Cavitation and its Effects

(A Case Study – Experiment performed by Dr. Kinnas and his students at MIT’s Cavitation tunnel)
What is Cavitation

“a general term used to describe the behavior of voids or bubbles in a liquid”

Cavitation occurs in liquids when the pressure is reduced to the vapor pressure at a given temperature of operation.

REMEMBER WATER BOILS WHEN ....

Pressure = 101 kPa (atmospheric)  
Temperature = 212 F (100 C)

Pressure = 1.7 kPa  
Temperature = 60 F (15.5 C)

BOILING OF WATER AT NORMAL TEMPERATURES IS CAUSING ...

CAVITATION

http://cavity.ce.utexas.edu/
Cavitation Number

\[ \sigma = \frac{P_\infty - P_v}{\frac{\rho}{2} v_\infty^2} \]

Where: \( \sigma = \) cavitation number

- \( P_\infty; P_v = \) ambient and vapor pressure (Pa)
- \( \rho = \) fluid density (kg/m\(^3\))
- \( v_\infty = \) velocity of upstream flow / trifoiler (m/s)

NOTE:
- Velocity (\( v_\infty \)) \( \uparrow \) cavitation number (\( \sigma \)) \( \downarrow \) CAVITATION occurs
How it “works”

In local regions of low pressure:
Vapor bubbles start growing

In the regions of higher-pressure downstream:
Bubbles collapse on the solid walls and result into very high local pressures (~800 MPa!)

Hub Vortex

http://cavity.ce.utexas.edu/kinnas/cavphotos.html#prop_ti
Problems

- increased noise
- pitting, accelerated erosion and damage to components
- vibrations
- loss of efficiency.
Benefit Uses

- Used in high power \textit{ultrasonics}
- Used to homogenize, or mix and \textit{break down particles}
- Used to cavitating \textit{water purification devices}
- Used for \textit{destruction of kidney stones} via shock waves
Case study

TRIFOILER
The World’s Fastest Sailboat

50.1MPH

Common Questions:

How can we overcome the resistance of water?

Why can’t we make it go faster?
Hydrofoil = Lifting surface

let a boat go faster by getting the hull out of the water

→ overcome the drag on the submerged hydrofoils instead of the drag on the hull
Top velocity HIGHER than bottom velocity \( (v_{\text{top}} > v_{\text{bottom}}) \)

Top pressure LOWER than bottom pressure (Bernoulli’s equation) \( \rightarrow \) LIFT

Lift increases with fluid velocity \( (U) \); Angle of Attack, Camber

INCREASE in U causes DROP in Top pressure
Cavitating Hydrofoil Experiment

Cavitation Tunnel

Pressure is decreased in order to simulate the effects of high speed flow

MIT Water Tunnel

http://web.mit.edu/mhl/www/photos.html

CE319F - Spring 2013 Cavitating Hydrofoil Experiment
Super-Cavitation

Top pressure DROPS $\rightarrow$ CAVITATION

Cavitation causes - loss of lift
- Increase of drag force

$\implies$ Slowing down the sailboat
MOVIE on Cavitating Hydrofoil
Take-home Messages

√ **Cavitation number** characterizes the amount of cavitation

\[ P_{\text{ambient}} \text{ INCREASES } \Rightarrow \text{Cavitation DECREASES} \]

√ **Forces** and **Foil Vibrations** become excessive as the cavity crosses the trailing edge of the foil

√ **Lift** is significantly decreased as the cavity becomes a super-cavity

*Super-Cavitation causes the barrier in the speed of the TRIFOILER*