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Multiyear Biological Research at Ice Harbor Dam: Adjustable-Blade Turbine Characterization

Aljon Salalila, Tao Huang, Jayson Martinez, Bob Mueller, Scott Titzler, Tao Fu, Jun Lu, Daniel Deng

Pacific Northwest National Laboratory

USACE Point of Contact:

Brad Trumbo, Karl Anderson, Jon Renholds

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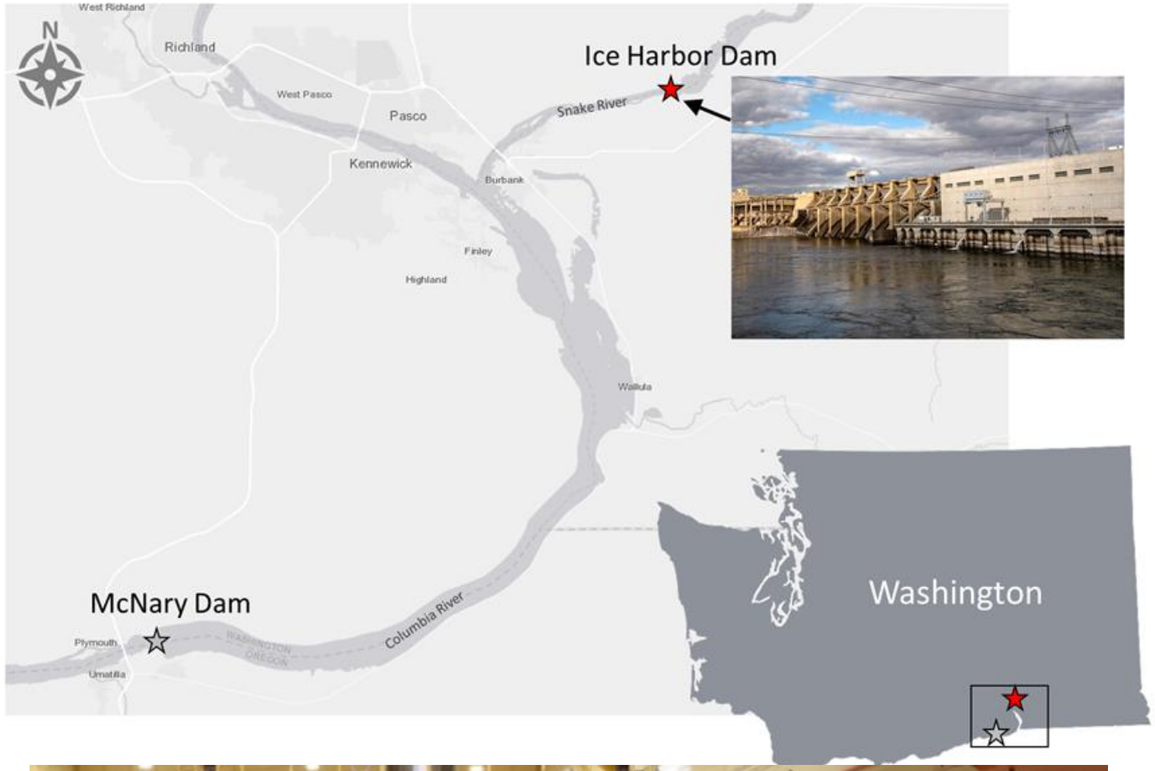
December 3, 2024. AFEP Review

Outline

- ❑ Project Background and Objectives
- ❑ Nadir Pressure Distribution of Unit 3 Adjustable-blade Turbine (U3AB) at three release depths
- ❑ Comparison of Nadir Pressure for Three Turbines (U1 Baseline; U2 Fixed-blade; U3AB)
- ❑ Estimated Survival Rates of U3AB Using Strike Metrics
- ❑ Comparison of Estimated Survival Rates for Three Turbines

Background

- Ice Harbor Dam (IHR) is the first within the Federal Columbia River Power System to have turbine runners replaced with the primary goal to improve fish passage survival
- Two improved fish passage turbine designs were developed for IHR
  - A fixed-blade runner at Unit 2 - Commissioned in 2019
  - An adjustable-blade runner at Units 1 and 3 – Unit 3 commissioned in 2023
- Baseline hydraulic characterization of the original Kaplan turbine was conducted at Unit 1 in 2015



Objectives

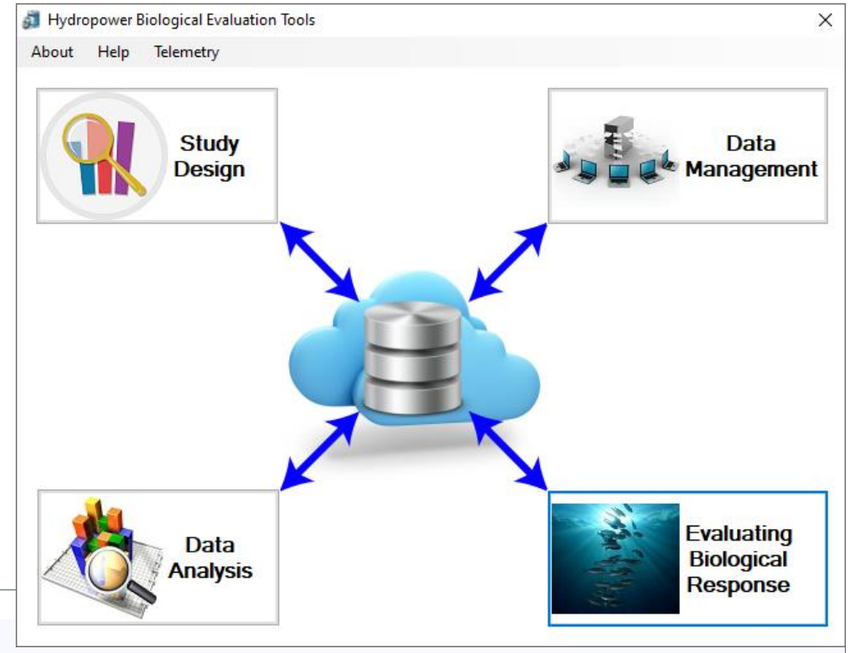
- Use the Sensor Fish (SF) device to characterize the physical conditions of the adjustable-blade turbine from Unit 3 (U3AB)
- Compare the passage conditions of Unit 3 with the results from the 2015 assessment of the original Kaplan turbine from Unit 1 as the baseline (U1BT) and the 2019 assessment of the fixed-blade turbine from Unit 2 (U2FB)
- Use the collected data to verify that design objectives/fish passage criteria were met

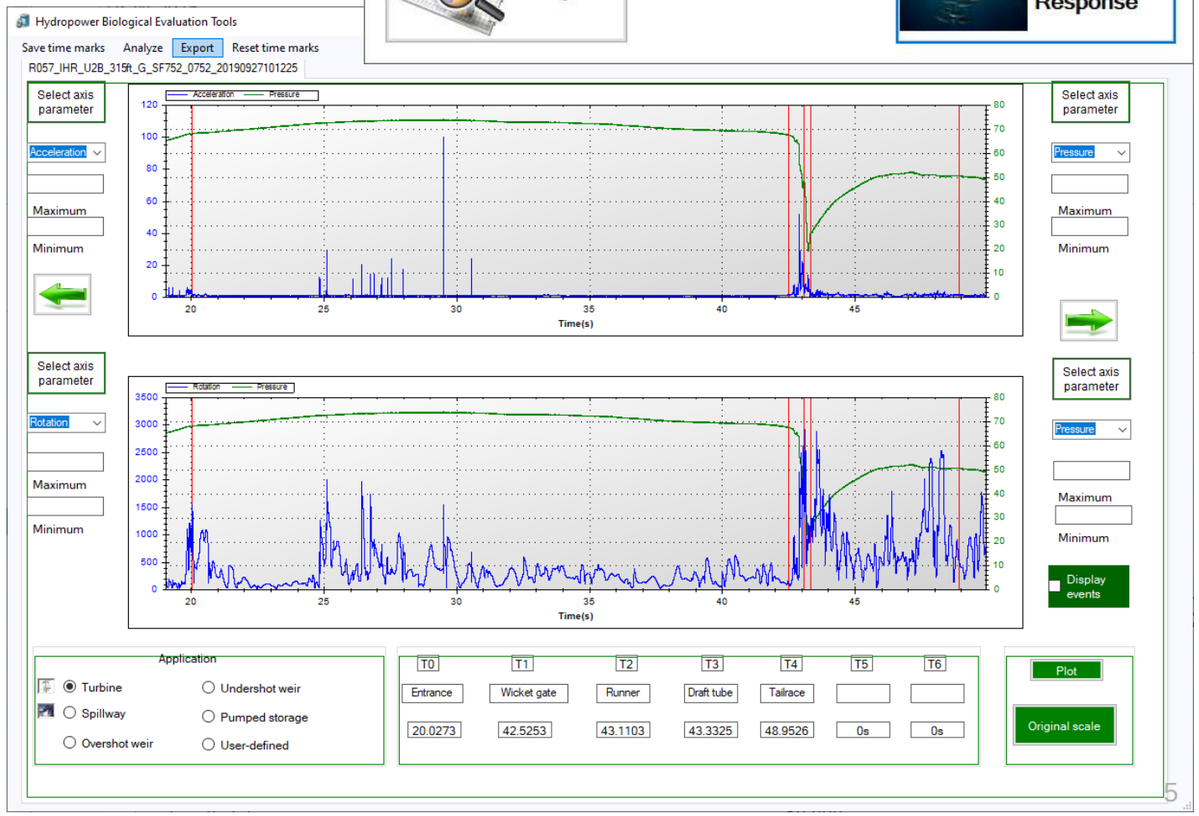
Sensor Fish Device

- Autonomous sensor package to understand physical conditions fish experience
- Sensor Fish Characteristics
  - Dimensions: 89.9 x 24.5 mm
  - Density: 1.01 mg/mm^3
  - Excess mass (wet weight): 0.5 g
  - Sampling rate: 2048 Hz
  - Maximum sampling time: 4 min
  - 3D acceleration: 0 - 200 g
  - 3D rotational velocity: 0 - 2000 ˚/s
  - Pressure: 0 - 203 psia
  - Temperature sensor: -40 - 125 ˚C
  - 3D orientation
  - Automatic floatation system
  - Built-in RF-transmitter

Sensor Fish Data Analysis

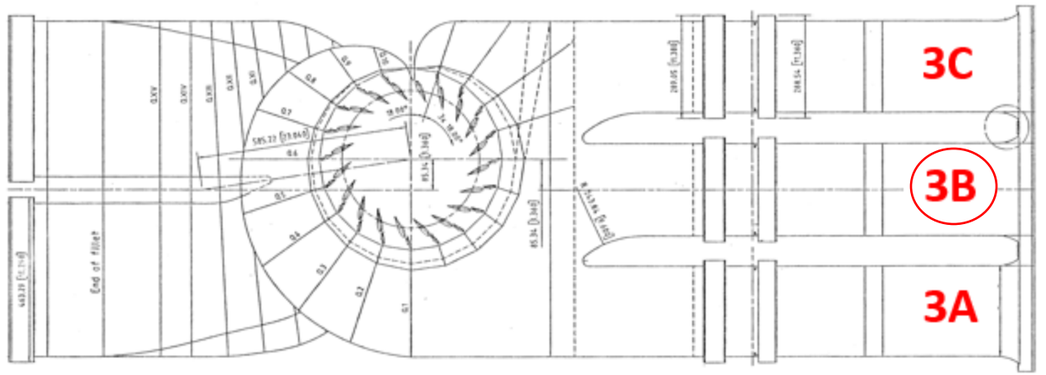
- Hydropower Biological Evaluation Toolset (HBET)
  - A tool set based on SF and other sensor data (e.g., acoustic telemetry) to evaluate the physical and biological performance of existing, refurbished, or newly installed hydro-turbines.
    - ✓ Study design tool
    - ✓ Data archiving
    - ✓ Data analysis tool
    - ✓ Tool for evaluating biological response (based on SF data)

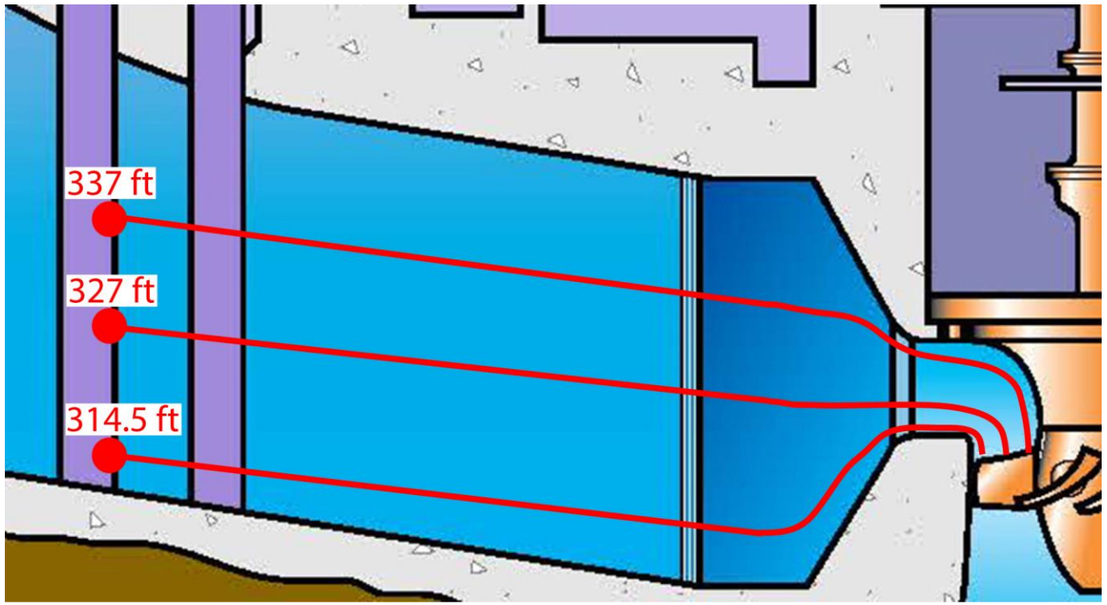




Deployment – Turbine Characterization

- SF Testing performed in Slot B of Unit 3
- Stainless steel release pipes installed to Submerged Traveling Screen frame for three different elevations
  - 337 ft
    - ✓ Targets blade hub
  - 327 ft
    - ✓ Targets middle of blade
  - 314.5 ft
    - ✓ Targets blade tip





Target Operating Points

- The turbine operations are head dependent
  - Target operating head is 96 ft
  - Actual head during this study was about 99 ft
- Four operating points:
  - Lower 1%
  - Peak
  - Upper-Mid
  - Upper 1%

Head	Target Operating Points for SF Releases (MW)			
ft	Lower 1%	Peak	Upper-Mid	Upper 1%
96	67.8	80.8	94.8	103.1
97	69.1	80.8	95.8	104.5
98	70.1	79.8	97.2	104.5
99	70.8	84.6	98.3	104.5
100	71.3	85.5	99.4	104.5

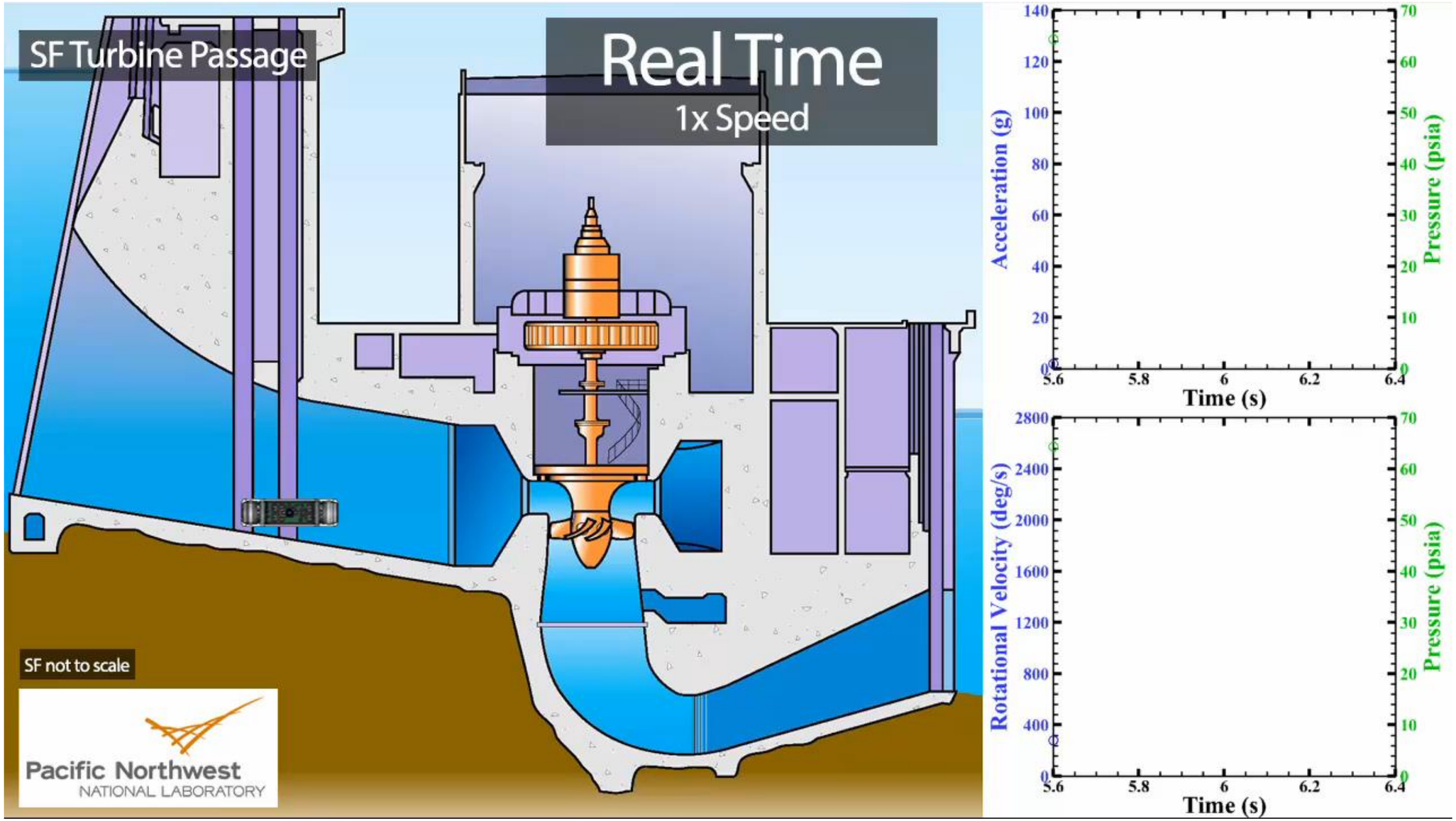
Note: Target values have a variability of ±1.5 MW.

Sample Sizes

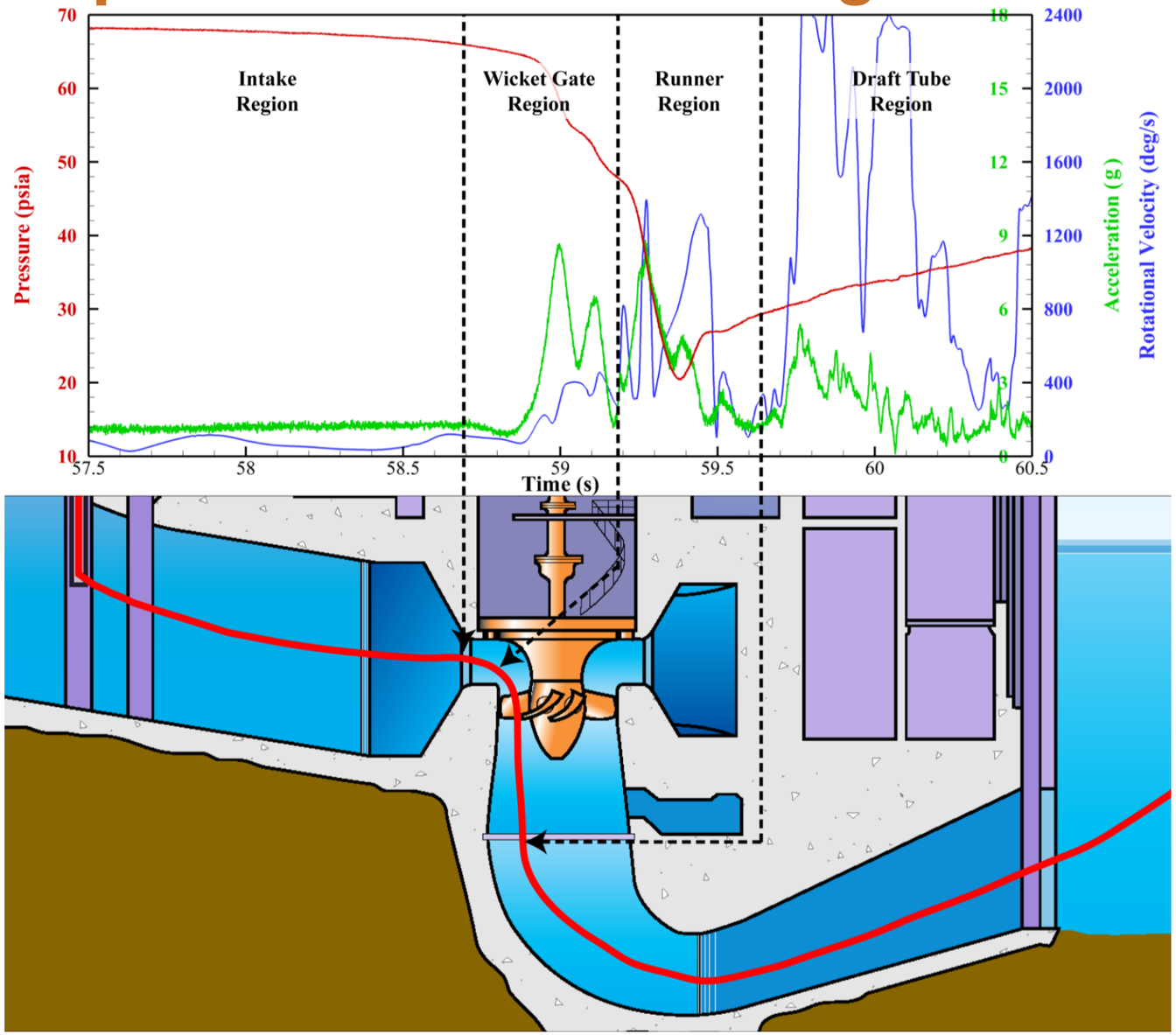
- Sample sizes for turbine characterization treatments:
  - Study design for detecting a difference of 1.0 psi:
    - ✓200 releases per operation (67 per treatment)
- Operations could not always be held exactly at the targets
- Used 5-minute operational data to calculate the target operating points for each SF release based on the corresponding head

SF Release Depth	Lower 1%	Peak	Upper-Mid	Upper 1%
Shallow (337 ft)	58	65	66	64
Middle (327 ft)	77	75	65	74
Deep (314.5 ft)	68	70	81	63
All	203	210	212	201

Example of a Turbine Passage - animation



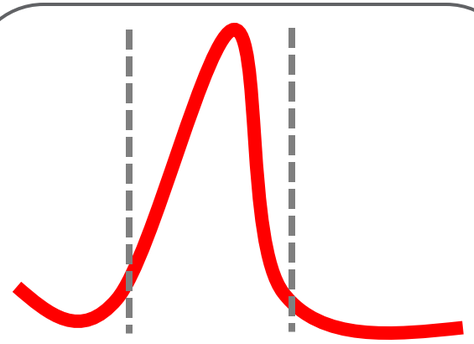
Example of a Turbine Passage



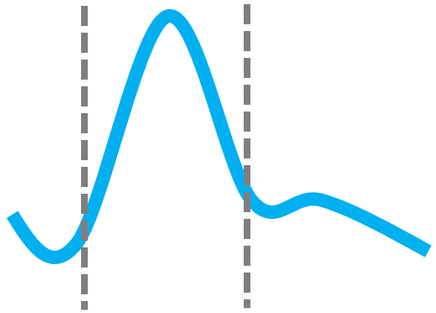
Development of Strike Metrics

Sensor Fish Data

Acceleration *vs. t*



Pressure *vs. t*



$$M_V := \Delta t \left\| \sum_{n=-3}^{3} (a_x[n], a_y[n], a_z[n])^T \right\|$$

F=ma

M_V *f(a, t)*

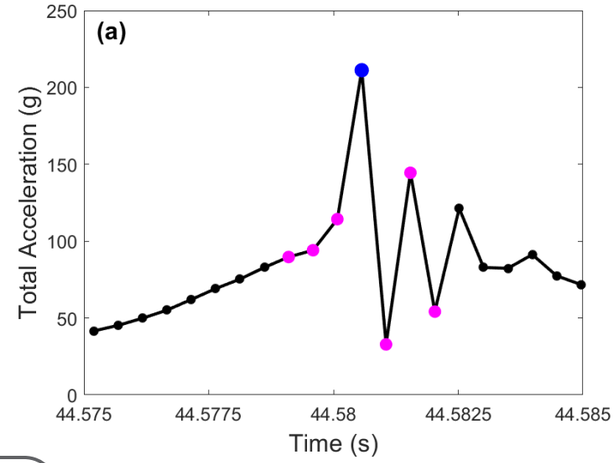
$f(M_V)$

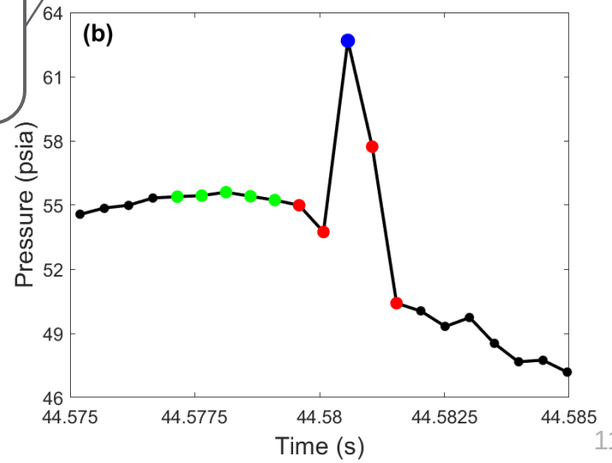
M_P *f(P, t)*

$f(M_P)$

$$M_P := \sqrt{\frac{2k}{\rho} |P_2 - P_1|}$$

Absolute Strike Injury Rate

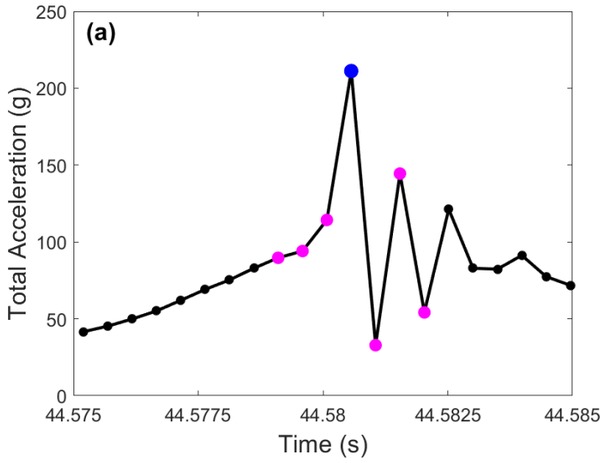


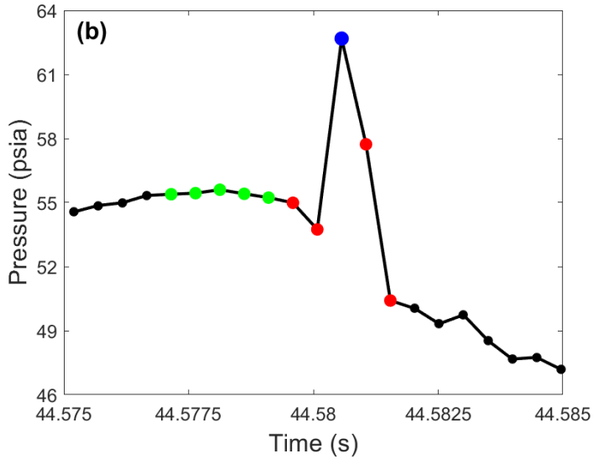


Development of Strike Metrics

$$M_V := \Delta t \left\| \sum_{n=-3}^{3} (a_x[n], a_y[n], a_z[n])^T \right\|$$

$$M_P := \sqrt{\frac{2k}{\rho} |P_2 - P_1|}$$





CDF of Strike Metrics

Threshold of Strike Metrics

Fish Survival Rate

- ✓ Compute M_V and M_P, *respectively*, for each severe exposure event ($\|a\| \geq$ **95 g**) that the Sensor Fish experiences.
- ✓ Retain the maximum values of M_V and M_P across all severe exposure events for the given SF release.
- ✓ If there are no severe exposure events, then set $M_V = M_P = 0$.

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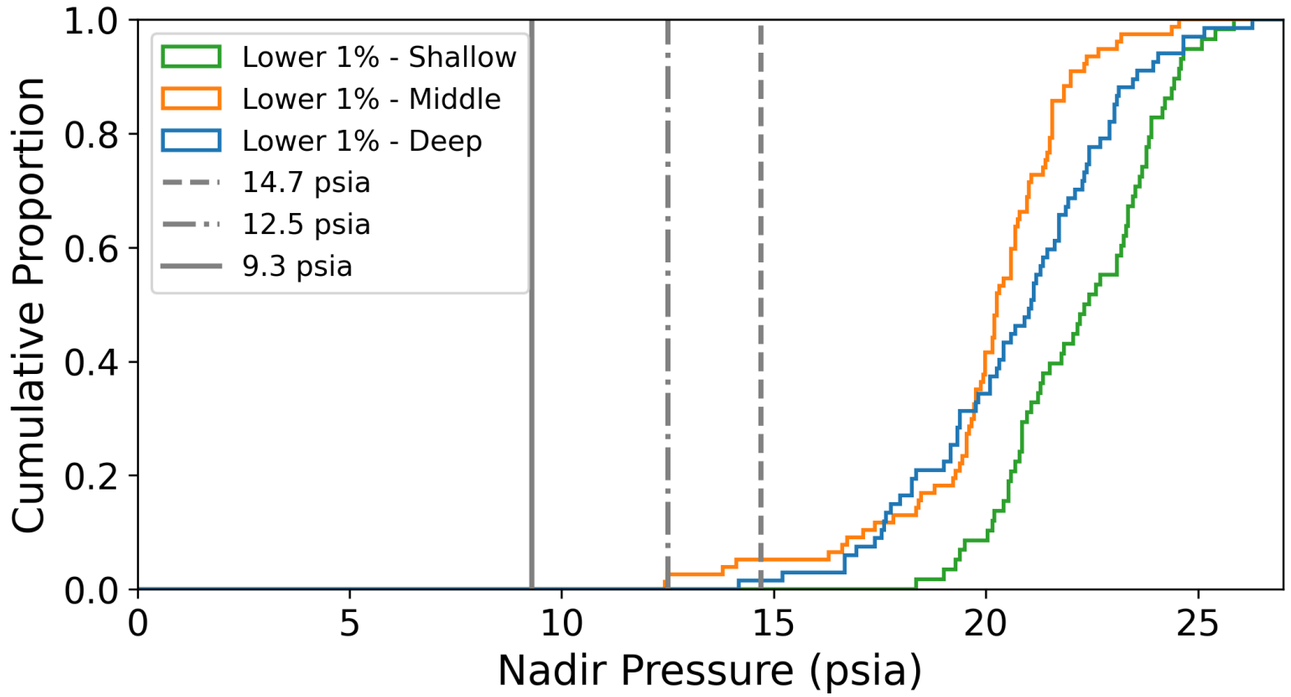
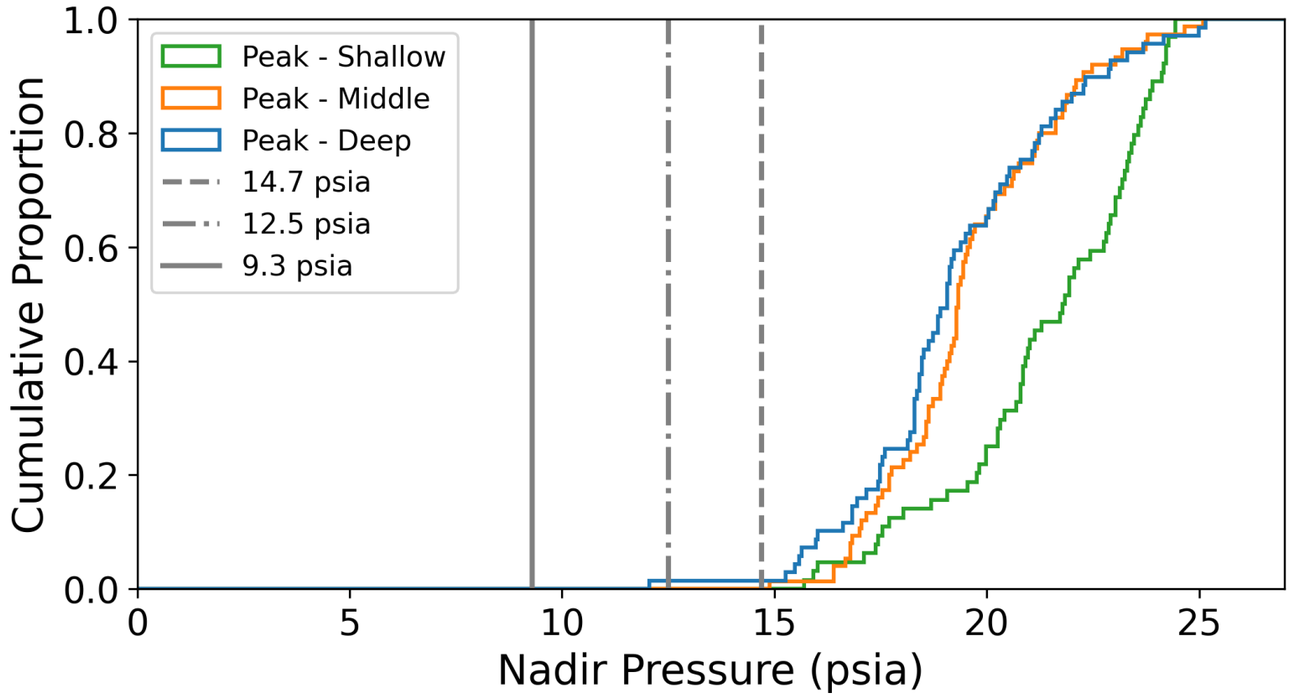
Nadir Pressure Distribution of U3AB at Three Release Depths

Normalized Nadir Pressure by Release Depth (U3AB - Lower 1%)



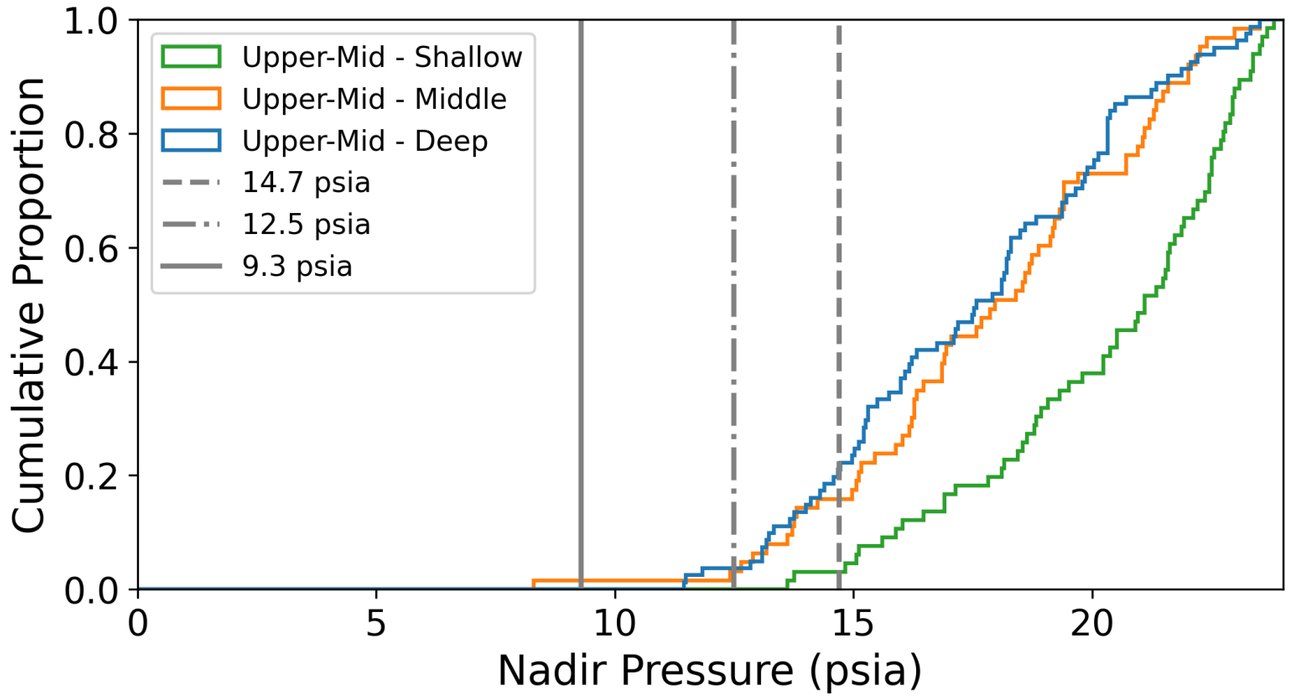
Release Depth	# of SF Releases	Mean Nadir (psia)	Nadir < 9.3 psia (%)	Nadir < 12.5 psia (%)	Nadir < 14.7 psia (%)
Deep	68	20.9	0.0	0.0	1.5
Middle	77	20.0	0.0	1.3	5.2
Shallow	58	22.3	0.0	0.0	0.0
Overall	203	21.0	0.0	0.5	2.5

Normalized Nadir Pressure by Release Depth (U3AB - Peak)



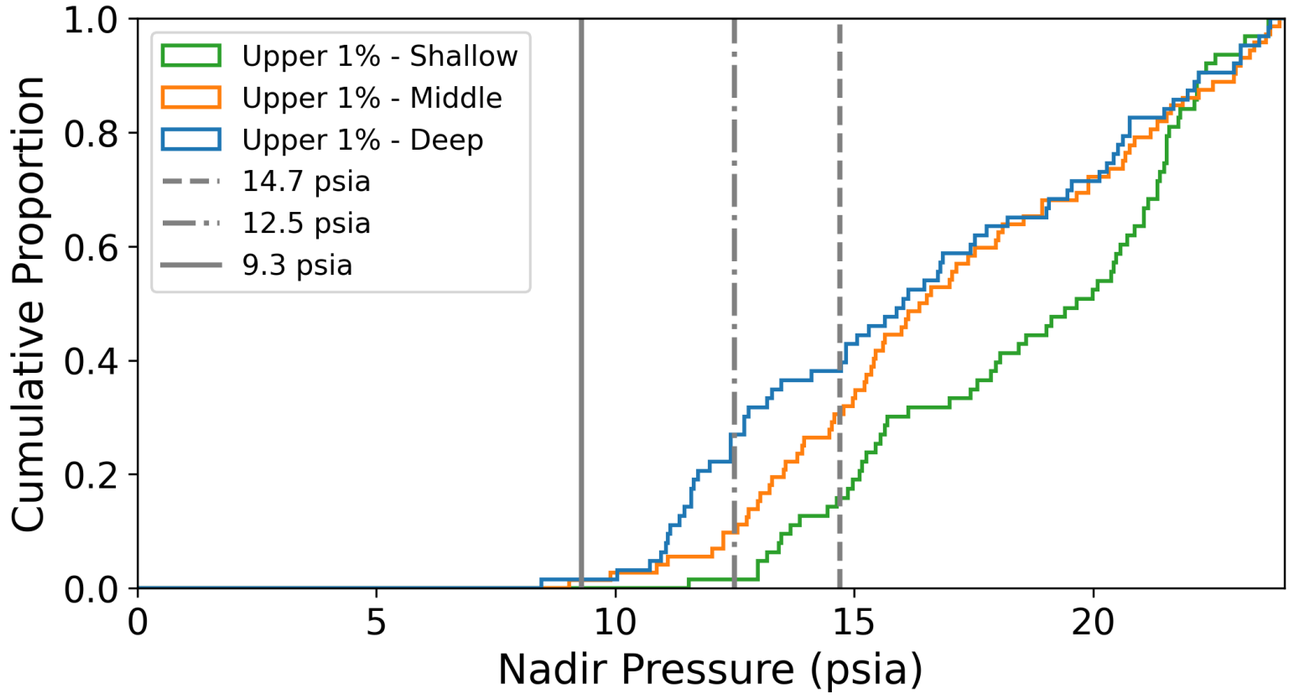
Release Depth	# of SF Releases	Mean Nadir (psia)	Nadir < 9.3 psia (%)	Nadir < 12.5 psia (%)	Nadir < 14.7 psia (%)
Deep	70	19.4	0.0	1.4	1.4
Middle	75	19.6	0.0	0.0	0.0
Shallow	65	21.5	0.0	0.0	0.0
Overall	210	20.1	0.0	0.5	0.5

Normalized Nadir Pressure by Release Depth (U3AB - Upper-Mid)



Release Depth	# of SF Releases	Mean Nadir (psia)	Nadir < 9.3 psia (%)	Nadir < 12.5 psia (%)	Nadir < 14.7 psia (%)
Deep	81	17.5	0.0	3.7	19.8
Middle	65	18.1	1.5	3.1	15.4
Shallow	66	20.3	0.0	0.0	3.0
Overall	212	18.6	0.5	2.4	13.2

Normalized Nadir Pressure by Release Depth (U3AB - Upper 1%)



Release Depth	# of SF Releases	Mean Nadir (psia)	Nadir < 9.3 psia (%)	Nadir < 12.5 psia (%)	Nadir < 14.7 psia (%)
Deep	63	16.4	1.6	27.0	38.1
Middle	74	17.2	1.4	9.5	31.1
Shallow	64	18.8	0.0	1.6	15.6
Overall	201	17.4	1.0	12.4	28.4

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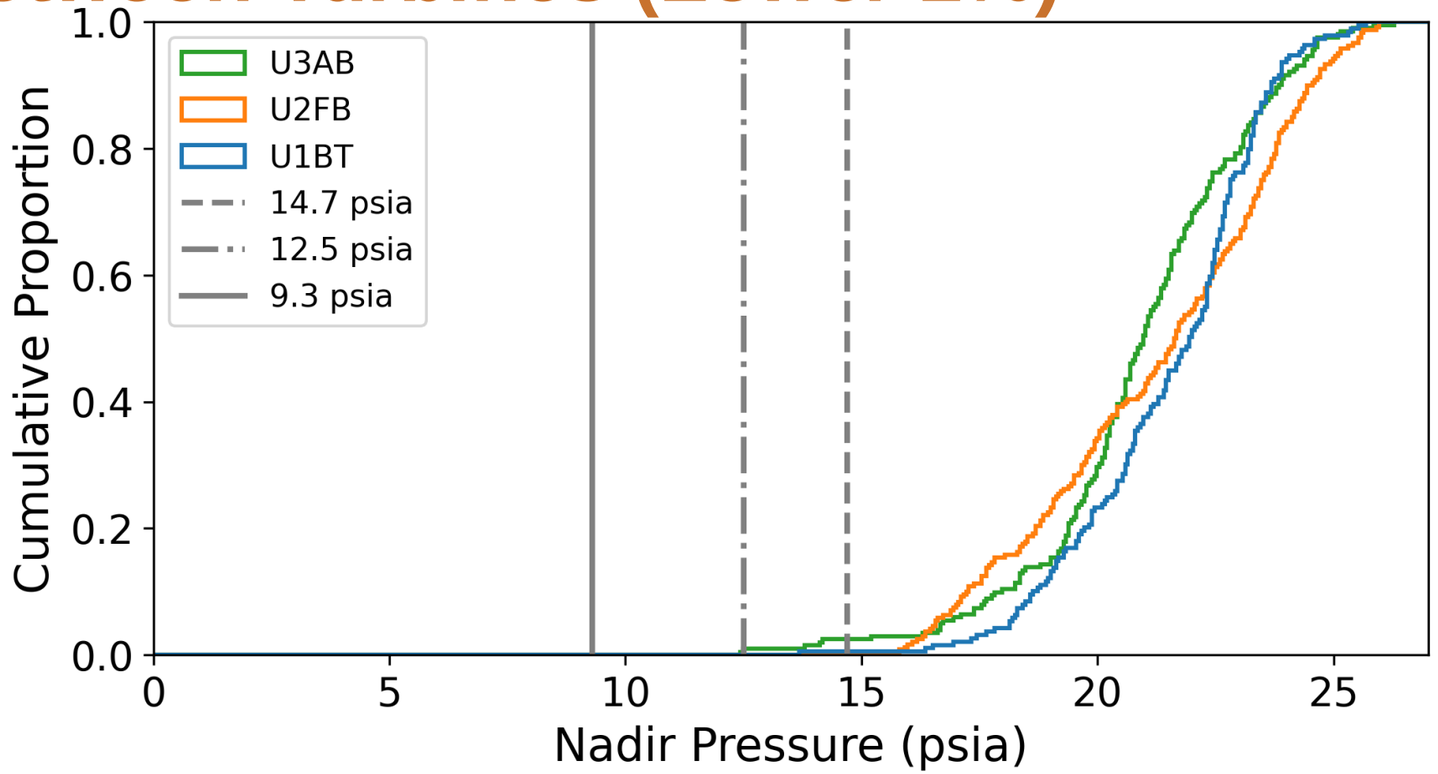
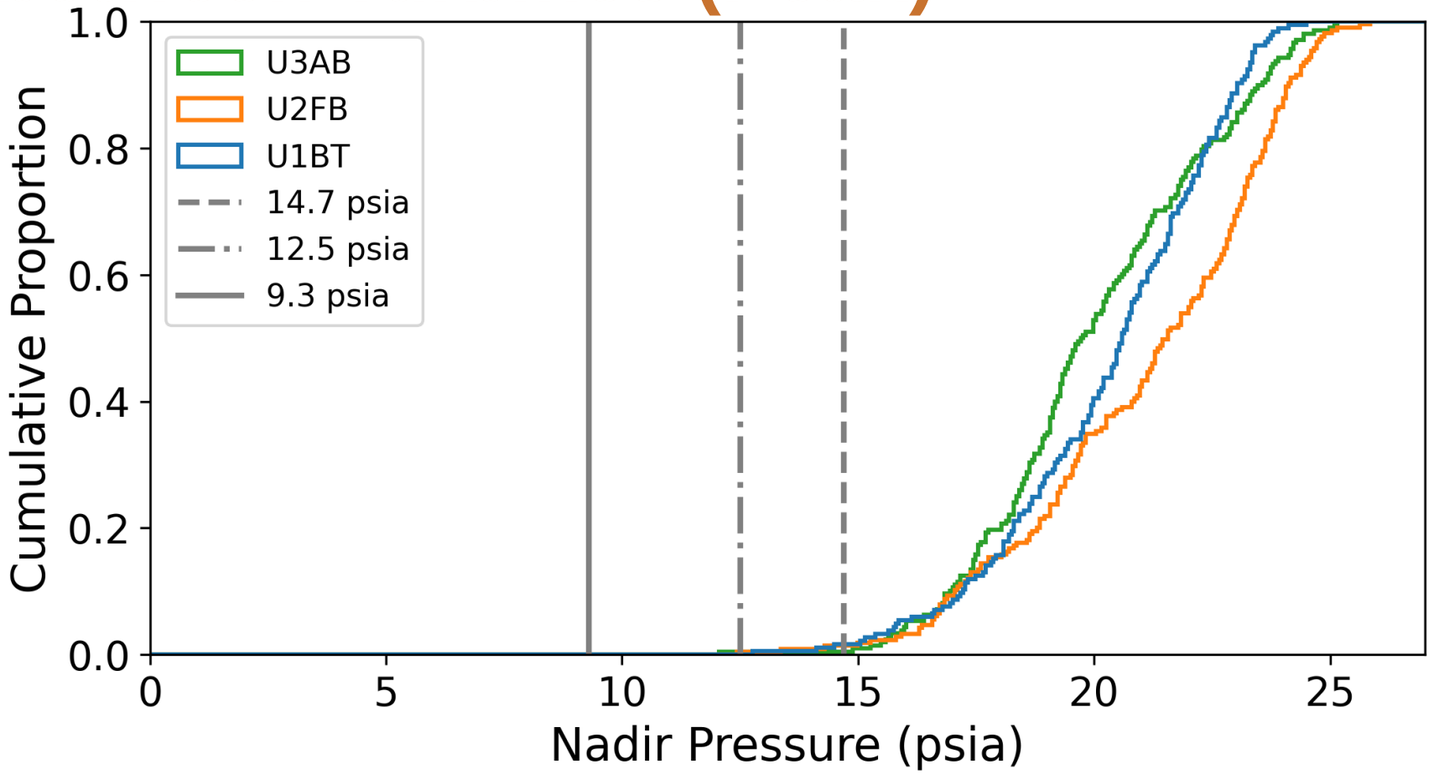
Comparison of Nadir Pressure for Three Turbines

Comparison of Normalized Nadir Pressure between Turbines (Lower 1%)



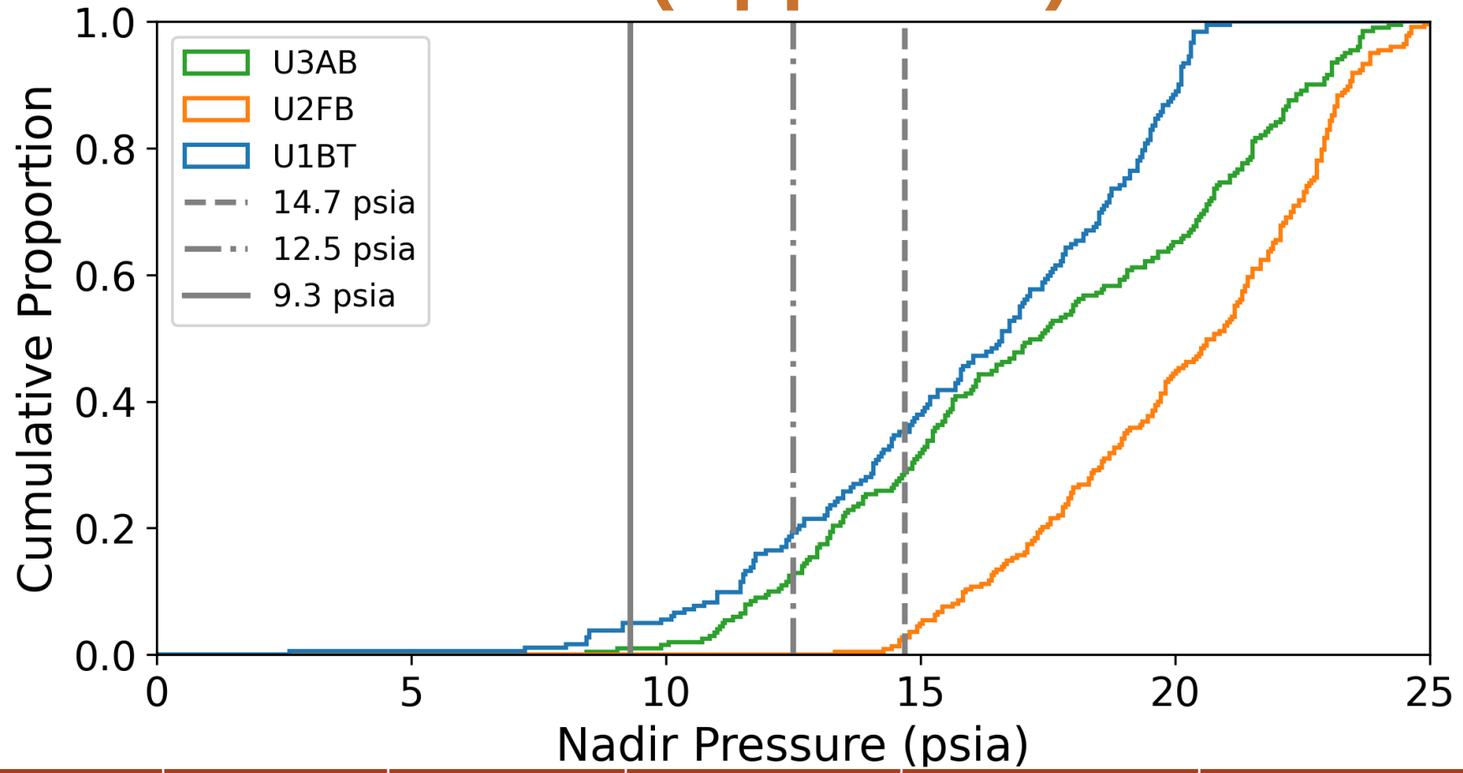
Study	# of SF Releases	Mean Flow (kcfs)	Mean Nadir (psia)	Nadir < 9.3 psia (%) (*p*-value)	Nadir < 12.5 psia (%) (*p*-value)	Nadir < 14.7 psia (%) (*p*-value)	*p*-value for CDF comparison
U3AB	203	9.3	21.0	0.0	0.5	2.5	N/A
U2FB	272	12.6	21.4	0.0 (1.00)	0.0 (0.31)	0.4 (0.10)	**< 0.01**
U1BT	189	8.7	21.6	0.0 (1.00)	0.0 (0.31)	0.5 (0.10)	**< 0.01**

Comparison of Normalized Nadir Pressure between Turbines (Peak)



Study	# of SF Releases	Mean Flow (kcfs)	Mean Nadir (psia)	Nadir < 9.3 psia (%) (*p*-value)	Nadir < 12.5 psia (%) (*p*-value)	Nadir < 14.7 psia (%) (*p*-value)	*p*-value for CDF comparison
U3AB	210	10.5	20.1	0.0	0.5	0.5	N/A
U2FB	223	13.0	21.4	0.0 (1.00)	0.0 (0.30)	1.4 (0.35)	**< 0.01**
U1BT	185	10.0	20.3	0.0 (1.00)	0.0 (0.30)	1.6 (0.29)	**< 0.05**

Comparison of Normalized Nadir Pressure between Turbines (Upper 1%)



- Percentages of observed nadir pressures below 9.3, 12.5, and 14.7 psia for U3AB were 3.9%, 6.8%, and 6.8% lower than those for U1BT, while significantly higher than those for U2FB.

Study	# of SF Releases	Mean Flow (kcfs)	Mean Nadir (psia)	Nadir < 9.3 psia (%) (*p*-value)	Nadir < 12.5 psia (%) (*p*-value)	Nadir < 14.7 psia (%) (*p*-value)	*p*-value for CDF comparison
U3AB	201	13.7	17.4	1.0	12.4	28.4	N/A
U2FB	225	13.5	20.6	0.0 (**< 0.01**)	0.0 (**< 0.01**)	0.9 (**< 0.01**)	**< 0.01**
U1BT	182	14.2	16.0	4.9 (**< 0.01**)	19.2 (0.07)	35.2 (0.15)	**< 0.01**

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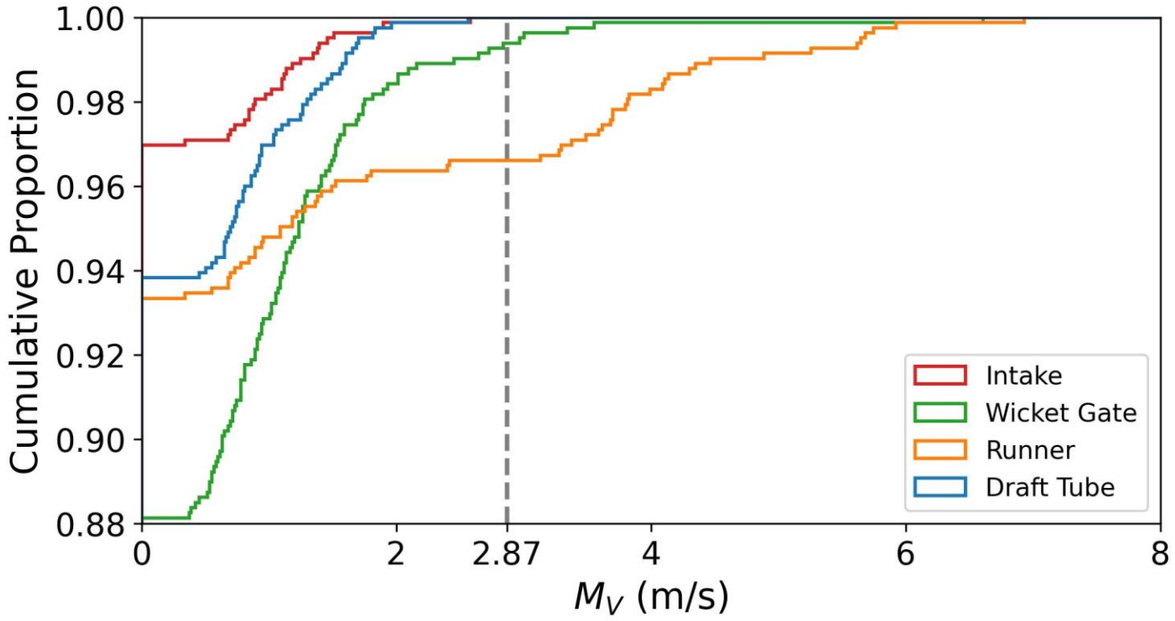
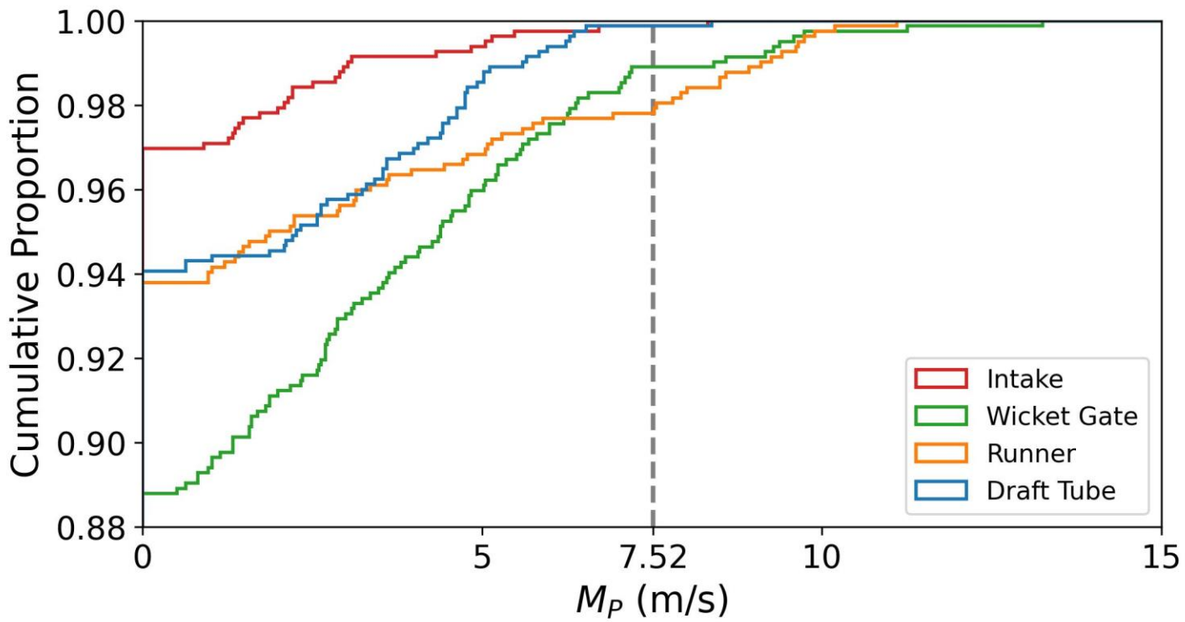
Estimated Survival Rates of U3AB Using Strike Metrics

Comparison of Survival Rates Estimated from Strike Metrics (Unit 3 - Characterization)

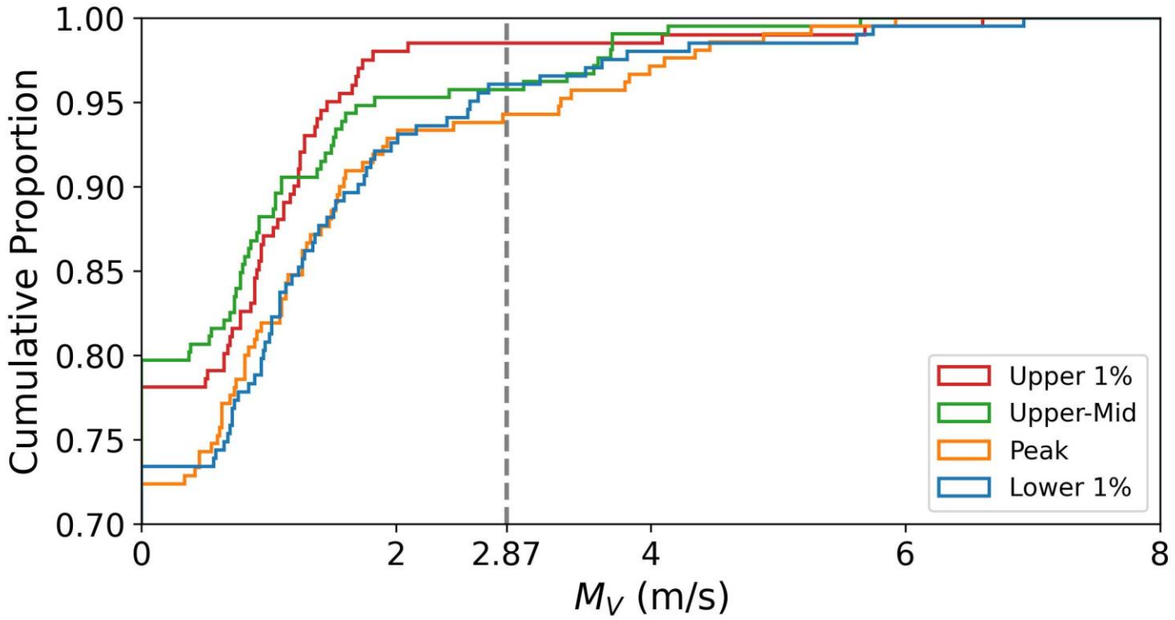


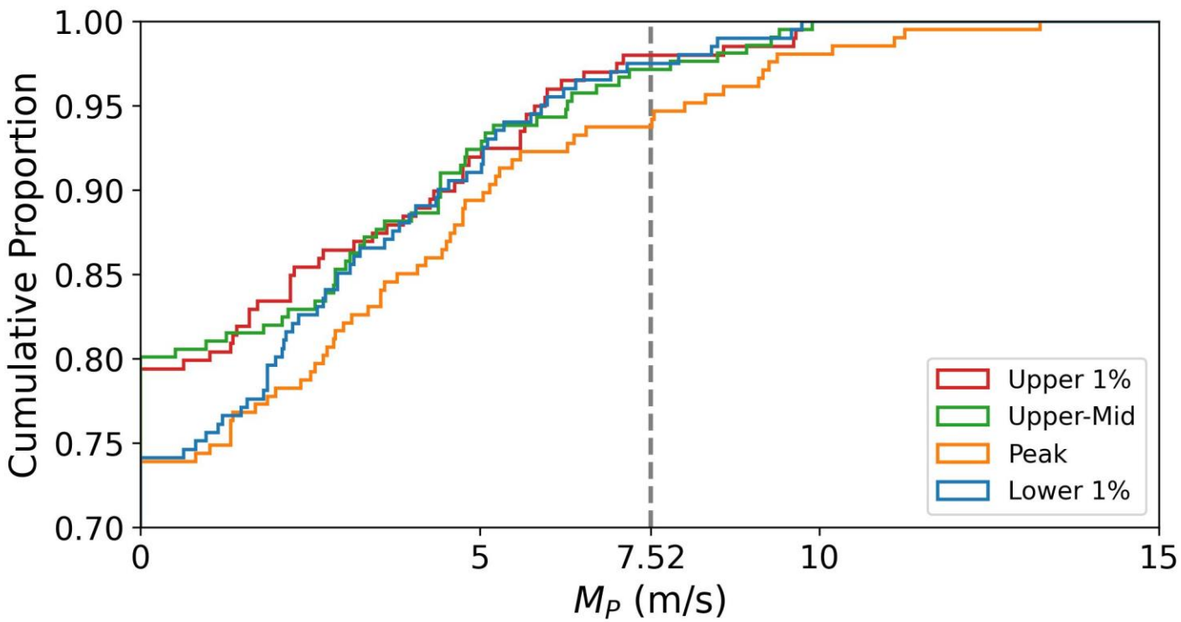


Hydraulic Region	Survival Rate Estimated from M_V CDF (%)	Survival Rate Estimated from M_P CDF (%)
Intake	100	99.94
Wicket Gate	99.41	98.34
Runner	96.69	97.45
Draft Tube	100	99.94

Notes: The thresholds of strike metrics (2.87 m/s for M_V and 7.52 m/s for M_P) were recalibrated based on the updated average live fish 48-hour survival rate (i.e., 97.75%) for U2FB.
Live Fish Data Source: Normandeau Associates. (2024). *Direct Survival and Injury of Juvenile Spring Chinook Salmon Passed through a Newly Designed Adjustable Blade Turbine at Ice Harbor Dam, 2023.*

Comparison of Survival Rates Estimated from Strike Metrics (Unit 3 - Characterization)





Operating Point	# of SF Releases	Survival Rate Estimated from M_V CDF (%)	Survival Rate Estimated from M_P CDF (%)	Live Fish 48-h Survival Rate (%)
Lower 1%	203	96.23	96.77	97.51
Peak	210	94.30	92.84	94.73
Upper-Mid	212	96.12	96.94	97.66
Upper 1%	201	98.70	97.15	97.74

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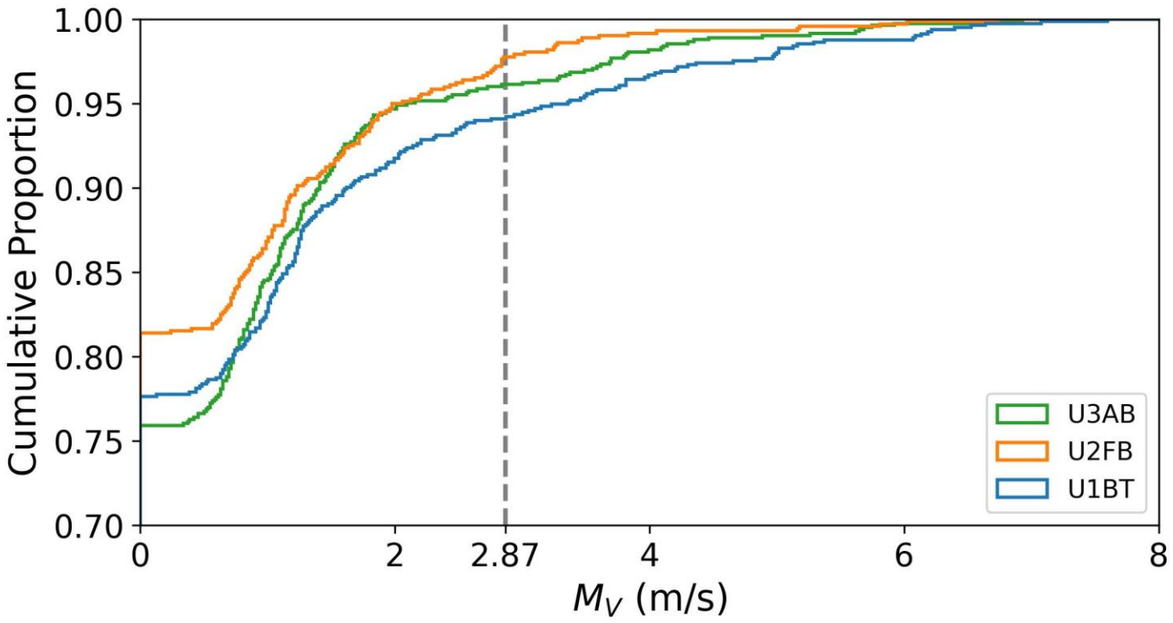
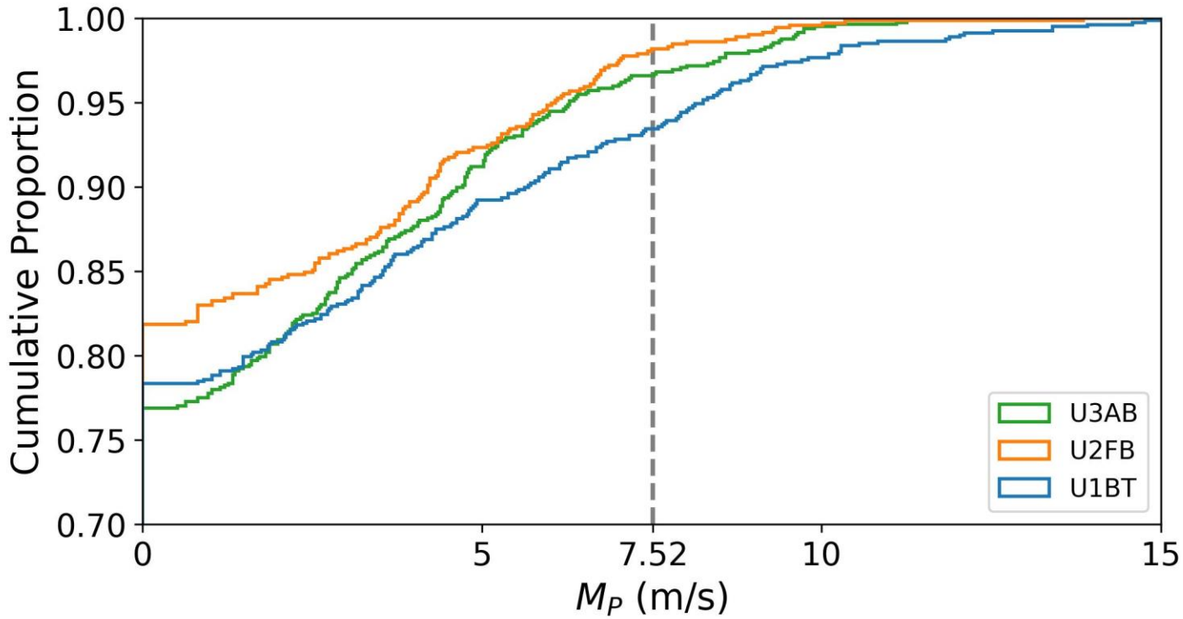
Comparison of Estimated Survival Rates for Three Turbines

Comparison of Survival Rates Estimated from Strike Metrics between Turbines





Study	Survival Rate Estimated from M_V CDF (%)	Survival Rate Estimated from M_P CDF (%)	Live Fish 48-h Survival Rate (%)
U3AB	96.14	95.75	96.91
U2FB (calibration)	97.75	97.75	97.75
U1BT	94.22	92.81	95.90

- The estimated survival rate for U3AB was higher than that for U1BT and lower than that for U2FB.

Summary

- SF were used to collect data to characterize the physical conditions of U3AB
- At Lower 1% and Peak operating points for U3AB, observed nadir pressures for more than 99% of SF releases were above 9.3 and 12.5 psia, and more than 97% of SF releases were above the atmospheric pressure level of 14.7 psia
- At the Upper 1% operating point, the percentages of observed nadir pressures below 9.3, 12.5, and 14.7 psia for U3AB were 3.9% (p-value < 0.01), 6.8% (p-value > 0.05), and 6.8% (p-value > 0.05) lower than those for U1BT, while significantly higher than those for U2FB (p-value < 0.01)
- Estimated 48-h survival rates for U3AB were higher than those for U1BT and lower than those for U2FB
- Overall, the results show that the fish passage conditions have improved for U3AB compared to U1BT

Acknowledgements

- **Funding support:**
  - U.S. Army Corps of Engineers, Walla Walla District
  - U.S. Department of Energy Water Power Technologies Office
- **U.S. Army Corps of Engineers:**
  - Brad Trumbo, Karl Anderson, Jon Renholds, Ricardo Walker, Chuck Chamberlain, Martin Ahmann, Ken Fone, Floyd Stredwick and the rigging crew
- **Pacific Northwest National Laboratory:**
  - Emily Akins, Ayla Bales, Brandon Boehnke, Jenn Brogdon, Margaret Giggie, Adam Hall, Joe Hawkins, Greg Kondyukov, Brett Pflugrath, Kate Deters, Richard Lundy, Zheng Hao Ma, Hongfei Hou, Rajesh Singh, Habilou Ouro-Koura, Rodrigo Ruiz, Cassandra Shaffer, John Stephenson, Benjamin Vaage, Kathy Lavender, Jill Janak, and Holly Campbell
- **Normandeau Associates**
  - Cory Hoffman and the other crew members

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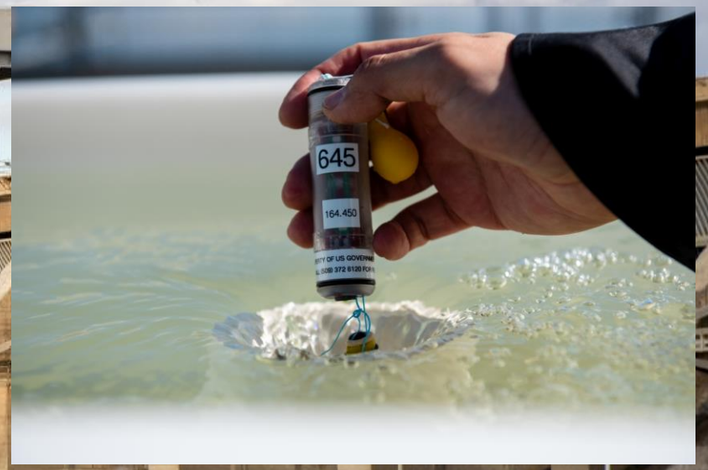
Questions?



Nadir Pressure Normalization – U3AB

- The pressure corresponding to the difference between the actual head (~99 ft) and the target head (96 ft) was used to normalize the nadir values for this study.