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Lecture No. 22: Cavitation – Physical basics – Hydrodynamic consequences

Plan of the lecture

1. Definition of cavitation

2. Cavitation inception

3. Forms of cavitation

    - sheet cavitation
    - bubble cavitation
    - vortex cavitation
    - transient forms of cavitation

4. Consequences of cavitation

    - reduction of efficiency of the fluid flow machinery
    - cavitation erosion
    - noise and vibration

5. Conclusion

Definition of cavitation

Cavitation is the phenomenon of the dynamic growth and decay of vapour-gas bubbles in the liquid, generated by the changes in pressure at (almost) constant temperature.

The process of cavitation is controlled by:

- **diffusion/degassing**
- **evaporation/condensation**
- **inertia of the fluid**
- **surface tension**
- **adhesion**
- **viscosity of the fluid**

Cavitation may occur in:

- **liquid gases – rocket fuel,**
- **liquid metals – coolants in nuclear reactors,**
- **natural liquids – working fluids in hydraulic machines (e.g. fuel in a Diesel engine),**
- **blood – in the flow through an artificial heart valve.**

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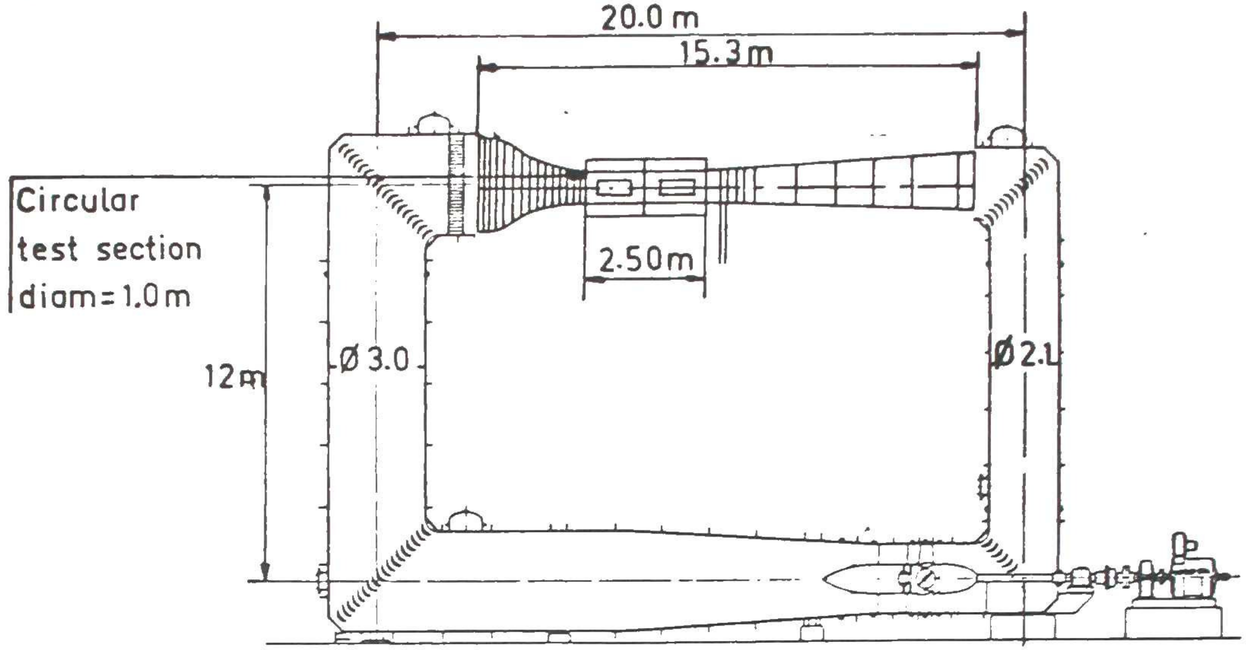
CAVITATION TUNNEL No 2 (1970) test section 1 (high speed section)



DESCRIPTION OF FACILITY: Vert plane, closed recirc. Two test sections

TYPE OF DRIVE SYSTEM: 4-bladed axial flow impeller with thyristor control

TOTAL MOTOR POWER: 736 kW

WORKING SECTION MAX VELOCITY: 23 m/s

MAX & MIN ABS PRESSURES: 600 kPa, 15 kPa

CAVITATION NUMBER RANGE: sigma > 0.1

The parameter describing similarity of the cavitation phenomena is the cavitation number (or index) σ

$$\sigma = \frac{p - p_v}{\frac{1}{2}\rho U^2}$$

where: *p* – pressure in the given point of flow

p_v **- critical vapour pressure, about 2000 [Pa]**

***U* – velocity of flow**

ρ – density of liquid

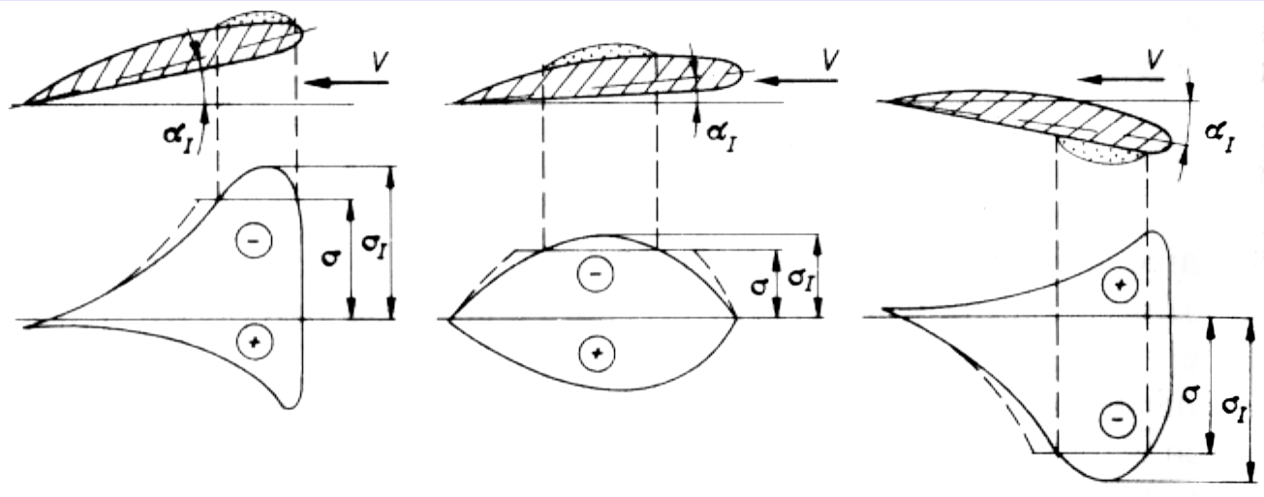
The simplified condition of cavitation inception has the form:

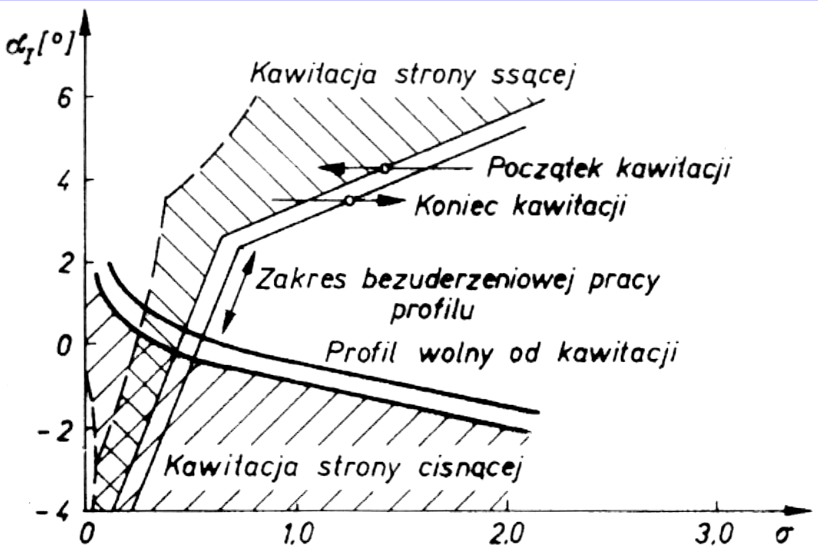
$$C_p = \frac{p_\infty - p}{\frac{1}{2}\rho U^2} \geq \sigma = \frac{p_\infty - p_v}{\frac{1}{2}\rho U^2} \quad \textbf{or:} \quad p \leq p_v$$

where: p_∞ **- pressure „far in front" of the object**

***p* – pressure in the considered point on the object**

Approximate assessment of the cavitation inception and its extent in different operating conditions of a profile



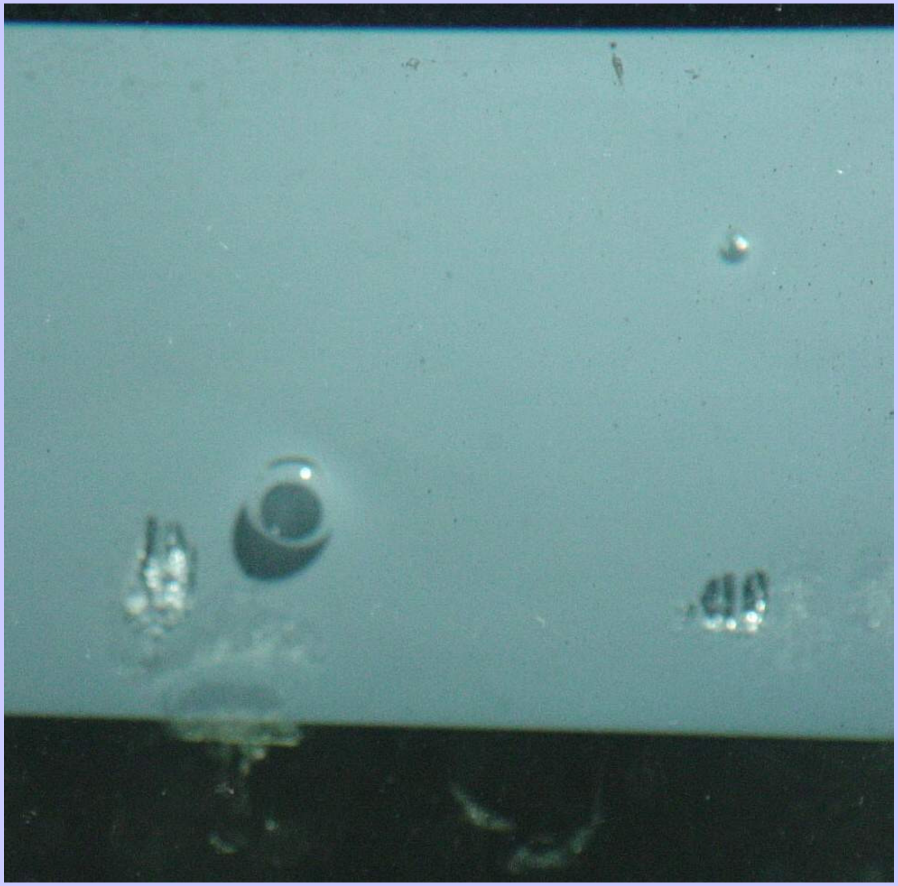


Cavitation diagram of a profile

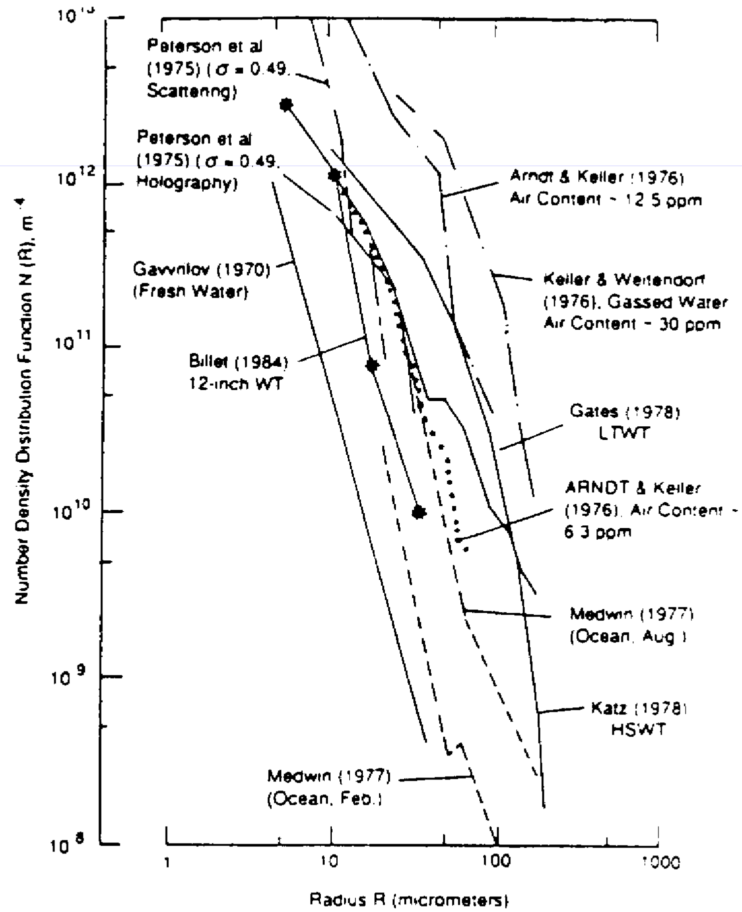
Inception of cavitation

Inception of cavitation occurs when the micro-bubbles naturally contained in a liquid are destabilised

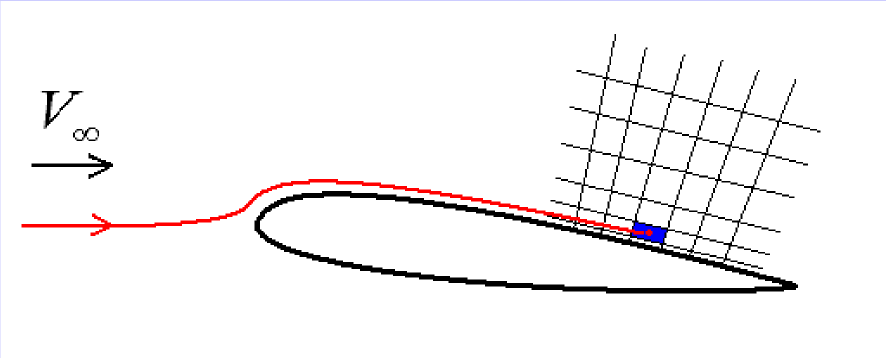
$$p_e = p_v + p_g - \frac{2\sigma}{R}$$

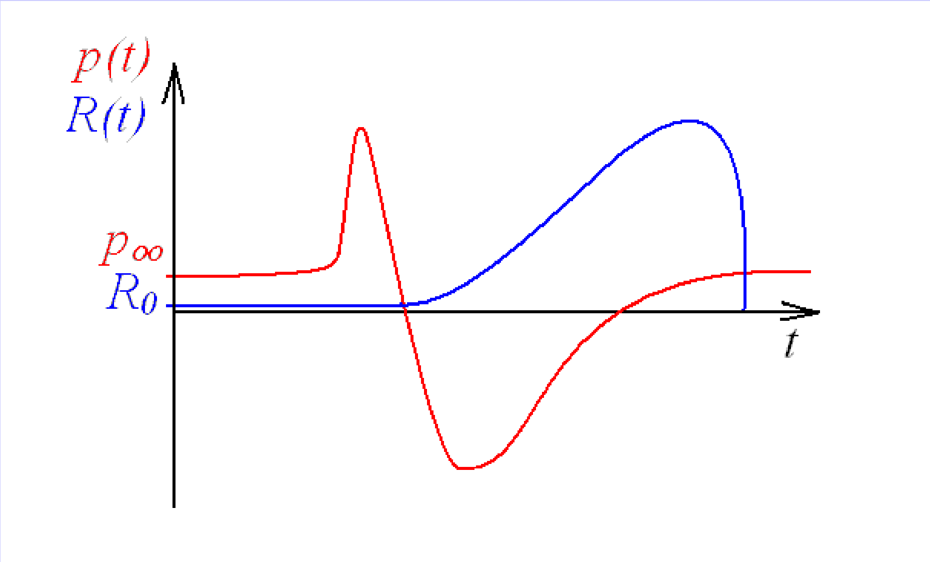


Distribution of micro-bubbles



The history of growth and decay of the cavitation bubble





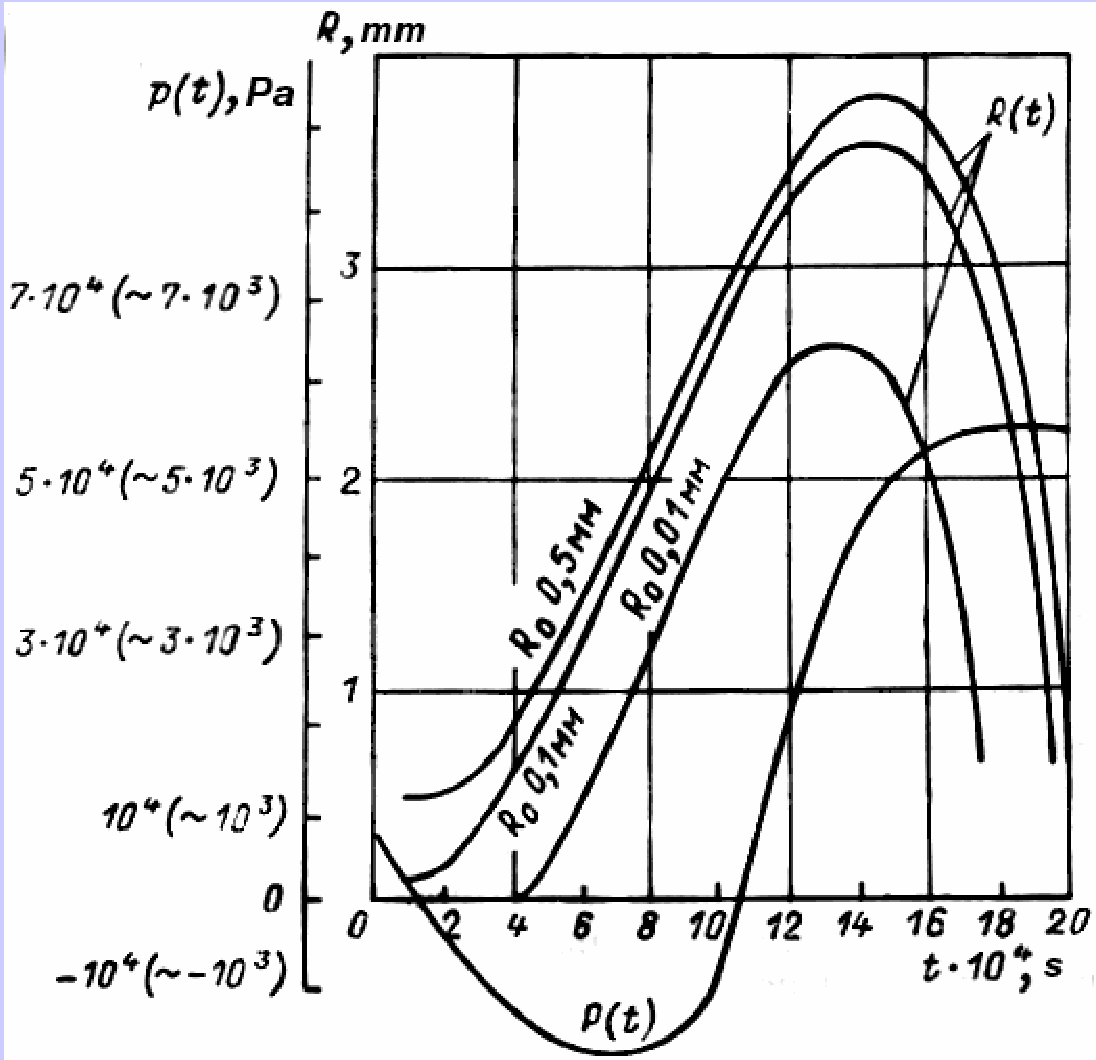
Rayleigh-Plesset equation

$$R\frac{d^2R}{dt^2}+\frac{3}{2}\left(\frac{dR}{dt}\right)^2+4\frac{\mu}{\rho R}\frac{dR}{dt}=-\frac{p_\infty+\frac{2A}{R}-p_v-p_g}{\rho}$$

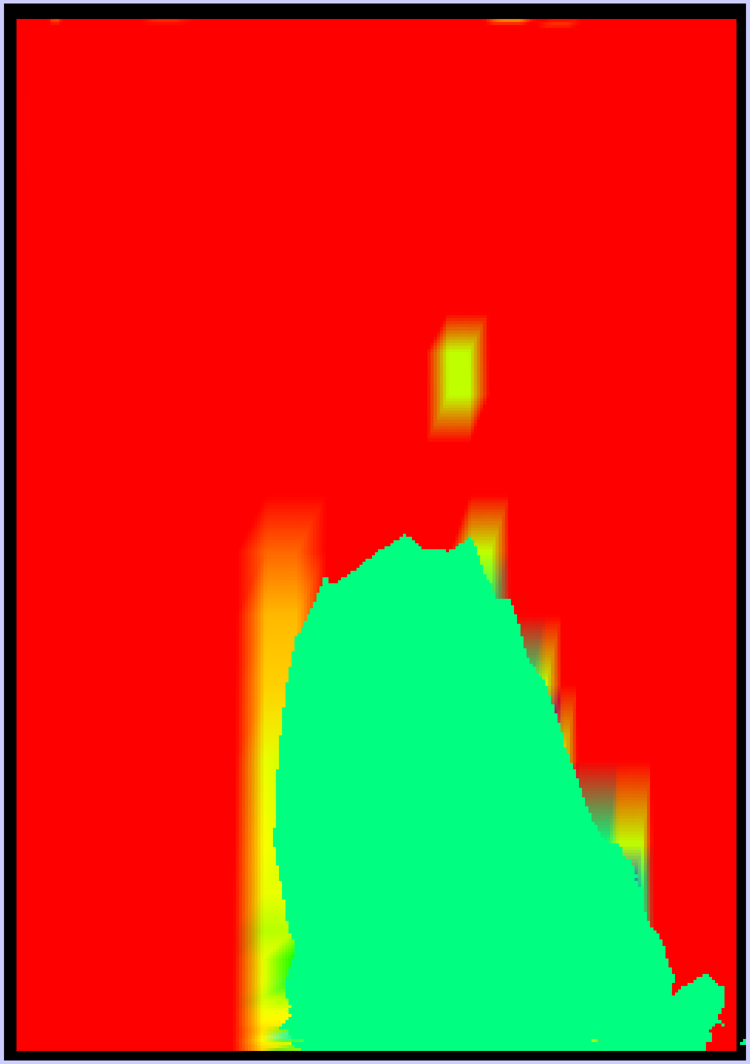
R **– radius of the bubble**

A **– surface tension of the liquid**

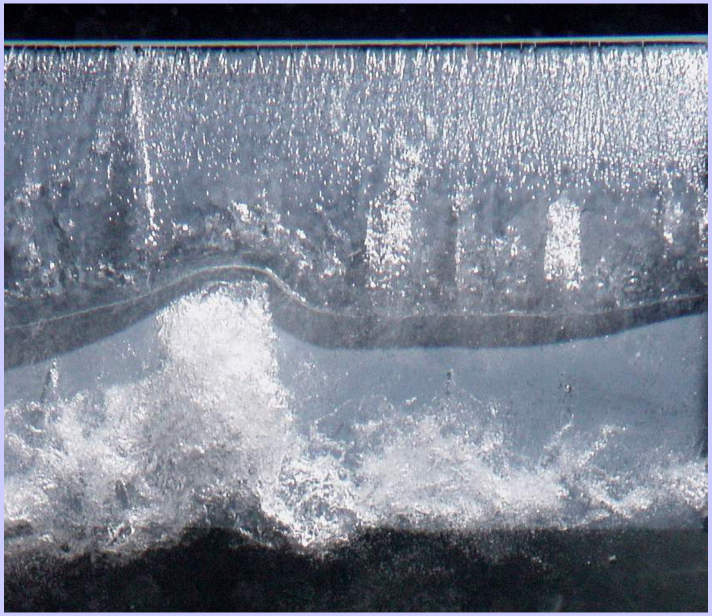
History of growth and decay of cavitation bubbles of diferent initial radii



Comparison of the calculated and observed cavitation extent

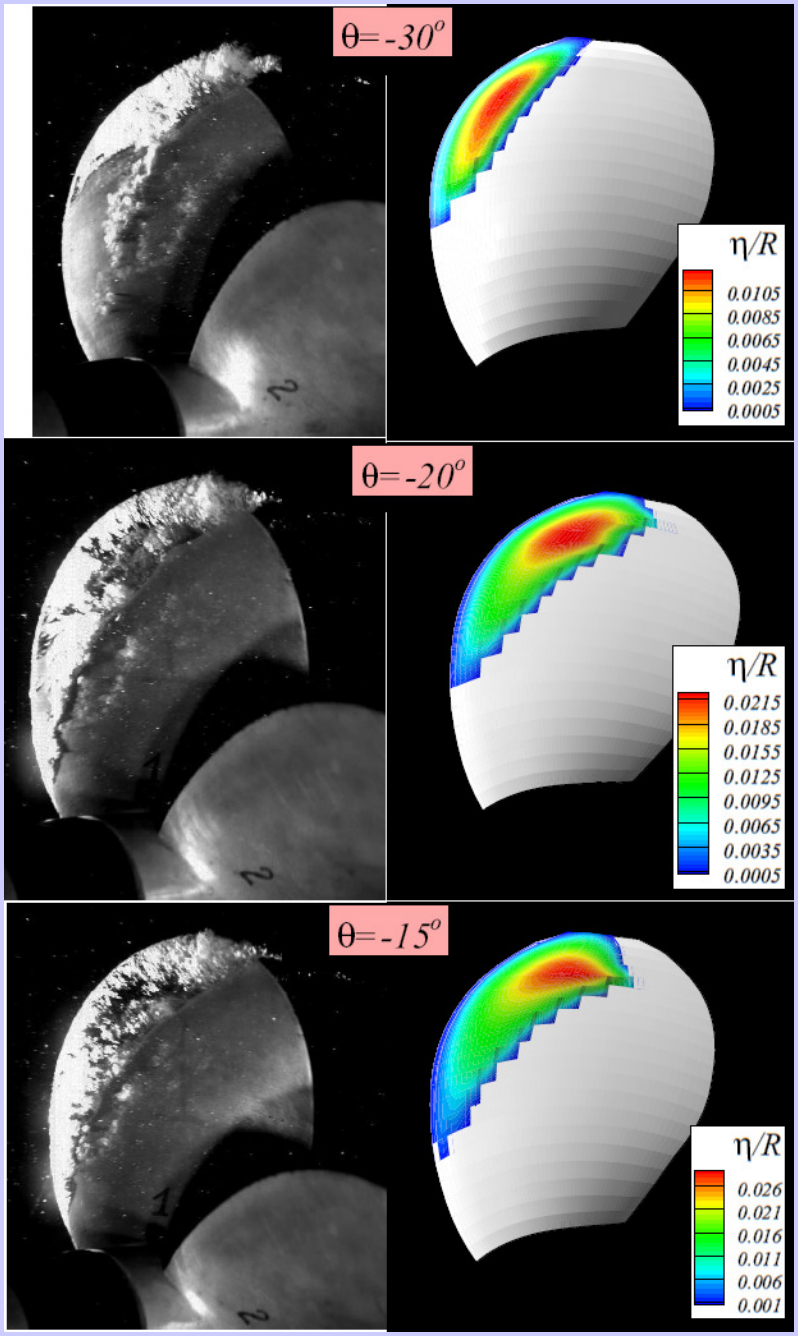


Forms of cavitation



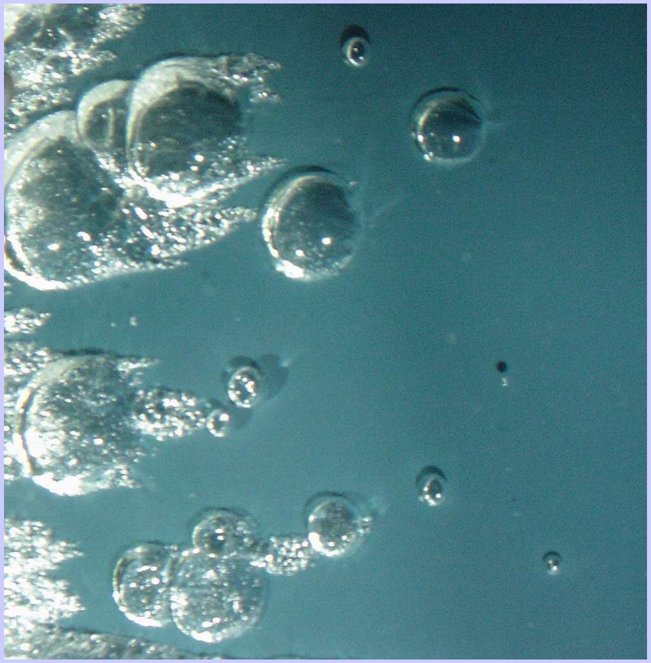
Sheet cavitation

High tension in fluid, acting sufficiently long to destabilize most of the micro-bubbles



Computational determination of sheet cavitation on the ship propeller blade, compared with the experimental observation

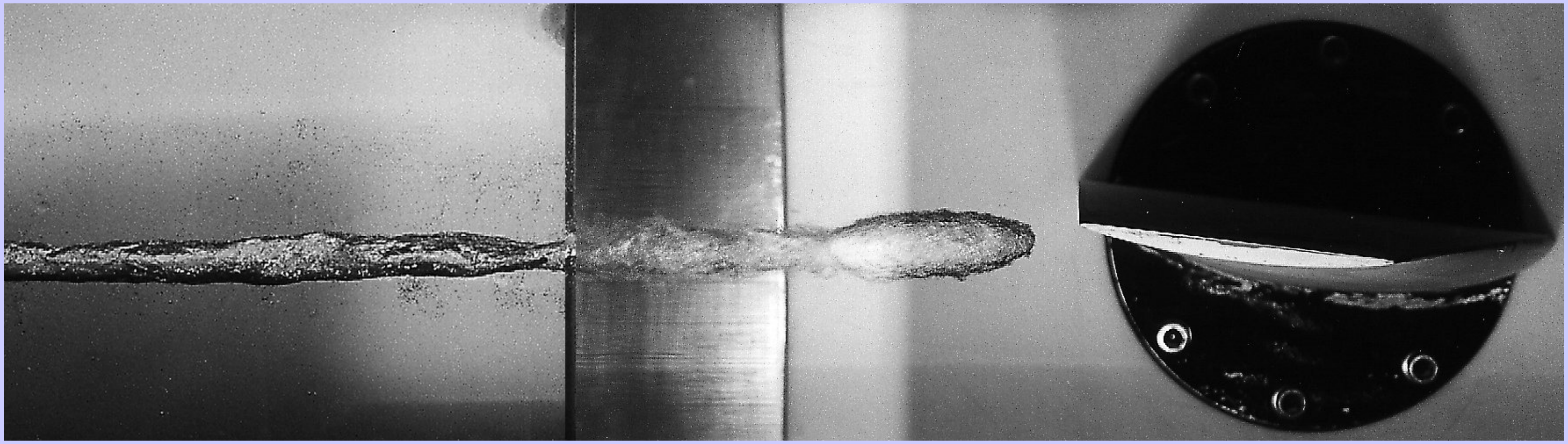
Forms of cavitation



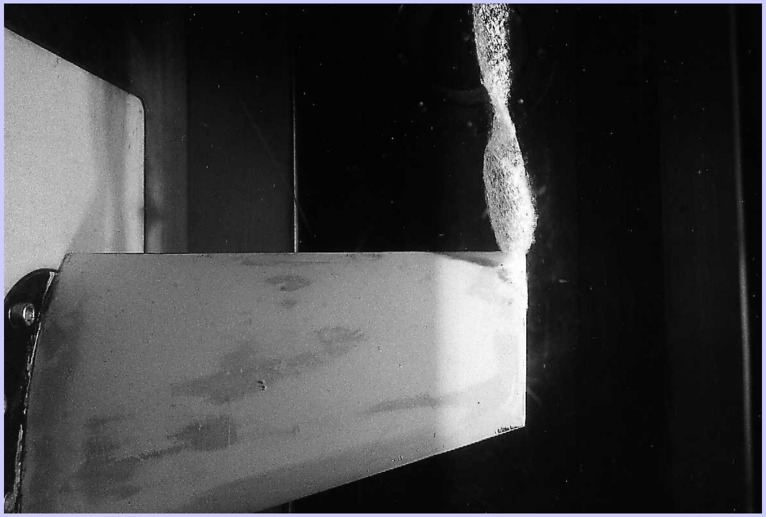
Bubble cavitation

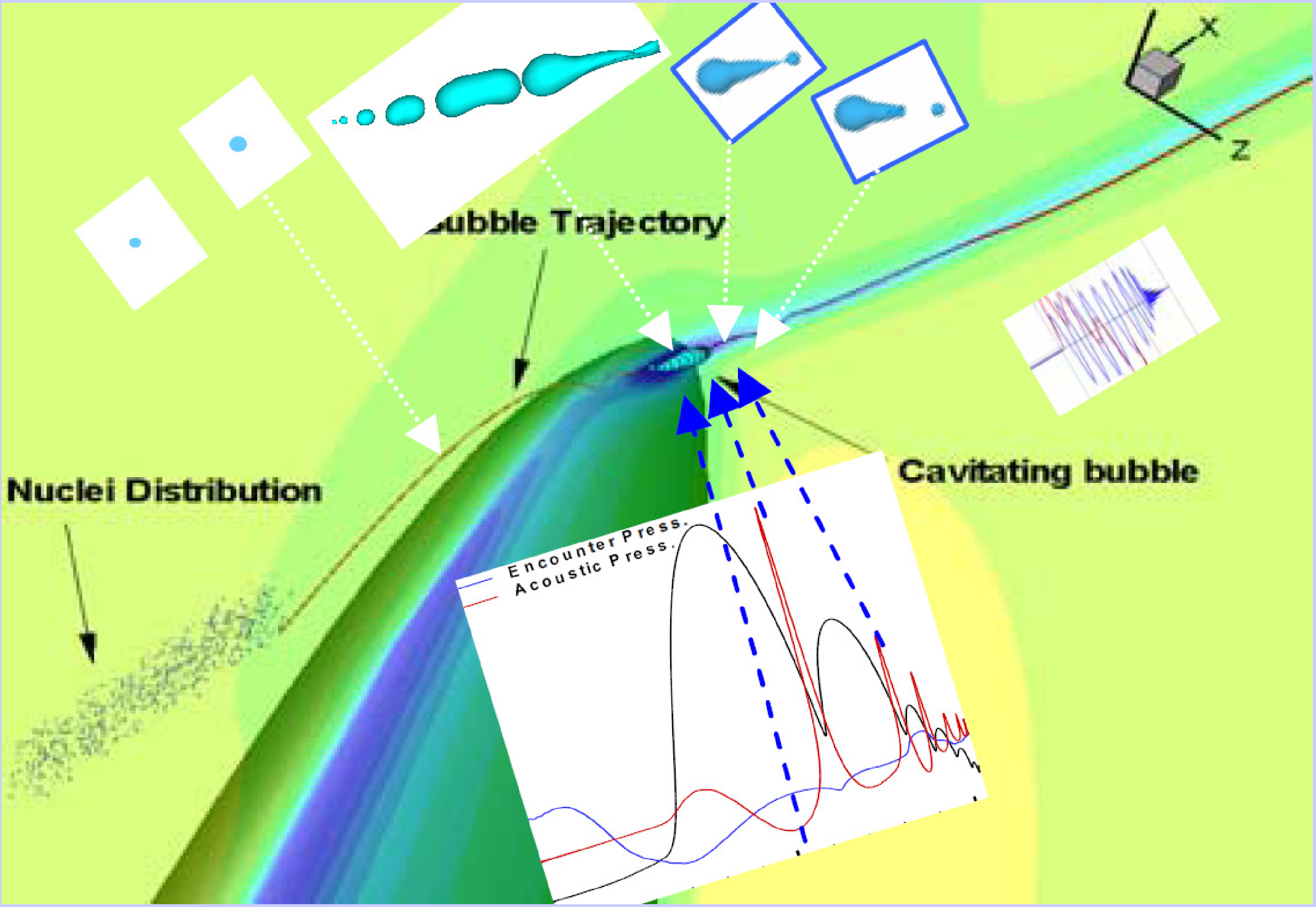
Low tension in the liquid, destabilising only the largest micro-bubbles, which are few and far between

Forms of cavitation

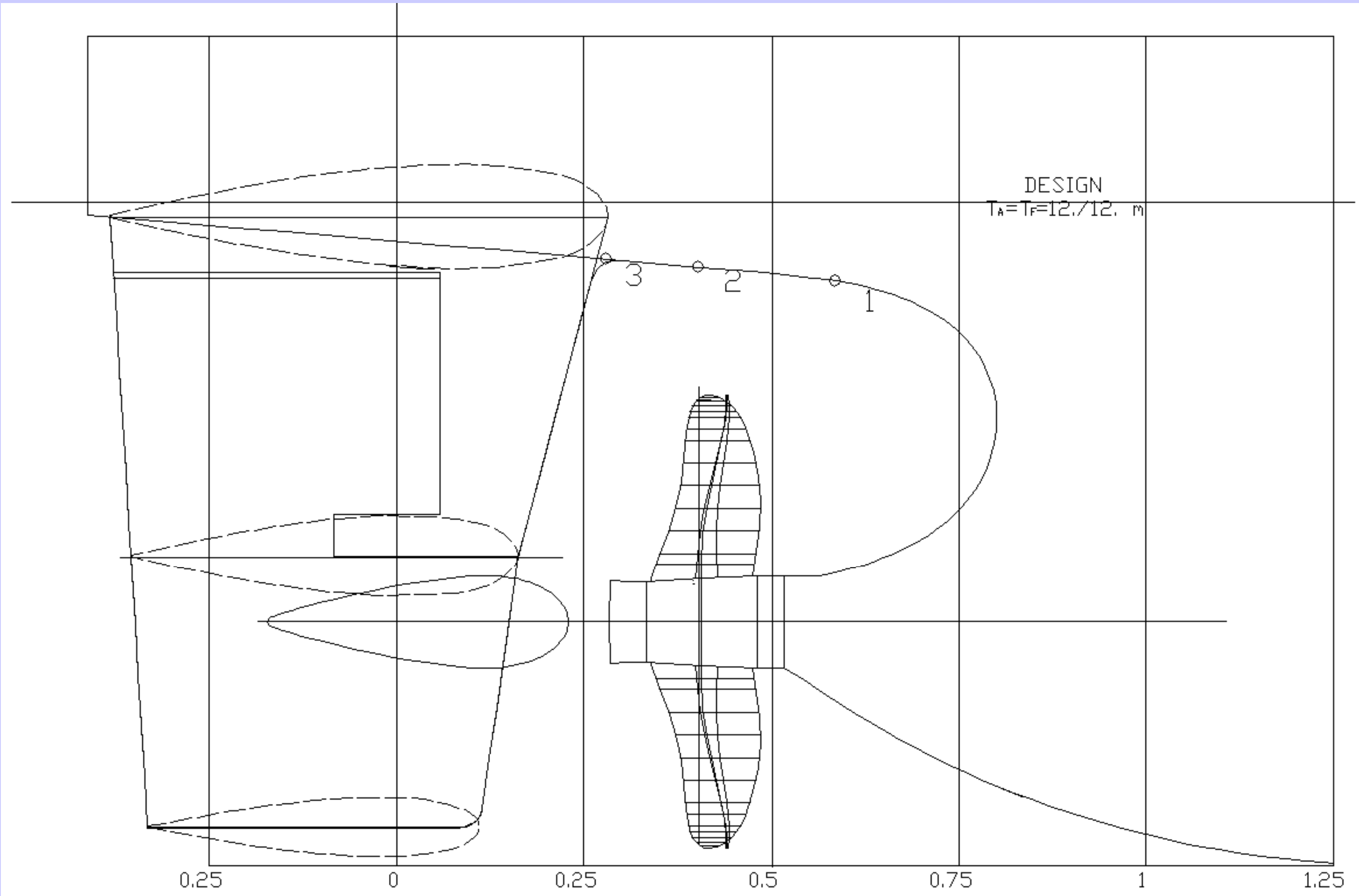


Vortex cavitation

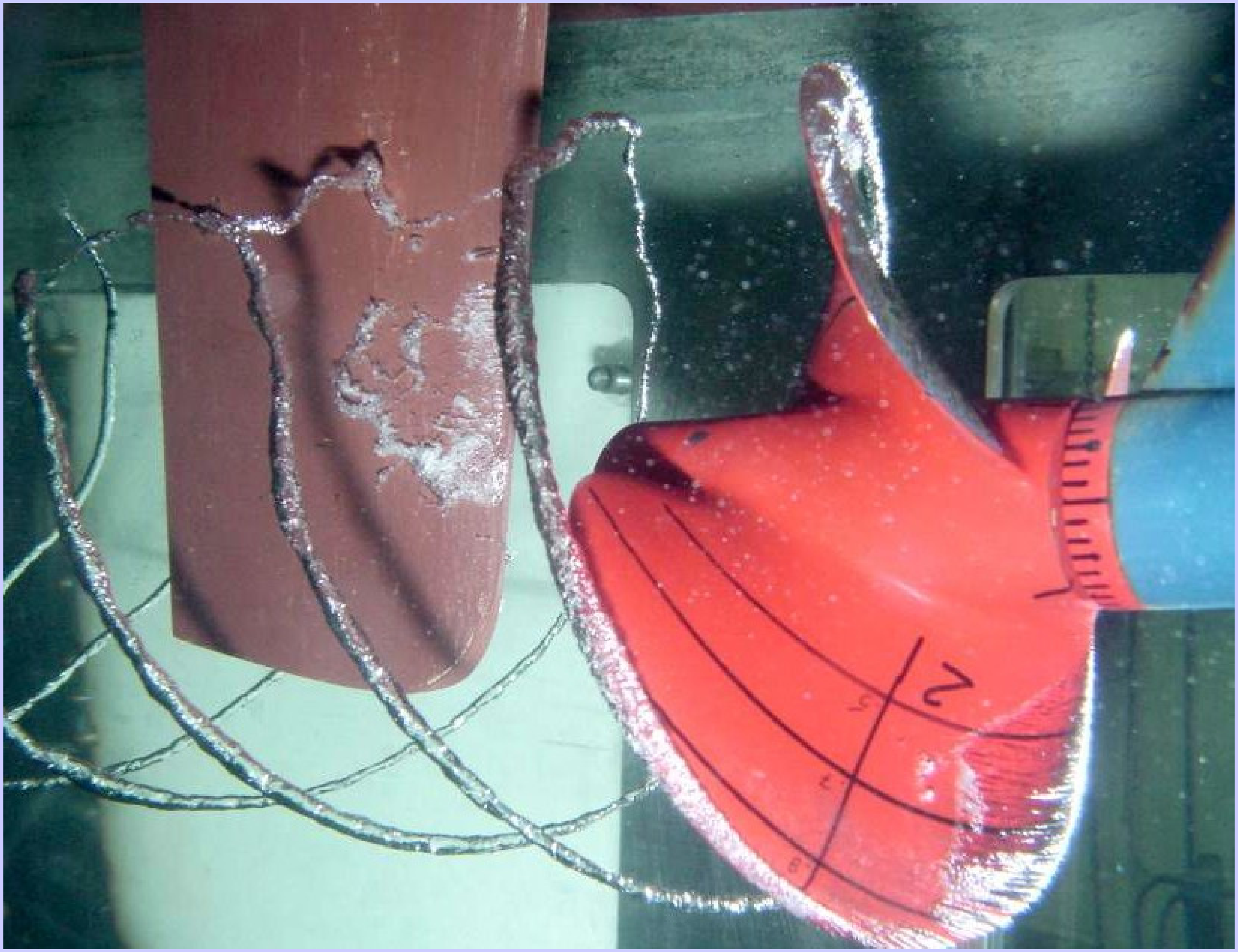




Mechanism of the vortex cavitation inception



Ship propeller – ruder configuration



The cavitating tip vortex on a ship propeller deformed by the rudder interaction

Pressure pulses generated by the cavitating tip vortex with and without rudder interaction

	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

Transient forms of cavitation

Cloud cavitation

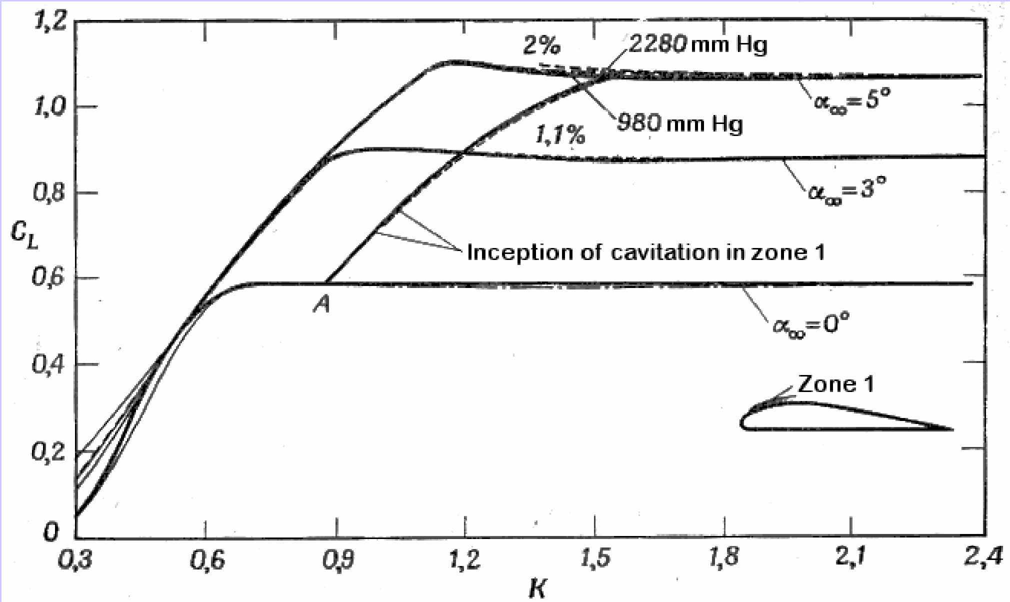
Increase of pressure in the fluid leads to the transient forms of cavitation

Consequences of cavitation

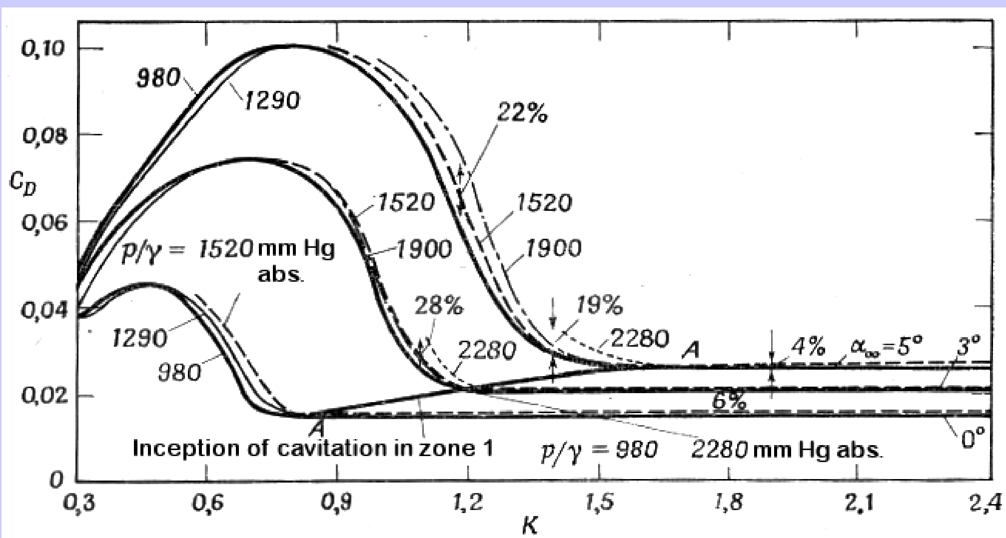
- reduction in efficiency of the fluid flow machinery
- cavitation erosion
- noise and vibration

Reduction of efficiency

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

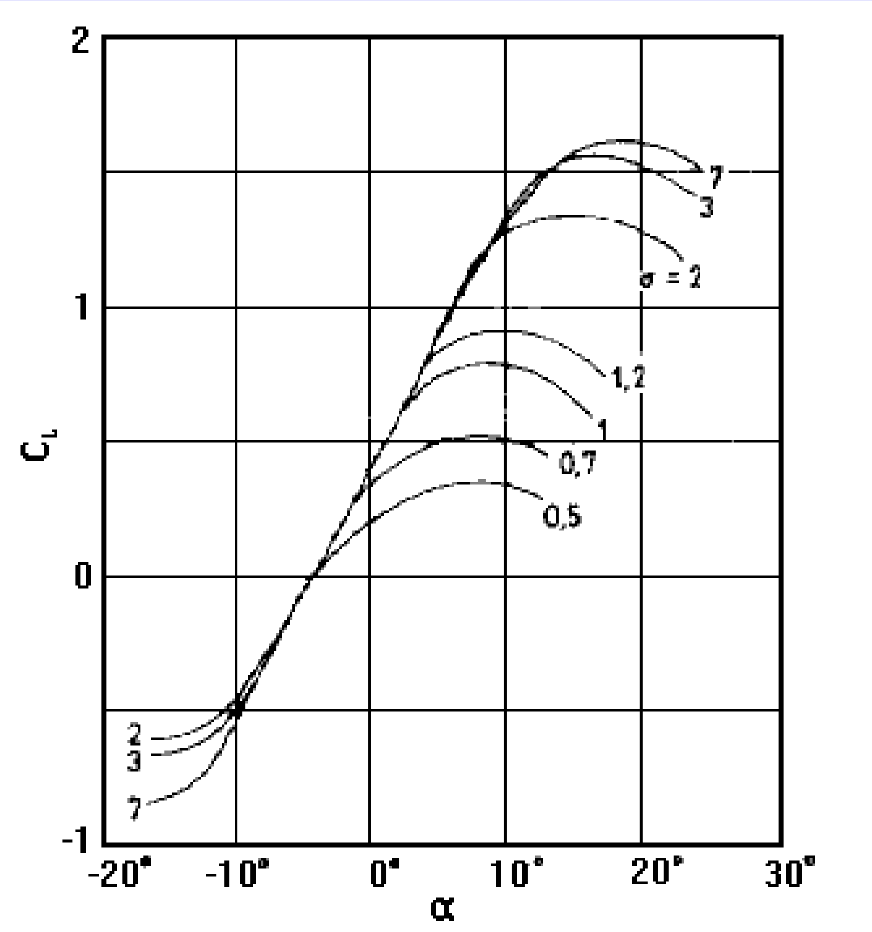


Dependence of the hydrofoil lift coefficient on the cavitation number and angle of attack



Dependence of the hydrofoil drag coefficient on the cavitation number and angle of attack

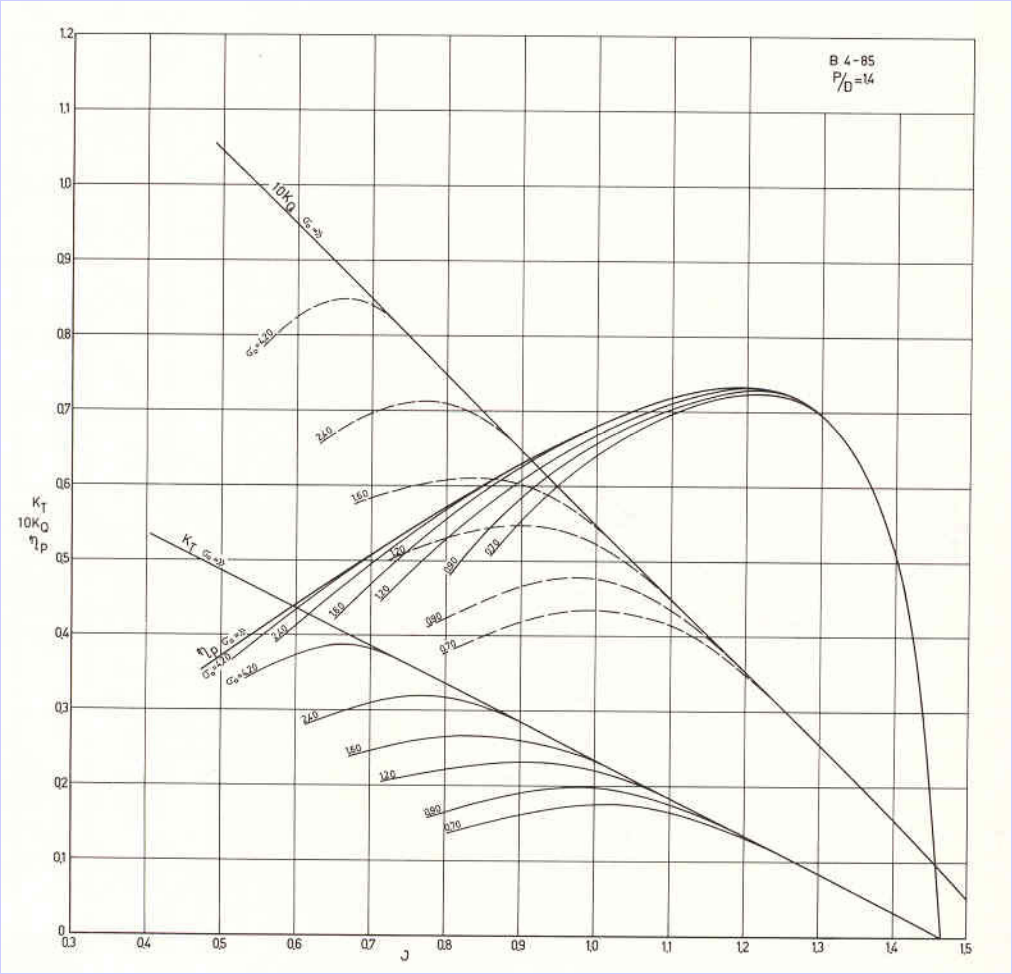
Reduction of efficiency



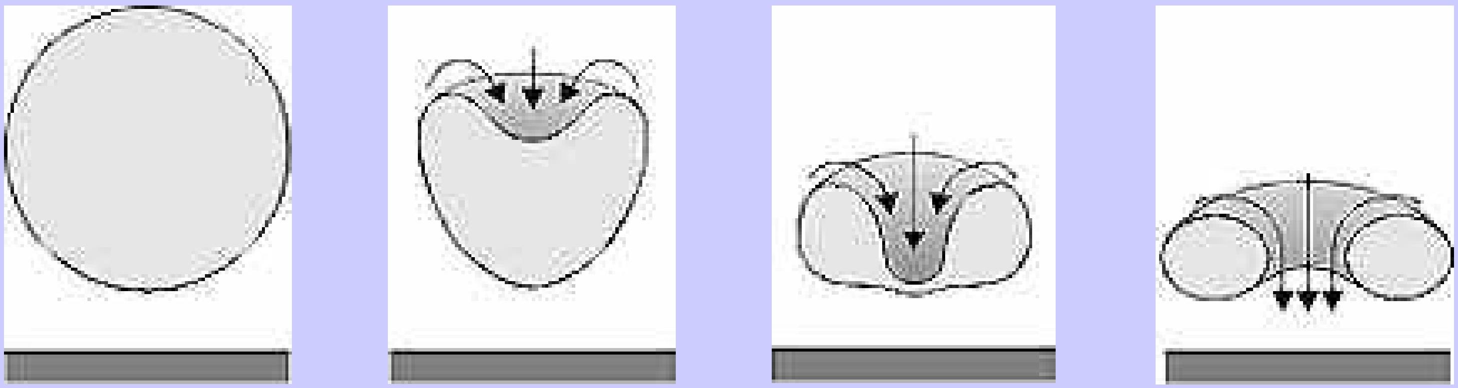
$$\sigma = \frac{p_0 - p_v}{\frac{1}{2}\rho v^2}$$

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

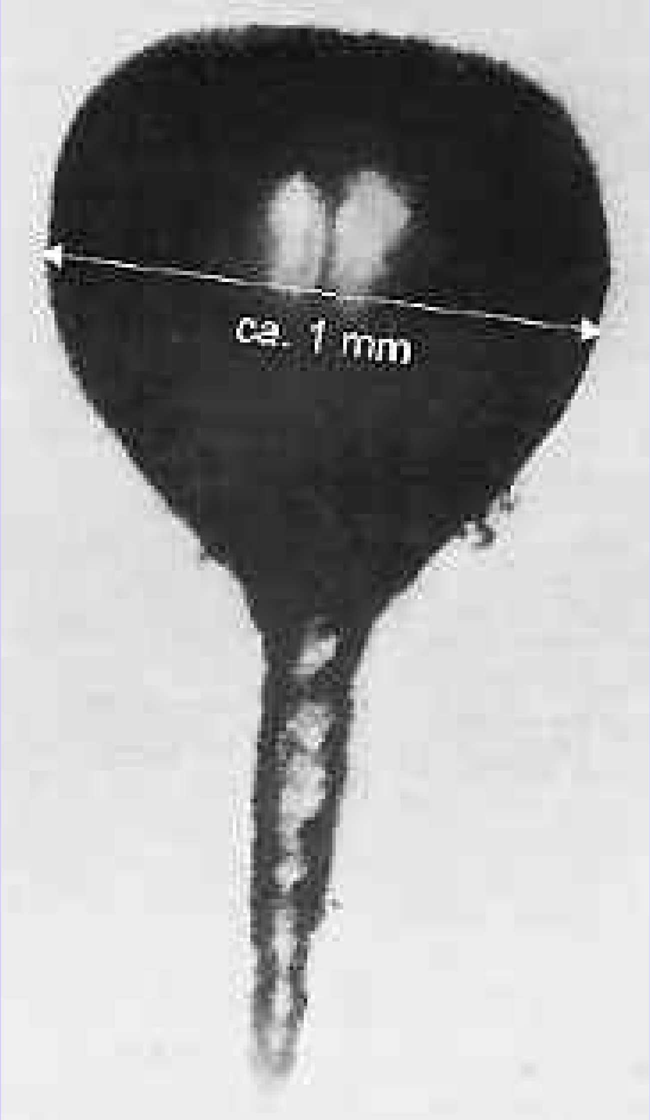
Influence of cavitation on the ship propeller efficiency



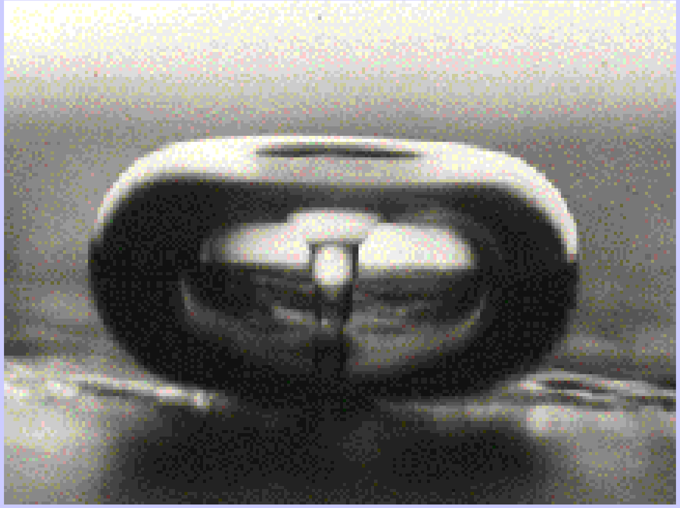
Cavitation erosion



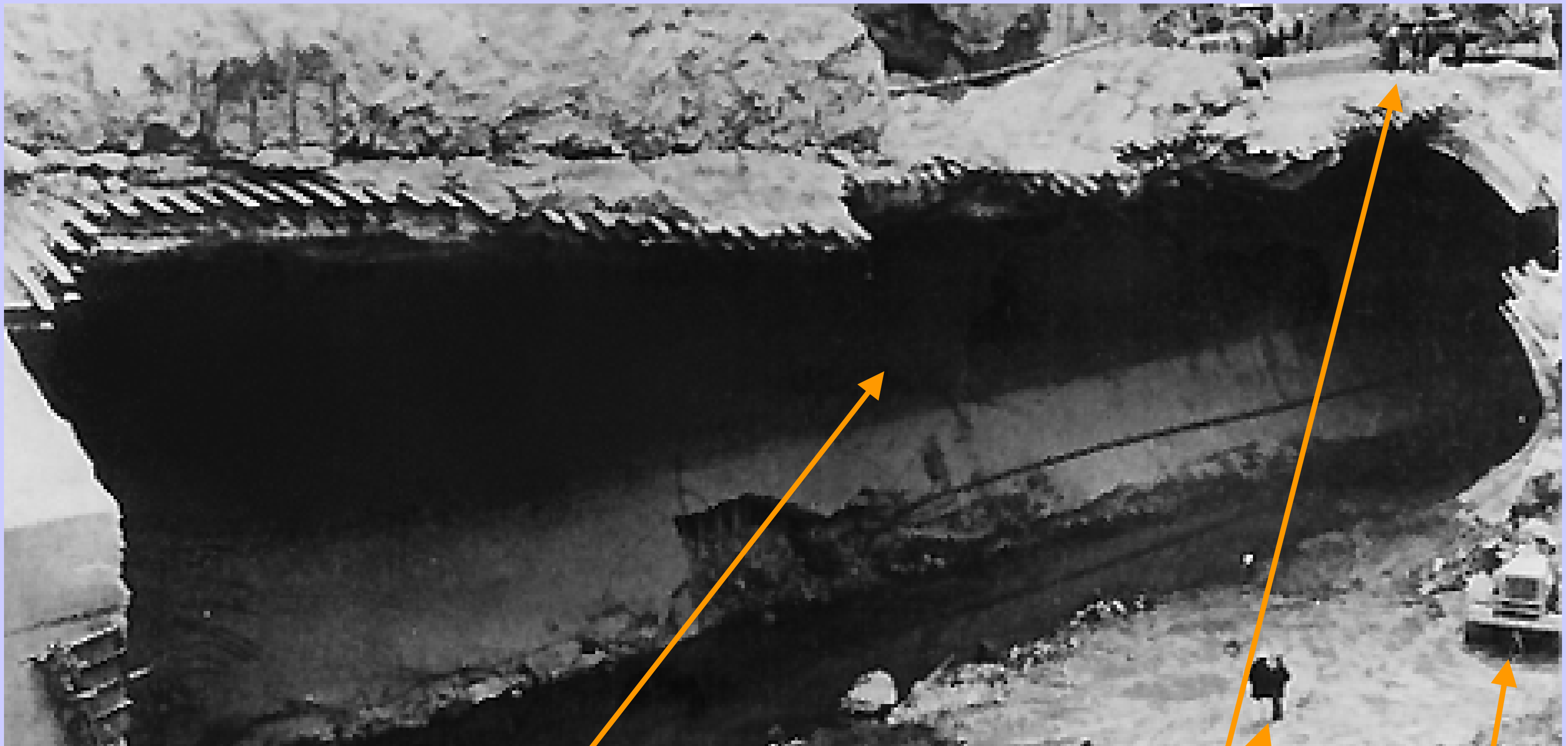
The process of decline of a cavitation bubble near a solid wall



The final stage of decline of the cavitation bubble near the solid wall



Consequences of the cavitation erosion

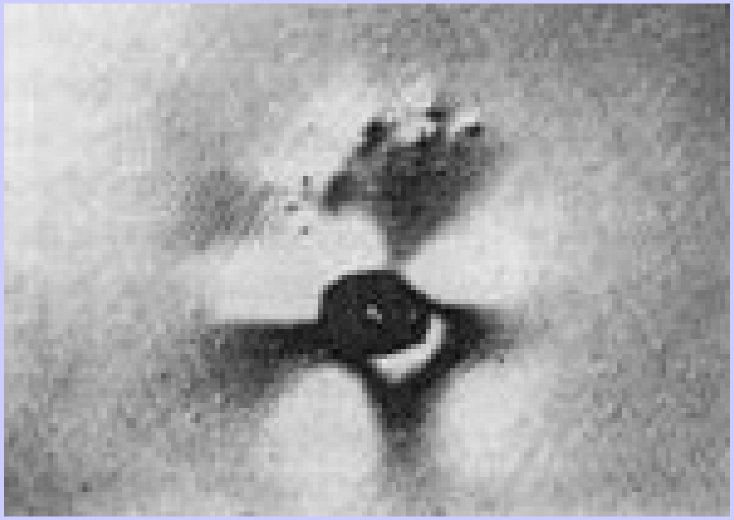


60-meter long damage of the inflow channel of the hydr-electric power station Tarbela Dam in Pakistan

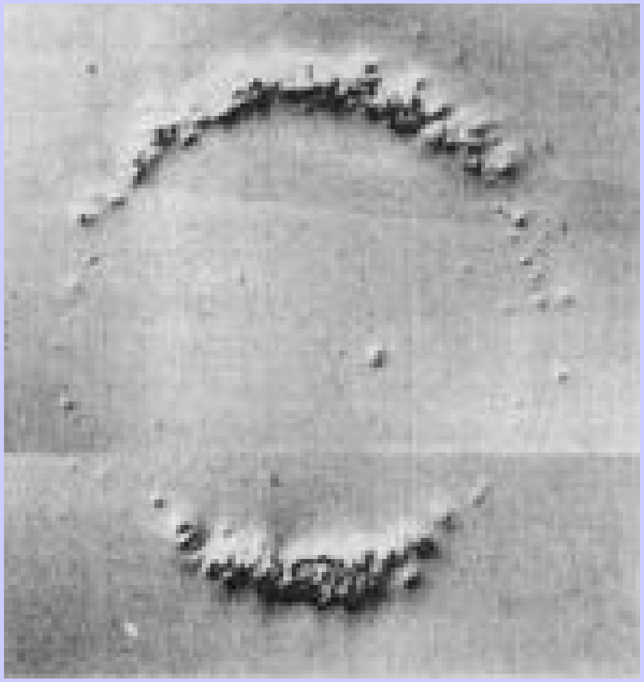
digger

people

Single erosion pits

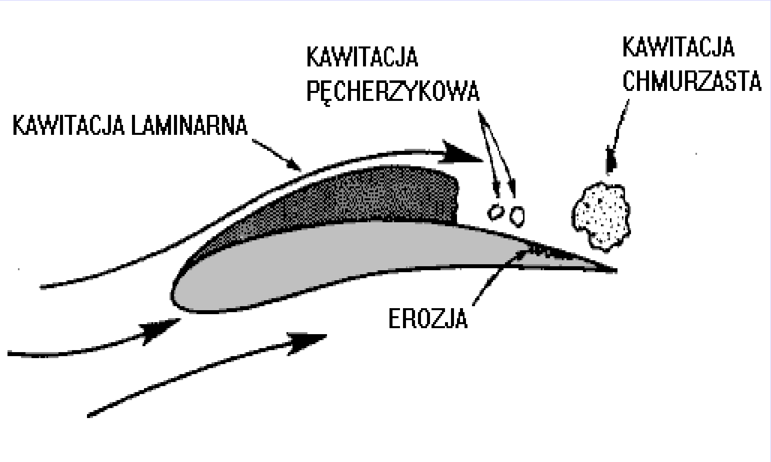


Pit generated by the jet of liquid passing through a bubble located very close to the wall

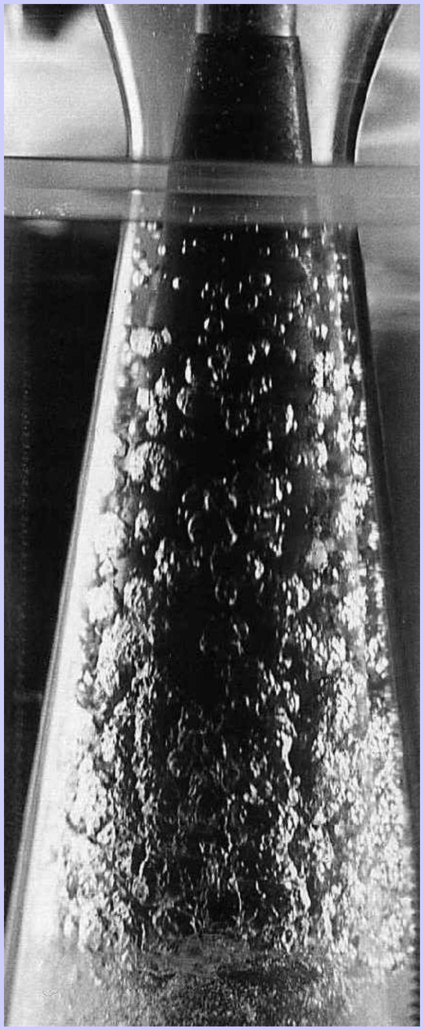


Pit generated by the secondary collapse of the toroidal ring of vortices created when the collapsing bubble is located a little farther from the wall

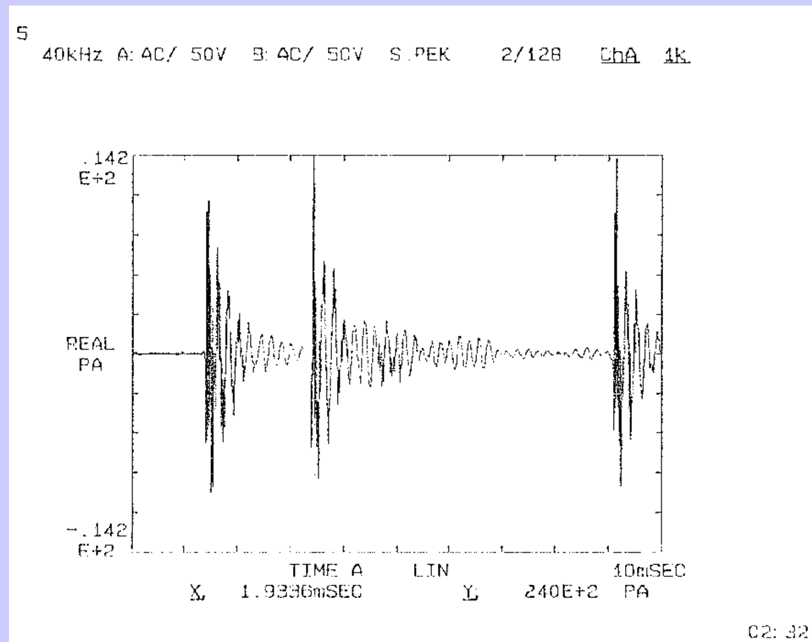
Erosion on the ship propeller blades



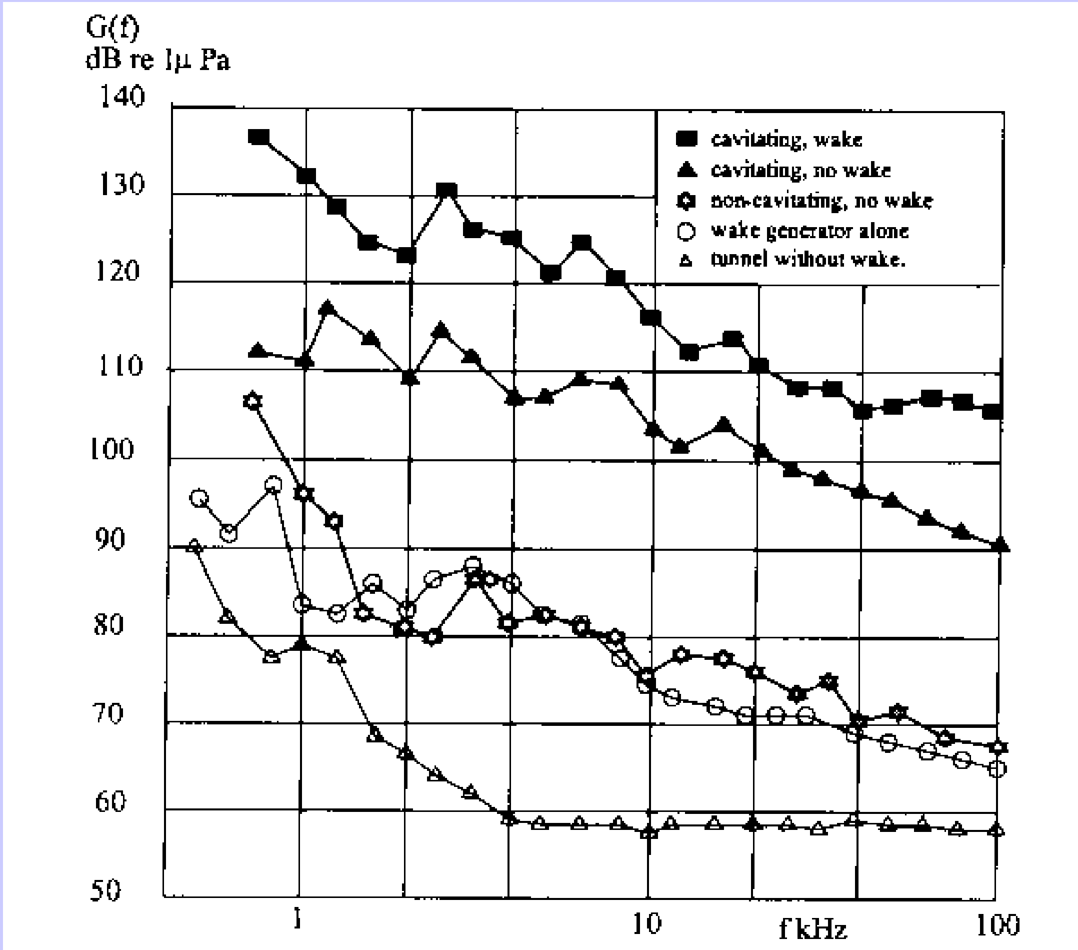
Noise



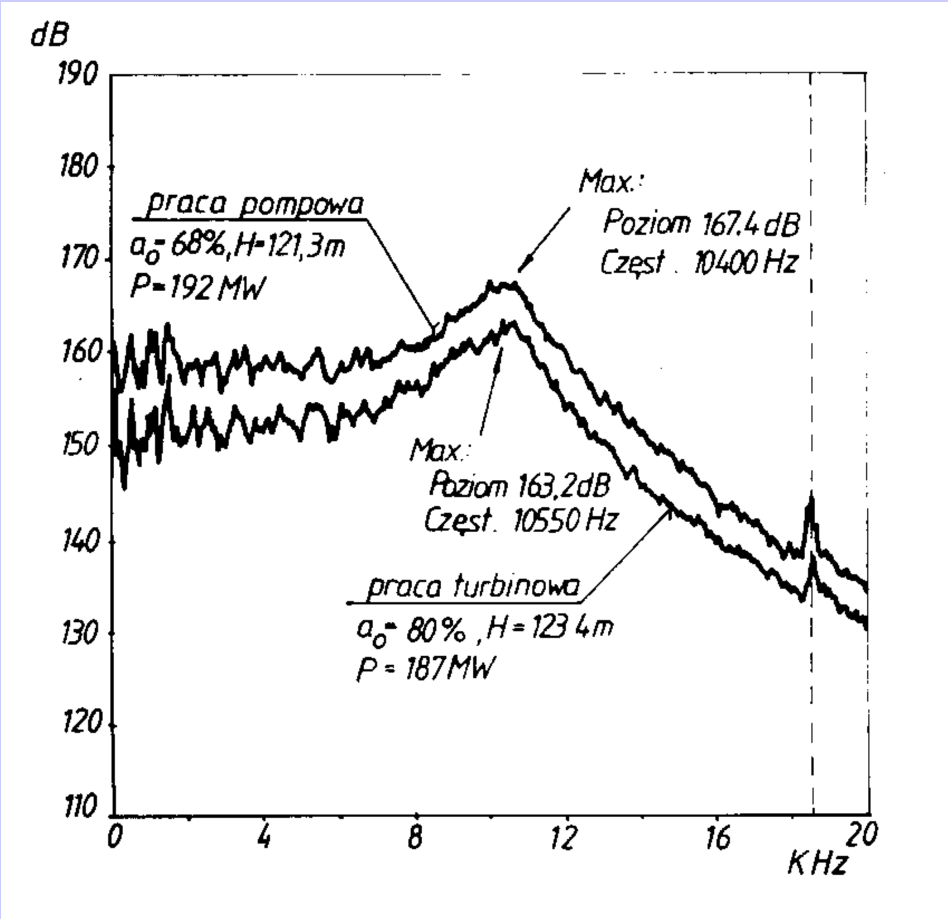
$$R\ddot{R}+\frac{3}{2}\dot{R}^2+\frac{2\sigma}{\rho R}+4\mu\frac{\dot{R}}{\rho R}=F(t)$$



Spectrum of noise generated by a ship propeller



Vibration



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

Conclusion

- All machines and devices in which liquid is the working fluid are susceptible to cavitation.
- Cavitation results in serious negative consequences, which may adversely affect the operation and may lead to the damage these machines and devices.
- Limitation or elimination of cavitation and its negative consequences requires special, complicated methods for design of these machines and devices, using modern experimental techniques and the most advanced theoretical and numerical methods.