J. Szantyr – Lecture No. 8 – Influence of Cavitation on the Operation of Fluid Flow Machinery

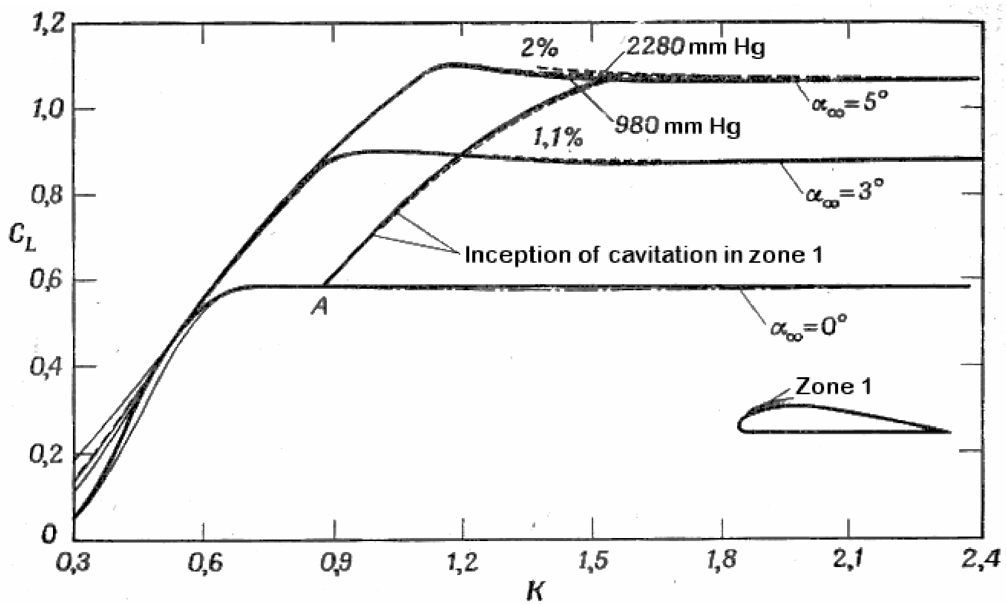
Cavitation has a negative effect on the operation of fluid flow machinery, causing the following unfavourable consequences:

- decrease of efficiency of fluid flow machines

- erosion of elements of fluid flow machines

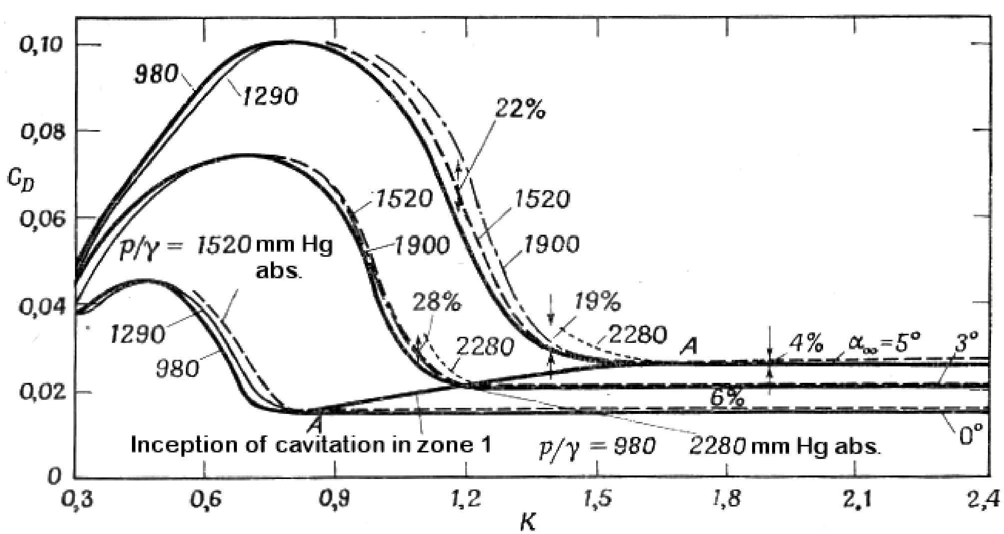
- generation of vibration and noise

Reduction of efficiency of machines



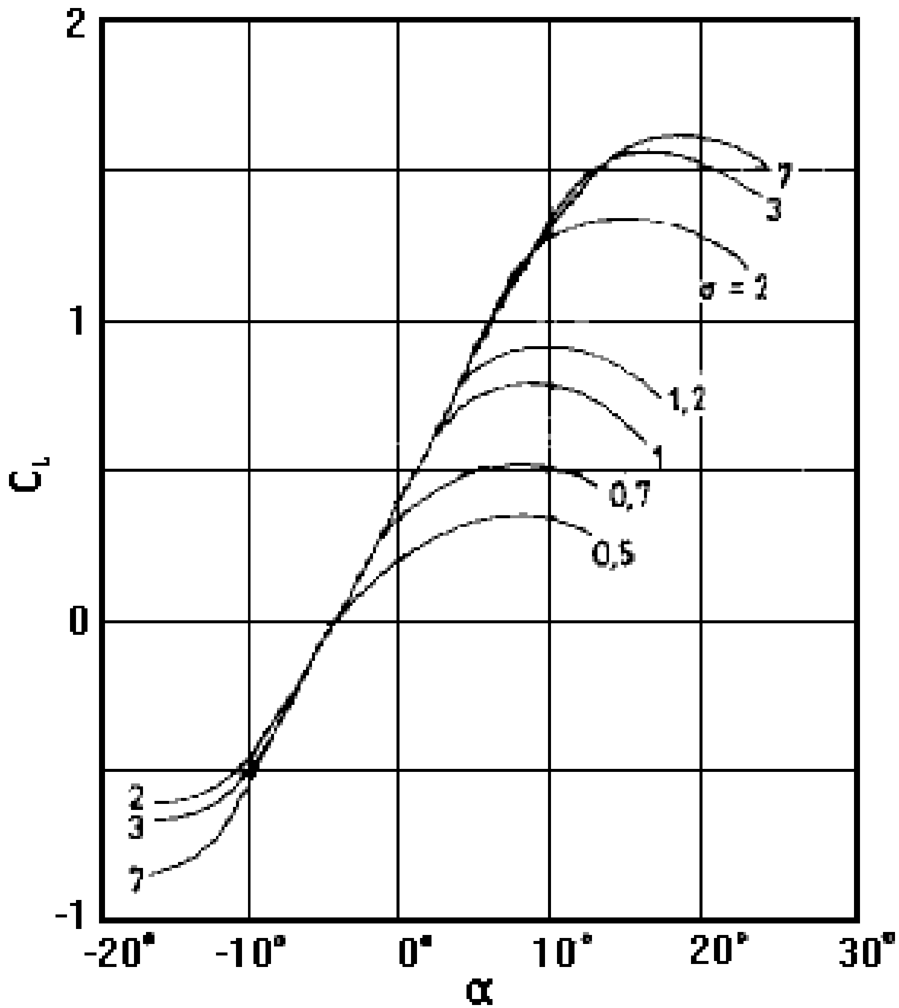
$$K=\sigma=\frac{p_0-p_v}{\frac{1}{2}\rho v^2}$$

←Cavitation modifies the pressure distribution on the lifting foils and reduces lift force (after initial small increase).



←Cavitation increases hydrodynamic drag of the lifting foils

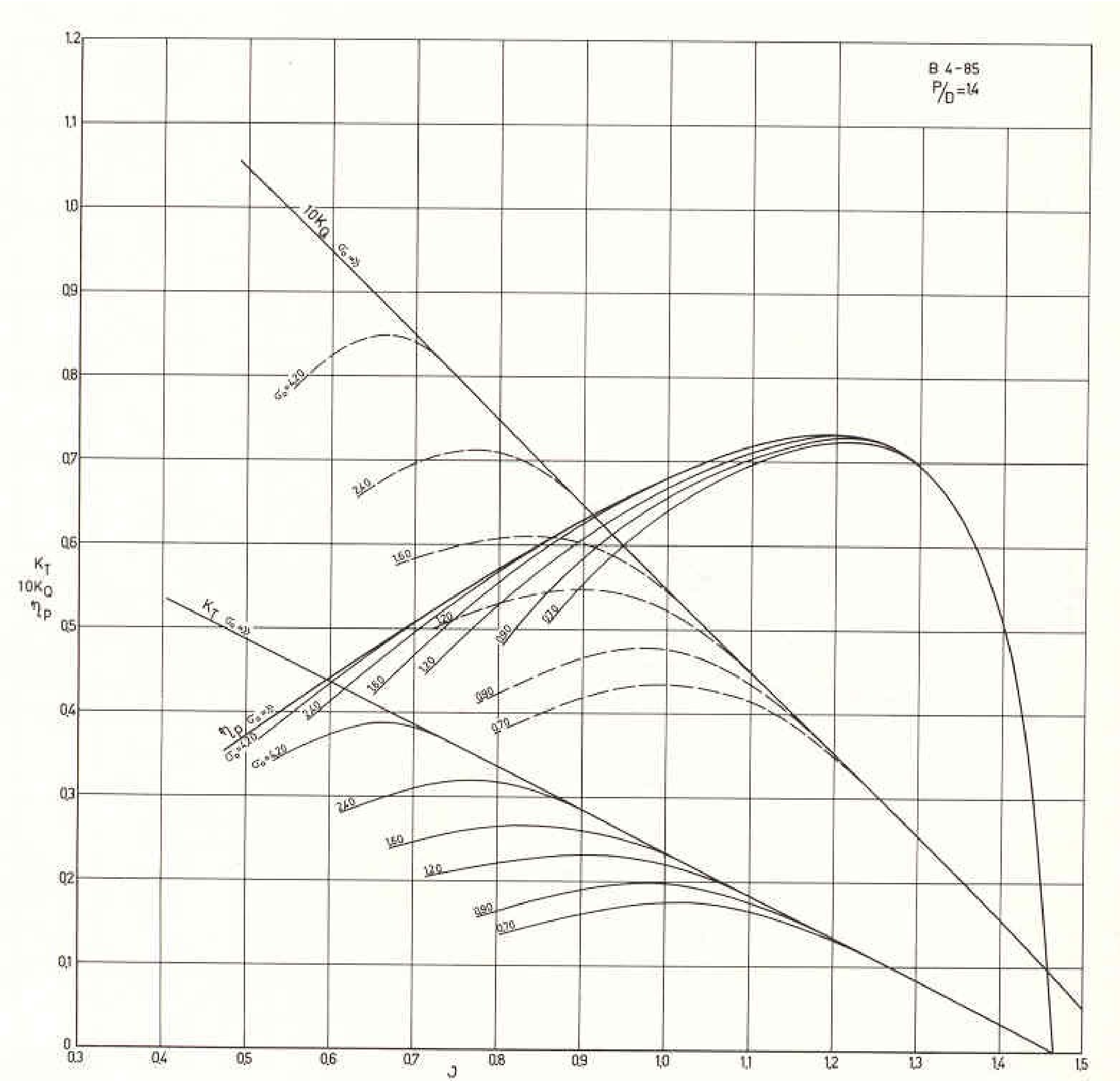
Reduction of efficiency of a lifting foil



$$\sigma = \frac{p_0 - p_v}{\frac{1}{2}\rho v^2}$$

Dependence of the lift coefficient C_l on the cavitation number σ for the NACA 4418 airfoil

Influence of cavitation on the marine propeller efficiency



The diagram shows dependence of marine propeller thrust, torque and efficiency on the advance coefficient and cavitation number.

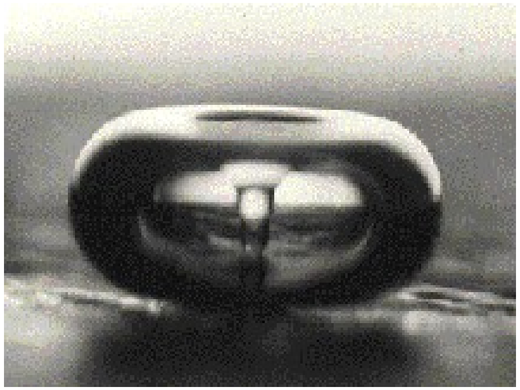
$$K_T = \frac{T}{\rho n^2 D^4}$$

$$K_Q = \frac{Q}{\rho n^2 D^5}$$

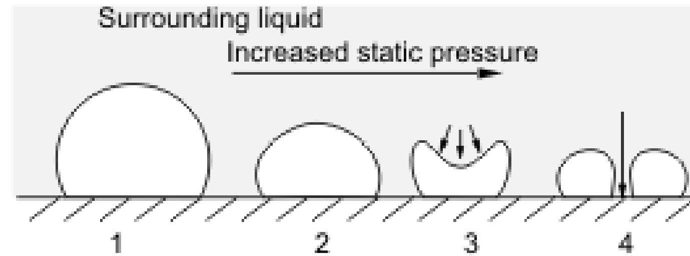
$$J = \frac{V}{nD}$$

$$\sigma = \frac{p - p_v}{1/2\,\rho V^2}$$

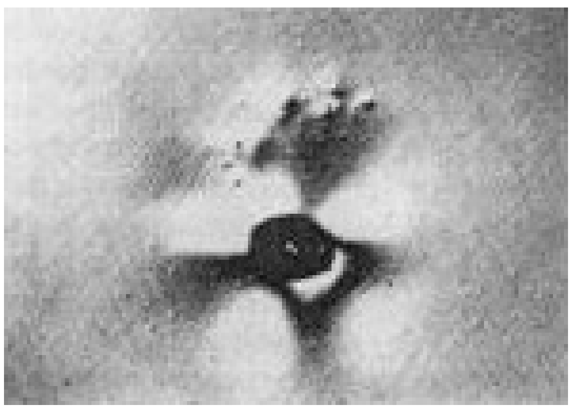
Erosion of the elements of fluid flow machinery



← Erosion is caused by cavitation bubbles imploding in the vicinity of elements of fluid flow machinery.

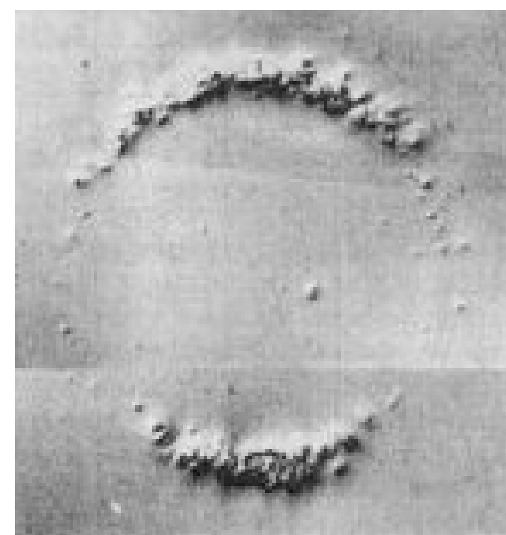


Cavitation bubble imploding close to a fixed surface generating a jet (4) of the surrounding liquid.



← At a very small distance from the wall the single erosion mark is caused by the stream of liquid shooting through the imploding bubble

At a larger distance from the wall the toroidal imploding bubble disintegrates into a ring of small bubbles, which implode individually and leave a toroidal erosion mark→



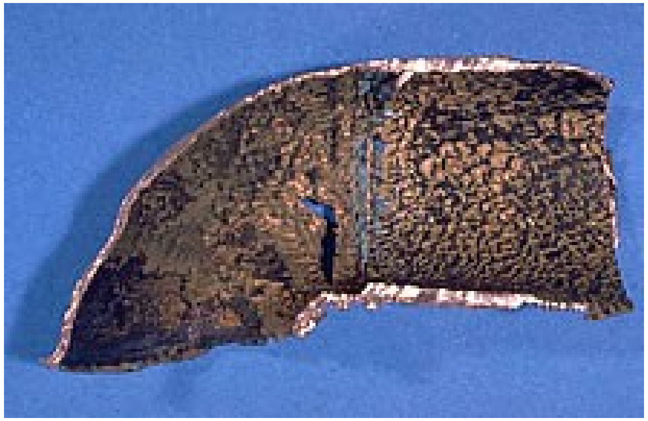
Examples of cavitation erosion damage to ships

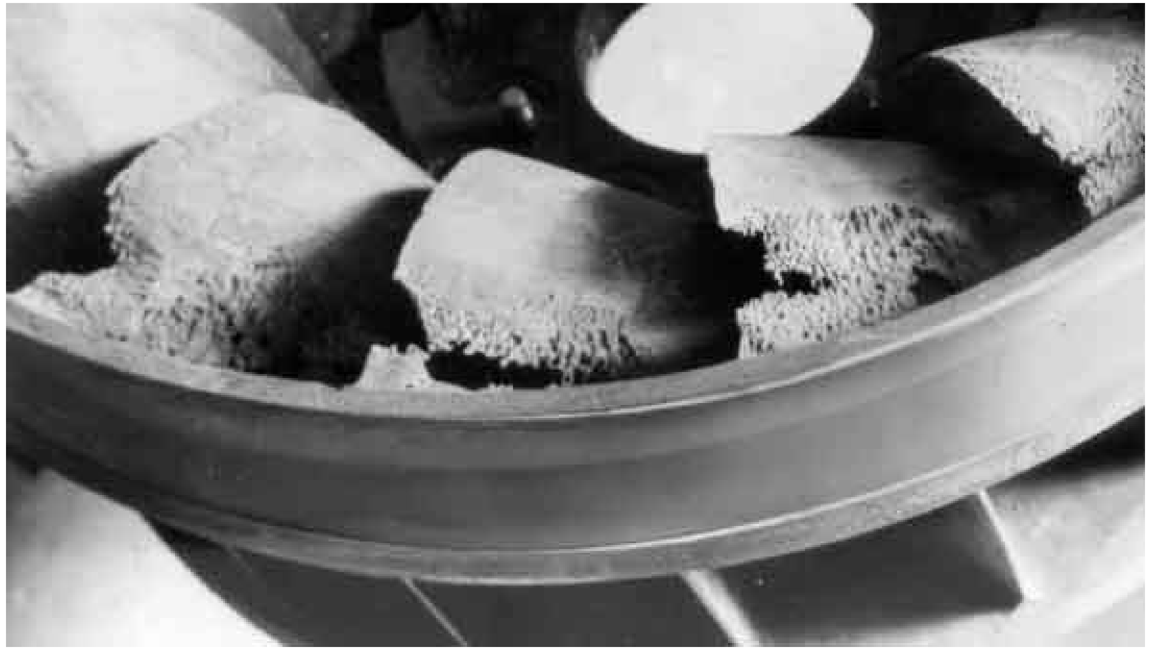
Initial phase of erosion on the marine propeller blade

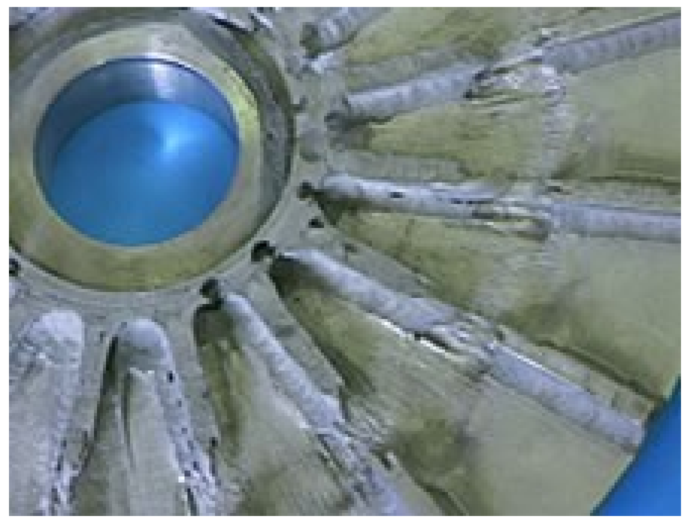
A piece of heavily damaged marine propeller blade

Erosion marks on the ship rudder

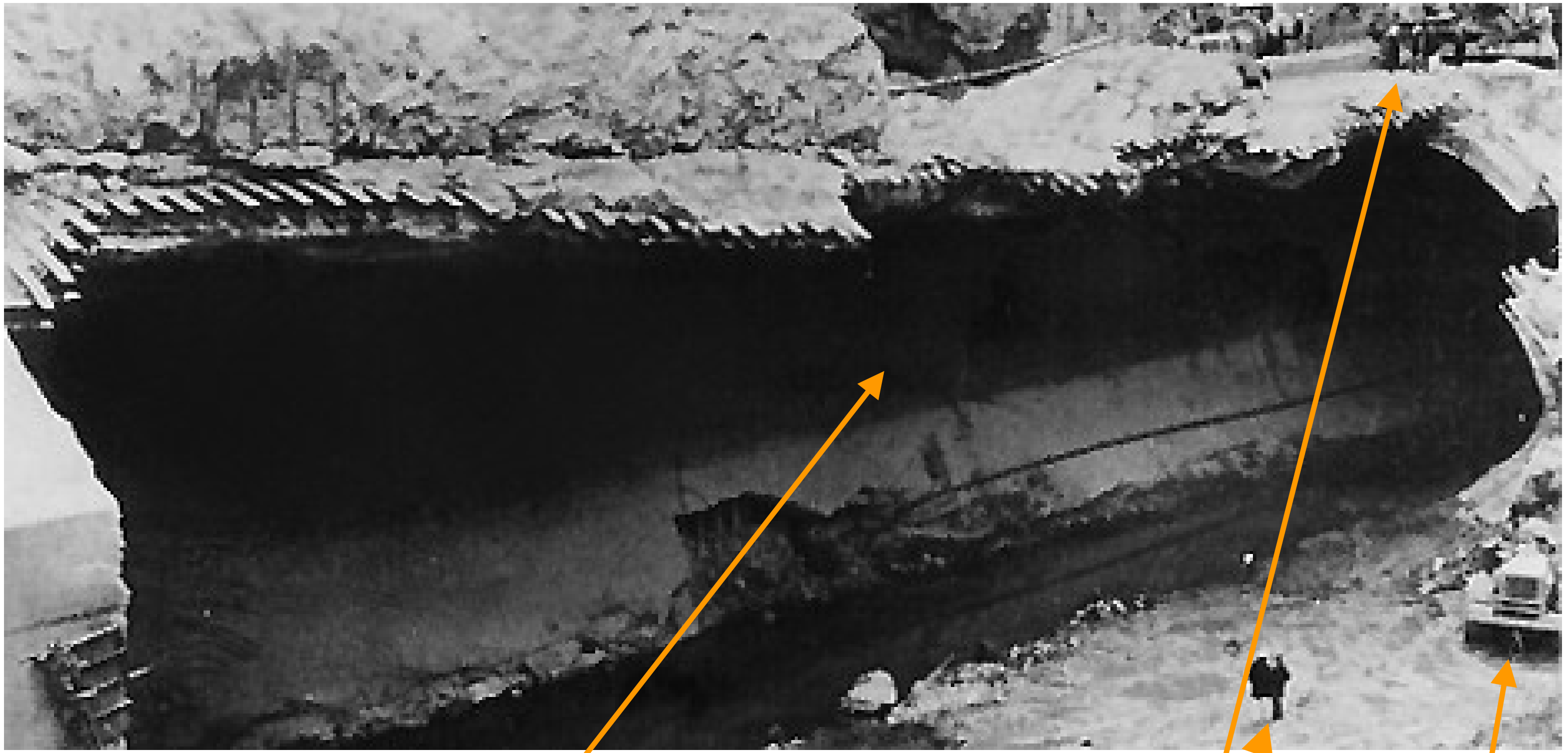
Examples of cavitation erosion damage on elements of fluid flow machinery







Consequences of cavitation erosion



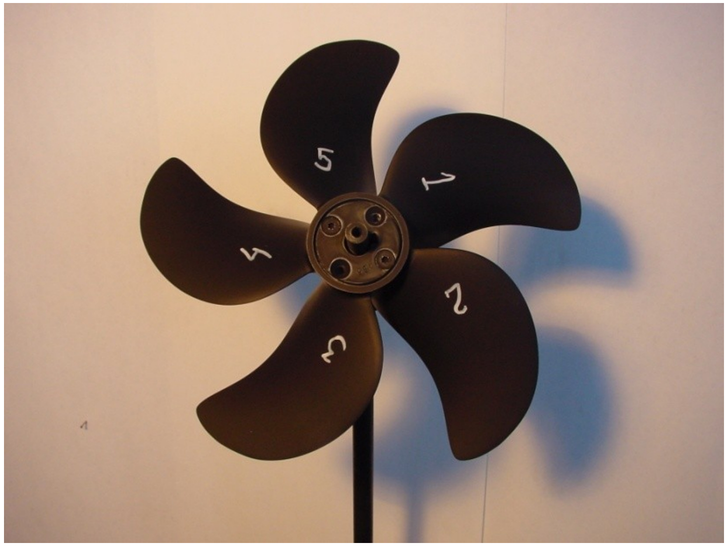
60 meters long damage of the channel supplying water to the turbine at Tarbela Dam power station in Pakistan

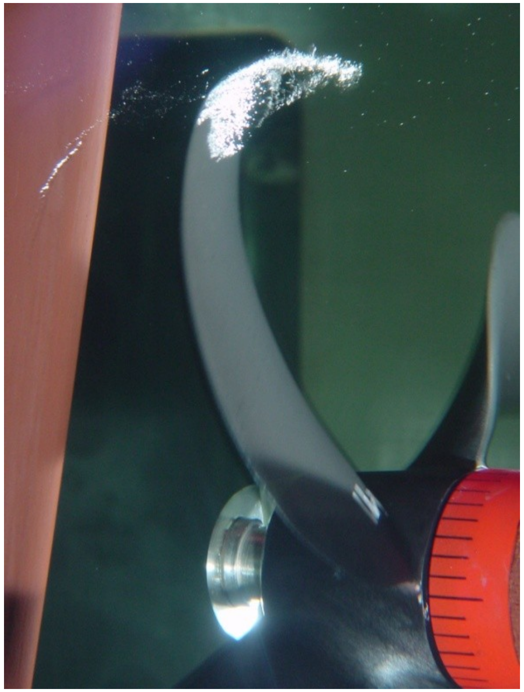
digger

people

The basic method for prediction of the danger of cavitation erosion on the full scale object is a specially arranged model test.

Marine propeller model covered with special paint→

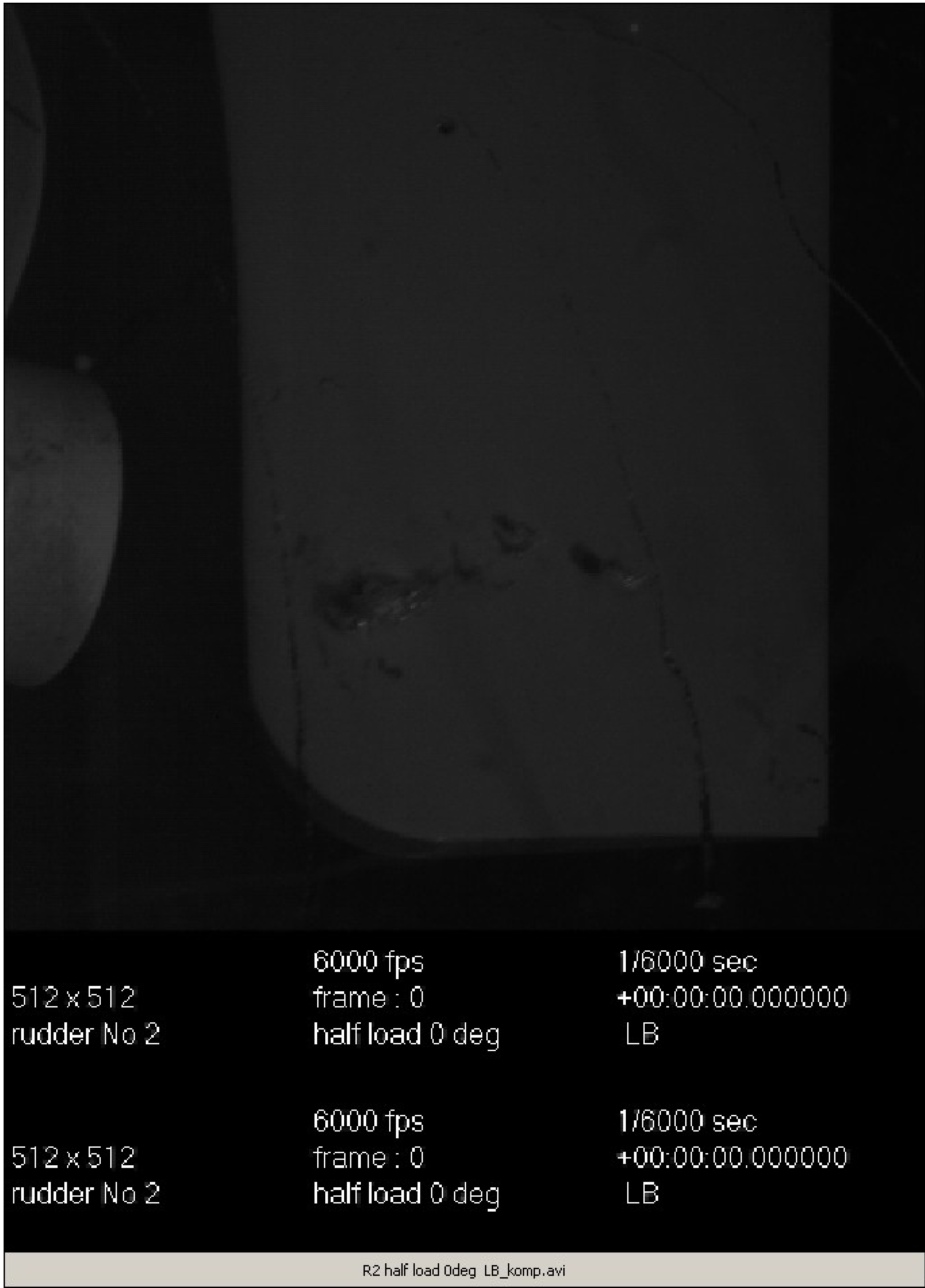




←Model during experiments in the cavitation tunnel

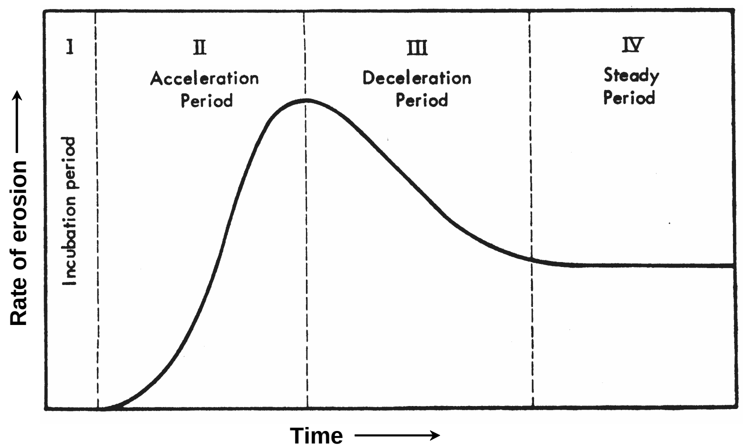
Results of the test (traces of erosion)→

Film taken by the high speed camera, showing unsteady cavitation phenomena on the model of a ship rudder during erosion tests in the cavitation tunnel

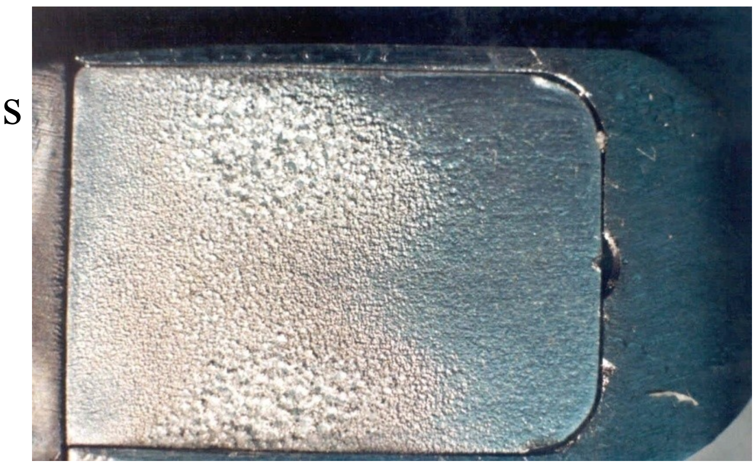


Results of the erosion test on the ship rudder model. Picture of the cavitation phenomena on the right, picture of erosion (red arrow) on the left. It may be seen that the most erosive form of cavitation is the cloud and bubble cavitation.

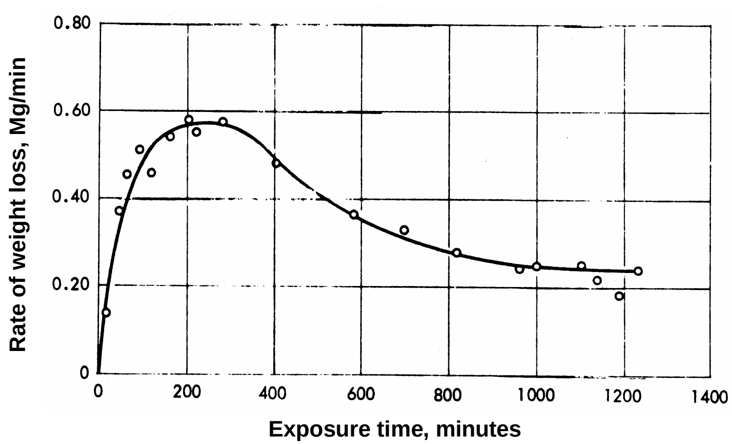
Apart from testing erosion on models of different objects, the research concerning cavitation erosion resistance of different materials is conducted. The samples of materials are placed in the special test stand with rotating disc and the intensity of erosion is assessed by measuring the loss of mass of a sample depending on the time of exposure.



←The process of erosion usually exhibits three phases



Aluminum sample after the erosion test

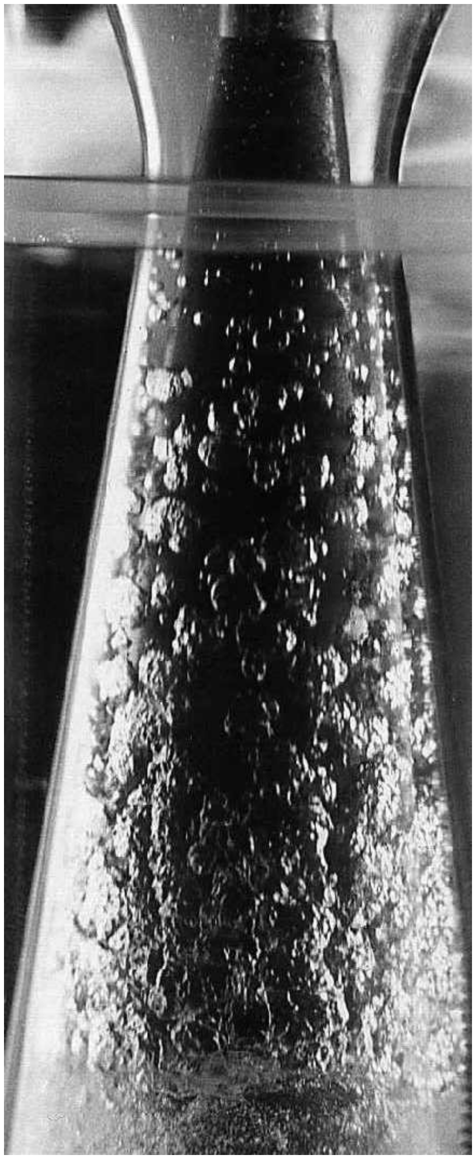


←Results of the erosion resistance test

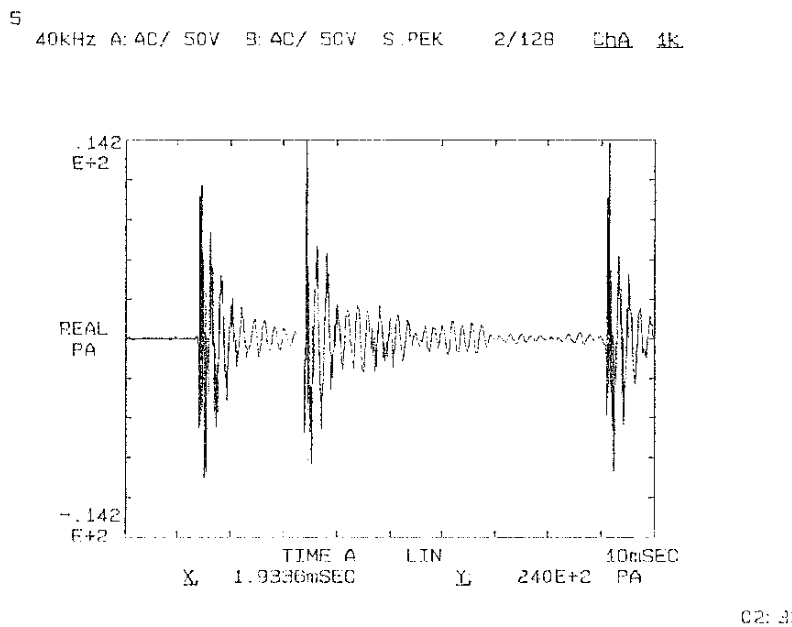
Generation of vibration and noise

Rayleigh – Plesset equation

$$R\ddot{R}+\frac{3}{2}\dot{R}^2+\frac{2A}{\rho R}+4\mu\frac{\dot{R}}{\rho R}=F(t)$$

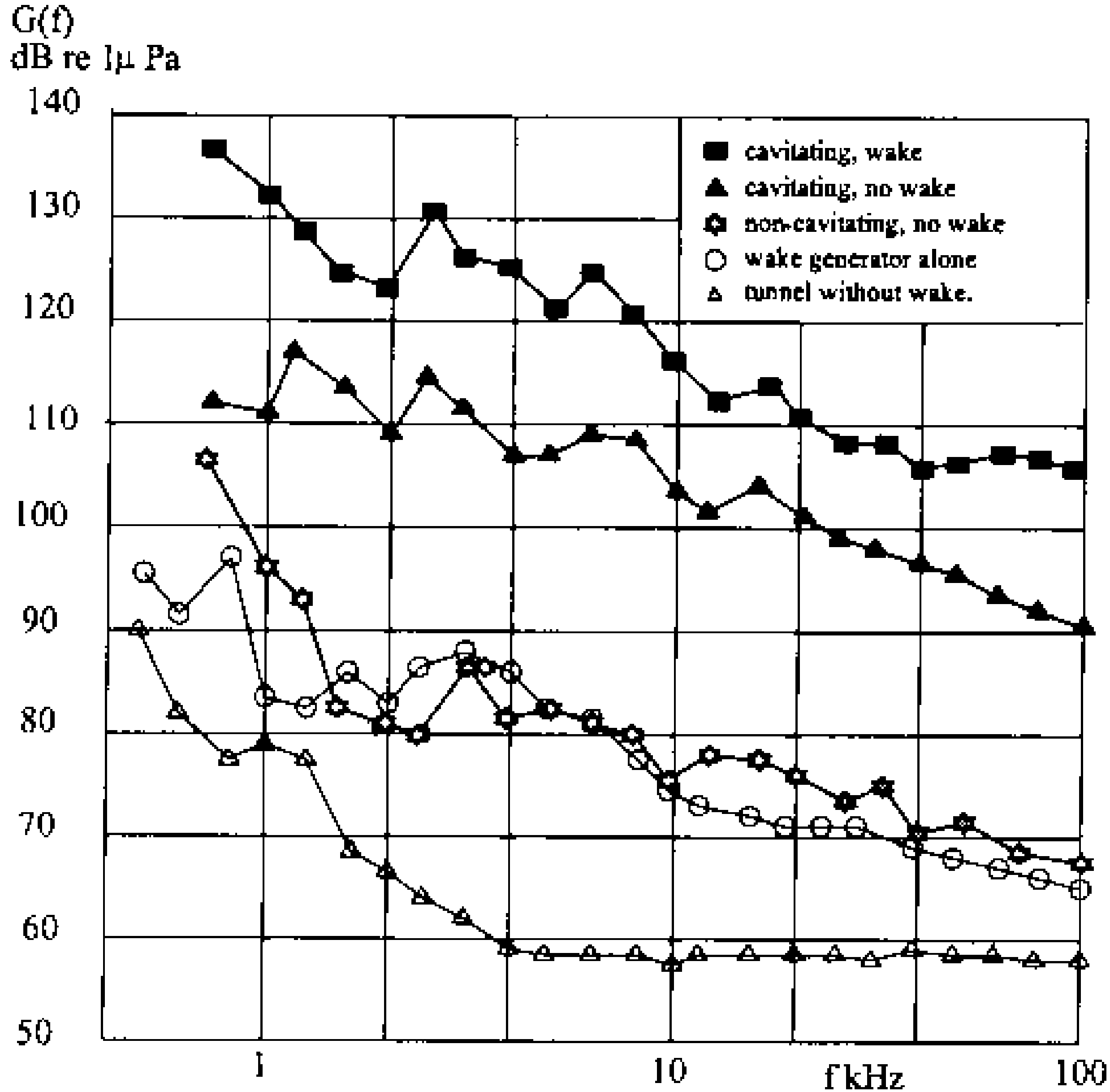


←Bubble cavitation induced in the Venturi nozzle

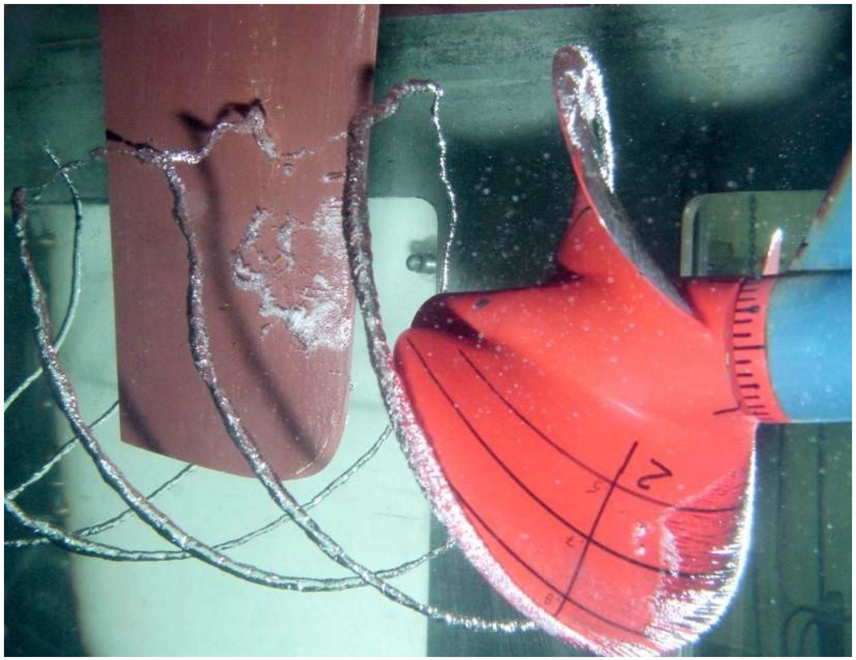


←Acoustic signals generated by single cavitation bubbles

Spectrum of noise generated by a marine propeller

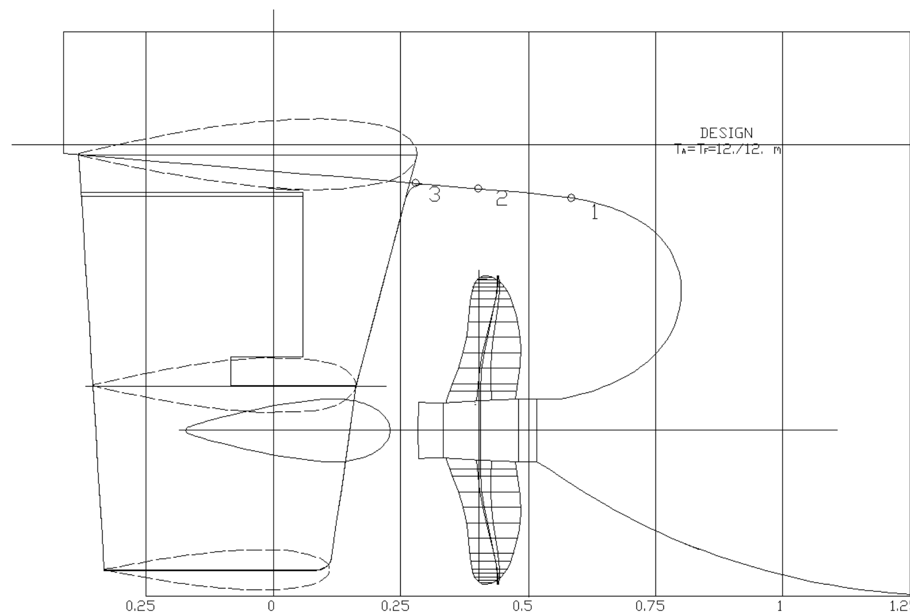


Model measurements of the pressure pulses generated by the cavitating propeller as the main source of vibration and noise



←View of the propeller model in the cavitation tunnel

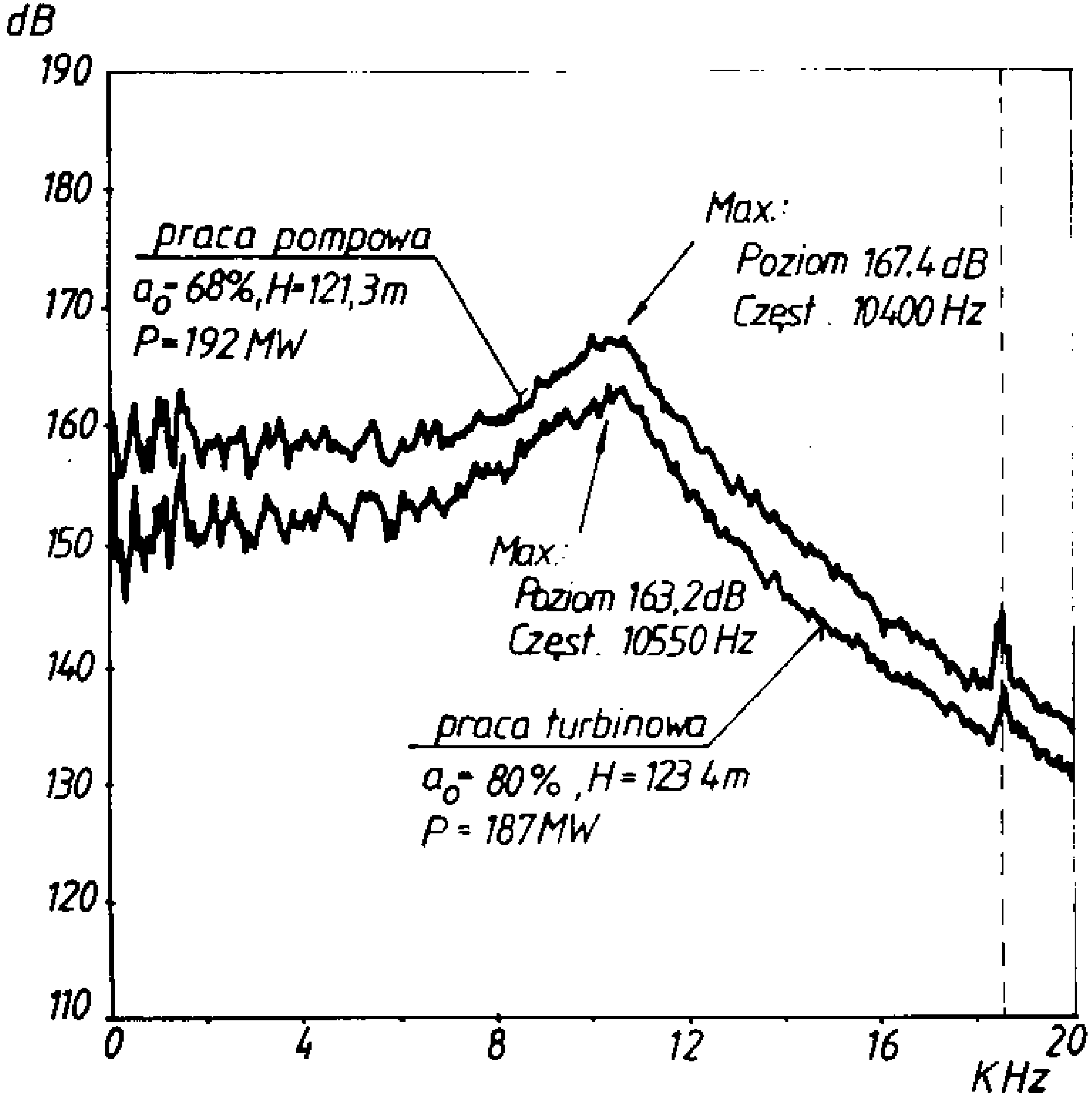
Location of the pulsating pressure measurement points on the stern part of the ship model→



Pressure pulsations (amplitudes of the first A1 and second A2 harmonic) generated by the cavitating propeller tip vortex with and without interaction with the rudder

	With rudder	With rudder	Without rudder	Without rudder
Point no.	A1[kPa]	A2[kPa]	A1[kPa]	A2[kPa]
1	0.976	0.773	0.730	0.569
2	2.630	2.960	1.963	2.310
3	2.731	3.036	1.560	2.071

Vibration



Comparison of vibration spectrum of the inlet pipe in the Żarnowiec power station during pumping and during turbine operation

Summary

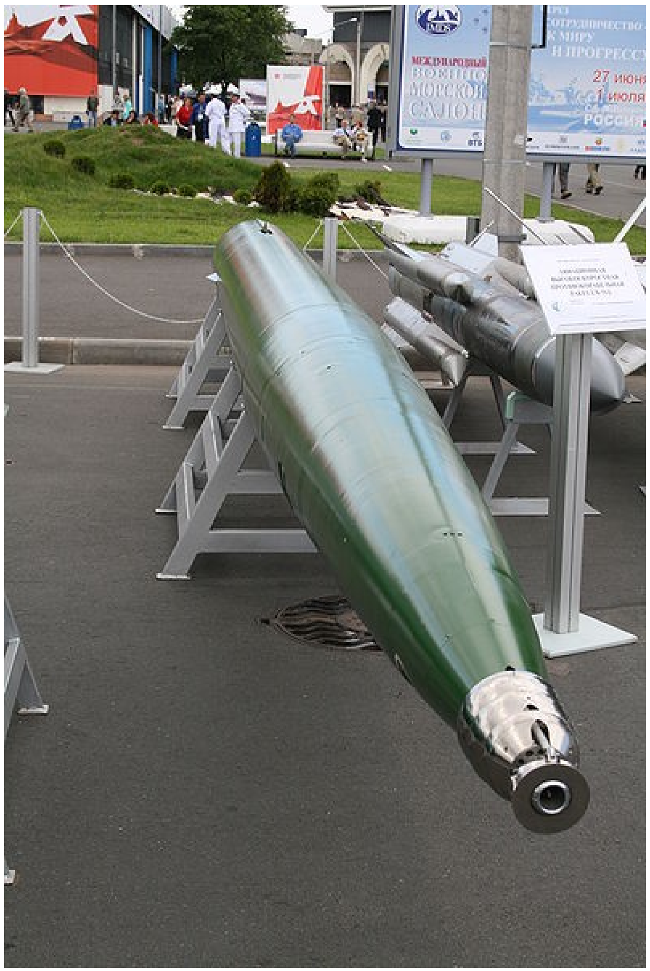
- All machines and devices having liquids as the operating medium are exposed to the danger of cavitation

- Cavitation has serious negative consequences, leading to distortion of the operating characteristics and erosion damage of these machines and devices

- Elimination or limitation of the cavitation extent and its negative consequences requires using special, complicated design methods, employing the most advanced experminental techniques and theories

A small positive appendix

Among „positive” consequences of cavitation the possibility of constructing high speed underwater objects employing supercavitation may be mentioned, like the torpedo achieving speed of over 100 meters per second, shown below.



Other positive applications of cavitation:

- Cleaning of surfaces in industrial applications

- Mixing and homogenization of components in the chemical and food industry

- In medicine – application in some medical procedures e.g. for destruction of kidney stones, destruction of cancerous tumors by High Intensity Focused Ultrasound (HIFU) etc.

Kidney stones disintegrated by cavitation→