The “Silver Elephant”

A cavitation tunnel built to a precision of hundredths of a millimeter

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Experimentation and testing are among the most tangible and visible activities in a development process. Such moments are even more impressive when the parameters of the test reach dramatic dimensions. One such testing environment is the “Silver Elephant”, built to evaluate the hydrodynamics of ships’ propellers.

An important issue in the design of ships’ propellers is cavitation. Cavitation occurs when bubbles of water vapor formed in low-pressure areas enter areas of higher pressure where they collapse. This process can lead to the rapid erosion of adjoining surfaces.

The Silver Elephant left Poland in January 2005 for Vietnam, where it will serve the rapidly developing shipbuilding industry. The beginning of this journey marked the conclusion of one of the largest and most challenging construction projects in the history of ABB Zamech Marine in Poland.

It is said, that everything in the Far East has to have a name. The same is true of cavitation tunnels and large test installations in general. The "Silver Elephant" had already acquired its name in the production hall at Elbląg, Poland, but its formal baptism took place at the Ship Design and Research Center (SDRC) Factbox 1 in Gdańsk. The name reflects the silver appearance the tunnel exterior, acquired through passivation, and the resemblance of the entire tube to a pachyderm with a curled trunk.

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1 Ready to take on great projects - the Elbląg factory of ABB Zamech Marine in Poland

Cooperation against cavitation

The story of this remarkable project began with a cooperation agreement signed by the Polish and Vietnamese governments. The developing shipbuilding industry in the Far East was one of the sectors to be offered Polish assistance. SDRC, as a leading specialist in hydrodynamics, was awarded a contract for the design and construction of a cavitation tunnel for a Vietnamese research center. SDRC prepared the conceptual design, and ABB Zamech Marine at Elbląg, Poland 1 was awarded the task of transferring this onto paper and manufacturing the tunnel. This was no normal order for that plant. Not only are such tunnels rarely built, but the tunnel's size Factbox 2 placed it far beyond anything so far supplied by the factory.

A cavitation tunnel is used to analyze liquid flow around the screw propeller of a ship and to evaluate and optimize the design of such propellers. However, marine propellers can be four or even eight meters in diameter. It is hardly practical to examine such large structures in such a tunnel. Not only would the tunnel have to be of gargantuan proportions, but the time and costs involved in iterating the design of the test propeller would not be acceptable. Models with a 20-centimeter diameter are used instead. The results of such tests can be scaled to permit accurate predictions about the properties of the full-size propeller 2.

Lethal bubbles

The action of a propeller causes currents and turbulences. The faster a fluid flows, the lower its pressure (Bernoulli's Principle). When its pressure is sufficiently low, water evaporates to form bubbles of vapor. These bubbles flow with the water until they enter zones of higher pressure where

Factbox 1 Ship Design and Research Centre

The Ship Design and Research Centre (SDRC) was founded in 1971 as a design, construction and research centre for the needs of the Polish shipbuilding and repair industry. Following organizational hardships in the early 90ies, the SDRC has defended its leading position in the market for hydromechanics, ship construction, material technology and corrosion. The end of the past decade revitalized the ship design activity of the company. The SDRC laboratories are made accessible to students and staff of technical universities, and great emphasis is laid on increasing the education quality and development of science. In April 2004, the SDRC was transformed into a state-owned company.

2 A real ship's propeller is far too large to be tested in a cavitation tunnel. This propeller is for ship B 8276 built by Gdynia Shipyard, Poland

Factbox 2 The "Silver Elephant" in numbers

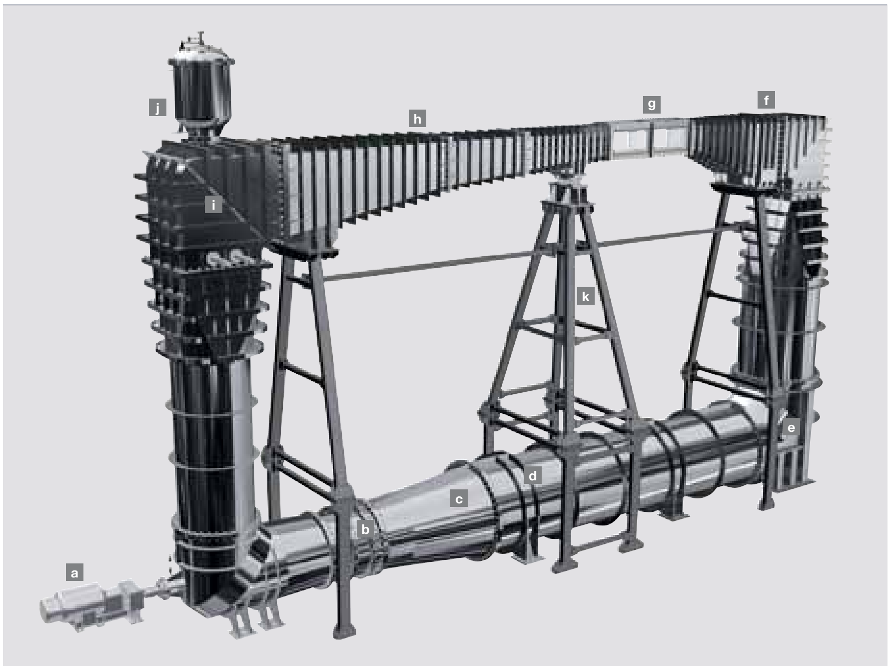
Length:	21 m
Height:	12 m
Volume of water held:	130 m^3
Mass of structure (without water):	60 t
Accuracy in perpendicularity of measurement chamber walls:	0.1 mm
Smoothness of inner plates:	Ra 0.8 to Ra 2.5
Bolts holding segments together (see also title picture):	M36

they implode. This action releases significant bursts of energy that spread through the water in the form of shock waves. The results are high noise emissions and vibrations, but worse still, cavitation can strike microscopic particles out of solid surfaces (such as the propeller blades). Over time this leads to erosion modifying the shape of the propeller and reducing its efficiency – with critical effects on the screw-propeller's life, the drive system and the fuel consumption.

An investment in cavitation investigation is thus an investment in the life and efficiency of the propeller being developed.

The tunnel itself is a circulatory water duct composed of four sections varying in shape and cross-sectional diameter 3. The tunnel is filled with water, and the model to be examined placed in the measuring chamber 3g 5 in its upper part. Doing some injustice to engineering vocabulary, one can say that the cavitation tunnel is an enormous steel tube with water pumped 4 in closed circulation. By generating a defined and controlled flow inside the measuring chamber, operating conditions for the screw propeller are simulated. Sensors located in the tunnel allow the careful study of the dynamic behavior of the propeller under different conditions. The results of such a study permit corrective measures to be introduced to the design.

3 The "Silver Elephant" cavitation tunnel



A 90 kW, 1500rpm electric motor a drives reduction gear with a transmission ratio of 1:6.3. The sub-units of this shaft are mounted on a common frame and coupled elastically. The water in the tunnel is pumped b by a four-blade ship-propeller at up to 200 rpm. The propeller elements are made of high-strength bronze. The pitch of the blades is adjustable. After leaving, the propeller, the water flows through a diffuser c, ie, a section of tubing that changes the water pressure through increasing its cross-section and then through a honeycomb straightener d that stabilizes the flow. The tunnel elbows e contain water guide vanes whose number and shape are different for every elbow. Before entering the measurement chamber, the water flows through the so-called confuser f. This stabilizes the water-jet as it leaves the elbow, and also modifies its pressure by reducing the cross-section. Careful hydrodynamic analysis and precise machining went into every part of the confuser.

The entire tunnel is located in a building. An upper floor permits access to the measurement chamber g. The chamber contains sensors which monitor various water parameters. Plexiglas window plates of 80 mm thickness are fitted in all four walls of this section to permit visual observation and filming of the test from different angles and the use of external instruments such as stroboscopes. Although primarily designed for propellers, the tunnel can also be used to test other parts such as ship hulls. Upon leaving the measurement chamber, the water enters a diffuser h. Water de-aerating elements are located in the tunnel elbow i and equalizing tank j. These help achieve required working parameters such as a positive or negative gauge pressure. The tunnel is supported and stabilized by brackets k of construction steel.

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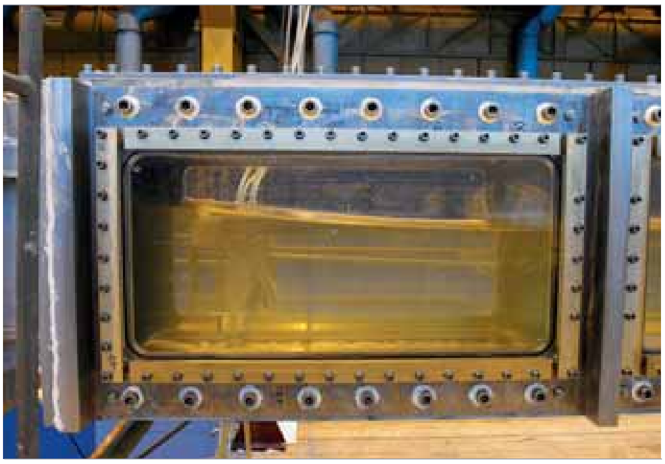
Chimera of a straight-forward project

In theory, everything looked great – a complete design, well specified requirements – all that was left to be done by ABB Zamech Marine was the preparation of detailed drawings and the welding and delivery of the tunnel. The contract was signed in December 2003 and ABB's engineers started work immediately. Each part of the construction – even the smallest and most insignificant detail was practically unique, adding to the challenge that lay ahead.

It was not, however, the design itself that posed the greatest challenge. The

4 The pump that keeps the water flowing is powered by an ABB frequency converter

5 A propeller design that has successfully braved the current in this measurement chamber is fit for the ocean



6 Numerous tests were required to verify and ascertain the tunnel's properties

seemingly "minor" requirement, specified by SDRC, to make the tunnel out of stainless steel became the key challenge. Precision engineering is a traditional strength of ABB Zamech Marine in Poland – the plant is able to work to accuracies of hundredths of millimeters. The key challenge, however, relates to the material chosen, ie, chromo-nickel plate. This material has a high thermal conductivity, making it impossible to join two plates by continuous welding. Work had to be interrupted repeatedly, prolonging the production time considerably. Construction of some sub-assemblies took twice or even three times as long as scheduled. The deformation of previously completed components posed considerable challenges. Frequently it was found that a part that had been prepared, assembled and welded on one day had, by the next day, acquired different dimensions. The steel grade selected has great strength, but is also quite ductile – requiring not only longer processing times, but also special tooling.

Despite all these challenges, the delivery date was met. Less than a year after signing the contract, SDRC could begin commissioning and calibrating the tunnel 6. Within two weeks, much specialized measuring equipment had been installed in the tunnel. Every cavitation tunnel has unique characteristics due to its shape and material. Hence, very detailed tests are required. These tests help determine scaling factors so that the results of model-based tests can be applied to the real propellers[1)].

Large numbers of pressure gauges, speed meters and specialized measuring instruments were fitted in all parts of the tunnel. The "Silver Elephant" was accepted by the SDRC with no reservations.

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Shipment for shipbuilding

The entire structure was disassembled into its components for shipment. Some of the smaller parts were packaged in containers, the larger ones were fixed on platforms, and finally the tunnel was loaded onto a ship.

Despite the complications encountered, this contract was profitable not only financially but also in terms of the lessons learnt. ABB's project team gained significant and valuable knowledge, with many established routines being reassessed leading to a more profound understanding of the underlying principles. Already at the design stage, knowledge was refreshed. The Elbląg factory is primarily a production plant, and although it does design new types of equipment, these activities are maintained within the confines of certain well-defined manufacturing processes. The "Silver Elephant" project has helped the factory step beyond this stereotype and attain new levels of creativity and flexibility in both mind and deed. From tackling various issues related to stainless steel, much new knowledge has been collected. This will provide access to new markets, both in terms of manufacturing know-how and as an endorsement for the company.

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Footnote

1) Water flow parameters are graduated on the basis of flow similarity (using Reynold's, Freud's Nuselt's and other numbers).