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M4Or1B-01: Carbon-fiber Composite Cryogenic Tank for Liquid Hydrogen: Thermo-structural Analyses

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The potential for use of cryogenic fuel in aviation and ground transportation industry is growing, and along with it, the need for light-weight tanks to store liquid & sub-cooled hydrogen. Fiber-reinforced composite materials, especially, carbon-fiber composites, are widely used in aerospace industry and have replaced Aluminum, Steel and in some cases Titanium in airframe and engine components. This motivates the case for using composites in the area of cryogenic applications for the transport industry, where weight is critical. Unique challenges exist for composite structures and materials under cryogenic conditions, in aviation and ground transport, given the long length of service, lasting years.

The RTX Technologies Research Center (RTRC) is designing and manufacturing a tank to store liquid Hydrogen (LH2) for heavy duty ground transport applications [1], through a DOE-HFTO program. This is a dual-tank concept, with an inner tank storing liquid Hydrogen under pressure, and an outer tank at atmospheric pressure. The final design follows a conformal geometry allowing for increased usage of cubic space while using a largely circular tank geometry. A preliminary design of this tank being analyzed takes for the form of a cylindrical geometry. This paper describes the thermo-structural response of this composite tank under bolt load, cooling and pressure loading.

The inner tank, holding liquid hydrogen under pressure, is made out of carbon fiber-polymer matrix composite, in a uni-directional tape form. A finite element (FE) model of the composite tank, its metal boss and polymer seal is set up in the commercial finite element software Abaqus [2]. The goal is to assess stresses in the tank and its seal, from mechanical and thermal loading. Compressive stresses arise in the tank due to bolt preload. Thermal stresses occur due to cool-down, at a microscale, from mis-match of the coefficient of thermal expansion between the fiber and polymer, and at a macroscale due to orientation of individual plies in a composite. This model investigates the development of thermal stresses at a macro-scale. The inner tank system is modeled with continuum shell and hexahedral elements. The applied load consists of a compressive bolt-load, thermal cool-down to 20K, and internal pressure in the tank. Orthotropic properties are applied to the composite plies of the tank. A continuum damage criterion is applied to capture potential intra-ply damage [3]. The resulting stresses in the tank from bolt preload and thermal cooldown are discussed. Seal deformation under compressive loading, critical to maintaining pressure in the tank, is also discussed.

References:

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