44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 14 – 17 2015
GEORGE R. BROWN CONVENTION CENTER

Eliminating cavitation damage in high-energy water injection pumps by suction impeller redesign

Tim Bastiaansen[1], Nico van den Berg[1], Frank Visser[1,3]
Yousuf S. Al-Shuhail[2], Saad A. Al-Ali[2], Abdulaziz N. Al-Qahtani[2]
[1]Flowserve, [2]Saudi Aramco, [3]Presenter

FLOWSERVE

ارامكو السعودية
Saudi Aramco

TEES
TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY

Contents

Introduction – Project Objective

Problem statement:

First-stage/suction impeller of high-energy high-speed water injection pumps (WIP's) is experiencing cavitation damage, resulting in not making the 40,000 hours life criterion.

Objective:

Design a new first-stage/suction impeller using Computational Fluid Dynamics (CFD) that will minimize (eliminate?) cavitation, thus improving lifetime, and verify this with a flow visualization test.

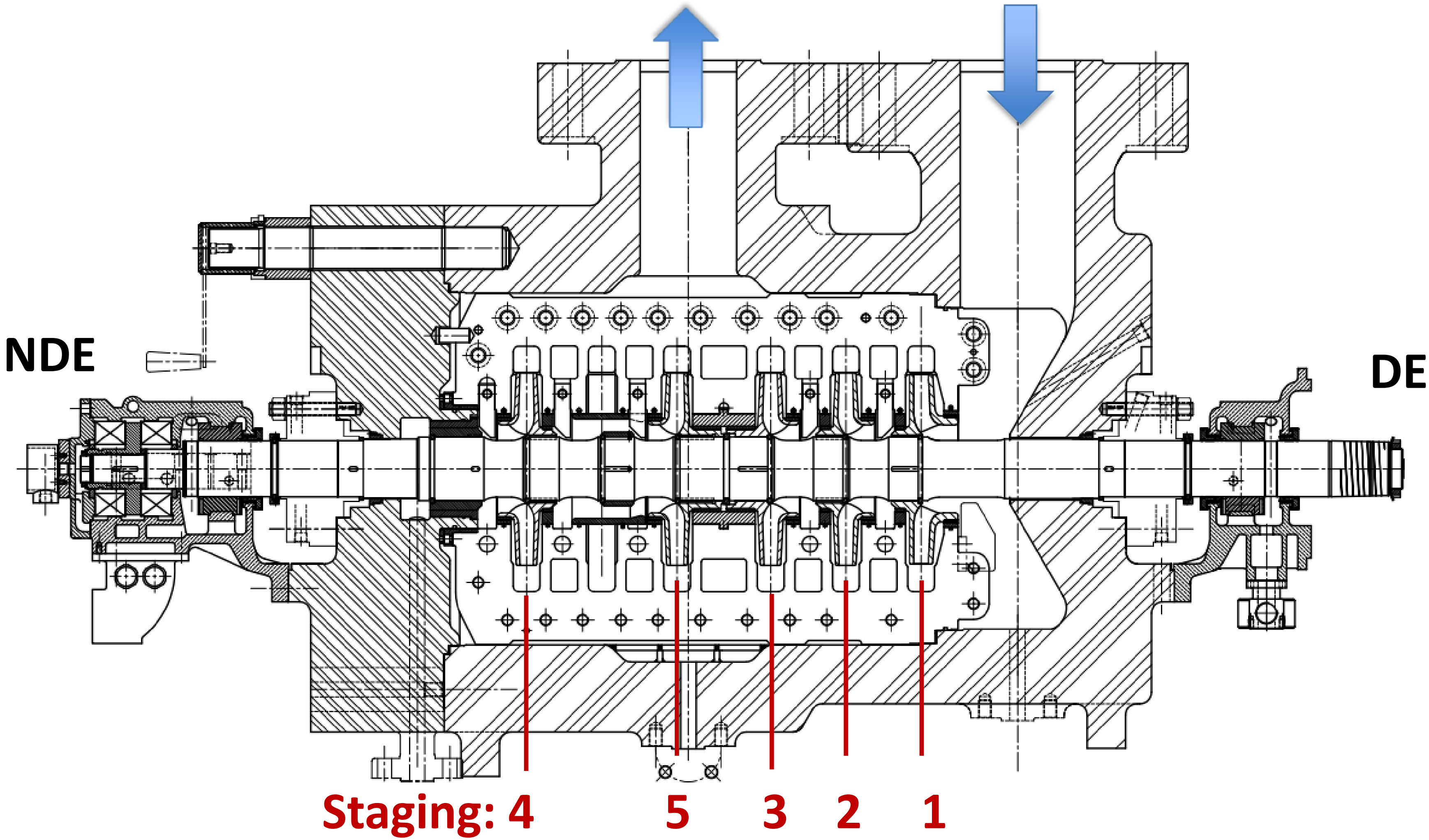
Introduction – Pump Info/History

➢ **Three identical high-speed multistage pumps in water injection service** (Pumps were ordered in 2001 and commissioned in 2005)

Some Details:

- Five stages (de-staged)
- Single suction first stage
- Between bearing
- Radial split barrel (API 610 BB5)
- Top-top nozzles
- High speed (5000 [RPM])
- Fluid: raw (formation) water
- Total Dissolved Solids (TDS): 11000 ppm

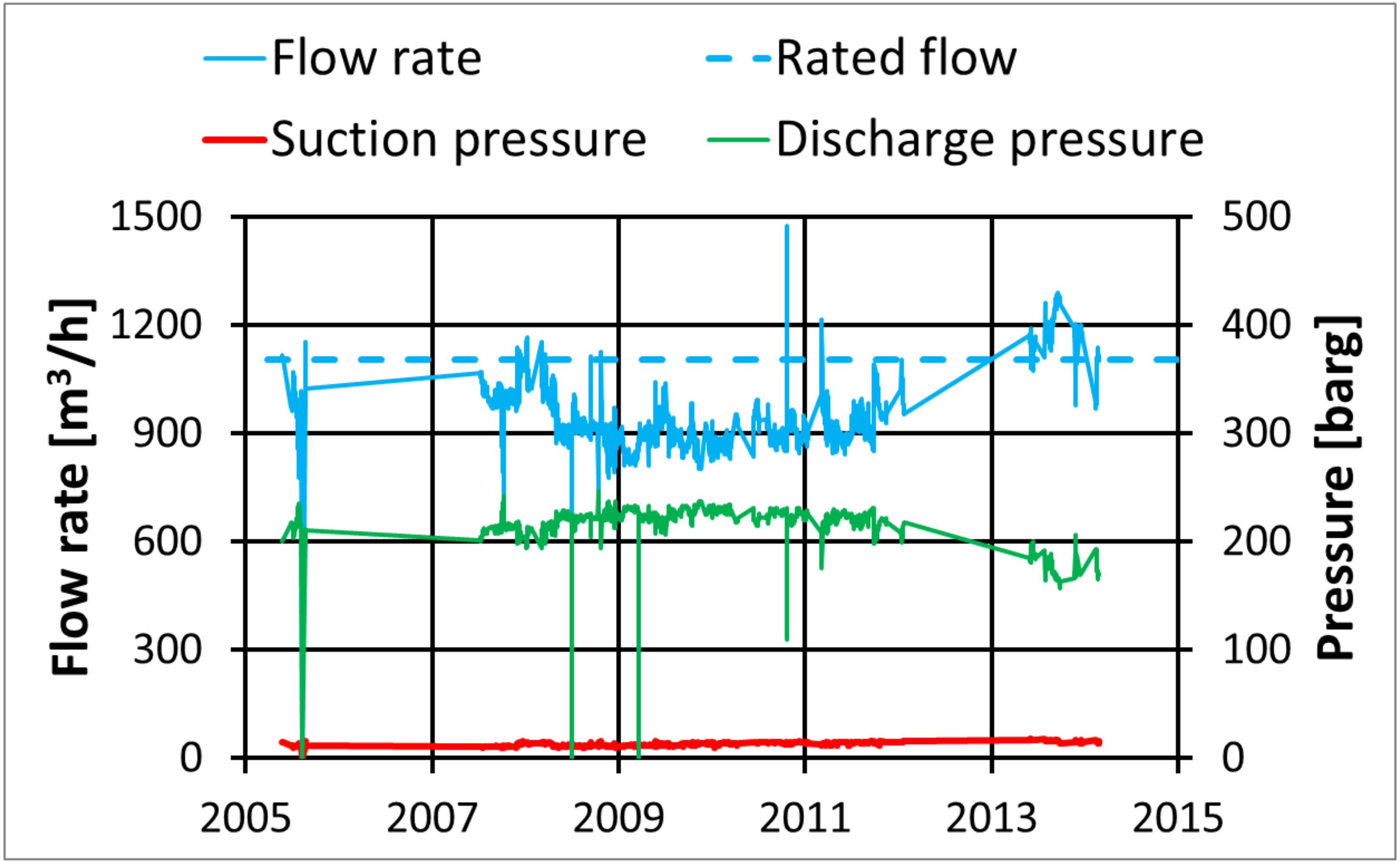
Introduction – Pump Info/History



Introduction – Pump Info/History

	Design	Operating range		
Flow	1104 (4861)	820 (3610)	1000 (4403)	[m^3/h] ([USGPM])
Head	1966 (6451)	2303 (7556)	2060 (6759)	[m] ([ft])
Temperature	74 (165)	79 (174)	79 (174)	[°C] (°F)
Power	8203 (11000)	6711 (9000)	7084 (9500)	[kW] ([hp])
Speed	4964	4964	4964	[RPM]
U_{EYE}	54.5 (179)	54.5 (179)	54.5 (179)	[m/s] ([ft/s])
NPSHA	98.8 (324)	106.7 (350)	121.9 (400)	[m] ([ft])
NPSH3	33.5 (110)	15.2 (50)	22.7 (75)	[m] ([ft])
NPSHA/NPSH3	2.95	7.0	5.33	[-]
$NPSH_{40000hrs}$	45.7 (150)	-	-	[m] ([ft])

Introduction – Field Operating Data



Introduction – Field Experience

2003 (FAT):
Vane leading edge reworked to meet rated NPSH3.

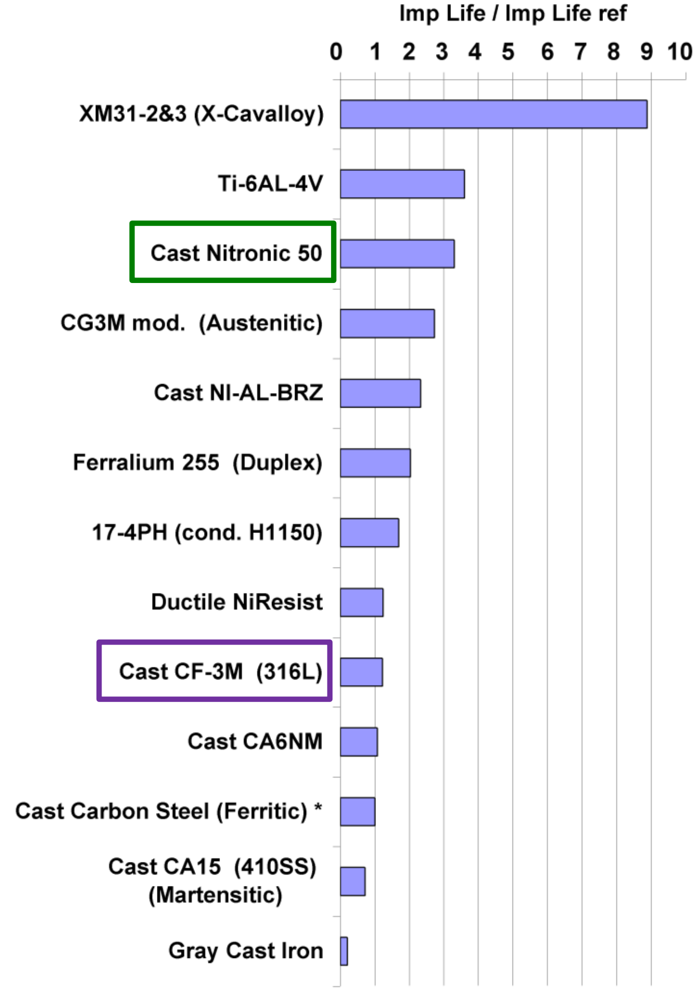
2008 (28000 hrs of operation):
- First stage impeller shows **cavitation** damage.

Introduction – Field Experience

2008 (First fix):
Upgrade impeller material from **316 stainless steel** to **Nitronic 50**

2012 (13000 hrs operation):
Nitronic 50 impeller shows same damage pattern
→ material upgrade did not work

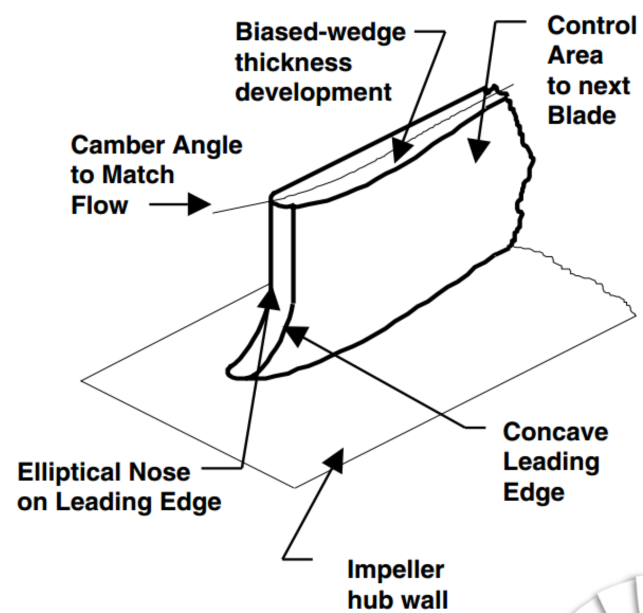
First-stage impeller needs to be redesigned to remedy the problem



Impeller Redesign

- **Key indicator** to drive the redesign process was the ***incipient cavitation*** Net Positive Suction Head characteristic (NPSHi)
  - NPSHi = level of NPSHA where the first vapor cavities appear (somewhere inside the pump/impeller)

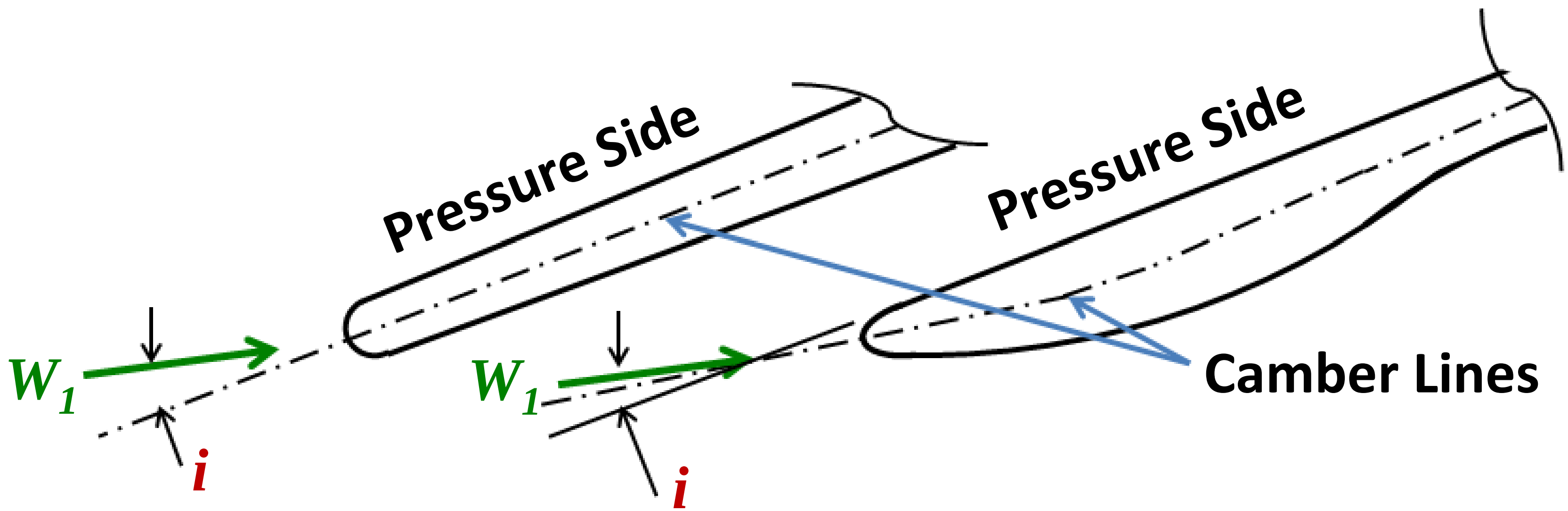
- **Key feature** to implement was a so-called **biased-wedge** blade thickness distribution, shaping the blade leading edge like an airfoil in order to have **minimum pressure drop** at the nose



Impeller Redesign

Conventional blade (symmetrical leading edge)

Biased-wedge leading edge

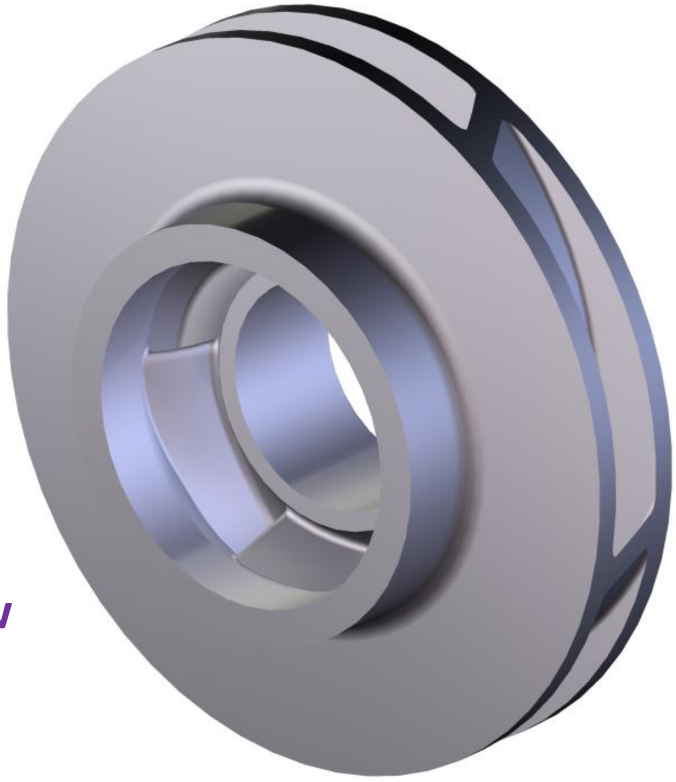


Improved incidence between W_1 and the camber line

Impeller Redesign

New design:

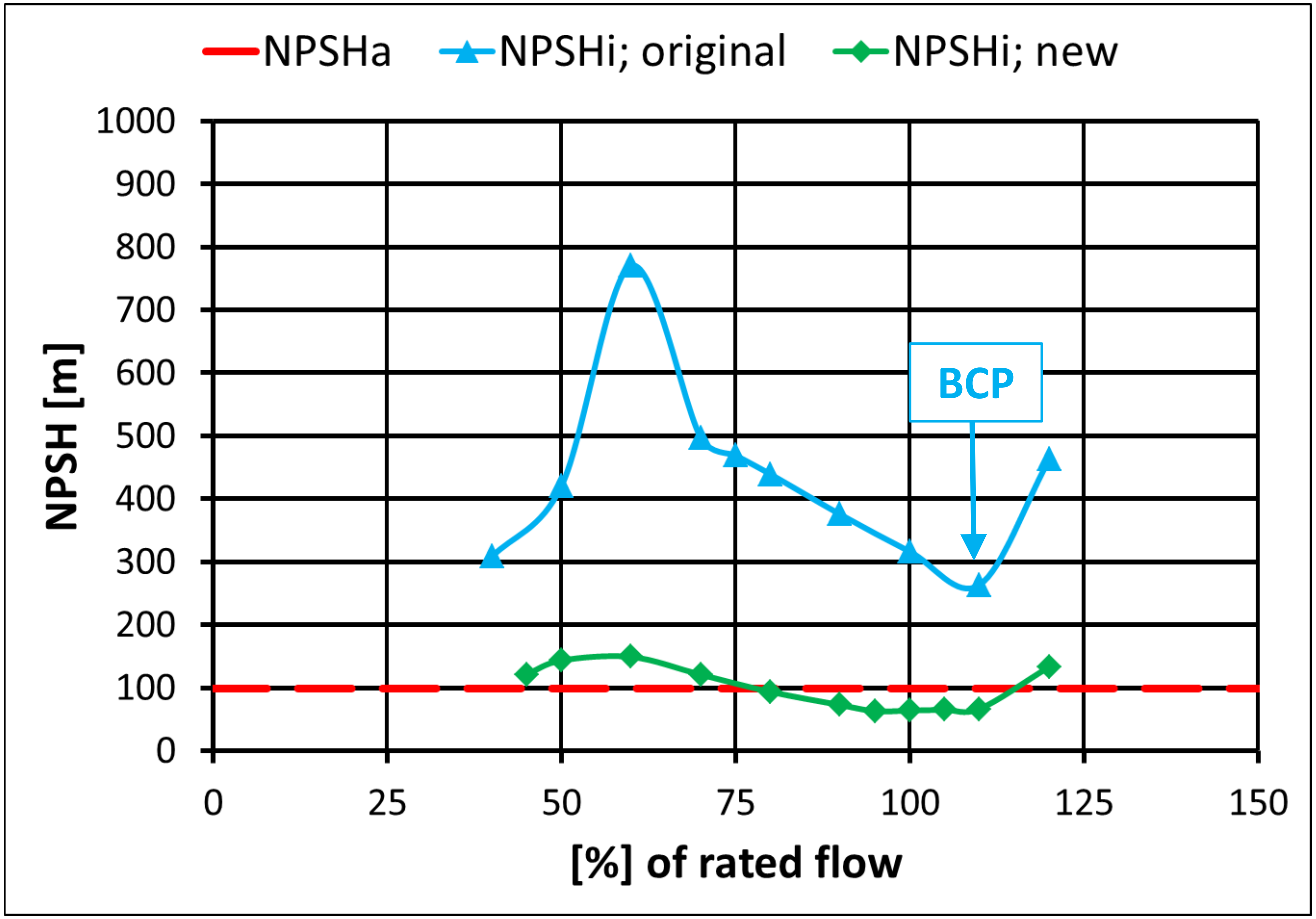
- Based on same parent impeller hydraulic as original
- **Five design iterations** were performed using in-house design tools driven by (CFD) NPSHi calculations
- Design decision criteria:
  - ➢ **BCP* near rated flow** (BCP > Q_{rated})
  - ➢ **NPSH3 < NPSHA @ max operating flow**
- Rapid prototyping (3D printing) was used to produce the final design



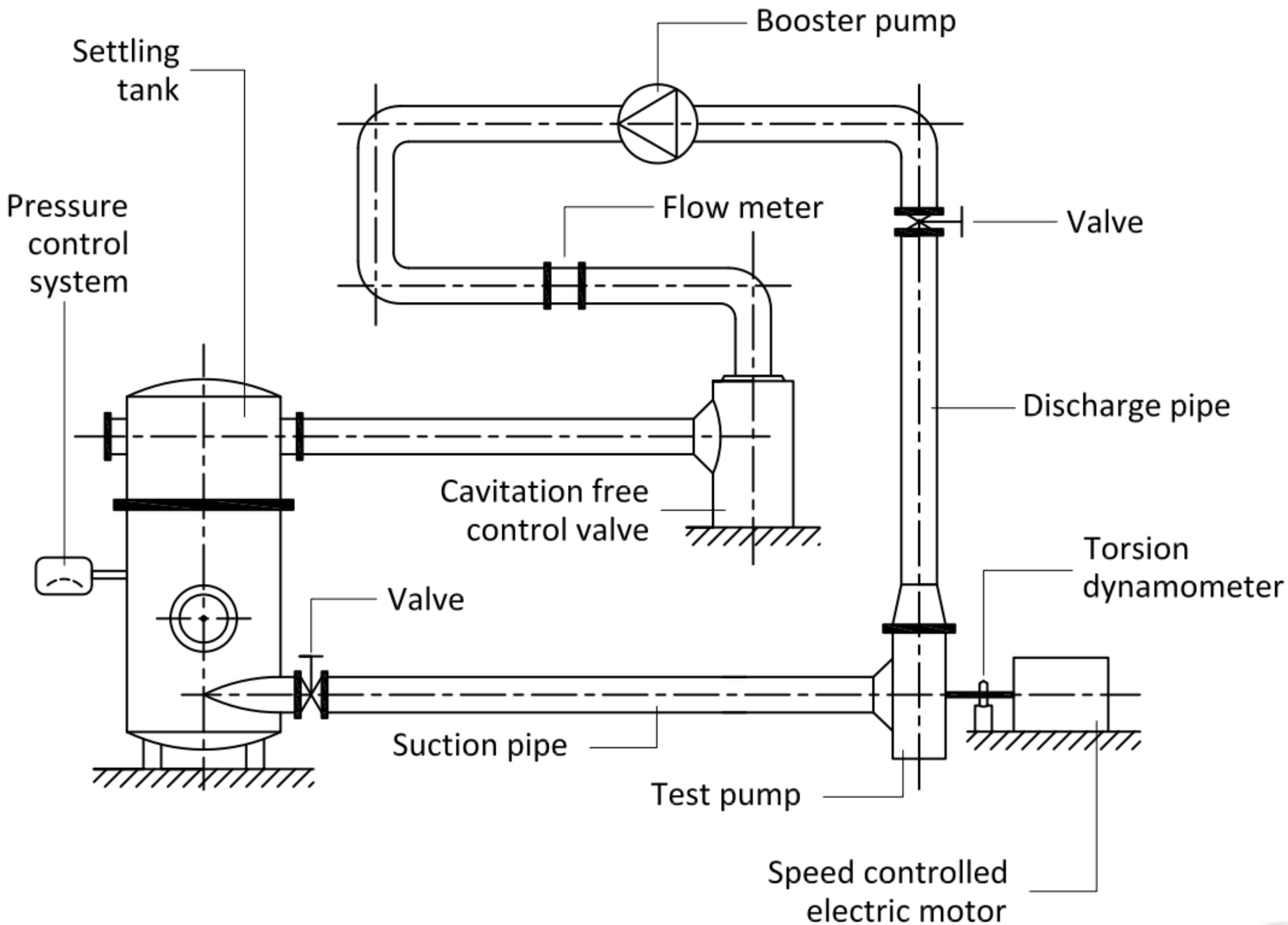
*BCP = Best Cavitating Point

Impeller Redesign

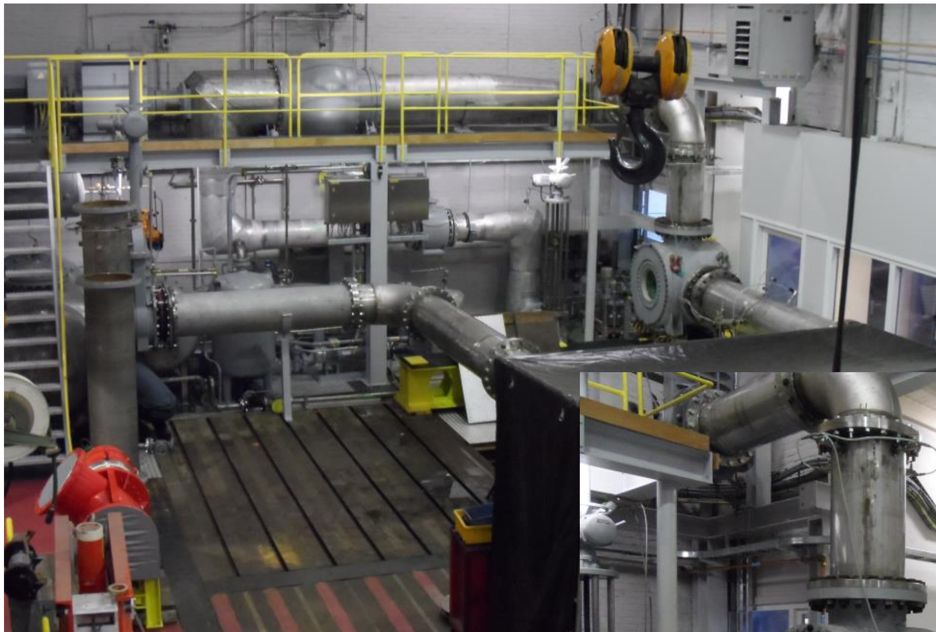
Results:

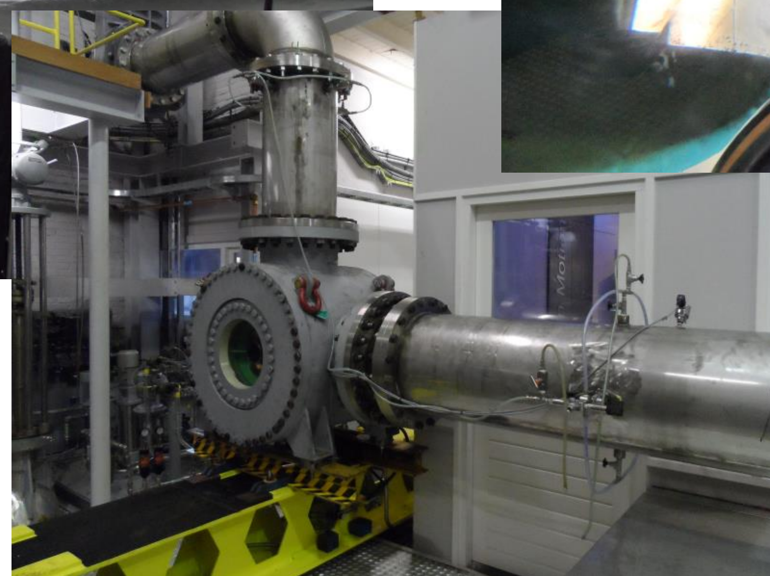


Verification – Flow Visualization test

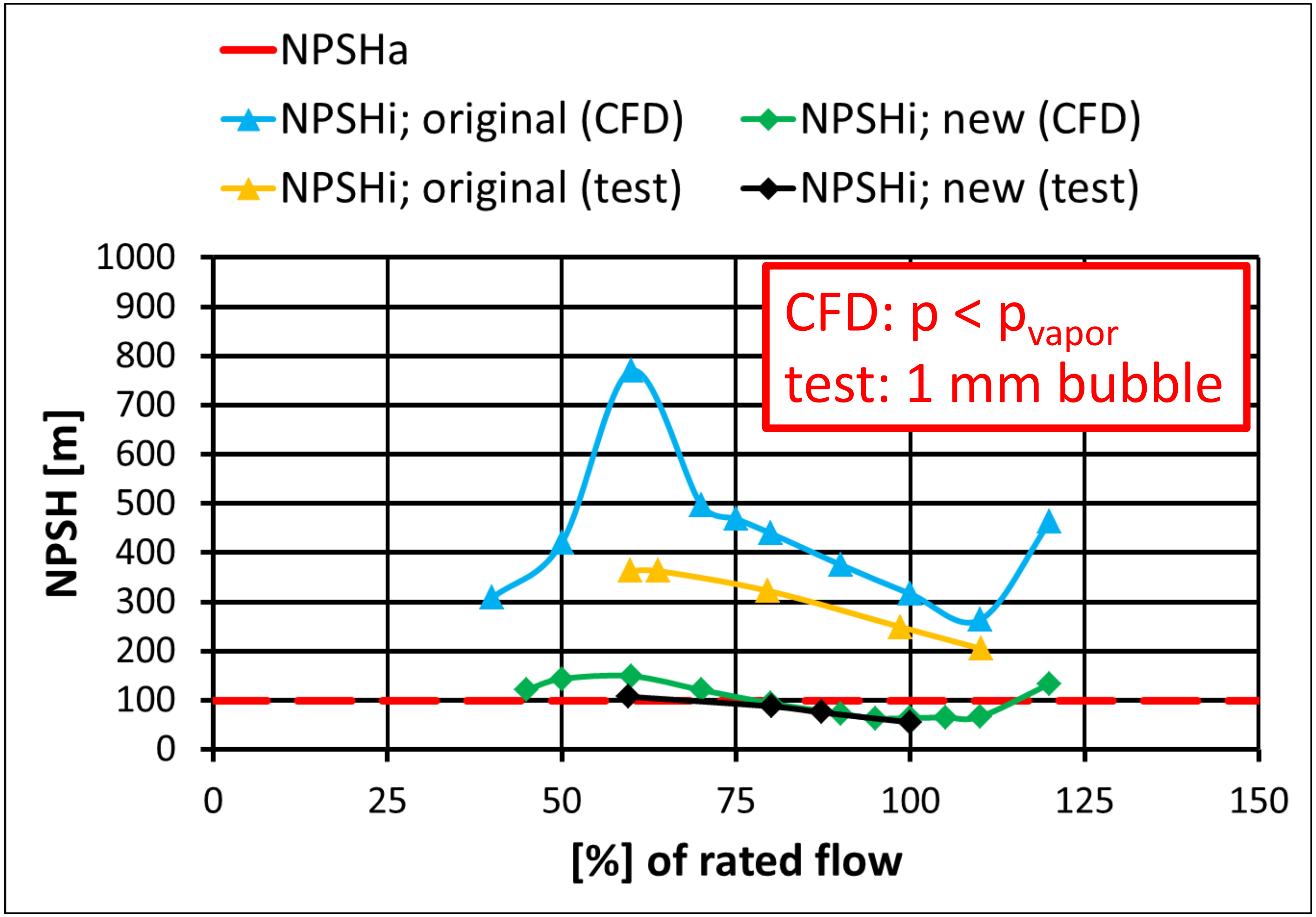


Verification – Flow Visualization test



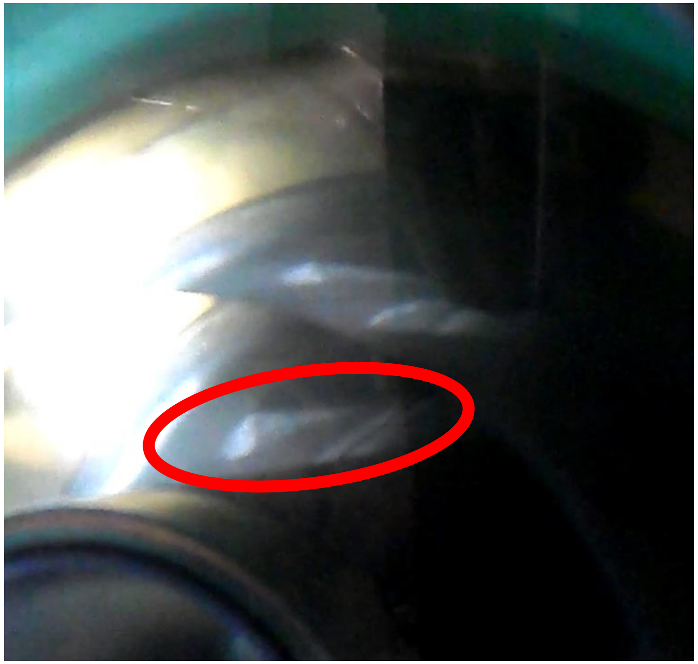


Verification – Flow Visualization test



Verification – Flow Visualization test

Original



New

Results @ rated flow and field NPSHA

Conclusion - Project results

- Impeller blade leading edge has been optimized to reduce (eliminate) cavitation.
- The improvement has been verified by flow visualization testing.
- Incorporating the **biased-wedge** design has resulted in:
  - **No cavitation from 70% to 100%+ of rated flow @ field NPSHA**
  - Only marginal cavitation ($L_{cav} < 5$ mm) will be present between 60% - 70% of rated flow
  - Impeller life criterion of 40.000 hours will be (easily) met, and exceed by far
- Pump with new first stage impeller was commissioned successfully in Q1 2015

Conclusions – Lessons learned

- A biased-wedge design can improve cavitation characteristics significantly, and even eliminate the occurrence of cavitation, for a wide range of flow rates
- The classical 3% head drop criterion is **inappropriate** for high energy pumps in water applications when having high impeller-eye peripheral speed
- Despite operating well above NPSH3, with a rated NPSH3 margin of nearly 3 (!) cavitation damage can occur, limiting impeller life below acceptable.

Conclusions – Lessons learned

- Revised customer standard:

Pump type	**NPSH3 curve**	**40000 hrs curve**	**Visualization test**	**Acceptance criteria**
All pumps	✓	✗	✗	NPSH Margin MCSF* - 120% > 1 [m] (3.3 [ft])
High energy water injection pumps	✓	✓	✗	Depth of penetration < 75% of vane thickness
Water injection pumps eye peripheral velocity > 47 [m/s] (154 [ft/s])	✓	✓	✓	Depth of penetration < 75% of vane thickness

*Minimum Continuous Stable Flow

✓ Required ✗ Not required

Thank you for your attention.

Questions?

For further reading:

Van den Berg, N., Bastiaansen, T., and Elebiary, K. 2015 “Predicting, improving and visualizing cavitation characteristics of first-stage impellers in high-speed, high-energy pumps.” ASME-JSME-KSME Joint Fluids Engineering Conference, July 26-31, Seoul, Korea, Paper No. AJK2015-33420