CASE STUDY:

Torlon PAI's Thermal Isolation, High Strength Keys to Weight-Saving Innovation in Composite Aircraft's Hydraulic System

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ADVANCED THERMOPLASTICS' ULTRA HIGH-PERFORMANCE AND DESIGN VERSATILITY SAFELY DISSIPATE LIGHTNING AND ENABLE WEIGHT-SAVINGS

The drive for more fuel efficient, comfortable, higher capacity commercial airplanes has led to the increasing use of carbon fiber composites in aircraft structures. Compared to metallic materials, they provide equivalent or enhanced structural strength within their service temperature ranges, offer far more design versatility, and deliver the added benefit of fuel-efficient weight reduction which can be leveraged to increase payload capacity. In fact, carbon-fiber composite materials have proven their performance and weight-saving advantages so successfully that they now make up approximately 50% of the weight of most modern commercial aircraft.

As would be expected with a significant shift in materials of construction, the shift from aluminum-skinned aircraft to composite external construction also required changes in materials and designs of components that make up the systems affected by the change to composite skins.

MANAGING LIGHTNING STRIKES

A major difference between aluminum-skinned aircraft and those made of composites is how they handle lightning strikes. Lightning sheets off aluminum skinned aircraft in flight, while electrically conductive carbon fiber composites absorb lightning strikes and must dissipate that energy.

One case where an opportunity for significant weight-savings depended on uncompromised electrical energy dissipation involved an aircraft's hydraulic system. The design concept had the hydraulic lines configured to pass through rather than around the aircraft's fuel cells. Making it a reality required structural thermal isolators that would carry the hydraulic lines and insulate them from lightning strikes while dissipating the electrical charge. The need to perform reliably- and within the fuel environment under severe thermal and physical demands narrowed the material options for the isolators and ultimately led to the specification of Torlon PAI.

WEIGHT-SAVING INNOVATION IN HYDRAULIC SYSTEMS

The innovative approach of running the hydraulic lines through the fuel cells capitalized on the properties of Torlon PAI and a design modification to dissipate electrical energy from lightning strikes.

Legacy designs route the hydraulic lines around the fuel cells. This requires much longer lengths of hydraulic tubing. The benefit of the new design approach is weight savings: shorter lengths of hydraulic lines weigh significantly less, especially when factoring in the weight of the fluid.

The design of the isolator assembly and the choice of the material were the keys to making this more efficient approach possible. The isolator requires a material that has low thermal conductivity over wide temperature variations, extremely high strength and stability, and resistance to hydraulic fluids and jet fuel. The isolator assembly itself must incorporate electrical insulation and dissipation capabilities that suppress any potential effects of lightning strikes. These complex factors excluded metallic materials and focused the engineering evaluation on high-performance polymers that are strong at high temperatures and thermally and electrically insulative.

ASSEMBLY DESIGN DETAILS

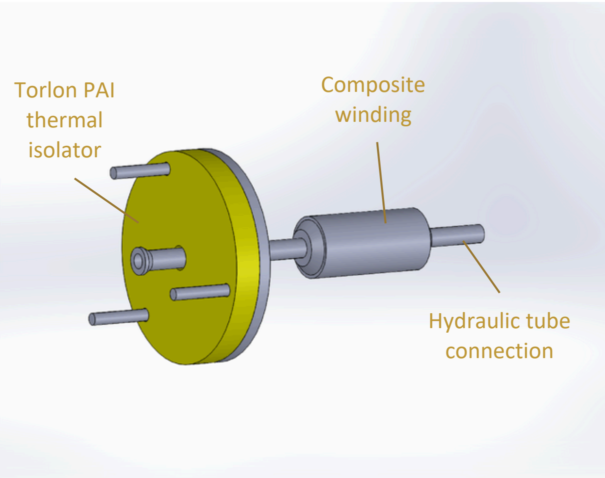

Figure 1: Schematic - thermal isolator assembly

The thermal isolators are backed by a metal flange and bolted into the fuel cells. The hydraulic lines for flight controls and other hydraulic systems pass through the fuel cells. To ensure lightning strike management, a composite winding is placed around the metal tubing through which the hydraulic fluid flows. The composite winding interrupts electrical current that would otherwise continue to travel down the hydraulic lines. In operation, the composite winding side of the thermal isolator assembly is immersed in jet fuel. The energy from lightning strikes is converted into heat in the semi-conductive composite windings. The fuel acts as the heat sink, cooling the composite winding as the electrical energy is dissipated.

MATERIAL SELECTION PROCESS

Early in the design stages, Drake Plastics, a technology leader in advanced polymer extrusion, machining, and injection molding, worked with Syensqo, a high-performance plastics resin supplier, to define material options that would meet the customer's application criteria.

The materials evaluation and prototype development program conducted at Drake's facility focused on several PEEK and Torlon PAI grades that included high-strength carbon and glass fiber reinforced formulations. However, the 150°C glass-transition temperature (Tg) or softening point intrinsic with the PEEK polymer - and therefore all its formulations - fell short of the performance requirements. PEEK also did not offer the resistance to creep from the physical loads exerted on the component at the required peak operating temperatures of the system.

Extensive qualifications at the specifier level were also conducted. This included "Tread Threat" analysis, a simulation of a tire blowout that repeatedly impacts the underside of the wing, to ensure critical components such as the thermal isolator assembly survive and function.

Torlon PAI's physical and thermal properties *(Table 1)* exceeded those of PEEK, were well within the performance requirements, and provided a margin of reliability for the component.

Table 1: Thermal and Structural Properties – Torlon PAI and PEEK

	Torlon 4203	30% GF Torlon 5030	KetaSpire PEEK	30% GF PEEK
Glass Transition Temperature (Tg), °C	280	280	150	150
Flexural Modulus, MPa @ 23°C	5,030	11,700	3,700	10,300
Flexural Modulus, MPa @ ≥ 200°C	3,590 @ 232°C	9,860 @ 232°C	320 @ 200°C	2,260 @ 200°C

*Data Source: Syensqo (formerly Solvay)**

TORLON PAI DELIVERED PERFORMANCE AND A MARGIN OF SAFETY

Performance attributes that made Torlon PAI the most viable candidate compared to other advanced polymers and metals included its inherently low thermal conductivity and thermal isolation capability, its high electrical insulation values, resistance to high temperatures under load, and its high structural strength and toughness.

The 280°C glass-transition temperature of Torlon PAI exceeds that of PEEK by an impressive 130°C and affords a significant margin of safety in the event of high temperature excursions.

Torlon PAI also satisfied the structural requirements of the components. It maintains its strength at the high temperatures involved in the system, making it an excellent weight-saving structural option compared to metals.

On thermal conductivity *(Table 2)*, Torlon PAI's value of 0.26 W/ mK afforded a significant benefit over stainless steel at 16.3 W/ mK and ensured low BTU/ hour heat transmission. This property of the material, and the precision-tolerance thicknesses of the finished Torlon PAI isolators, combine to keep heat from transmitting to the aircraft's composite structures.

Table 2: Thermal Insulation Property Comparison

	Torlon PAI	KetaSpire PEEK	Stainless Steel	Aluminum Alloy
Thermal Conductivity (w/m – K)	0.26 – 0.80	0.1 – 0.3	16.3	150

*Data Source: Syensqo (formerly Solvay)**

TWO TORLON PAI GRADES WERE ULTIMATELY SPECIFIED

The final system designs and placement of the hydraulic lines resulted in two different performance criteria. As a result, two grades of Torlon PAI were specified, allowing material efficiency with no sacrifice in performance or reliability of the overall system. Torlon 4203, an unreinforced grade, easily satisfied the performance requirements of one thermal isolator design, while 30% glass fiber reinforced Torlon 5030 was chosen for the second design where the anticipated physical loads required the material's higher structural strength.

NEAR-NET SHAPES YIELD MATERIAL-EFFICIENT PARTS WITH LOW COST INJECTION MOLDS

The production volumes required for different configurations of the isolators led Drake to recommend injection molding near-net shapes, then post-machining them to exact tolerances.

Certain thermal isolator designs were ideal for injection molding Tolron PAI near-net shapes in low-cost tooling, then finish-machining parts to specification.

The technique involves using low-cost injection molds to make blanks very close to the desired part configuration. The blanks are post-machined to specified dimensions with very little material loss. The combination of low-cost molds and materials efficiency helps keep overall costs in line. It is ideal for unit volumes that are higher than those suited to fully-machining shapes, but below quantities that justify the investment in production tooling for finished parts.

HIGH-PERFORMANCE POLYMERS IMPROVE DEPENDABILITY AND EFFICIENCY

In addition to their efficiency and design benefits, high-performance polymers enhance the dependability of components, particularly in situations involving hard impacts, and when exposed to chemicals and aviation fuels. They provide toughness, electrical insulation and thermal isolation, and are highly resistant to fatigue failure and corrosion. They also allow more innovative designs, and are easier to convert into complex finished components by an array of processes including extrusion, machining and injection molding.

**Syensqo is the new corporate designation for the former Solvay Specialty Polymers business.*