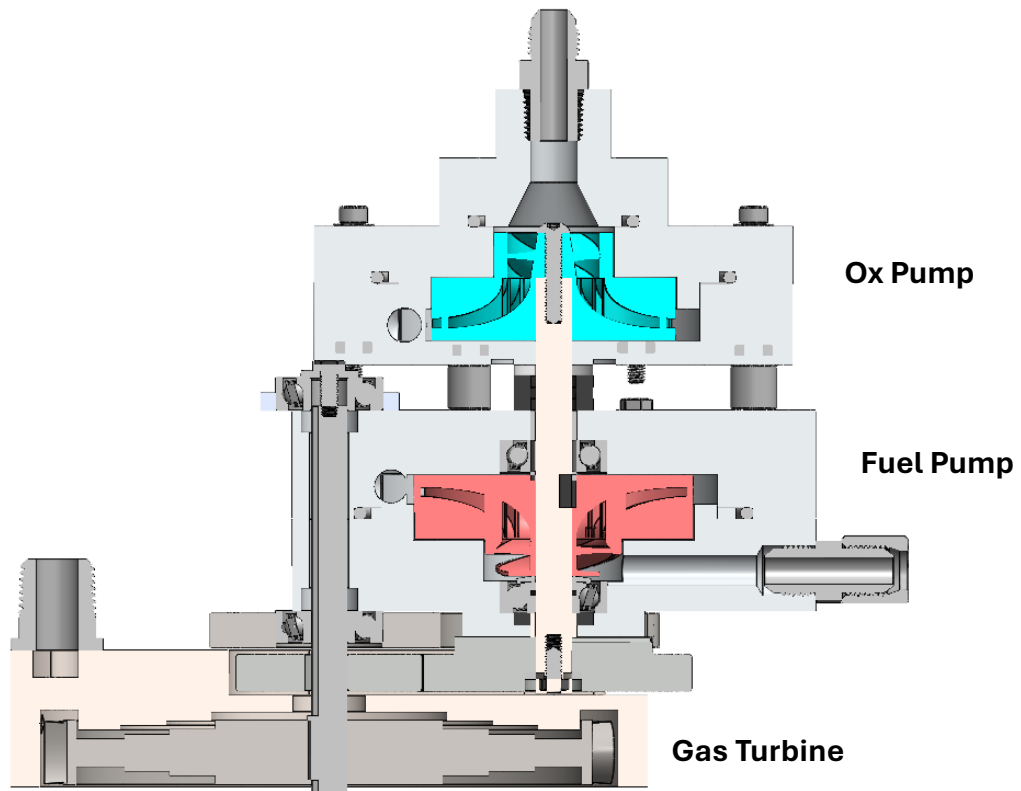


Turbopump Testing Recap



Summary

I (Brendan Morgan) designed/analyzed/machined/welded/integrated one complete turbopump, with serious design work beginning in September 2023 and the first test occurring the night of June 16-17 2024.

I'm calling the test a "spinflaw" (turbine spin-up + pump waterflow). The turbine is spun up using pressurized nitrogen gas from bottles, and water is flowed through both pumps. The nitrogen gas is attempting to simulate a 0.557 kg/s (1017 SCFM) gas flow from a theoretical gas generator. The water is attempting to simulate a 4.5 kg/s flow of liquid oxygen and a 3.8 kg/s flow of 75% ethanol fuel. It is attempting to pressurize the oxidizer outlet to 428 psi and the fuel outlet to 448 psi.

Most design and analysis work can be found on my github and google drive (though some things are quite unpolished and unorganized):

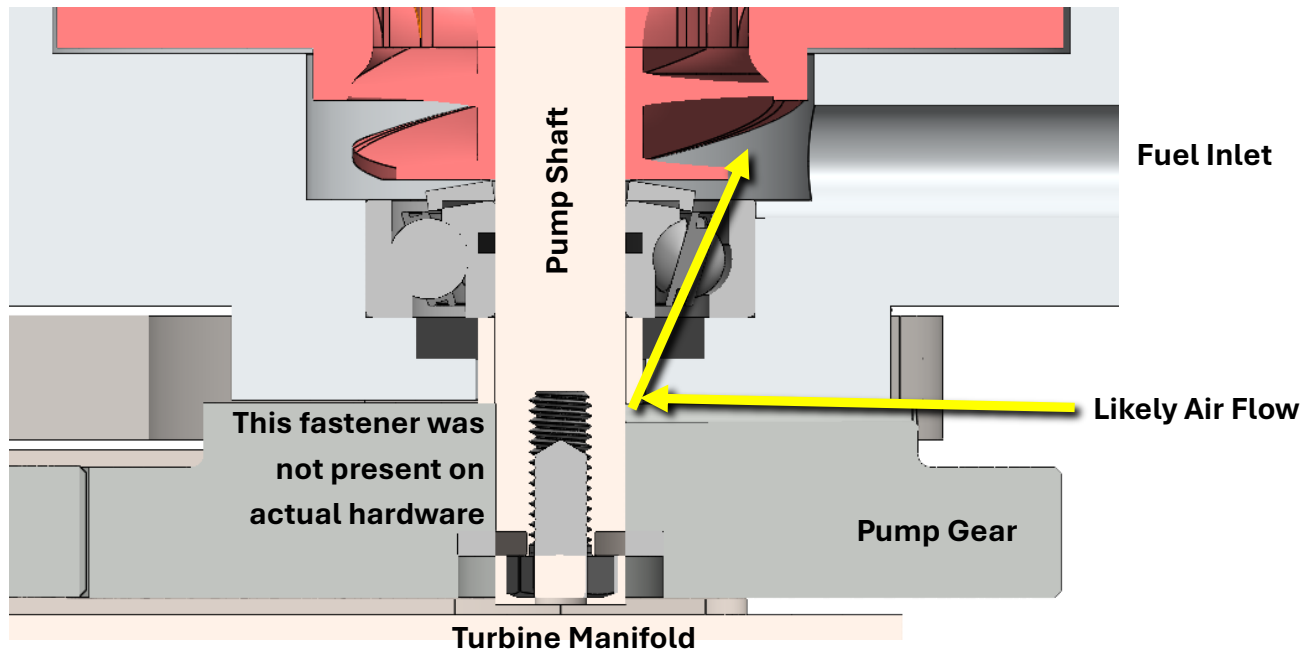
<https://github.com/BrendanJMorgan/Engine-Development>

https://drive.google.com/drive/u/0/folders/1xzCn_89ndQEU2PsFcl7RbZjL71s8Y_nX

Wins and Strong Points

- The fact that it worked at all is surprising to me.
- Little to no noticeable water leakage around any of the seals, barring a little dribbling on one side of the fuel pump. This was expected and discussed later.
- No noticeable structural damage on the pumps or turbine.
- Packing seals performed well as far as I can tell, though they should be inspected when the turbopump is taken apart later.
- Turbine seemed pretty balanced for the relatively minimal work I put in to doing so.

Main Issues



- 1) Fuel pump flow was almost nonexistent compared to lox pump. I am pretty sure this is because it was not properly sealed along its shaft, on the side close to the inlet and inducer. This is really the only relevant difference I can think of between the two pumps that could cause this. It could have been aspirating a lot of air into its inlet, more than water – maybe there was a high-pressure stream of air coming out the outlet but it's impossible to know from the video.

My intent was to put packing seals in the pictured gap, but because it rests against the bearing it jammed the balls when I tried this; I was not able to rotate the shaft by hand at all. I opted to not put any seal at all here because of lack of time and naively hoping that the clearance between the shaft and hole was small enough to kinda seal it. I knew water was going to leak out before the test started (which it did at a very slow dribble that doesn't really affect anything), but I hadn't thought about the fact that air would leak in during the test, in the opposite direction.

So that's a simple design oversight – I'm thinking now I may be able to correct this by adding a small, specifically dimensioned washer of some kind that separates the bearing from the packing seals, and adding a packing seal back in. Or I may switch the open ball bearing to a sealed ball bearing and take the hit on max shaft

RPM, especially since the real speed isn't getting close anyways. This test *did* demonstrate that packing seals work (at least to some degree), because there was a packing seals separating the fuel and lox pumps. If they did not work then the lox pump would have been aspirating air from the fuel pump and had similarly anemic performance.

- 2) The first test spun great, overcoming any friction, but subsequent tests ground to a halt. We could hear (and verified from videos) that the turbine would begin spinning up for a few seconds at most and then slowed to a stop. After reapproaching, I would try to spin the turbine by hand and each time it would feel caught until I worked it around a little bit and it would start spinning freely again. Some parts (especially the gear and fuel pump casing) were slightly warmer than the other parts. To be clear, everything was quite cold from water splashing around and adiabatically expanded nitrogen gas flowing through the system (both the dome regs and nitrogen bottles were fully iced up on their surface), but those parts were close to more room temperature.

So I think it's pretty clear the issue was a sudden spike in friction when it started spinning, and one that would not have appeared in the first test. In light of this I am pretty sure the issue is the pump gear sliding up along the shaft and coming in contact with the steel of the turbine manifold. A couple days ago I had angle grinded the pump shaft shorter and forgot to redrill and tap a bolt hole on its end which was to be used for the retention of that gear. So the gear was just friction fit axially onto the shaft (it still had a shaft key for rotation/torque so that wasn't an issue). I didn't fully remember this until integration was almost done, but I naively rationalized the fit was tight enough (I had to hammer it on originally, it was close to an interference fit probably) that I could leave it so I didn't have to take it all apart and put back together (which can take hours sometimes). Last night I noticed what was originally a tight fit had gotten progressively looser from fiddling around with the system. So about an hour or so before the test, I was able to place some 5 minute epoxy on the shaft around both sides of the gear (using a 3/32" welding rod, that's how thin the gap was). I think this epoxy job was enough for the first test to work. But because everything got quite cold and wet, the epoxy probably shattered and/or washed away at some point before the second test. Then the pump gear slid down the shaft during that test and the gear started rubbing on steel and brought the whole thing to a halt.

- 3) The rotation rate was way too low, so the whole system underperformed. Looking at the audio spectrum, there is a strong peak around $3750 \text{ Hz} \times 60 \text{ s/min} \times 40 \text{ blades/revolution} = 5625 \text{ RPM}$; the target for turbine speed is 30,000 RPM (and pump speed should be 20,000 RPM). This is almost certainly mainly because the nitrogen flowrate was much too slow. Target was $\sim 1000 \text{ SCFM}$, but a rough estimate of the actual rate would be $2 \text{ bottles} \times 230 \text{ SCF} / \sim 2.5 \text{ min} = 184 \text{ SCFM}$. Turbine speed is theoretically a linear function of gas \dot{m} , which completely tracks: $1017 \text{ SCFM} / 184 \text{ SCFM} \times 5625 \text{ RPM} = \sim 31000 \text{ RPM}$. So I think it is valid to say there is no speed problem with the turbopump itself, only the nitrogen feed to it.

I suspect the primary issue is the size of the orifice built into the bottle itself. I think it is possible a smaller effect might be a limitation of the dome reg when it gets quite cold; both regs were entirely iced up on their surface at the end of the test. I don't think pressure loss through the feed system is a major issue because Alex did a test of this and there was very little difference between the supply reg pressure and the pressure downstream of the dome regs, and everything is a straight shot from there down to the manifold orifices without opportunity for significant losses.