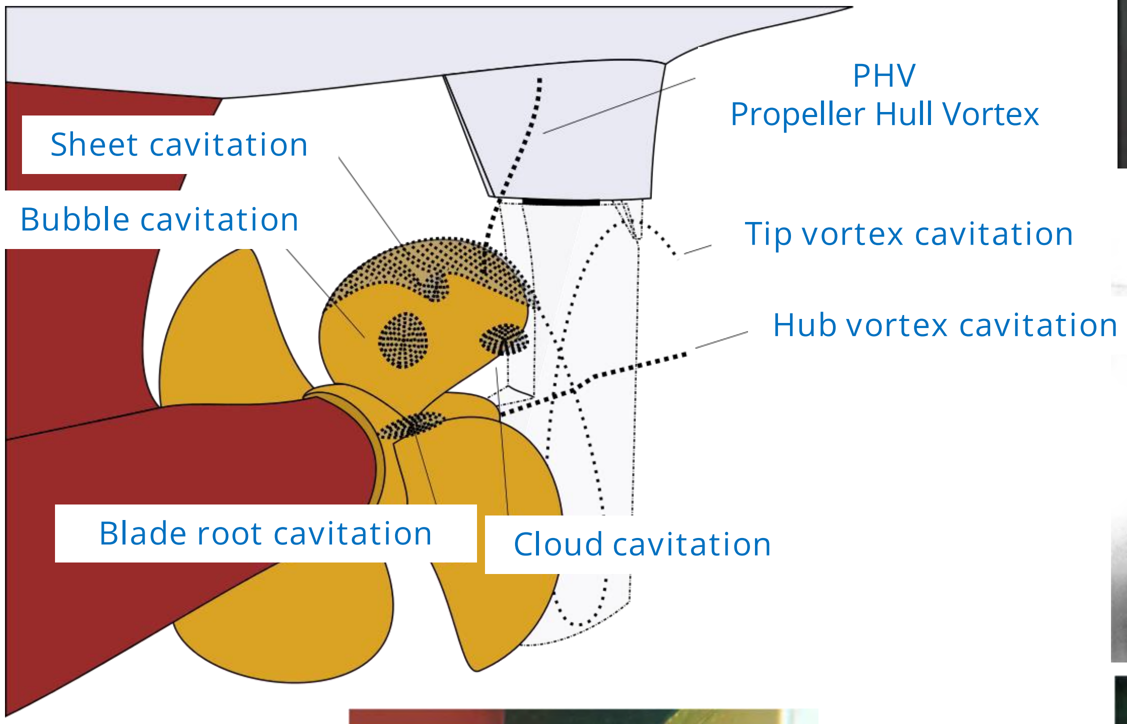


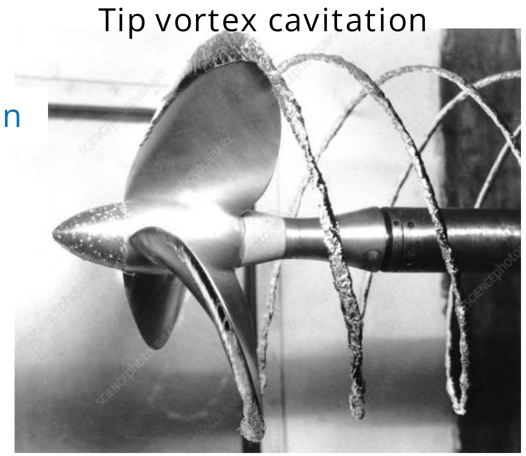
- **Losses of propulsive performance:** Disturbances of the flow, of the pressure gradient and reduction of thrust.
- **Increased maintenance costs:** Damage and erosion to propeller blades, rudder and appendages.
- **Reduction of comfort conditions aboard the ship:**
  - Significant increase on the vibration levels in the ship due to the increase in pressure pulses.
  - Significant increase on the structural and airborne noise in the spaces of the ship.
- **Increased on the underwater radiated noise by the ship and deterioration and reduction of "stealth".**

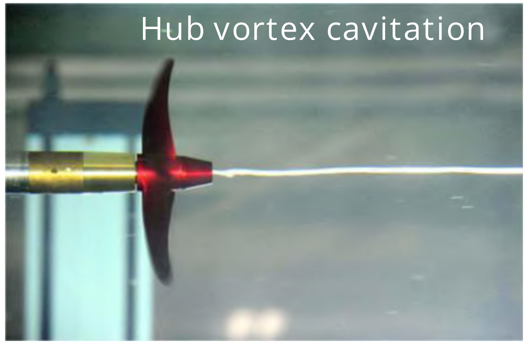
Cavitation. Types







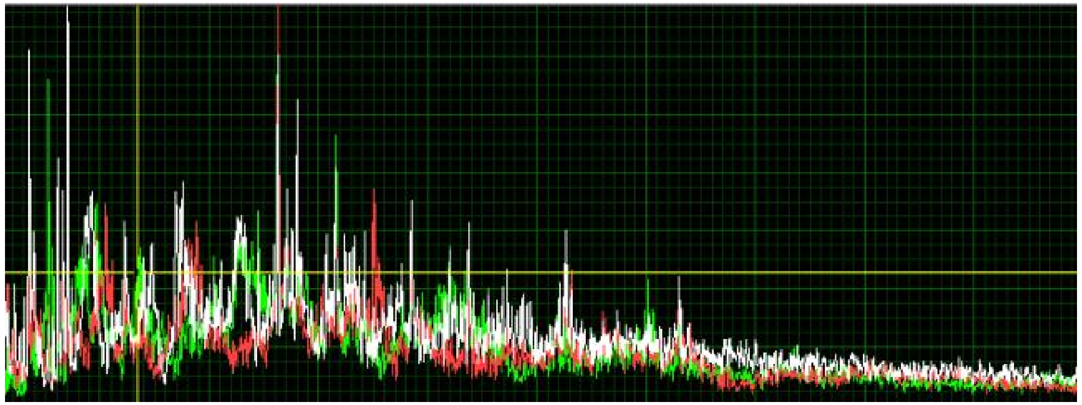


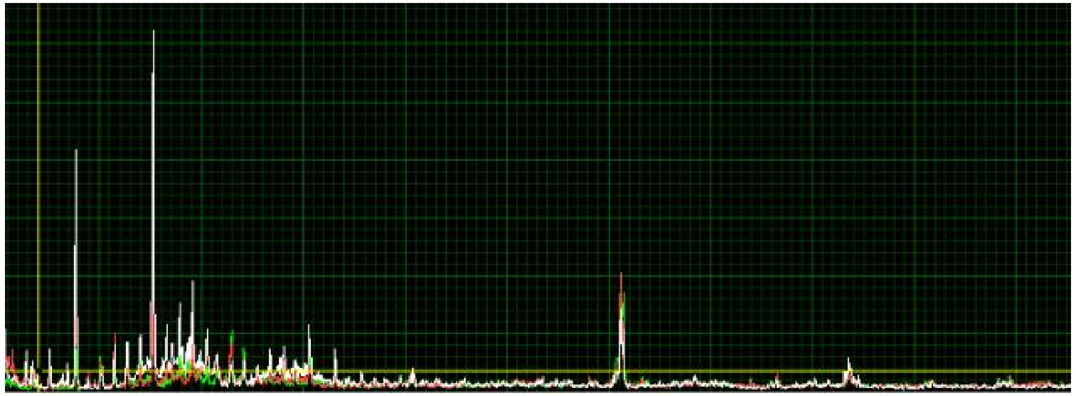


Cavitation. Cavitation & Noise

The noise and vibrations generated in the ship by cavitation have the following characteristics:

- Broadband (random) noise, caused by the growth and collapse of a large number of individual cavitation bubbles in water.





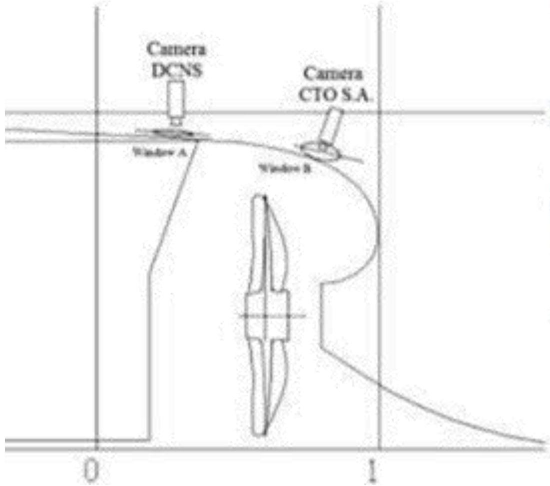
Noise at the tonal frequencies of the blade pass frequency and its different broadband harmonics (random) are caused by the volume fluctuations of the blade vortex cavities and blade tips.

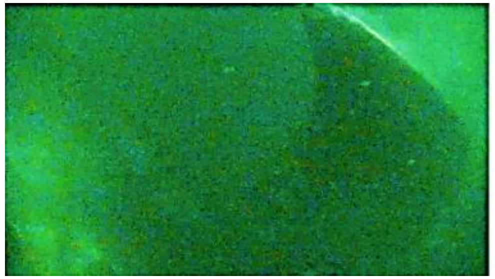
Cavitation. Damage due to Cavitation

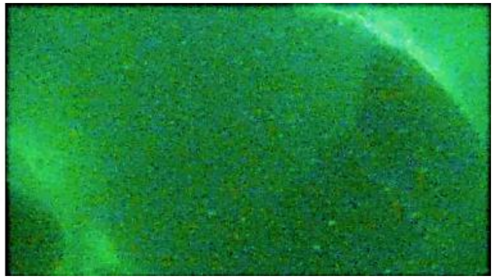
Cavitation. Current visualization methods

All of them require important modifications in the structure of the ship and/or external means that impair the performance of the hull.

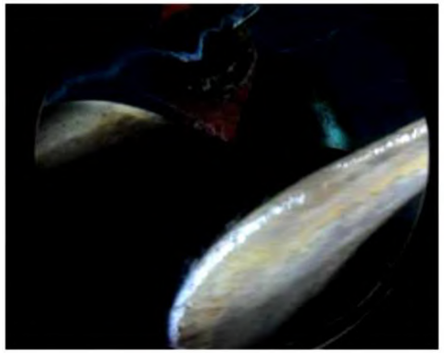
Temporary windows



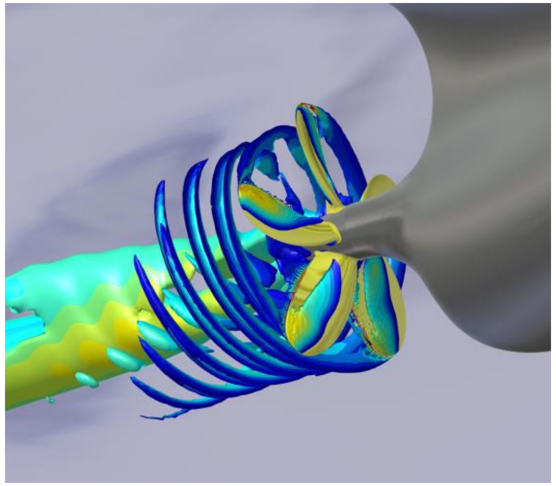


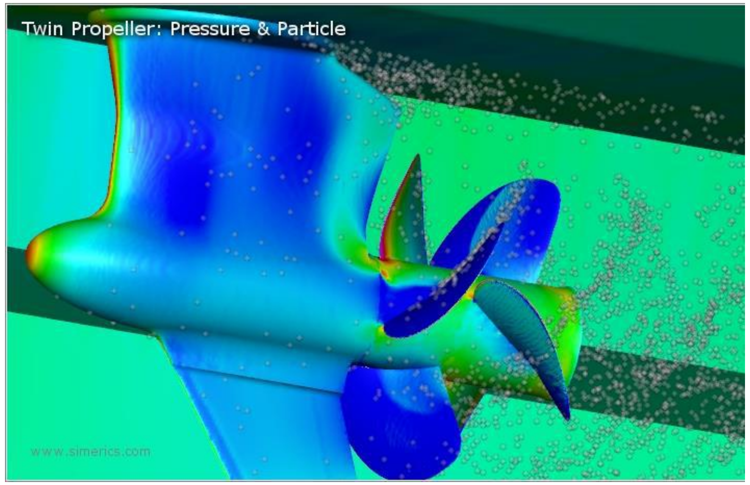


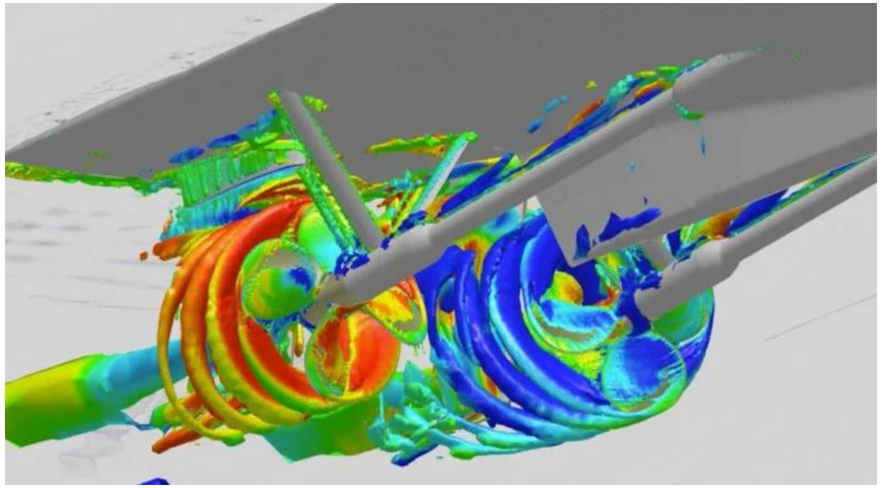
Cameras outside of the hull

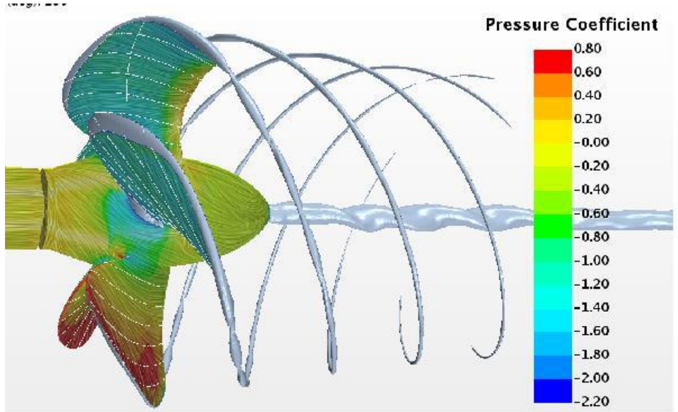


Cavitation. *"State of the Art"*

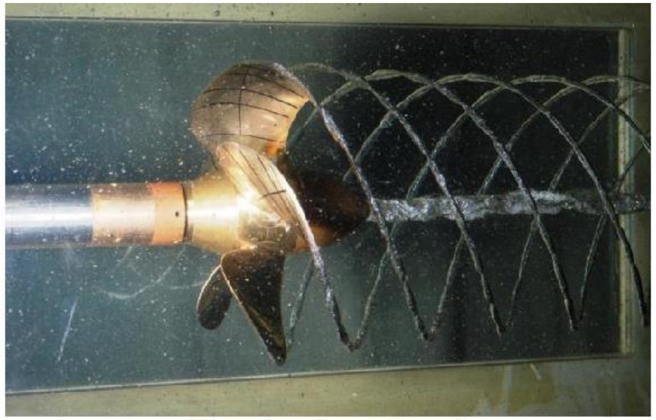








CFD ("open water" domain, corrected J=0.995)



Experiment, cav. tunnel

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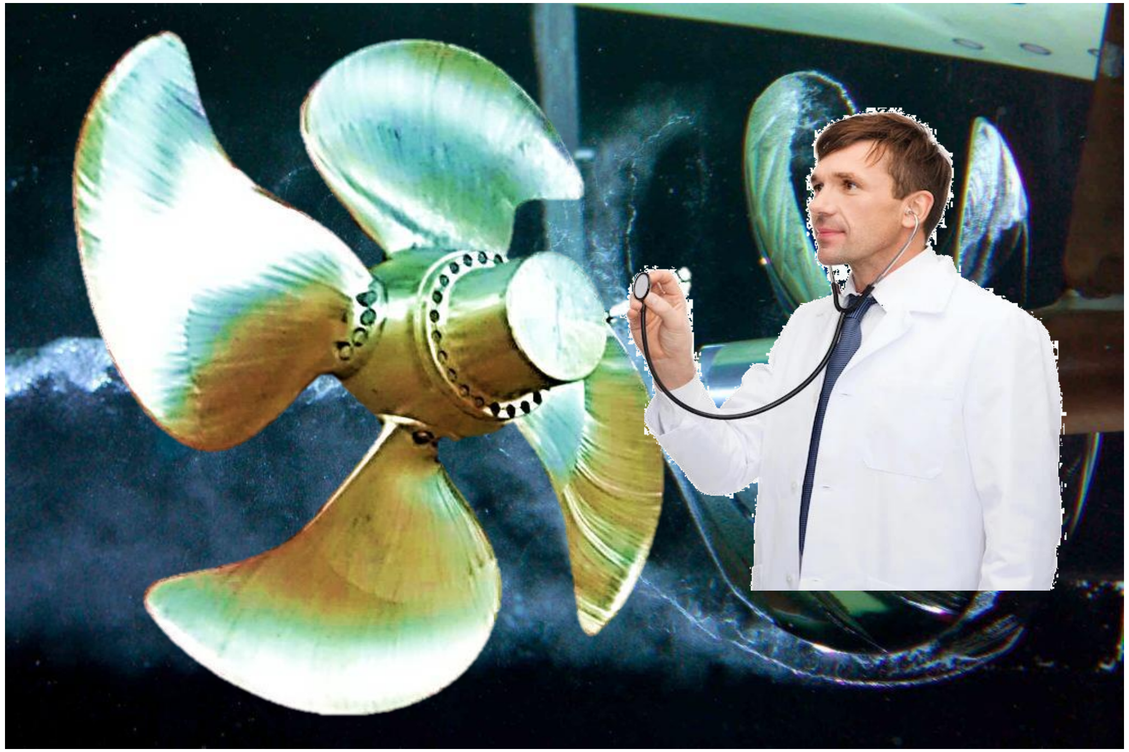
Cavitation. *The problem still persists*

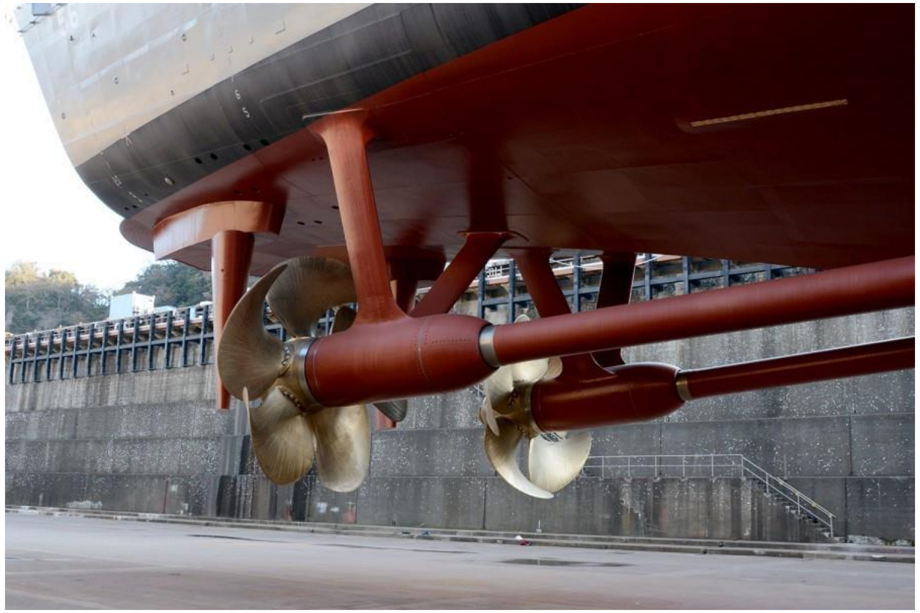
If we cannot eliminate Cavitation and its consequences...



Let's control it!

Cavitation. Its Control

For a given design, *the control of propeller cavitation* includes, among others, the following aspects:



When does **cavitation** start?

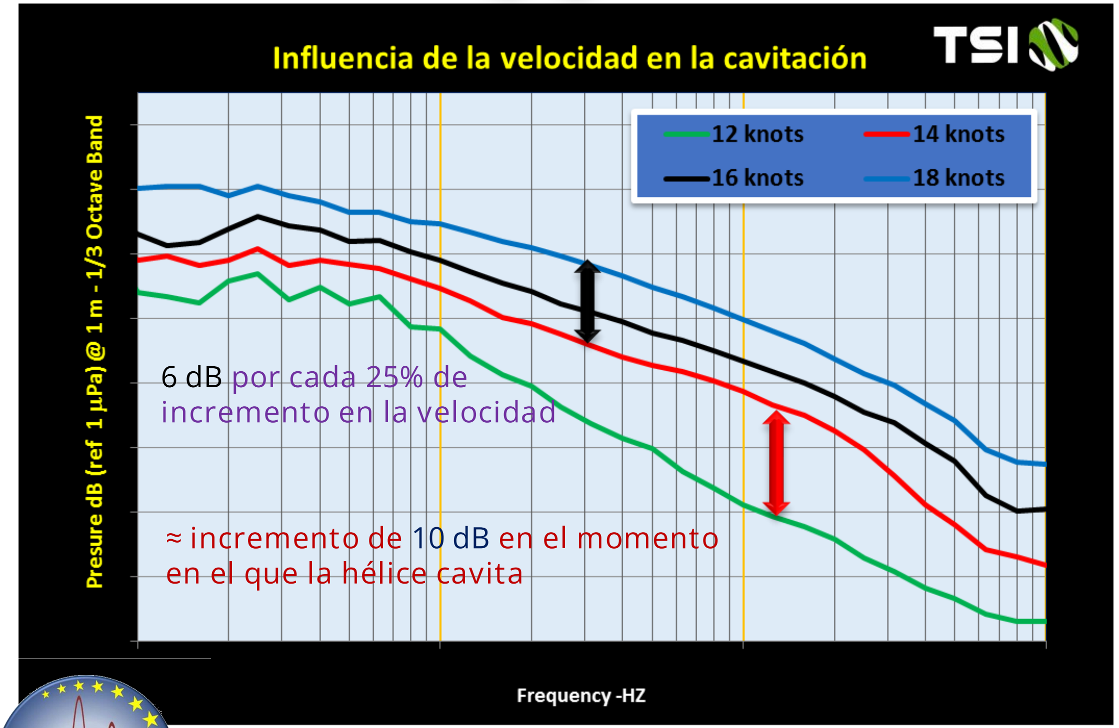
How **intensely** does it occur?

Under what ***operating conditions*** does it take place?

What are the **parameters** that allow its **identification**?

Cavitation. Its Control. Identification parameters

The Acoustic Signature



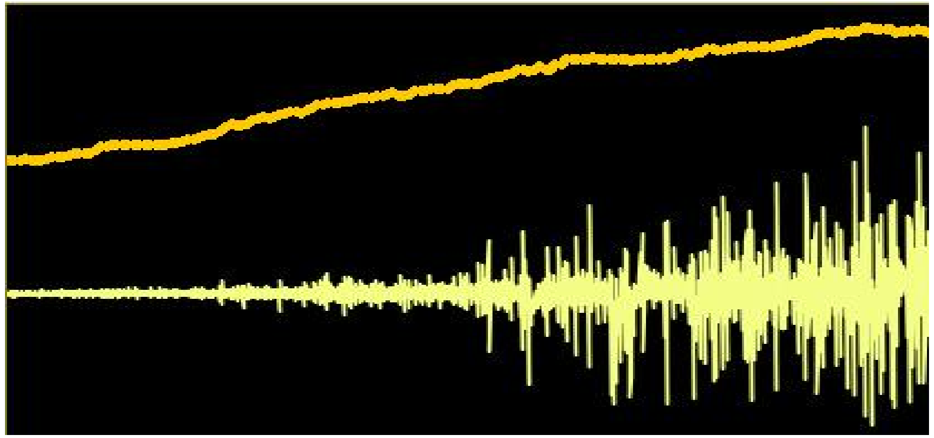
- It would allow to identify the cavitation.
- Approximation to quantifying its severity.

But…..

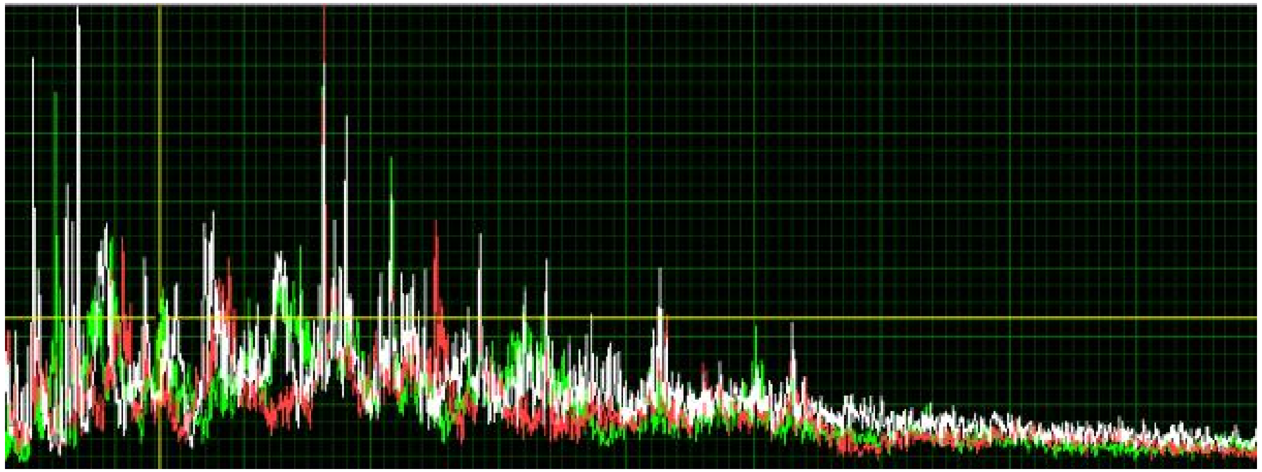
- It would require intervention in the hull of the ship.
- Very sophisticated equipmen.

Cavitation. Its Control. Identification parameters

Noise / Vibrations



Vibrations in the ship's structure due to the increase in pressure pulses.



Structural noise (4500 m/s) in the steel due to the “random” excitation induced by the implosions of the bubbles.

Cavitation → Vibrations / Structural Noise

Cavitation Control. System Requirements

- Know **when and how** the ship's propellers cavitate, in order to adapt to the limitations established in those navigation areas where it is necessary. In this way it will be achieved:
  - Preserve the marine environment.
  - Avoid damage on propeller and propulsion system.
  - Limit excessive emissions due to loss of performance.
- **Easy installation**, with zero impact on the availability of the ship.
- **Without modifications** to the hull or its structure.
- **Adaptable** to any type of ship, regardless of its size and/or function.
- *With the ability to collect data from all possible navigation situations*

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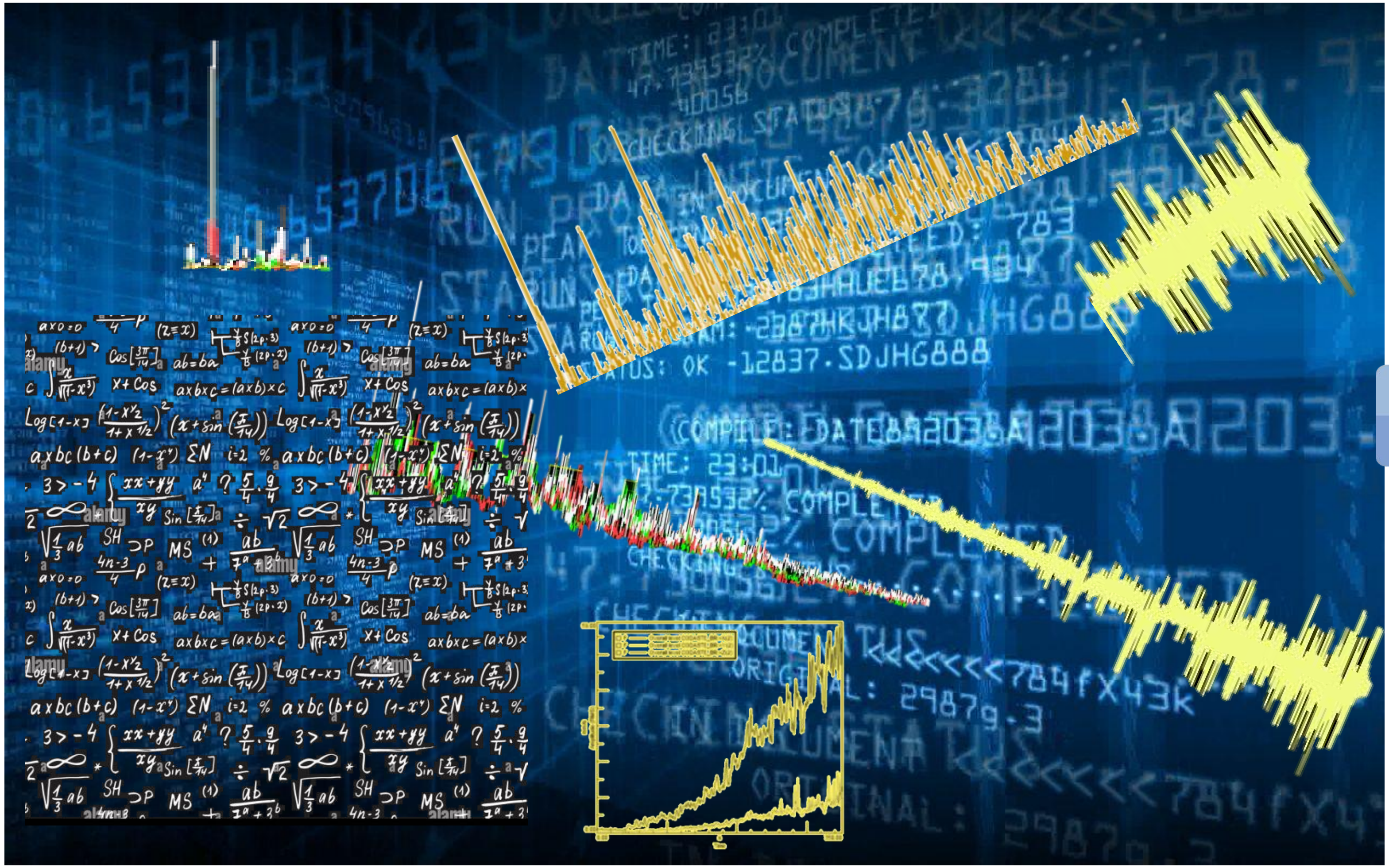
Cavitation Control. The System

After 5 years of private investigation…..



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Cavitation Control. The System

Ni-CDS

Non-intrusive
Cavitation Detection
System

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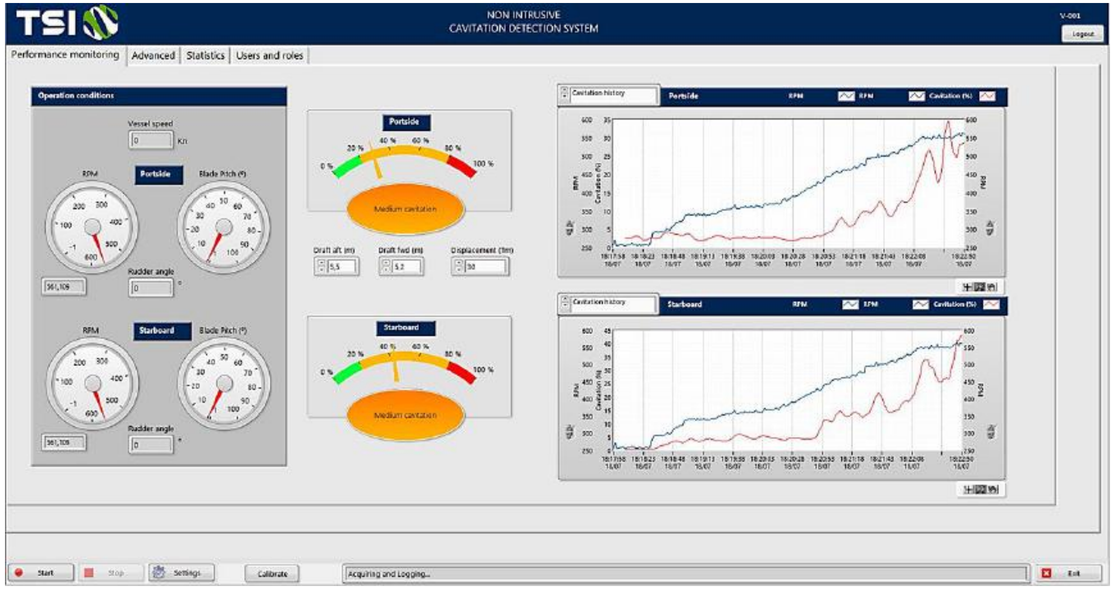
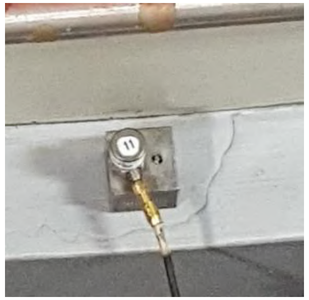


Cavitation Control. Ni-CDS. System components

Instrumentation

Accelerometers installed in the internal structure of the ship.

Tachometer in the shaft line.



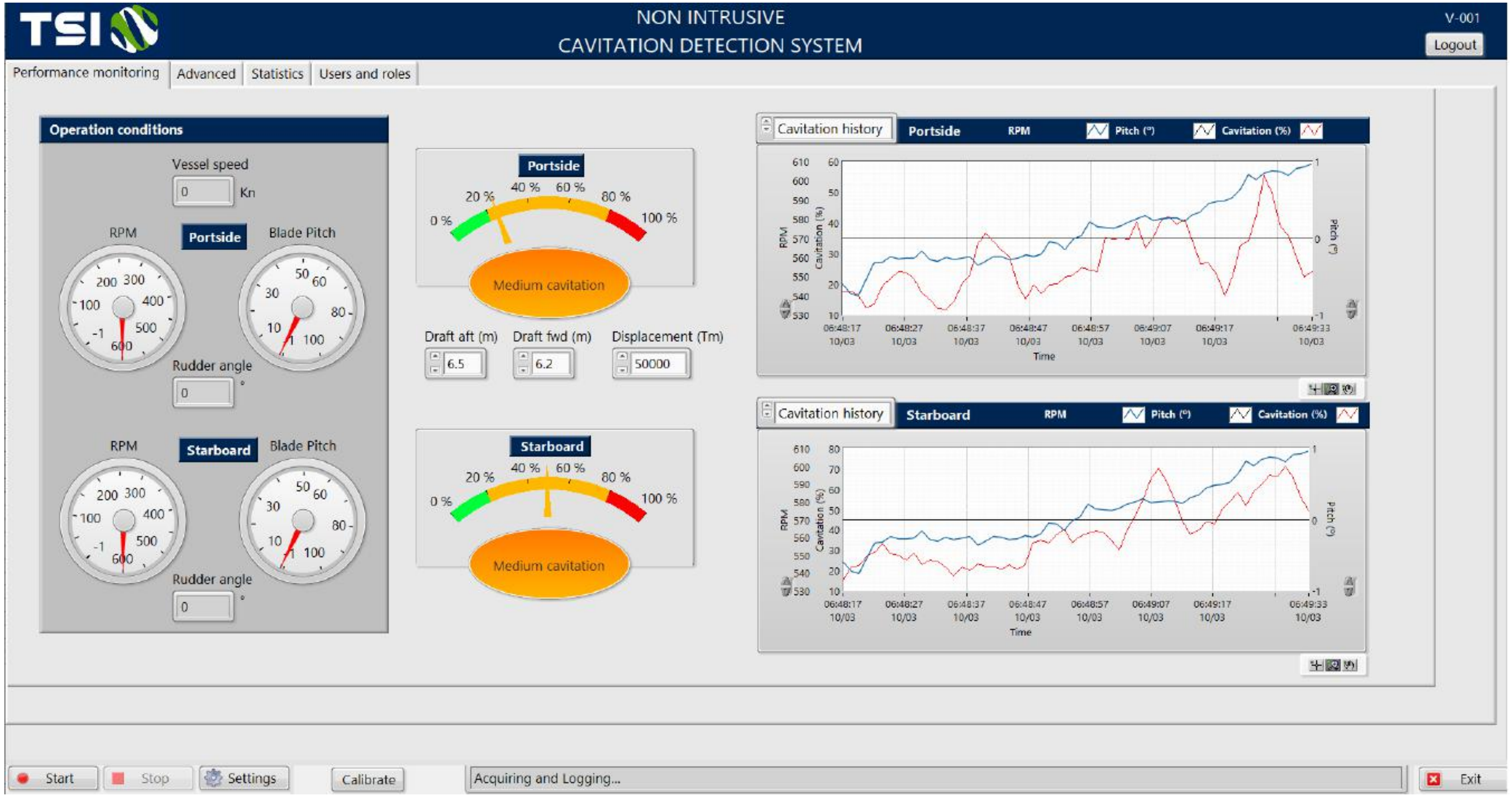
Data Acquisition System

Signal acquisition and processing system. It allows the entry of static parameters:

- blade pitch,
- rudder angle,
- ship speed, etc.

Cavitation Control. Ni-CDS. System components

Graphical Display



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Cavitation Control. Ni-CDS. System Architecture

Inputs

Data Processing and detection

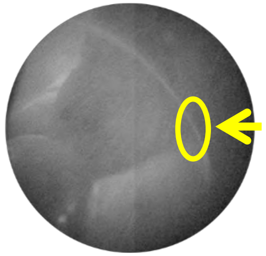
Outputs

Quasi-static parameters: θ BP, φ Rudder, etc

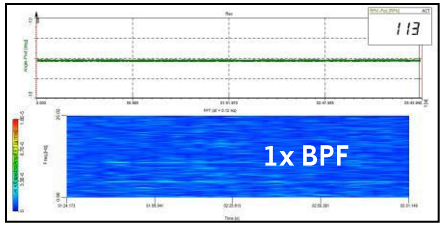
Type: Analog, Modbus TCP

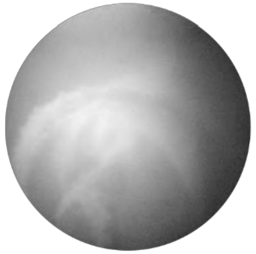
RPM

Accelerometers

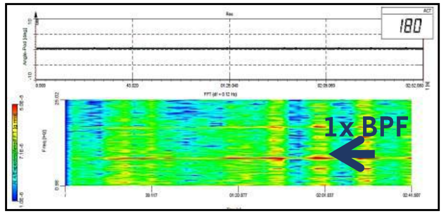


Vortex cavitation

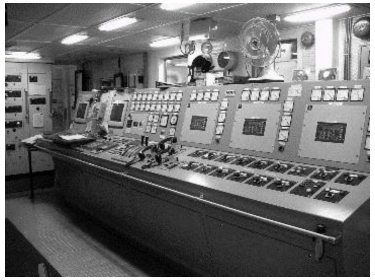




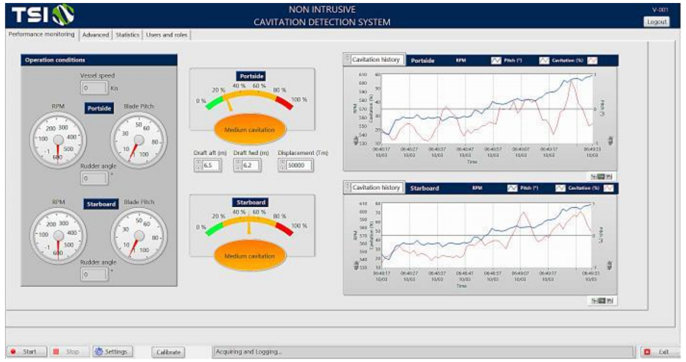
Cloudy cavitation



Screen in bridge



Screen in engine control room



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Cavitation Control. Ni-CDS. Main features

- Standalone or integrated configuration into the bridge navigation systems or the engine control room.
- Quick integration of the electronic and display units.
- Visual/acoustic alarm and graphic displays at the bridge navigation systems and engine control room.
- Identification and continuous monitoring of propellers' cavitation condition.
- Data collection for statistical purposes and production of a database with the propellers' behavior history.
- Supports to ensure reliable propellers operation.
- Calibration to adapt the algorithm parameters to the specific operating conditions of each vessel.
- Report generation, data export and remote access to data.
- Flexible and customizable to customer's needs.

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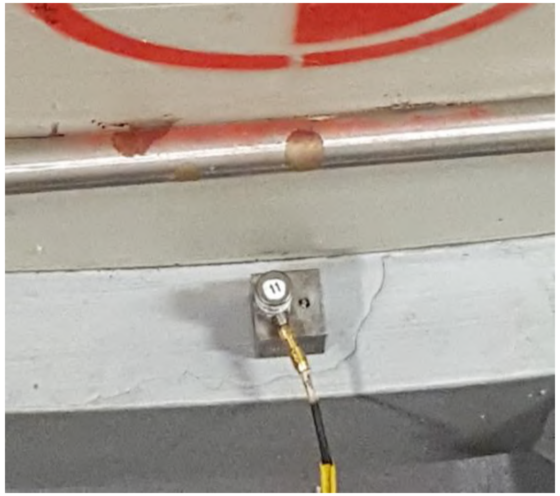
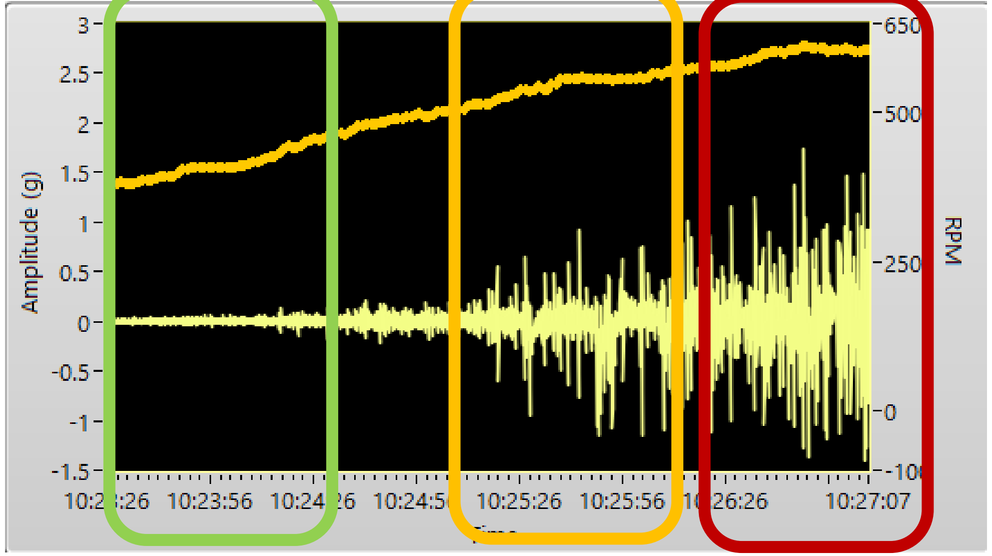
Cavitation Control. Ni-CDS. Main Benefits



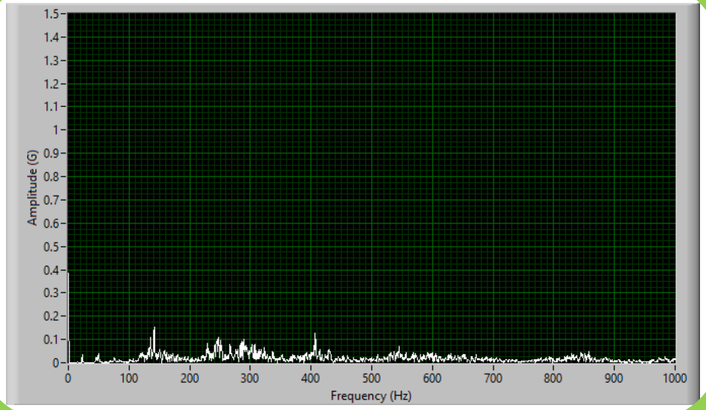
- Increased lifetime of cavitation-affected elements: rudder, propeller, etc.
- Accurate control of cavitation intensity, allowing navigation in noise restricted areas.
- Reduction of on board vibration level.
- Reduction of the underwater radiated noise signature.
- Optimization of the vessel performance in terms of emissions of and fuel consumption.
- Detection of undesirable operating conditions.
- Non-intrusive installation.
- Control of "silent modes" for Military sub-surface ships and submarines.
- Cost-effective system.

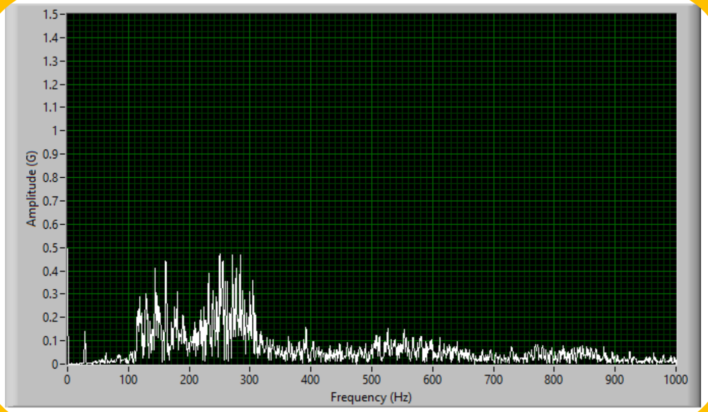
Cavitation Control System. Fundamentals & Operating mode

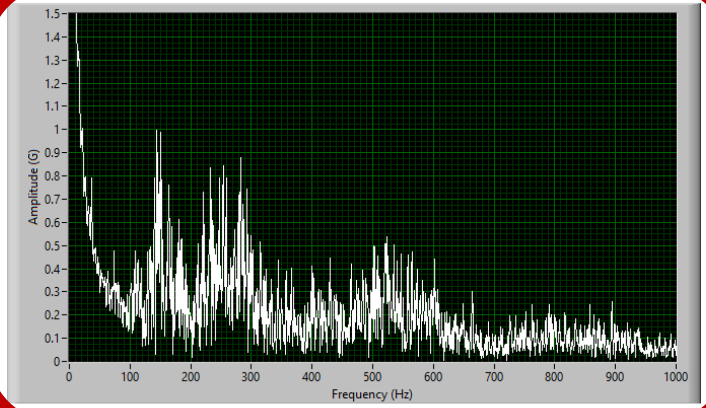


Time signal

Vibrations







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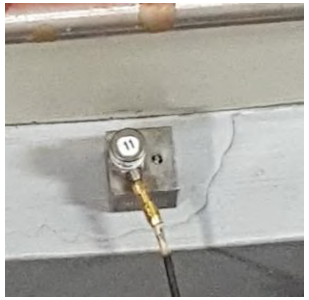
Cavitation Control System. Fundamentals & Operating mode



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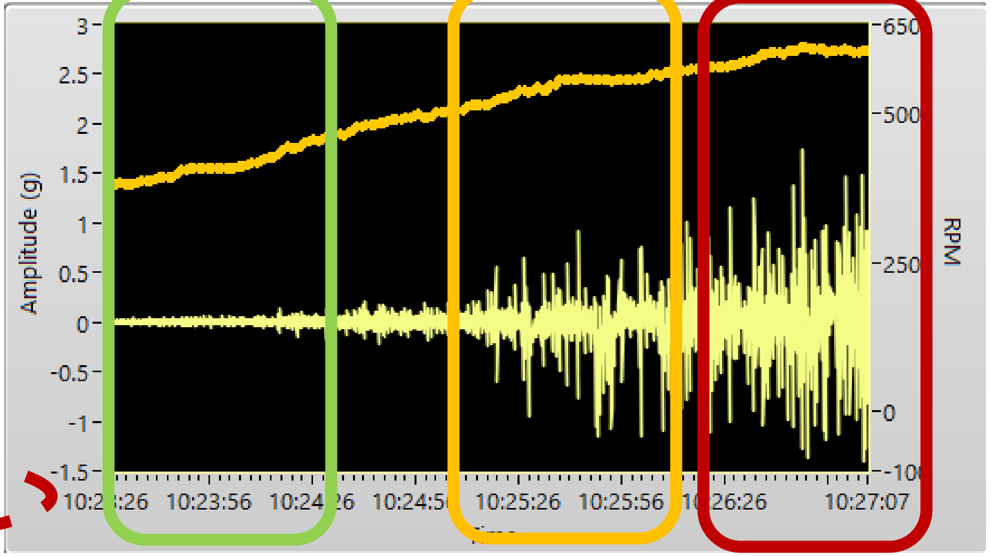
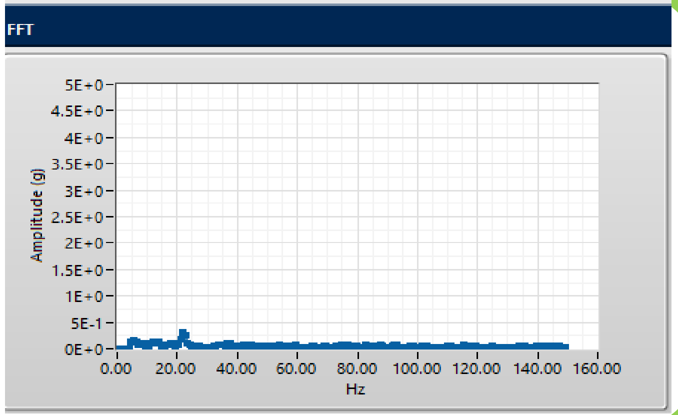
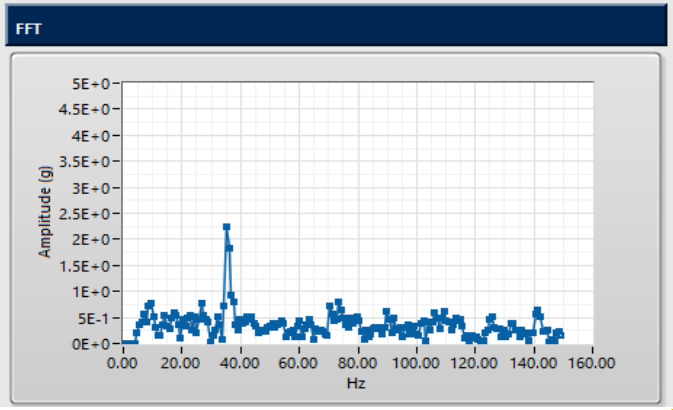
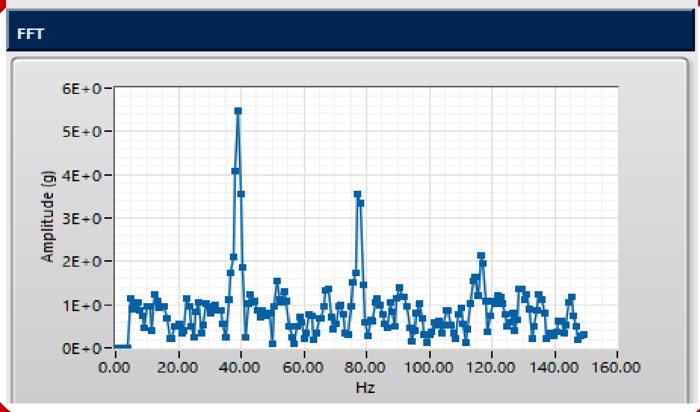
Cavitation Indicator



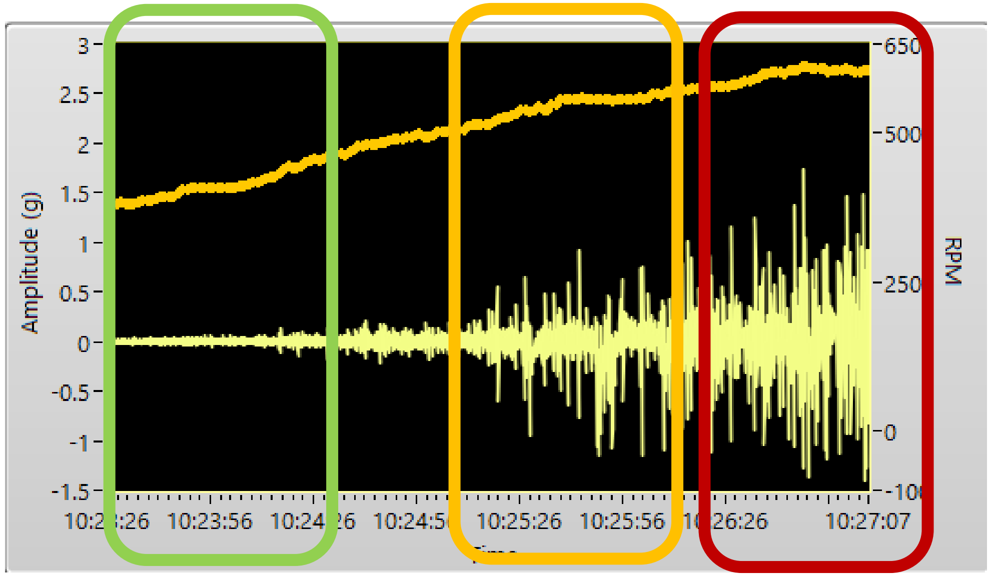
Time signal





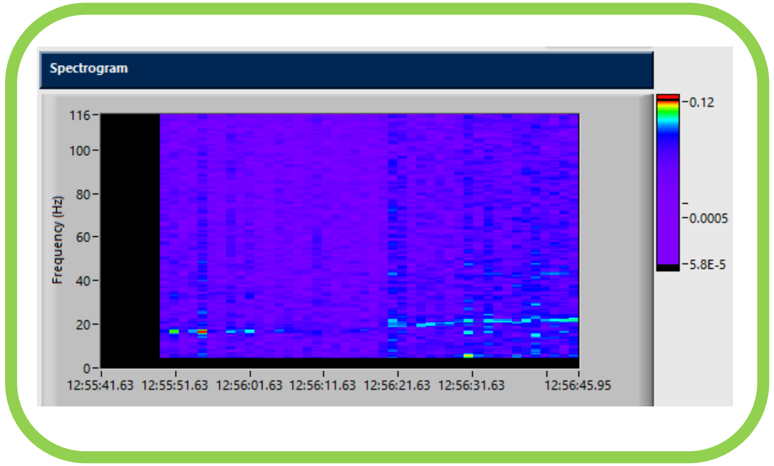


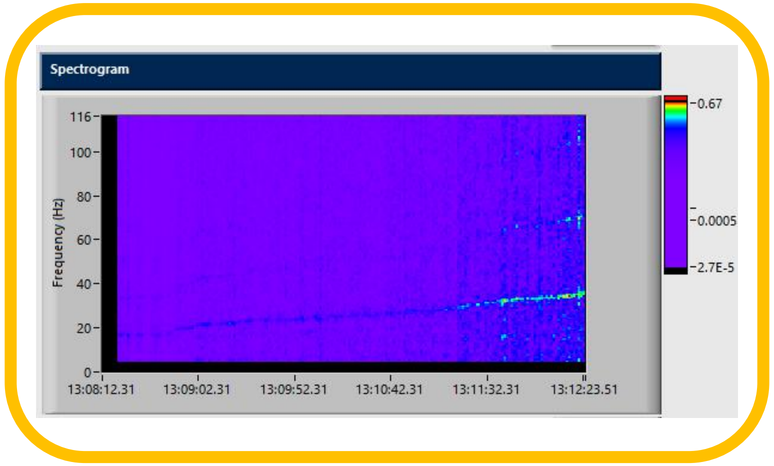
Cavitation Control System. Fundamentals & Operating mode

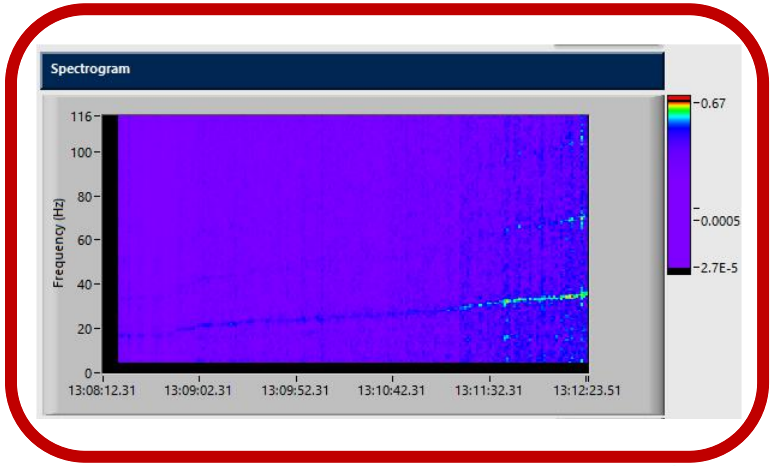


Time signal

Spectrogram







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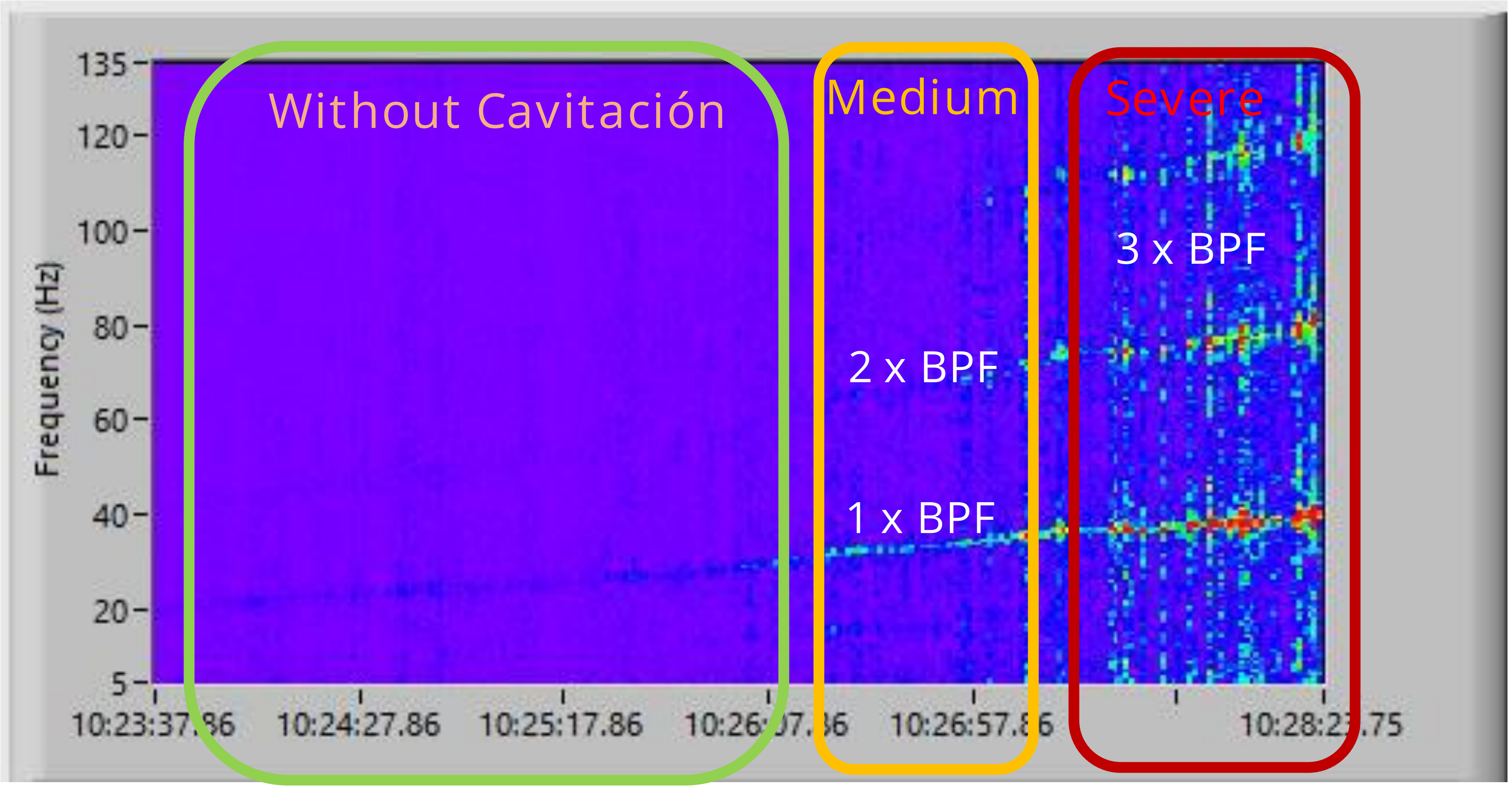
Cavitation Control System. Fundamentals & Operating mode



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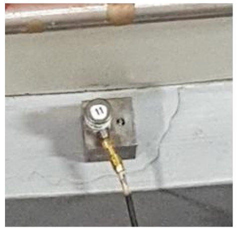
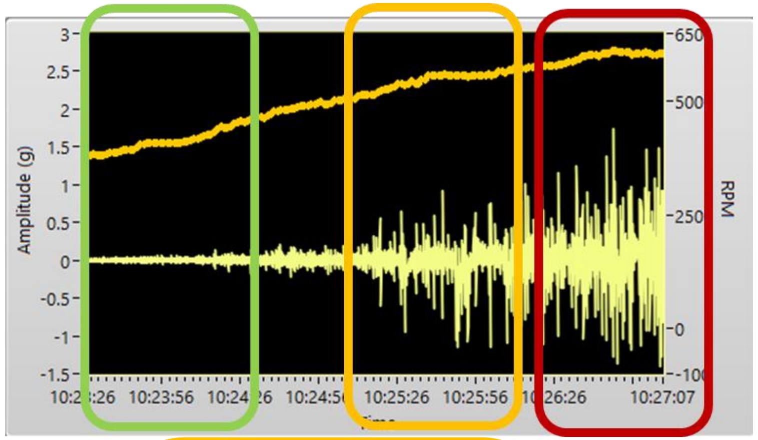
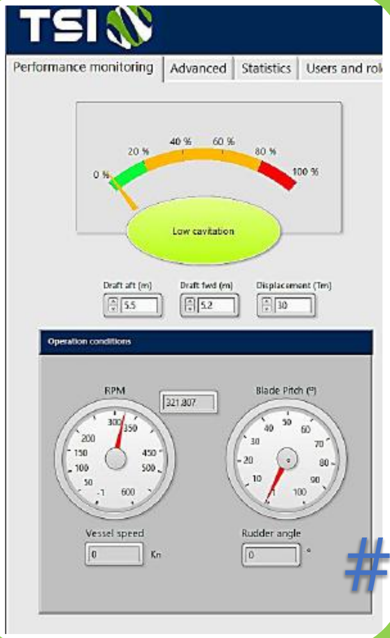
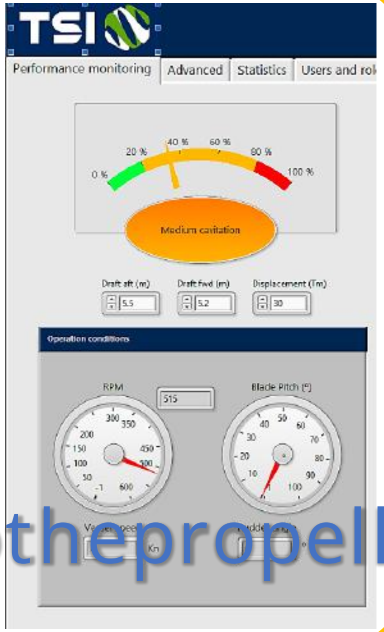
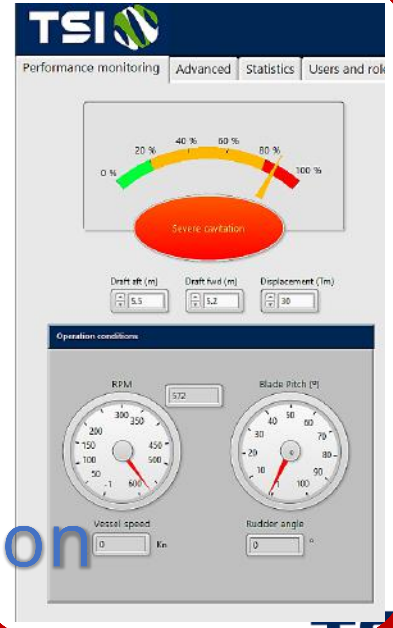
Cavitation Control System. Fundamentals & Operating mode







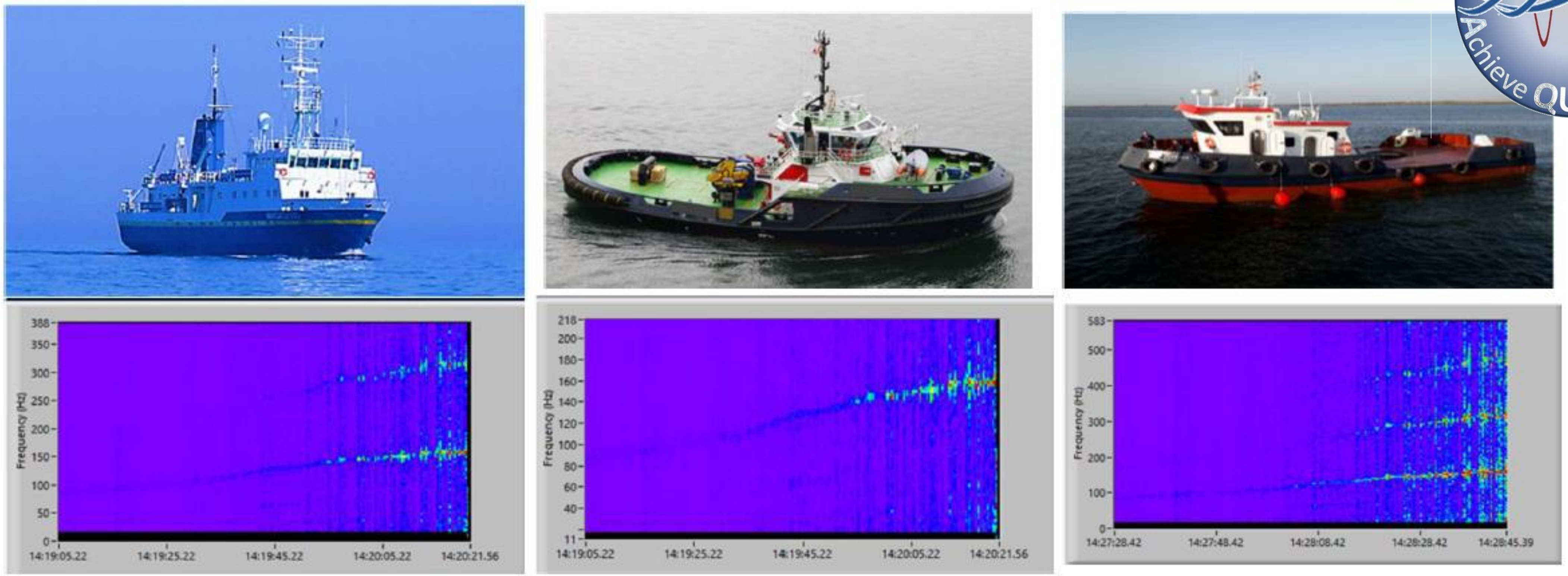




#listeningtothepropellercavitation

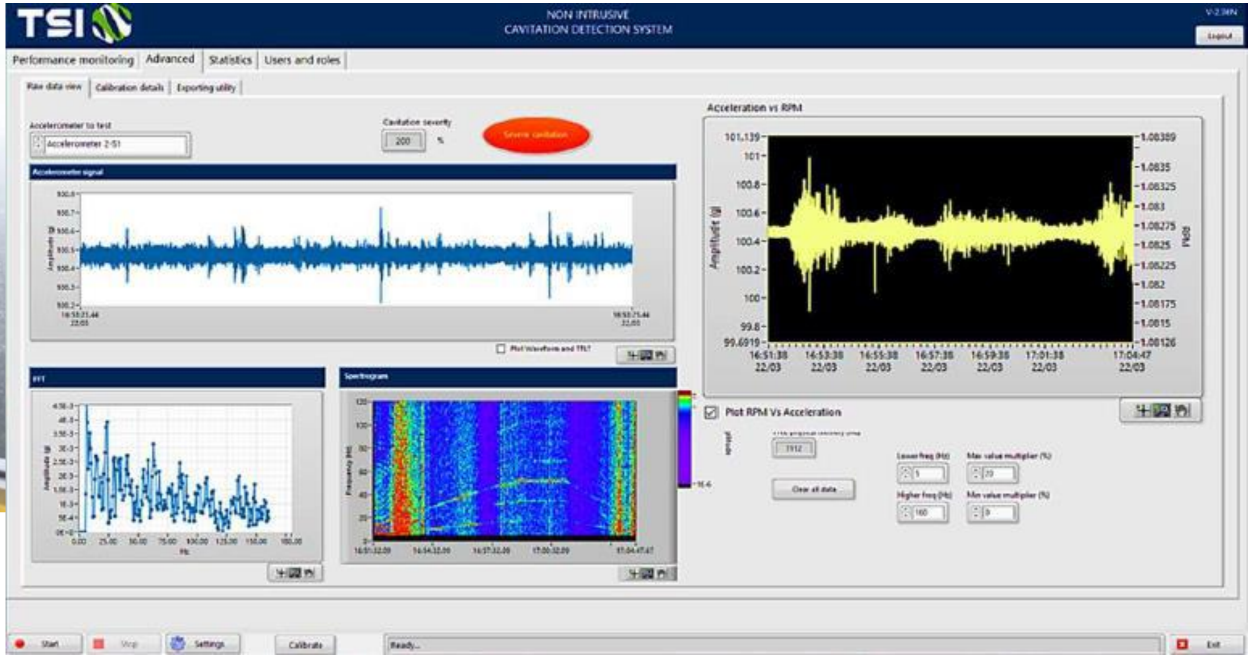
D. Publio Beltrán / D. Richard García / D. Luis Piqueras

Cavitation Control System. Experimental Validation



*Note: For confidentiality, the vessels in the image do not correspond to the spectrograms.

Cavitation Control System. Experimental Validation



Validation at INTA-CEHIPAR- Canal de Experiencias Hidrodinámicas de El Pardo
(Pending completion)

Cavitation Control System. Experimental Validation

VIII CONGRESO INTERNACIONAL DE DISEÑO E INGENIERIA NAVAL

Saturn
Developing Solutions for Underwater Radiated Noise

Last Experimental Validation (November 2022) within the framework of the SATURN Project, H2020 program, on the ship "Ángeles Alvariño", owned by the Spanish Institute of Oceanography.

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Conclusions

In view of:

- The impossibility of eliminating cavitation, its consequences and costs,
- The growing pressure from the Scientific Community, International Organizations (IMO) and States (Flags), to reduce noise in the Oceans,
- Shipowners' Requirements for Reduction of Noise Radiated into the Water by Vessels,
- Strategic value of the "Stealthy" in military ships,

The first non-intrusive system for continuous control of cavitation in terms of *"identification"* and *"quantification of its severity"* is available, with all the advantages that this entails:

Reduction of consumption, emissions, maintenance costs and impact on the Environment and Marine Fauna.

Developed and funded by an SME in the Spanish Maritime Sector!

Hope You enjoyed the Presentation.

Many Thanks for your attention!

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