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To: *Dr. David Willy*

From: *HCC26*

Date: *03/20/2026*

Re: *Final Testing Plan*

Background/Objectives

By conducting this lab we intend to learn about the different effects of water speed on our turbine system, possible realistic turbine efficiency, optimal rotation resistance, and potential failure points. This will be done using a hydraulic bench at the Thermal Fluids lab with a scaled down turbine and Prony brake. Water at different inlet speeds will be sent through the turbine system and mechanical energy will be collected. Five different water speeds will be measured using a bucket timer method from the water bench 0.1 L/s to 1 L/s or maximum output in rough increments of 0.2 L/s. In addition to that, six different dead weights will be used to see the effect of tension in the Prony brake on the power. After the experiment is conducted, calculations will be made to see the efficiency of the system and compare our results to what they should be theoretically.

Methods

When setting up for this experiment the first thing that needs to be done is making sure the Prony brake is all set up and ready to go outside of the testing lab. This means that the turbine will be fully mounted onto the Prony brake and the shaft will be connected to the drum snugly and securely. The turbine will be able to spin and pull on the string nice and smoothly.

Once the turbine and Prony brake are ready and the experiment can be tested, the first step is to securely attach the Prony brake setup to the hydraulic bench by using its suction legs and a tight fit into the bench ensuring it stays in place. The water tube will then be placed in front of the turbine by the stand mount.

Before the force data is to be recorded the mass flow rate Q (L/s) is recorded using the bucket timer method. This is done by having one individual from the team measure the time taken for the bucket to fill to 5 liters, another team member would write these measurements down,and the last team member would be controlling the bench flow control valve and draining the bucket once the measurement was finished. We will do this three times before each new testing speed to get the new average flow rate.

Once this is all set up the experiment can truly begin. The net force output of the turbine will be measured using the Prony brake which acts on the rotating shaft of the turbine. Greater force applied by this Prony brake will cause the turbine to rotate slower. Two force values will be measured from the brake, one from the force gauge and the other from the dead weight. The dead weight will be increased from 0g to 500g in roughly 100g increments as seen in figure #. The dead weight will be attached to the string by a hook through a hole at the end. This carrier and corresponding weights will be provided by the lab. The weight will fall through a hole in the board ensuring it provides tension on the cable. With both forces, the net force output of the turbine is equal to gauge force minus the dead weight force.

Also while collecting force data, one team member will be using the tachometer to measure the rpm of the turbine for its corresponding flow rate and dead weight. This will be done for each run for five total different flow rates and six different dead weights totalling 30 runs for this experiment.

Calculations

Once all the trials have been completed, we will have a data set for all three measurements: force, flow rate, and rpm. With these data values and some other measured ones like weight, tube diameter, and turbine diameter, the power and efficiency can be calculated. Ideally this would also be compared to the electrical power extracted. Like all experiments this experiment relied on and used many important and less important equations. Some equations are used to convert numbers to different units or get a simple calculation to move on with the process. Others are the equations that the experiment will rely on and are setting out to test and understand.

The first couple equations used are just meant to find simple values that were easily found. To get started with the two measured variables: time (t) in seconds, and volume (V) in liters; equation 1 was used to find Volumetric flow rate in Liters per Second.

$$\mathrm{Q} = V/\mathrm{t} \tag{1}$$

After finding the volumetric flow rate, that value can be used in equation 2 to calculate the velocity (V) of the water in m/s coming out of the nozzle. This is done by dividing that flow rate over the area (A) of the nozzle opening in m^2.

$$\mathrm{V} = \mathrm{Q}/\mathrm{A} \tag{2}$$

The angular velocity was calculated from the measured rotation speed from the tachometer by conversion from rpm to rad/s. This angular velocity is used to calculate the velocity of the bucket (U) using the turbine radius through equation 3 below.

$$U = \omega \cdot r_{turbine} \tag{3}$$

The torque output from the turbine was calculated using the net force output measured by the Prony brake multiplied by the radius of the turbine. By multiplying this output torque with the angular velocity of the turbine, a power output (W_O) can be found as seen in equation 4 below.

$$W_O = T \cdot \omega \tag{4}$$

Now all that's needed is to calculate the efficiency of the turbine which will be done by calculating and comparing the power in to the power out. To find the power into the system, we need to know the pressure at the end of the water (p) which can be found by using the density (ρ) and velocity of the water (V) as seen below in equation 5.

$$p = \tfrac{1}{2} * \rho * V^2 \tag{5}$$

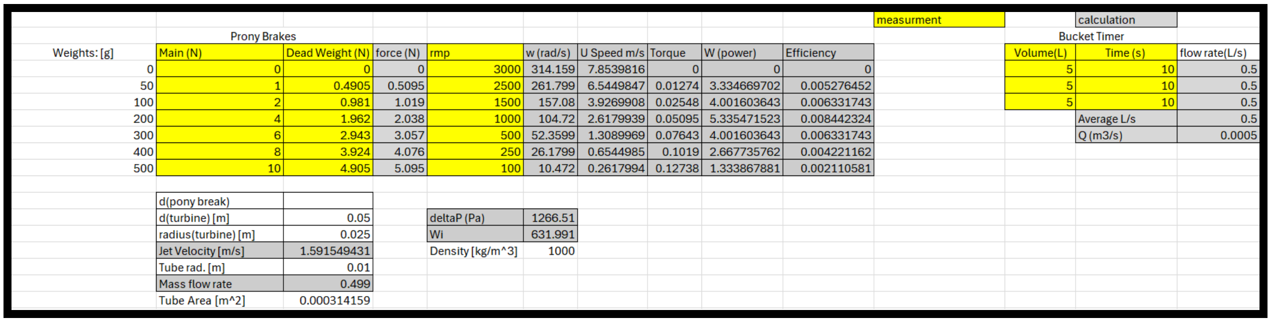
The input power into the turbine can now be calculated using the flow rate of the water jet and the dynamic pressure reading of the tube as seen in equation 6 below.

$$W_i = Q \cdot p \tag{6}$$

The real efficiency of the turbine can then be calculated using the input power and calculated power output of the turbine as seen in equation 7.

$$\eta = W_O / W_i \tag{7}$$

Theoretical Values



measurment | calculation

Prony Brakes

Weights: [g]	Main (N)	Dead Weight (N)	force (N)	rmp	w (rad/s)	U Speed m/s	Torque	W (power)	Efficiency
0	0	0	0	3000	314.159	7.8539816	0	0	0
50	1	0.4905	0.5095	2500	261.799	6.5449847	0.01274	3.334669702	0.005276452
100	2	0.981	1.019	1500	157.08	3.9269908	0.02548	4.001603643	0.006331743
200	4	1.962	2.038	1000	104.72	2.6179939	0.05095	5.335471523	0.008442324
300	6	2.943	3.057	500	52.3599	1.3089969	0.07643	4.001603643	0.006331743
400	8	3.924	4.076	250	26.1799	0.6544985	0.1019	2.667735762	0.004221162
500	10	4.905	5.095	100	10.472	0.2617994	0.12738	1.333867881	0.002110581

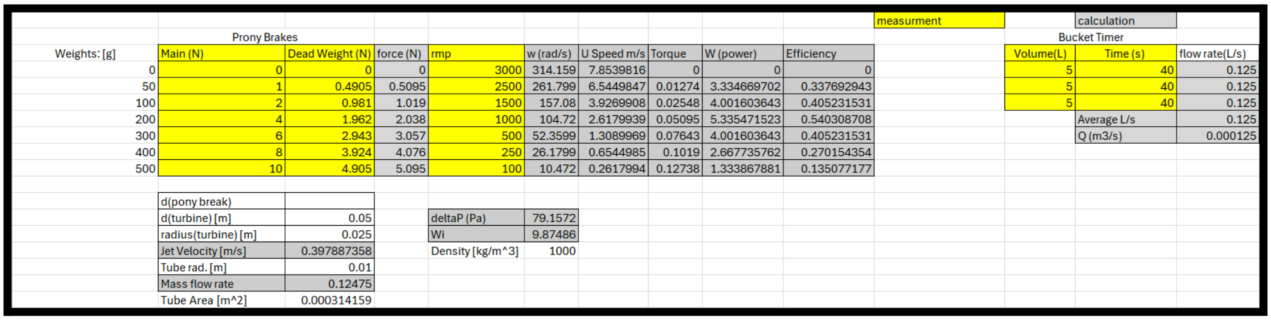
Bucket Timer

Volume(L)	Time (s)	flow rate(L/s)
5	10	0.5
5	10	0.5
5	10	0.5
	Average L/s	0.5
	Q (m3/s)	0.0005

d(pony break)	
d(turbine) [m]	0.05
radius(turbine) [m]	0.025
Jet Velocity [m/s]	1.591549431
Tube rad. [m]	0.01
Mass flow rate	0.499
Tube Area [m^2]	0.000314159

deltaP (Pa)	1266.51
Wi	631.991
Density [kg/m^3]	1000

Figure 1: Theoretical High Speed Values



measurment | calculation

Prony Brakes

Weights: [g]	Main (N)	Dead Weight (N)	force (N)	rmp	w (rad/s)	U Speed m/s	Torque	W (power)	Efficiency
0	0	0	0	3000	314.159	7.8539816	0	0	0
50	1	0.4905	0.5095	2500	261.799	6.5449847	0.01274	3.334669702	0.337692943
100	2	0.981	1.019	1500	157.08	3.9269908	0.02548	4.001603643	0.405231531
200	4	1.962	2.038	1000	104.72	2.6179939	0.05095	5.335471523	0.540308708
300	6	2.943	3.057	500	52.3599	1.3089969	0.07643	4.001603643	0.405231531
400	8	3.924	4.076	250	26.1799	0.6544985	0.1019	2.667735762	0.270154354
500	10	4.905	5.095	100	10.472	0.2617994	0.12738	1.333867881	0.135077177

Bucket Timer

Volume(L)	Time (s)	flow rate(L/s)
5	40	0.125
5	40	0.125
5	40	0.125
	Average L/s	0.125
	Q (m3/s)	0.000125

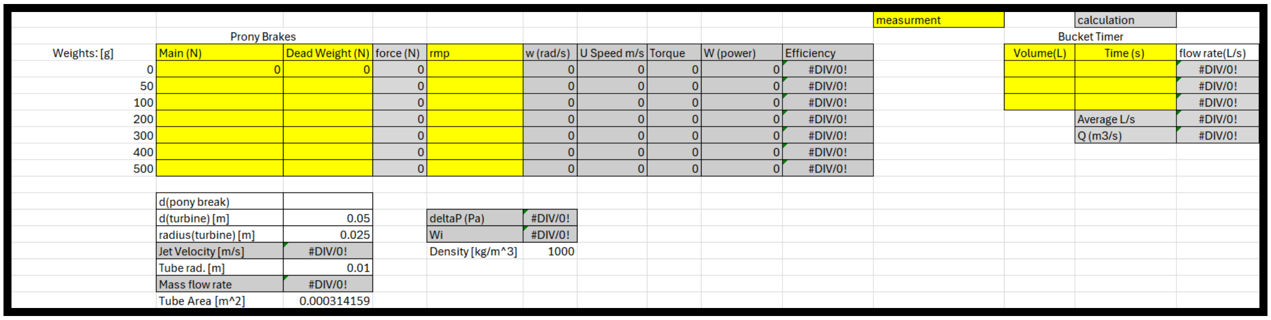
d(pony break)	
d(turbine) [m]	0.05
radius(turbine) [m]	0.025
Jet Velocity [m/s]	0.397887358
Tube rad. [m]	0.01
Mass flow rate	0.12475
Tube Area [m^2]	0.000314159

deltaP (Pa)	79.1572
Wi	9.87486
Density [kg/m^3]	1000

Figure 2: Theoretical Low Speed Values

As seen in the figures above, using some theoretical values for the likely forces attained, rotational speed, and flow rate a potential power output is revealed to us. Since the model is scaled down to such a high degree, the power and efficiency will not show hyper realistic data to what the turbine will actually collect, but through this process it will give a good guideline of how the turbine will react. With that said, the theoretical power range for this experiment is to be inside of 1 Watt of power to 6 Watts of power. It should theoretically peak at around medium weight (~200g) resistance. Lastly, with higher speeds, the work in becomes much higher for an efficiency that is lower, giving us an efficiency range of 1% on the quick end and 75% on the slow side. Through actually running this experiment, seeing how efficient the turbine truly runs will be helpful for us.

Result Tables



measurment

calculation

Prony Brakes

Weights: [g]	Main (N)	Dead Weight (N)	force (N)	rmp	w (rad/s)	U Speed m/s	Torque	W (power)	Efficiency
0	0	0	0		0	0	0	0	#DIV/0!
50			0		0	0	0	0	#DIV/0!
100			0		0	0	0	0	#DIV/0!
200			0		0	0	0	0	#DIV/0!
300			0		0	0	0	0	#DIV/0!
400			0		0	0	0	0	#DIV/0!
500			0		0	0	0	0	#DIV/0!

Bucket Timer

Volume(L)	Time (s)	flow rate(L/s)
		#DIV/0!
		#DIV/0!
		#DIV/0!
	Average L/s	#DIV/0!
	Q (m3/s)	#DIV/0!

d(pony break)	
d(turbine) [m]	0.05
radius(turbine) [m]	0.025
Jet Velocity [m/s]	#DIV/0!
Tube rad. [m]	0.01
Mass flow rate	#DIV/0!
Tube Area [m^2]	0.000314159

deltaP (Pa)	#DIV/0!
Wi	#DIV/0!
Density [kg/m^3]	1000

Figure 3: Result Table

As seen in the past figures 1 & 2 for the theoretical values, figure 3 above shows how and where we will enter our data when running the experiment. Five of these tables will be used for the five different water outputs. The dead weight will remain the same across each water speed but the rest of the yellow boxes will be where data collected will be sent. Force measured from the force gauge will be sent in and rpm measured from the tachometer will be collected for each weight. The bucket timer will also be measured three times before the runs as mentioned before. Once the data is collected the results will fill in due to the excel equations already made.

Specification Sheet Preparation

To evaluate whether the turbine system meets both customer and engineering requirements, a specification sheet was developed based on the Quality Function Deployment (QFD). This sheet links measurable experimental results to the most critical system performance criteria identified in figure 4.

Since not all Customer requirements can be directly tested in a laboratory environment, the specification sheet distinguishes between experimentally validated requirements and those assessed through modeling, simulation, or design assumptions.

Table 5.1 Customer Requirements Evaluation

Customer Requirement	Evaluation Method	CR Met? (Y/N)	Client Acceptable? (Y/N)
Reliable Power Supply	Measured power output vs flow rate	Testing Pending	
Structural Integrity	Assessed through dam constraints and material assumptions	Testing Pending	
Competitive Cost	Estimated through LCOE Modeling	Testing Pending	
Recreational Preservation	Not Testable	Testing Pending	
Low Environmental Impact	Environmental Impact Study	Testing Pending	
Long Life Expectancy	Not Testable	Testing Pending	
Regulatory Compliance	Not Testable	Testing Pending	

Table 5.2 Engineering Requirements & Testing Results

Engineering Requirement	Target	Tolerance	Measured Value	ER Met? (Y/N)	Client Acceptable? (Y/N)
Power Output (W)	1 - 6 W	± 0.5 W	Testing Pending		
Efficiency (%)	10 - 75 %	± 5 %	Testing Pending		
Flow Rate (L/s)	.1 - 1 L/s	± .05 L/s	Testing Pending		
Rotational Speed (RPM)	100-3000 RPM	± 5 %	Testing Pending		
Torque Output (Nm)	.01 - .13 Nm	± 5 %	Testing Pending		

Competitive Cost ($/kWh	$.08/ kWh	± $ .03/kWh	Testing Pending		

Customer Requirements And Engineering Requirements Discussion

The system performance was evaluated at a preliminary level by comparing predicted and partially measured results against the engineering requirements (ERs) and customer requirements (CRs) identified through the Quality Function Deployment (QFD). At this stage, the analysis represents a preliminary design assessment, with full experimental validation to be conducted in future testing.

Customer Requirements Evaluation

The primary customer requirement of reliable power supply is expected to be satisfied based on the predicted power output trends derived from analytical modeling and initial calculations. The system demonstrates the ability to generate consistent power across a range of operating conditions, indicating that it is capable of meeting reliability expectations once fully tested.

The requirement for competitive cost was evaluated using estimated cost of energy (LCOE) calculations. Based on a target of approximately $ 0.08/kWh with a tolerance of ± $0.03/kWh, the design appears to fall within a feasible and competitive range for small-scale hydropower systems. This assessment is based on modeling and will require validation after experimental testing.

Customer requirements such as structural integrity, recreational preservation, long life expectancy, and regulatory compliance were not experimentally tested at this stage. These requirements are instead addressed through design assumptions and standard engineering practices, and will require further verification during later stages of development.

The requirement for low environmental impact was assessed qualitatively. Given the small-scale and low-head nature of the system, minimal environmental disruption is expected; however, this has not yet been formally evaluated.

Engineering Requirements Evaluation

The engineering requirements were assessed using theoretical calculations and preliminary data. The power output requirement (1–6 W) is expected to be achieved based on predicted system behavior, though this will be confirmed during physical testing.

The efficiency of the system is estimated to fall within the acceptable range of 10–75%, acknowledging that small-scale systems typically exhibit lower efficiencies due to mechanical and flow losses. Final efficiency values will be determined experimentally.

The flow rate requirement (0.1–1.0 L/s) is defined based on the intended operating conditions of the system and will be controlled during testing.

The rotational speed (RPM) range (approximately 100–3000 RPM) is derived from theoretical angular velocity calculations and represents the expected operating range of the turbine.

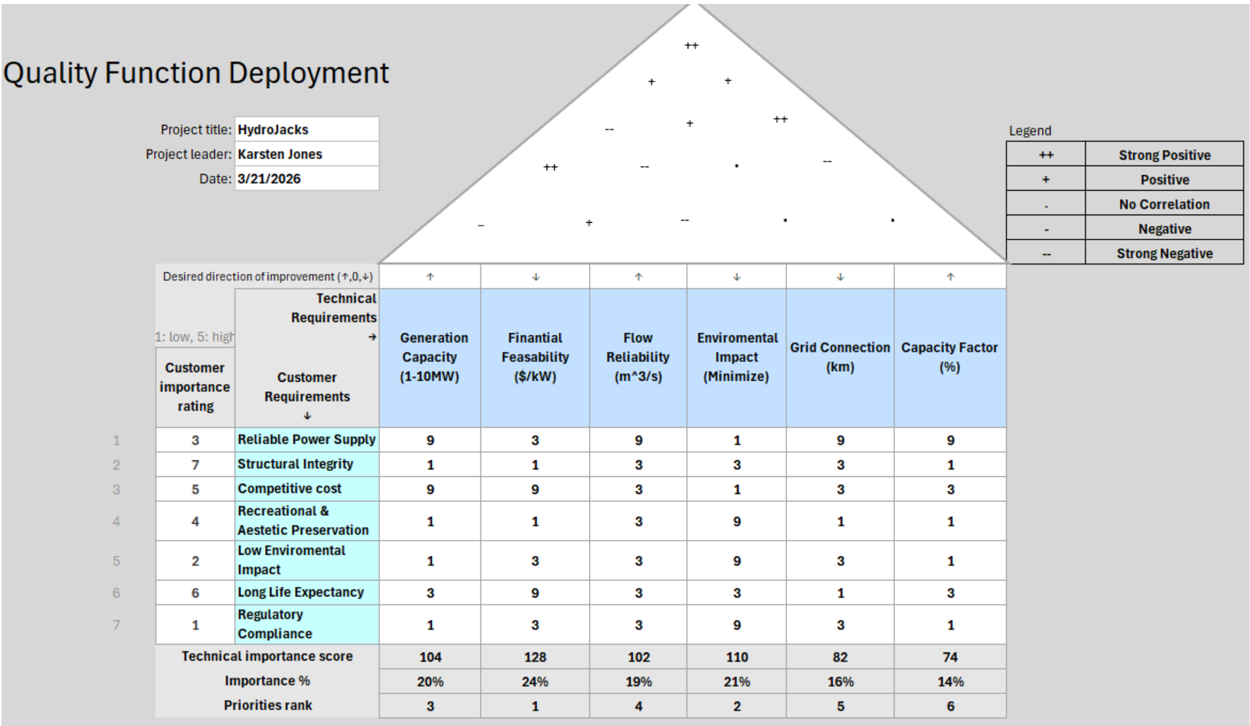
The torque output, calculated using the Prony brake relation, is predicted to range from approximately 0.0127 Nm to 0.1274 Nm. This relationship is based on theoretical loading conditions and will be validated during experimental testing.

Finally, the competitive cost requirement is supported through analytical estimation and remains within the acceptable tolerance range, pending confirmation with model data.

Overall System Assessment

At this stage, the system meets the majority of the engineering and customer requirements from a design and analytical standpoint. While several requirements have not yet been experimentally verified, the theoretical values suggest the system is technically feasible and aligned with the priorities identified within the QFD and a scaled down perspective. Future work focuses on experimental validation of power output, efficiency, torque and flow behavior to confirm the system meets all requirements under real operating conditions

QFD and Requirements



Quality Function Deployment

Project title: HydroJacks
Project leader: Karsten Jones
Date: 3/21/2026

Legend

++	Strong Positive
+	Positive
.	No Correlation
-	Negative
--	Strong Negative

	Customer importance rating (1: low, 5: high)	Technical Requirements → / Customer Requirements ↓	Generation Capacity (1-10MW)	Finantial Feasability ($/kW)	Flow Reliability (m^3/s)	Enviromental Impact (Minimize)	Grid Connection (km)	Capacity Factor (%)
	Desired direction of improvement (↑,0,↓)		↑	↓	↑	↓	↓	↑
1	3	Reliable Power Supply	9	3	9	1	9	9
2	7	Structural Integrity	1	1	3	3	3	1
3	5	Competitive cost	9	9	3	1	3	3
4	4	Recreational & Aestetic Preservation	1	1	3	9	1	1
5	2	Low Enviromental Impact	1	3	3	9	3	1
6	6	Long Life Expectancy	3	9	3	3	1	3
7	1	Regulatory Compliance	1	3	3	9	3	1
	Technical importance score		104	128	102	110	82	74
	Importance %		20%	24%	19%	21%	16%	14%
	Priorities rank		3	1	4	2	5	6

Figure 4: QFD

As seen in figure 4, a lot of the customer or technical requirements focus more on the analysis of the turbine at a certain dam site rather than the turbine itself. Things like the environmental impact, financial feasibility, recreational and aesthetic preservation, and long life expectancy can not really be tested in the lab. This experiment focuses more on how the turbine might act under different conditions. The goals of this experiment are to understand how and when the turbine will be most efficient, how consistent the turbine will perform, and ideally how efficient the transition to real power will be. Along with these, we will also be looking for any potential failure or oversights about the turbine that we haven't noticed before. This whole experiment is to give us foresight on a couple requirements like generation capacity, structural integrity, flow reliability, and grid connection. While this experiment does not give results to most customer requirements, other things like our flow duration curve and sam model simulations will be doing the heavy lifting on customer requirements.

Top Level Testing Summary

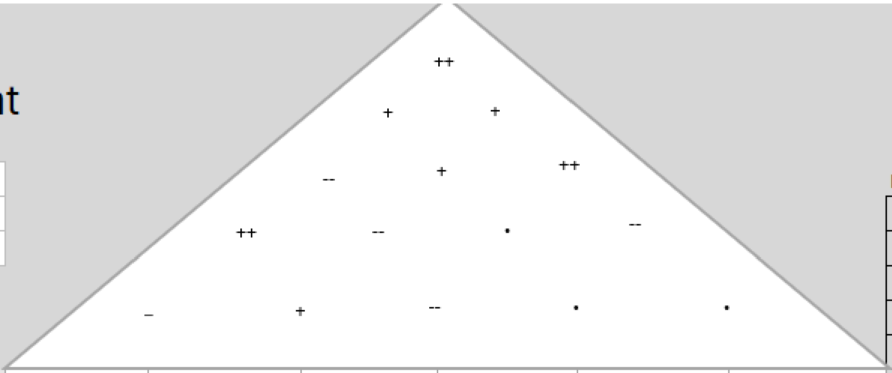
Experiment/Test	Relevant DRs	Equipment Needed	Other Resources
Part 1 - Turbine spin	-Turbine same model as actual -Turbine fits for experiment -Turbine spins	-Hydraulic bench -Turbine w/ all parts -Tachometer -Force gauge	-Access to Thermal Fluids lab -4 teammates for testing
Part 2 - Prony brake	-Shaft spins smoothly -Drum collects energy efficiently -Doesn't fall apart	-Prony brake made by: shaft, drum, wood parts, bearings, 3D print, & rope	-Crafting equipment -Excel spreadsheet to place results
Part 3 - Energy collection	-Transmitter work -Generator collect energy -Batter save and read energy	-Transmitter -Generator -Battery	-Electrical Engineering subteam
Part 4 - Translation to actual analysis	-The turbine behaves in an expected way	-Turbine -Prony brake -Hydraulic bench	-Real world data

Conclusion

For this testing, the important things are mainly the design requirements like simply the turbine spinning and collecting work/power. There are engineering requirements that relate like the amount of power being extracted, but for the purposes of our competition and the reality of a scaled down model, actual power levels are not that impactful. The electrical and energy extracting portion of the test would be nice to see how mechanical power actually translates to real power. Unfortunately we do not believe the energy team will finish the build before testing so its planning has not been put into motion. The goal after the test is to revise and rerun though so on a second or third test the electrical section of this lab may be taken into effect. Overall this model is just here to give us a helpful and more mindful understanding of real world effects. Additionally, the build and test phase, while optional, provides valuable validation data and strengthens overall design justification.

Quality Function Deployment

Project title: **HydroJacks**
Project leader: **Karsten Jones**
Date: **3/21/2026**



Legend

++	**Strong Positive**
+	**Positive**
.	**No Correlation**
-	**Negative**
--	**Strong Negative**

	Desired direction of improvement (↑,0,↓)		↑	↓	↑	↓	↓	↑
	1: low, 5: high	**Technical Requirements →**						
	Customer importance rating	**Customer Requirements ↓**	**Generation Capacity (1-10MW)**	**Fintantial Feasability ($/kW)**	**Flow Reliability (m^3/s)**	**Enviromental Impact (Minimize)**	**Grid Connection (km)**	**Capacity Factor (%)**
1	3	**Reliable Power Supply**	**9**	**3**	**9**	**1**	**9**	**9**
2	7	**Structural Integrity**	**1**	**1**	**3**	**3**	**3**	**1**
3	5	**Competitive cost**	**9**	**9**	**3**	**1**	**3**	**3**
4	4	**Recreational & Aestetic Preservation**	**1**	**1**	**3**	**9**	**1**	**1**
5	2	**Low Enviromental Impact**	**1**	**3**	**3**	**9**	**3**	**1**
6	6	**Long Life Expectancy**	**3**	**9**	**3**	**3**	**1**	**3**
7	1	**Regulatory Compliance**	**1**	**3**	**3**	**9**	**3**	**1**
	Technical importance score		**104**	**128**	**102**	**110**	**82**	**74**
	Importance %		**20%**	**24%**	**19%**	**21%**	**16%**	**14%**
	Priorities rank		**3**	**1**	**4**	**2**	**5**	**6**