



Wildcat Rocket Engineering Club

**Regeneratively Cooled Nozzle Design
Presentation**

Presenters

- Jeff Buskirk– Chief Engineer
- Douglas Sheppard– Propulsion Manager
- Colin Ryan – Intro Project Manager
- Aaron Rockholt – Regen Chamber Lead
- Bobby Briones – Electro Chemical Lead

Design Overview

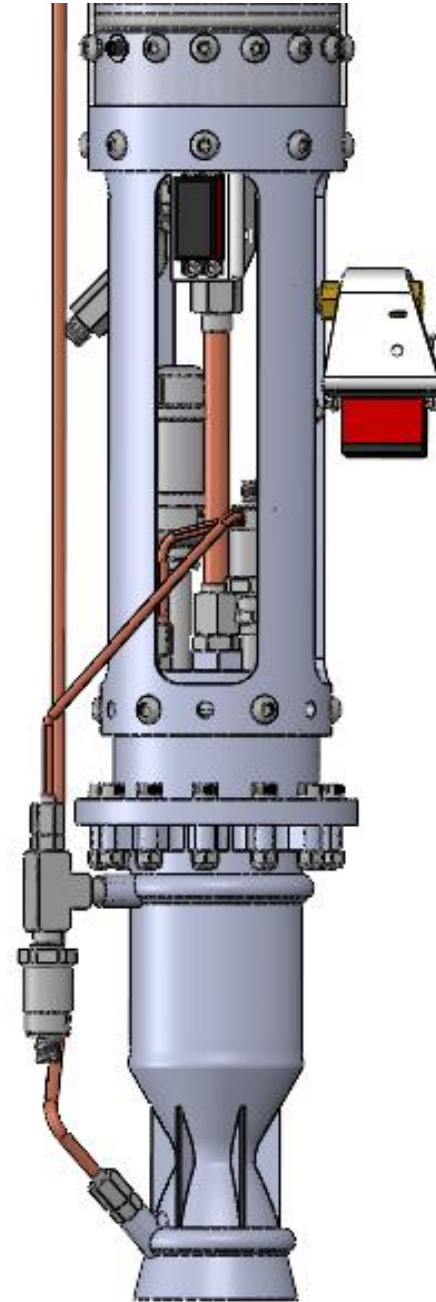
Jeb Lite — a regeneratively-cooled bipropellant rocket engine, N₂O / E98 ethanol

Jeb Lite — Engine Overview

- Regeneratively-cooled bipropellant engine (WREC's first additive regen design)
- Replaces prior ablative-cooled “Jeb” engine — goal is a reusable test platform
- N₂O oxidizer / E98 (98% ethanol) fuel, pintle injector
- Inconel 718 chamber, nozzle, and pintle — additively manufactured (LPBF)

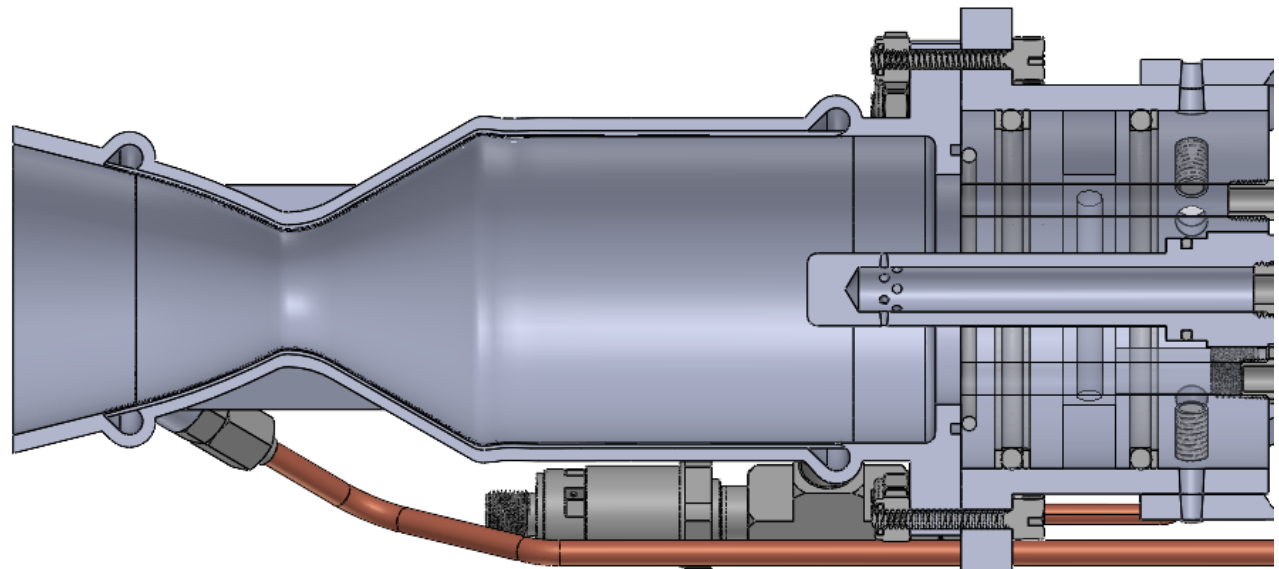
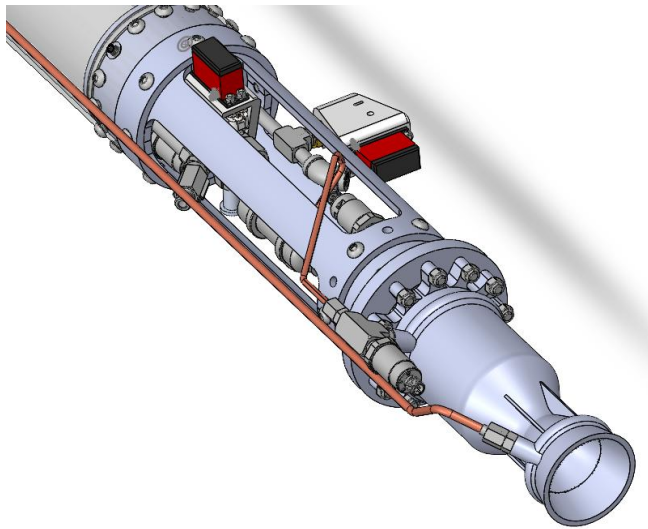
Parameter	Value
Thrust	590 – 650 lbf
Chamber pressure	437 psi (eff.)
Mixture ratio O:F	4.29
Throat / chamber dia.	1.16 in / 3.00 in
Expansion ratio	5.62 : 1
Burn time	6.14 s
Specific impulse	148.5 s (simulated)

Performance basis: HalfCat engine sizing tool (WREC design database)



Full Vehicle-Level CAD — Jeb Lite Assembly

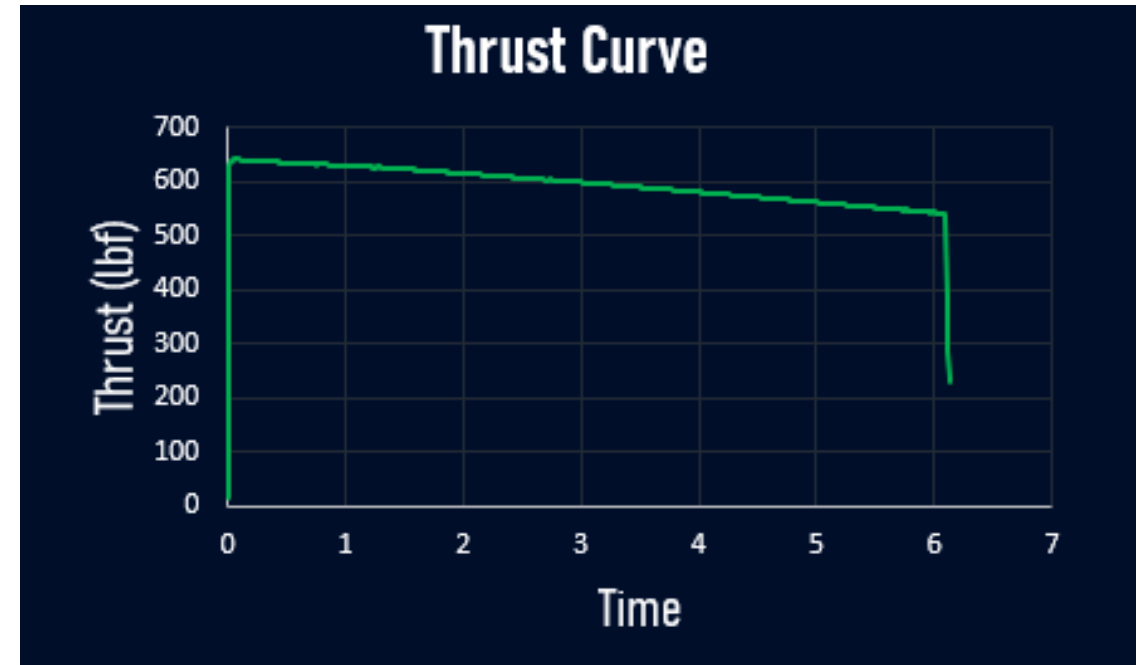
- Complete engine assembly: injector, chamber/nozzle liner, cooling jacket, mounting interface, and instrumentation bosses



Performance Simulation — HalfCat Sizing Tool

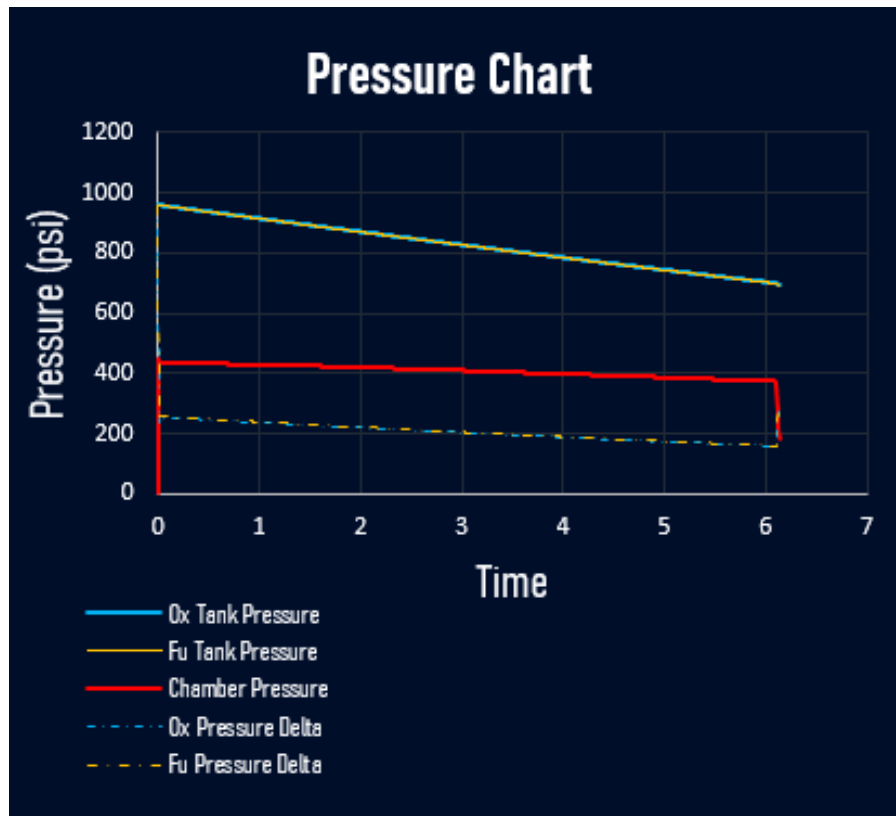
- Half Cat tool for N2O/E98 bipropellant performance
- Combustion properties from CEA-consistent gas tables (γ , MW, T_0 , c^*)
- C^* -efficiency-derated to an effective operating point for hardware design:
 - Ideal (CEA): $T_0 = 3150$ K, $c^* = 1589$ m/s
 - Effective ($0.65 \eta c^*$): $T_0 = 1325$ K, $c^* = 1477$ m/s
- Outputs drive both hot-gas heat transfer and structural load cases

Output	Value
Initial thrust	651.6 lbf
Oxidizer / fuel flow	3.55 / 0.83 lbm/s
Total impulse	16,420 N·s



HalfCat Simulation — Additional Performance Detail

- Full simulation covers chamber pressure buildup, C* efficiency assumption, and injector pressure-drop sizing across the burn



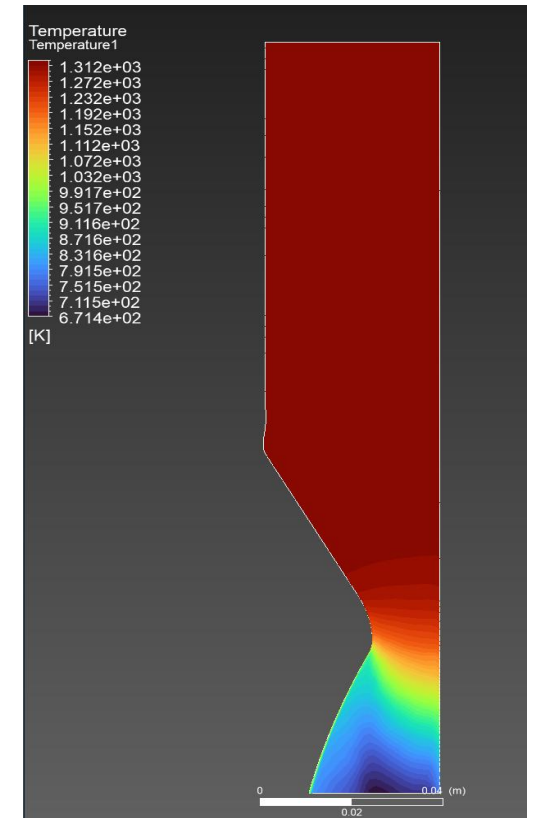
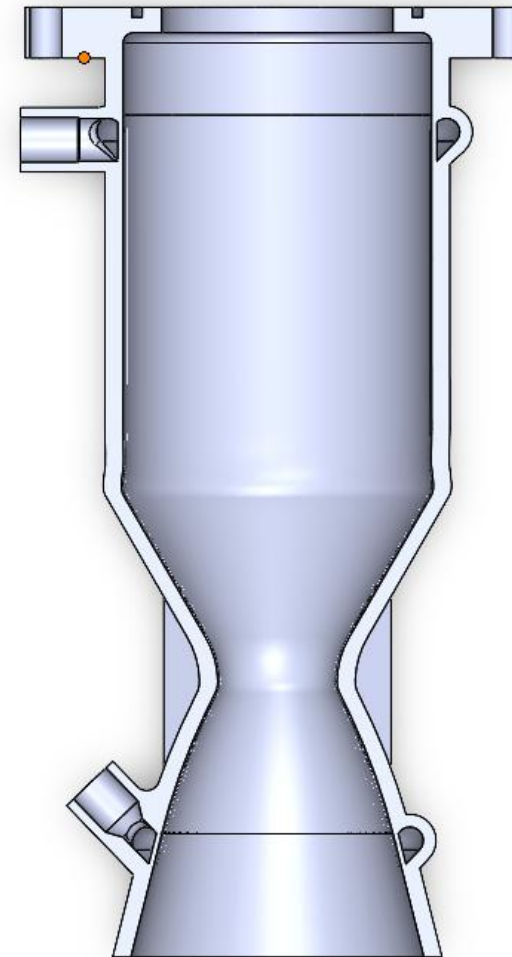
NOZZLE	
Throat Diameter	1.160 in
Throat Area	6.8E-04 m ²
Exit Diameter	2.750 in
Exit Area	3.8E-03 m ²
Exit Half Angle	15 °
Expansion Ratio	5.62
Exit Pressure	13.2 psi
Flow Condition	IDEALLY expanded
Flow Separation	NO
Nozzle Efficiency	95%
THRUST CHAMBER	
Chamber Diameter	3 in
Chamber Length	4.75 in
Contraction Ratio	6.7
Char. Length (L*)	31.77 in
Chamber Volume	5.5E-04 m ³
C* Efficiency	65%
Temperature	1926 F

RESULTS v1.3.10	
Chamber Pressure	438 psi
Initial Thrust	642 lbf
Burn Time (FUEL)	6.13 s
Mixture Ratio (O:F)	4.289
Mass Flow Rate	1.993 kg/s
Overall Efficiency	61%
Tank Ratio (O:F)	4.981
Oxidizer Injection Δ	157 psi
Oxidizer Stiffness	36%
Fuel Injection Δ	158 psi
Fuel Stiffness	36%
Specific Impulse (S)	146 s
Specific Impulse (C)	134 s
Total Impulse	16188 Ns
58%	N-Class
Classification	N2610
Manufacturer	HCR

Regenerative Channel Design

- 60 printed coolant channels around the chamber & nozzle
- 1 mm channel height, 0.3 mm hot-wall thickness, Inconel 718
- Sized station-by-station (56 axial stations) balancing:
 - coolant pressure drop
 - channel aspect ratio / land width
 - hot-wall temperature vs. Inconel 718 service limit

Wall Check (worst station)	Inconel 718
Hot-wall temperature	651 °C (limit 870 °C — PASS)
Thermal stress	402 MPa
Regime	LCF (yields), $\sim 10^3$ – 10^4 cycles



Hot-Gas Heat Transfer — Bartz Method

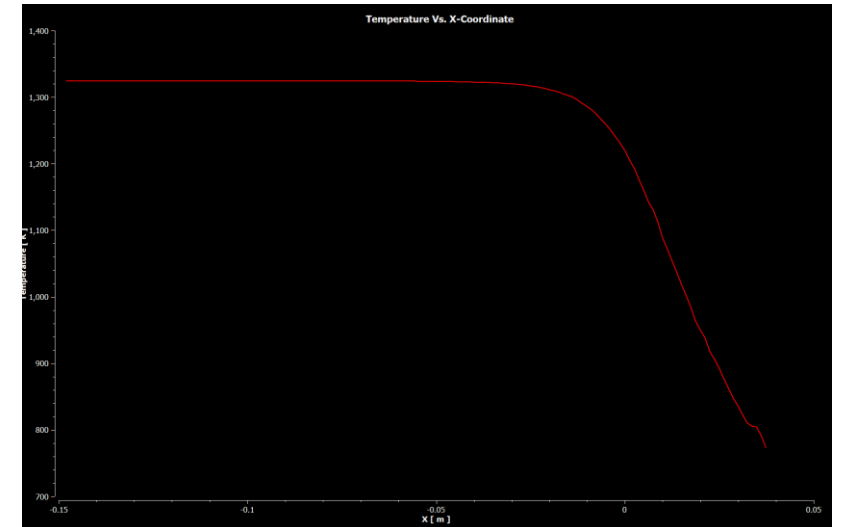
- Hot-gas wall driven by a Bartz-correlation convective boundary condition:

$$h_g = \frac{0.026}{D_t^{0.2}} \left(\frac{\mu^{0.2} c_p}{Pr^{0.6}} \right) \left(\frac{P_c}{c^*} \right)^{0.8} \left(\frac{D_t}{R_c} \right)^{0.1} \left(\frac{A_t}{A} \right)^{0.9} \sigma$$

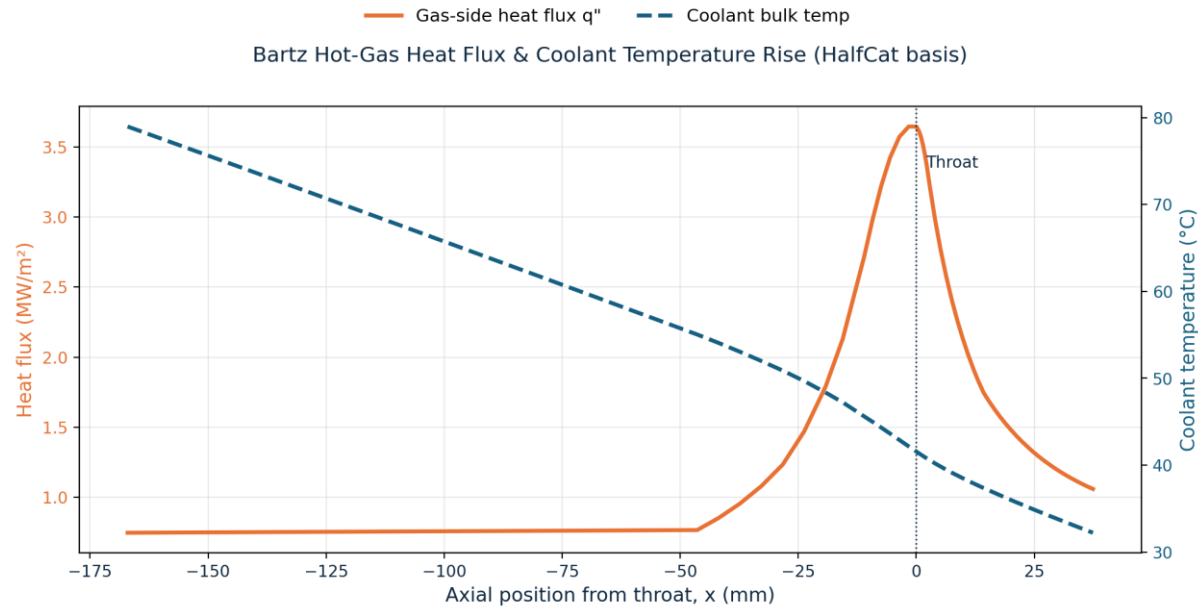
$$T_{aw} = T_0 \frac{1 + r \left(\frac{\gamma - 1}{2} \right) M^2}{1 + \left(\frac{\gamma - 1}{2} \right) M^2}, \quad r = Pr^{1/3}$$

$$q'' = \frac{T_{aw} - T_c}{\frac{1}{h_g} + \frac{t_{wall}}{k_{wall}} + \frac{1}{h_c}}, \quad T_{wg} = T_{aw} - \frac{q''}{h_g}$$

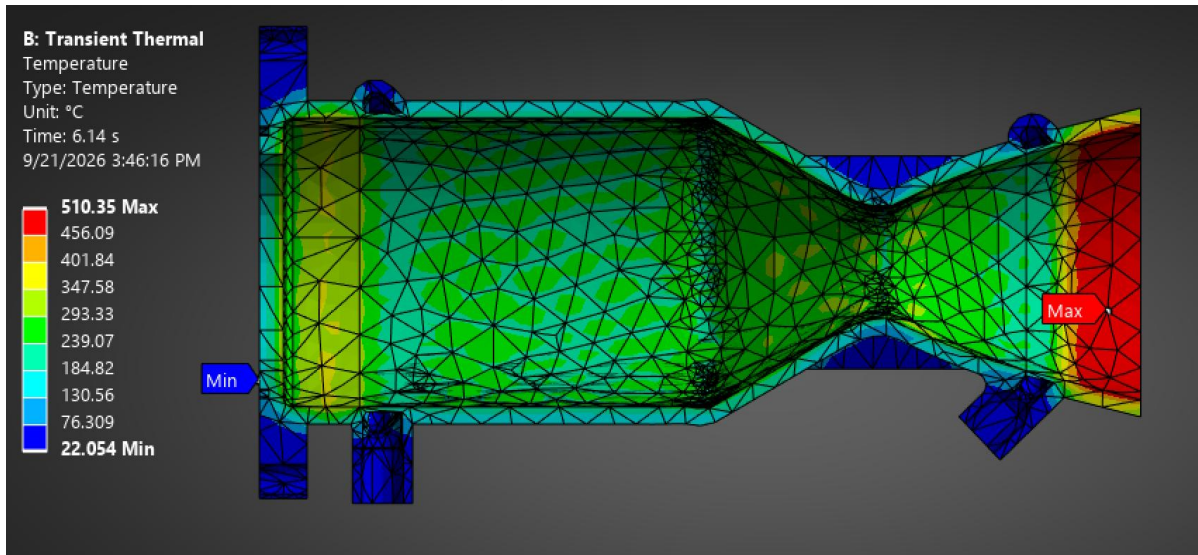
- h_g = gas-side film coeff., T_{aw} = adiabatic wall (recovery) temp., σ = wall-temp. correction
- Coolant-side film coefficient from Dittus–Boelter; wall conduction from Inconel $k(T)$



Conjugate Heat Transfer — ANSYS Results



- Bartz heat-flux & convection profiles imported into ANSYS Mechanical as spatially-varying boundary conditions
- Transient Thermal solve over the full burn duration
- Peak hand-calc heat flux: 3.64 MW/m² near the throat
- Coolant (E98) enters at nozzle exit (32 °C), exits chamber head-end at 79 °C — counter-flow



ANSYS Transient Thermal

Peak wall temp

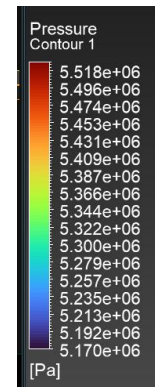
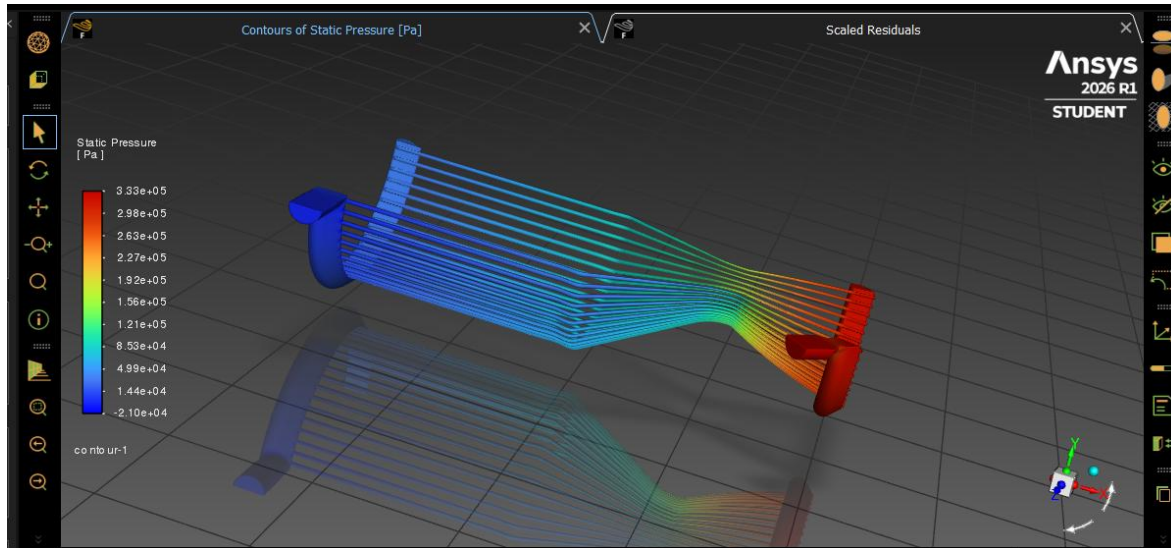
510.35 °C @ t=6.14s

vs. hand-calc

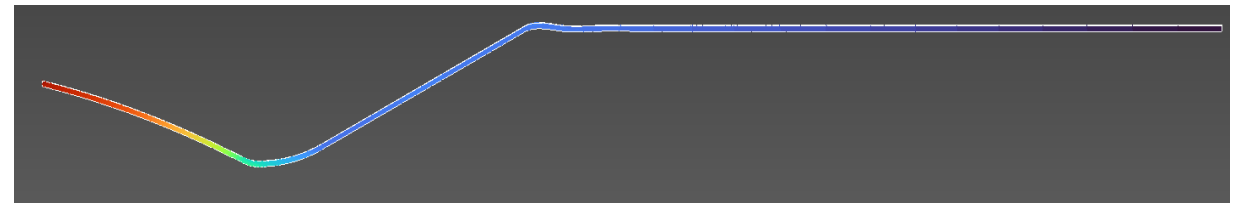
Consistent ✓

Coolant-Side CFD — Flow Through the Regen Channels

- 3D CFD of E98 flow through the 60-channel jacket — resolves what the 1D Dittus-Boelter hand calc cannot:
 - channel-to-channel flow maldistribution
 - local hot spots at manifold turns / land-width transitions
 - true pressure drop vs. the 1D estimate used for pump/tank sizing



Roughly 51 psi
pressure loss at 9
Micrometers avg.
Surface Roughness

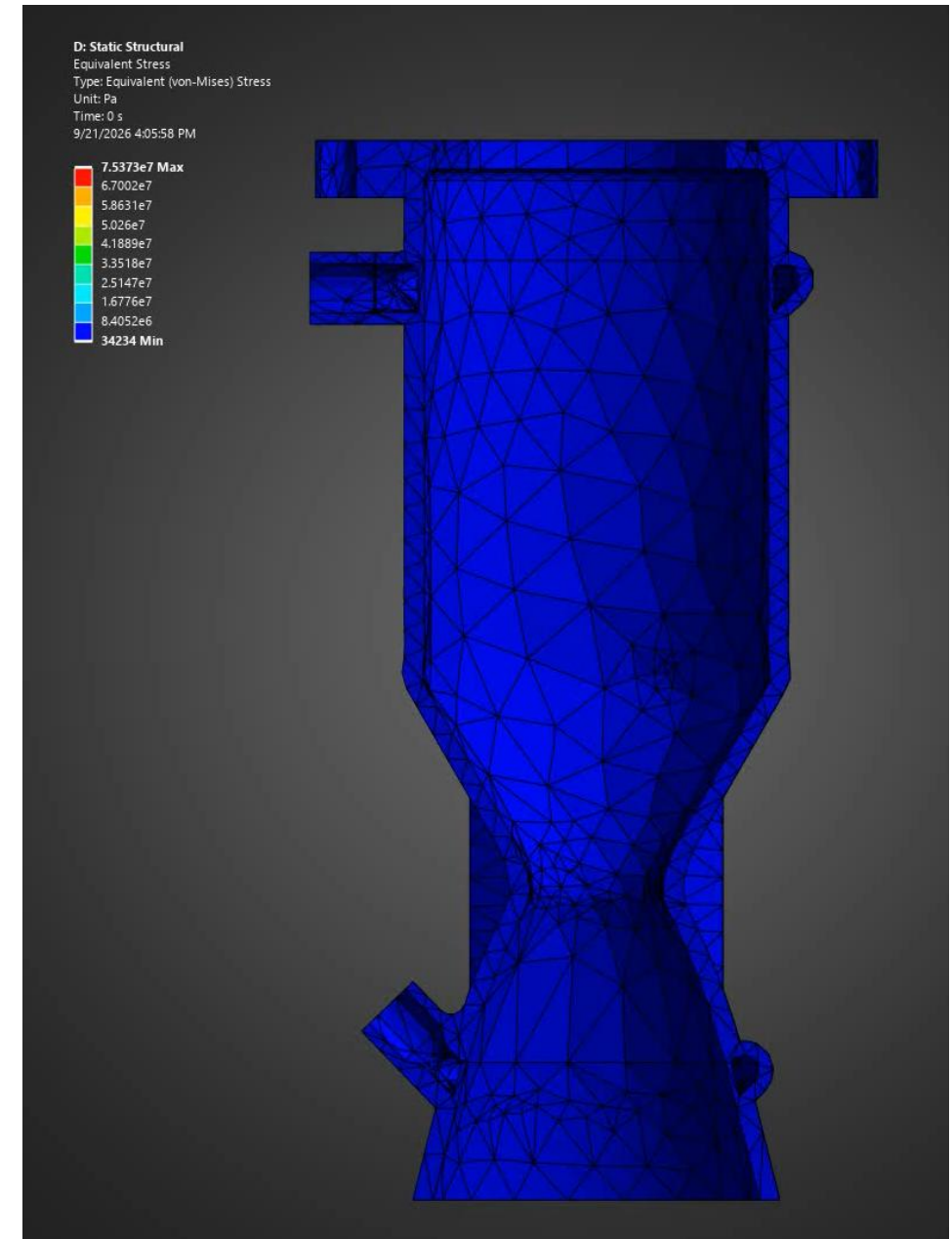


Status: run — planned to cross-check the Bartz/1D-network result before hot-fire

Structural Verification — Static Structural FEA

- Imported Body Temperature (from Transient Thermal) drives thermal expansion load
- Inconel 718 modeled with temperature-dependent (multilinear isotropic hardening) plasticity — 25/200/400/600/800°C data points
- Constraint scheme: Frictionless Support at mounting face + periodic cut faces, single vertex constraint for rigid-body removal
 - (replaces initial Fixed Support, which produced a non-physical 940 MPa artifact from over-constrained thermal expansion)
- Max principal stress evaluated away from constraint boundaries

Status: constraint correction applied — final validated stress run in progress

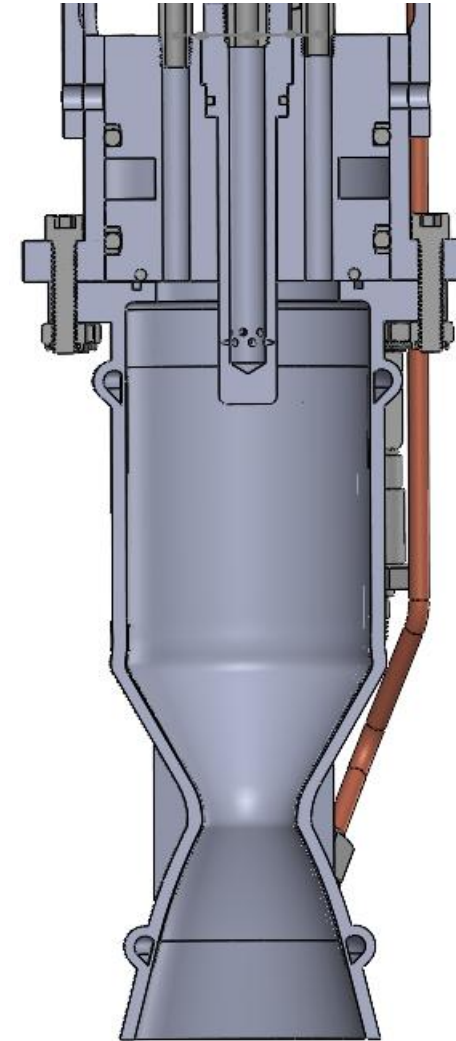
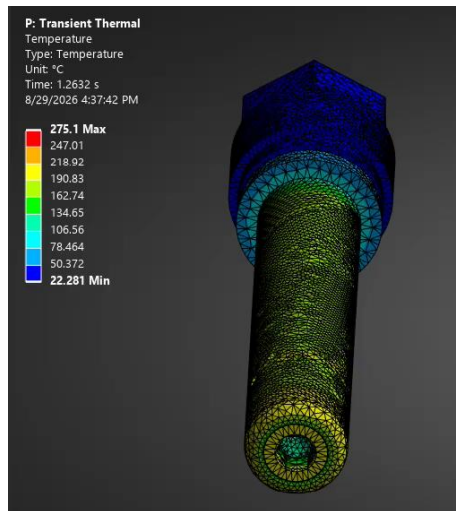


Pintle Injector Thermal Analysis

The most aggressive thermal environment in the engine — worked from first principles

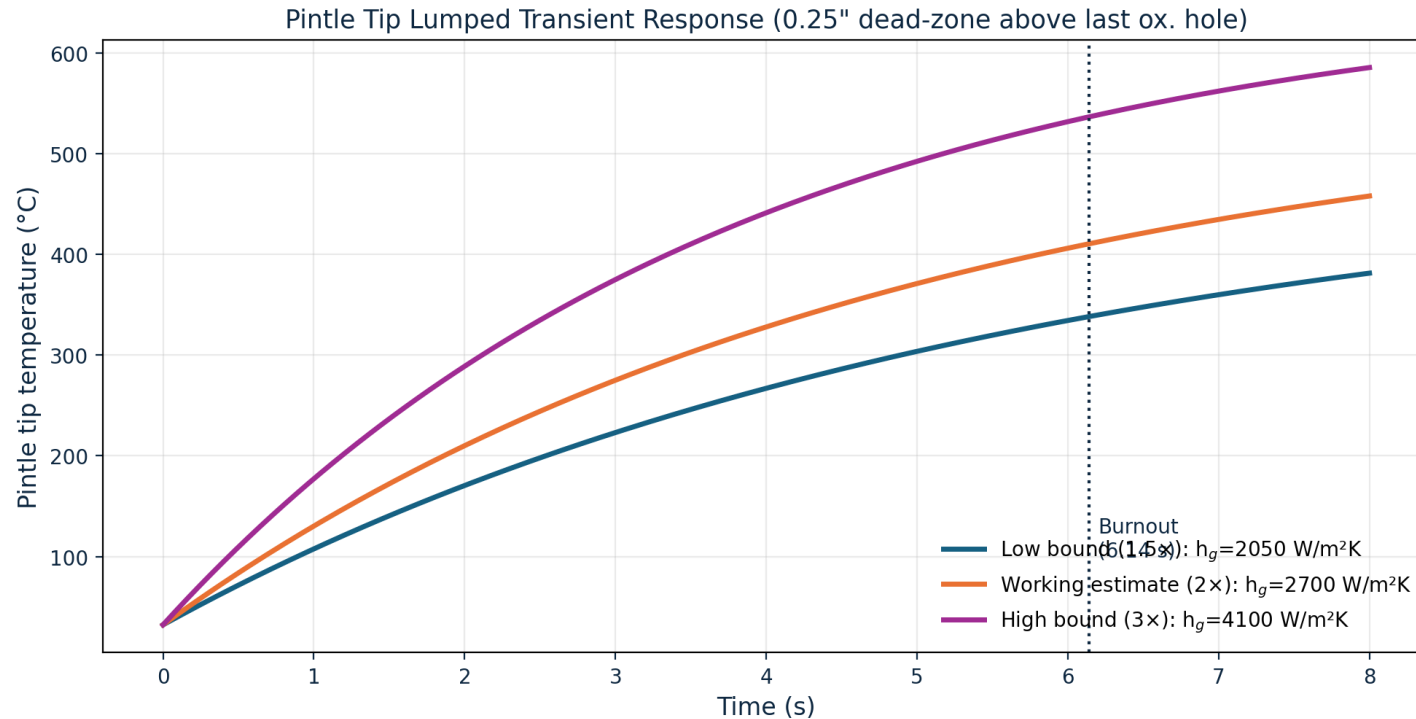
Pintle Injector — Geometry & Cooling Scheme

- Central-post pintle, 12 radial oxidizer orifices
- Post OD: 0.710 in; bore ID sized for 1/4 NPT tap
- Overall pintle height: 1.0 in
- Oxidizer orifices located 0.75 in below the injector face
 - Leaves a 0.25 in “dead-zone” tip above the last actively-cooled point
 - heated on the face, cooled by conduction
- Actively cooled by N₂O flowing through the central post before exiting radially — same regenerative principle as the chamber wall



A stagnation/recirculation region — standard Bartz boundary-layer scaling does not directly apply

Pintle Tip — Transient Thermal Estimate



- 0.25 in dead-zone modeled as a lumped thermal mass between the gas-side flux and the coolant-clamped base
- Thermal time constant $\tau \approx 4.9 \text{ s}$ (working case) — burn (6.14 s) reaches ~75% of steady state
- Result: tip temperature 340–550 °C at burnout, 410 °C working estimate

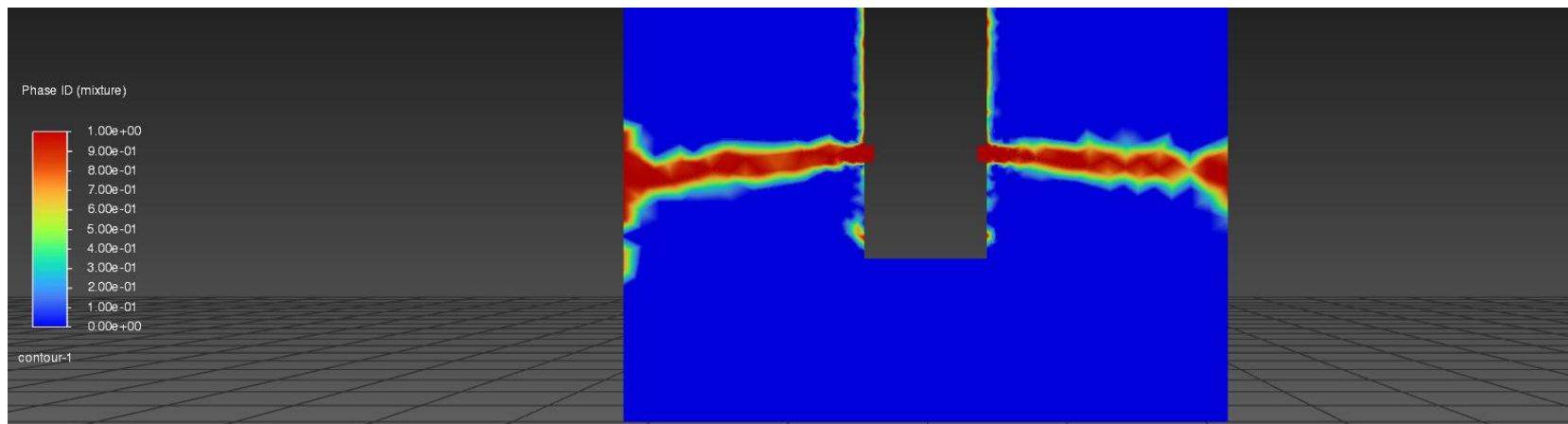
6061-T651 reference	
Pintle tip (est.)	~250 °C

Injector Cold-Flow & Spray Characterization

- Pintle spray fan angle and atomization quality are set by the Total Momentum Ratio (TMR) between the radial oxidizer jets and the axial fuel sheet:

$$TMR = \frac{(\dot{m}V)_{ox}}{(\dot{m}V)_{fuel}}, \quad \dot{m}V = \dot{m} \sqrt{\frac{2\Delta P}{\rho}}$$

- Water/inert cold-flow testing planned to verify spray fan angle and mixing uniformity before hot-fire



Manufacturing, Verification & Test

From printed part to validated, tested hardware

Manufacturing Approach

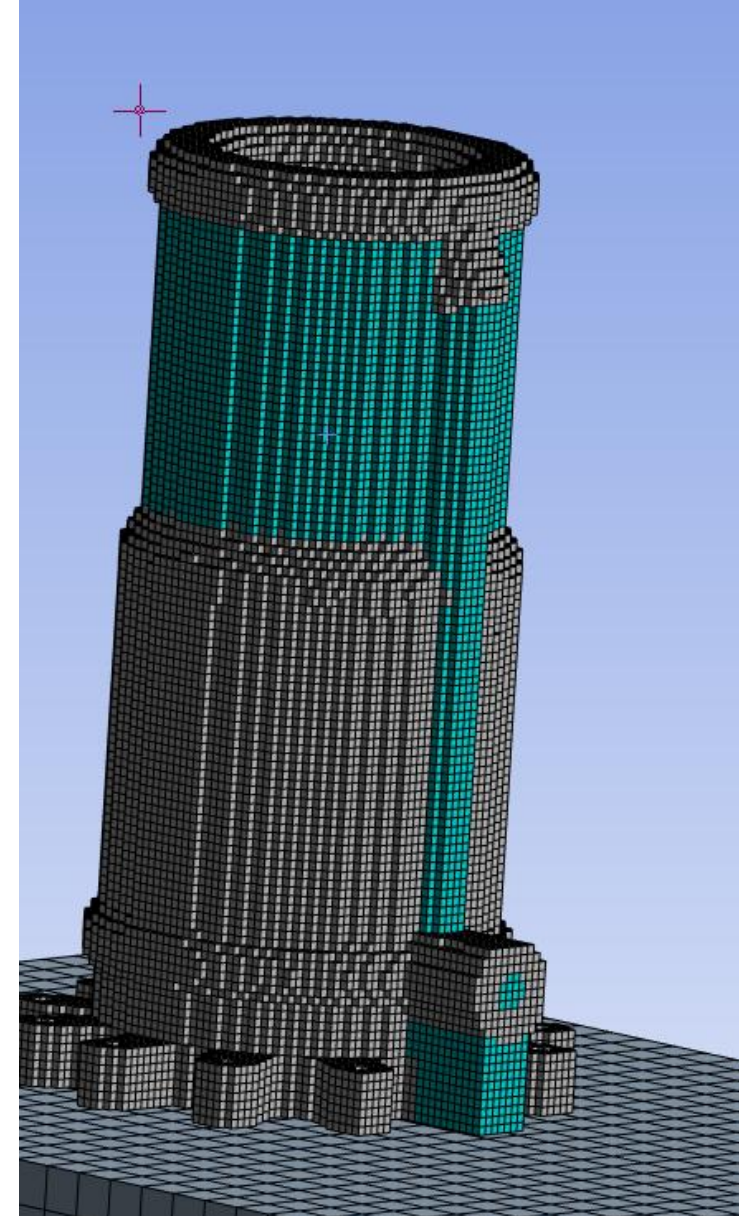
- Chamber liner and cooling jacket: laser powder-bed-fusion (LPBF) additive manufacturing
- AM is what makes coolant channels this fine, and this closely conformal to the hot-gas wall, possible at this scale
- Post-processing: support removal, stress-relief heat treatment, internal channel flow-check



Property	316SS	Inconel 718
k (W/m·K)	19	17
Yield (MPa)	102 (worst stn.)	860
Service limit	870 °C	1000 °C
Melting point	1400 °C	1336 °C

Design for Additive Manufacturing (DfAM)

- Self-supporting internal channel geometry — no internal support structures required for powder removal
- Overhang angles kept within LPBF process capability (design target: $>45^\circ$ from horizontal)
- Minimum wall/channel feature size checked against laser spot size and powder particle size
- Build orientation chosen to minimize support contact on functional (hot-gas / coolant) surfaces
- Powder-removal access verified for every internal passage — no fully blind cavities



Post-Processing & Inspection Plan

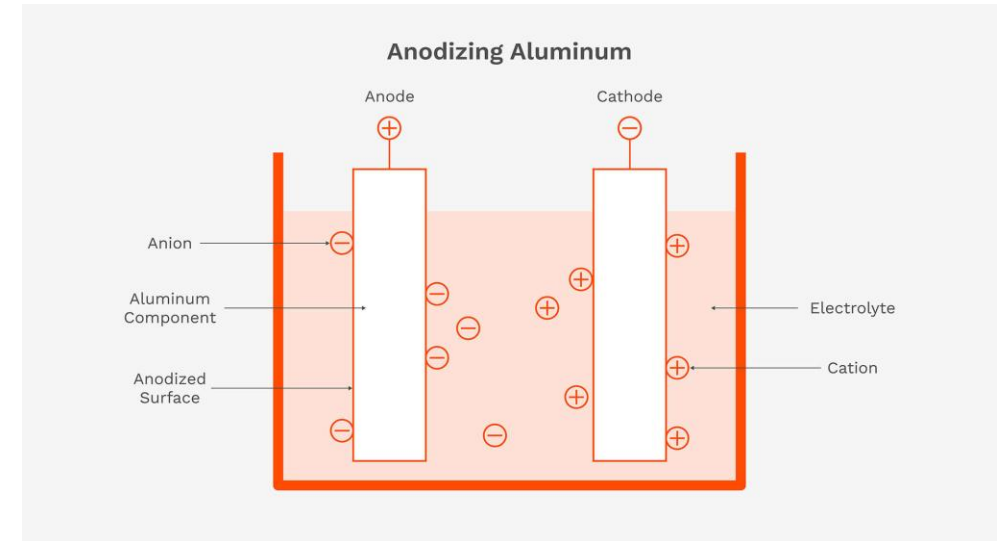
- Stress-relief heat treatment prior to support removal
- Support removal & internal channel flow-check (verify no blockage / powder residue)
- CT scan of internal coolant channels — the only way to verify as-printed channel geometry since they're not visually accessible
- Dimensional inspection of critical interfaces (mounting face, injector threads, sealing surfaces)
- Witness coupons printed alongside the part for tensile testing of as-built material properties



Surface Treatment — Aluminum anodization

- Coating thickness:
Type II: 25 μm
Per MIL-PRF-8625
- Application:
Aluminum parts for corrosion, wear, and other surface protections.
- Process:
Clean/degrease $\rightarrow$ etch $\rightarrow$ anodize
- Masking:
Threads and mating surfaces, using PTFE tape or Paraffin Wax.

Anodization Infographic



Visualizations of masking methods



Anodization — QA & Inspection

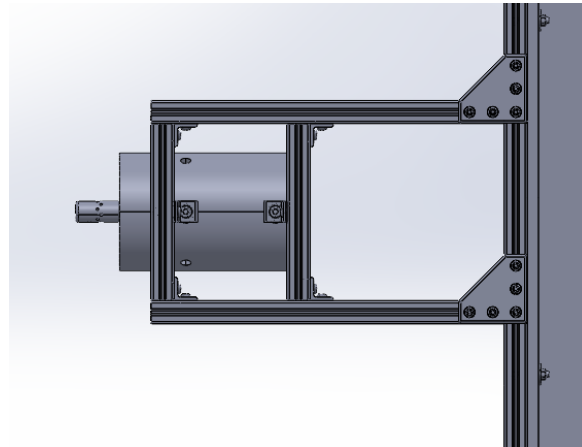
- Coating thickness verification:
Eddy current probing
- Visual inspection: coverage, finish uniformity, and defects
- Performance testing:
Electrochemical tests with PalmSens Pico potentiostat.
- Critical dimensions: verify masked and close-tolerance features after anodizing

Visualization of Type II anodization.



Test Plan

- Cold-flow (water/inert gas – CO₂): verify coolant & oxidizer flow rates, pressure drop, injector spray pattern against predictions
- Instrumentation: wall/coolant thermocouples, chamber & line pressure transducers, load cell
- Static hot-fire test campaign at WREC's test stand — validate thermal & structural predictions against real data
- Post-test teardown & inspection — compare predicted vs. observed wall temperature / erosion / discoloration



Project Timeline — Spring 2027

Weeks	Milestone
1–2	Finalize print-readiness (support structures, build orientation) on existing geometry
3–7	Procure powder, LPBF print liner + jacket + pintle, post-process (support removal, stress-relief, channel flow-check)
8–10	Assemble engine, integrate instrumentation, cold-flow checkout
11–13	Hot-fire test campaign
14–16	Reduce test data, compare vs. predictions, document results