A Lightweight, Composite, Liquid-Hydrogen Feedline

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205–544–7169

One of the many technological needs in making a single-stage-to-orbit vehicle a reality is being able to reduce component weight. Making components lightweight can lead to an increase in mass fraction and vehicle performance. One area with potential for substantial weight savings is the use of graphite/epoxy composite feedlines for the vehicle propulsion system. Typical feedlines for vehicles are made from aluminum or stainless-steel materials. An estimated weight savings of nearly 50 percent over conventional metallics could be achieved by using composite feedlines. This potential weight savings makes the use of composite materials a very attractive feature for future single-stage-to-orbit vehicles.

Under a cooperative agreement contract (NRA 8–11) between MSFC and McDonnell Douglas Aerospace, a team was formed to develop and demonstrate the use of a composite feedline for flowing liquid hydrogen. The authority to proceed was given in July 1994, with the objective of delivering a fully flight-qualified feedline in August of 1995. The feedline would then be installed onto the DC–XA vehicle for flight. In order to reduce the development costs of this new technology and also meet the delivery schedule, the work was divided between MSFC and McDonnell Douglas, making the best use of the talent and resources each organization had to offer. McDonnell Douglas was tasked to perform the design and analysis of the composite feedline, while MSFC was tasked to manufacture, assemble, and perform all feedline testing.

The composite feedline designed is used to supply liquid hydrogen at 50 pounds per square inch gauge from the liquid-hydrogen tank sump to the liquid-to-gas conversion system onboard the DC–XA vehicle. The liquid-to-gas conversion system is used to supply propellants to the reaction-control thrusters for vehicle attitude control. This particular feedline incorporates five advanced technology features. The first is the use of graphite/epoxy material, and the second is the manufacture and use of elbows made from composite. (Many feedlines today involve very complex geometries and are rarely straight lengths.) Third is the manufacture and use of flanges made from composite. Fourth is the ability to join a composite tube to a composite tube. (Since some feedlines may not be feasible to make in one piece because of complex geometry or other constraints, it will become necessary to be able to join composite lines together.) Finally, the fifth feature demonstrated is the ability to join a composite tube to a metallic tube. (In propulsion feed systems, there will inevitably be areas where a feedline will contain a metallic component, typically a bellows or flex joint. It then becomes necessary to be able to join that metallic component to the composite part of the feedline.) The successful demonstration of all five of these technology features is key in the ability to use composites for vehicle feed systems.

The flight composite feedline is 2 inches in diameter (fig. 65). The line consists of a composite flange joined to a 90-degree composite elbow using a composite splice joint. The 90-degree elbow is then joined to a 45-degree elbow using another composite splice joint. The other end of the 45-degree elbow is joined to a reducer made from titanium material. The graphite/epoxy material selected for the elbows and flange was IM7/8552, an eight-harness prepreg weave. The material used for the composite splice joints was unidirectional IM7/8552 prepreg. All three joints (two composite-to-composite joints and one composite-to-titanium joint) were bonded using Hysol EA9394 adhesive. The material selection was based upon materials testing performed by McDonnell Douglas during its development program for the National Aerospace Plane.

Tooling for each composite item was designed and fabricated. Each composite item was then fabricated in MSFC's Productivity Enhancement Complex. Each component was fabricated by hand-layup onto the tooling. Once the part was hand-layed onto its tooling, it was then oven cured. After the oven cure, the composite part was removed from the tooling, and final machining was made on the part to meet its final dimensions. After each composite component passed its final inspection, the components were adhesively

FIGURE 65.—Lightweight, composite, liquid-hydrogen feedline.

bonded together using the splice joints. The best method found for applying adhesive into the splice joints was by injecting the adhesive through four 90- degree clocked holes (0.10 inch in diameter) drilled into each end of the splice. This ensured uniform coverage of the adhesive and proved to be a much simpler process.

After fabrication of the composite items, a rigorous test program was begun to qualify the design for flight. Three development test articles were assembled. Development test article No. 1 incorporated a composite flange, a composite 90-degree elbow, two composite-to-composite splice joints, and a composite-to-titanium joint. This article was subjected to helium-leakage tests, a proof-pressure test at 75 pounds per square inch gauge, a 58-thermal-cycle test between – 423 °F and +145 °F, a hydrogen-leakage test, and, finally, a burst-pressure test at 125 pounds per square inch gauge. The test article passed all tests. The helium leakage measured was no greater than 10 E– 08 cubic centimeters per second magnitude. The hydrogen leakage from the entire test article was no greater than 0.5 standard cubic inch per minute, which is the lowest threshold of the measurement system used. Development test articles Nos. 2 and 3 were fabricated in order to perform structural strength tests of the adhesive joints at liquid-hydrogen temperature. The composite-to-composite joint failed at 9,215 pounds of axial load. The composite-to-titanium joint failed at 8,709 pounds of axial load.

After successful completion of the development test articles, a prototype feedline was fabricated. This test article was built to the exact configuration of the flight feedline. The prototype feedline was subjected to a vibration life test to qualify the flight feedline for eight DC–XA flights. The feedline was vibration tested to approximately 28 Grms for a duration of 78 minutes in each axis. The vibration test was performed with liquid hydrogen at 50 pounds per square inch gauge inside the feedline to simulate the operating temperature and pressure. The posttest inspections revealed the feedline successfully passed this vibration test. No damage to the feedline was observed, and it passed the posttest helium-leakage test.

The actual flight feedline has been built and has successfully passed its acceptance testing. The feedline was subjected to helium-leakage tests, a proof-pressure test at 75 pounds per square inch gauge, a 10-thermal-cycle acceptance test between – 423 °F and +135 °F, and a vibration test.

To date, this work has shown the feasibility of applying composite materials in a feedline design for liquid hydrogen. The feedline has passed all of its critical tests. The feedline is now being integrated into the DC–XA vehicle for its first flight in early 1996.

Sponsor: Office of Space Access and Technology

Industry Involvement: McDonnell Douglas Aerospace, Huntington Beach, California