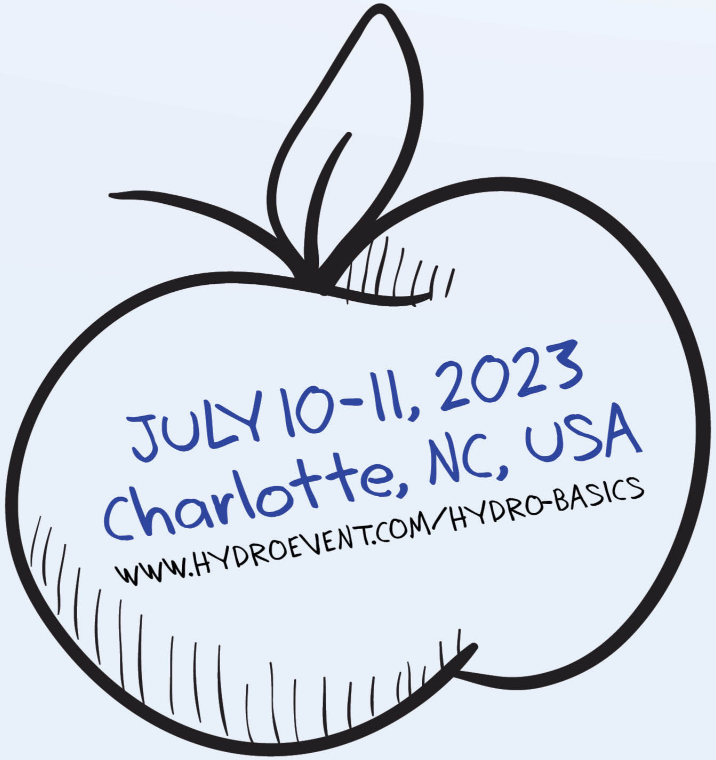
Waterpower®

HYDRO BASICS COURSE



Co-located with: HYDROVISION INTERNATIONAL

Organized By: HYDRO TRAINING INSTITUTE

Turbine Basics

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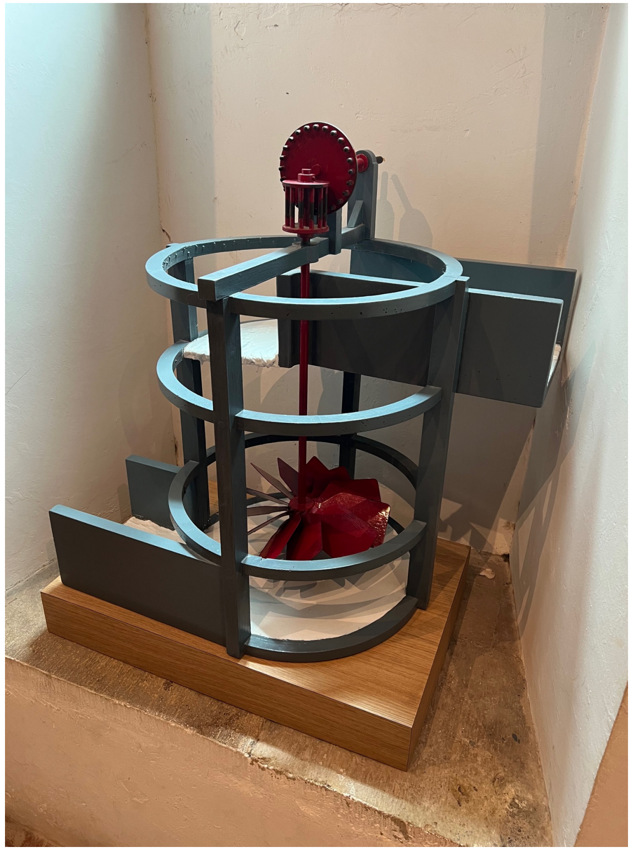
POP QUIZ

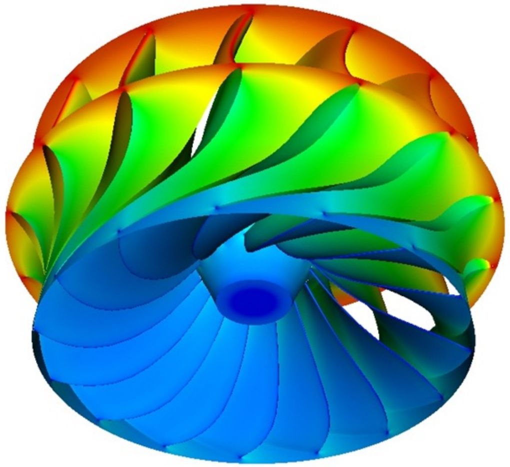


Circa 1505

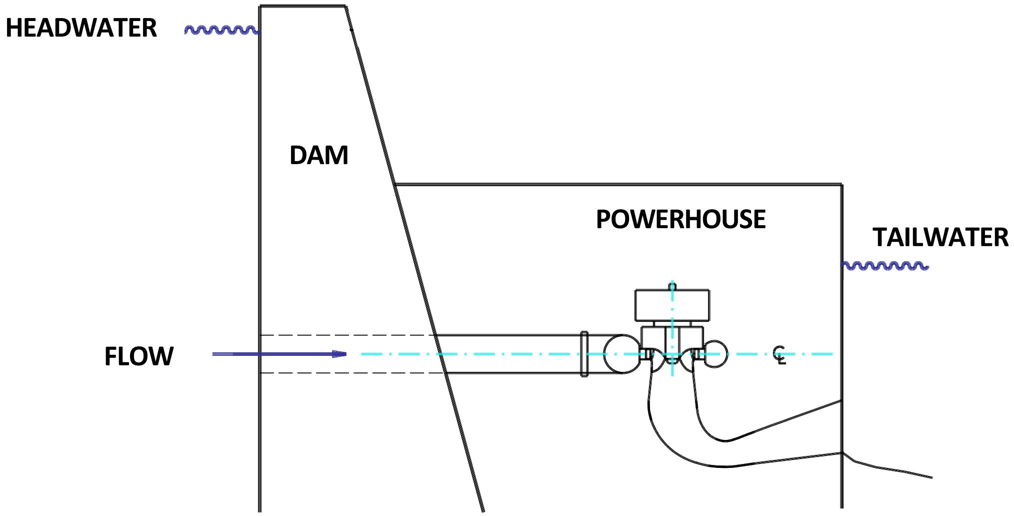
Leonardo da Vinci

Hydroturbine Equipment Overview

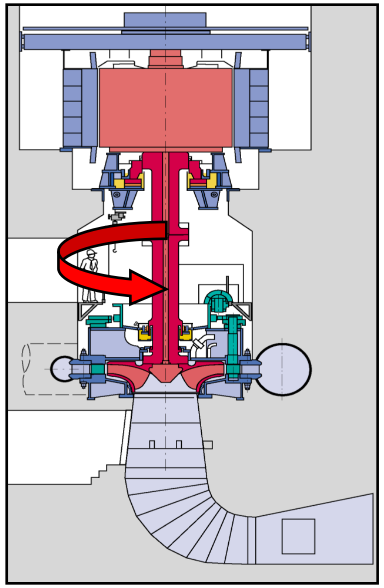
- General Overview
- Basic Types of Turbines
- Various Turbine Examples
- Cavitation and Vortices
- Performance Curves
- What's New?
  - Analysis Techniques
  - Fish Friendly Turbines
  - Low Head Options
  - Turbine Aeration



Slice Through the Powerhouse

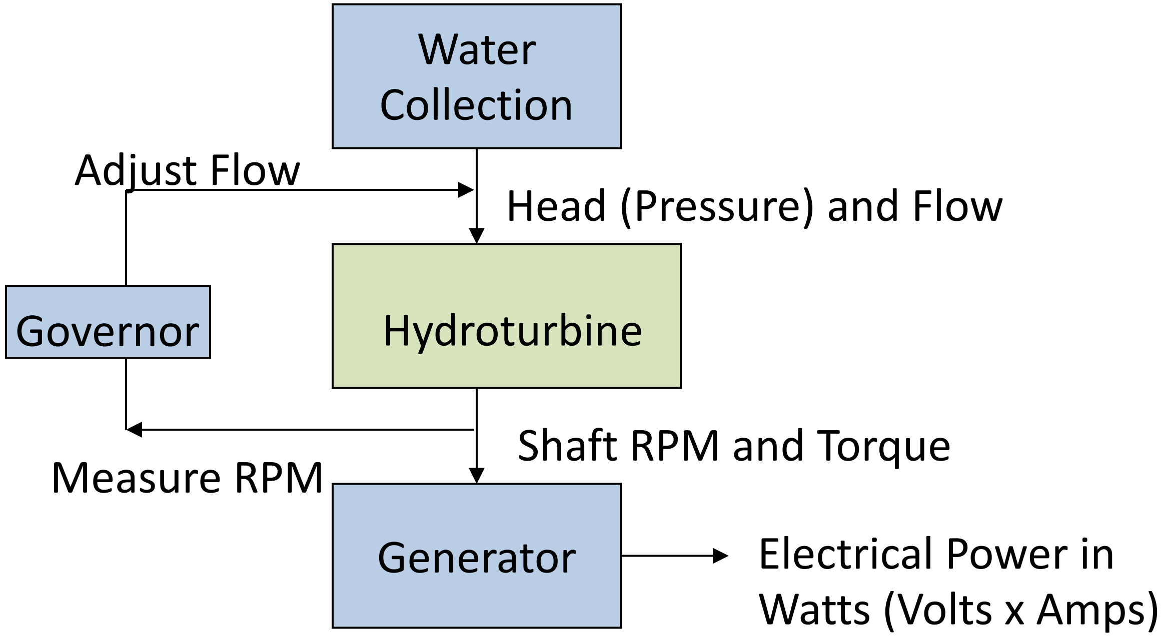


What does a Hydroturbine do?



- It converts the kinetic and potential energy of the water (flow and head) into the mechanical energy of a rotating shaft (speed and torque/power).
- The primary part of the turbine that rotates in contact with the water is called a “runner”.
- The single most important factor in turbine hydraulic design is “available head”.

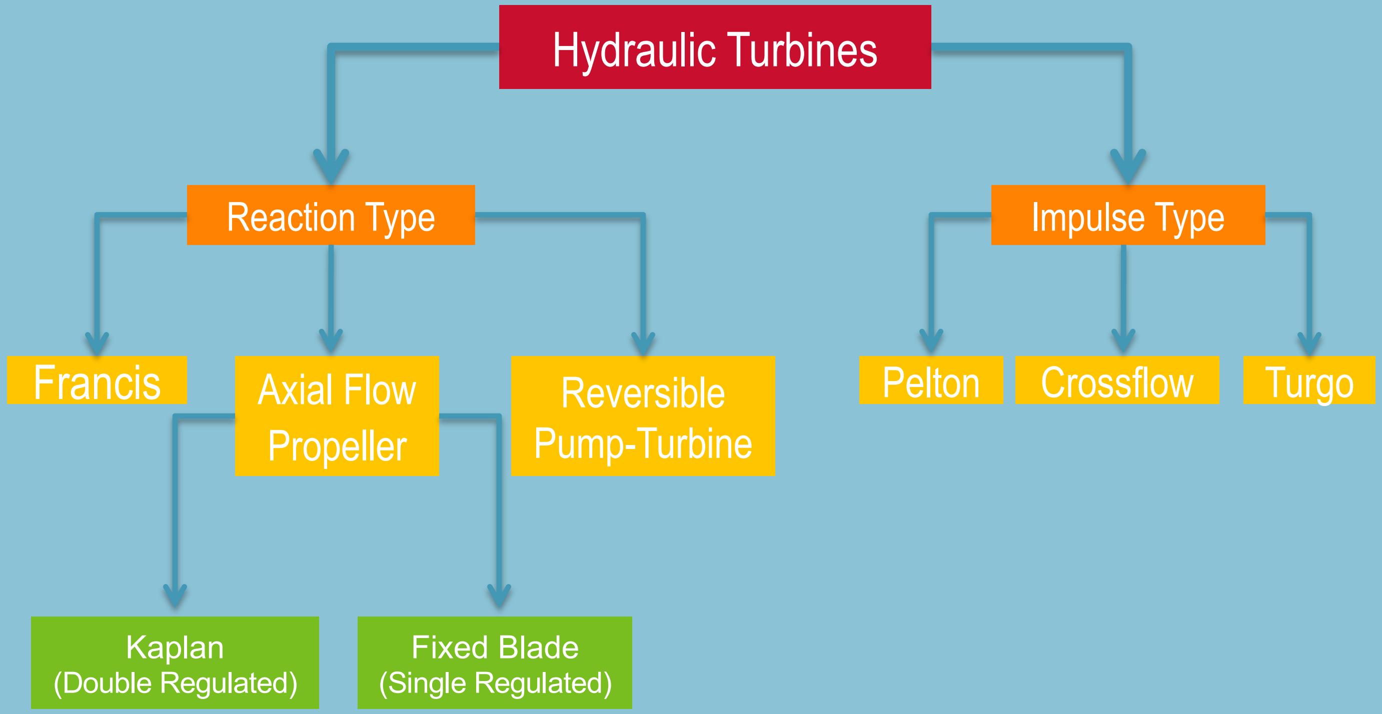
Where a Hydroturbine Fits



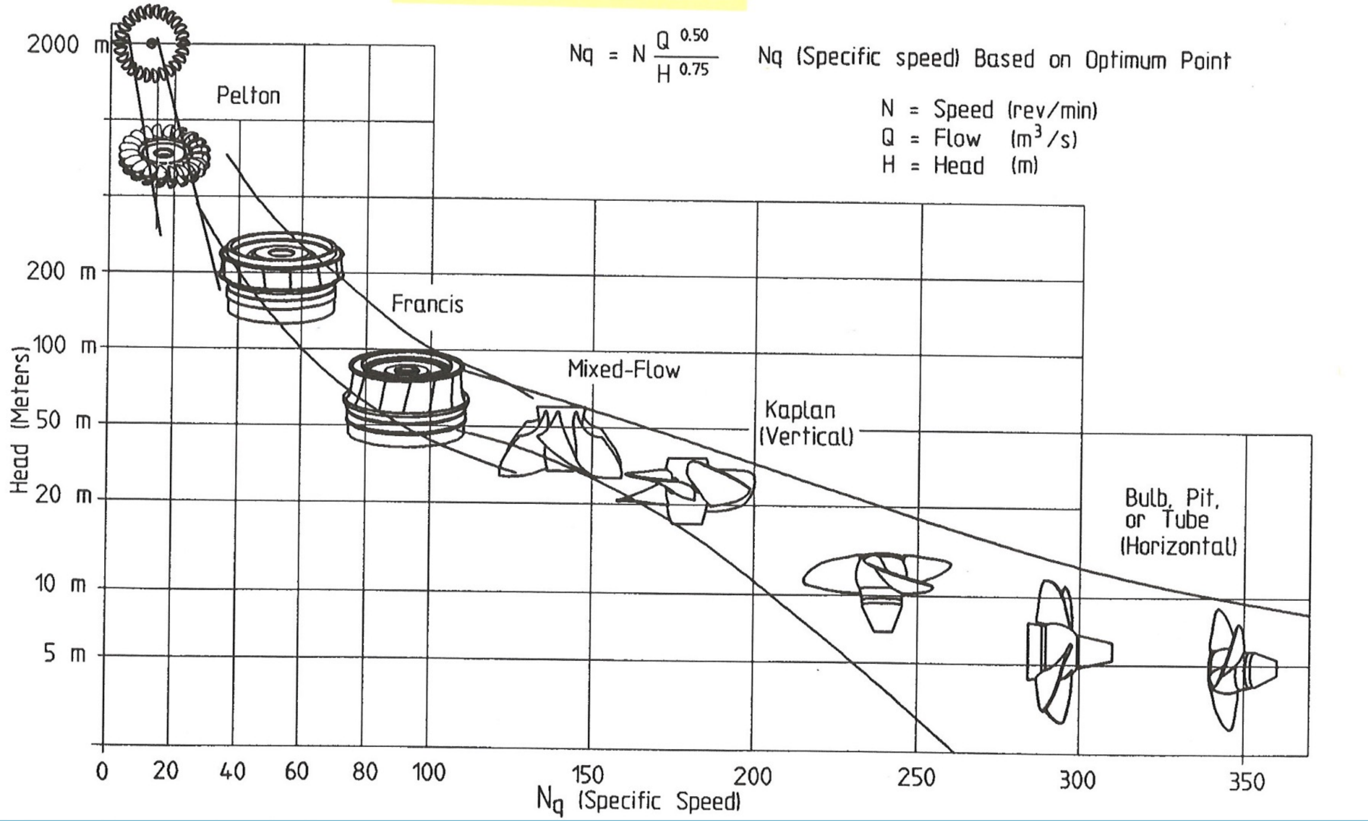
Two Basic Types of Turbines

- Impulse turbines (Pelton)
- Reaction turbines (Francis, Propeller, or Kaplan)

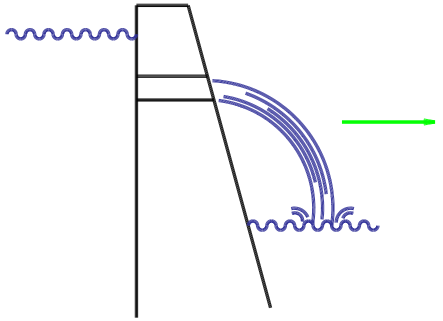
Hydraulic Turbine Family Tree



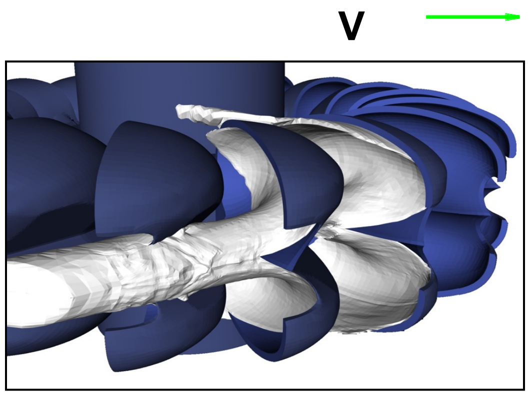
Turbine Selection

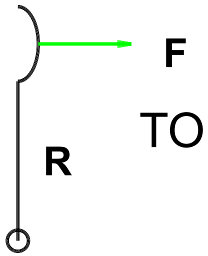


The Principle of the Impulse Turbine



$V = (2gH)^{.5}$

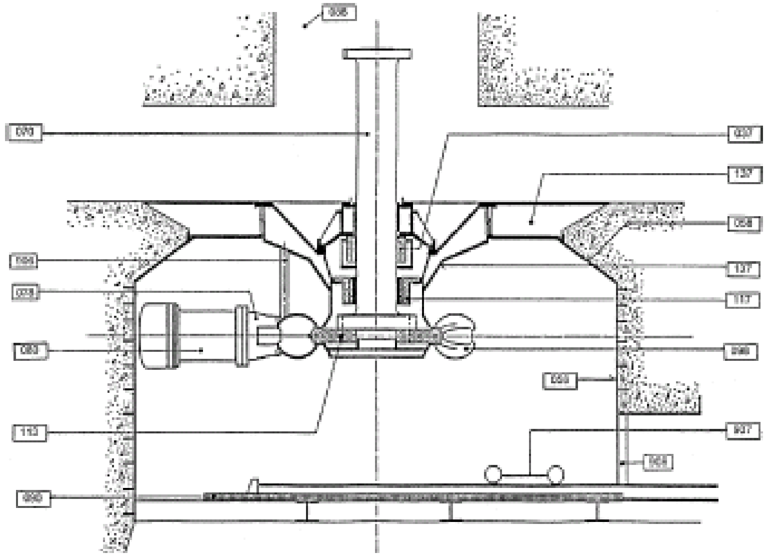


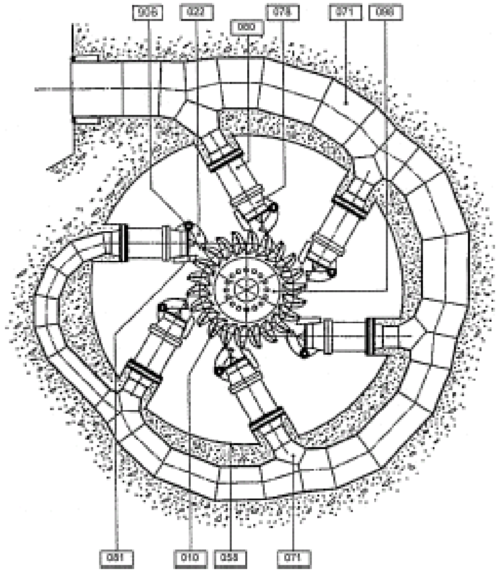


$$\text{TORQUE} = F * R$$
$$= pQVR$$

Devil Canyon Impulse Turbine Wheels

Impulse (Pelton) Turbine Nomenclature



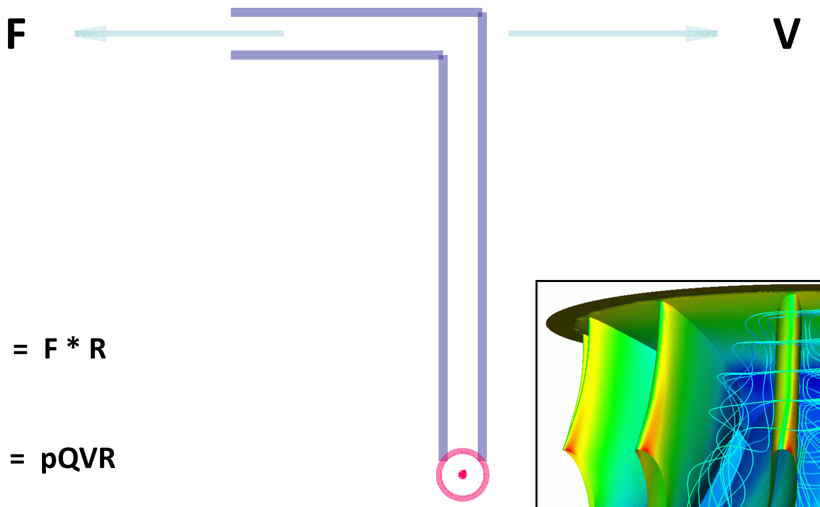


- 070 Main Shaft
- 906 Deflector Shaft
- 078 Nozzle
- 080 Nozzle Pipe
- 113 Runner Disk
- 090 Inspection Platform
- 088 Pit
- 037 Guide Bearing

- 137 Turbine Cover
- 058 Turbine Housing
- 117 Shaft Seal
- 098 Runner
- 907 Runner Cart
- 908 Runner Door
- 906 Deflector Shaft
- 022 Deflector

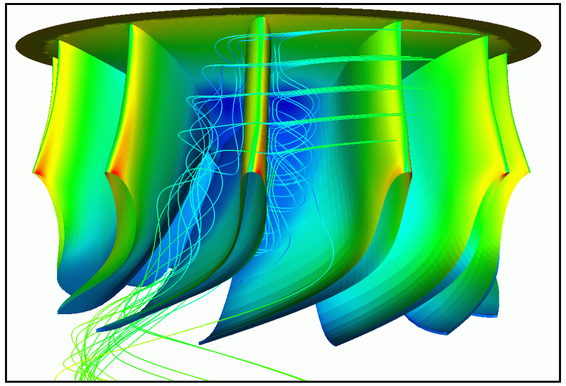
- 080 Nozzle Pipe
- 078 Nozzle
- 071 Manifold (Spiral Case)
- 098 Runner
- 081 Nozzle Sheild
- 010 Bucket
- 058 Turbine Housing

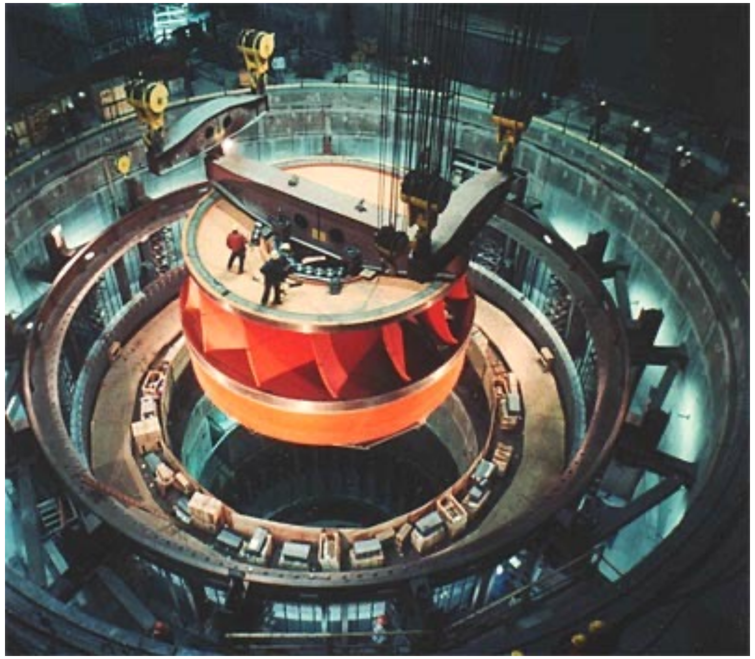
The Principle of the Reaction Turbine



TORQUE = F * R

= pQVR





<u>Reaction Turbine</u>

Grand Coulee Francis
Turbine Runner

US Bureau of
Reclamation

Reaction Turbine

Propeller Runner

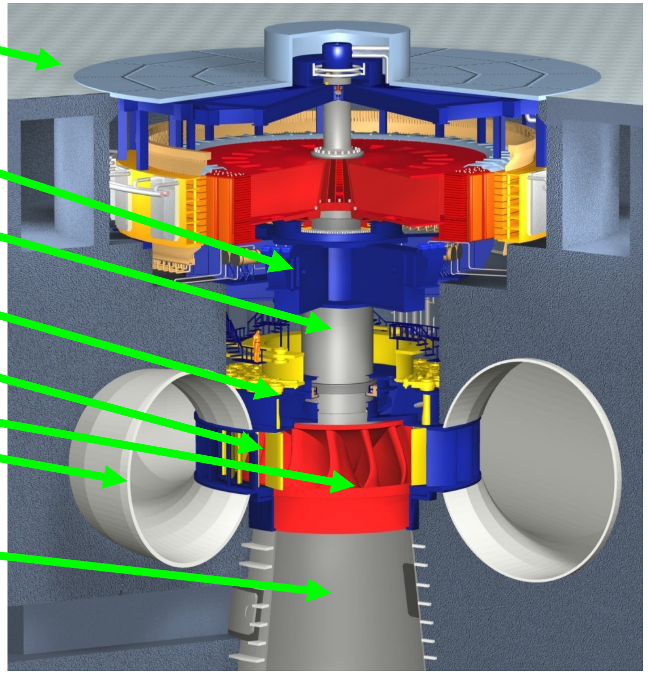
<u>Reaction Turbine</u>

Kaplan Runner

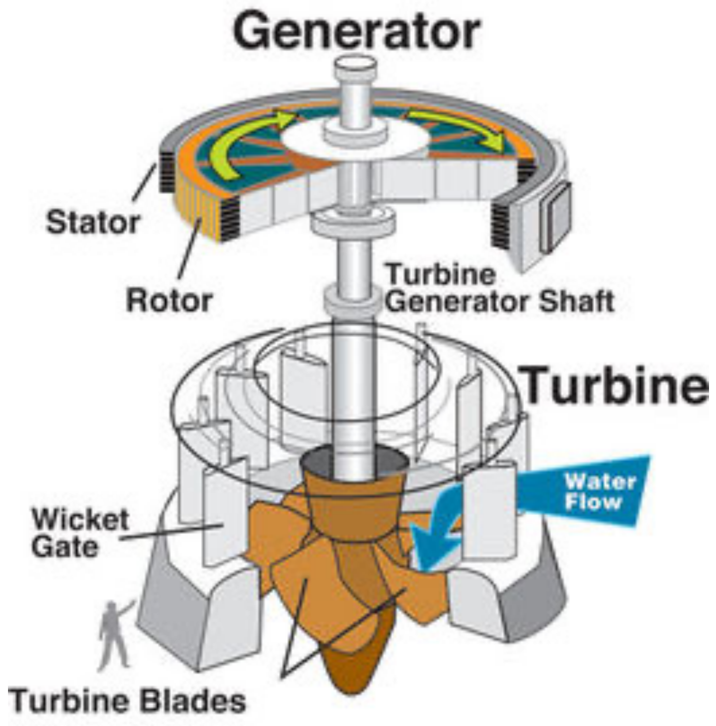
Murray Lock and Dam

Typical Vertical Turbine Arrangement

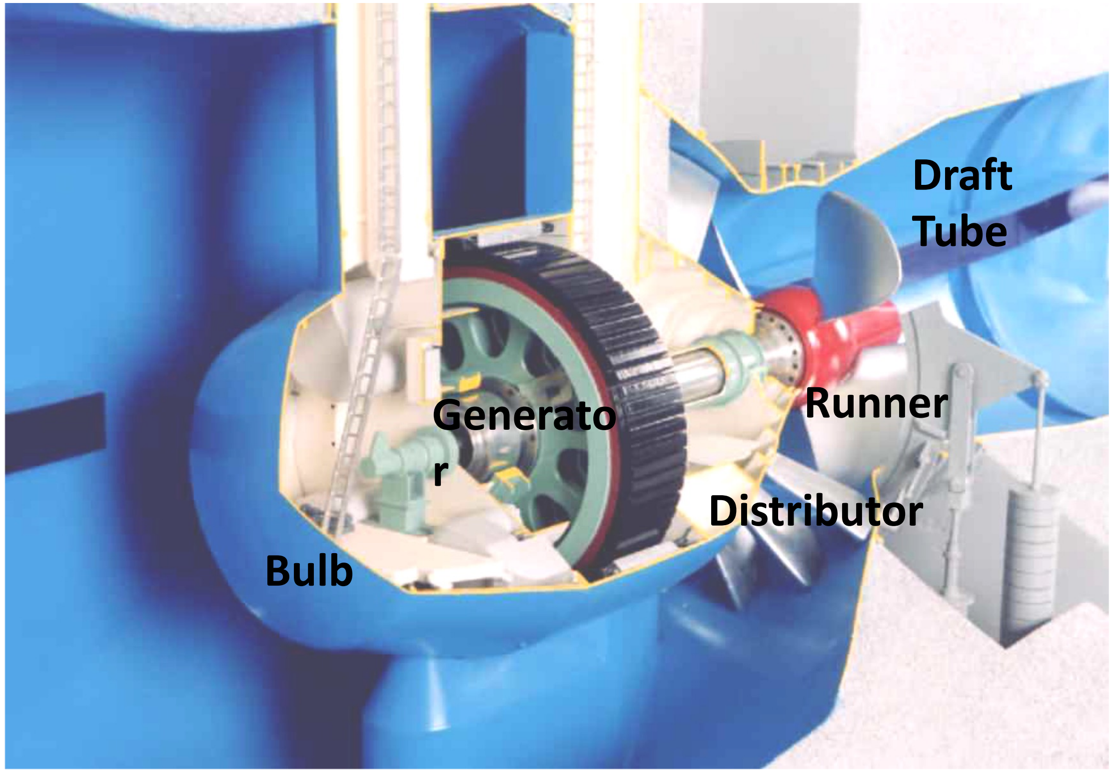
- Generator
- Thrust Bridge
- Main Shaft
- Distributor
  - Wicket Gates
- Runner
- Spiral Case and Stay Vanes
- Draft Tube



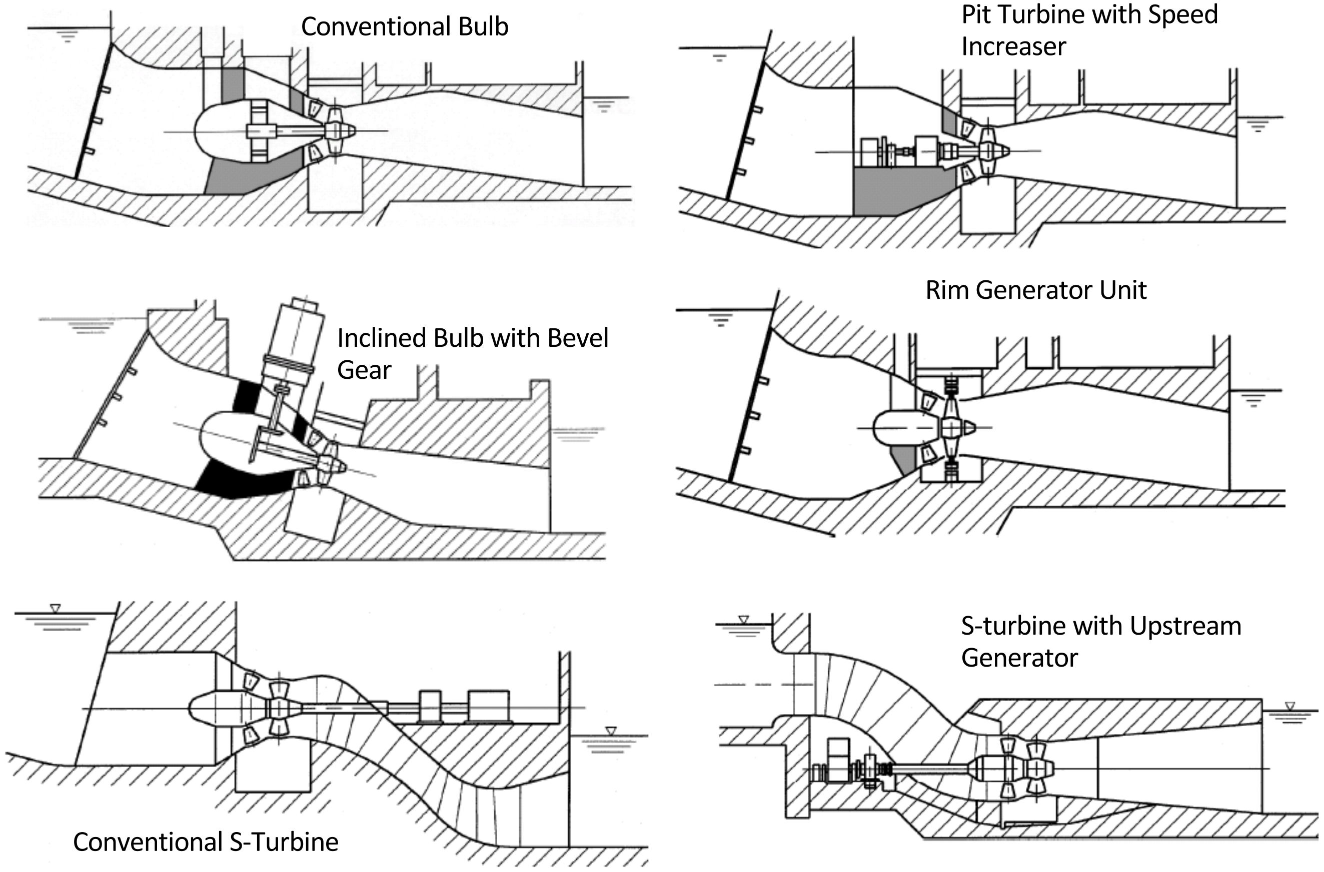
Typical Vertical Kaplan Arrangement



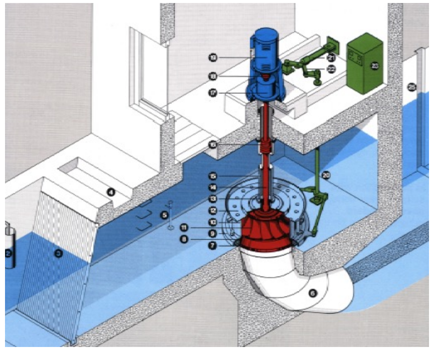
Typical Horizontal Bulb Turbine Arrangement



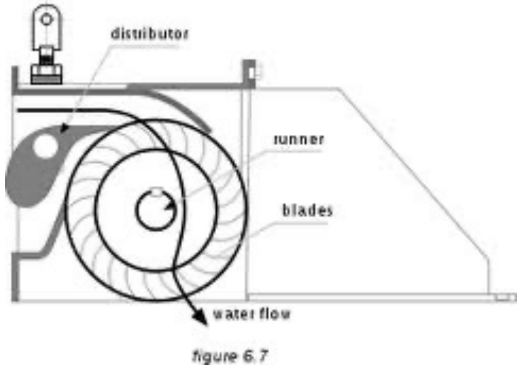
Types of Tube Units



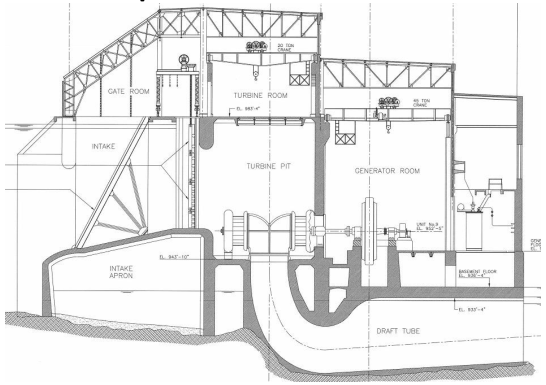
Alternative Turbine Arrangements



Open Flume Francis



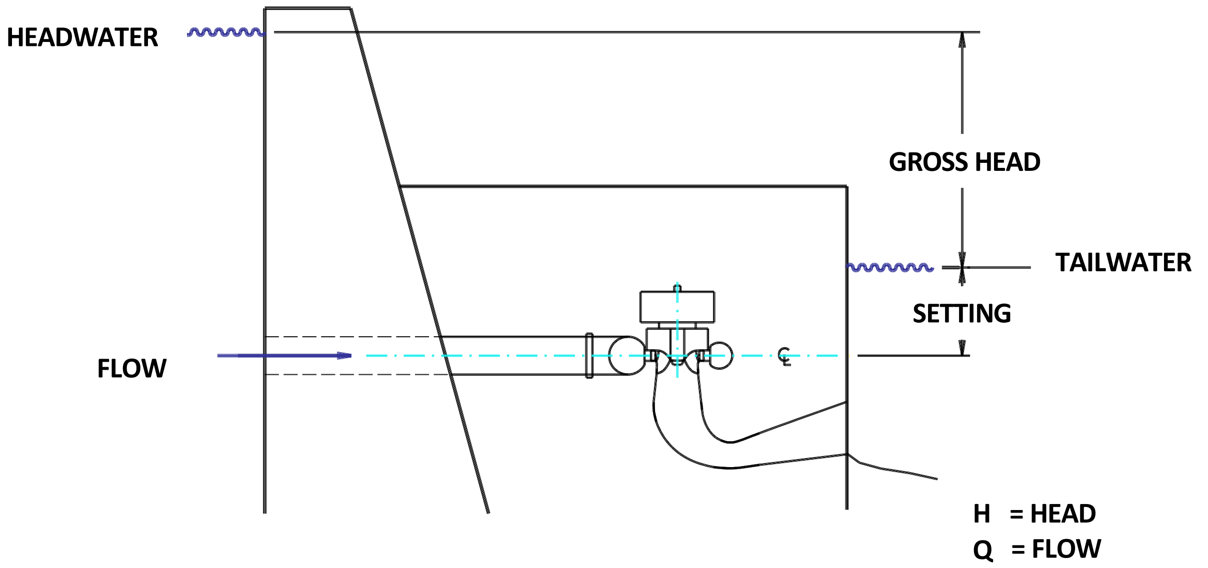
Cross-flow Turbine



Camelback Duplex Turbine

Seagull Turbine

Terms



Rotating Speed Terms

- **Synchronous Speed** – Normal operating rpm of the unit. The generator **is** synchronized to the electrical grid.
- **Asynchronous Speed** – The generator **is not** synchronized to the electrical grid. Normal operating rpm of the unit can vary.
- **Runaway Speed** – Highest possible **steady state** rotating speed; when the generator disconnects from the grid and the turbine fails to shut down. Usually at highest gross head and maximum wicket gate opening. Point of zero net torque.
- **Overspeed** – A speed greater than synchronous speed; likely due to an unexpected disconnection from the grid (load rejection). The turbine begins to shut down when this occurs. Peak speed may only be momentary, but **can be greater than runaway due to transient pressure rise**.

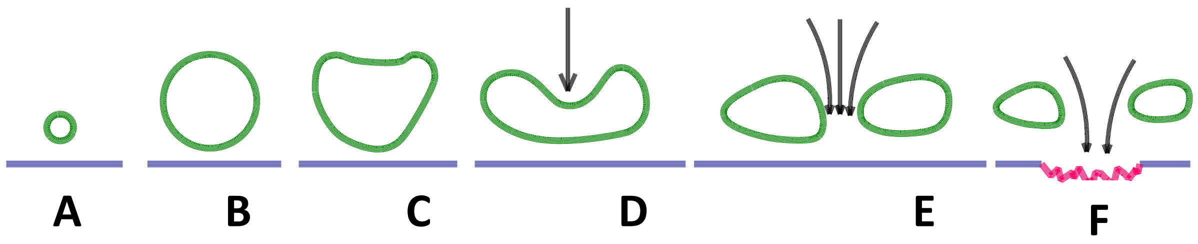
Cavitation

= Where a liquid has a brief change of state to gas due to a momentary drop in pressure.

COLLAPSE OF AN INDIVIDUAL BUBBLE

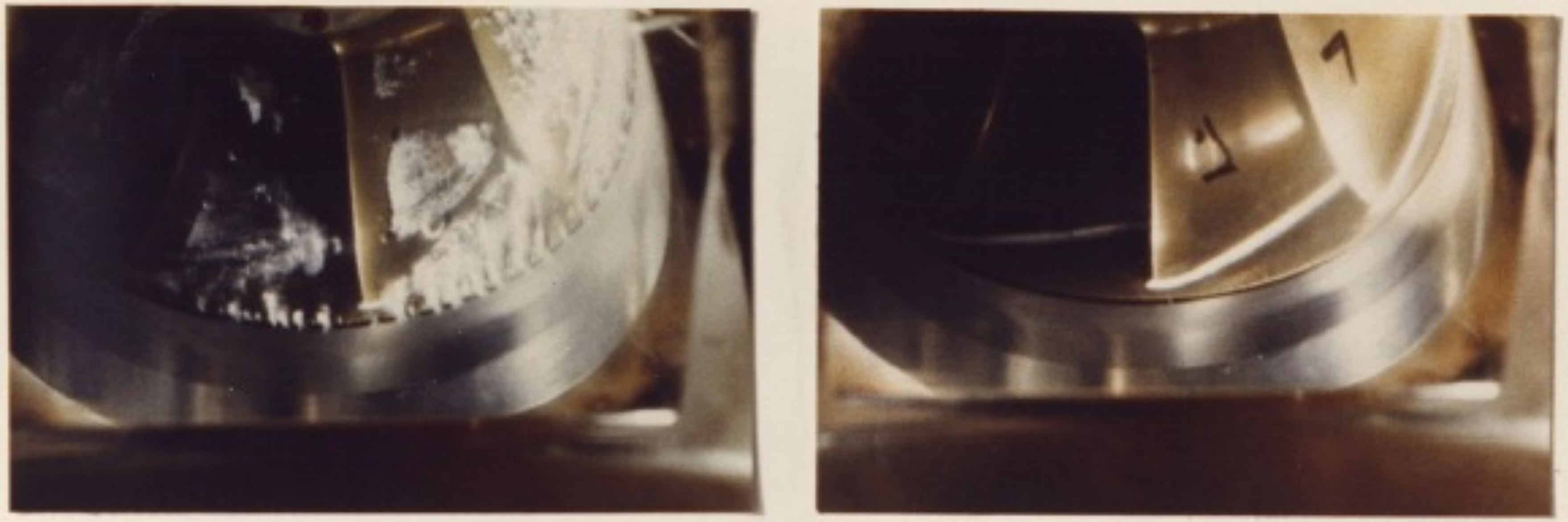
SUBSEQUENT JET FORMATION IN CHARACTERISTIC STAGES

BUBBLE COLLAPSE CLOSE TO WALL
FLOW ⟶ DIRECTION



A. Beginning of bubble formation
B. Moves to lower pressure and grows
C. Moves to higher pressure and begins depression on side opposite to wall
D. Entrance of liquid into the growing depression
E. Jet formation
F. Pitting

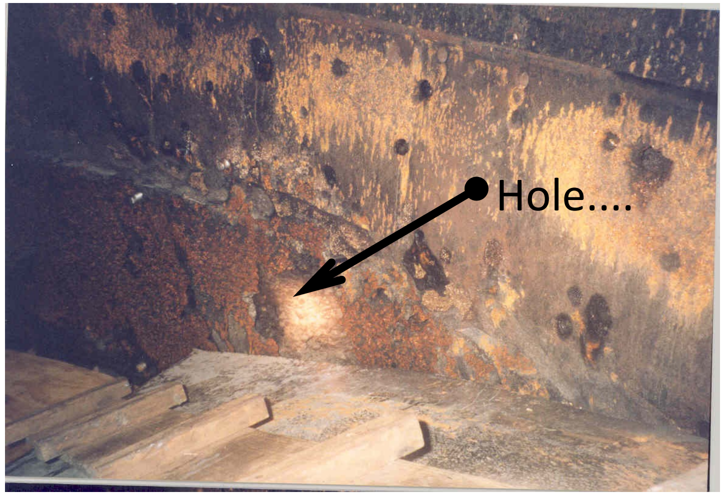
Turbine Characteristics: Cavitation



$Q_{1200}=.231$ G.O.$=22$MM $\sigma=.061$

$Q_{1200}=.307$ G.O.$=28$MM $\sigma_p=.176$

Cavitation Damage – Not Good!

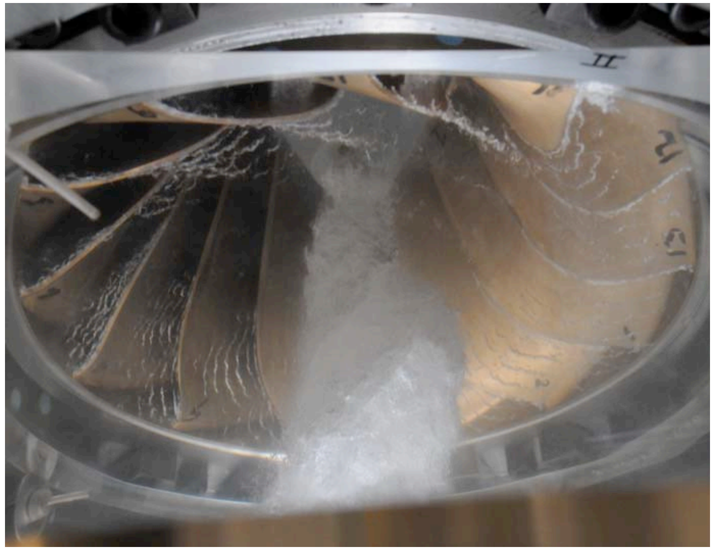


What can you do about Cavitation Damage?

- Weld repair to “as new” condition...$$$...expensive and won’t last
- Fix it with really good materials...$$$...still won’t last
- Lower the runner relative to tailwater...not practical
- Run at reduced output...$$$...may not help much
- Re-contour hydraulic shape in place…$$$...expensive but may be necessary
- Re-runner with a new hydraulic design...$$$...may be the most economical long-term solution

There is no simple solution for solving a cavitation problem.

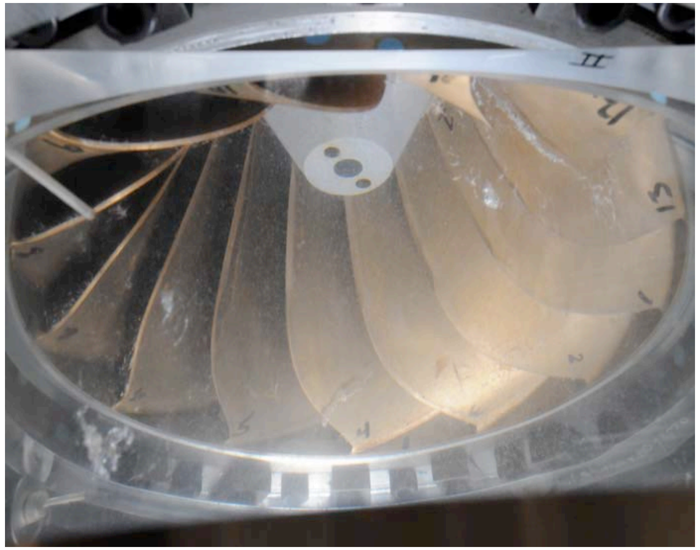
Vortices



Torch
(occurs past Peak Efficiency flow)

Cork-Screw

(occurs at Part Load)



Channel
(occurs at Low Flow)

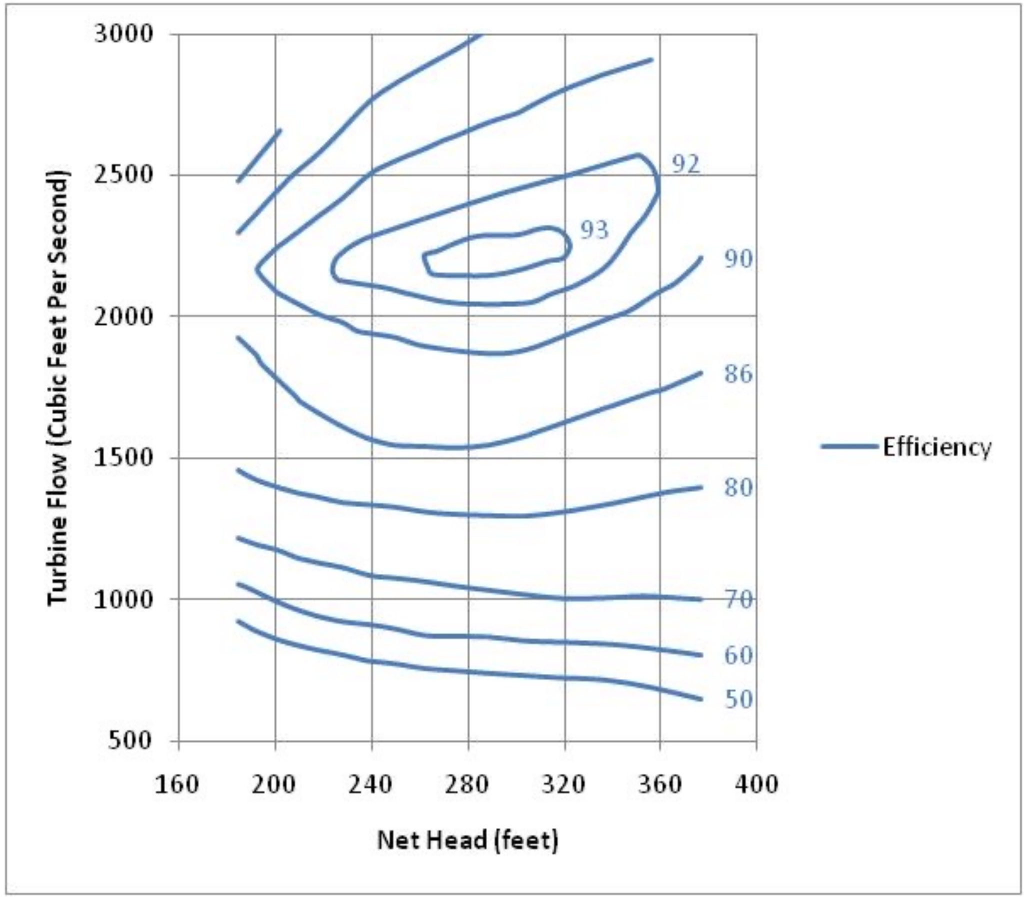
Power and Efficiency

$$P = \rho g Q H \eta$$

$$\eta = \frac{P}{\rho g Q H}$$

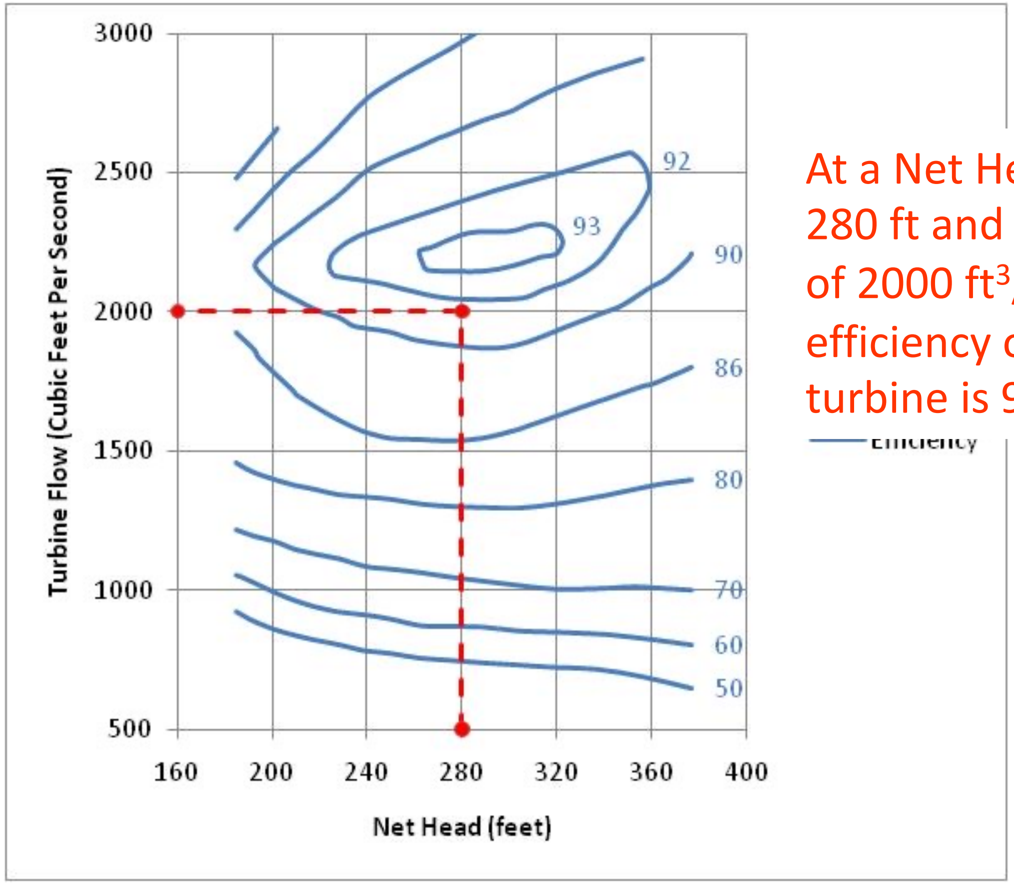
- P = Power or Turbine Output (MW)
- ρ = Density of Water (kg/m^3)
- g = Gravity (m/s^2)
- Q = Flow (cms)
- H = Net Head (m)
- η = Turbine Efficiency

The Turbine Hill Curve



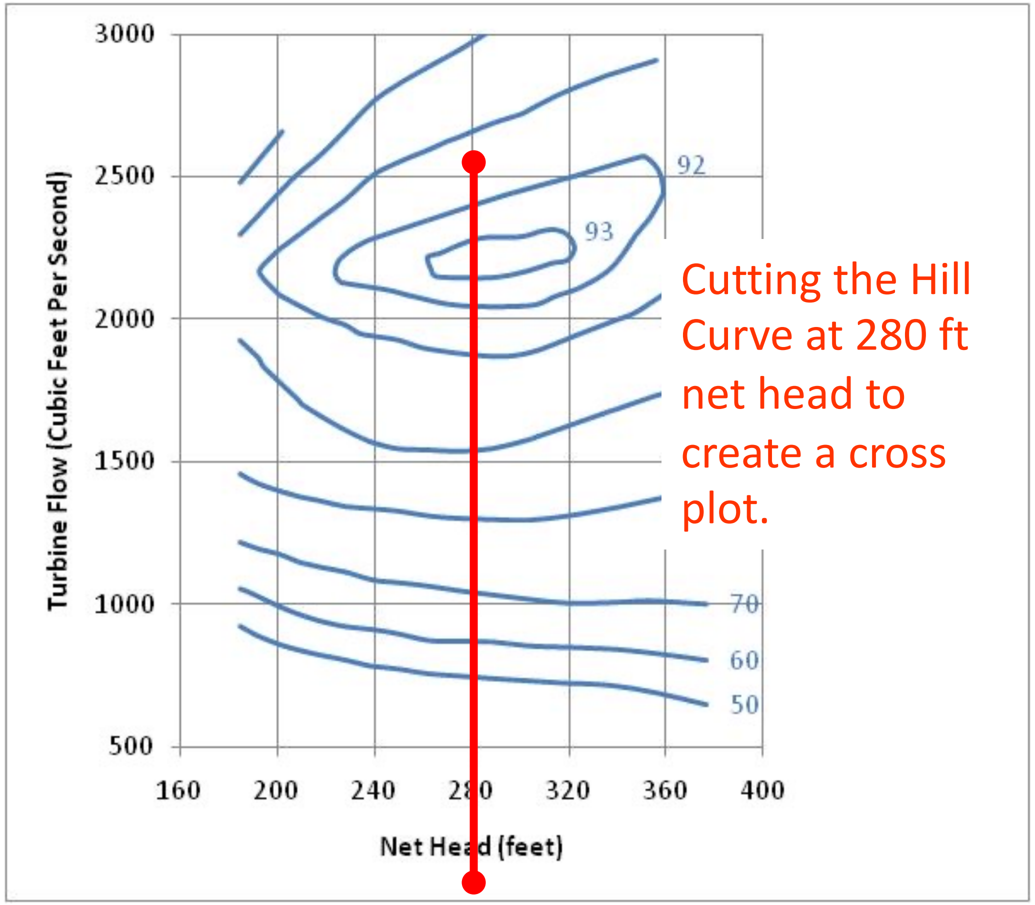
What if there was a Z-axis?

Reading a Turbine Hill Curve



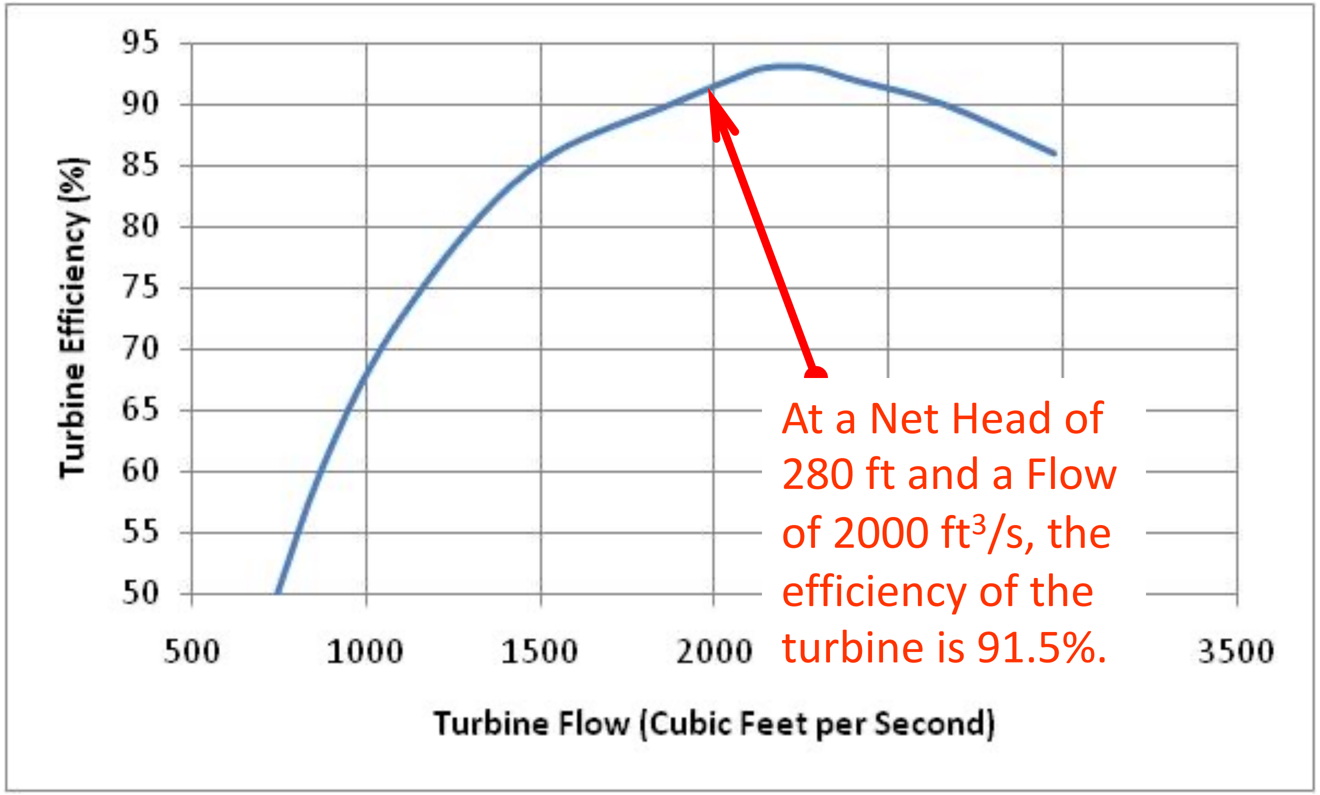
At a Net Head of 280 ft and a Flow of 2000 ft^3/s, the efficiency of the turbine is 91.5%.

Cutting the Hill Curve to Create a Cross Plot

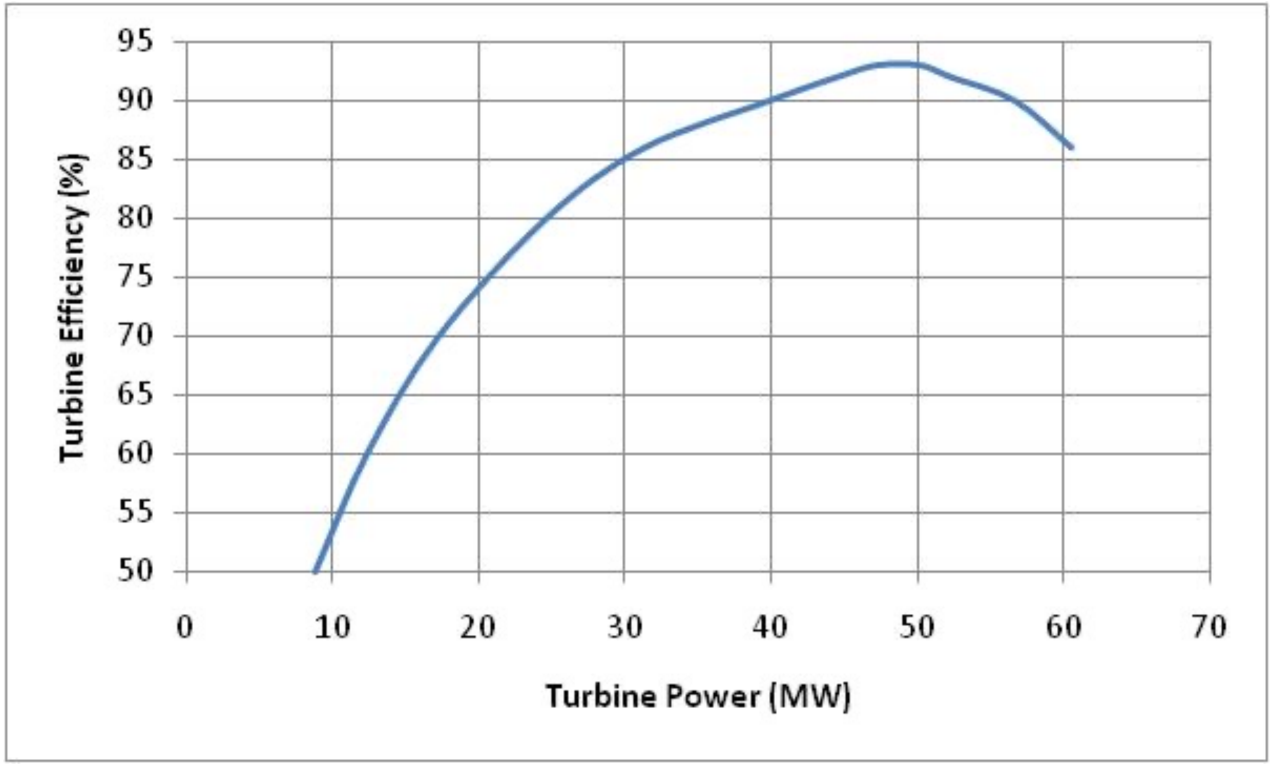


Is Net Head constant for a given Gross Head?

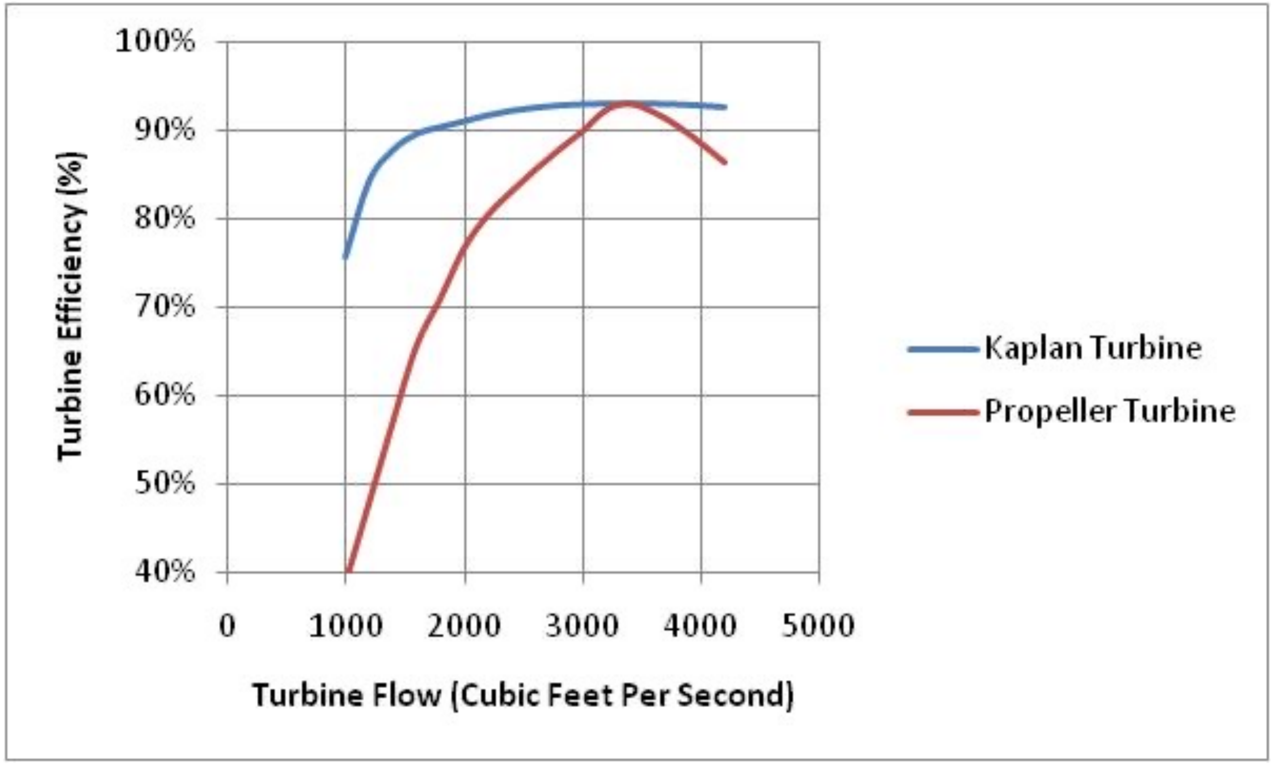
Typical Performance Curve – Cross Plot



Typical Cross Plot Performance Curve at a given Net Head



PERFORMANCE OF AXIAL FLOW MACHINE WITH AND WITHOUT ADJUSTABLE BLADES



Rough Power Estimate at 85% Efficiency

English

kW = Q * H * **0.072**
Q = Flow in Cubic Feet Per Second
H = Head in Feet

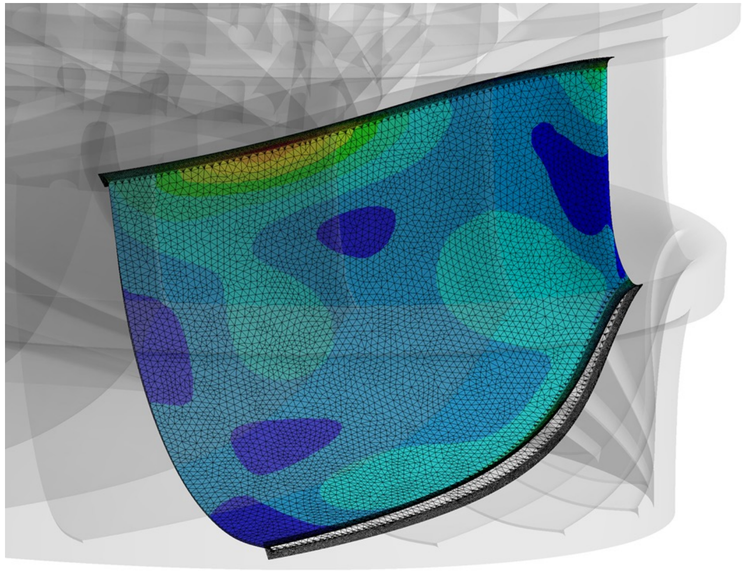
Metric

kW = Q * H * **8.3**
Q = Flow in Cubic Meters Per Second
H = Head in Meters

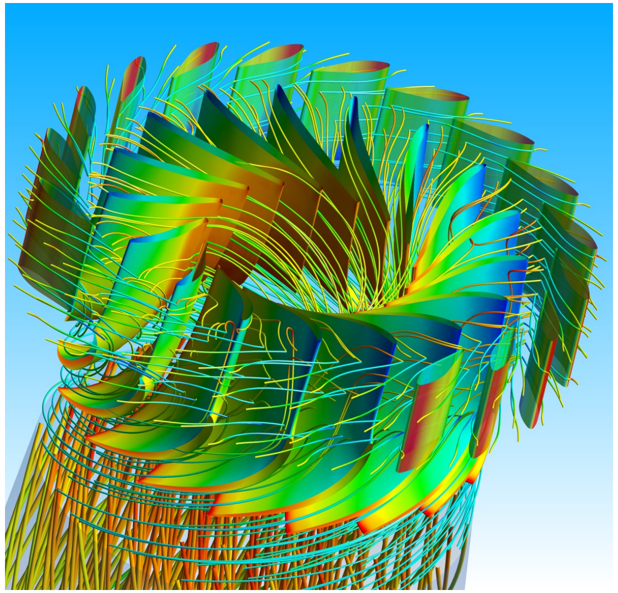
What’s New?

Computer aided engineering technologies have had a significant impact on performance levels for hydro turbine designs and on the hydro turbine business over the last 30 years

- FEA – Finite Element Analysis – Mechanical Analysis

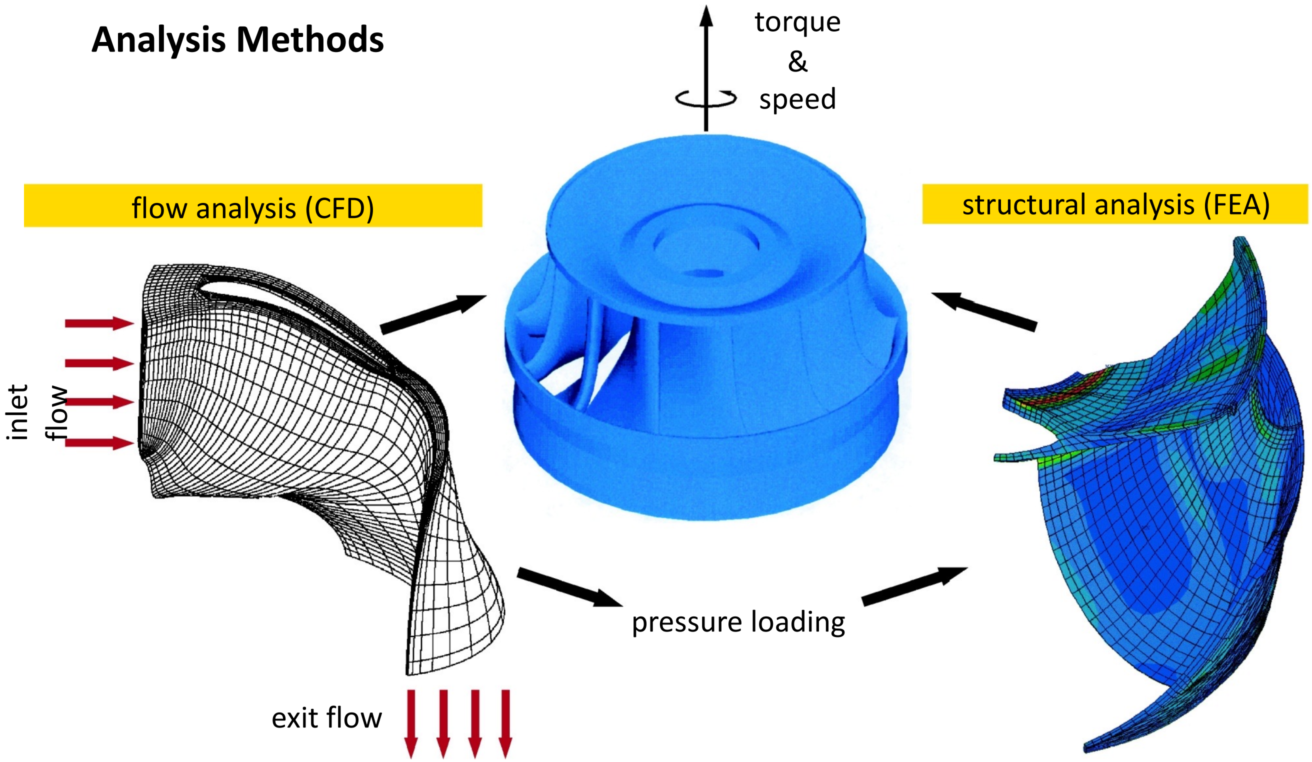


- CFD – Computational Fluid Dynamics – Flow Analysis



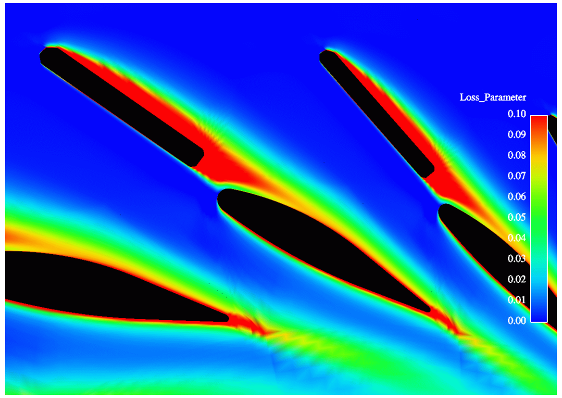
Simultaneous Engineering

Analysis Methods

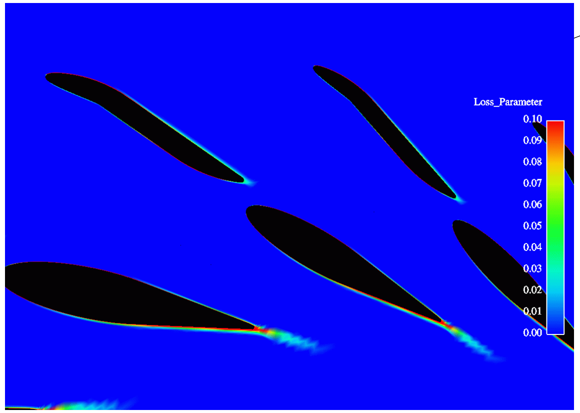


Flow Analysis to Determine Stay Vane / Wicket Gate Modification

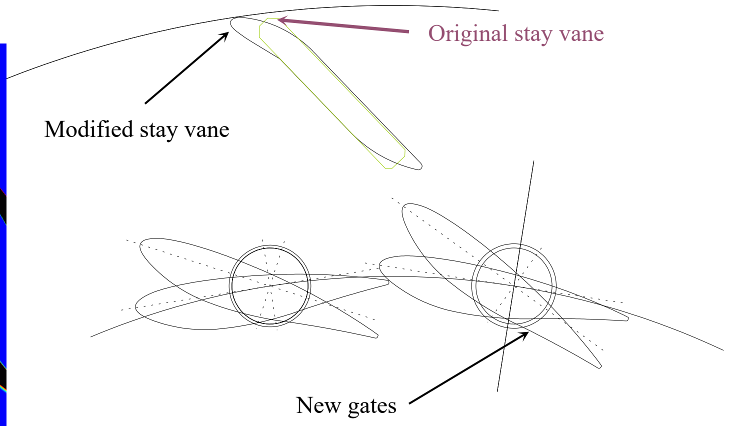
Original stay vane / wicket gate



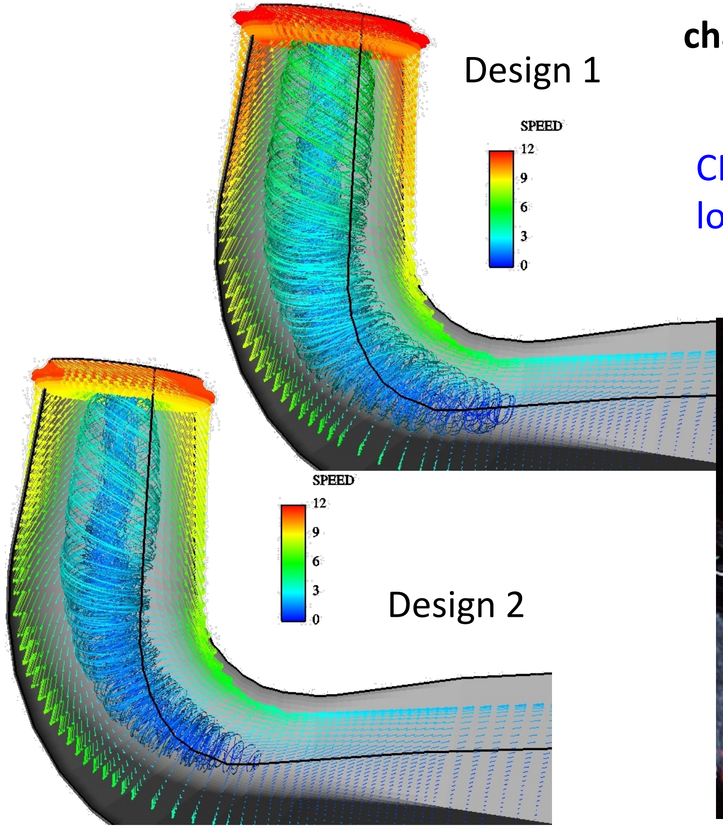
- Original stay vanes are crude and not aligned well with the flow causing higher loss in both SV and WG
- Improvement in stay vane and wicket gate design reduce significantly the overall distributor losses



Modernized stay vane / wicket gate

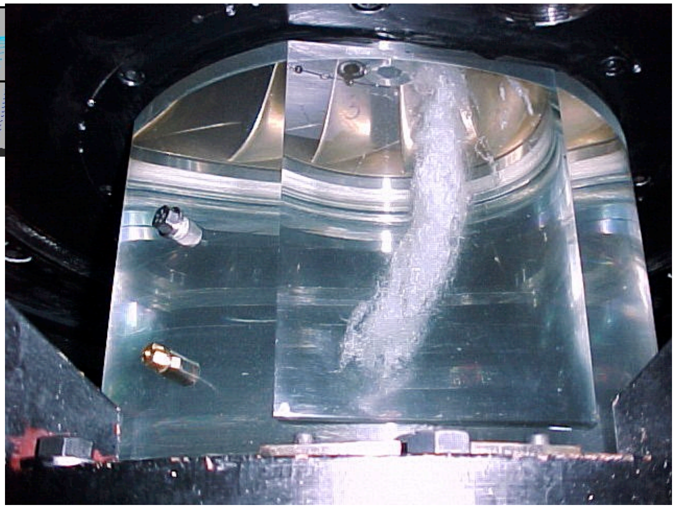


CFD of Runner/Draft Tube Behavior at Part Load



Draft Tube - Runner velocity distribution characteristics at part load

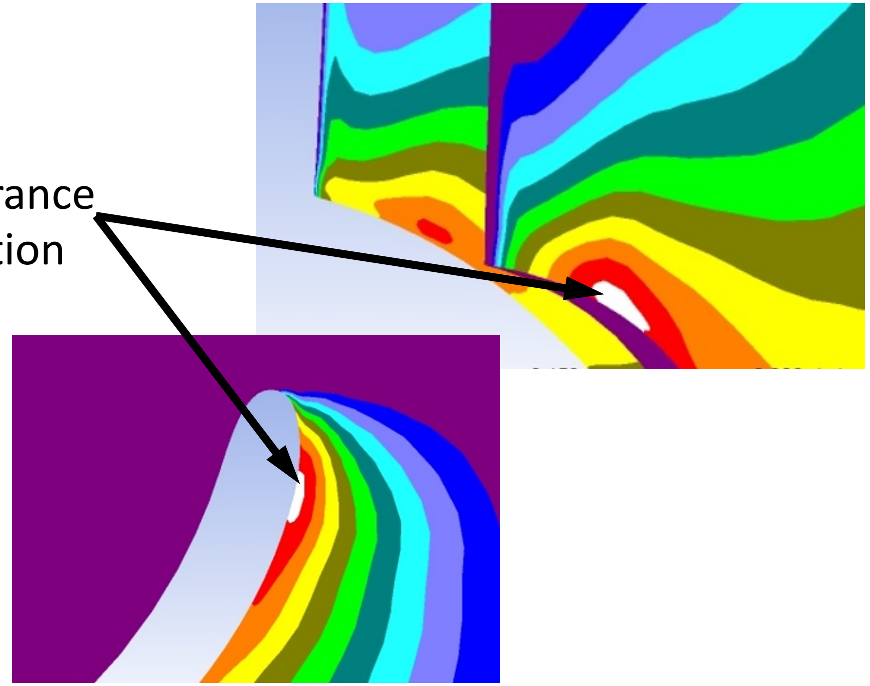
CFD tools being used to evaluate part load performance stability tendencies



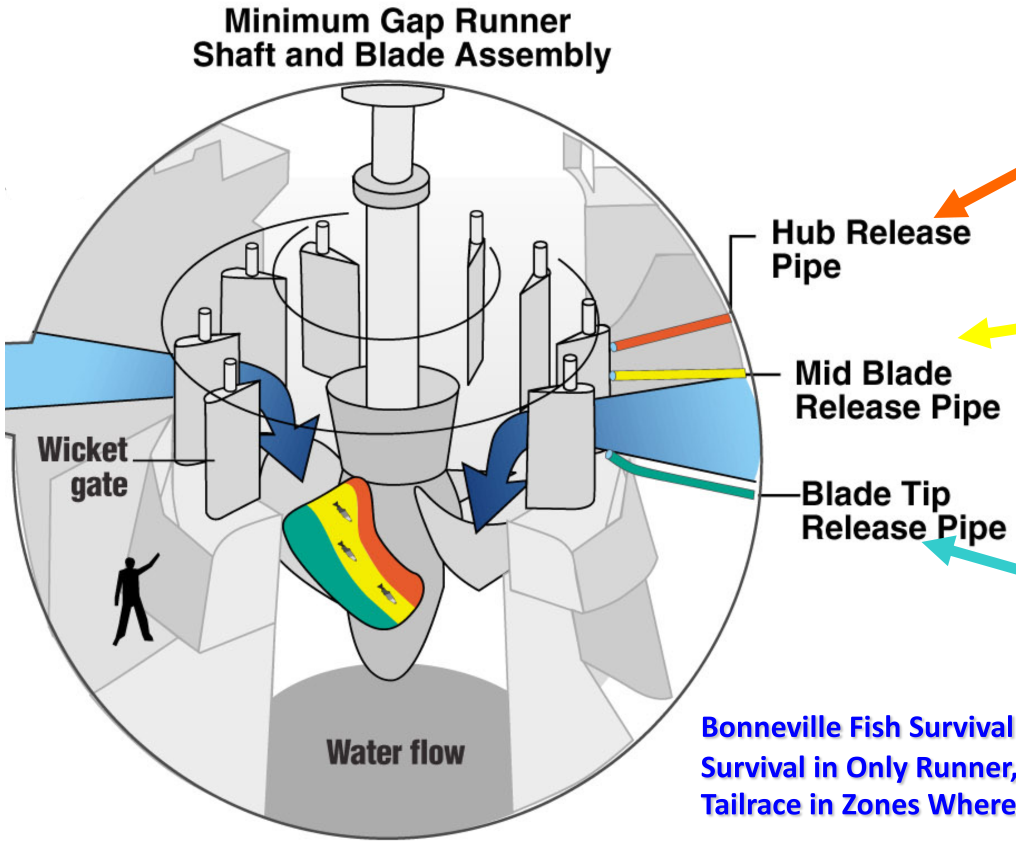
CFD for Cavitation Analysis

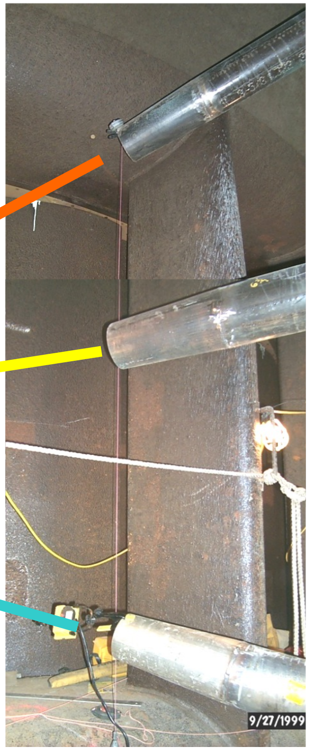
- CFD tools work well for cavitation identification and reduction.
  - They can be used as a Numerical Test Stand (NTS)

Turbine Entrance Edge Cavitation Visualized



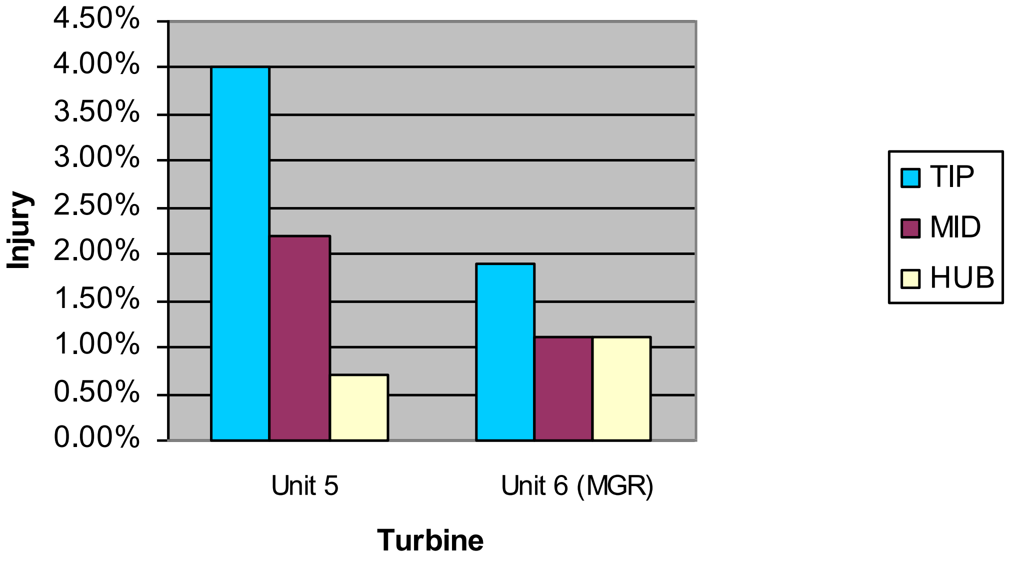
Bonneville Fish Survival Tests





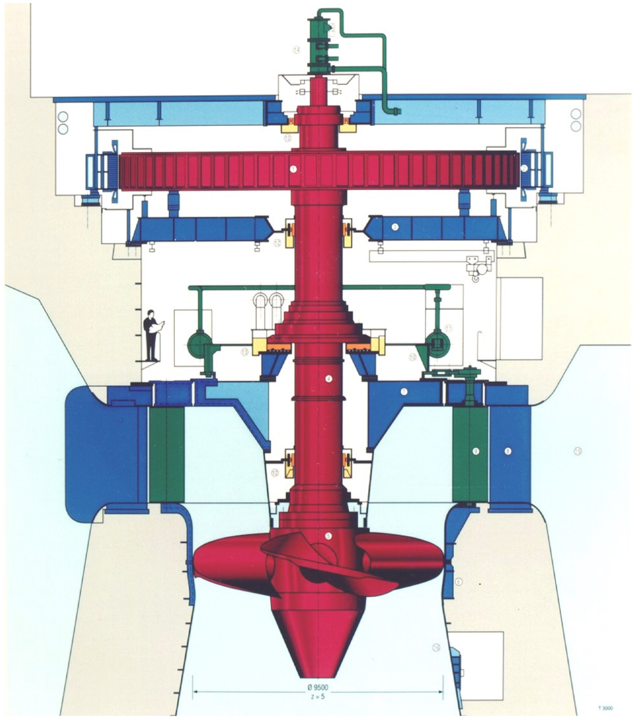
Bonneville Fish Survival Tests Evaluated Survival in Only Runner, Draft Tube and Tailrace in Zones Where Fish Passed

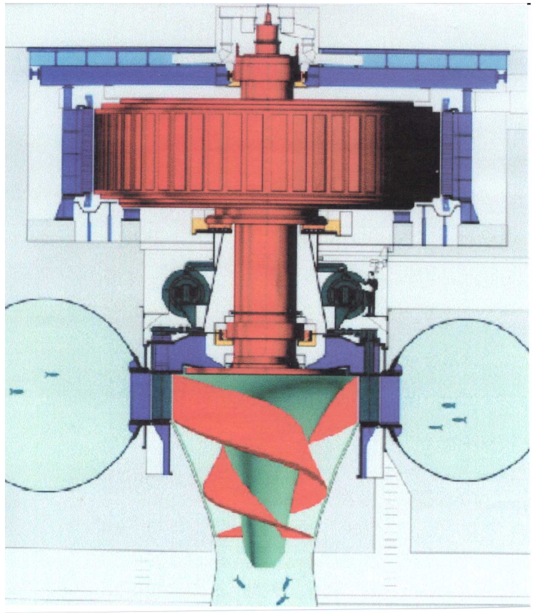
Bonneville Fish Survival Test Results



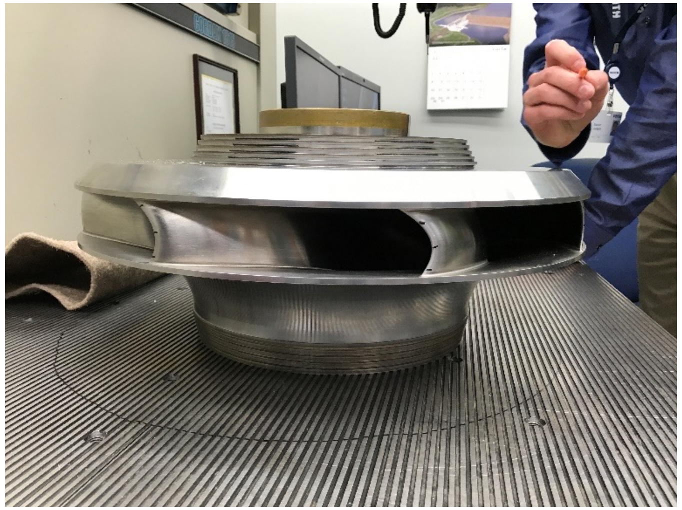
- **Injury defined by examination of the fish and includes live and dead fish**
- **Average fish injury % at Unit 5 (existing runner) = 2.5%**
- **Average injury % at Unit 6 (MGR runner) = 1.5%**
- **Unit 6 MGR design produced 40% less fish injury than existing units**

ALDEN / NREC ADVANCED FISH-FRIENDLY TURBINE



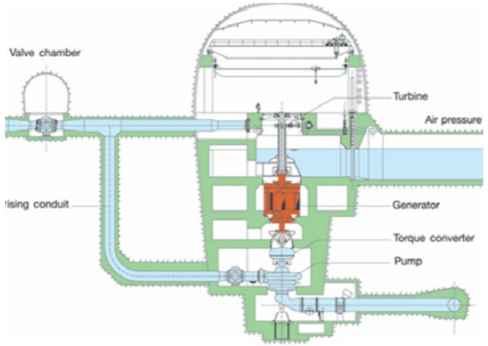


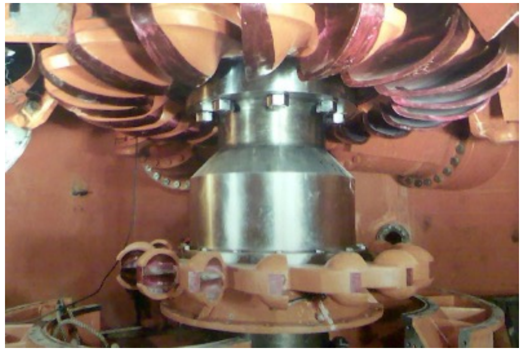
Pump-Turbine Technology

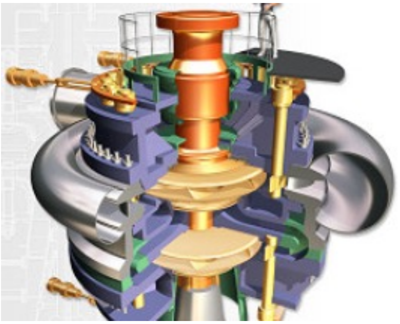


- Increased flexibility to integrate **Solar** and **Wind** power
- Pumping regulation with variable speed technology
- Faster mode changeover
- Faster ramping rates
- Energy storage on a **massive scale**

Alternate Configurations: Variable Speed, Ternary Units, Counter-rotating Pelton, Two Stage Pump-turbines





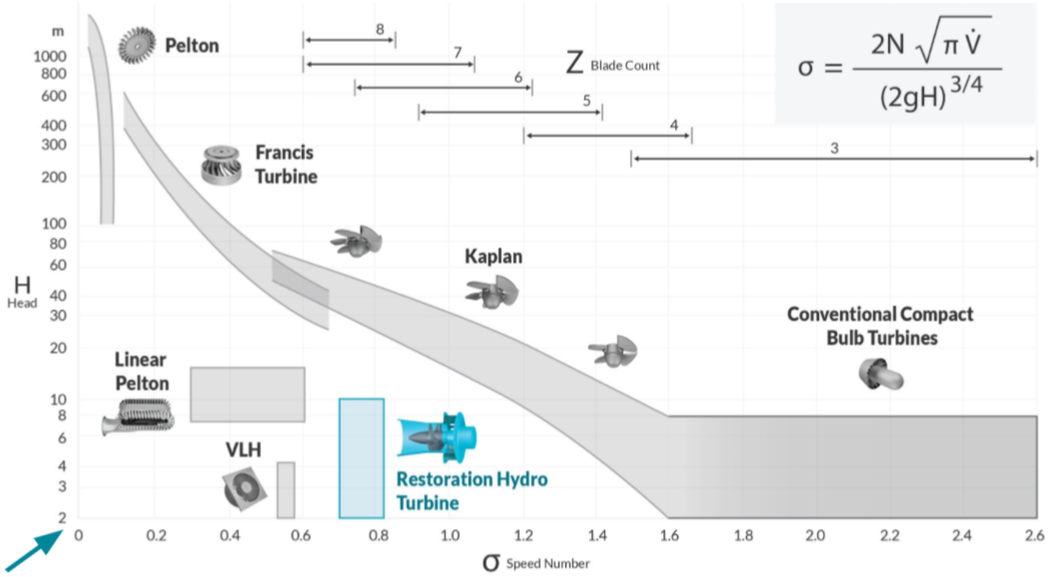


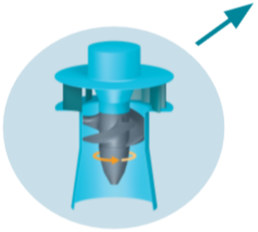
Advancements in Low Head Technology

- New configurations create cost effective solutions in small channels and diversions
- Larger locks and bypass structures may consider matrix-type turbines
- Kinetic turbines (“no”-head)

Rethinking Low-Head Hydro

Efficient, Compact, Fish Friendly, Simple Low Head Turbine





Turbine speed number and blade count directly correlate to fish passage.

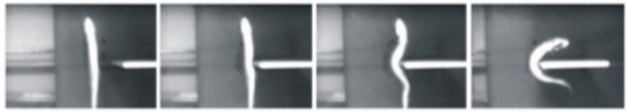
Open design space for medium speed number, low blade count, fish friendly, low head, cost-effective solution.

That expands the universe of what's possible for new hydro → **Restoration Hydro**.

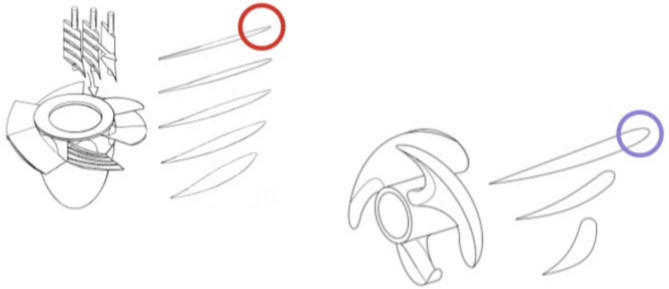
NATEL ENERGY

Fish-friendly low head turbines with low-cost civil works

Fish L=250 mm; Blade t=10 mm; V=7.3 m/s



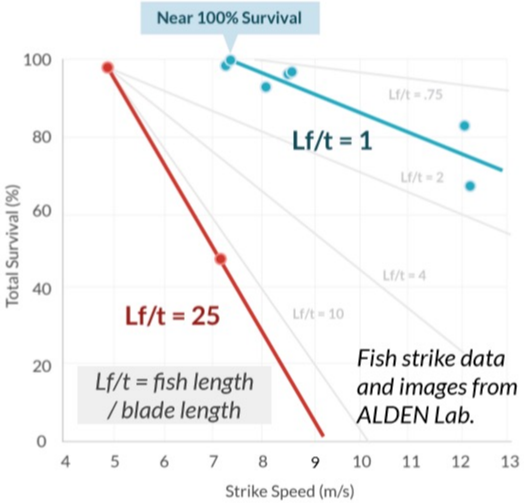
Conventional: (thin blades, fish die)

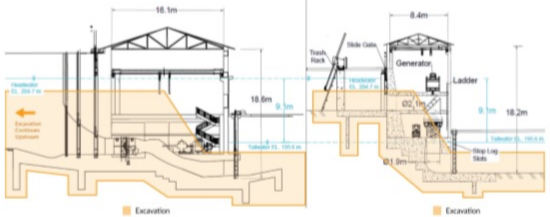


Fish L=150 mm; Blade t=150 mm; V=7.3 m/s

Fish friendly: (thick blades, fish live)

- Large region of high pressure safely decelerates fish before impact
- Patent Pending, Natel Energy

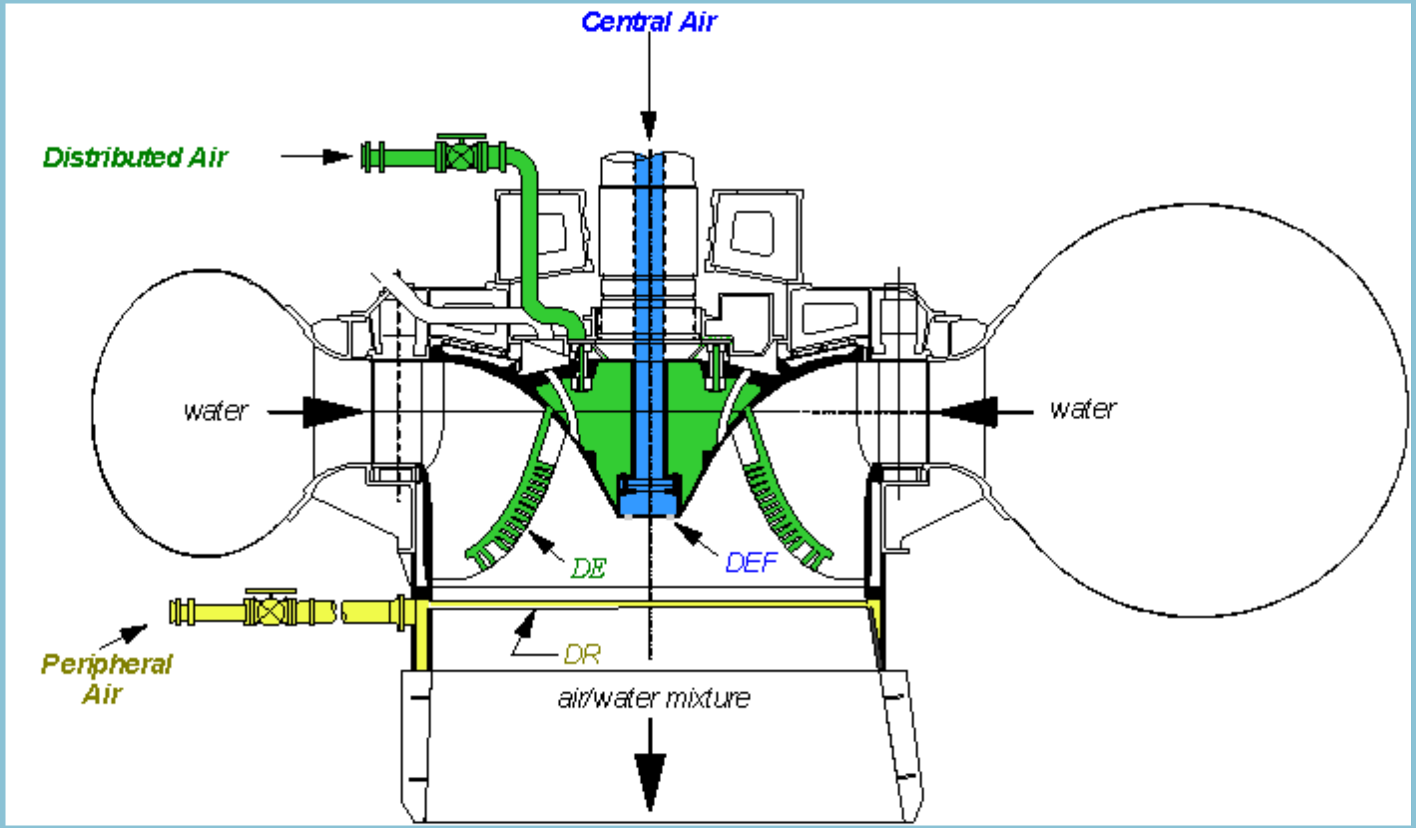




Fish safe, with low-cost civil works:

Small powerhouse, ~40% less excavation; ~25% less concrete vs conventional high speed propeller.

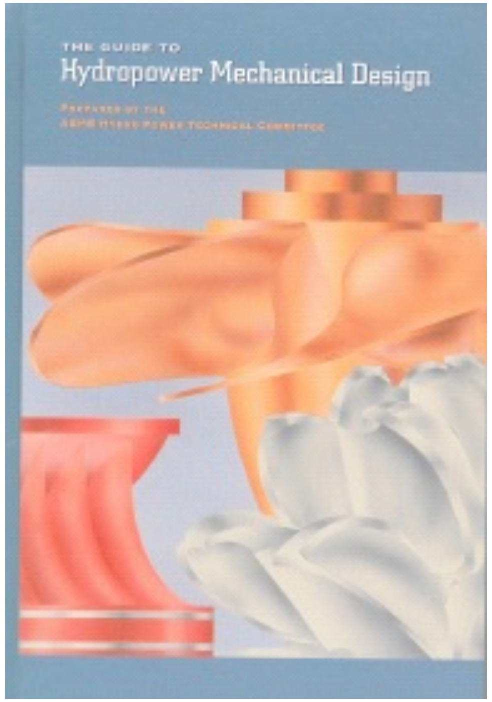
Turbine Discharge Aeration: DO Enhancement



Turbine Reference Codes

- ASME PTC 18; IEC 60041 – Field Acceptance Testing
- IEC 60193 – Model Acceptance Testing
- IEC 60609 – Cavitation
- IEC 61364 – Nomenclature
- IEC 60994 – Vibration
- IEC 60645 – Commissioning
- IEC 61366 – Technical Specification
- IEC 62270 – Automation
- IEC 61116 – Small Hydro

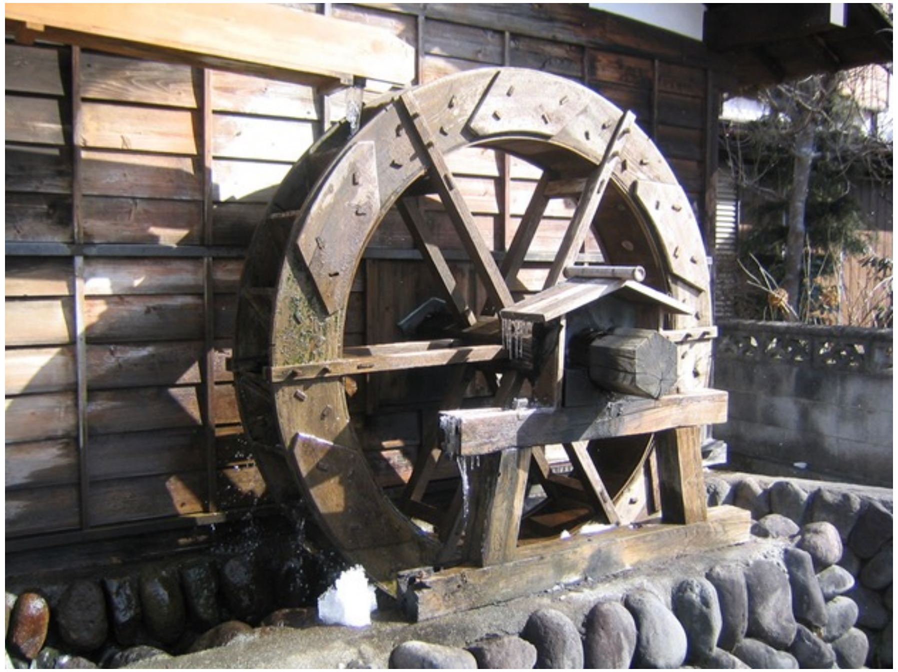
Reference:



"Hydropower Mechanical Design",
by ASME Hydro Power Technical Committee, HCI Publications.

POP QUIZ

What type of turbine is shown below?



Impulse

POP QUIZ

What type of hydraulic turbine did Leonardo da Vinci envision?

Reaction

POP QUIZ

- Can overspeed during a load rejection event exceed runaway speed?

YES

- "Runaway" speed is a steady state condition at the point of …. ?

Zero Net Torque

- A generator or generator-motor has a "design overspeed" that must be greater than the anticipated …… ?

Transient overspeed or Runaway overspeed whichever is greater.

Questions?