Cryogenic Fuel Tank Design for Orbital Launch Vehicles

This document summarizes a structural design concept for a cryogenic fuel tank used in space launch vehicles. The focus is on thermal insulation, material selection (Al-Li alloys vs. CFRP composite structures), and mitigation of boil-off losses.

Thermal Insulation

• Multi-Layer Insulation (MLI) with 30–40 reflective layers.
• Vacuum-jacketed shells to reduce convective/conductive heat flux.
• Vapor-Cooled Shields (VCS) using vented gas for secondary protection.
• Spray-on foam insulation (SOFI) in non-vacuum zones.
• Minimization of thermal bridges through GFRP/PEEK supports.

Material Selection

• **Al-Li Alloys (2195/2050):** High strength-to-weight, proven heritage, friction-stir welded orthogrid/isogrid structures.
• **CFRP + Metal Liner:** 15–30% lighter, tailored stiffness, requires liners (Al/Ti/polymer) for LH■ permeability, challenging NDI.

Safety and Boil-Off Mitigation

• Target heat flux: LH■ ≤ 2–5 W/m²; LOX ≤ 5–10 W/m².
• Boil-off ≤ 0.05–0.2% per day in vacuum storage.
• Autogenous pressurization and vent/recondensing systems.
• 2oo3 redundancy on relief valves; cryo-compatible seals and ESD control.
• Continuous monitoring (P, T, level sensors, fiber-optic strain gauges).

Key Requirements

Parameter	Target Value
Working Pressure	LH■: 2.5–3.5 bar; LOX: 2–3 bar
Proof Pressure	≥ 1.25–1.5 × Pwrk
Burst Pressure	≥ 2.0 × Pwrk
Heat Flux	LH■ ≤ 5 W/m²; LOX ≤ 10 W/m²
Boil-Off Rate	≤ 0.2% per day

Trade-Off: Al-Li vs CFRP

Criteria	Al-Li (2195/2050)	CFRP + Liner
Mass	Baseline (1.0)	0.7–0.85 ×
Maturity	High	Medium (LOX/CH■), Low (LH■)
Leakage	Reliable	H■ permeation risk
Manufacturing	FSW, orthogrid	Filament winding, autoclave
NDI/Repair	Accessible	Complex (delamination, impact)
Cost (NRE)	Lower	Higher

Recommendations

For current upper-stage applications:

- Use Al-Li 2195 orthogrid with friction stir welding.
- Employ common bulkhead with integrated VCS screen.
- Apply vacuum + MLI + VCS insulation strategy.
- Implement autogenous pressurization and boil-off return.
- Perform full cryo proof, slosh, and vibration testing.