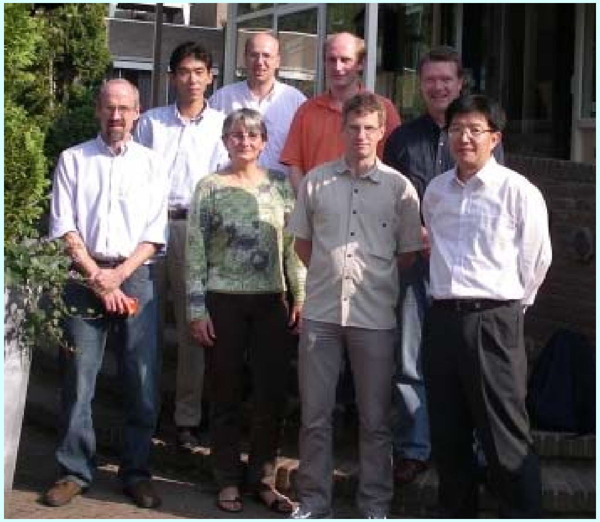
Report of the Specialist Committee on Cavitation

Presented by L. Briançon-Marjollet - France

25th International Towing Tank Conference
Fukuoka, Japan
16 September 2008

Committee



Membership

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– *Bassin d'Essais des Carenes -France*

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– *Hyundai Heavy Industries - South Korea*

Dr. Scott Gowing

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– *Saif University of Technology - Iran*

Mr. Erik Van Wijngaarden

– *Maritime Research Institute Netherlands - The Netherlands*

Dr. William Zierke - Secretary

– *Applied Research Laboratory - United States*

Meetings

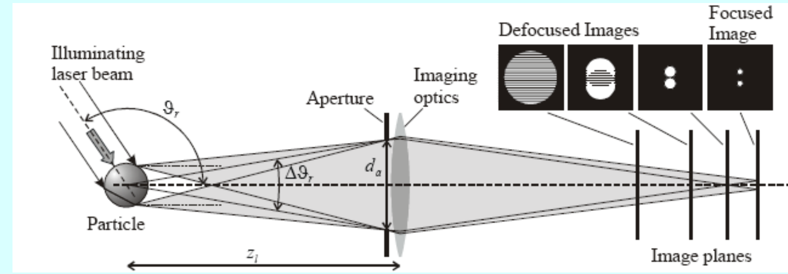
Val de Reuil, France
– 17 and 18 January 2006
Wageningen, Netherlands
– 15 and 16 September 2006
Göteborg, Sweden
– 23 and 24 April 2007
Washington, United States
– 7-9 November 2007

Events

Questionnaire for assessing current state of the art of cavitation modeling

24th ITTC Recommendations:

- Review the application of computational methods and new experimental methods to the prediction of cavitation, including cavitation dynamics and its influence on pressure fluctuations.
- Review advances in multiphase flow modeling of cavitation and its potential to predict inception, erosion, and induced pressure fluctuations.



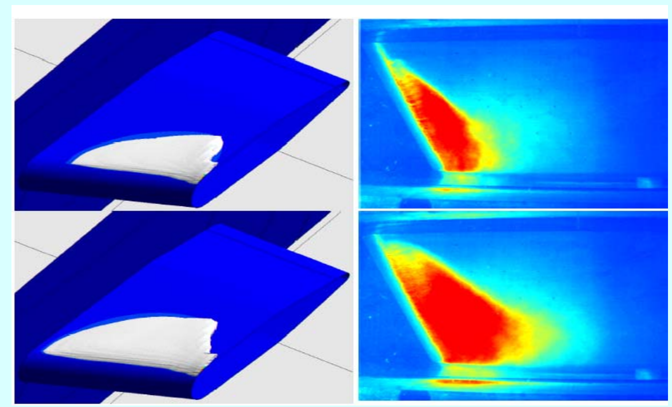
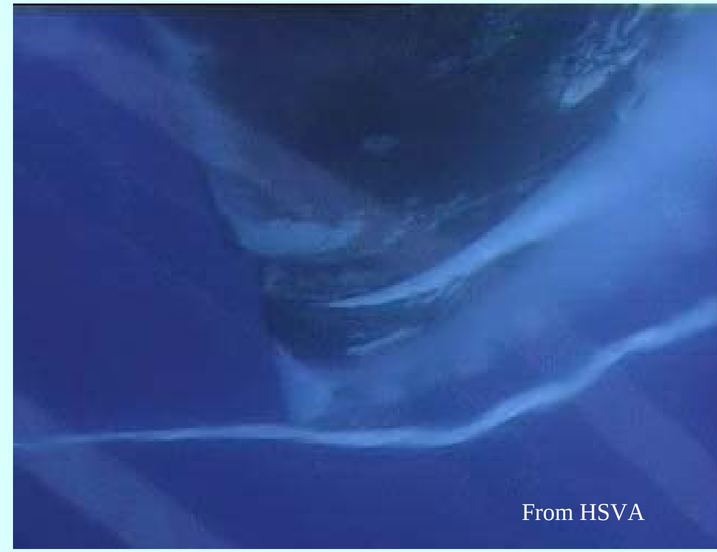



Photo Roll-Roys-Kamewa

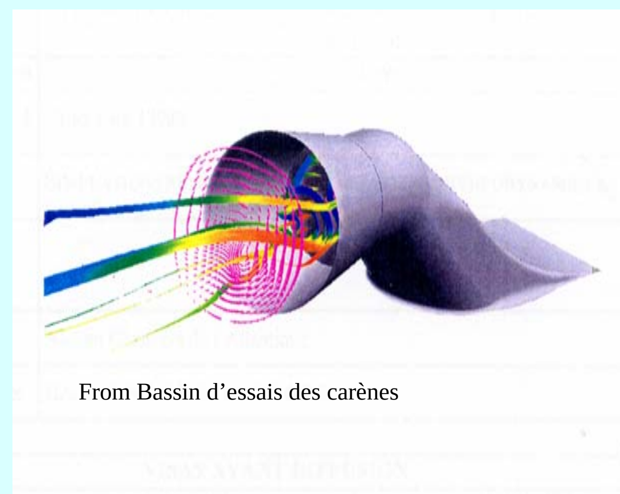
- Review methods and develop guidelines for the prediction of cavitation and erosion damage for unconventional rudders or rudders behind highly-loaded propellers.
- Review methods of modeling the cavitation behavior of waterjets (inlets and pumps), including scale effects. Develop guidelines or procedures. Liase with the Propulsion Committee.

Report Outline

- **CAVITATION SURVEY**
- **CAVITATION MODELING**
  (Recommendation 1)
- **MULTIPHASE FLOW CAVITATION MODELING**
  (Recommendation 2)
- **RUDDER CAVITATION**
  (Recommendation 3)
- **WATERJETS CAVITATION**
  (Recommendation 4)



From HSVA



From Bassin d'essais des carènes

Cavitation Survey - 1

- Background Information:
- Cavitation Modeling Capability:
- Cavitation Experimental Capability:
- Rudder Cavitation:
- Waterjet Cavitation:
- Summary Information:

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Send to

179 organizations

29 organizations from 14 countries completed the survey on a **website** established by the committee,

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Send to → 179 organizations

29 organizations from 14 countries completed the survey on a **website** established by the committee,

•45%: Model basin, Towing tank
•28%: University
•17%: Shipyard or propeller manufacturing
•10%: Consultant

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- 45%: Model basin, Towing tank
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- 86%: ITTC member
- 69% make cavitation performance predictions for sponsors
- 65% design hardware with cavitation performance
- 38% commercially market codes or models for use in making cavitation performance predictions

Cavitation Survey - 2

- **Cavitation Modeling Capability (96%)**
  - 100% use numerical and/or empirical method:
    - Empirical and potential-flows methods: reasonable accuracy for trade-off studies
    - Varied opinion on CFD
  - 57% perform cavitation modelling with commercial CFD software
  - 25% develop their own CFD code or use university developed codes
  - Majority feel that:
    - The use of CFD with multiphase flow modelling is important for cavitation prediction
    - Erosion, noise, and higher-order pressure pulses will take several years

- **Cavitation Experimental Capability (75%)**
  - Little information regarding new experimental techniques or new measuring equipment

Cavitation Survey - 3

- **Rudder Cavitation (51%)**

  - 93% perform rudder cavitation tests
  - 83% perform tests with a rudder installed behind a propeller in a non uniform flow (wire screens, dummy models, or complete ship models)
  - 75% use visual observation (42% use high-speed video)
  - 50% perform paint tests as an addition to visual observation

  - 80% responded on modeling rudder cavitation:
  - 50% perform calculation for the rudder alone (with non-uniform upstream flow)

  - Most institutes emphasis that most rudder cavitation phenomena (gap, sheet, and vortex) as well as the range of rudder angles where problem occur are **under-predicted**

- **Waterjet cavitation (38%)**

  - 31% ran a variety of tests (pump loop for waterjet pump alone, waterjet inlet alone)
  - 24% provide information on cavitation modelling
  - 18% (2 organizations) use multiphase flow CFD (cavitation breakdown)

24th ITTC Recommendations

- Review the application of computational methods and new experimental methods to the prediction of cavitation, including cavitation dynamics and its influence on pressure fluctuations.

- Review advances in multiphase flow modeling of cavitation and its potential to predict inception, erosion, and induced pressure fluctuations.

- Review methods and develop guidelines for the prediction of cavitation and erosion damage for unconventional rudders or rudders behind highly-loaded propellers.

- Review methods of modeling the cavitation behavior of waterjets (inlets and pumps), including scale effects. Develop guidelines or procedures. Liase with the Propulsion Committee.

Cavitation Modeling
New Experimental Methods - 1

- LDV: Scanning technique allows faster data rate and near surface measurements.
- PIV: finer spatial scales (higher resolution of CCD). SPIV for 3D. Flow upstream propeller and rudder. DPIV and HPIV for nuclei measurements.
- Photography and Video Measurements: full-scale use (boroscope, high-speed video)
- Cavitation Erosion Measurements

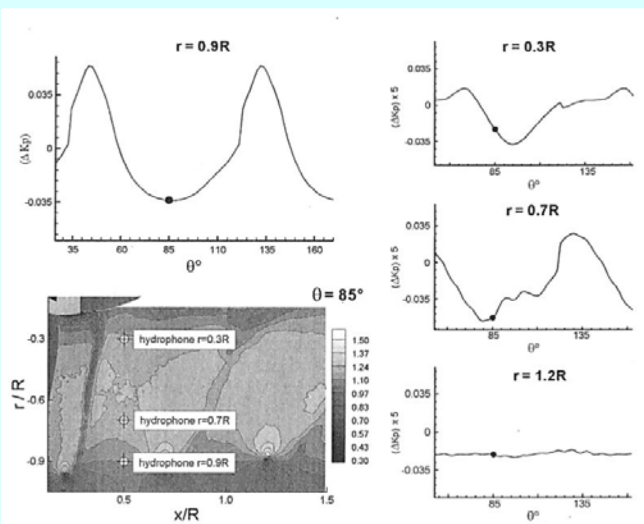
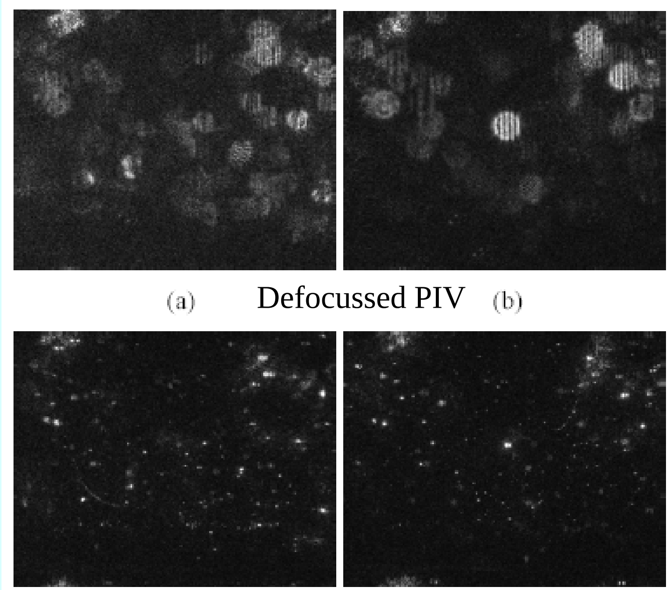


Photo Marin

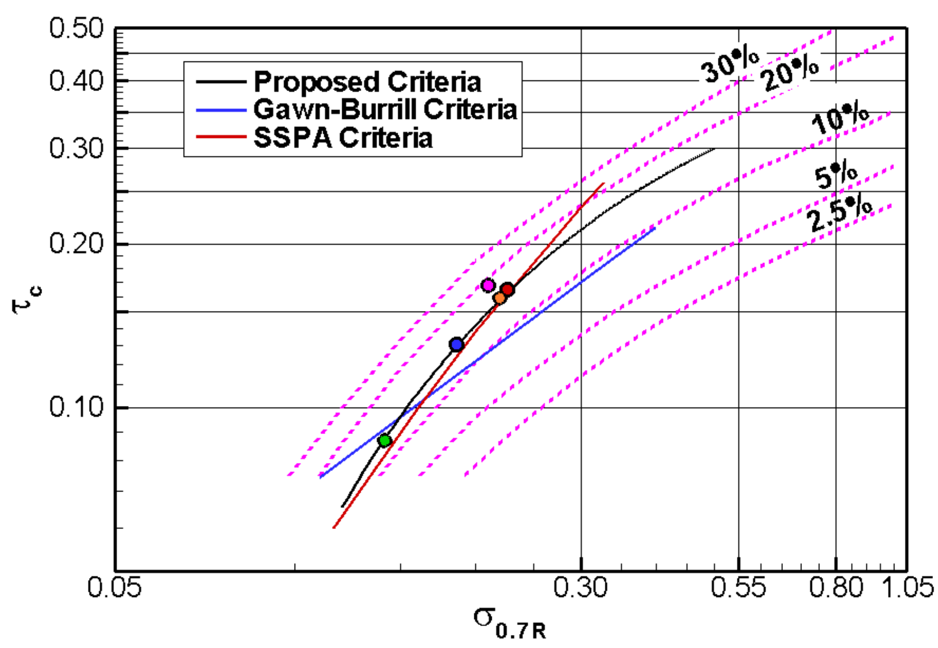


(a) Defocussed PIV (b)

(c) Focussed PIV (d)

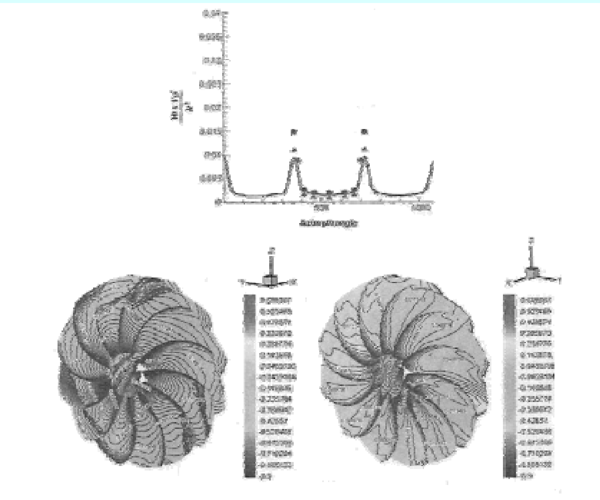
Cavitation Modeling Computational Methods - 2

- Empirical Methods: still indispensable for design
- Potential-Flows Methods: useful for design optimization
- RANS Solvers without Multiphase-Flow Modeling: for surface cavitation inception



Cavitation thrust breakdown prediction by Black (2007).

Cavitation modeling
Noise and pressure fluctuation Prediction - 3



Comparison of calculated and measured pressure contours and cavity volumes by Seol et al. (2005)

- The cavitation volume histories compared reasonably well with experiments
- Discrepancies: wake prediction (scale effects), tip vortex
- The high-frequency sources from collapsing cavitation are ignored. Further research is needed to predict noise at those frequencies.

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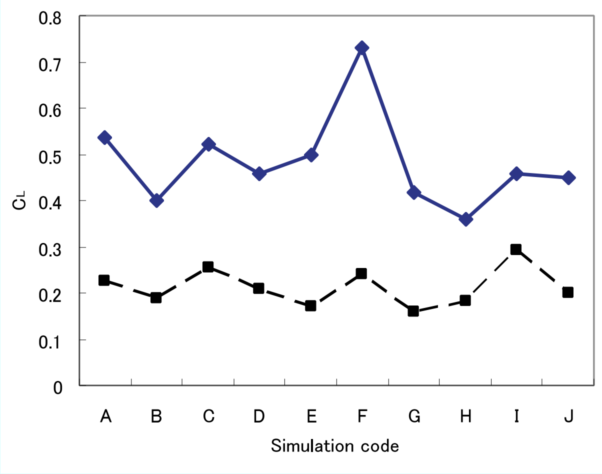
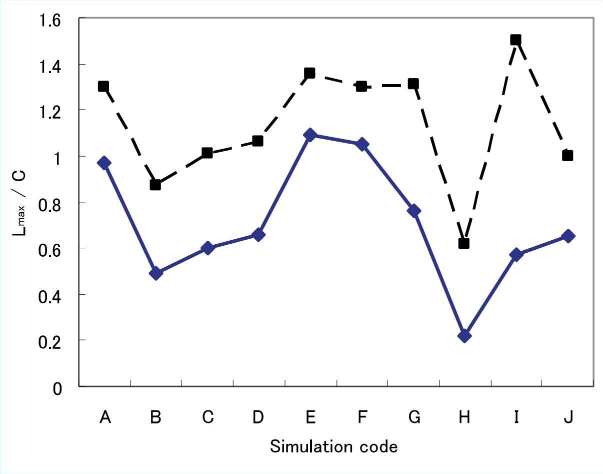
Multiphase-Flow Modeling - 1

- Multiphase-flow modeling: CFD codes involving void fraction or at least two phases. Used in combination with RANS simulation, DES, or LES
- Based on the concept of phase averaging: homogeneous mixture of vapor and liquid
  - derive mixture density from pressure via equation of state (barotropic model)
  - transport equation for the volume fraction parameter with creation and destruction terms

- Numerous papers on numerical multiphase flow modeling. Many fundamental studies and validation are on simple geometry and concern global aspects of the flow → need high-quality tests with unsteady local measurements for finer validation.

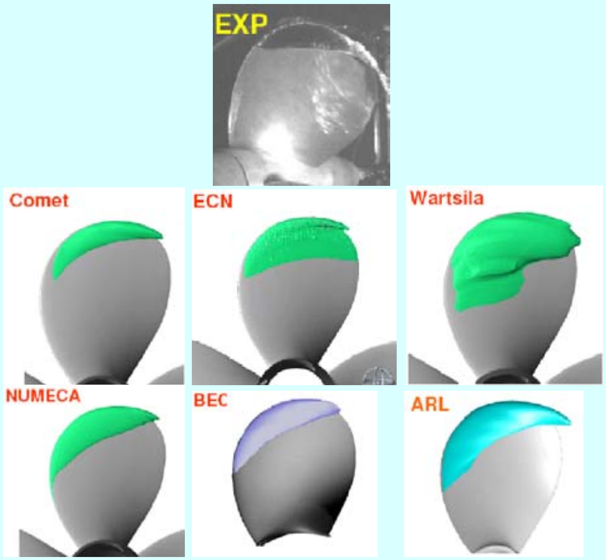


Computed lift coefficient (from CAV 2003)

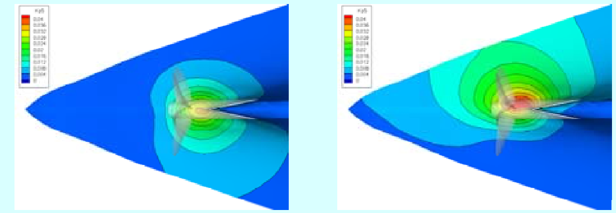


Computed maximum cavity length (from CAV 2003)

Multiphase-Flow Modeling - 2

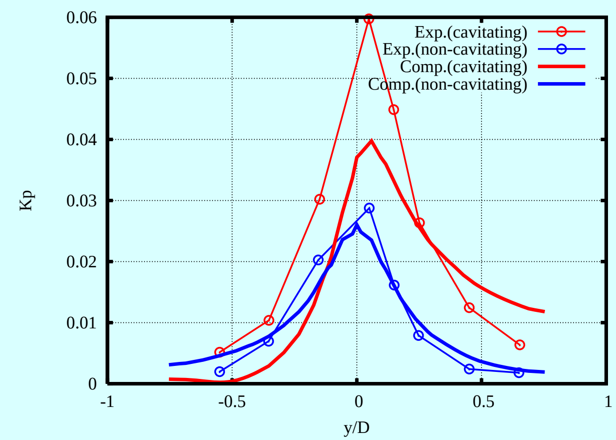


Comparison of measured and computed cavity patterns
(vapor volume fraction c_V=0.5)—
as reported by Streckwall and Salvatore (2007)



Without Cavitation With Cavitation

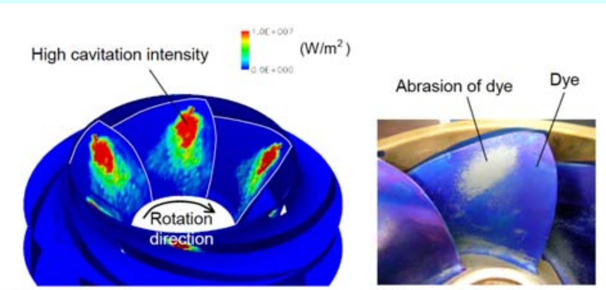
Magnitude of the pressure fluctuations on the hull surface
at the blade frequency, as predicted from a RANS simulations
by Kawamura et al. (2008)



Comparison of the measured (o) and computed hull surface pressure fluctuations at the blade frequency, as given by Kawamura et al. (2008). Cavitating flow and non cavitating

- Application to engineering flows, pumps, and propellers
- Prediction of cavitation inception
- Cavitation-induced pressure pulsations

Multiphase-Flow Modeling - 3



(a) Predicted cavitation intensity (b) Visualized cavitation erosion area

Predicted *cavitation intensity* and comparison with the result of an experimental paint test, as given by Fukaya et al. (2006)

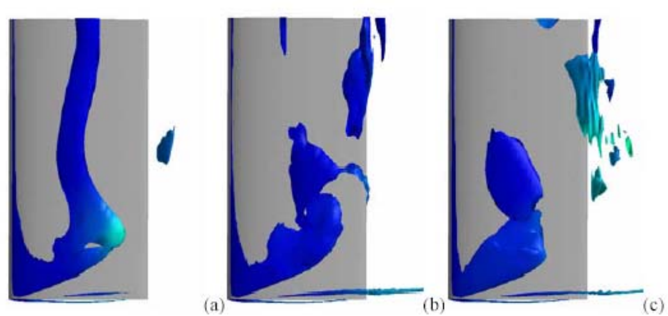


Figure 9. Suction side of the wing as seen from above. Iso-surfaces the volume fraction γ=0.25coloured by the pressure. (a) Time t=0.01, (b) t=0.02 and (c) t=0.035.

From Persson and al. Cav2006

- Cavitation erosion (frequency of bubble collapse events or standard deviation of the void fraction)
- Cavitation thrust breakdown:
  - Centrifugal pumps
  - Propellers
- Prediction using LES and DES
  - Recent research
  - To have a better resolution of local and instantaneous pressure fields → to improve the prediction of cavitating flow, especially for unsteady, cloud mechanisms, vortex interaction

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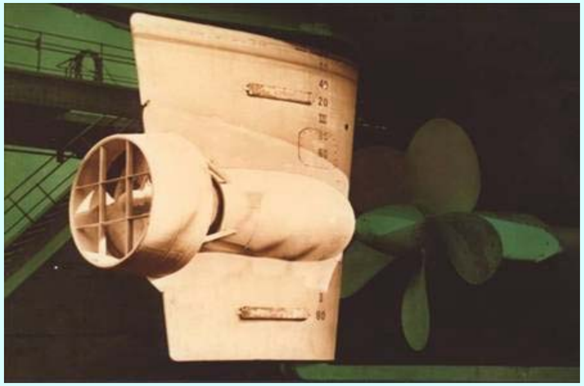
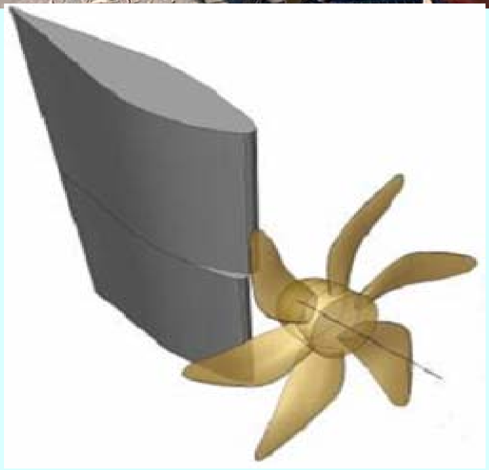
Erosion on Unconventional Rudders - 1

What Is an Unconventional Rudder?



95% are symmetric spade or semi-spade rudders
→ all others are unconventional

- Active generation of additional rudder forces (motor propeller unit, rotating cylinder)
- Passive generation of higher rudder forces (plate, flap)
- Improvement of propulsion performance (twist, rudder bulb)
- Improvement of cavitation performance → often convert a conventional rudder to an unconventional one (twisted rudder, plate, scissors ..)

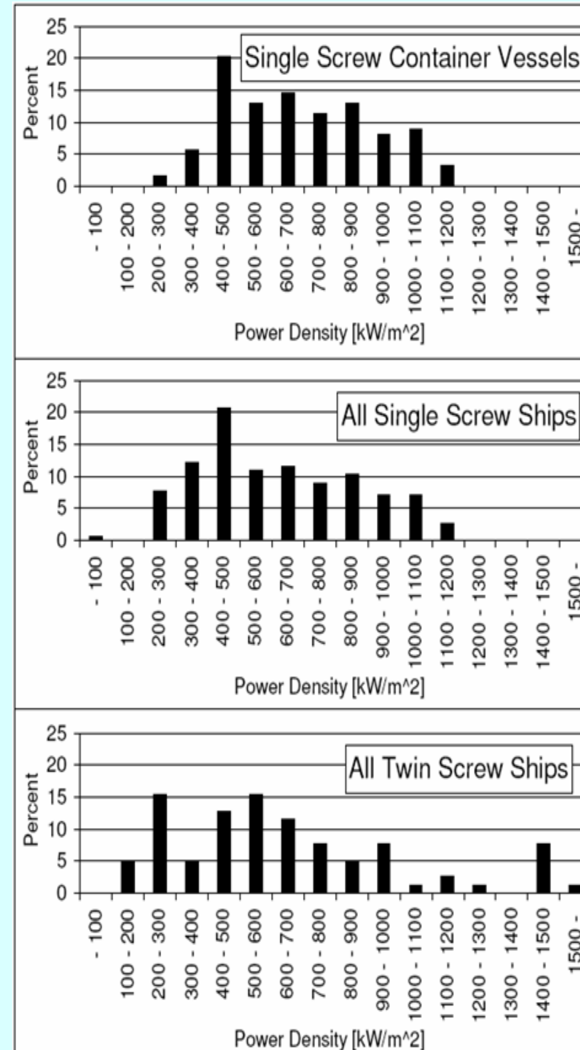


Erosion on Unconventional Rudders - 2

What Is a Highly-Loaded Propeller?

2/3 of all sea-going ships have a power density < 800 kW/m^2

Highly-loaded = propeller power density >800 kW/m^2

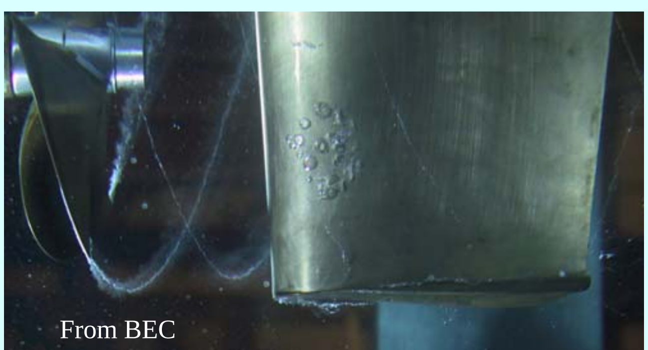


Erosion on Unconventional Rudders - 3

- 24th ITTC report of specialist committee on erosion is applicable
- Plus some *additional aspects*
  - More complex geometry: many gaps, more sharp edges
  - Propeller loading increase the non-uniformity of the inflow
  - Boundary layer thickness (especially in gaps) or vortex strength is highly Reynolds number dependent, so is the corresponding cavitation

High-efficiency rudder

Semi-spade rudder modified to reduce cavitation



From BEC

Erosion on Unconventional Rudders - 4

Recommendations:

- Those from the 24th ITTC
  - Test complete unit of rudder and propeller
  - Tests at off-design conditions
- Exact reproduction of complex rudder geometry
- Local Re > 300,000
- Investigations on wider range of rudder angles
- Larger-scale part model can be used (calibration is necessary)
- Use procedure written by the committee


From HSVA

➢ **Procedure for Predicting Cavitation – Induced Erosion Damage on Propellers, Rudders and Appendages – ITTC Procedure 7.5-02-03-03.5**

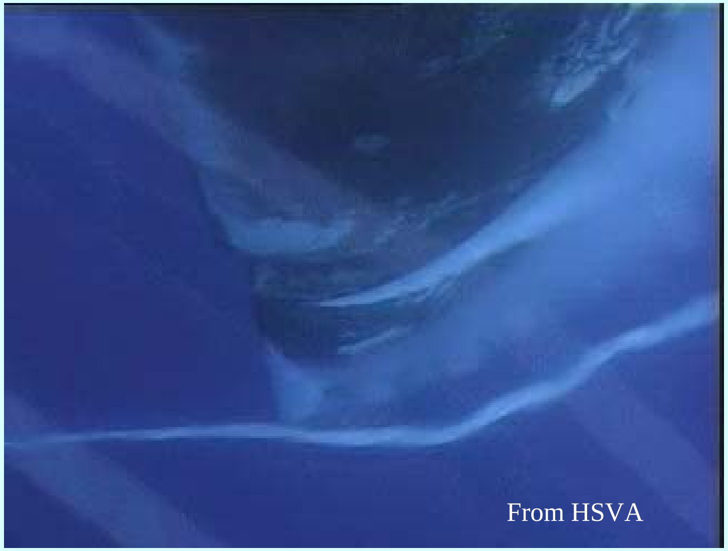
➢ **Procedure for Prediction of cavitation and erosion damage for unconventional rudders or rudders behind highly loaded propellers – ITTC Procedure 7.5-02-03-03.7**

➢ **Tests as based on cavitation tests according to ITTC – Procedure *7.5-02-03-03.1***

Erosion on Unconventional Rudders - 5

Suggestions for Future Investigations:

- Application of rudder leading-edge roughness
- Intentional widening of gaps during model tests
- Full-scale rudder observations (with high-speed video) and monitoring of rudder erosion damages
- Improvement of soft-ink method



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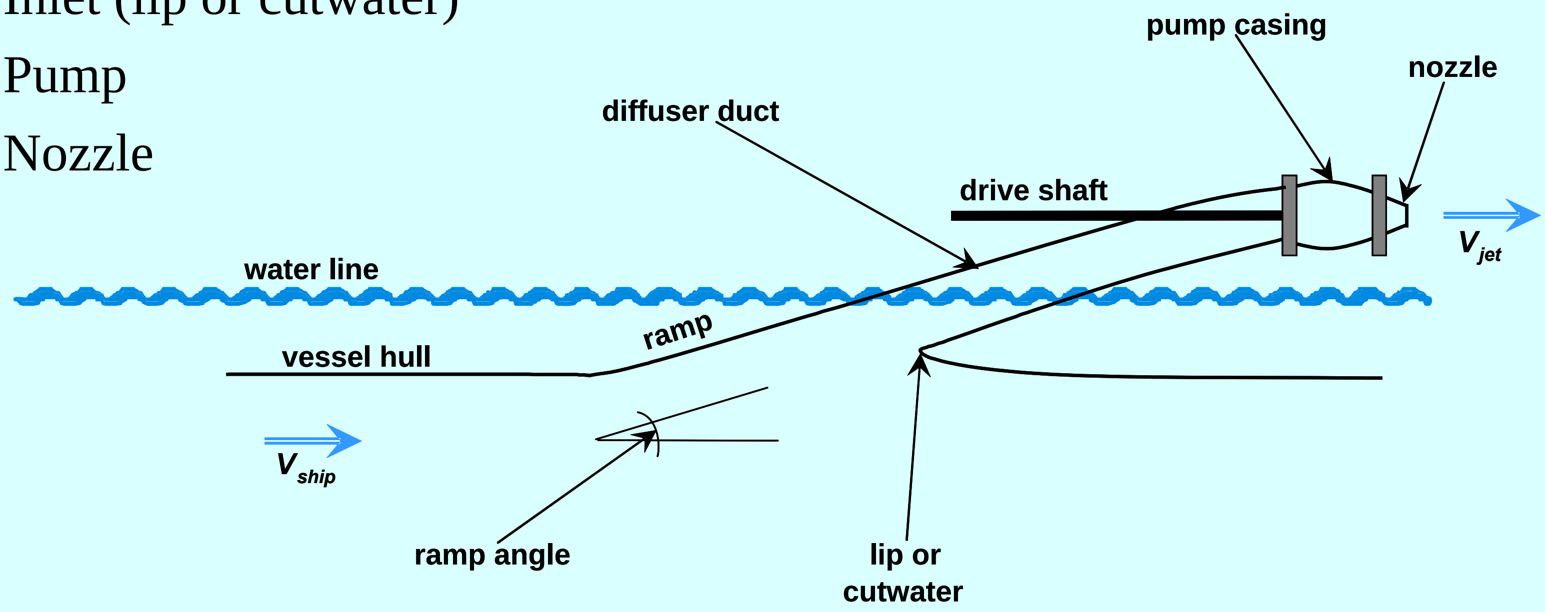
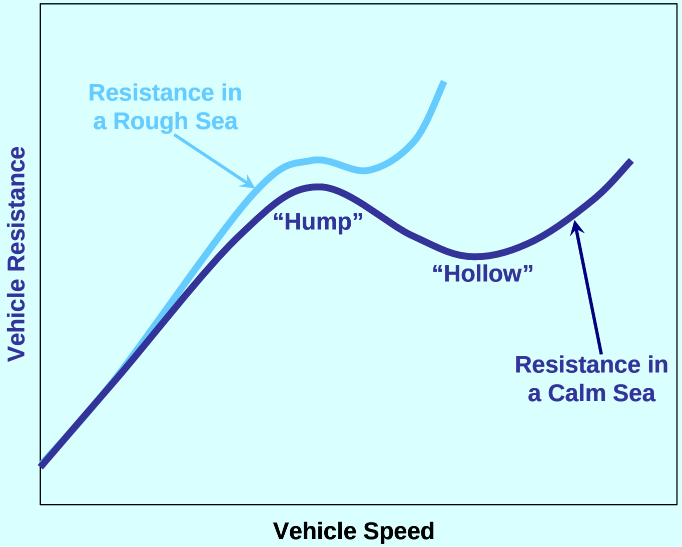
Waterjets Cavitation -1

- Previous committees on waterjets deliberately disregarded the effect of cavitation on the powering characteristics and possible erosion effects
- So, the present committee gave an extended introduction to cavitation issues and focussed on more specific and historical cavitation issues for the different components of a waterjet
  - Inlet (lip or cutwater)
  - Pump
  - Nozzle

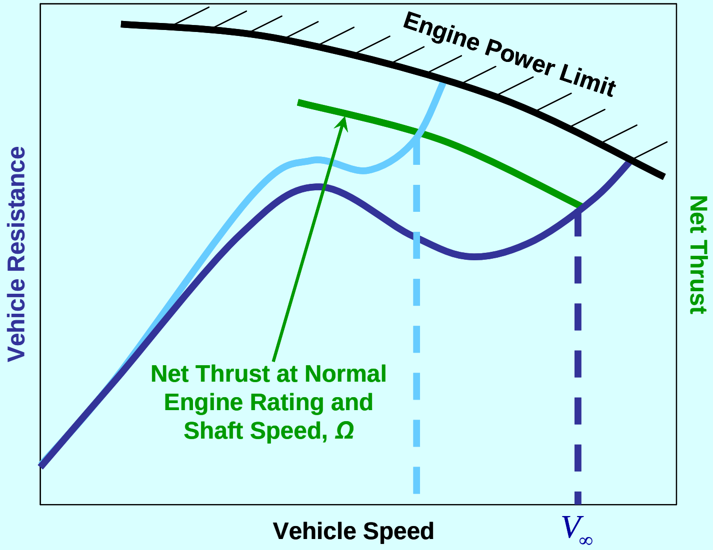


Waterjets Cavitation -2



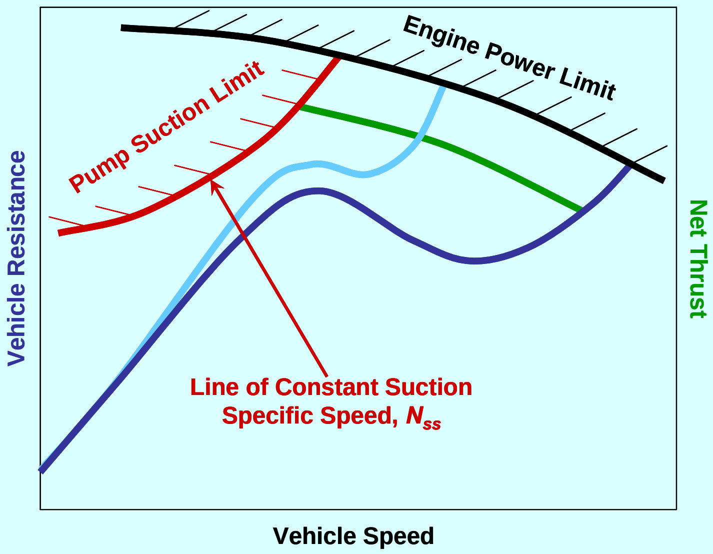
- Ship resistance curve depending on sea state and ship speed

Waterjets Cavitation -2



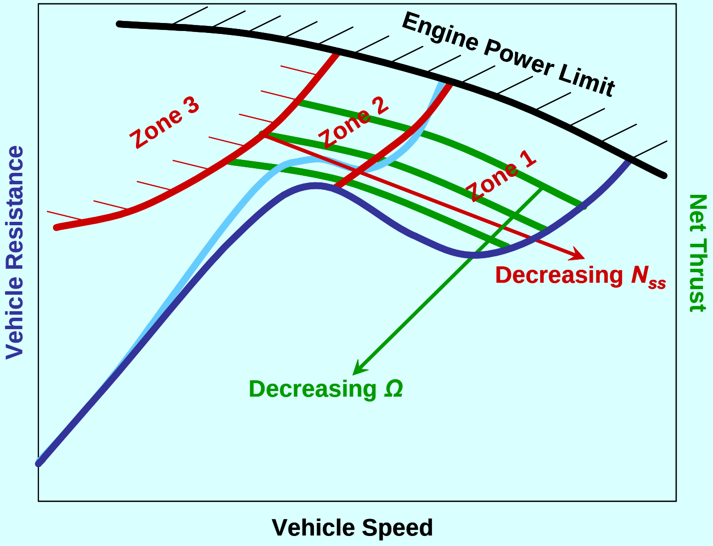
- Net thrust curve for a waterjet

Waterjets Cavitation -2



- Limiting value of suction specific speed for cavitation breakdown

Waterjets Cavitation -2



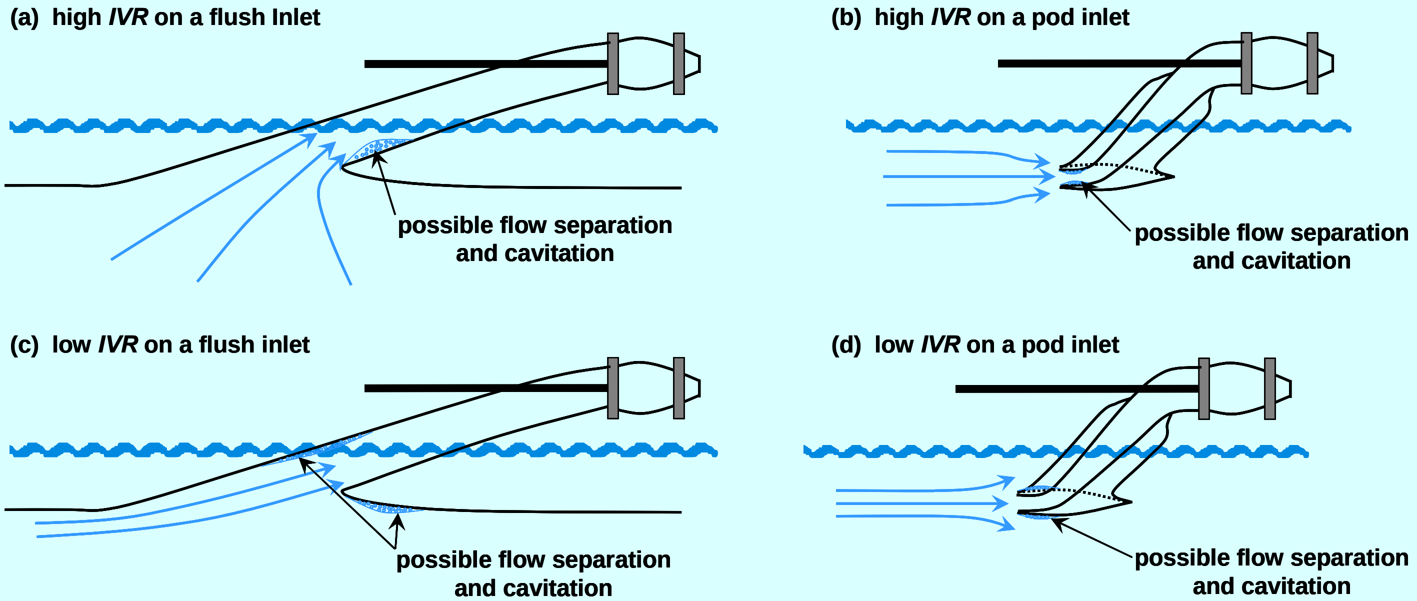
- Zone 1: unrestricted (intermittent cavitation)
- Zone 2: developed cavitation (vibration and noise increase)
- Zone 3: prohibited (beyond pump suction limit)

Waterjets Cavitation -3

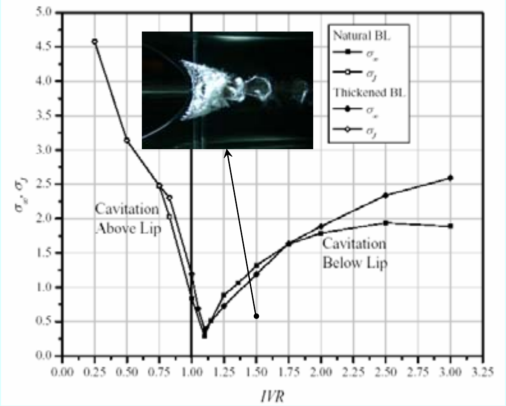
- Waterjet and associated hull is a specific propulsion system:
  - Specific resistance versus ship speed
  - Ship boundary layer ingested by the waterjet

- Contrary to a propeller, often it is not possible to test the exact waterjet model **and** hull in a cavitation tunnel or towing tank:
  - Due to model scale → size of the waterjet
  - Due to model cost

Waterjets Cavitation - 4



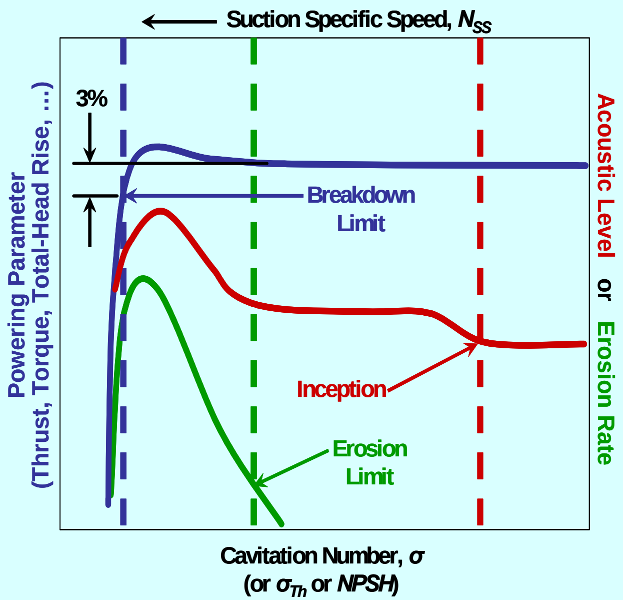
- Inlet generate losses, flow separation managed by inlet velocity ratio (IVR) → modify pump inflow:
    - CFD
    - Tests in cavitation tunnel



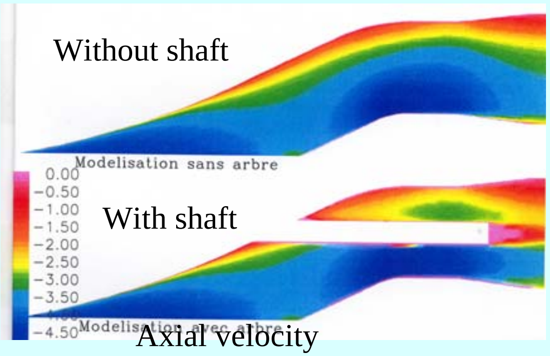
Lip cavitation inception with the waterjet inlet ingesting a natural and thicknened boundary layer, as measured by Brandner and Walker (2006)

Waterjets Cavitation - 5

- Pump limitations: thrust breakdown, vibration

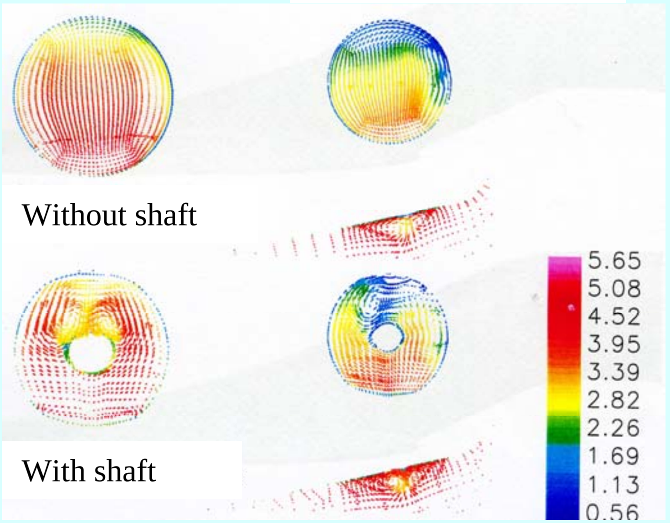


Generic schematic of pump cavitation performance (for a given flow rate)



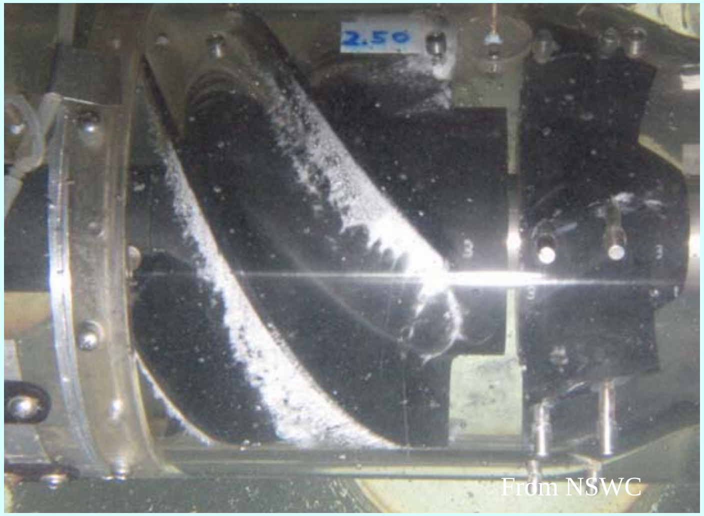
Axial velocity

Transverse velocity



Calculation Bassin d’essais des carènes

Waterjets Cavitation - 6

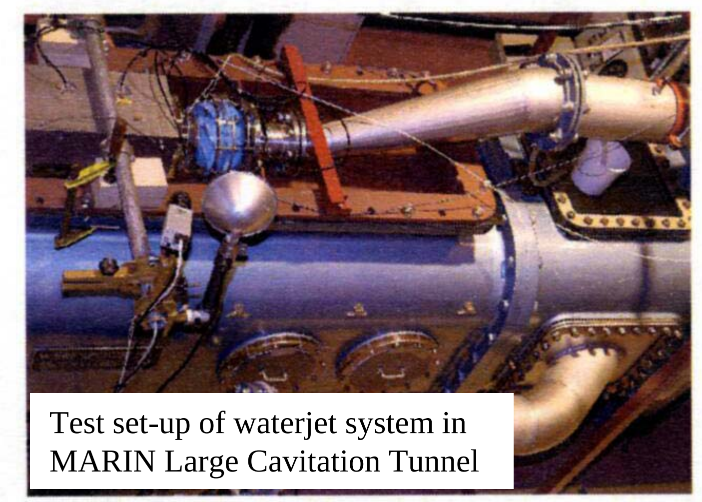


- Self-propulsion tests → no cavitation (low Reynolds number)
- Pump-loop tests → necessary but not sufficient, need interaction with inlet and shaft wake

➢**Procedure and guidelines for modeling the behavior of cavitation in waterjets– ITTC Procedure 7.5-02-03-03.8**

➢**Tests as based on cavitation tests according to ITTC – Procedure *7.5-02-03-03.1***

Waterjets Cavitation - 7



Test set-up of waterjet system in MARIN Large Cavitation Tunnel

From NSWC

- Waterjet system tests → more representative, allow boundary layer control upstream the inlet
- Numerical: RANS with multiphase flow began to be used

➢**Procedure and guidelines for modeling the behavior of cavitation in waterjets– ITTC Procedure 7.5-02-03-03.8**

➢**Tests as based on cavitation tests according to ITTC – Procedure *7.5-02-03-03.1***

Conclusions

- Empirical methods are still indispensable for design
- Potential-flow methods are useful for design optimization
- RANS with multiphase-flow models largely employed in research. Need more precise tests for validation. Become used more frequently for customers.
- Cavitation rudder (conventional or not) remains a challenge. Special tests had to be validated and developed especially when Reynolds number effect is important (gap, vortex).
- Waterjet cavitation:
  - For breakdown, pump-loop tests are sufficient
  - For other cavitation issues, waterjet system tests are recommended
  - Need full-scale measurements and comparison with tests

Conclusions

- Inception of surface cavitation:
  - Single-phase RANS
  - Model-scale testing
  - Potential-flow methods
- Inception of vortex cavitation:
  - Model-scale testing + Empirical-scaling method
  - Single-phase RANS + Empirical-scaling method
- Full-scale pressure fluctuation:
  - Model-scale testing
- Cavitation erosion:
  - Model-scale testing + Empirical-scaling method
- Thrust breakdown:
  - Model-scale testing
  - Multiphase RANS

Recommendations

- Adopt the new procedures:
  - 7.5-02-03-03.7: Prediction of Cavitation and Erosion Damage for Unconventional Rudders or Rudders behind Highly-Loaded Propellers
  - 7.5-02-03-03.8: Modeling the Behavior of Cavitation in Waterjets