Modernization of water turbine flow passages

by
Jacek Swiderski, P. Eng.
Swiderski Engineering Inc.
Ottawa, Canada

- **Virtual hydraulic laboratory**, developed as a result of numerous practical applications.
- **Computational Fluid Dynamics (CFD)** - established its strong presence in the hydropower industry as trusted engineering tool.
- Study and analysis of the hydraulic diagnostics allow developing an **upgrade strategy**
- Selected practical applications of **Computational Fluid Dynamics (CFD)** based on commercial software package (CFX).
- Selected practical applications of **Finite Element Analysis (FEA)** based on commercial software package (SolidWorks).

Reasons for modernization of water turbines

Reason 1 – Design deficiency – mechanical (structural)

- Frequent mechanical failures requiring extensive periodic repair work

Reason 2 – Change in operating parameters

- Changes in demand from the grid

Reason 3 – Change in hydraulic conditions

-Changing hydrological conditions, which occurred after many years of operation,

Reason 4 - Design deficiency possibly due to mistaken determination of hydrological conditions

- Most often in low-head installations

results of mechanical and hydraulic diagnostics along with preliminary developed solution require positive economic assessment for the decision to upgrade

Design upgrades methodology

Phase 1:

Hydraulic diagnostics of a fully homologous numerical model of the entire hydraulic system
- verification of CFD results with available field test results
- tuning the numerical model.

Phase 2:

Design optimization using general Evolutionary Algorithm (EA)

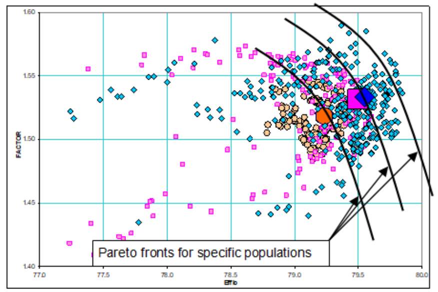
MODOA (Muli-Objective Design Optimization Algorithm)

EVOLUTIONARY STAGE

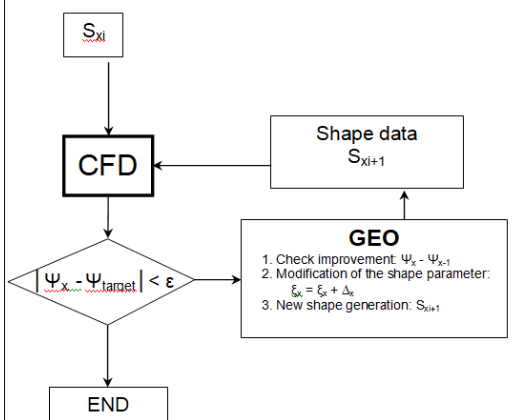
Series of CFD analyses for shapes: S_1, S_2...... S_i...... S_n

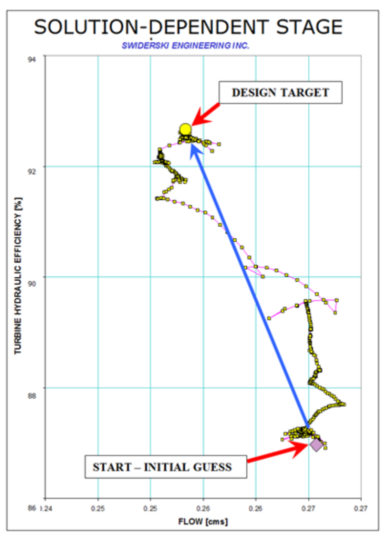
Calculation on set of shape parameters, which would bring best performances for the given population

Generation of next population: S_{x1}, ... S_{xk}



SOLUTION-DEPENDEND STAGE





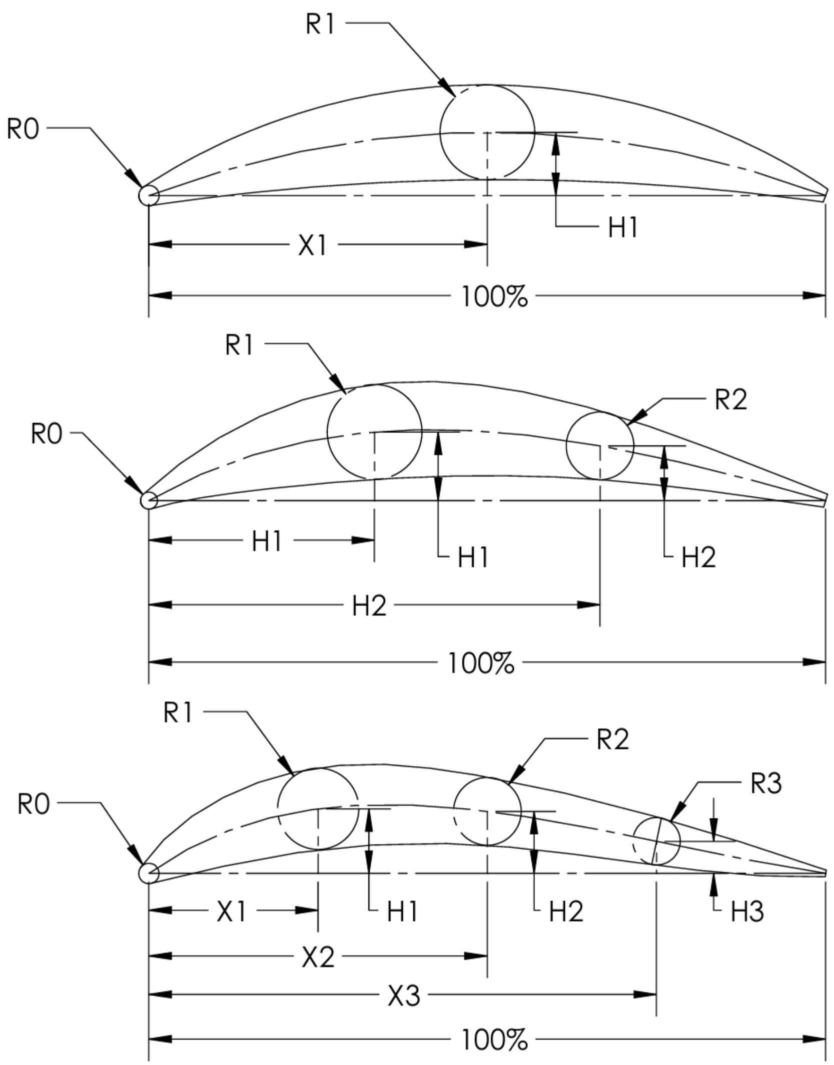
Ψ_x - quality factor
ξ_x - active geometry parameter
Δ_x - rate of change of ξ_x
ε - proximity of the solution ($\varepsilon \sim \Psi_{target}/1000$)

EVOLUTIONARY STAGE

SOLUTION-DEPENDENT STAGE

Hydropower SE Applied CFD WATER TURBINES DESIGN

MODOA (Muli-Objective Design Optimization Algorithm)

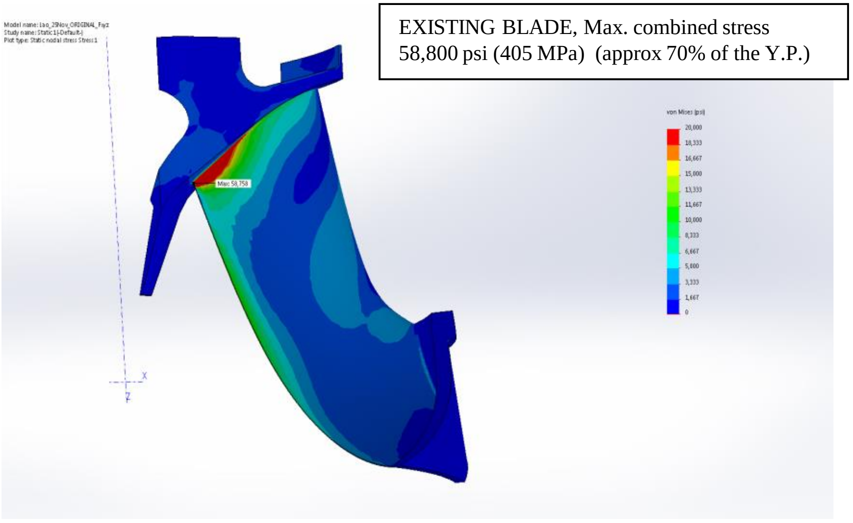


Shape manipulation is the result of manipulating the airfoil angle and the shape parameters, which determine the two-dimensional airfoil shape described by the parameters Xi, Hi, and Ri.

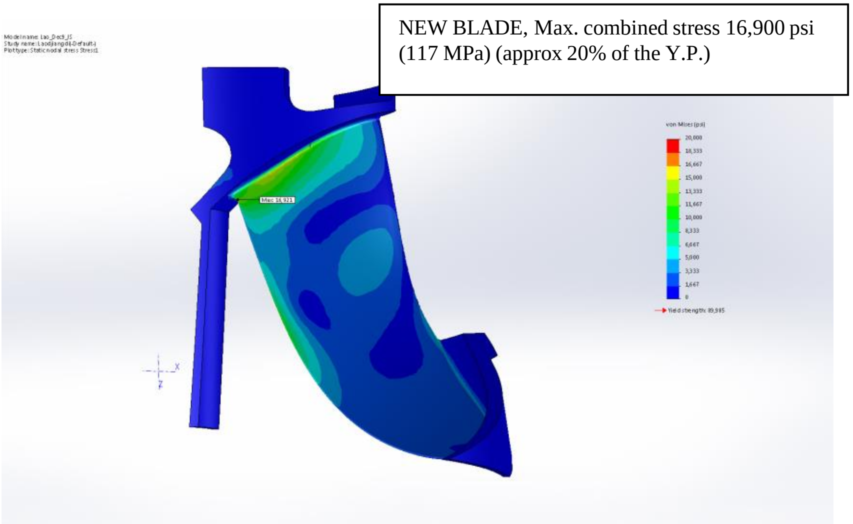
Usually the first two parameterization steps facilitate achieving relatively quickly a reasonable solution, although parameterization with steps with n>3 are necessary to get final 2% to 4% gain in hydraulic efficiency

Xi, Hi, Ri, i = 0…n
Stage 1: n = 1
Stage 2: n = 2
Stage 3: n = 3

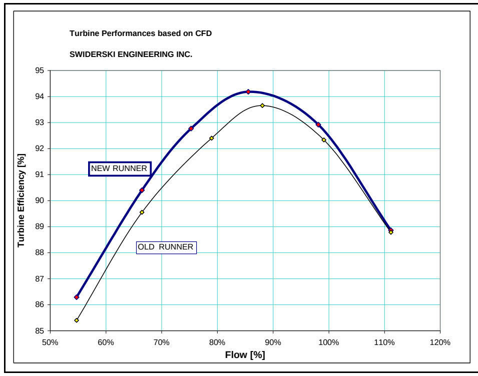
EXAMPLE 1 - Design deficiency

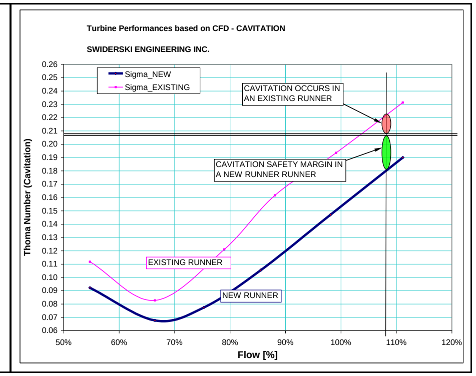


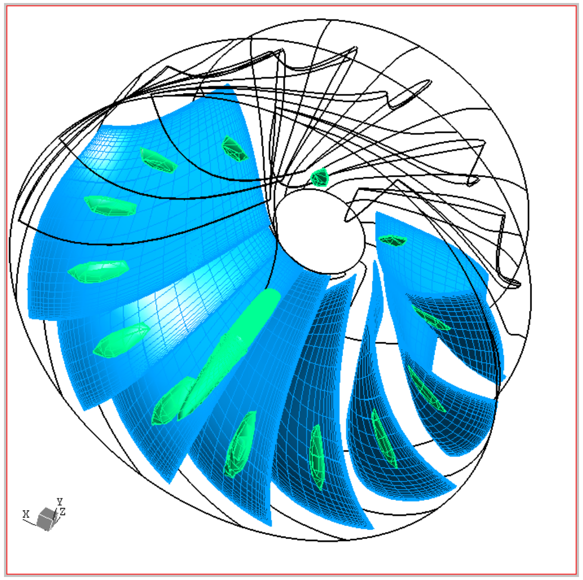
EXISTING BLADE, Max. combined stress 58,800 psi (405 MPa) (approx 70% of the Y.P.)



NEW BLADE, Max. combined stress 16,900 psi (117 MPa) (approx 20% of the Y.P.)

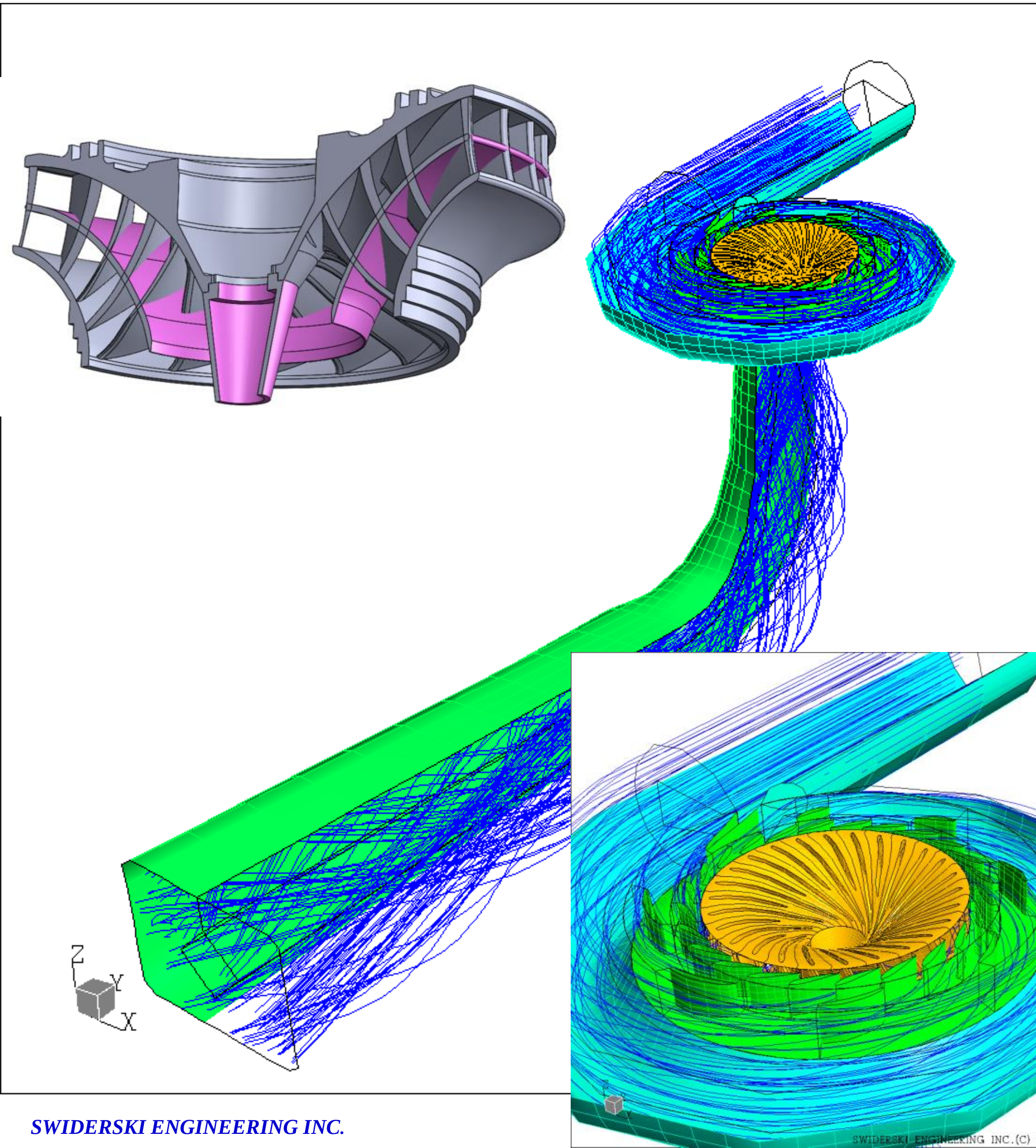




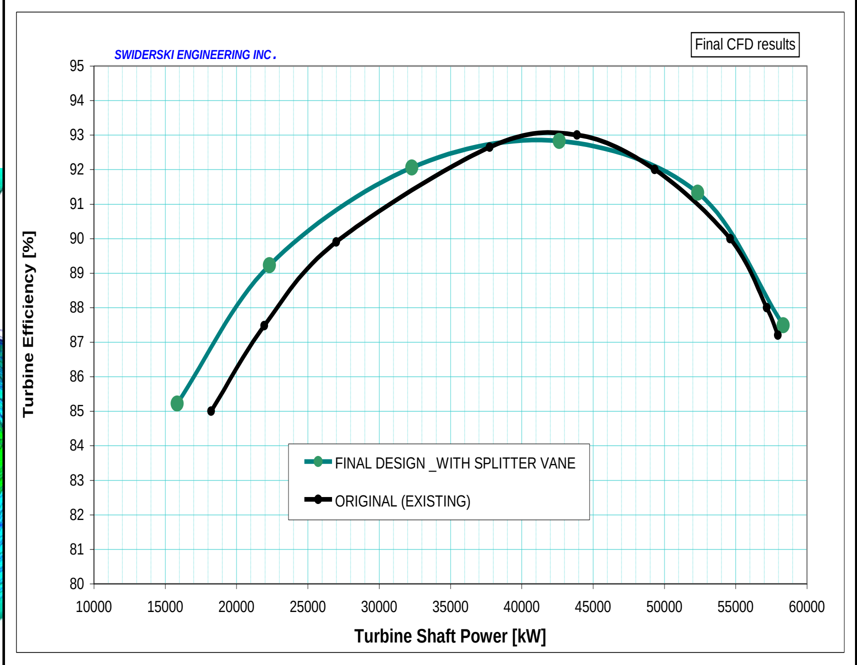


The goal: to reduce the frequency of repairs or eliminate them altogether. The rotor of the newly installed Francis turbine required a major overhaul every two years since its inception. Blade cracks and cavitation pitting required turbine disassembly and resulted in two months of downtime.

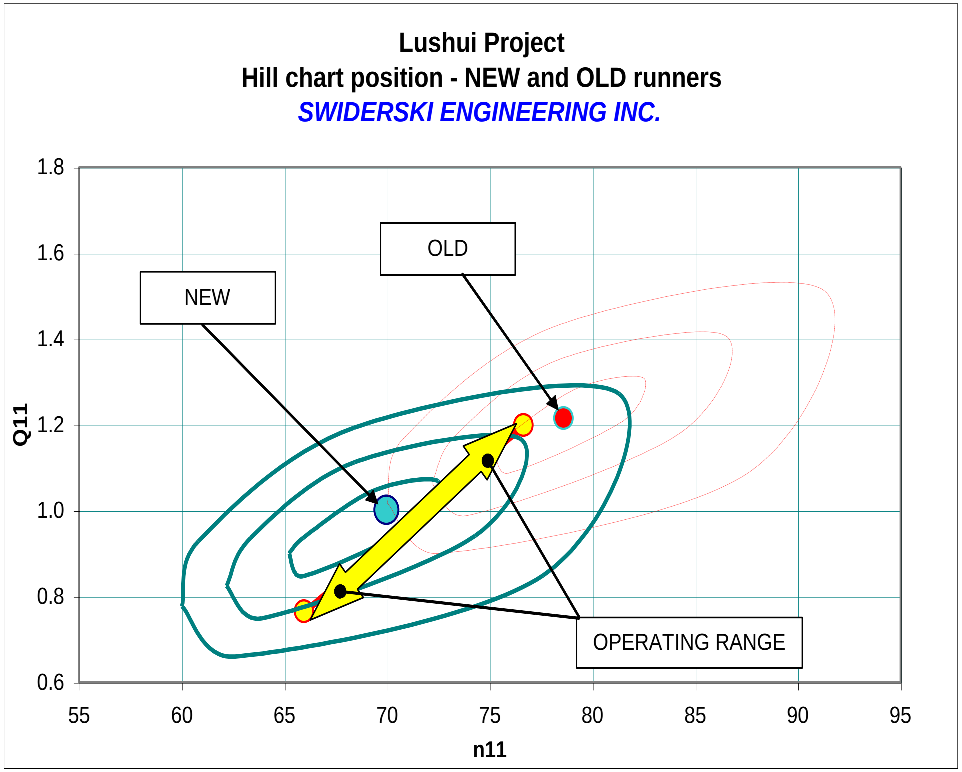
EXAMPLE 2 – Change in operating parameters

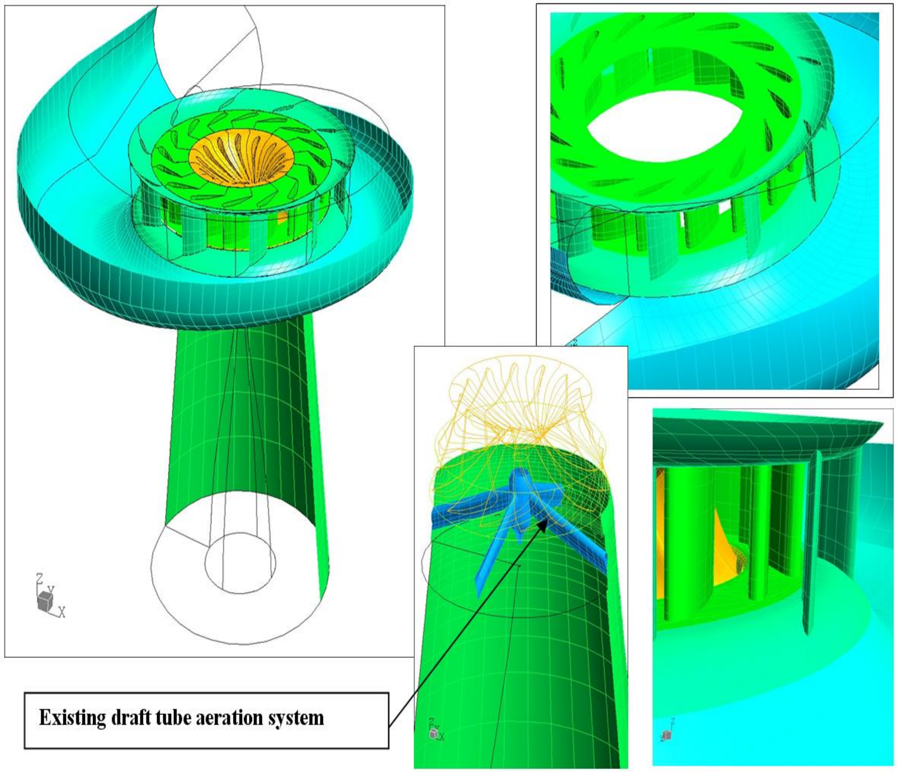


The original runner allowed for stable operation in the 75%-105% minimum load range. Changing hydrological conditions, which occurred after many years of operation, as well as demand imposed by the national electrical grid required additional operation of the turbine at 30%-60% load. However, within this range, operational instability in both the turbine set (increased vibrations) and the supply pipeline significantly exceeded acceptable standards.



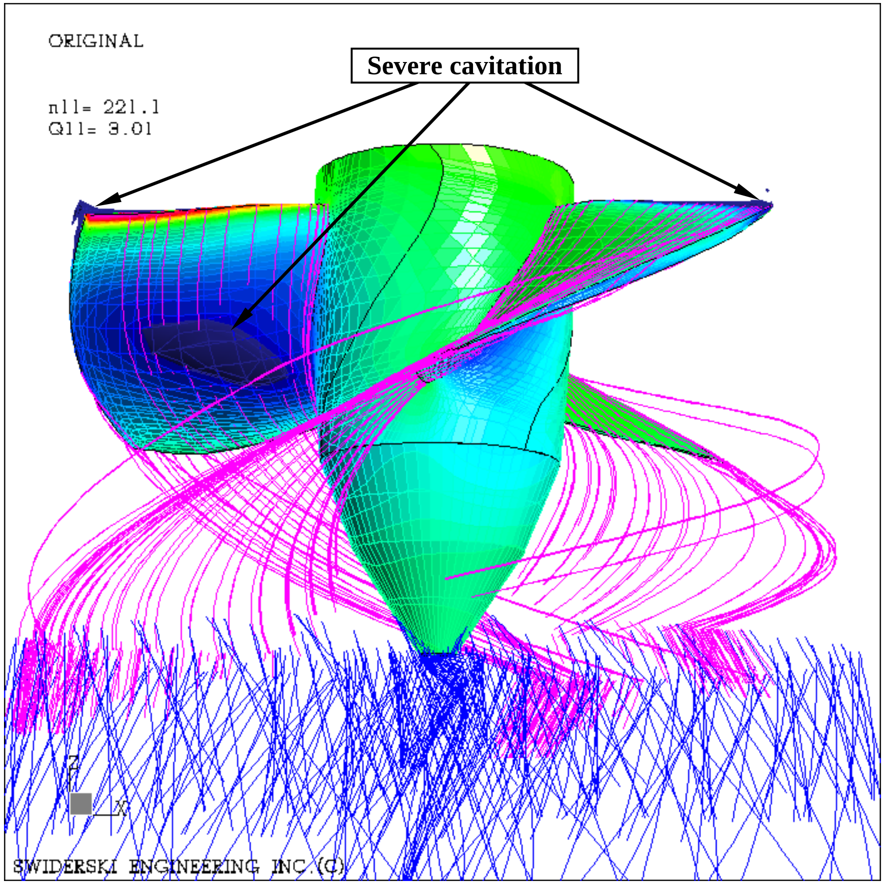
EXAMPLE 3 – Change in hydraulic conditions



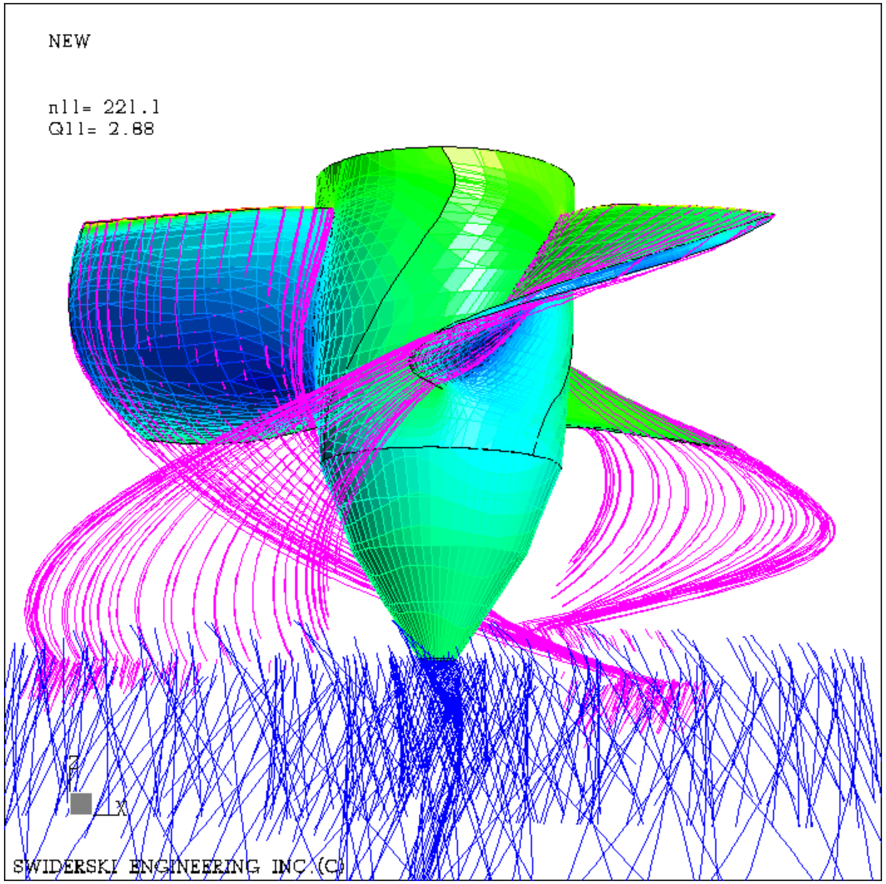


The configuration of the Lushui generating station and its complex hydrological conditions result in large head and flow variations at the dam, which affect the operation of the power-generating equipment. Also, over the years, the hydraulic conditions have changed due to natural erosion of the riverbed.

EXAMPLE 4 - Design deficiency possibly due to mistaken determination of hydrological conditions



$P_{11} = 19.4$



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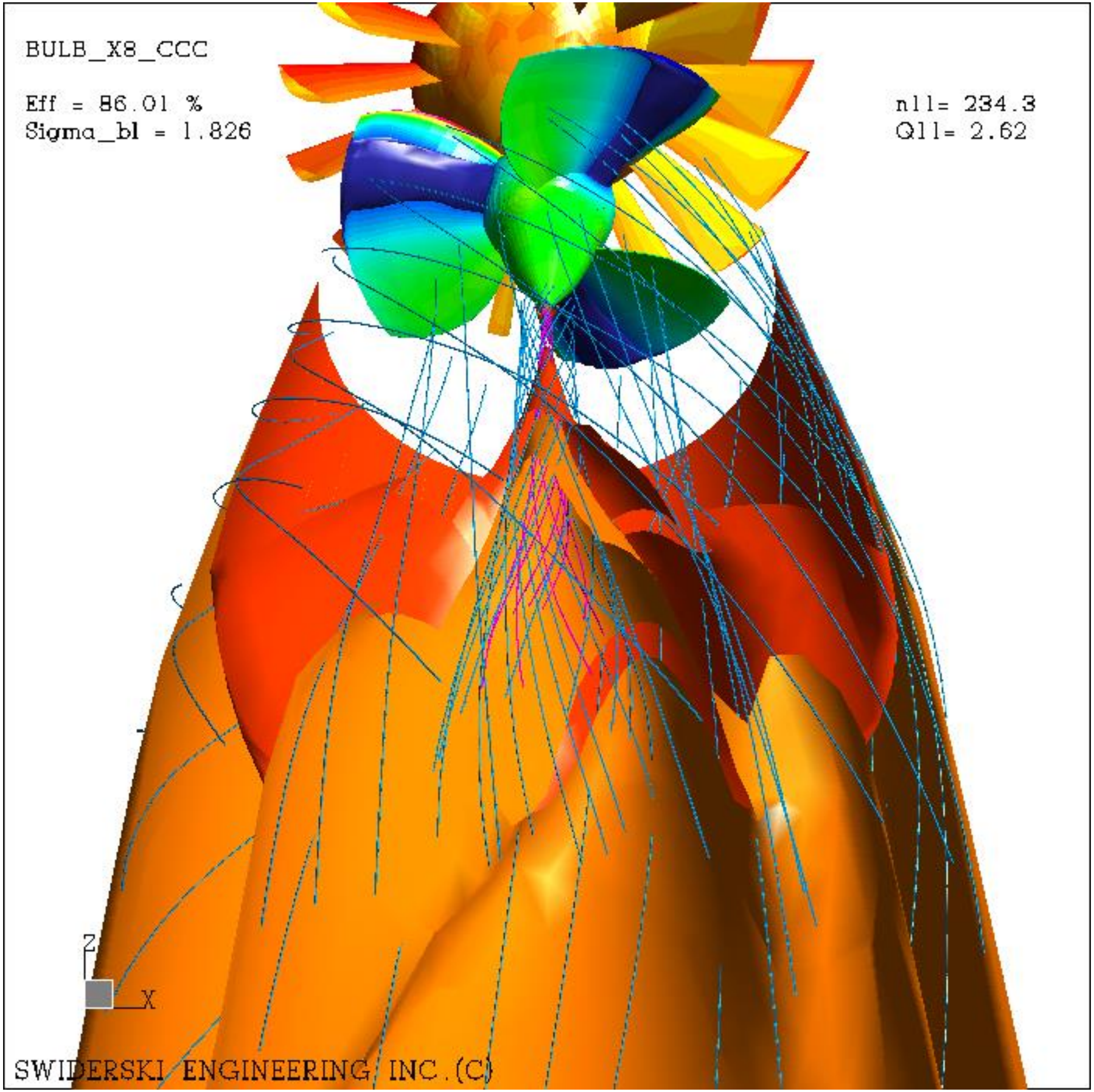
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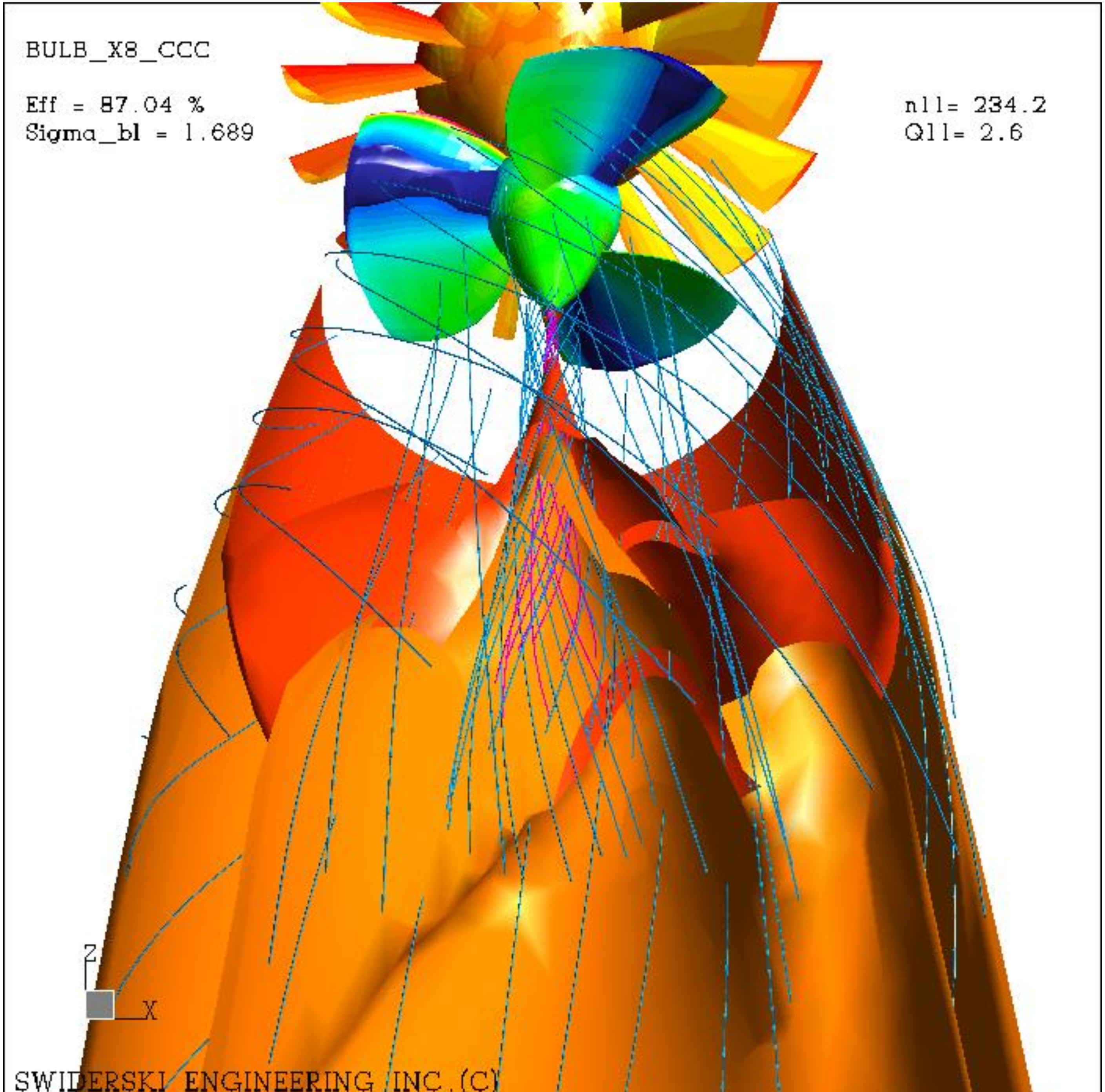
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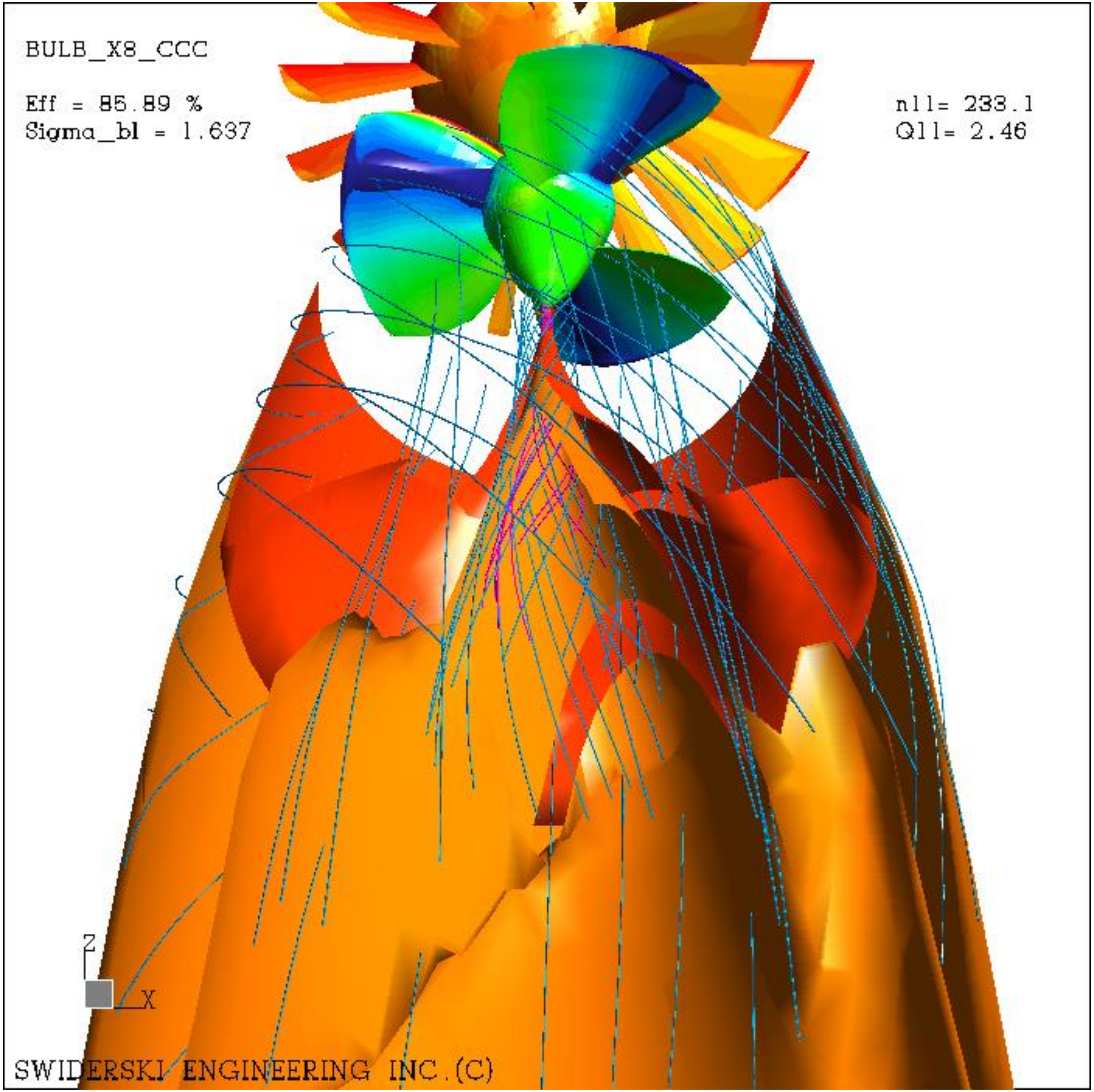
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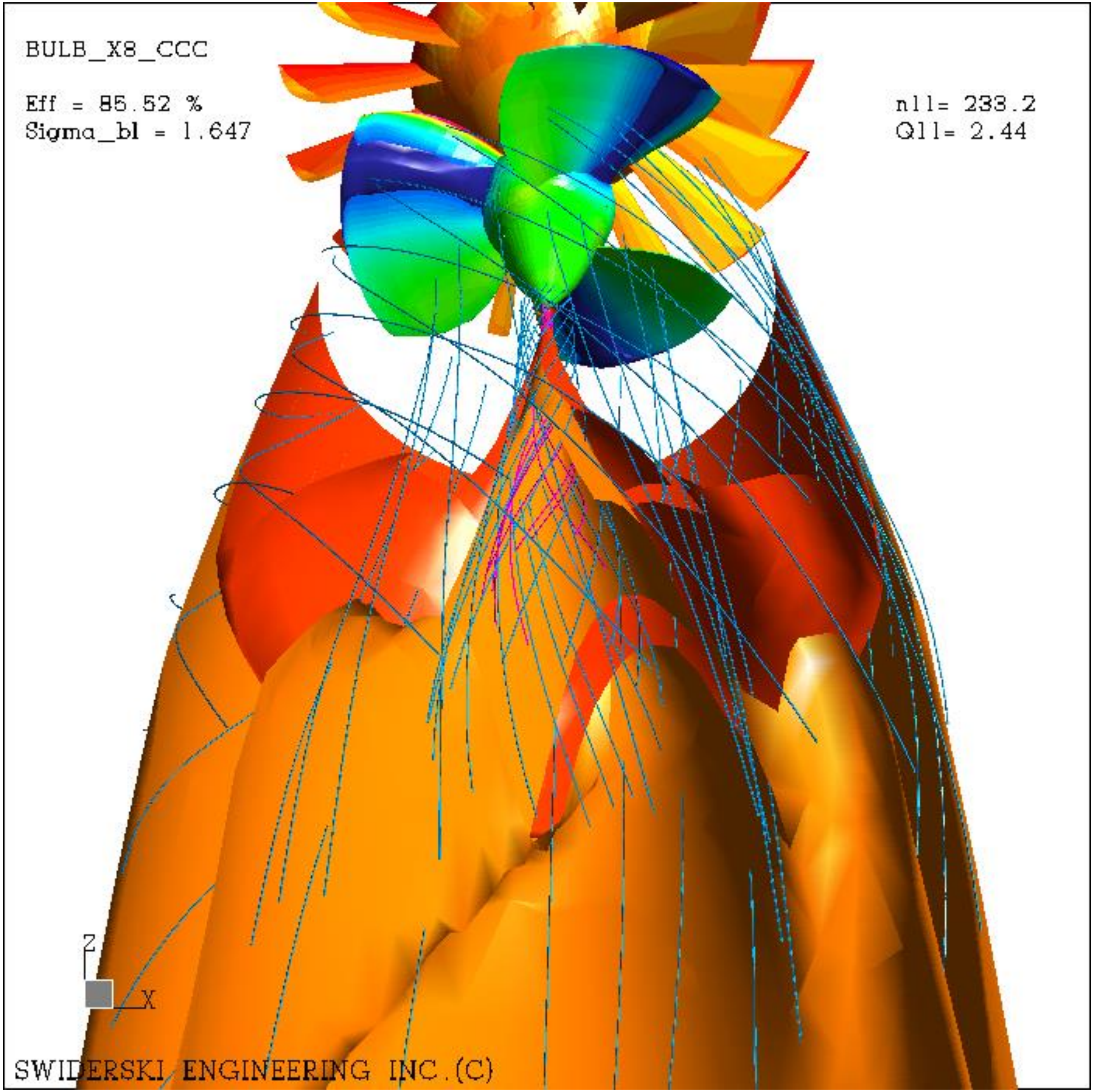
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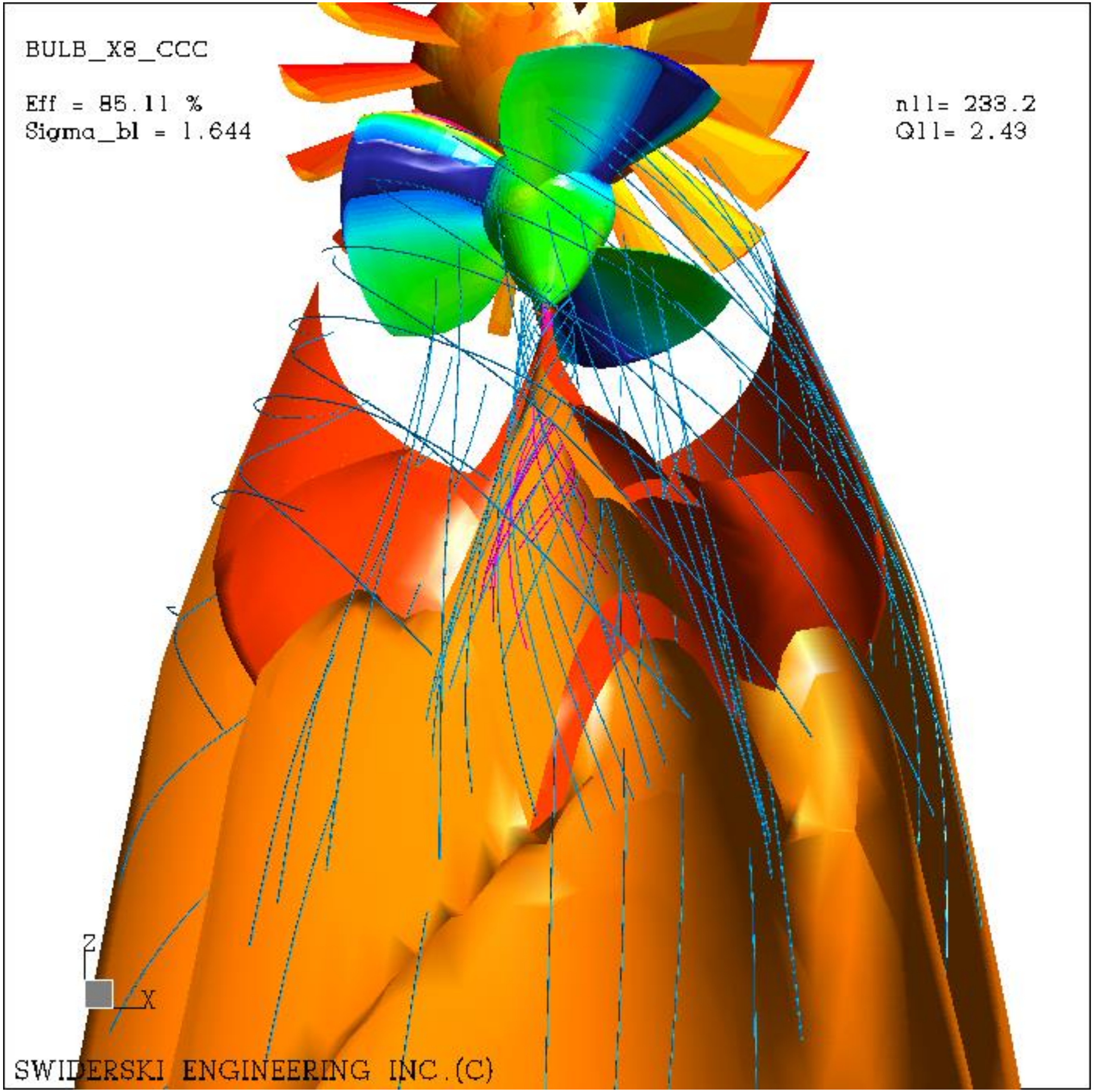
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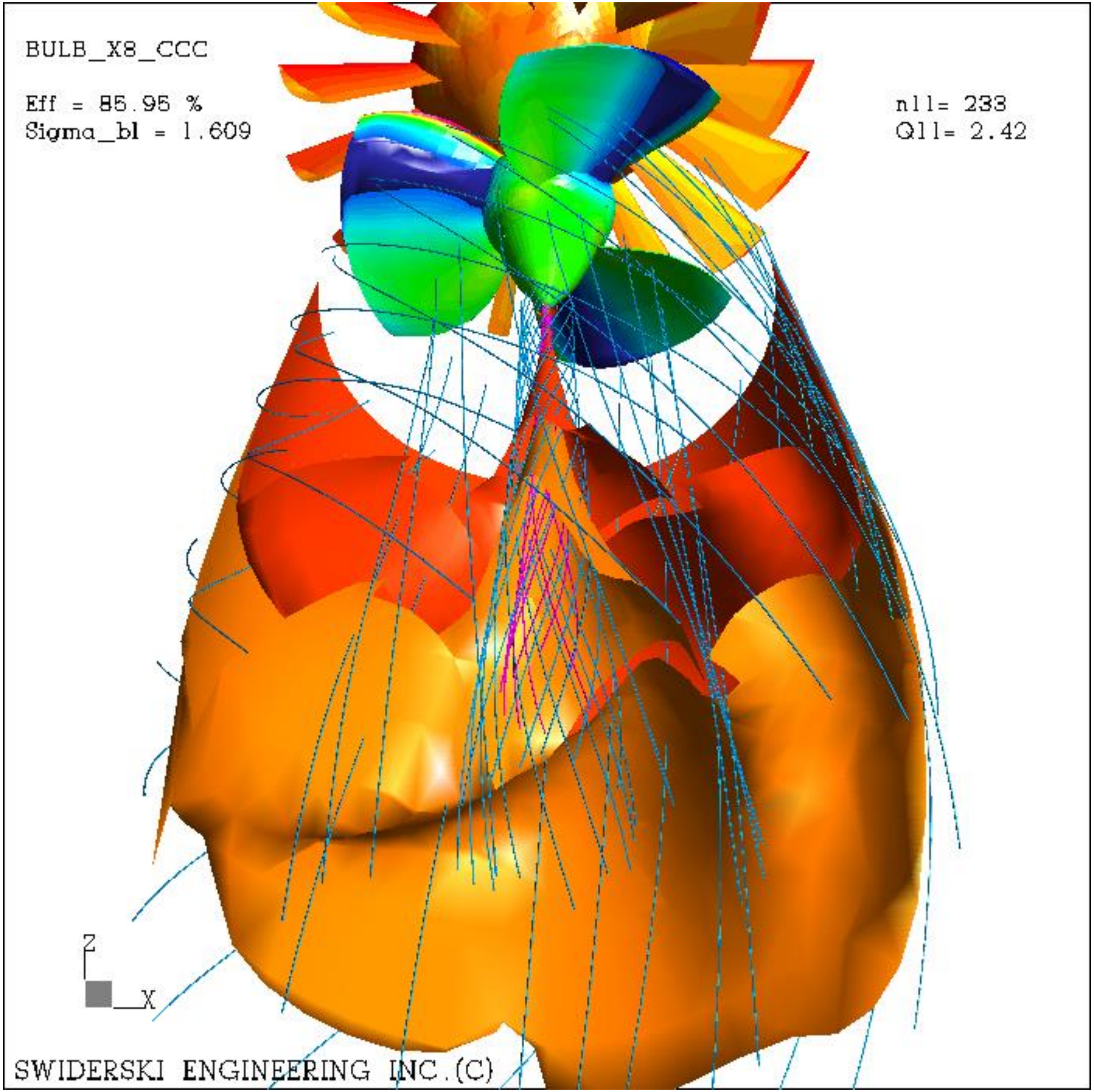
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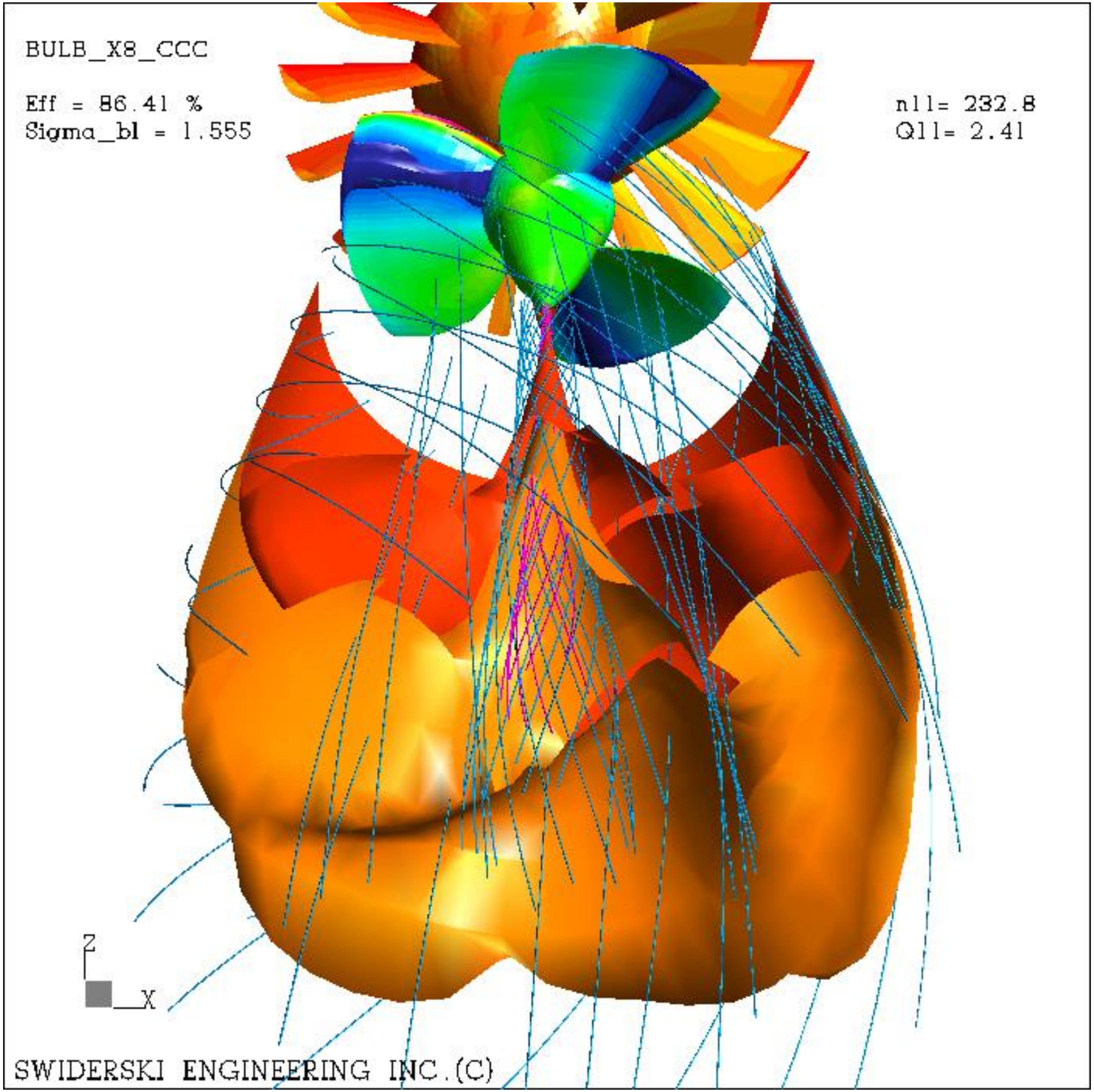
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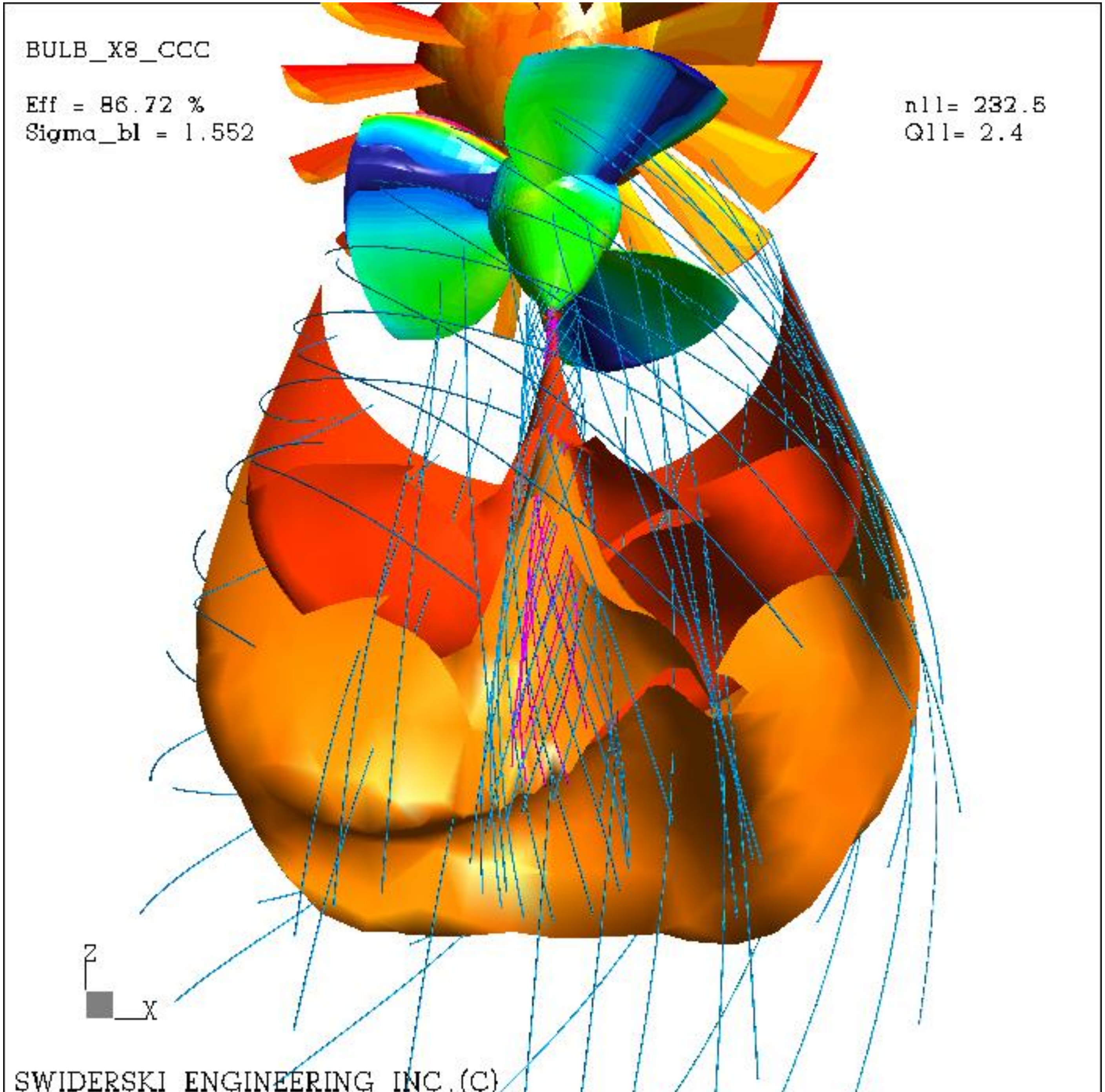
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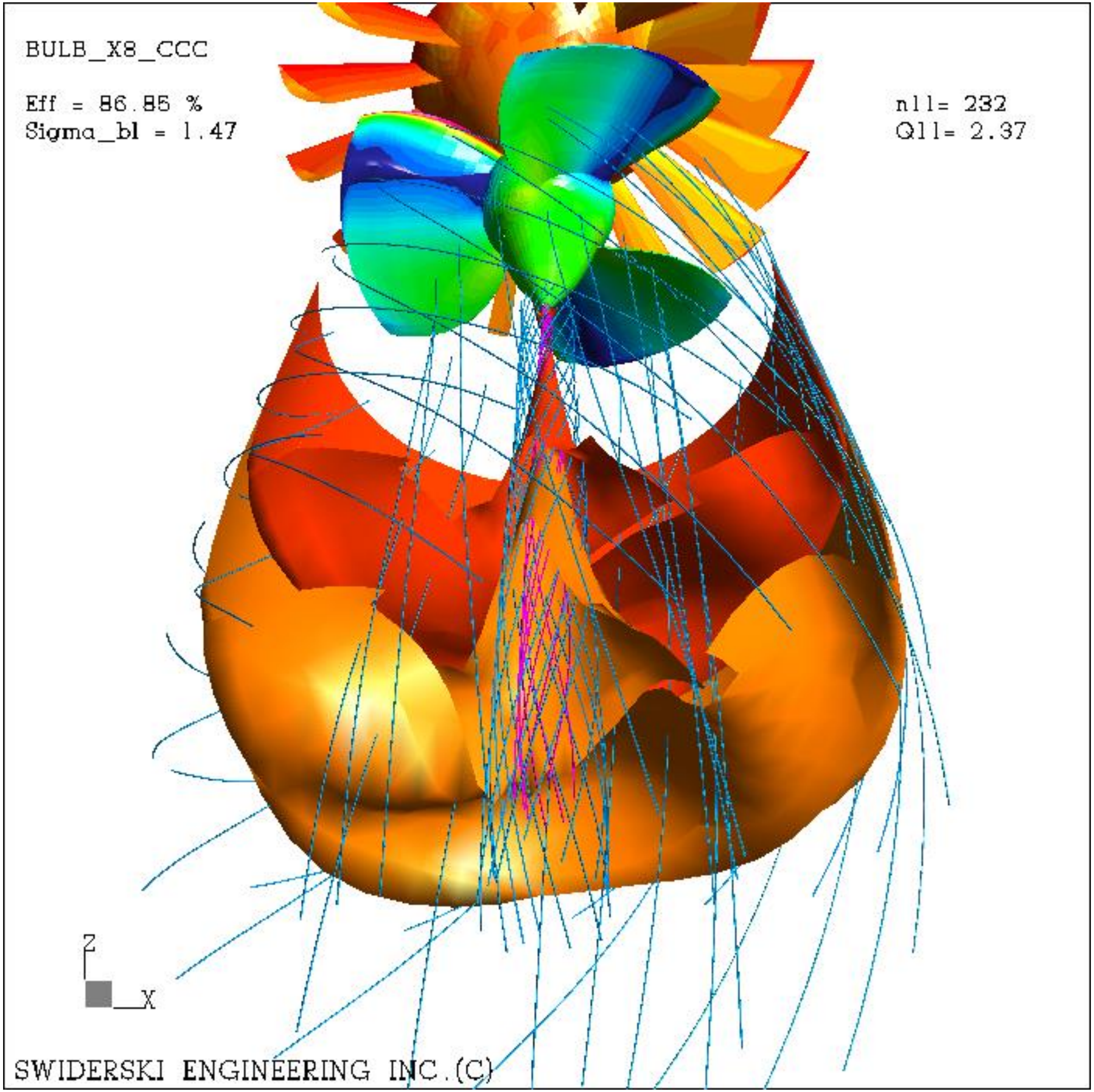
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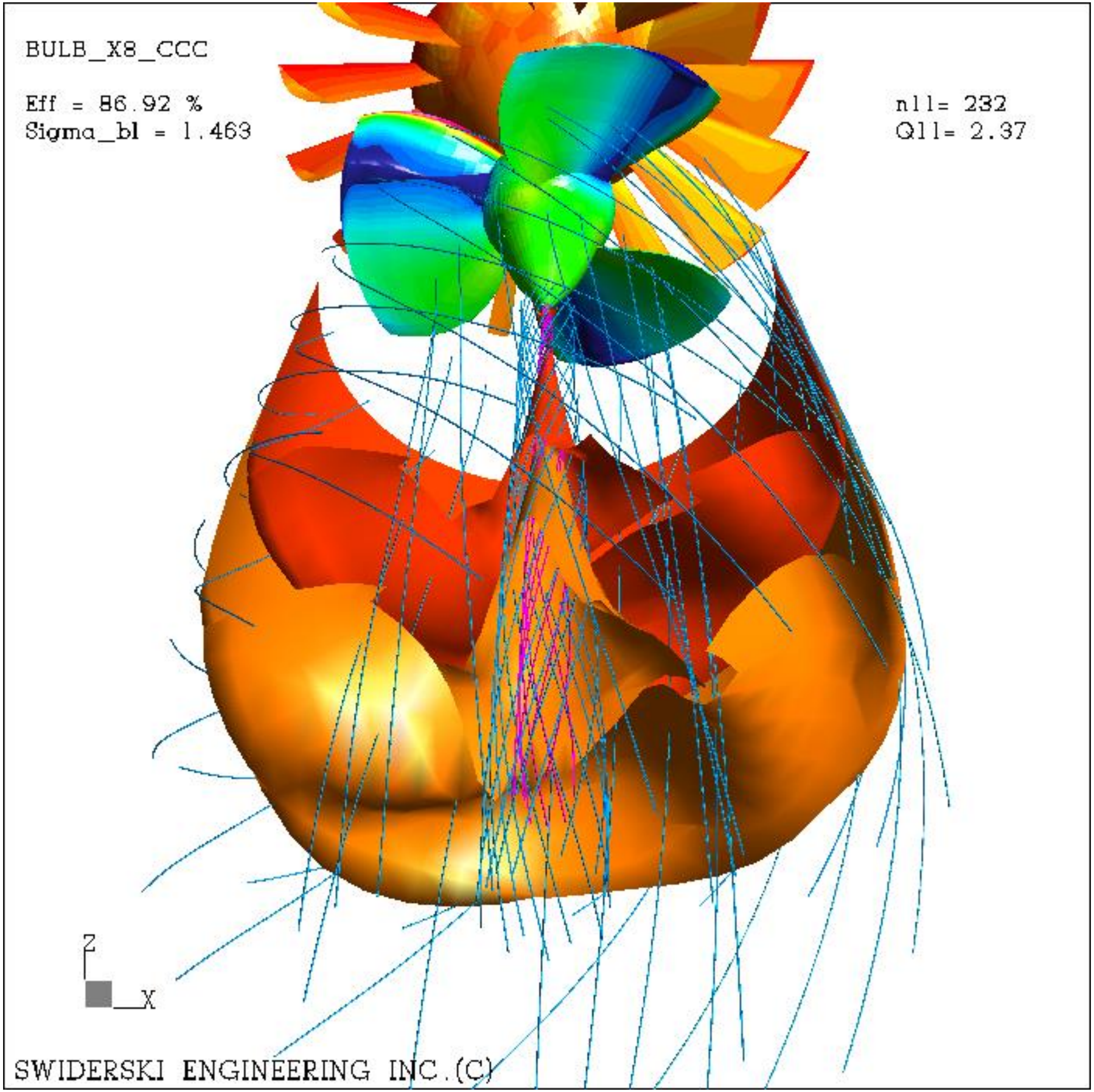
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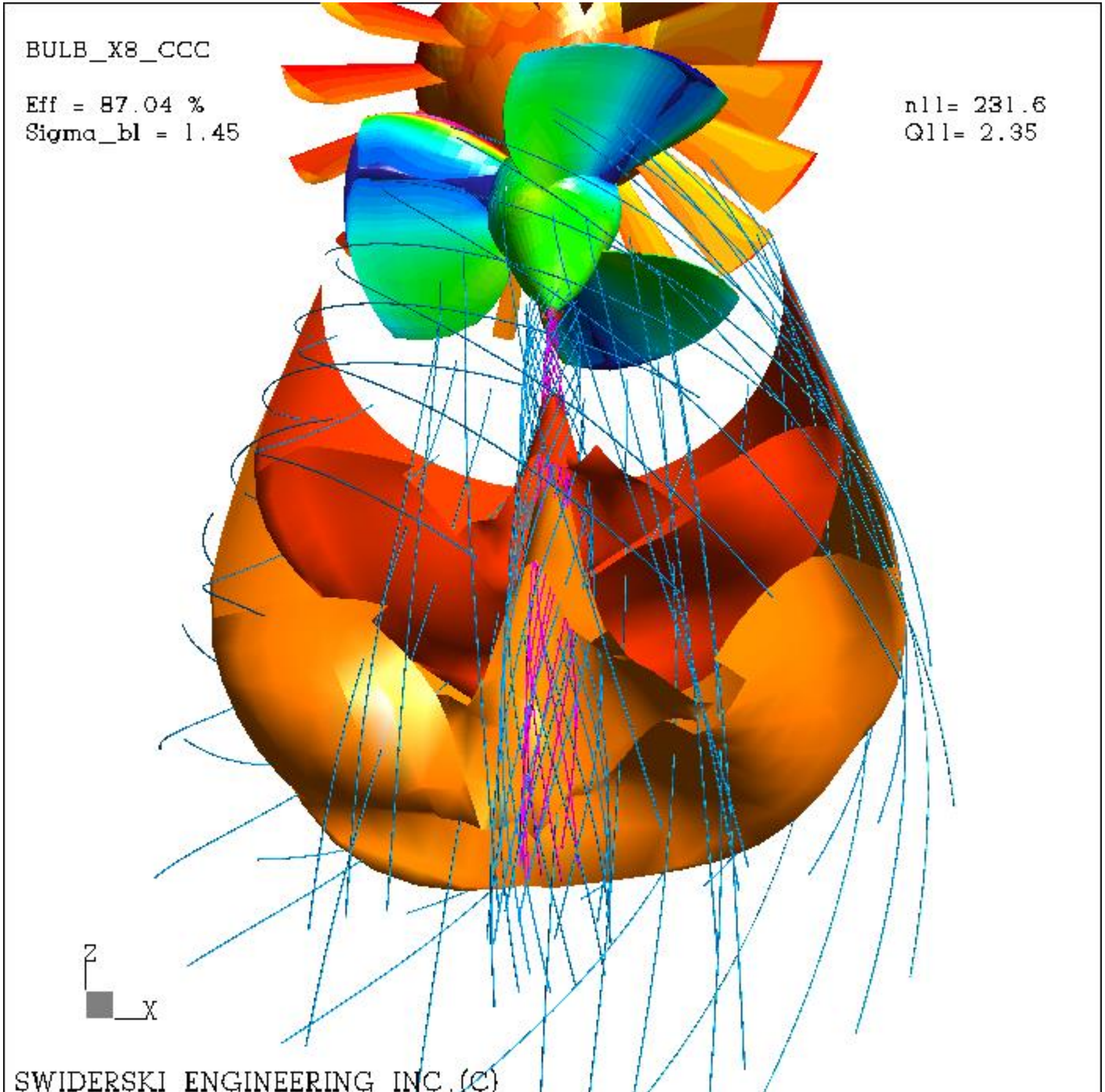
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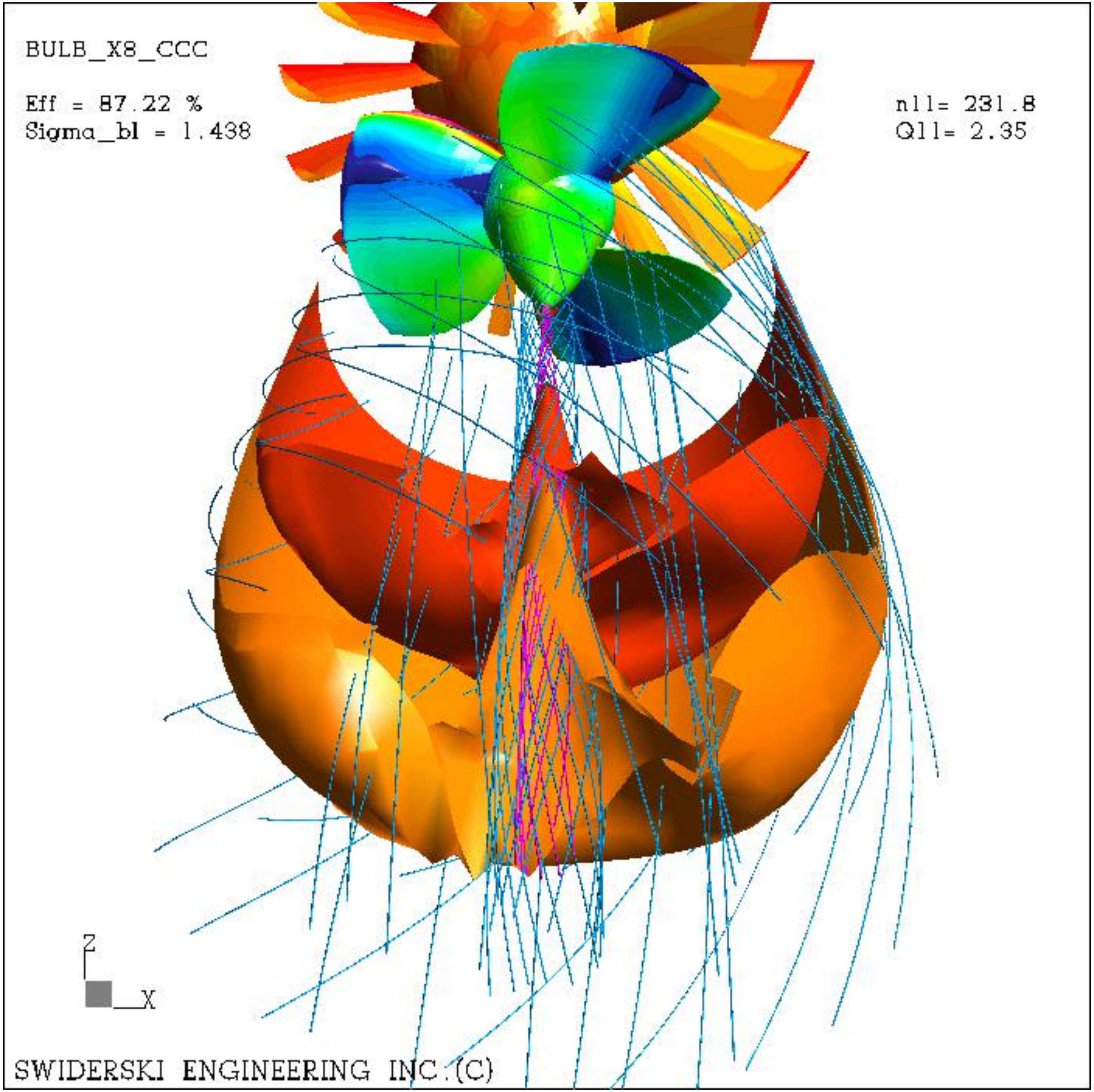
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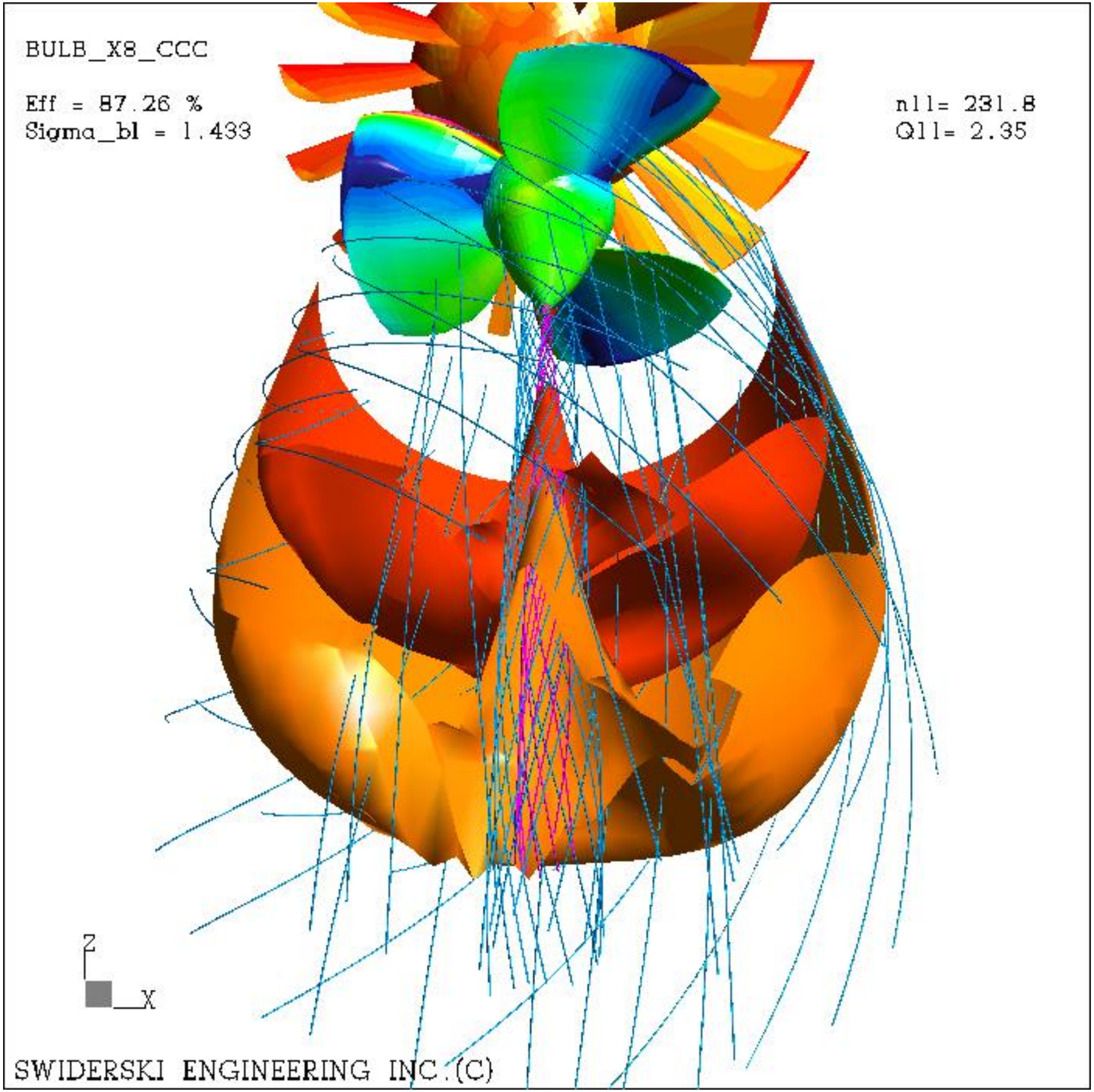
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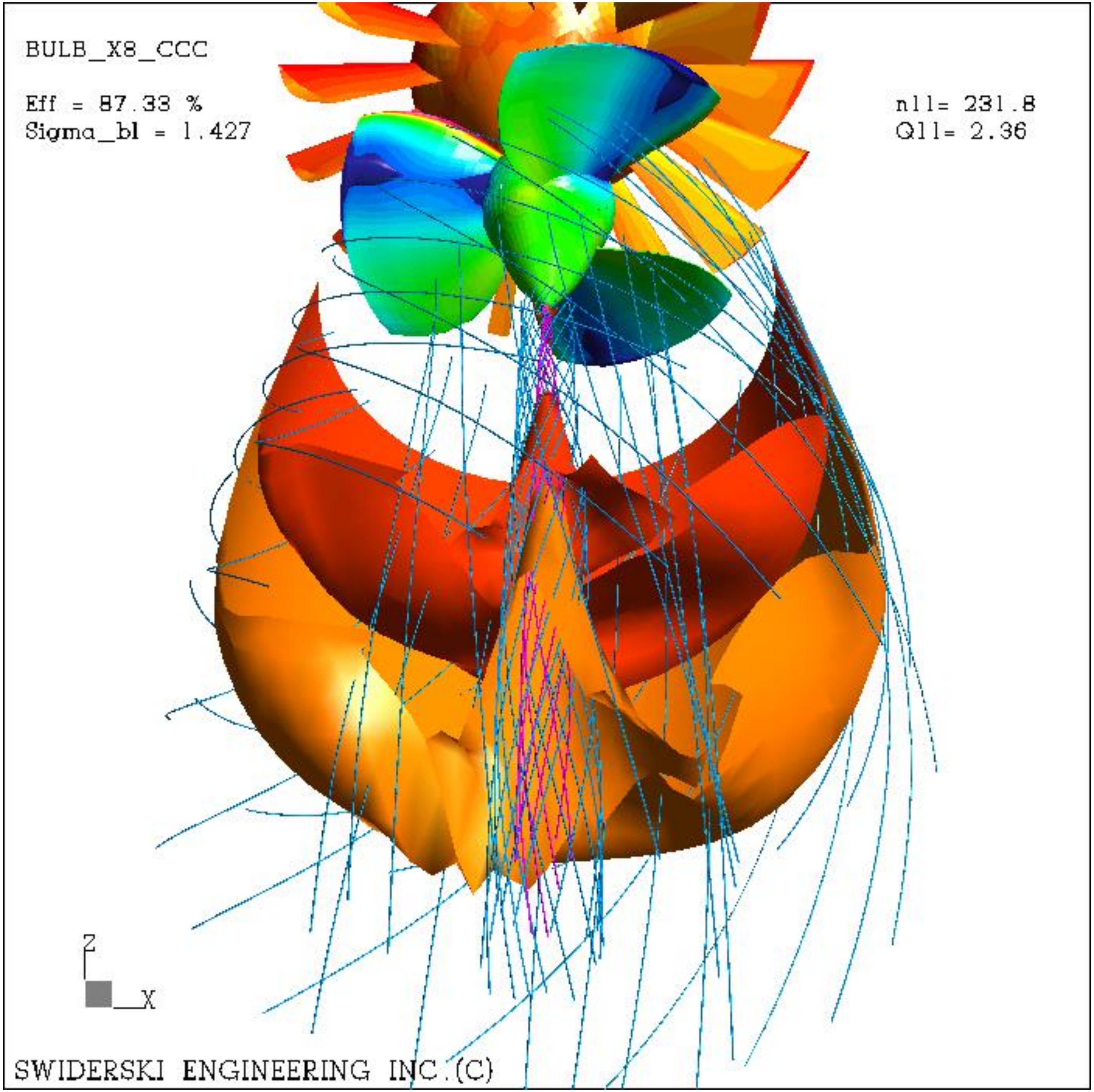
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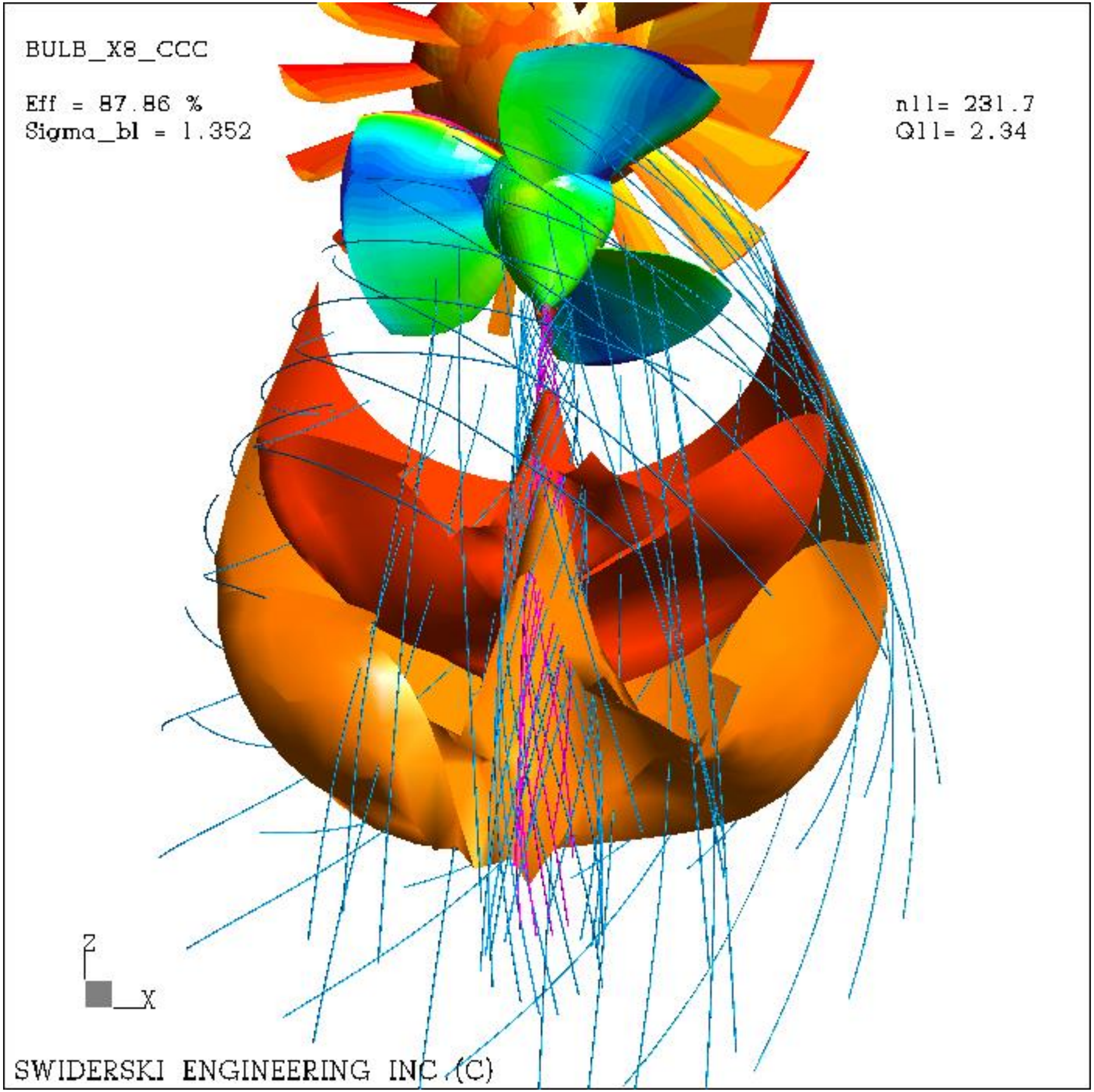
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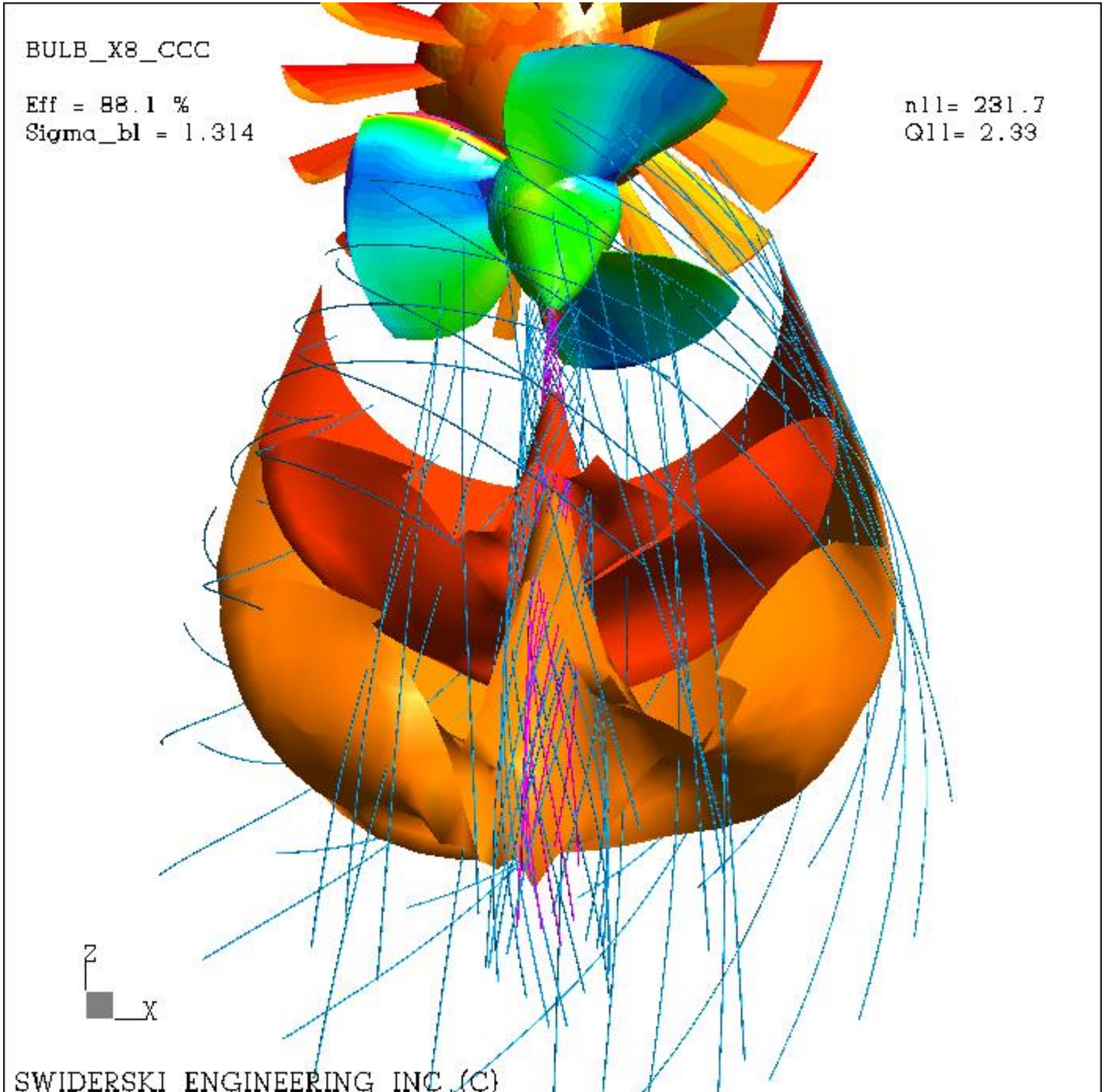
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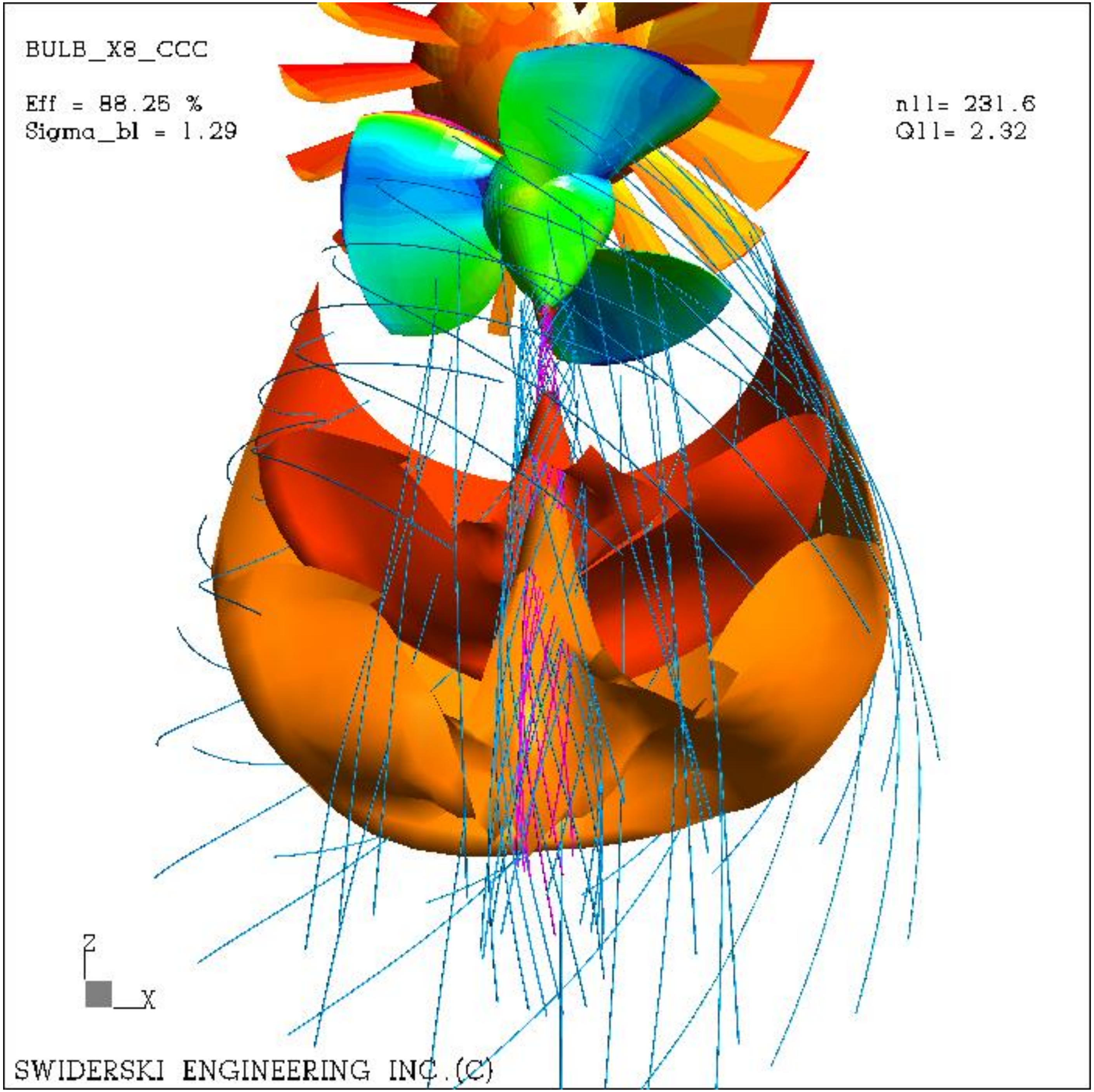
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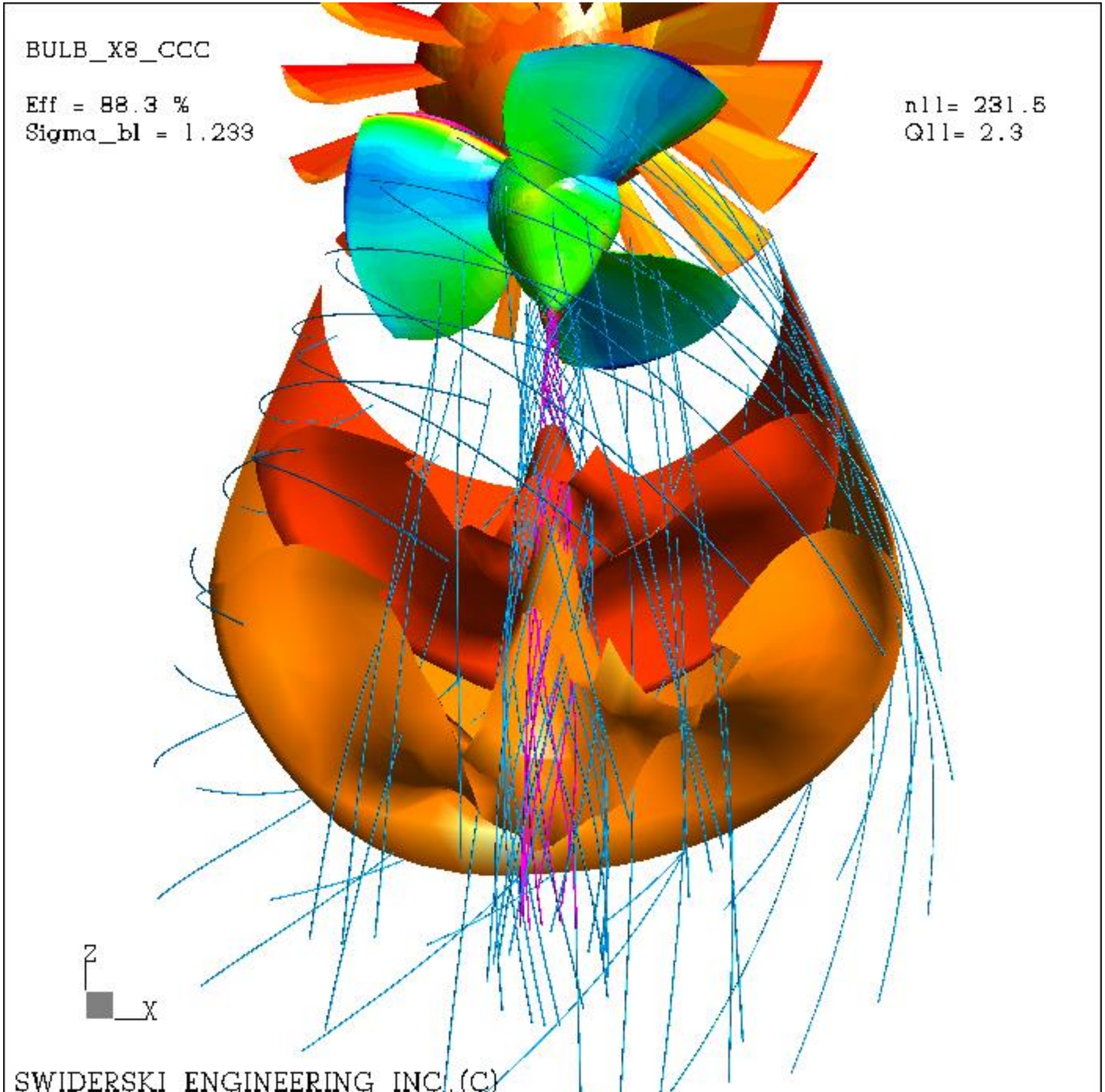
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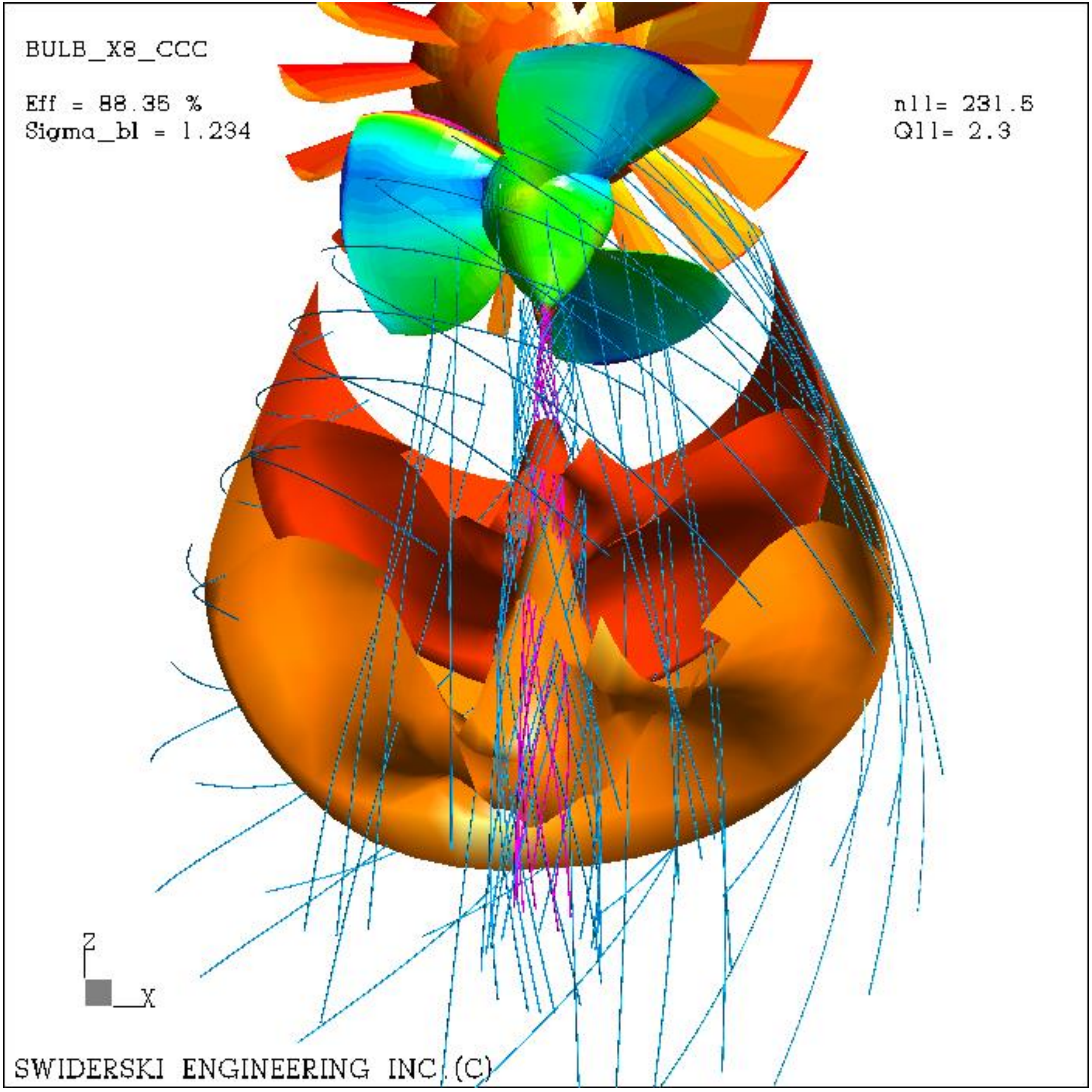
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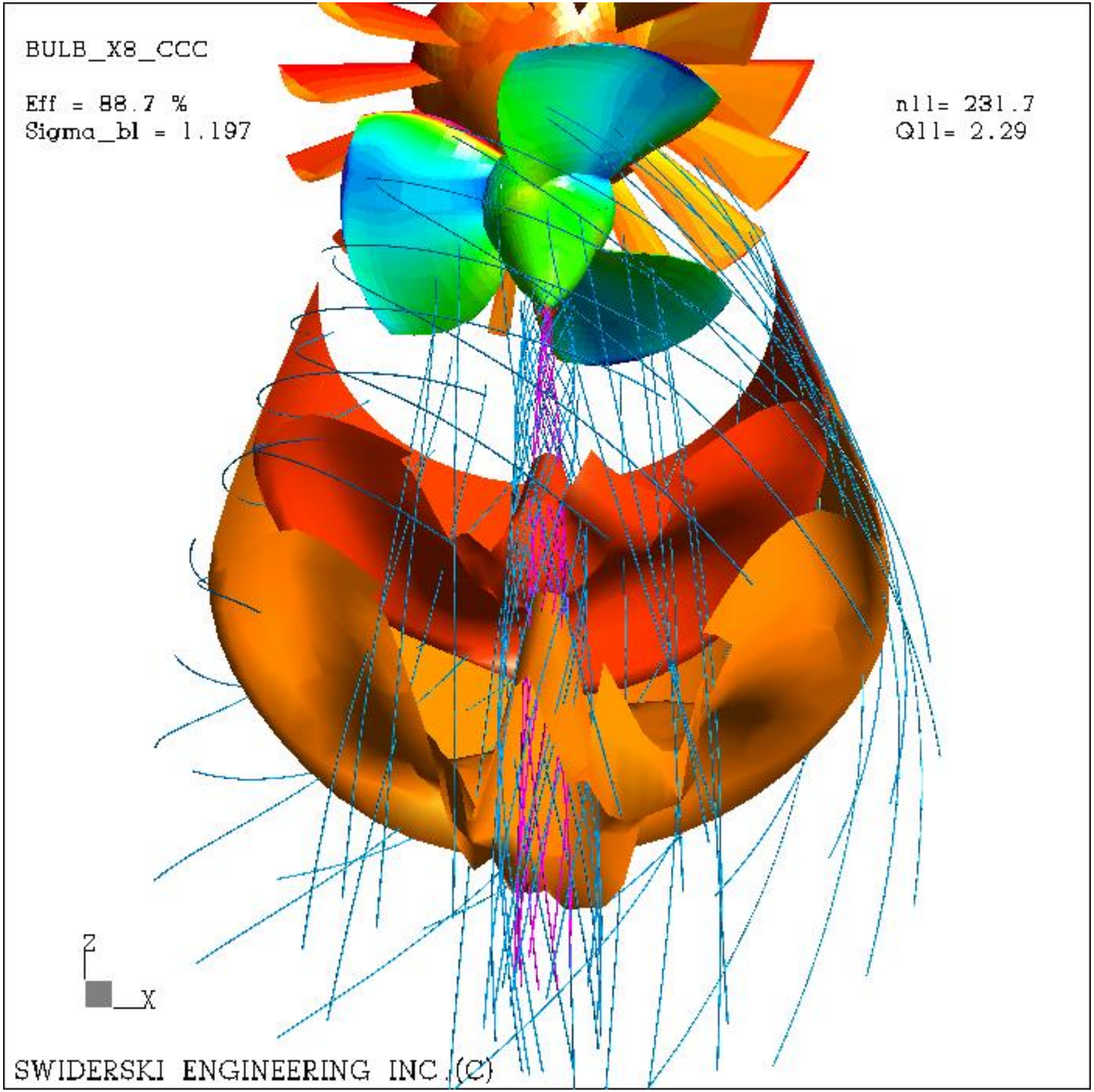
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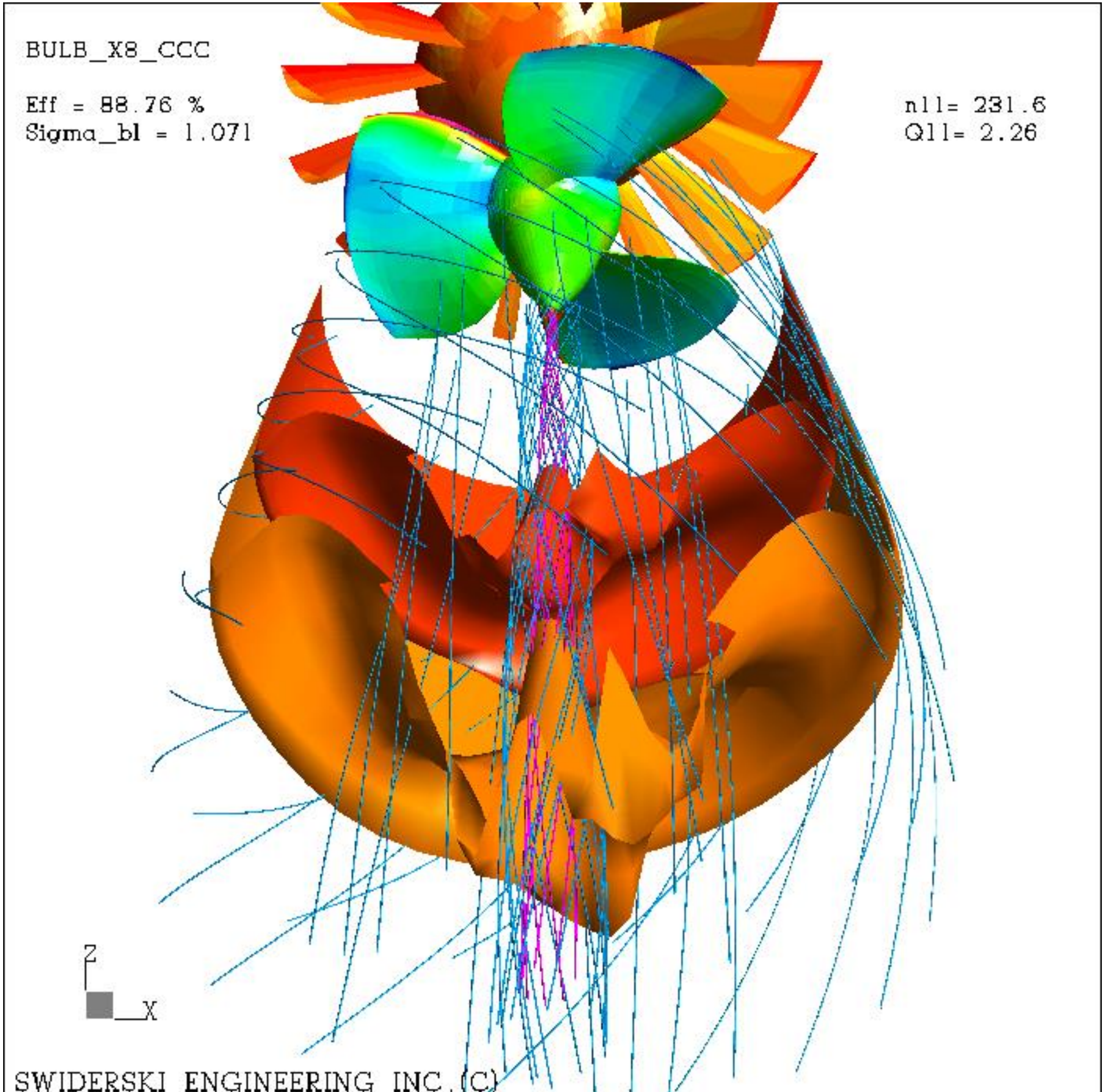
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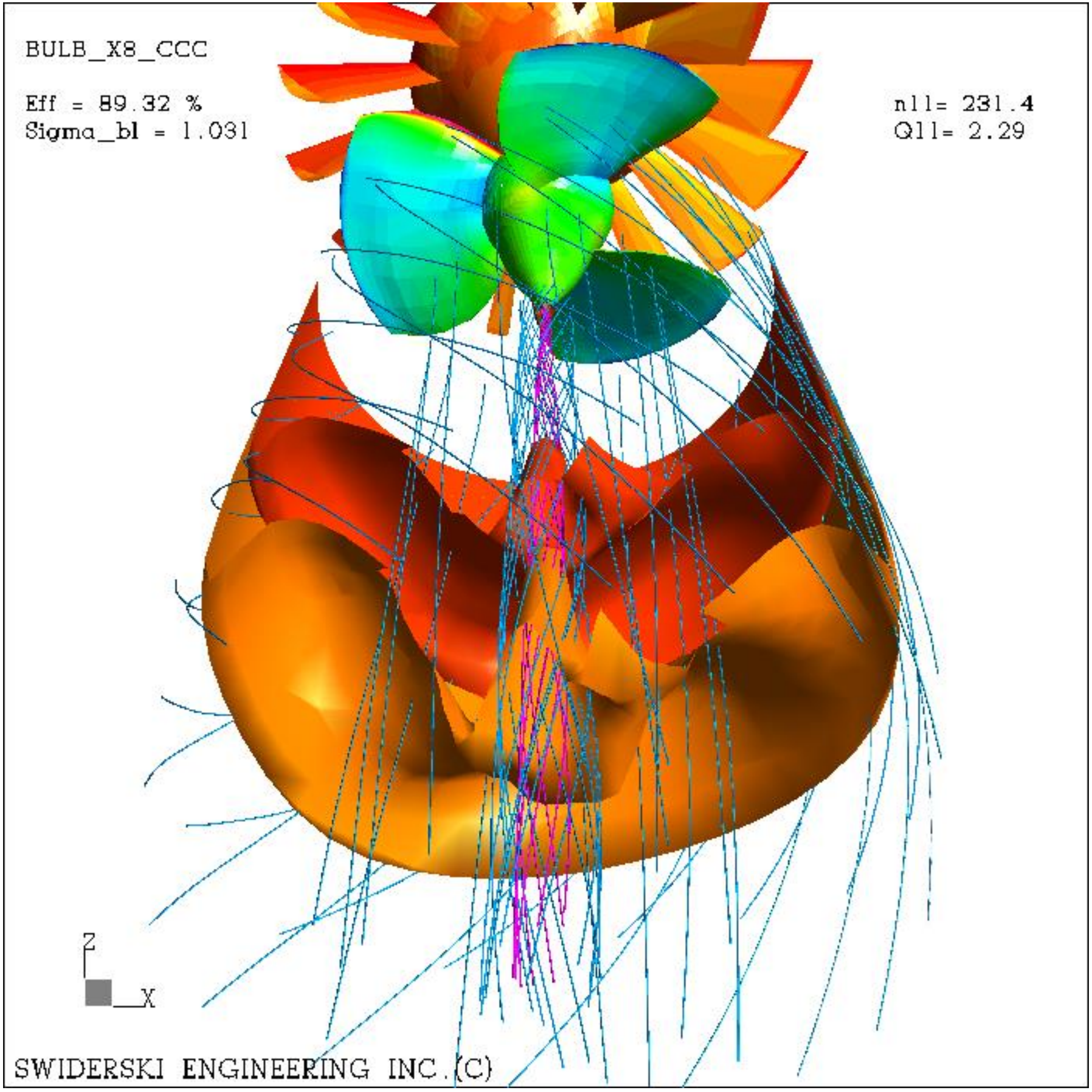

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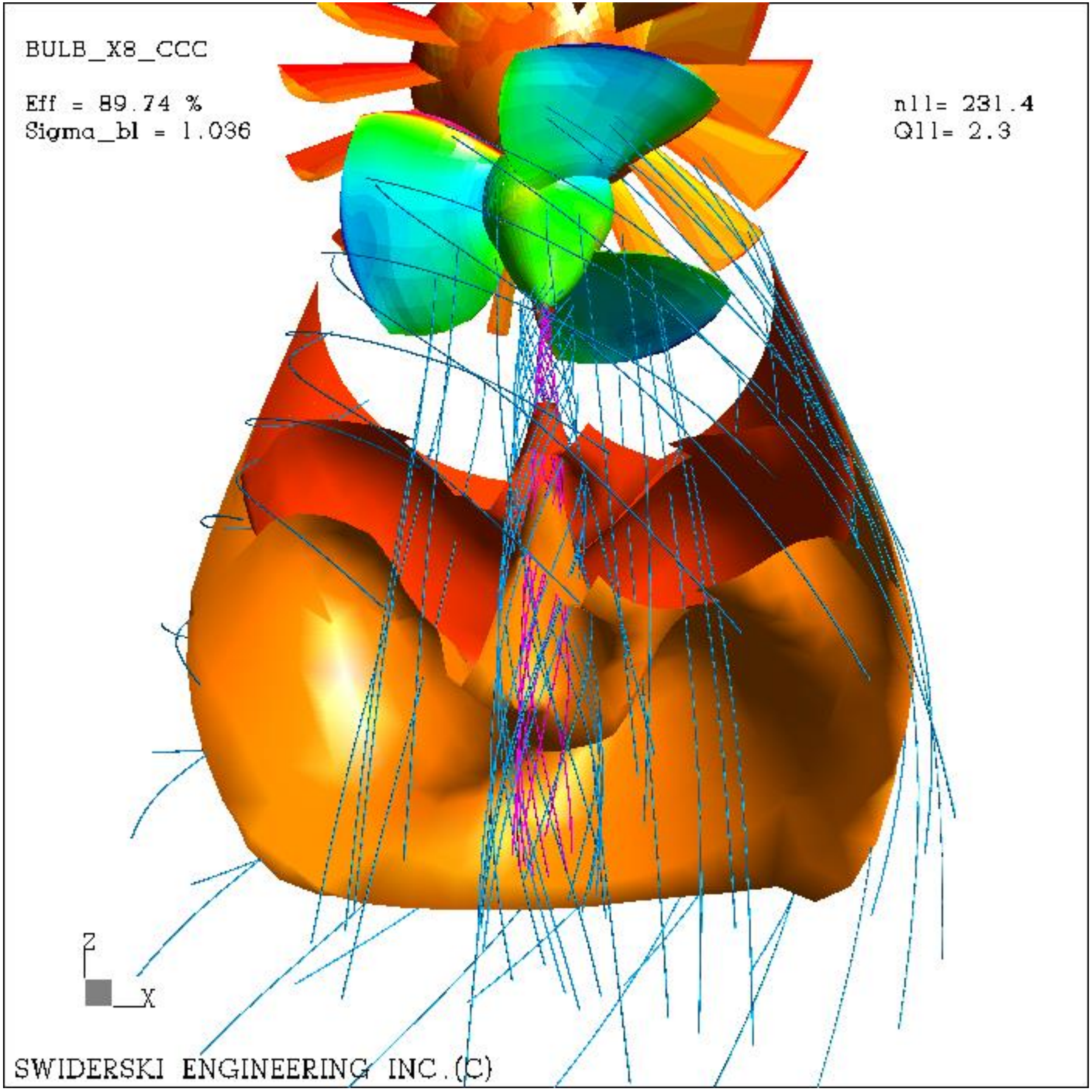
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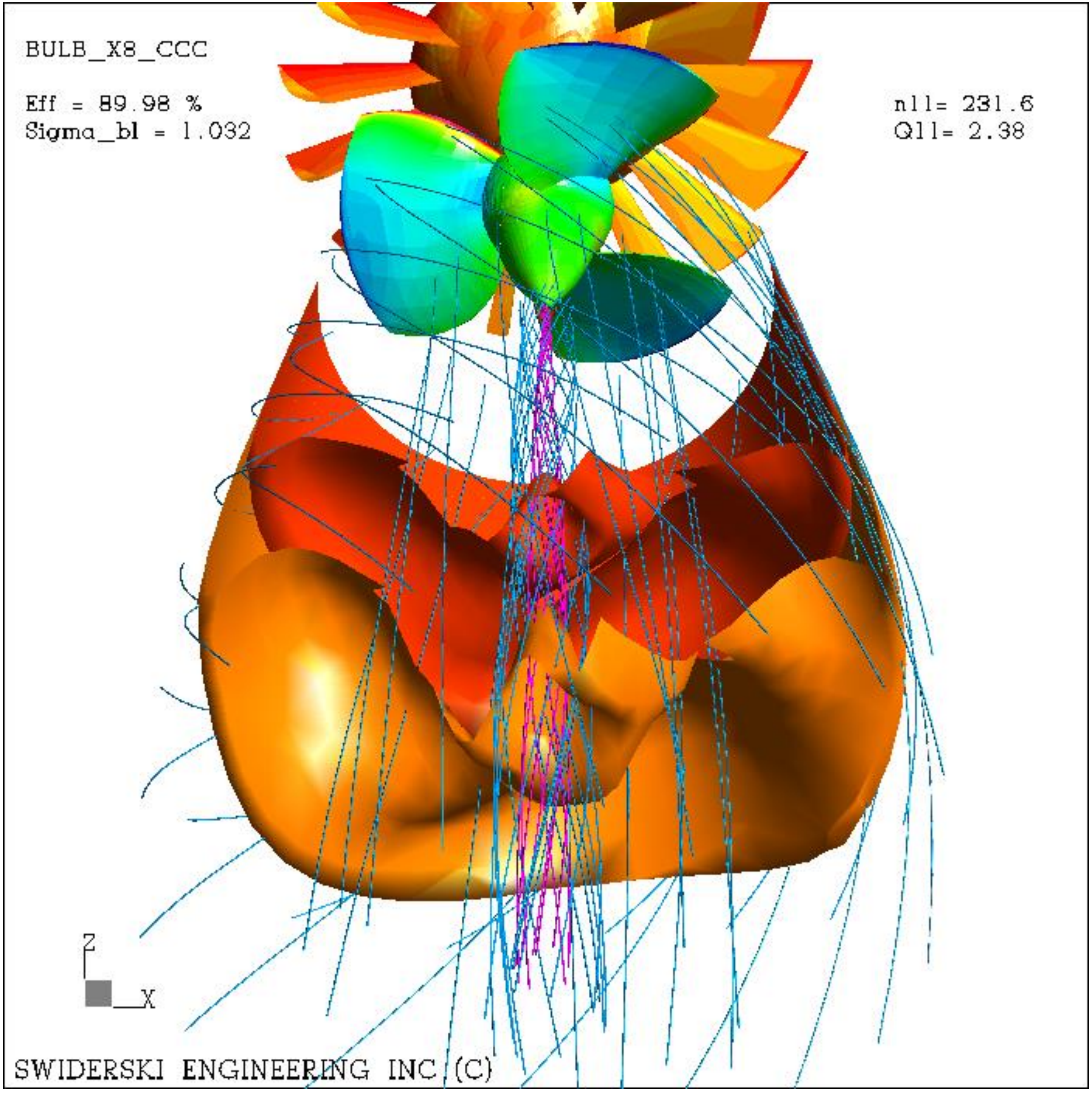
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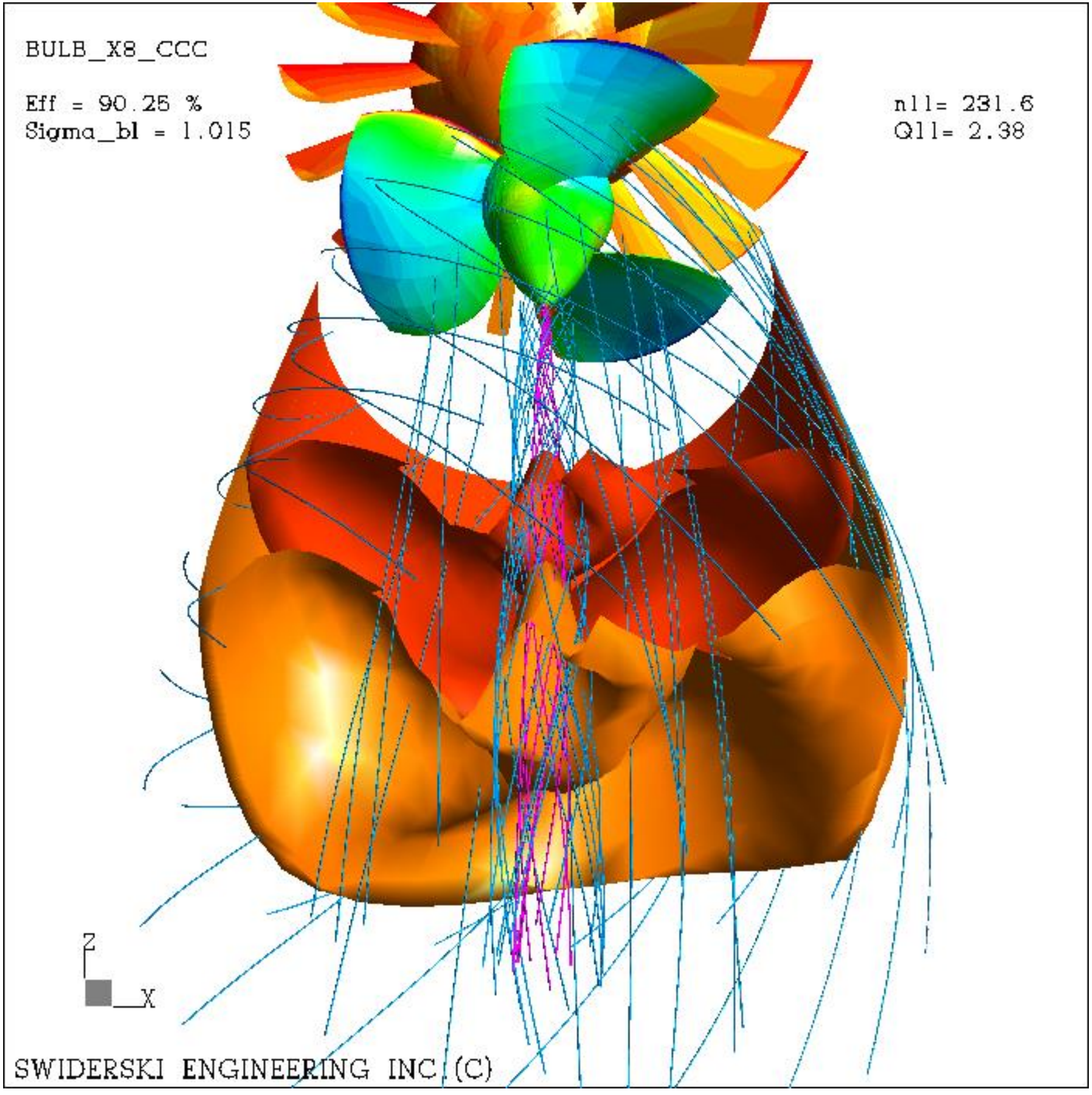
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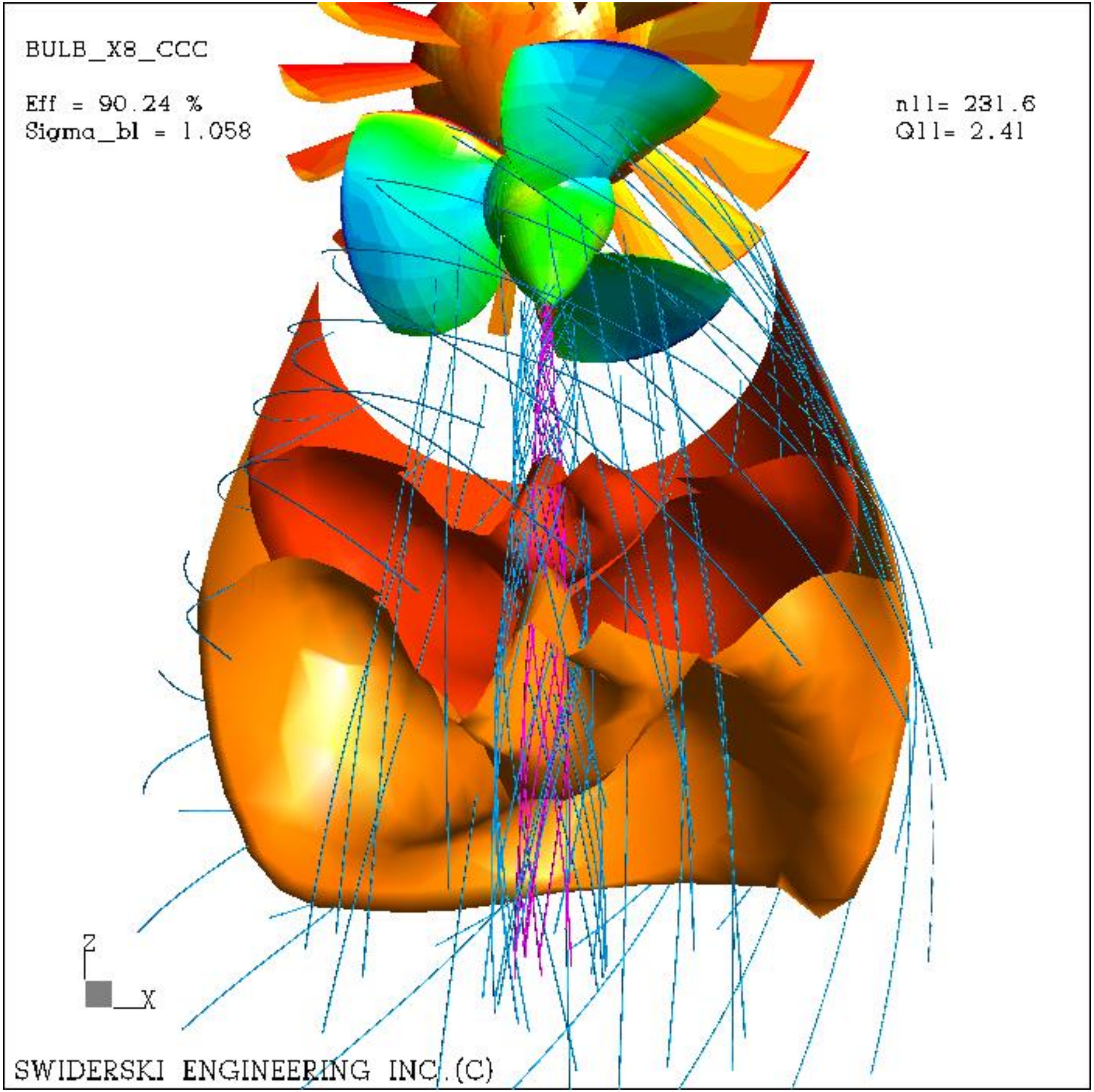
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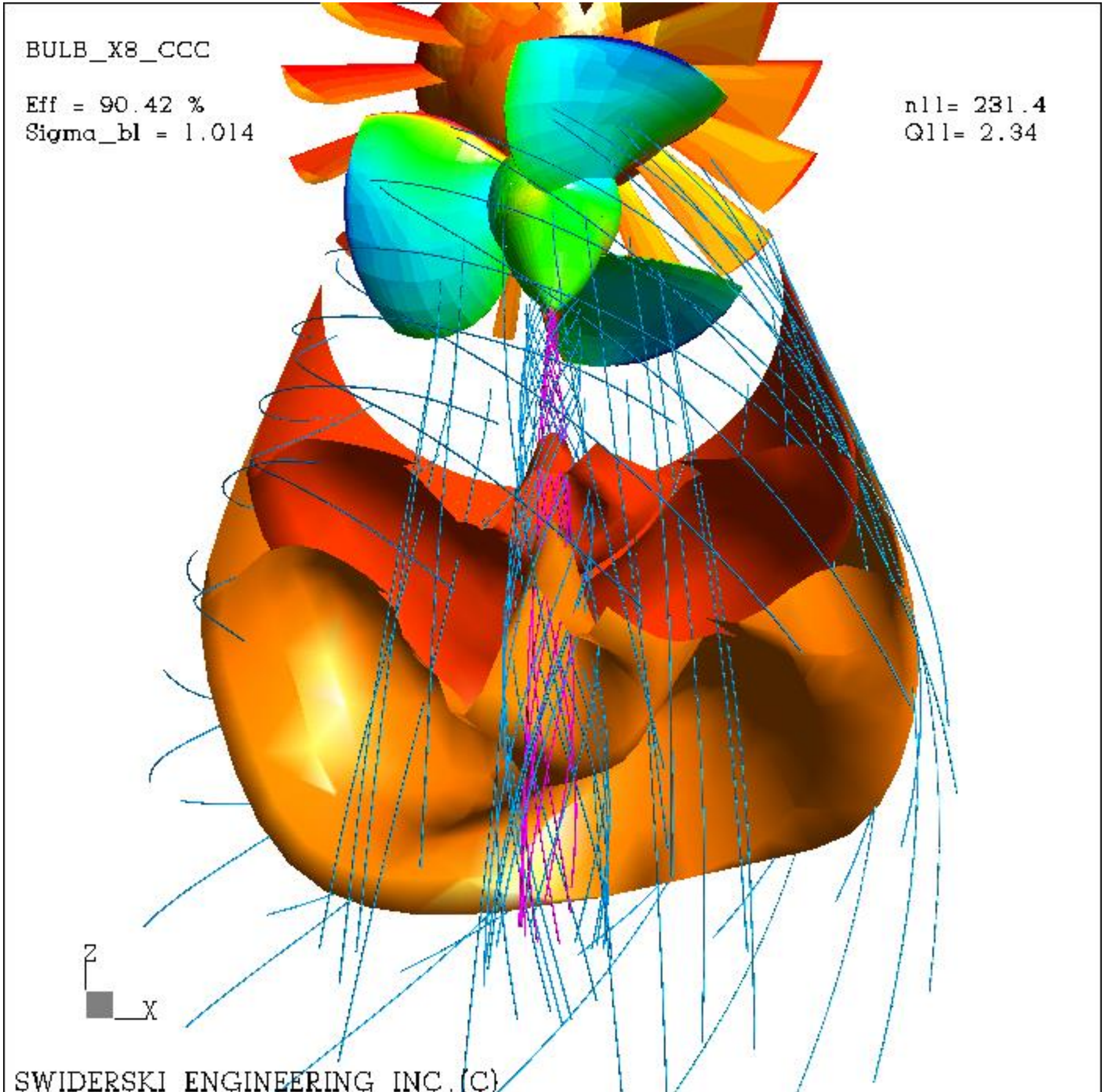
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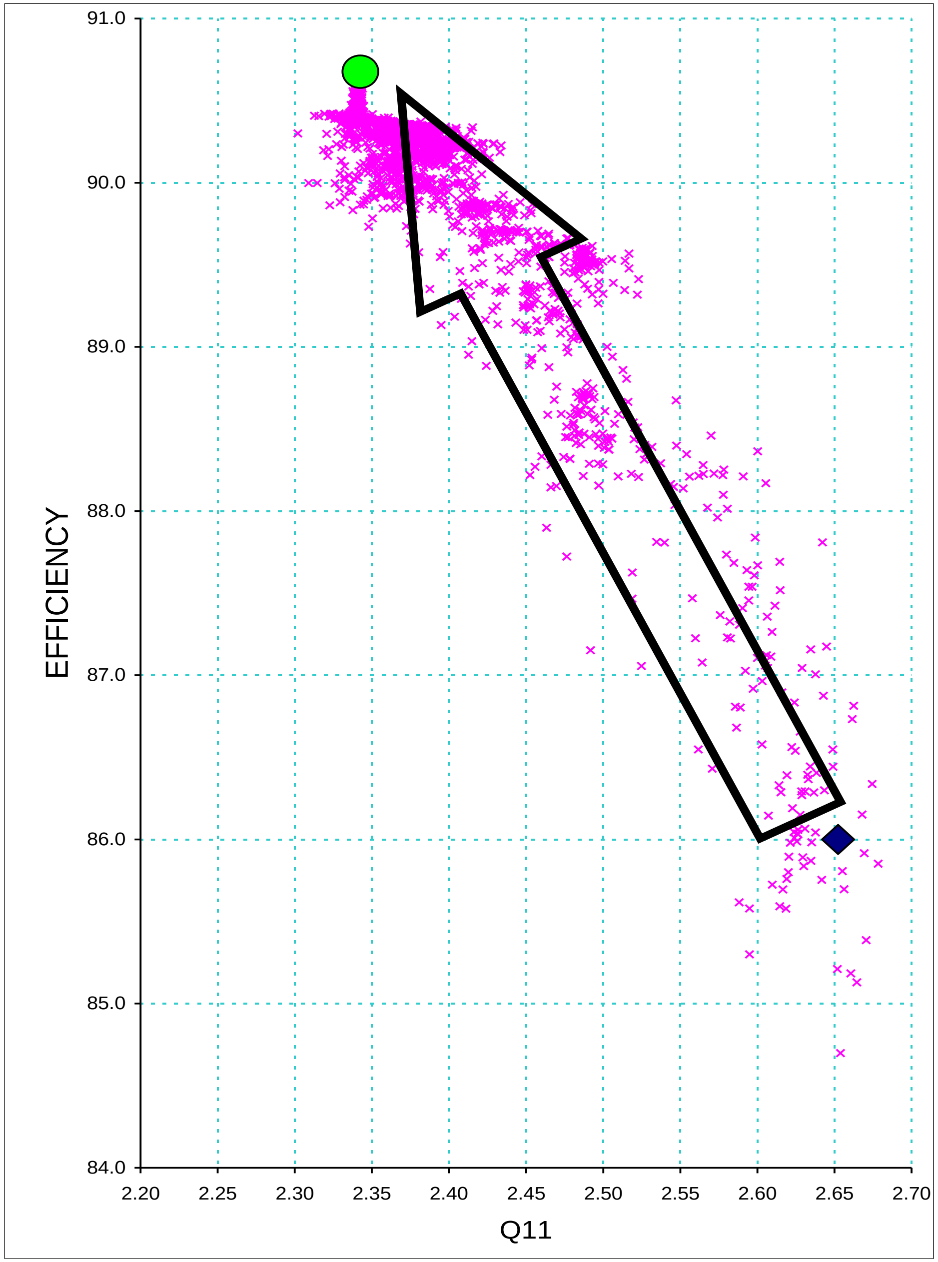
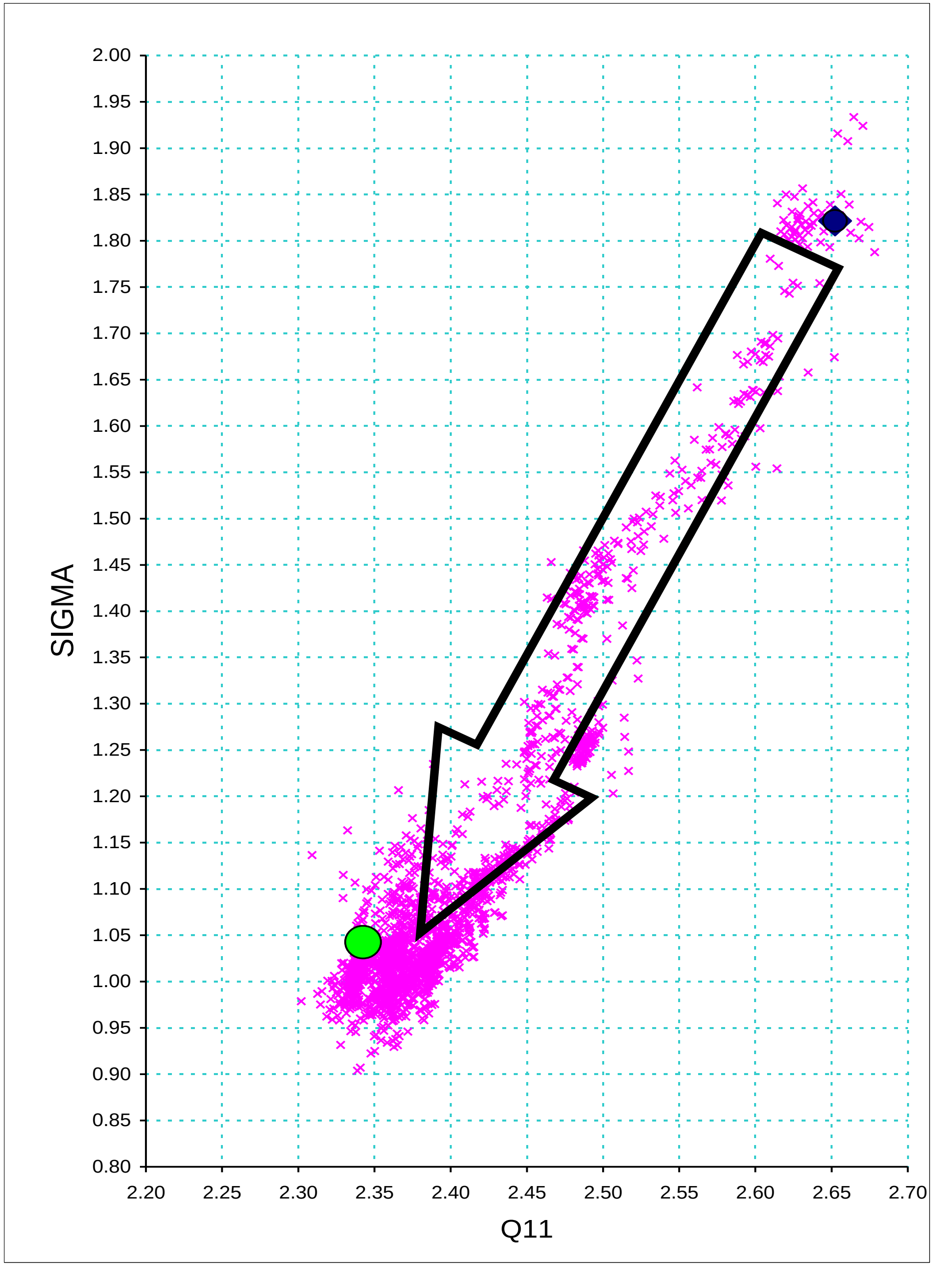
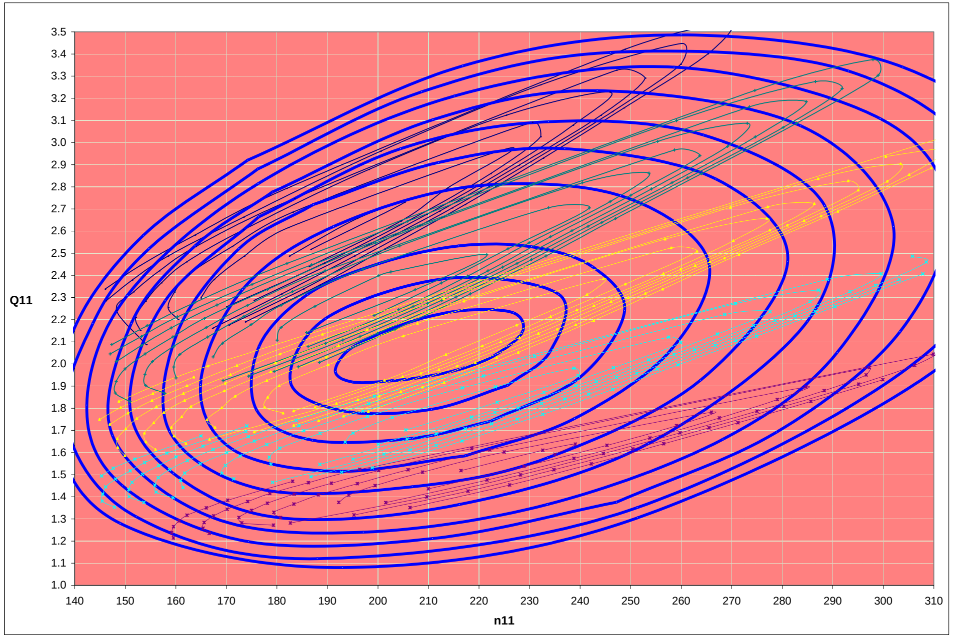
SWIDERSKI ENGINEERING INC.(C)

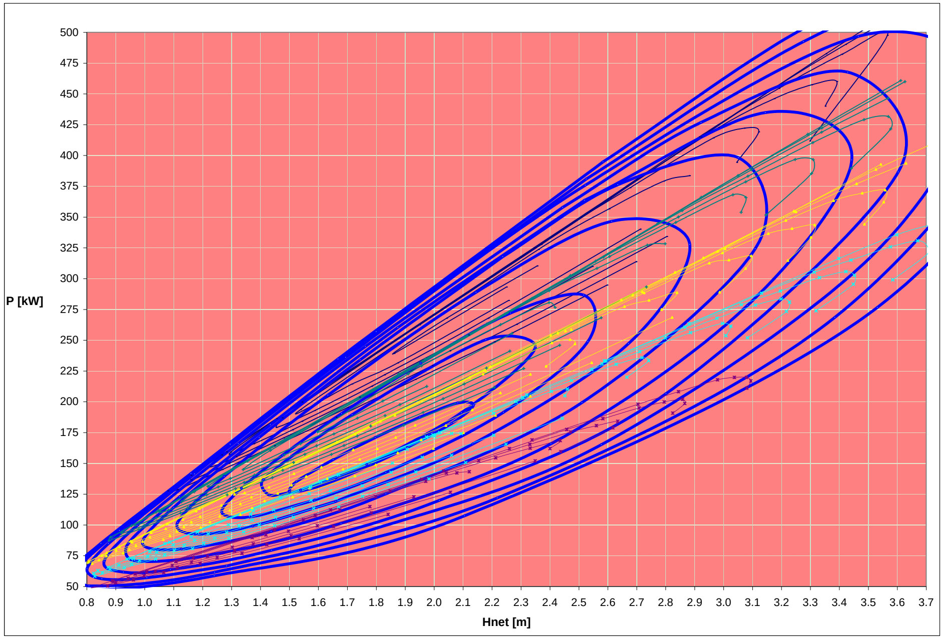
Optimization process - history

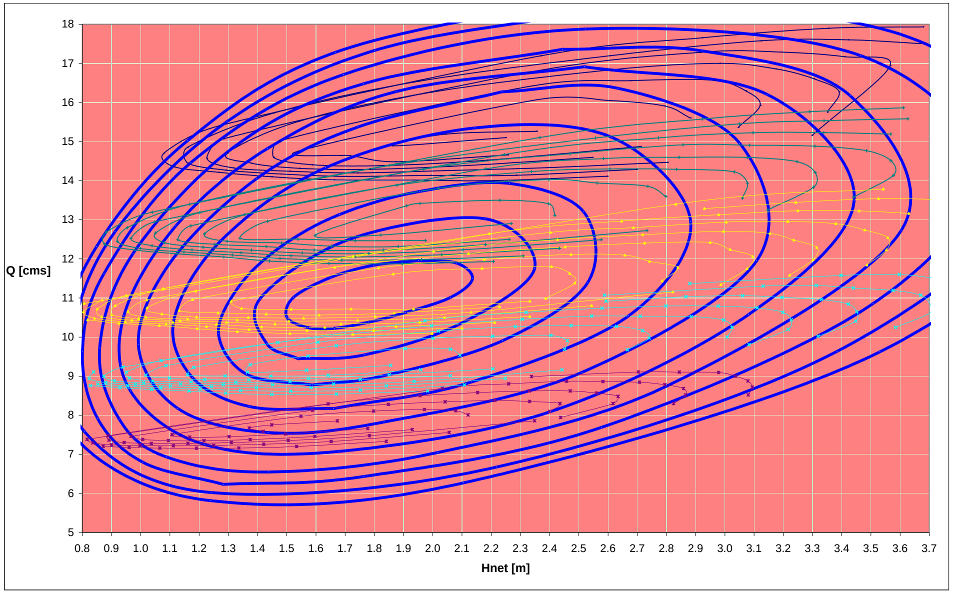




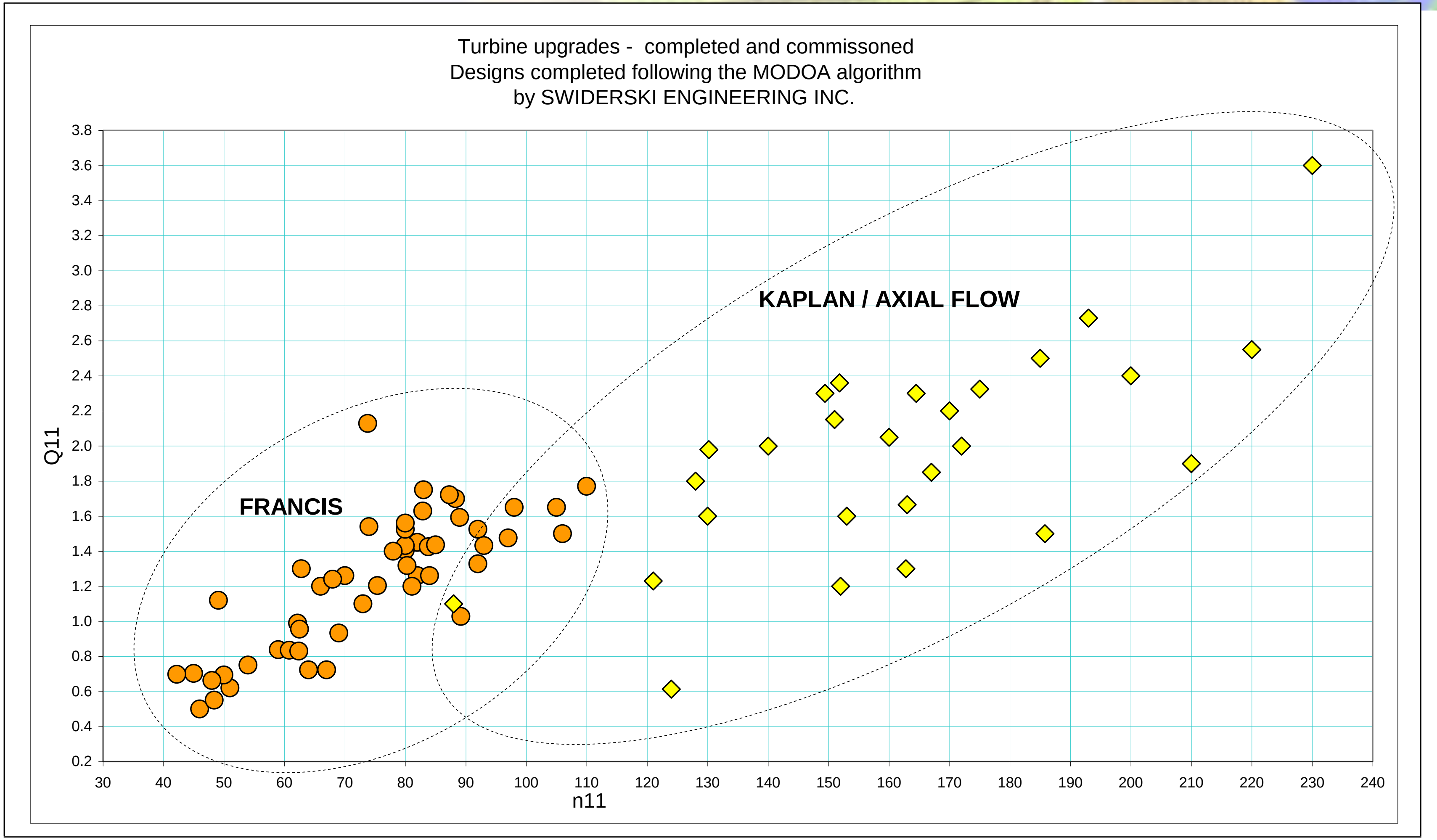
Optimized turbine – hill chart







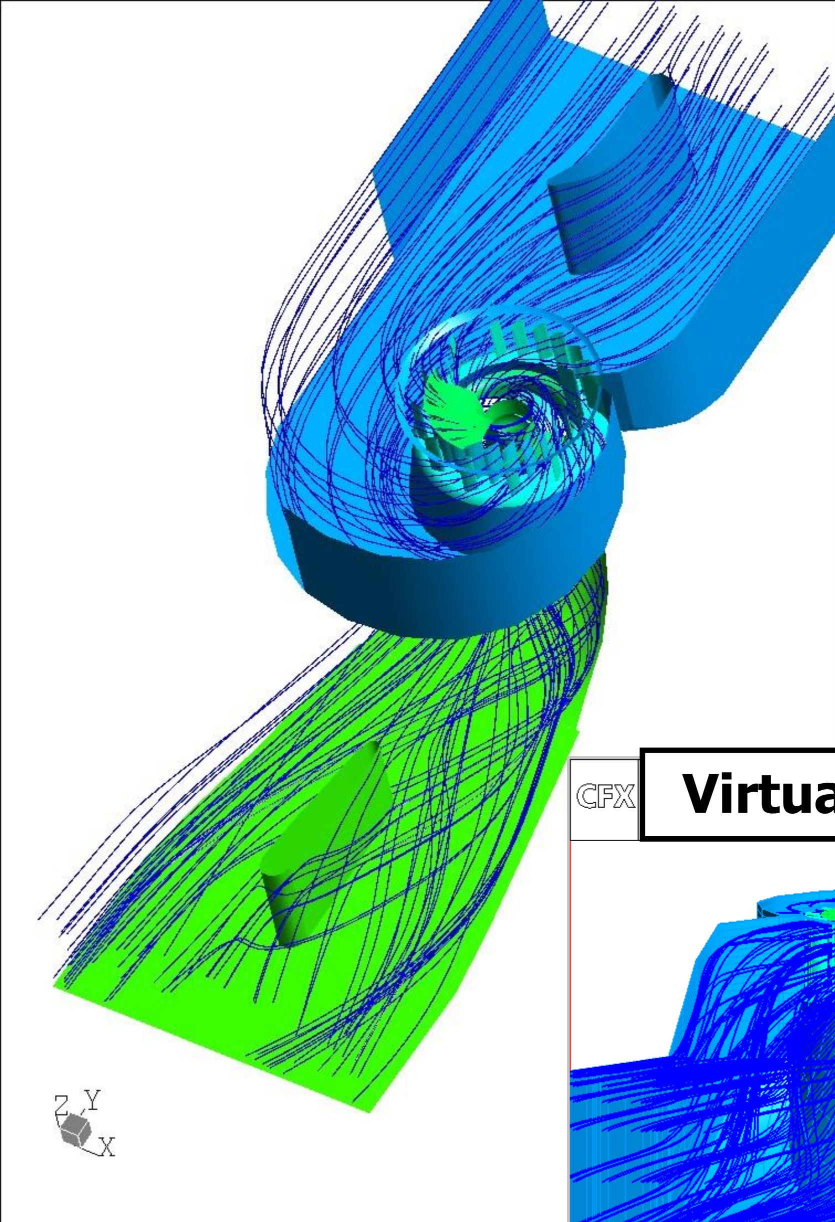
Modernizations completed

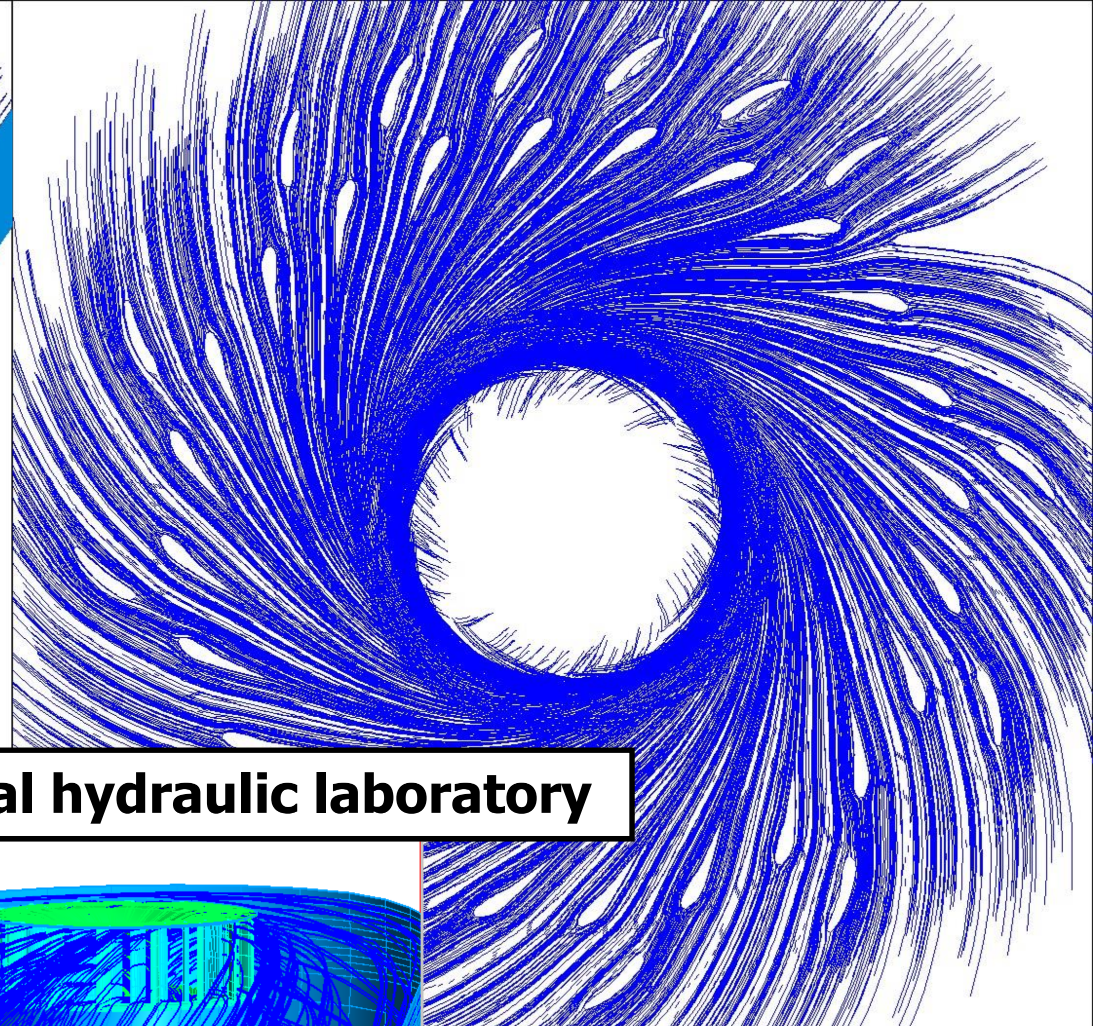


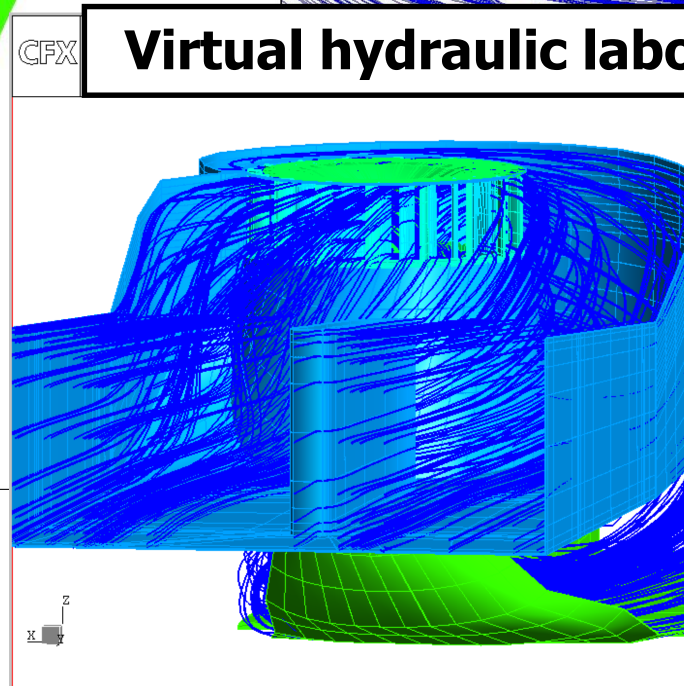
56 designs of Francis turbines or runners were completed, over 117 runners built.

27 designs of Kaplan and/or Axial Flow turbines were completed, 39 runners built.

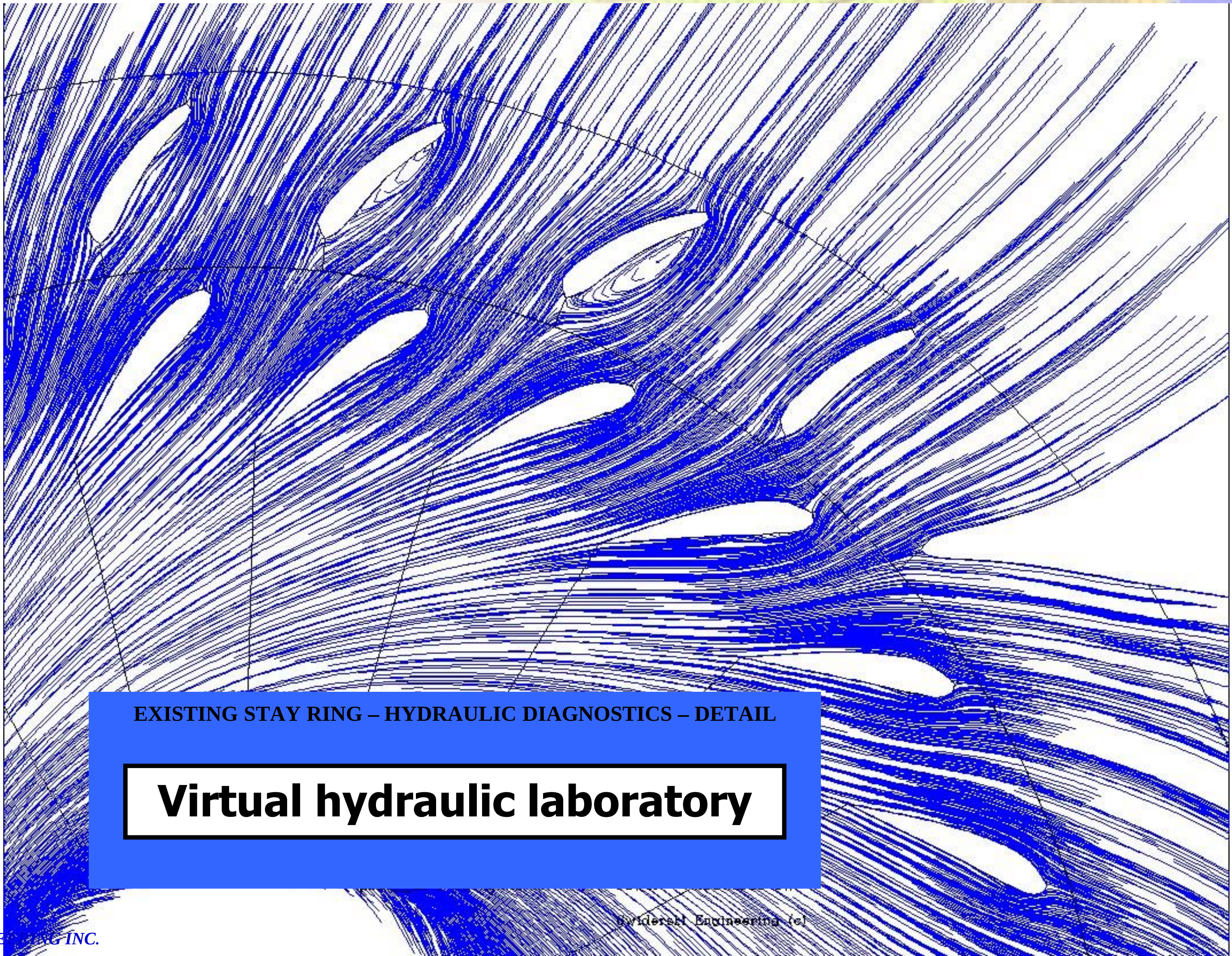
Virtual hydraulic laboratory





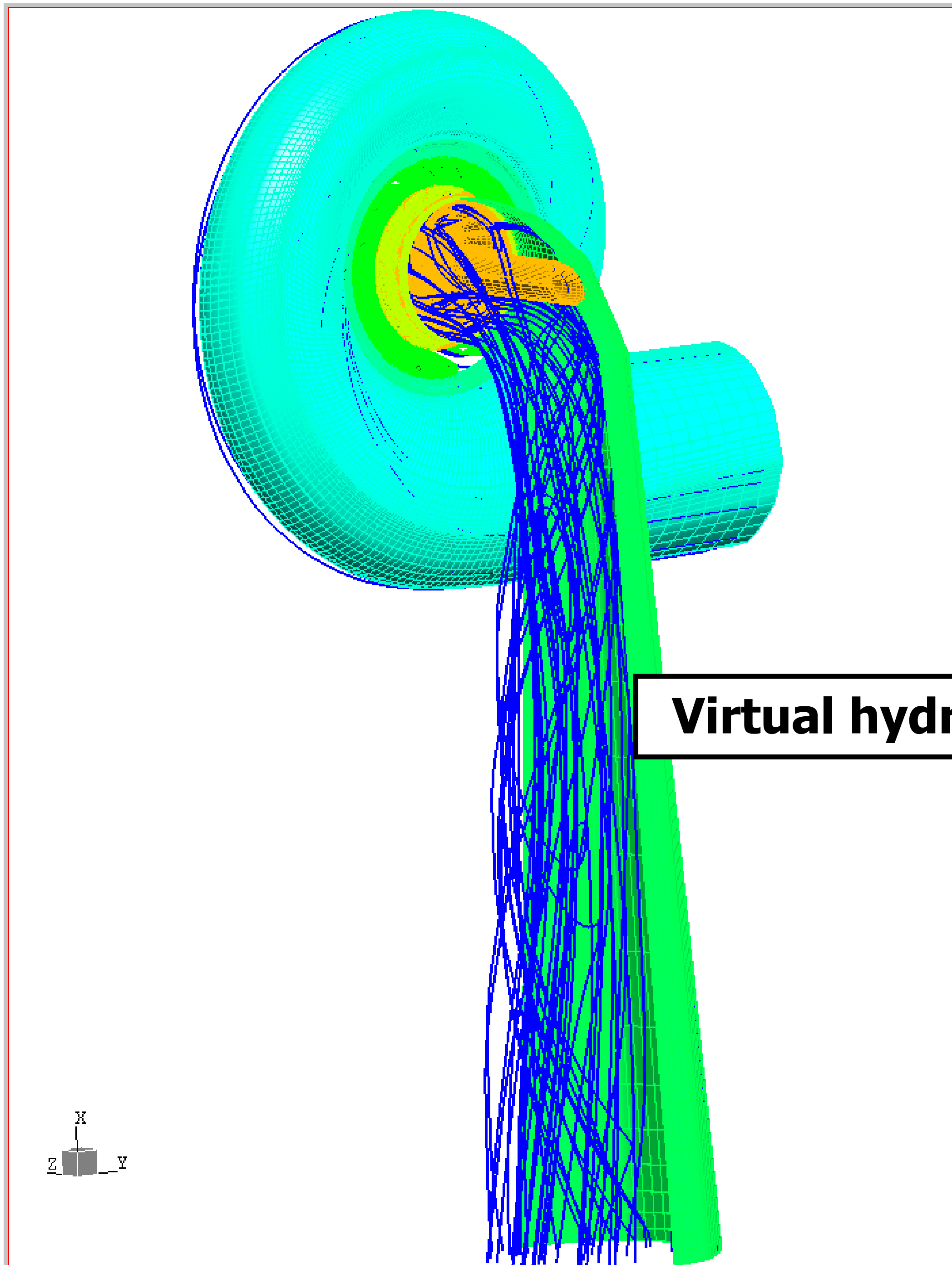


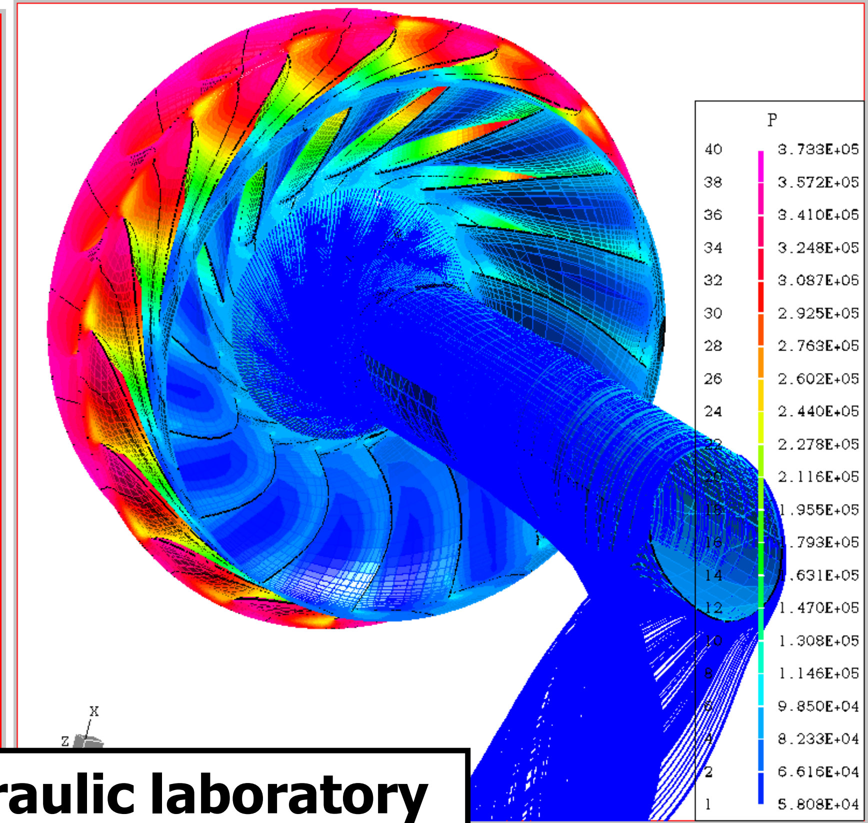
Hudraulic diagnostics – sample 1



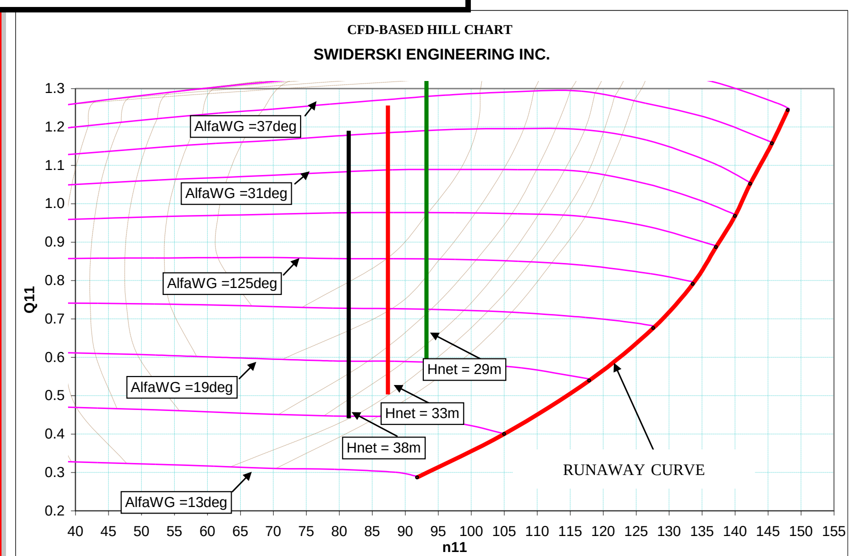
EXISTING STAY RING – HYDRAULIC DIAGNOSTICS – DETAIL

Virtual hydraulic laboratory

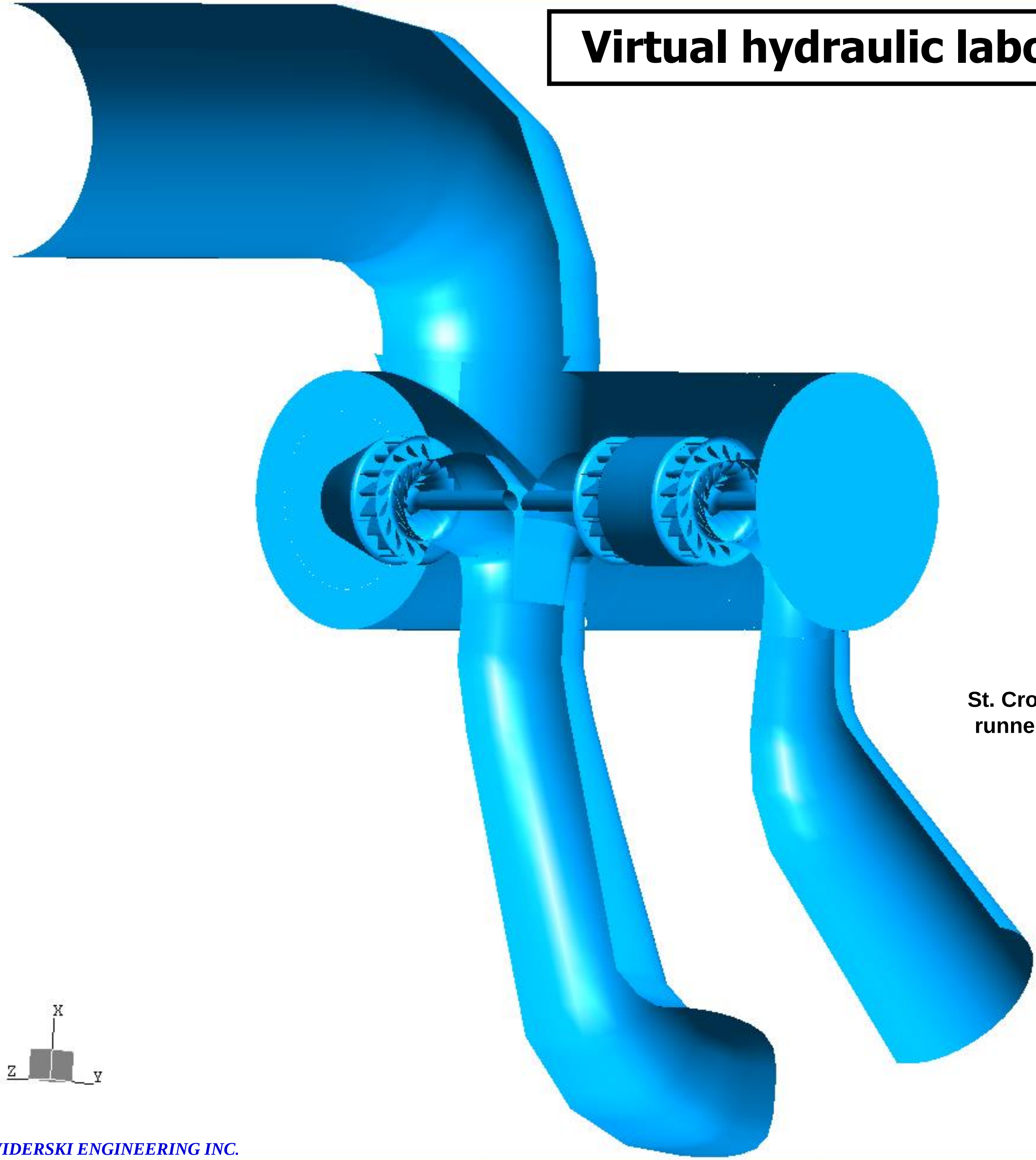




Virtual hydraulic laboratory

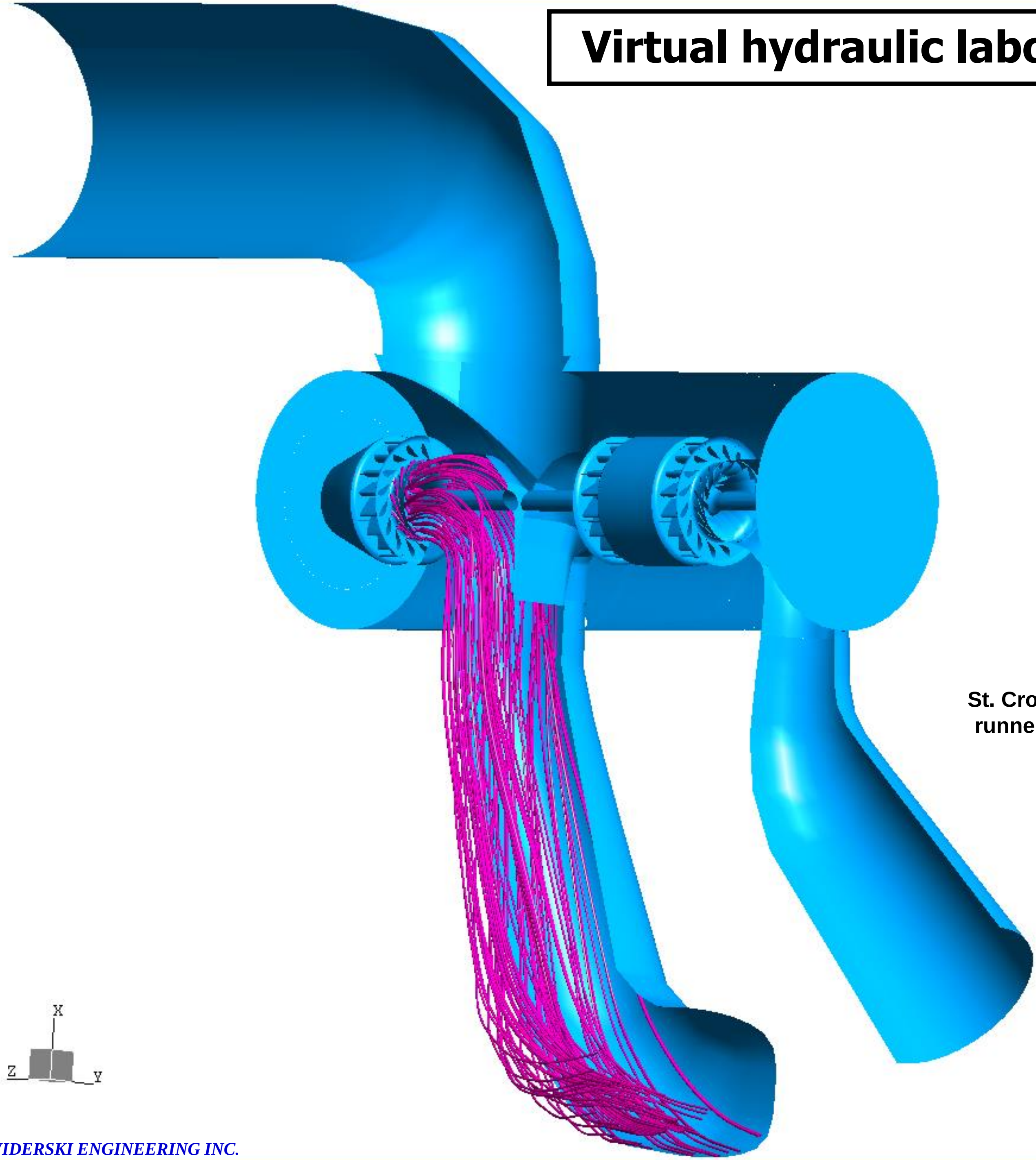


Virtual hydraulic laboratory



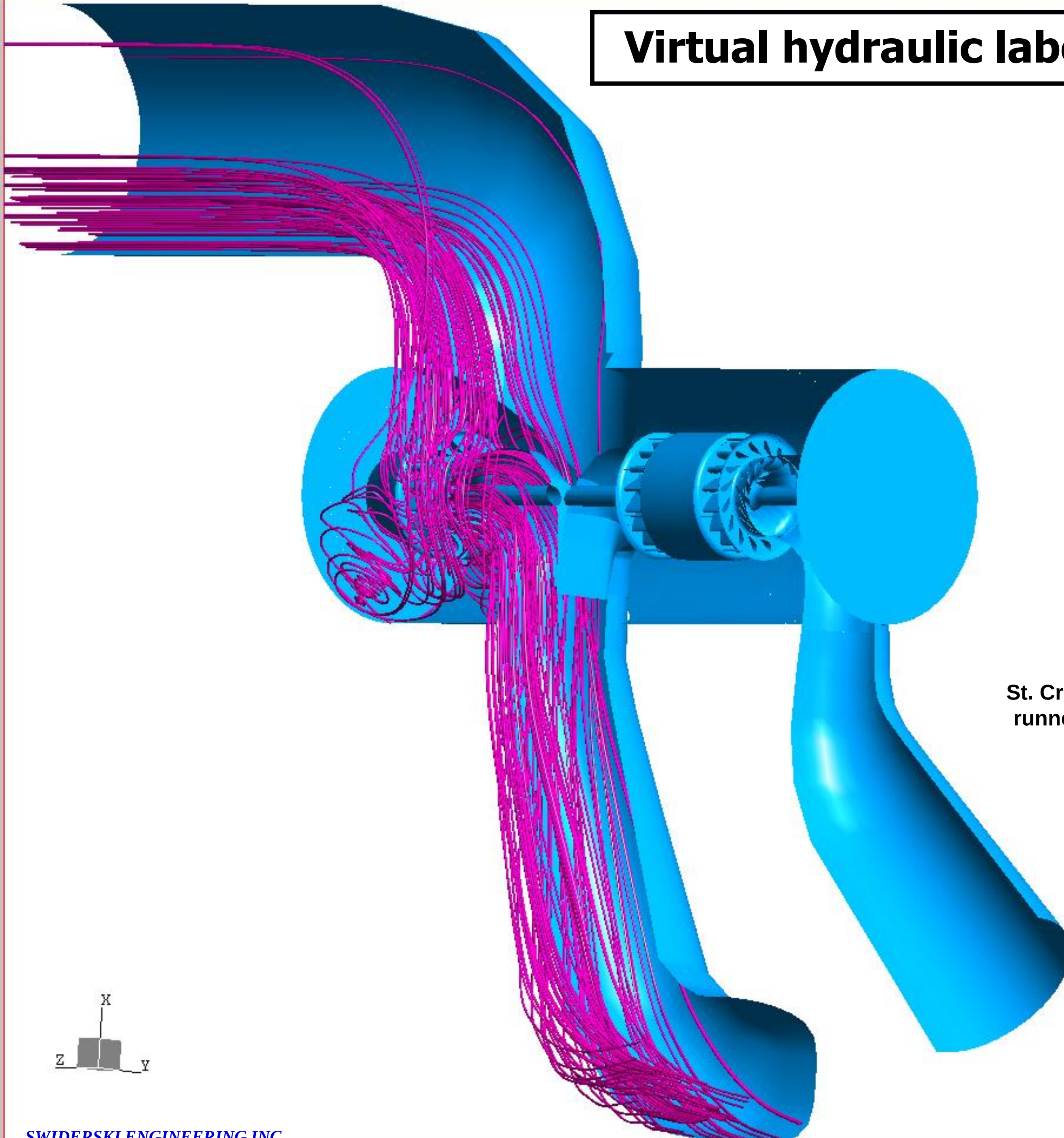
St. Croix Project –
runners upgrade

Virtual hydraulic laboratory



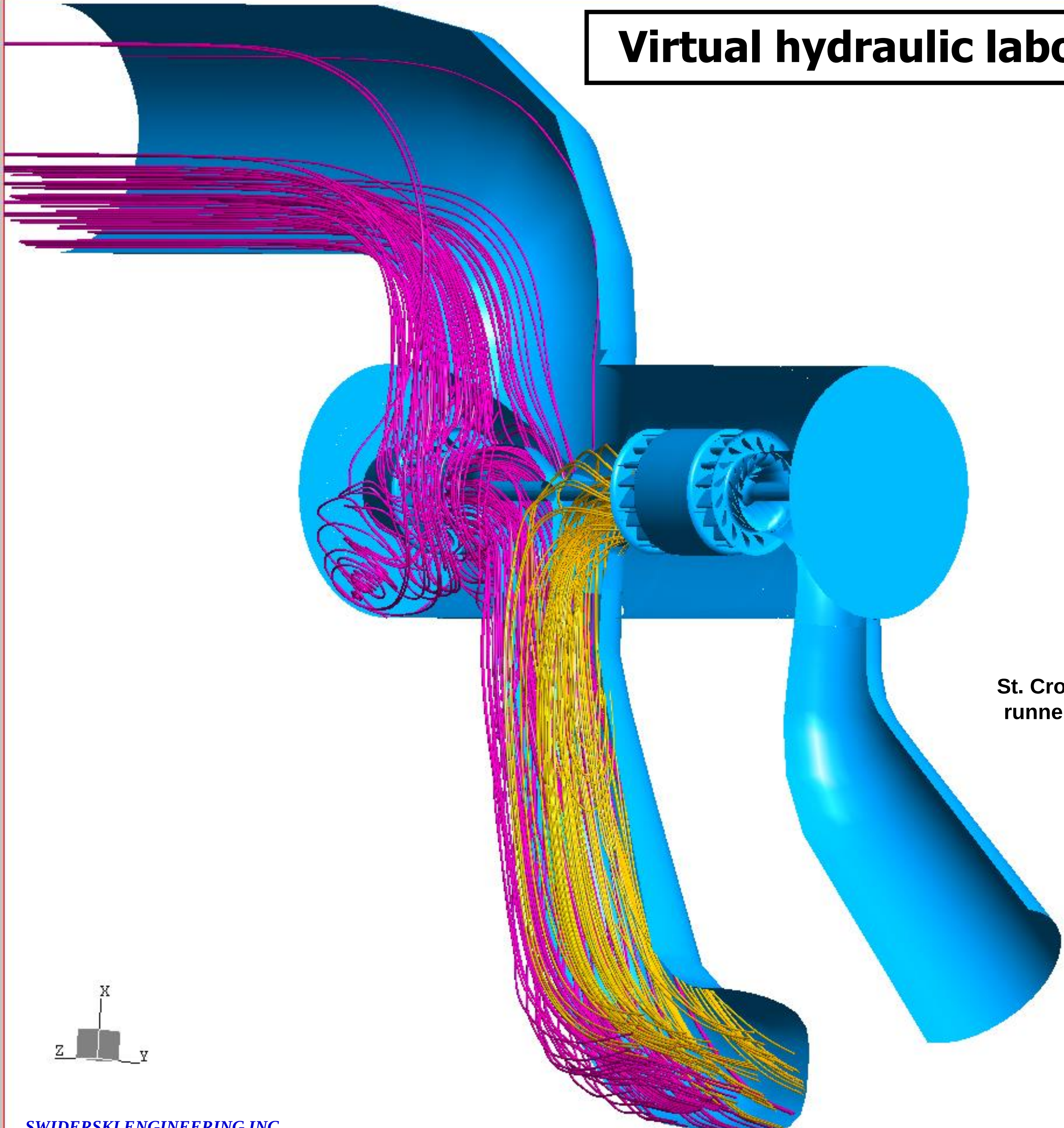
St. Croix Project – runners upgrade

Virtual hydraulic laboratory



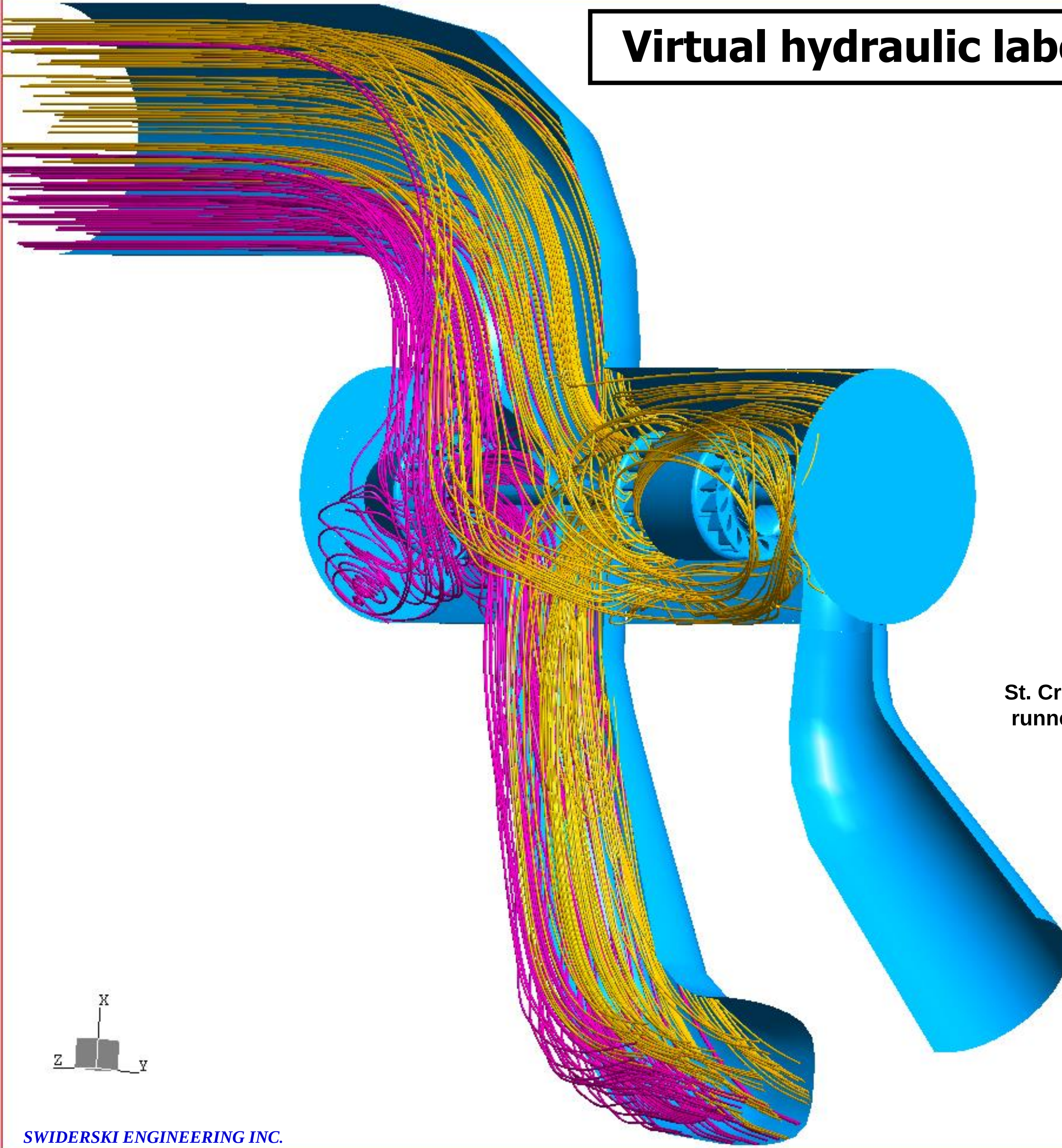
St. Croix Project – runners upgrade

Virtual hydraulic laboratory



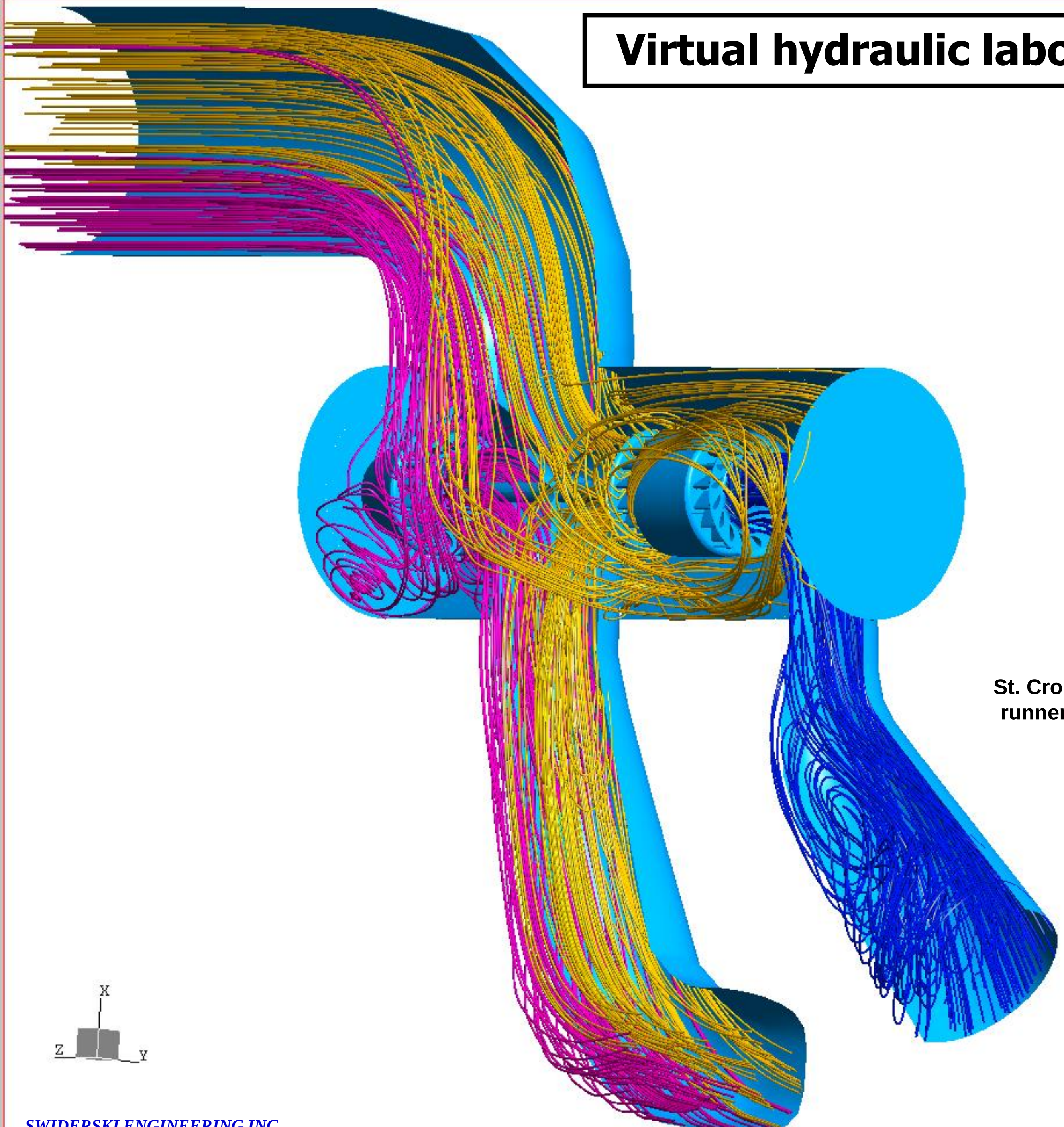
St. Croix Project –
runners upgrade

Virtual hydraulic laboratory



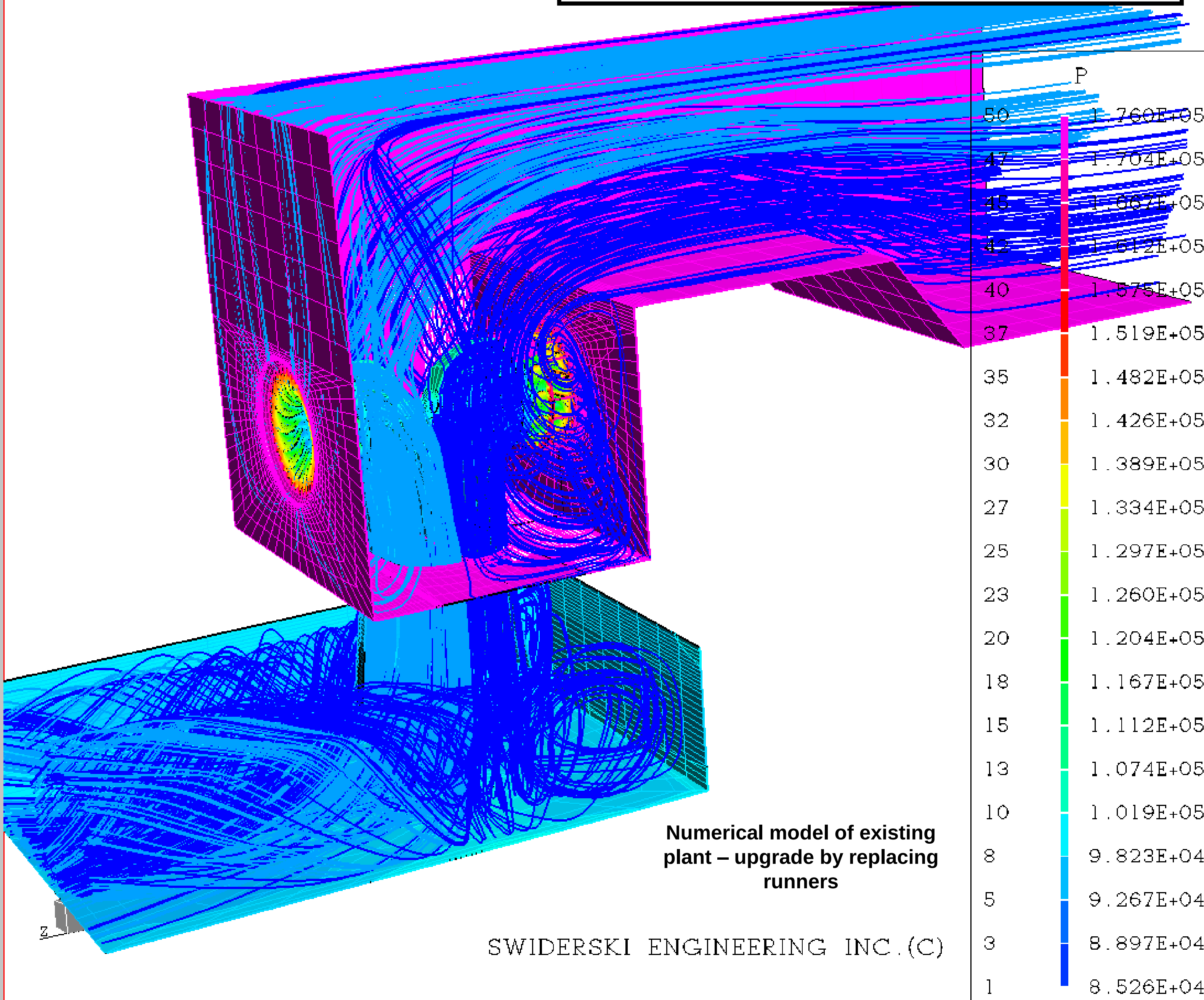
St. Croix Project –
runners upgrade

Virtual hydraulic laboratory

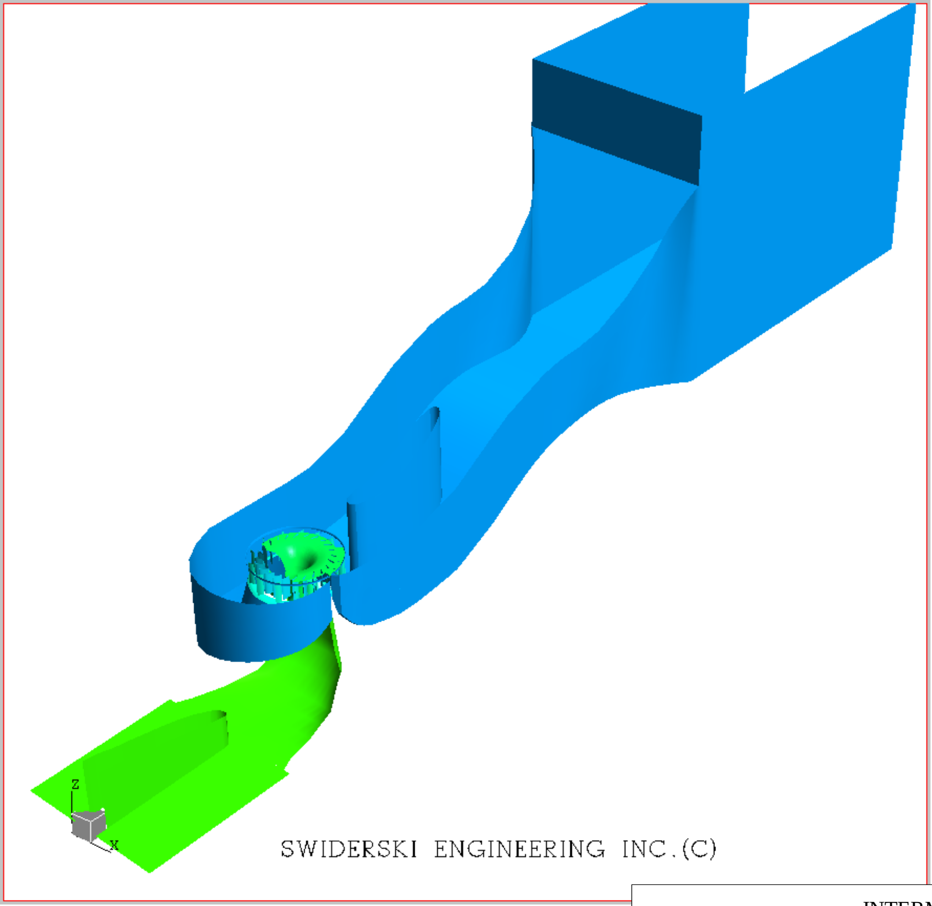


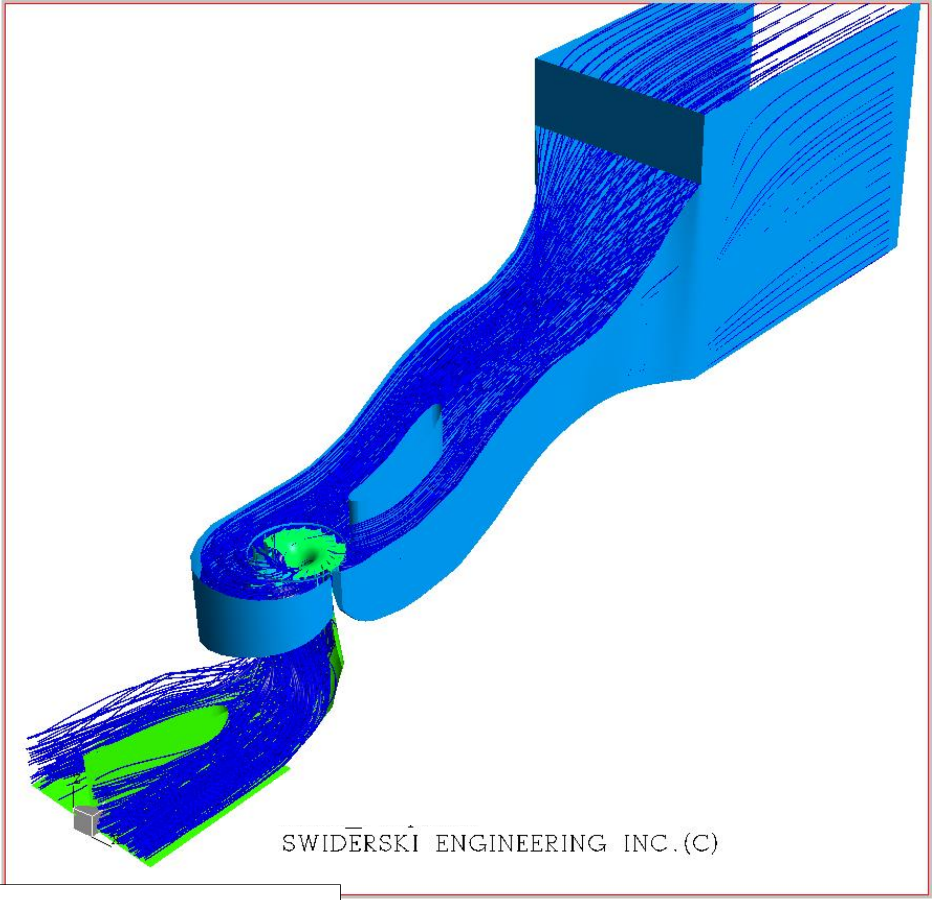
St. Croix Project – runners upgrade

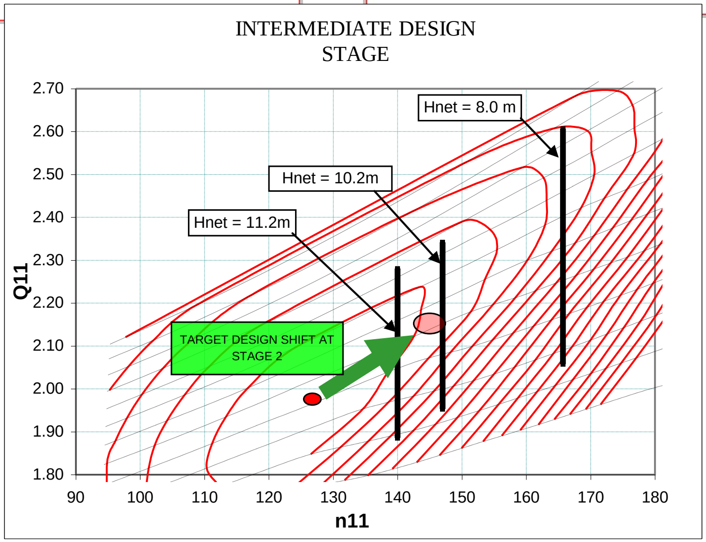
Virtual hydraulic laboratory



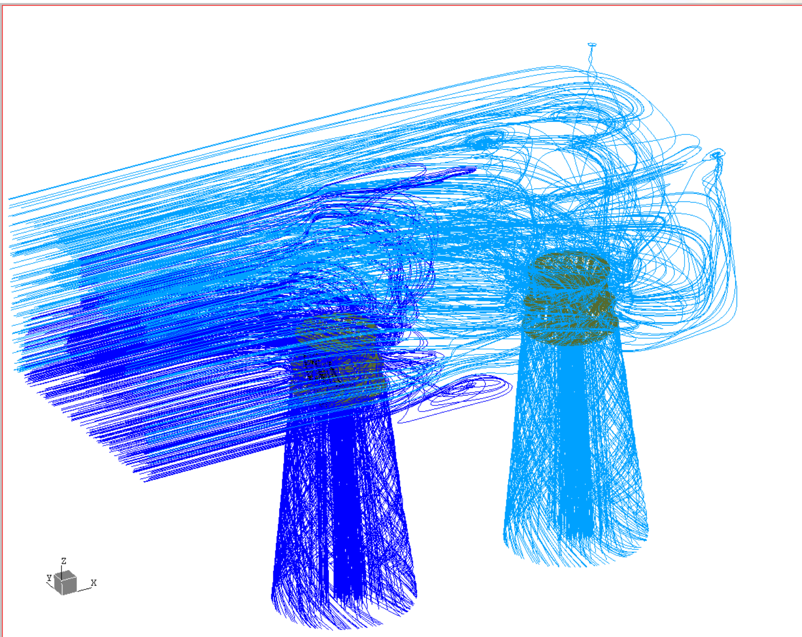
Numerical model of existing plant – upgrade by replacing runners

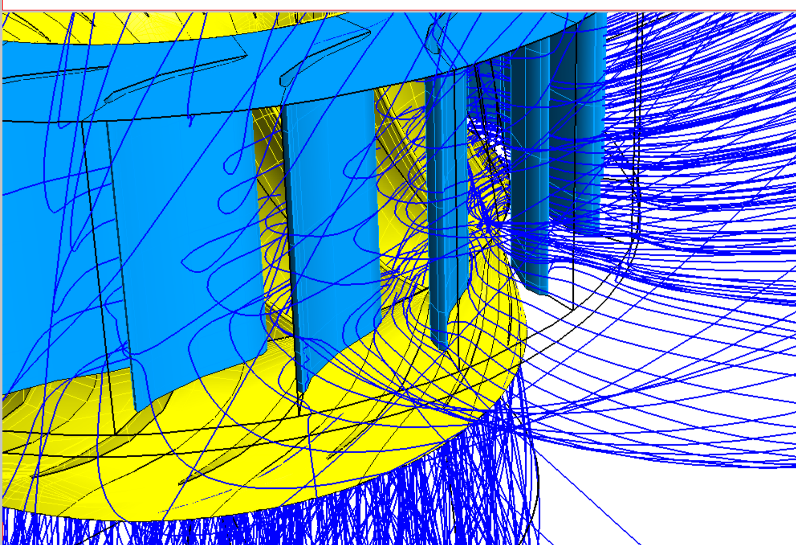

SWIDERSKI ENGINEERING INC.(C)


SWIDERSKI ENGINEERING INC.(C)


INTERMEDIATE DESIGN
STAGE
Hnet = 8.0 m
Hnet = 10.2m
Hnet = 11.2m
TARGET DESIGN SHIFT AT
STAGE 2
Q11
n11
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
1.80
90
100
110
120
130
140
150
160
170
180

Hydraulic diagnostics – sample 2



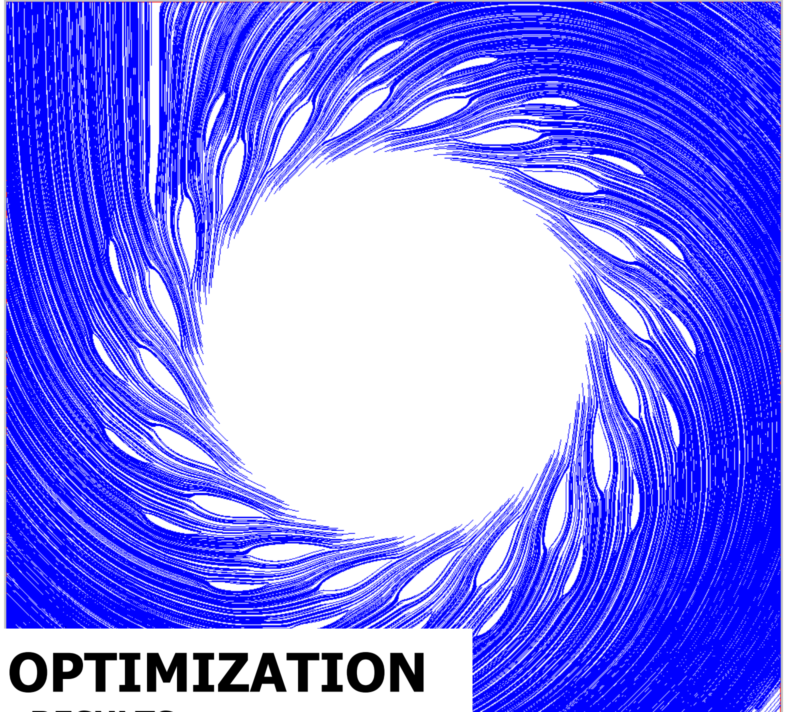


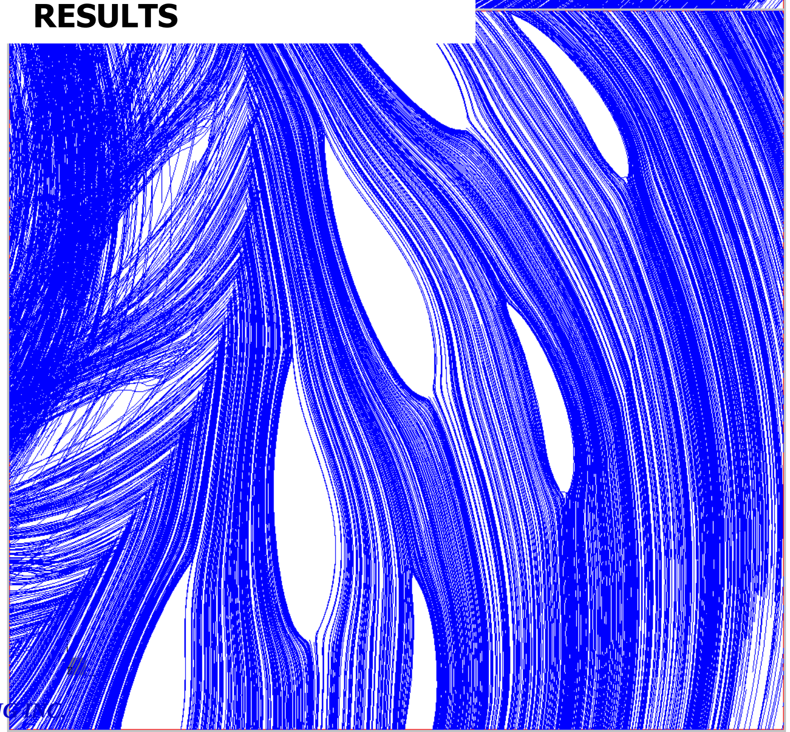
GLENN FERRIS PROJECT

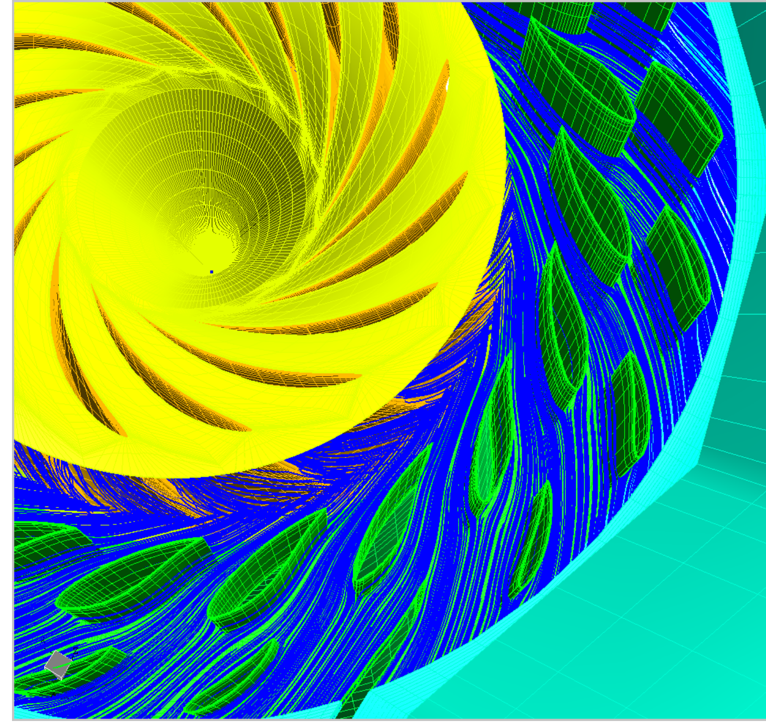
UNITS 1 - 6

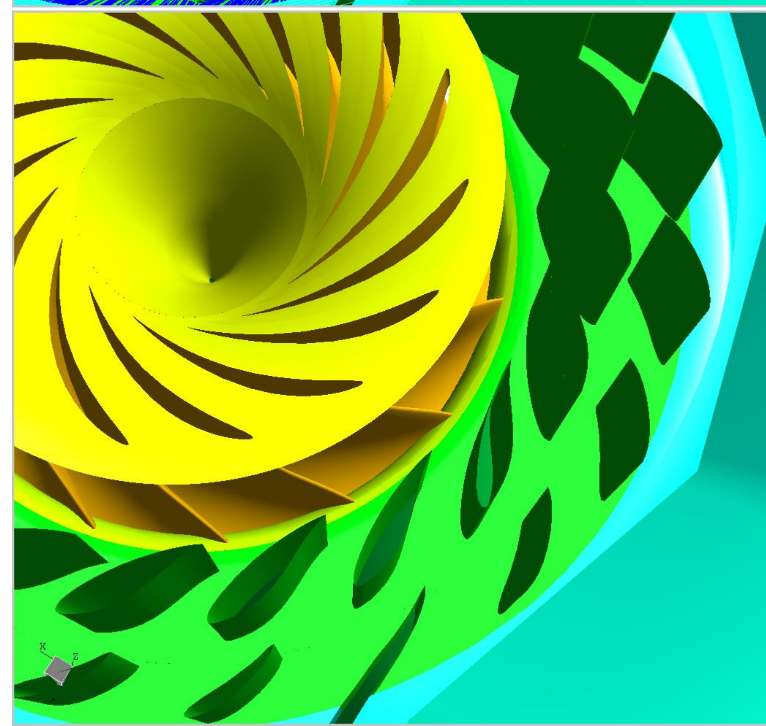
DESIGN OPTIMIZATION

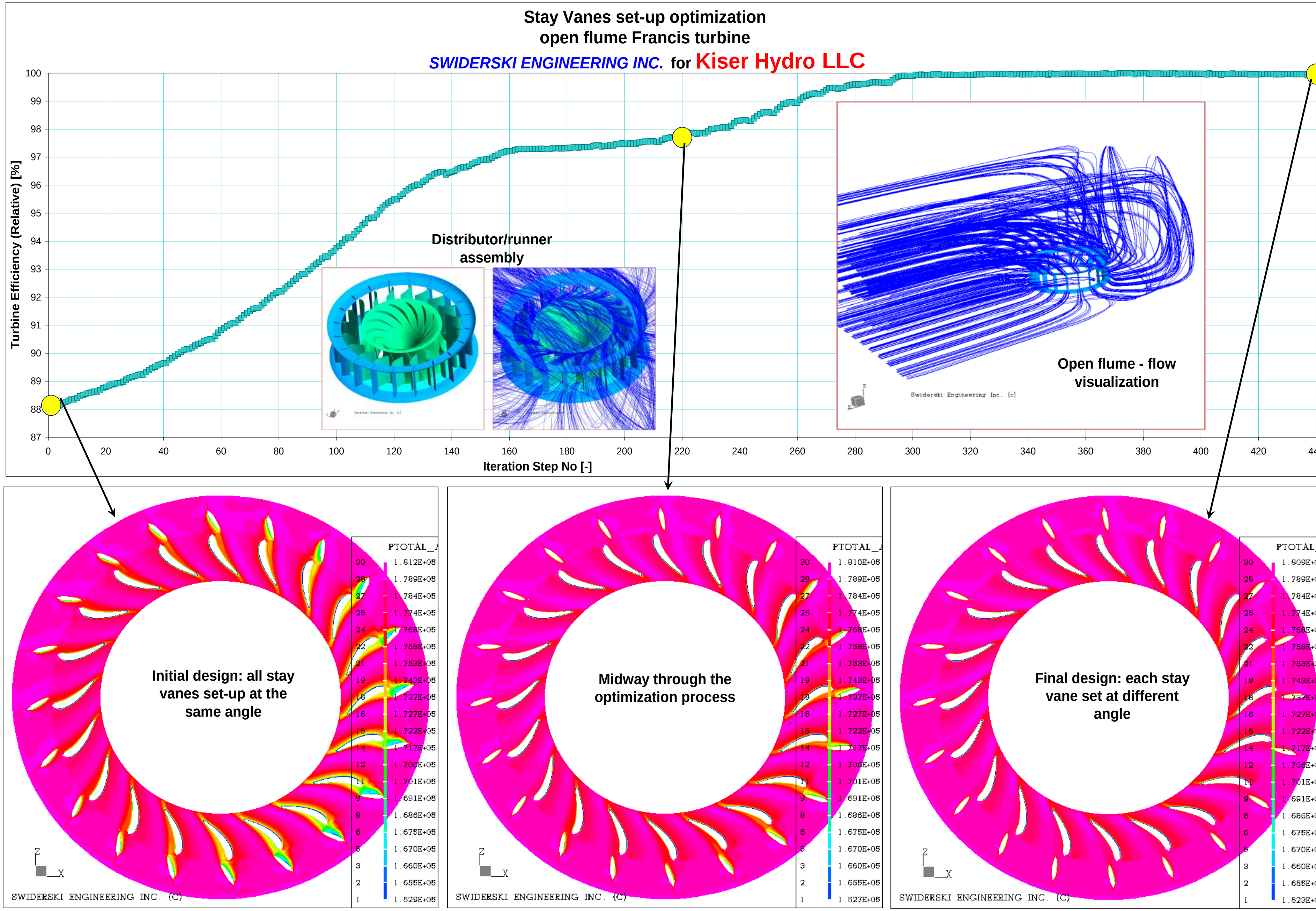
RESULTS







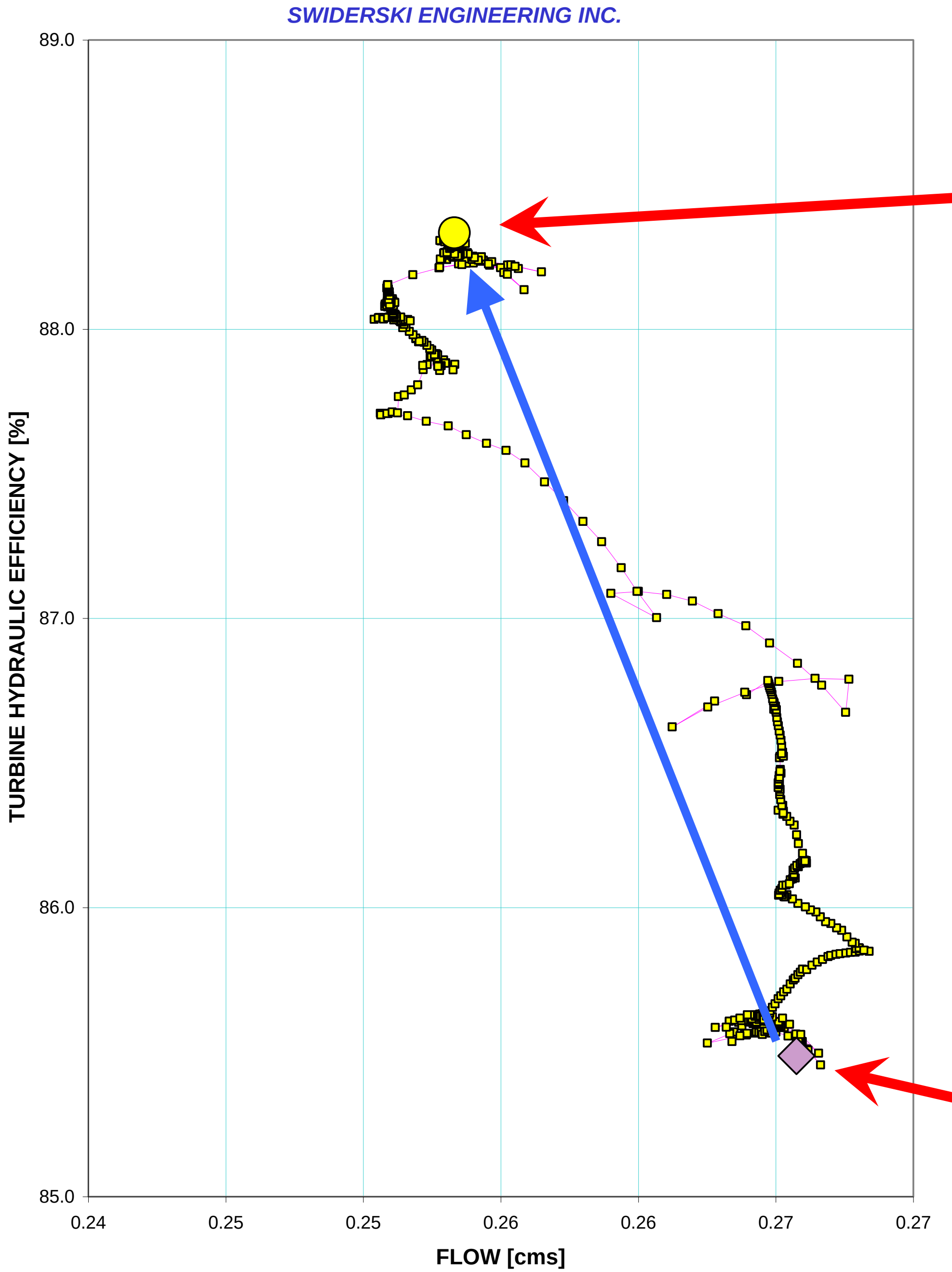



Stay Vanes set-up optimization
open flume Francis turbine
SWIDERSKI ENGINEERING INC. for Kiser Hydro LLC
Turbine Efficiency (Relative) [%]
Iteration Step No [-]
Distributor/runner assembly
Open flume - flow visualization
Initial design: all stay vanes set-up at the same angle
Midway through the optimization process
Final design: each stay vane set at different angle
PTOTAL
SWIDERSKI ENGINEERING INC. (C)
SWIDERSKI ENGINEERING INC. (C)
SWIDERSKI ENGINEERING INC. (C)

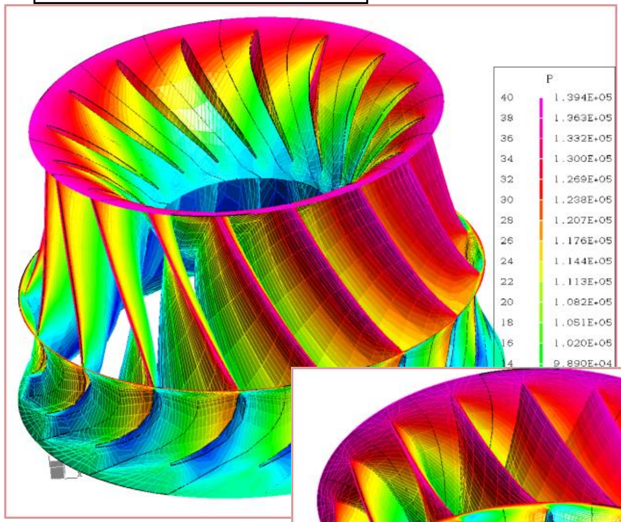
SOLUTION-DEPENDENT STAGE

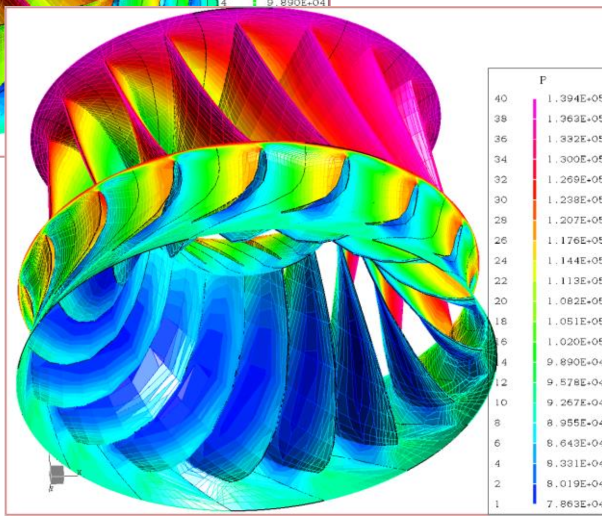
DESIGN OPTIMIZATION

HISTORY OF THE PROCESS



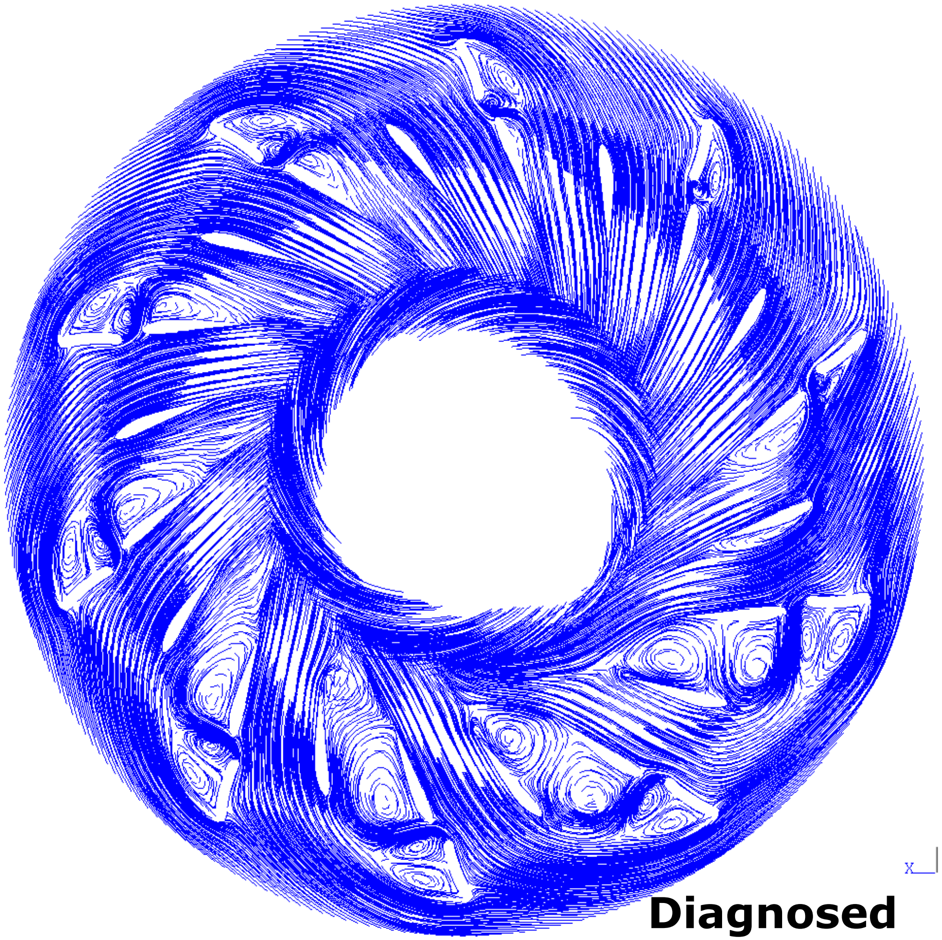
DESIGN TARGET



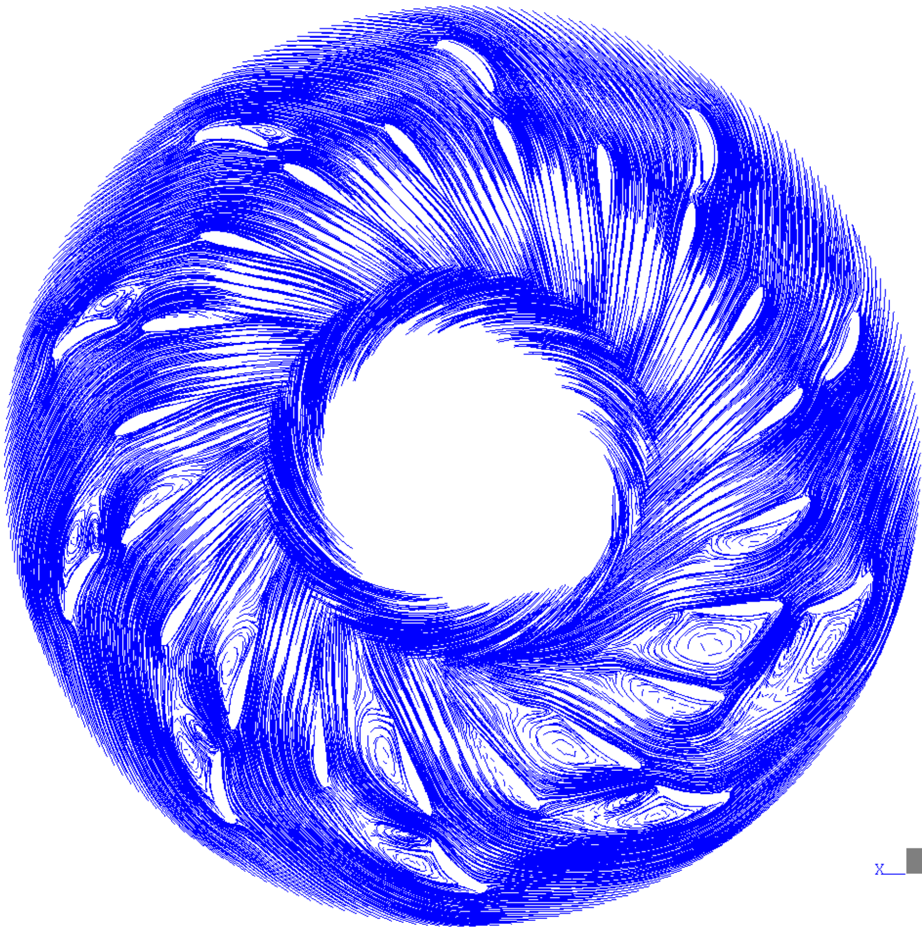


START – INITIAL GUESS

Hydraulic diagnostics – sample 3



Diagnosed



Modernized

Modification of the stay vanes resulted in approx. 8% increase in energy production

Modernization of water turbine flow passages

by

Jacek Swiderski, P. Eng.
Swiderski Engineering Inc.
Ottawa, Canada

THANK YOU