

Ultralight Linerless Composite Tanks for In-Space Applications

Kaushik Mallick[‡] and Michael L. Tupper*

*Composite Technology Development, Inc., Lafayette, Colorado 80026
phone: 303-664-0394, email: kaushik@ctd-materials.com*

Lorie Grimes-Ledesma and Joseph C. Lewis

*California Institute of Technology, Jet Propulsion Laboratory
4800 Oak Grove Drive, Pasadena CA 91109-8099*

Jeffrey Welsh

*Air Force Research Laboratory (AFRL/VSSV)
3550 Aberdeen Ave SE, Kirtland AFB, NM 87117-5776*

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Background

NASA solar system exploration missions are undergoing a transition from fly-by observers to missions that orbit, land on, and return samples from planetary bodies. These missions are more demanding of propulsion capability, driving the mass of propulsion systems ever higher, even as the mass of electronics is reduced. As a result, the total propulsion system mass (dry mass) has increased from as little as 10 percent of spacecraft mass on Viking, to 28 percent on the originally planned Europa Orbiter (Figure 1). Significant materials technologies are required to achieve the efficiencies that will make future propulsion systems viable and minimize propulsion system mass growth. Although ultimately in-space propulsion systems will likely utilize non-chemical propulsion technologies like nuclear propulsion, near to mid-term explorations will likely continue to utilize advanced chemical propulsion systems.

Typically, the propulsion tank is the single highest dry mass item of an in-space chemical propulsion system. Monolithic titanium construction is the current state-of-the-art for chemical propellant tanks, while composite over-wrapped pressure vessels (COPV's) with a metallic liner are the current state-of-the-art for solar electric propulsion (SEP) tanks. In both cases, the metallic liner is used to provide a permeation barrier,

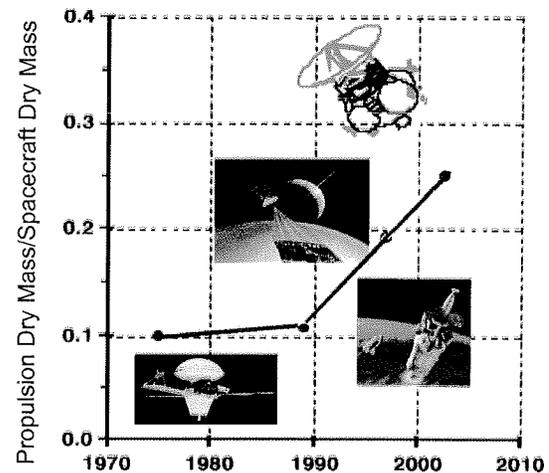


Figure 1 - Chemical propulsion system mass has grown over 250 percent as function of time and overall spacecraft mass.

preventing gas leakage through the composite. By eliminating the liner, a major portion of the tank mass, cost and fabrication time be saved. However, fiber-reinforced composites using state-of-the-art matrix resins are too permeable when subjected to the high strains characteristic of highly efficient in-space tanks. A significant material development effort will be required to fabricate ultralight linerless composite tanks (ULLCT's) for enabling nuclear propulsion systems for in-space applications.

[‡] Senior Engineer

* Vice President

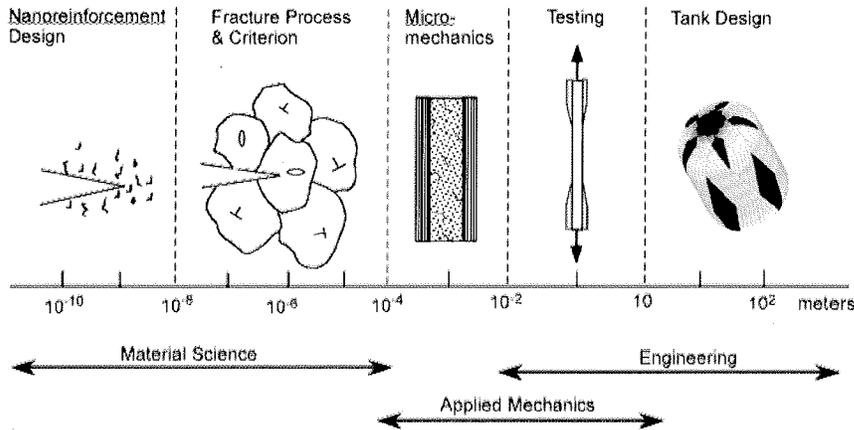


Figure 2. Breadth of expertise required for developing linerless composite tanks.

Ultralight Linerless Composite Tank

Since the late 1980's, there has been substantial interest in developing and testing composite linerless tanks for launch vehicle and spacecraft applications. Linerless composite tanks have been identified by both NASA and DoD as an enabling technology for future reusable launch vehicles (RLV's), where they may offer up to a 40 percent weight reduction compared to conventional tanks, allowing increased reactant storage and/or reduced launch mass. Similar, if not more convincing, justifications support their use in in-space propulsion systems, where reduction of overall system mass is of paramount importance. Structural weight reductions will translate directly to additional payload margins, and thus improved mission capabilities and reduced cost.

A program has been proposed to NASA to develop a technology that will provide helium containment at the high strain levels required to create low mass tanks for in-space propulsion applications. The specific goal of the program is to develop linerless composite tanks that will successfully contain small molecule gases, such as He, at 10,000 psia for a target mission life of 15 years. The materials used in the program will withstand the high strains that are characteristic of low-mass composite tanks, without allowing any significant loss of stored gas. ULLCT's will reduce the overall space vehicle mass, and reduce the cost and complexity of tank manufacturing. The program will leverage from ongoing SBIR programs at CTD for linerless composite tanks being developed for DoD/MDA's space program. The latter focuses on materials that provide structural integrity and adequate microcrack resistance of composite materials under exposure to harsh chemicals of large molecules and temperature differentials during

tank operation. In contrast the material development effort for ULLCT's for in-space propulsion needs to focus on containment of small molecule gases such as helium often used as a purge gas. In either case, the effort spans the range from nano-scale material science efforts to macro-scale tank design activities, as shown schematically in Figure 2.

Linerless composite pressure vessels for in-space propulsion must be highly optimized structures with successful helium containment presenting the largest engineering hurdle. Based on a factor of safety of 1.5 and an A-basis composite strain-to-failure of 1.5 percent for unidirectional composites, the principal strain in the composite tank shell (along the hoop direction in 3) at the mean operating pressure (MEOP) is calculated to be 1 percent. A 1 percent strain level is not detrimental to the structural integrity of the tank laminate, but is likely to cause microcracking in the helical plies. The goal, therefore, is to develop a material that can limit the leakage rate of gaseous He to 10^{-4} scc/sec at 1% strain level. Detailed results of the ongoing material development efforts and testing plans will be presented in the proposed paper.

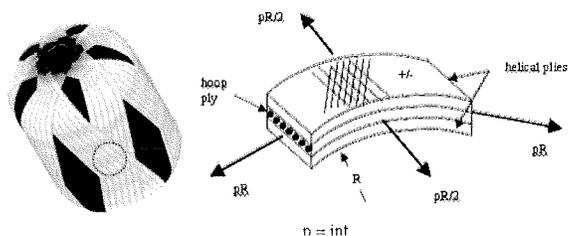


Figure 3. Results in a filament wound composite tank shell