Design and performance of a 3D printed liquid hydrogen tank with vapor cooled shielding for use in unmanned aerial vehicles

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MOTIVATION

Unmanned aerial systems (UASs) perform critical tasks such as observation and reconnaissance where use of manned aircraft is cost prohibitive or dangerous. While aircraft guidance and remote sensing technology have rapidly developed, propulsion systems for small scale UASs have not dramatically changed, typically relying on internal combustion engine (ICE) technology. ICE propulsion systems are noisy and produce significant vibrational loads on the airframe and payload while presenting mechanical wear issues. Electrical propulsion systems using battery power are quiet and impart minimal vibrational loads to the aircraft, but are limited to flight times typically less than one hour. Fuel cell powered propulsion systems using hydrogen are a compelling alternative that combine the quiet, reliable attributes of electrical propulsion with flight times that approach that of gasoline powered UASs.

GOAL

UAS manufacturers are currently developing fuel cell powered variants of their gas powered aircraft. Fueling options include compressed gas and cryogenic liquid hydrogen. A liquid hydrogen storage system was determined to provide higher energy density (MJ/m^3), specific energy (MJ/kg) and gravimetric capacity (H_2 wt%) than a high pressure (350 or 700 bar) gas system. Our goal is to design, build, and validate a liquid hydrogen storage system that integrates the heat exchanger into the tank wall to minimize system mass and volume while reducing heat flux into the tank.

DESIGN

- Cooling in vapor channels enhanced by para- orthohydrogen conversion
- 3D printed shells allow for complex heat exchanger flow geometry
- Copper electroplating on shells creates hydrogen permeation barrier
- Integrated temperature sensors and heater provide mass flow control
- Insulation material minimized by relying on vapor cooling
- CryoGel (aero gel derivative) used for remainder of thermal barrier
- Insulating cavities filled with CryoGel are evacuated
- Carbon fiber overwrap carries 70 psig pressure loads
- Primary and secondary pressure relief valves
- SnapTite cryogenic liquid hydrogen quick release fill valve
- Patent pending

MODELED PERFORMANCE

- CFD modeled in COMSOL Multiphysics
- Governing equations dictated by laminar flow regime
- 34 W heat extracted from tank using cold hydrogen gas as refrigerant
- 16 W heat rejected by CryoGel insulation layers
- 4.3 W heat into liquid vaporizes sufficient hydrogen for flight

TESTING

- Tensile test of 9 3-D printable liner materials in liquid nitrogen
- Testing bond adhesion joints
- Conducting cryo testing of tank prototype in July 2015 and assembling

FIGURE 1. Rendering of tank and manifold without carbon fiber overwrap.

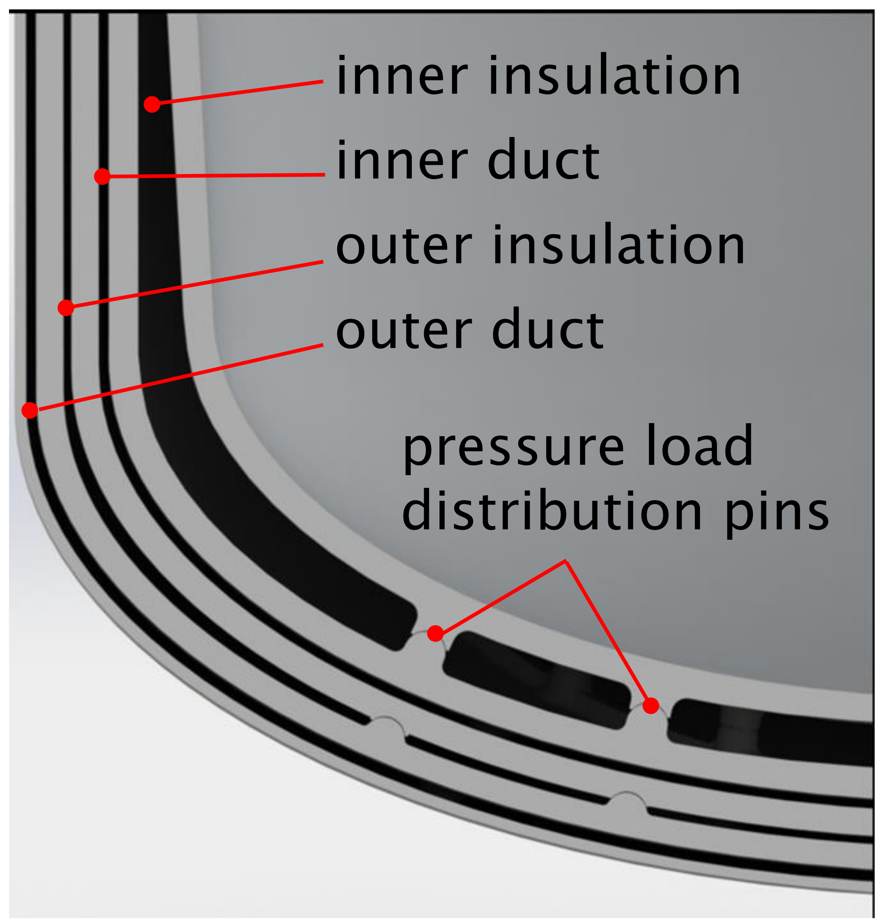

FIGURE 2. Cross-section of tank reveals gas passages and inert gas filled / insulated layers.

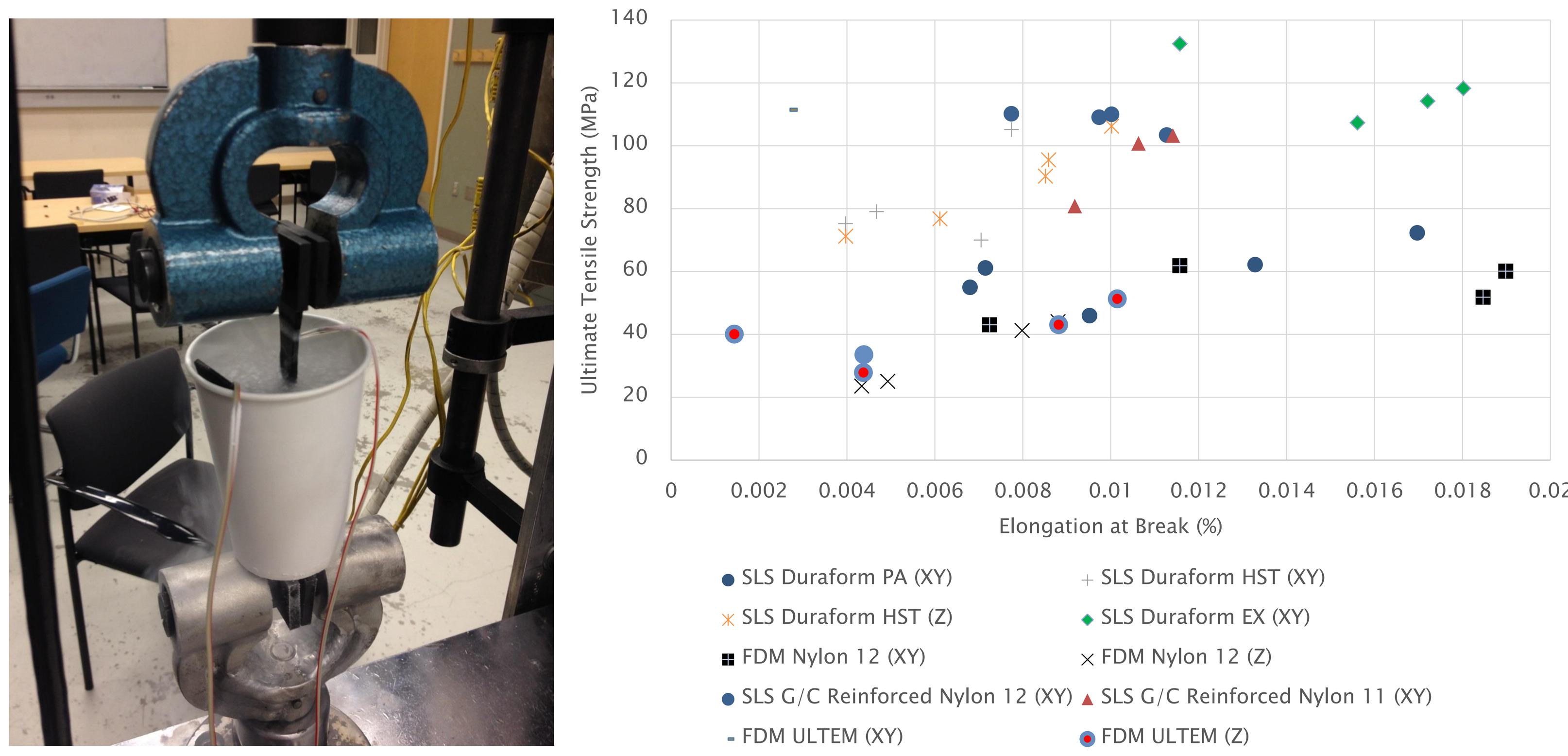

FIGURE 3. Cryogenic tensile testing of 3-D printed candidate material coupons.

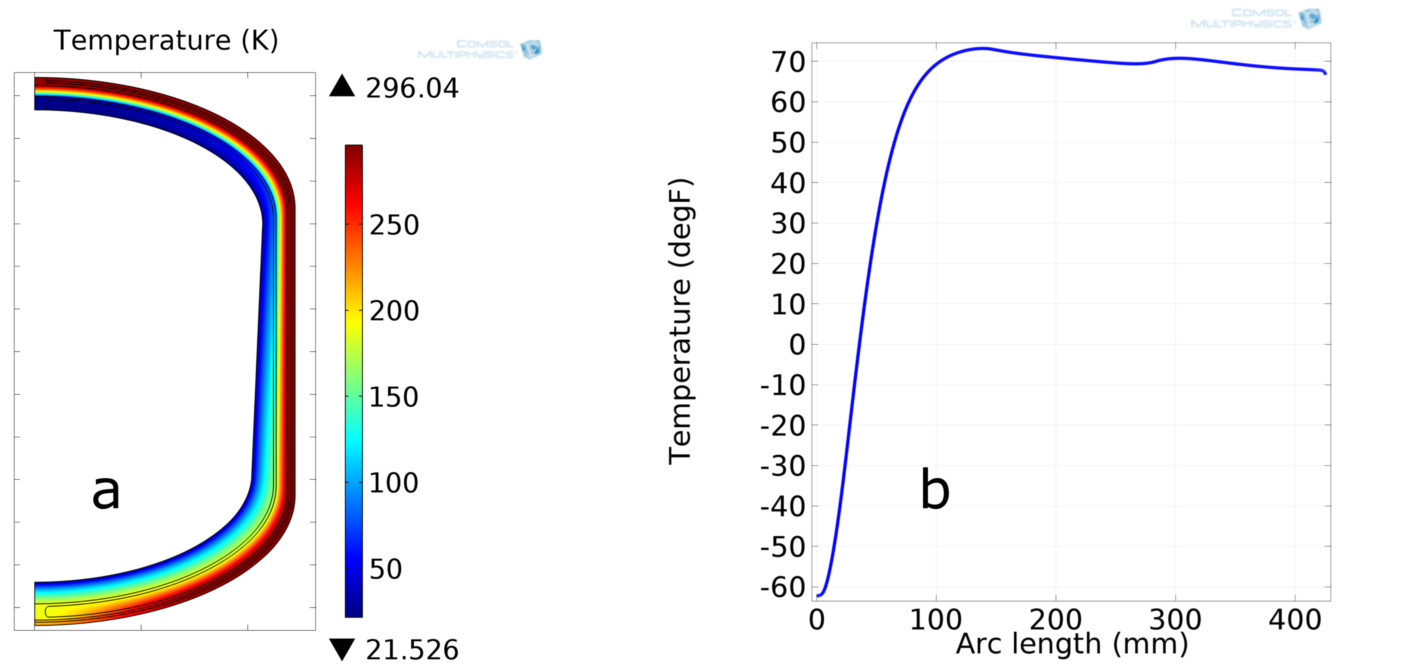

FIGURE 4. a) Axisymmetric thermal model of tank at equilibrium during flight conditions. b) exterior temperature

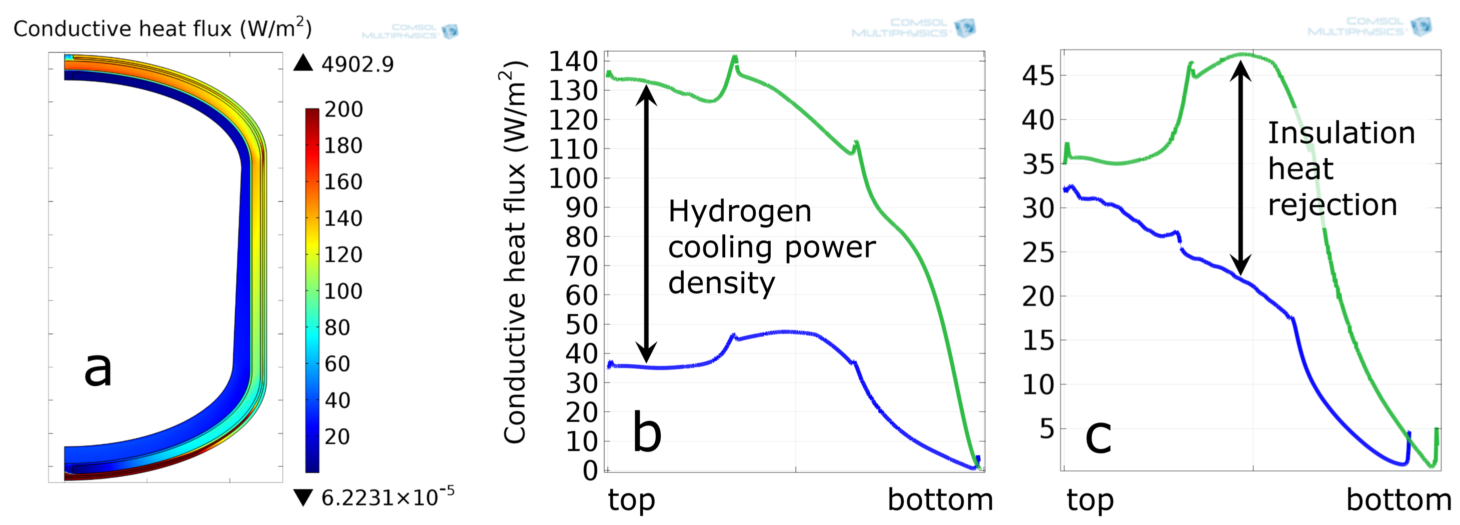

FIGURE 5. Conductive heat flux across (a) overall tank wall, (b) inner duct and (c) inner insulation layer.

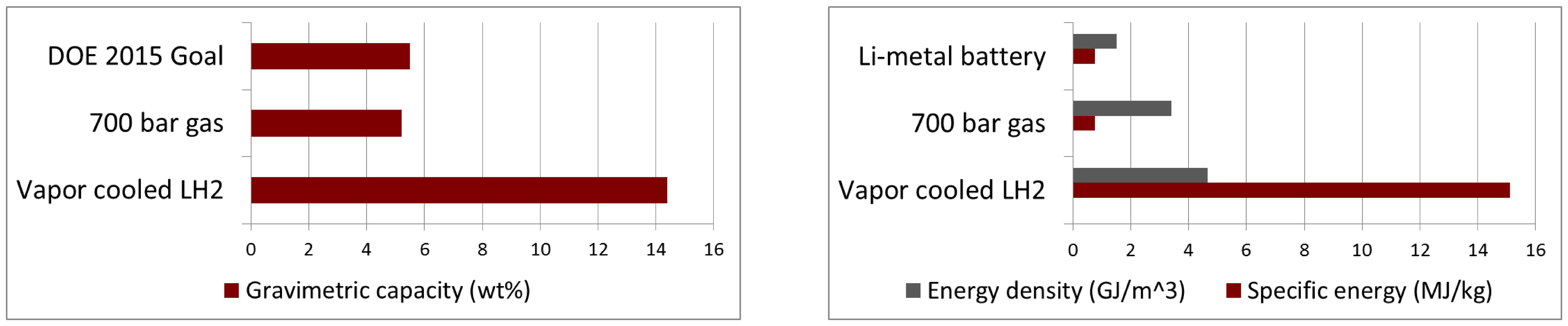

FIGURE 6. Vapor cooled tank system performance metrics.

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