

July 2025 Hot Fire Summary

BSEP Engine 2 maiden test

On the 1st of July the BSEP Engine 2 was hot fire tested at Airborne Engineering Ltd.

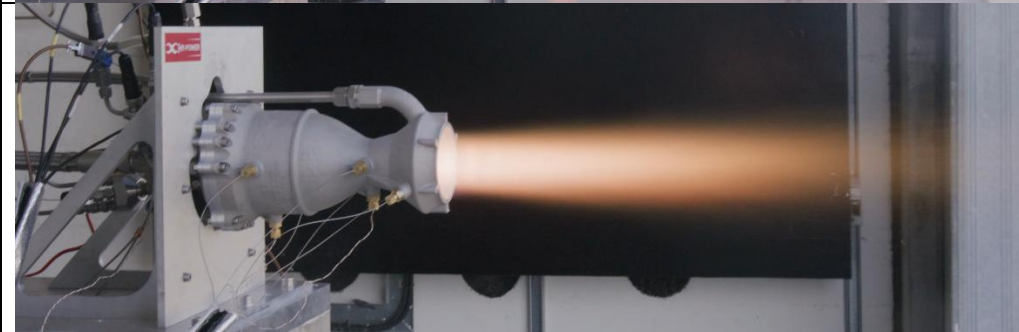
Property		Design Value	Average	Peak	Min	Unit
Nominal thrust		5.0	1.59	3.78	1.02	kN
Burn duration		5.0	5.0			s
Specific Impulse		198.32	114.13	249.55	73.90	s
Fuel		99% IPA 1% PDMS	99% IPA 1% PDMS			[-]
Oxidiser		N ₂ O	N ₂ O			[-]
Fuel mass flow rate	Target	0.64	0.36	0.93	0.0	kg/s
Ox mass flow rate	Target	1.93	1.06	1.14	0.96	kg/s
OF mass ratio (Meas)		3.01	2.96	inf	1.19	[-]
Chamber Pressure		20	7.02	10.63	3.36	bar

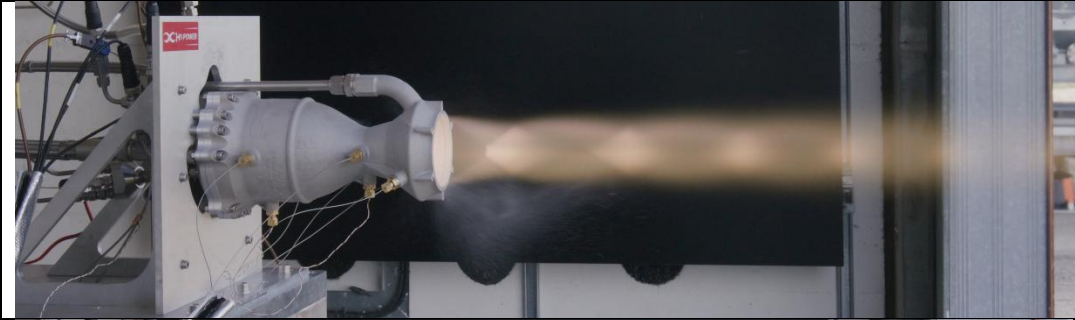
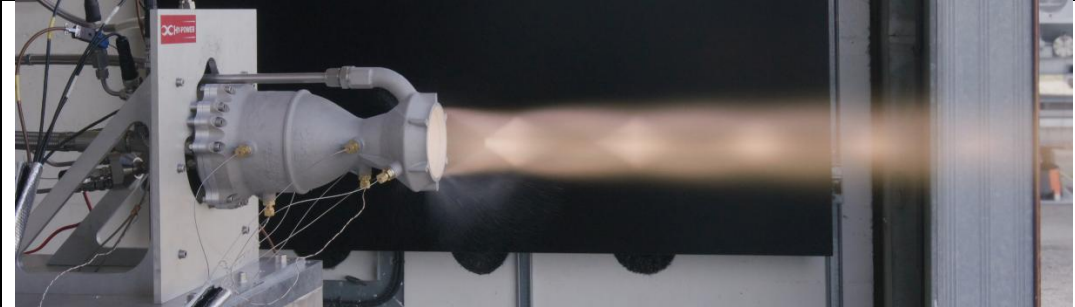
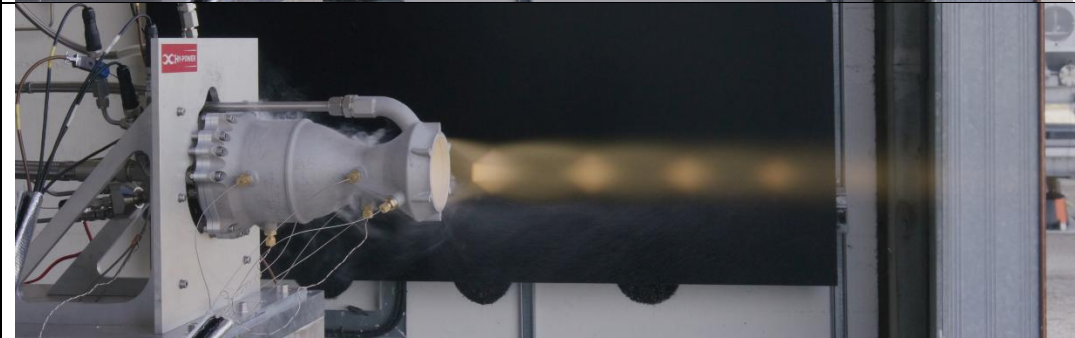
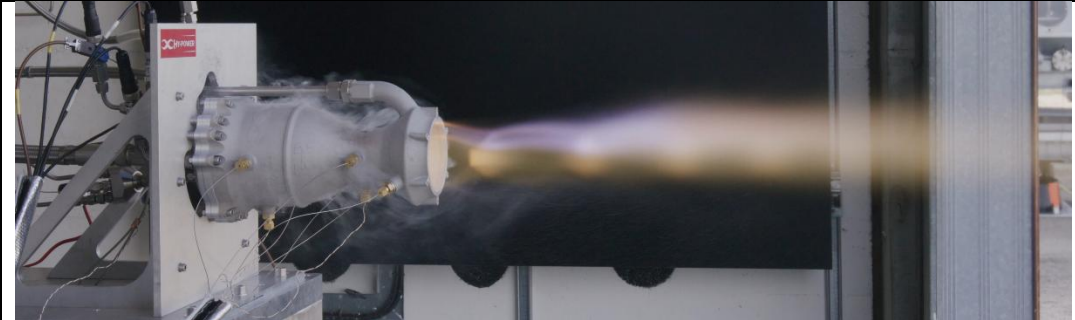
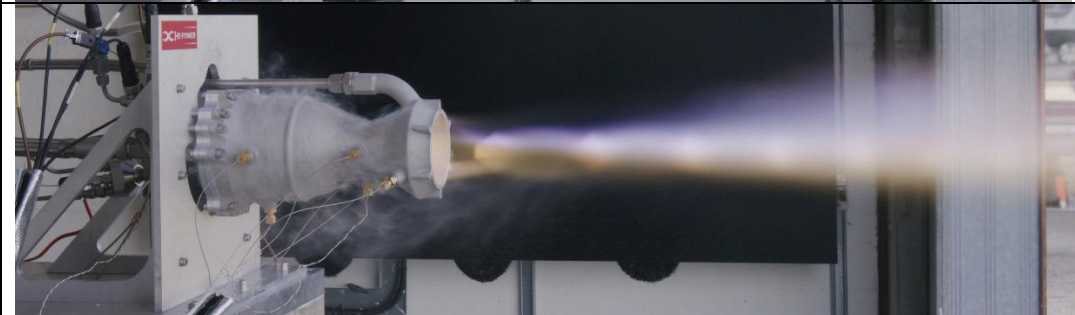
Measurements taken as the mean average between 1 – 5 s.

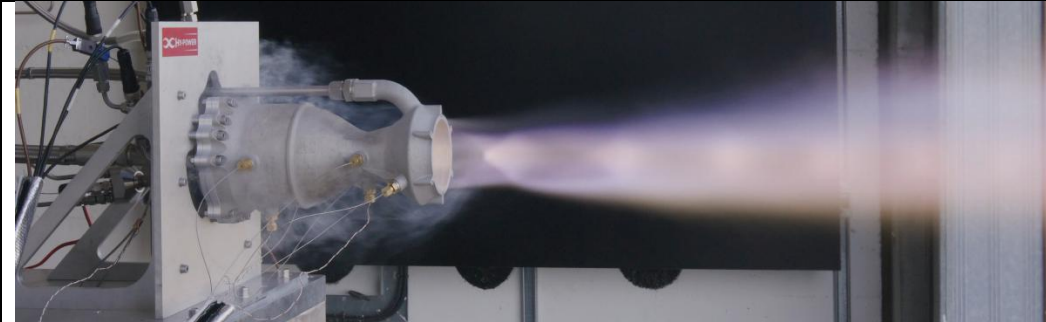
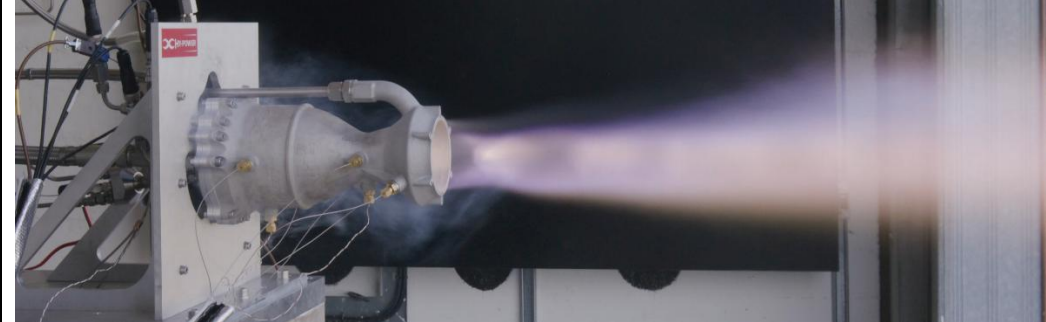
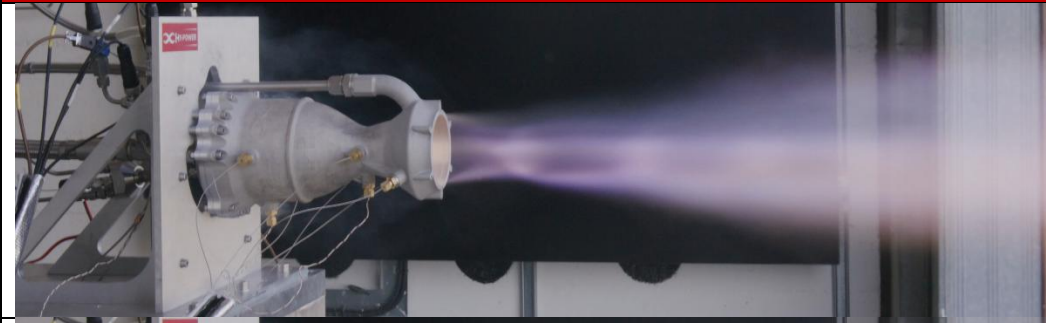
The burn can be split into 5 clear segments:

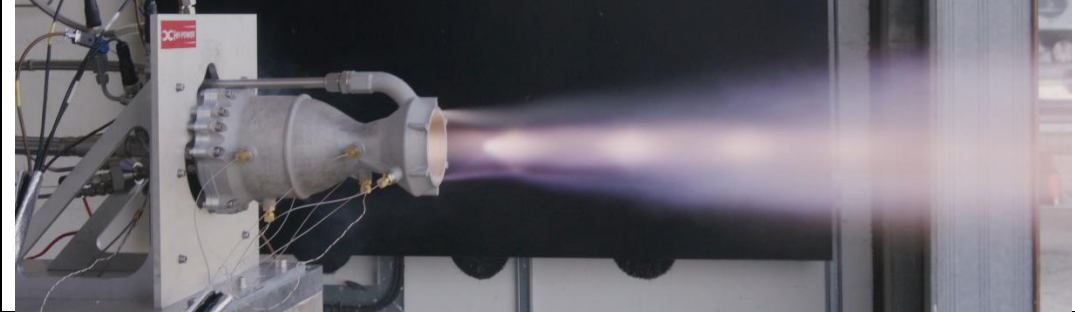
- Ignition: – 0.73
- Low Fuel Burn: 1.04 – 2.10
- Burnthrough: 2.10 – 4.16
- High Fuel Burn: 4.16 – 5.21
- Shutdown 5.21 –

Image	Value
Ignition Phase	
	0.27

	0.38
	0.48
	0.49
	0.57
	0.77
Low Fuel Phase	

	1.18
	1.20
	1.92
Burnthrough Phase	
	2.12
	2.28

	3.09
	3.49
	3.57
High Fuel Phase	
	4.29
	4.72

	5.05
Shutdown Phase	
	5.42

What we believe happened is illustrated in the images above and the graphs below. After a successful ignition from Airborne's torch igniter, the plume dies down and then fully ignites around T+1.04. Instead of achieving the full 5kN of thrust and bright white plume we were expecting (since it should have been similar to our previous engine), only ~1.5kN of thrust were produced and the plume is weak, hazy and yellow. The IPA mass flow then drops to virtually 0kg/s for ~0.53s and then actually 0kg/s for ~0.39s.

This lack of fuel mass flow is due to swarf, that was inside the regen cooling channels and chamber manifold, being forced into the injector and clogging it. Surprisingly, the flame doesn't die out, only weakening, until T+2.10 where we believe burnthrough occurred.

Since no fuel was flowing, nothing was cooling the chamber. The film cooling holes were completely blocked by the swarf so it effectively didn't exist. The PDMS fuel additive can't deposit if no fuel is flowing, so it effectively didn't exist. The regenerative cooling was blocked so we believe the coolant was boiling and stagnant which means it couldn't absorb heat from the inner wall, so it effectively didn't exist. All this combined with the fact that it was burning extremely ox rich makes it extremely unsurprising that the chamber failed.

At T+2.12, the plume begins to turn purple and the IPA mass flow rate begins to increase. This is where the first channel burst, followed by a few more, completely changing the colour of the plume. At this point, Airborne's fuel valve has a stroke trying to keep up with the rapid sudden change in IPA mass flow, leading to weirdness throughout all the data and an unstable burn.

Finally, at T+4.16, the IPA mass flow stabilizes and the engine completes its full duration burn in a relatively steady state.

In conclusion, the chamber performed admirably given its conditions and the fact that the injector worked throughout the chaos and abuse is a promising sign in validating the design.

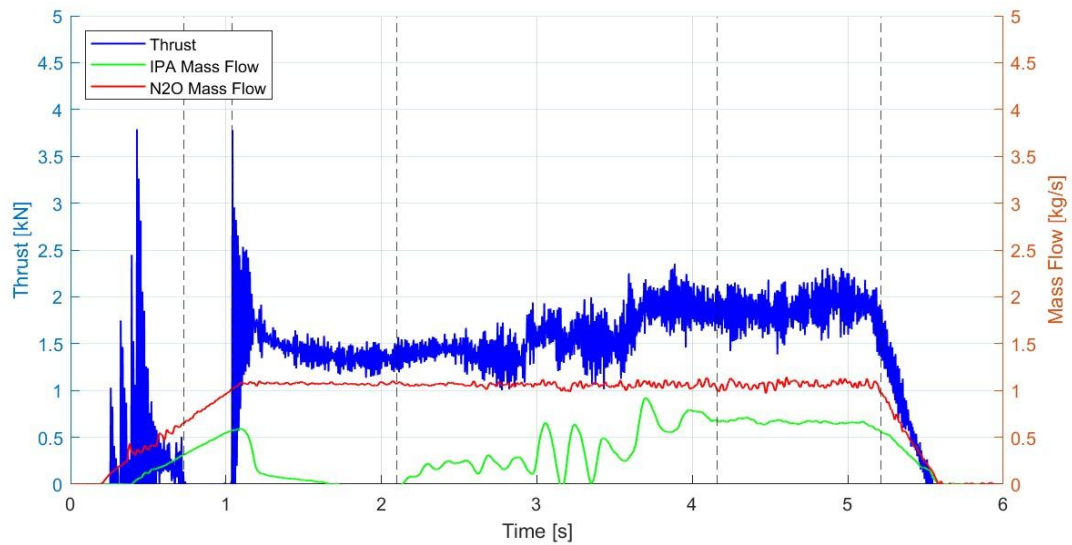


Figure 1, graph showing Thrust and mass flows against Time. The different phases of the burn can clearly be seen in the Thrust and IPA mass flow lines while the N2O remains steady but below the desired value. Each spike in the IPA mass flow line could be a channel bursting and Airborne's fuel valve compensating for it.

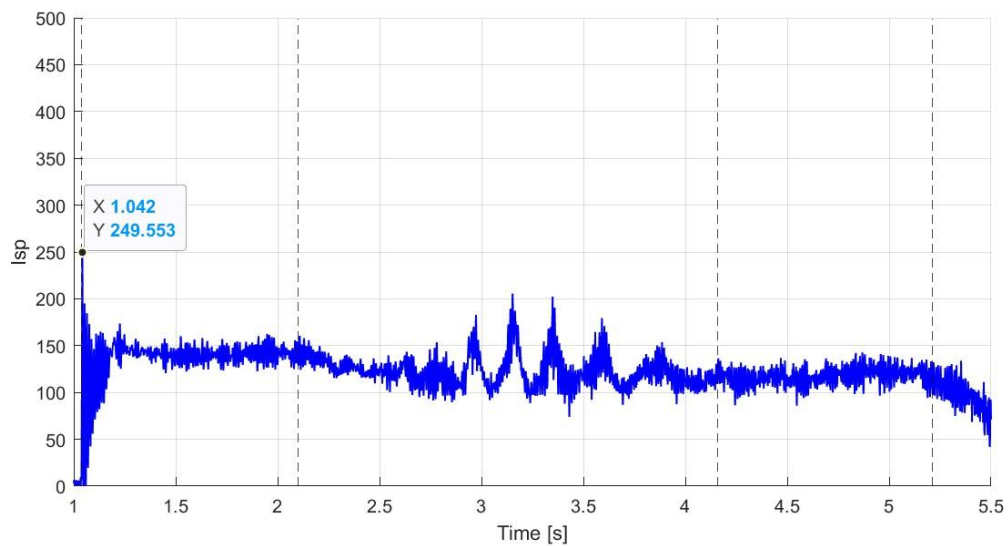


Figure 2, graph showing the Specific Impulse against Time. Clearly peaks and ~250s an gets close to 200s multiple times throughout the burn. Otherwise its really really bad so only look at the peaks thanks.

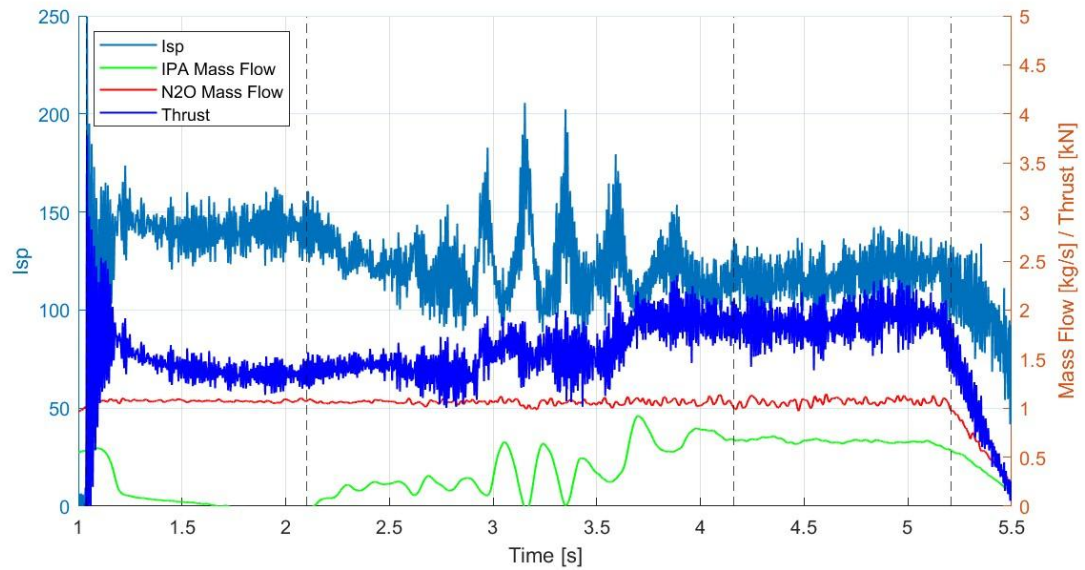


Figure 3, graph combining Figure 1 and Figure 2. Specific Impulse goes crazy when the IPA mass flow has a stroke.

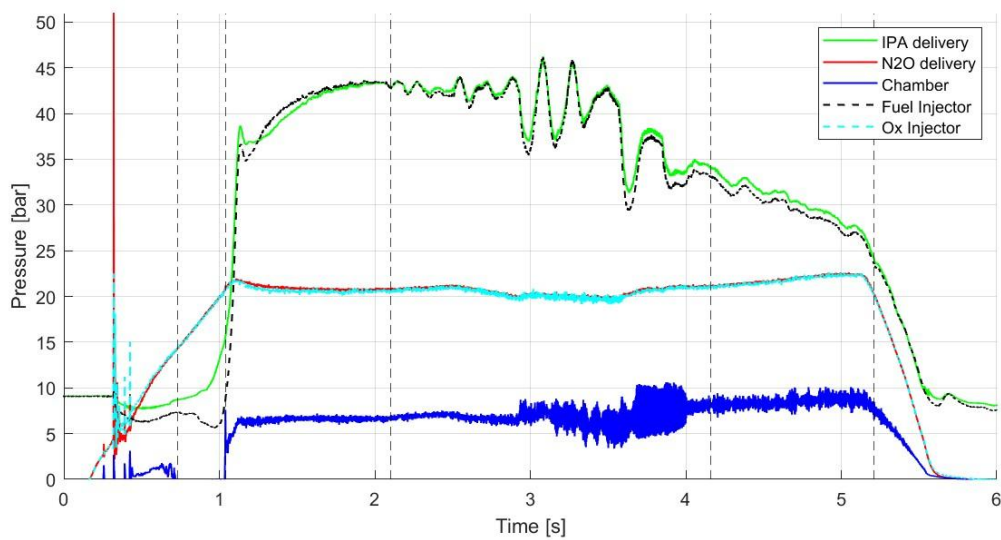


Figure 4, graph showing the pressure data. The pressures inside the injector manifolds can be seen to line up pretty much exactly with the delivery pressures. The chamber pressure remains low throughout the burn, following the pattern of beginning lower, having a stroke, then returning slightly higher. Also worth noting the IPA pressure is ~10 bar higher than expected and the chamber pressure ~10 bar lower than expected, resulting in a net 20 bar greater pressure drop on the inner wall of the chamber between the cooling channels and the combustion area.

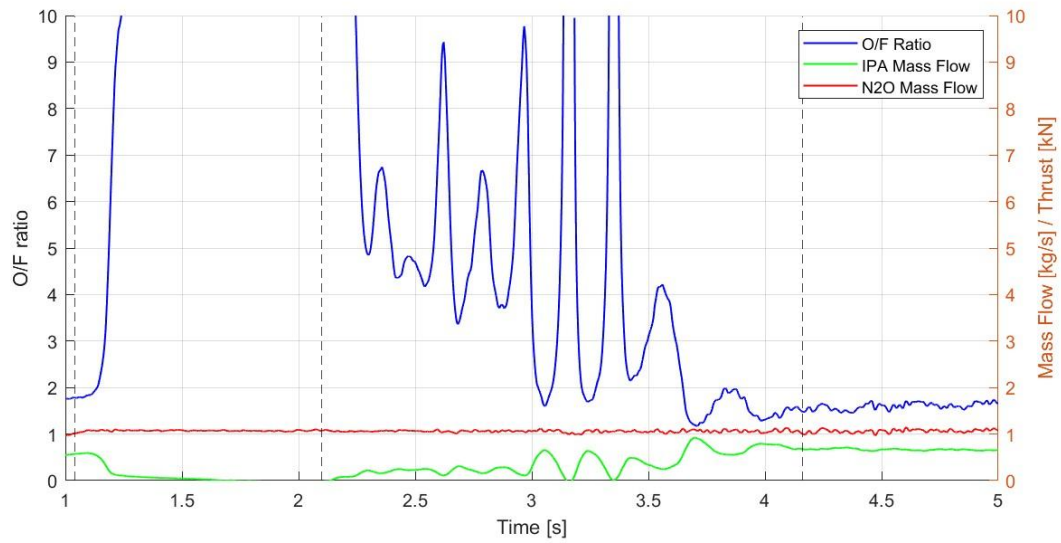


Figure 5, graph showing the mass flows and O/F ratio against Time. As expected, the O/F ratio begins extremely high, most likely abetting the chamber failure. It then swiftly proceeds to have a stroke, and stabilize below the designed ratio.

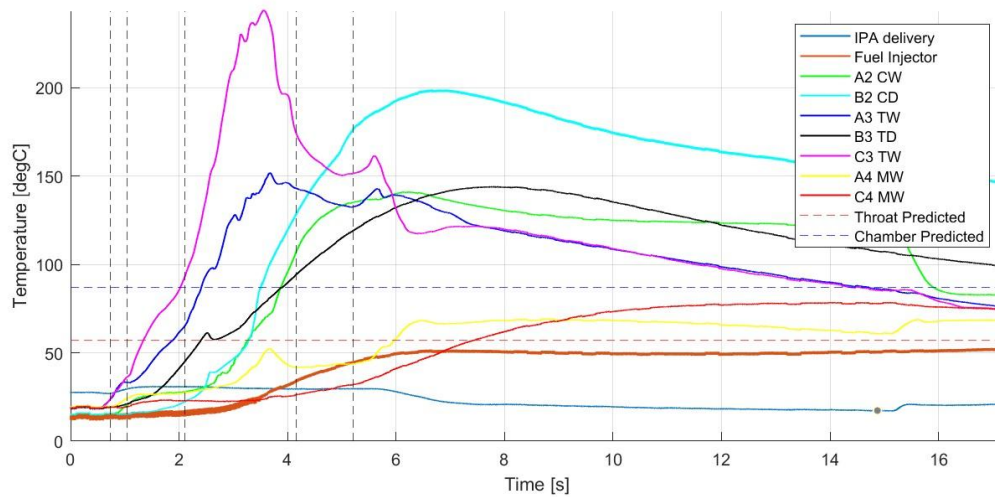


Figure 6, graph showing thermocouple data. See BSEP 2025 CDR for diagram explaining thermocouple placement. A, B, and C run across $\frac{3}{4}$ of the chamber. 2 is on chamber wall, 3 is at throat, and 4 is in chamber manifold. B thermocouples are dry, the rest are wet. More clear thermal data of specific parts and explanations shown below.

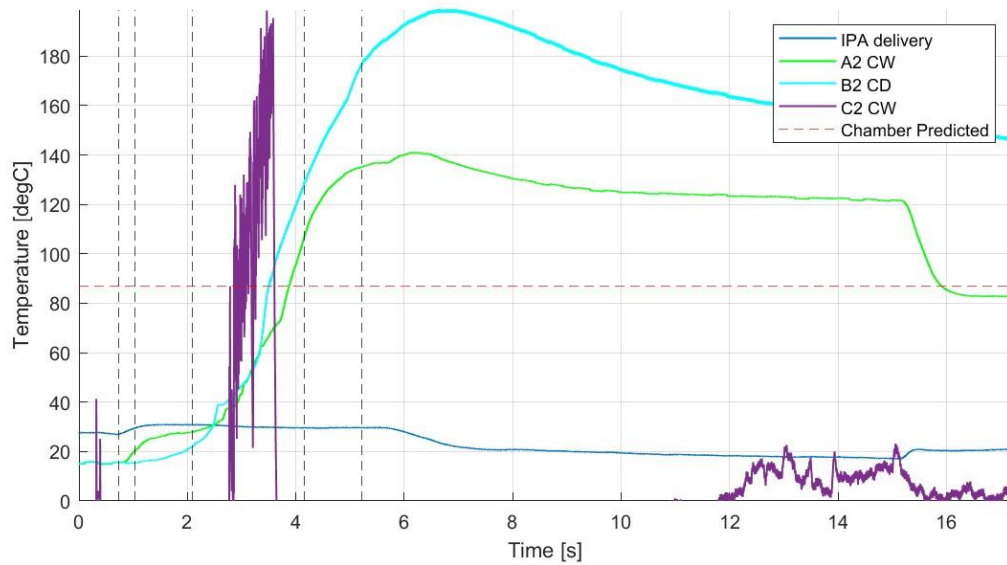


Figure 7, graph showing chamber thermocouple data. C2 will be ignored since it seems to have some sort of issue. A2 is directly reading the coolant temperature and by the end of the burn it is well above the predicted value. B2 also clearly demonstrates the Aluminium doesn't reach steady state even though it was assumed it would during a nominal burn.

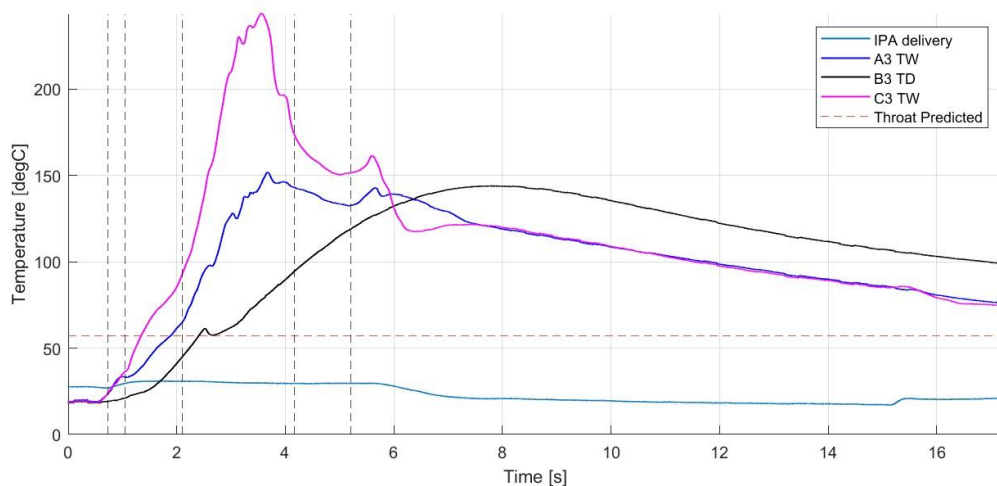


Figure 8, graph showing throat thermocouple data. It is immediately apparent that the throat coolant temperatures are higher than the chamber coolant temperatures. This is extremely disturbing since in our regen system it should always be the opposite, with more heat being added to the coolant as it moves past the throat. This further reinforces the fact that there was no coolant flow. The throat coolant temperatures during the burn also exceed the predicted value by almost 200 degrees and is almost certainly boiling. The C side also seems to be significantly hotter than the A side, which can also be seen in the damage itself. They do line up after the burn though as things cool down which is a good sign of their accuracy.

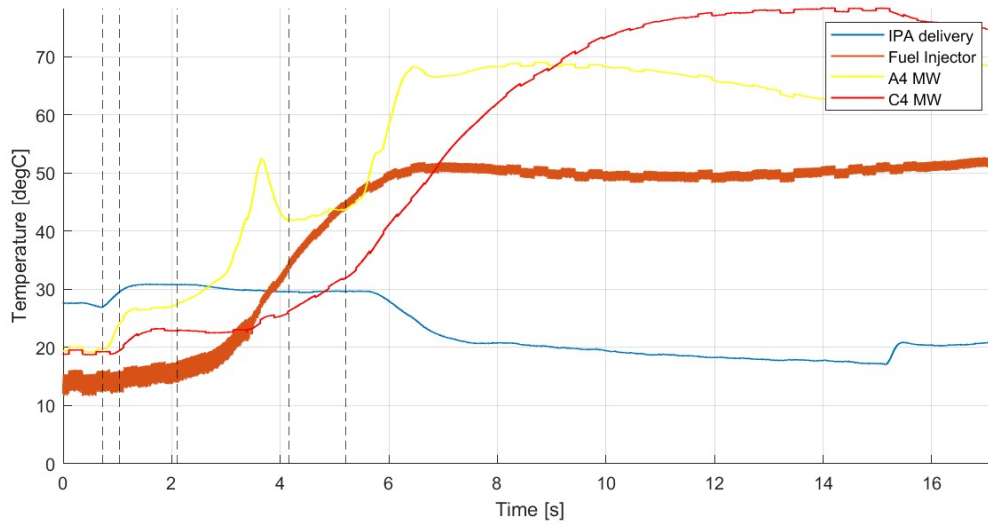


Figure 9, graph showing the chamber fuel manifold and injector fuel manifold thermocouple data. A4 and C4 should be identical but A4 seems to have some anomalies so no conclusions can be drawn from that.

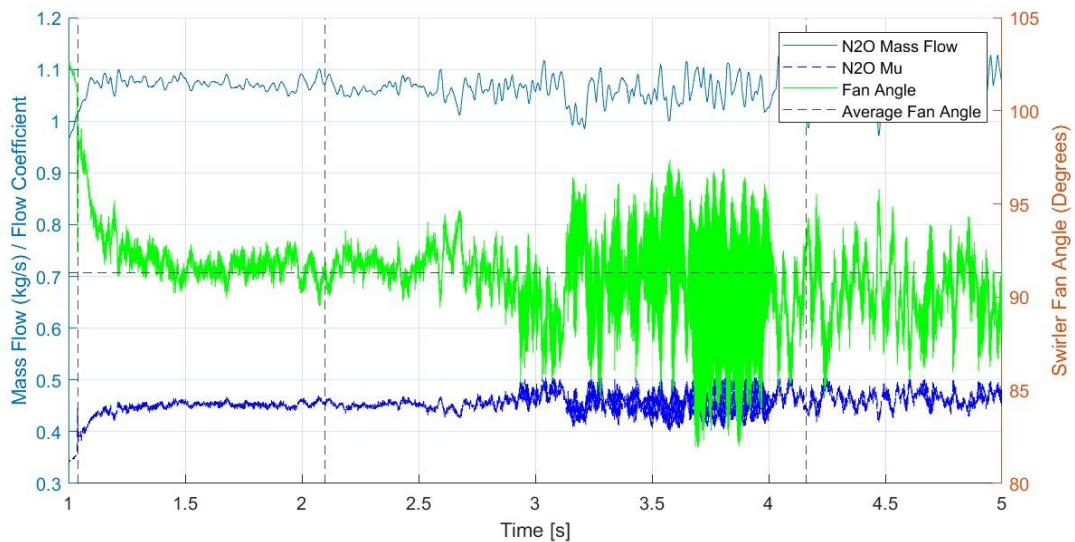


Figure 10, graph showing Injector fan angle against time. For a coaxial swirl Injector, one of the main performance factors is the fan angle (angle of swirled spray cone exiting swirler elements). Since IPA mass flow was unreliable, only the N2O flow was analysed. Originally, the fan angle was designed to be 90 degrees and initial 3d printed elements validated the design. However, due to manufacturing constraints, the angle was changed to 110 degrees and the efficacy of this new angle was only semi-validated during hasty 3d print tests. After processing the data, the average fan angle calculated was 93 degrees. This number is none-conclusive since N2O's 2-phase characteristics lead to a large error bar and the fuel wasn't accounted for. Nevertheless, if the fan angle was truly close to the calculated 93 degrees under these extremely arduous conditions, it's a good step in validating the coaxial swirl design.

Tear Down

Chamber

Clear bursts can be seen in the chamber. There are 5 major ones and a lot more smaller cracks. Almost every other channel has bulged significantly. This all happened at the same elevation inside the chamber. At first we thought this was where the oxidizer fan from the swirlers were hitting the wall, but the angle doesn't match. The "popping" of the channels is most likely a combination of the elevated inner wall temperature (due to lack of cooling and higher O/F ratio) degrading the strength of the Aluminum (see CP-1 strength graphs in BSEP 2025 CDR) and the increased pressure delta across the inner wall.

The throat is clearly melted due to the lack of cooling and high temperatures. Thin cracks and holes also appear throughout. Also noticeably no PDMS deposition is observed.

The major bursts are clustered and line up exactly where the swirl elements are located. So do the largest streaks of melting at the throat.



Figure 11 & 12, Swarf can be seen trying to escape through the burst channels



Figure 13 & 14, Channels are clearly filled with swarf. Popping and bursts clearly visible as well as throat melt streaks.



Figure 15, Close-up on throat.

Injector

Injector damage was much less significant. Lots of swarf was uncovered during removal, some O-rings were damaged, and some holes were blocked by swarf. After thorough cleaning it should be reusable.

We believe the swarf was introduced during chamber post-machining when the baseplate was CNCed off. It was not caught during low-pressure water flows since the water just flowed around the swarf instead of pushing it all out.



Figure 16, Injector plate immediately after it was taken off of the chamber. Swarf everywhere.



Figure 17, inside Injector. Swarf clearly visible in the fuel collection manifold. Swirl element O-rings broken and missing.



Figure 18, close-up of film cooling hole. Completely blocked by swarf.

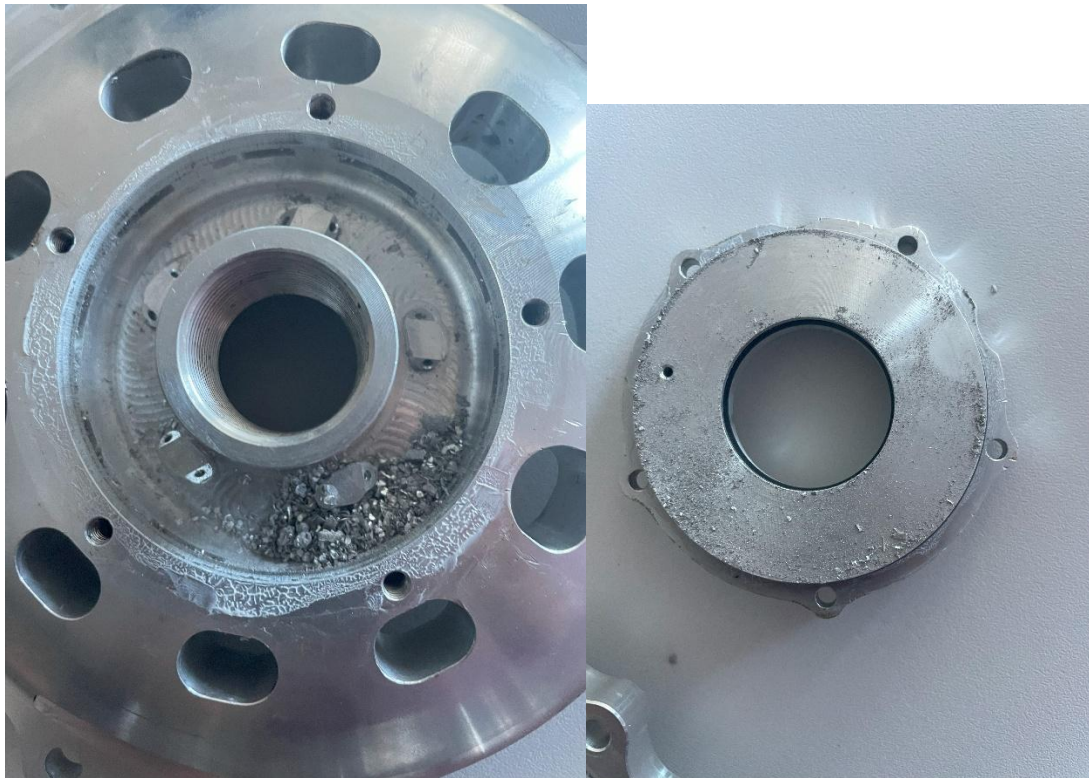


Figure 18 & 19, Injector fuel cap and fuel manifold after removal. Huge amounts of swarf deposited inside.

Test Setup

