

Tech focus

This month's focus describes how some companies went about testing new products and technologies.

New liquid rocket engine cycle fares well in test

A rocket engine combining the latest innovations underwent successful testing recently, helping move forward America's only staged combustion liquid booster rocket engine now in development.

The IPD (Integrated Powerhead Demonstration) is a ground demonstrator engine program. At NASA's Stennis Space Center near Bay St. Louis, MS, the engine reached steady-state 100% operation, demonstrating main-stage performance. It was the first U.S. demonstration of the full-flow staged-combustion (FFSC) cycle. The IPD engineers had conducted 21 of 26 tests and accumulated 300 s of operation up to the latest 100% power level test.

Capable of generating about 250,000 lb of thrust, the engine uses liquid oxygen and liquid hydrogen. The FFSC cycle uses a fuel-rich pre-burner to drive the fuel turbopump and an oxidizer-rich pre-burner to drive the oxygen turbopump. Because all of the propellants are burned in the pre-burners, more mass flow is available to drive the turbines than in a conventional staged-combustion cycle. The additional power enables lower turbine temperatures and less stress, translating into longer turbine life—a key factor for reusable rocket engine life.

In addition, the use of oxidizer-rich gas in the oxidizer turbine and fuel-rich

gas in the fuel turbine eliminates the need for a complex propellant seal for the pumps. This increases engine system reliability. The engine also includes a hydrostatic bearing technology that literally floats the turbine shaft on rocket propellants, eliminating wear and enabling high reusability.

Featuring high-performance, long-life technologies and materials, the engine has been designed for use in up to 200 flights.

The IPD engine has been designed, developed, and tested through the combined efforts of **Pratt & Whitney Rocketdyne** and **Aerojet**, under the program direction of the **U.S. Air Force Research Laboratory (AFRL)** and technical direction of NASA's Marshall Space Flight Center. Pratt & Whitney Rocketdyne is the systems integrator and also provides the fuel turbopump, oxidizer turbopump, main injector, main combustion chamber, engine control system, and other engine systems components. Aerojet provides the fuel and oxidizer pre-burners, nozzle, and fuel pre-mixer. The combustion devices include formed platelet technology in the injector designs, and milled channel technology in the nozzle.

Technologies developed during the program are directed at achieving the goals of the Integrated High Payoff

Rocket Propulsion Technology program and NASA's Exploration Technology Development program: to double the performance of rocket propulsion systems over the 1993 state of the art, and to decrease the costs of access-to-space for commercial and military customers.

"We continue to pave new technological ground each day, currently developing and test firing the first new liquid rocket engine cycle in the last 35 years," said Stephen Hanna, IPD Program Manager for AFRL. "That dates back to the early development days of the space shuttle's main engine."

"Our intent is to validate new propulsion technologies that can be used in a new generation of rocket engines," said Don McAlister, Pratt & Whitney Rocketdyne IPD Program Manager. "The IPD itself will not be flown, but its technologies will find their way into future rocket engines and will be especially valuable for NASA's vision for space exploration."

The project is managed from AFRL at Edwards Air Force Base, CA, with technical support from the Marshall Space Flight Center. Test operations and facilities are provided by NASA's Stennis Space Center.

Patrick Ponticel



The IPD engine reached steady-state 100% operation—the first U.S. demonstration of the full-flow staged-combustion cycle.

Bending over backwards for double-tube solution

Double-wall tubing is commonly used in aircraft fuel lines to capture and drain potential leakage in accordance with safety and certification requirements. Most double-wall tube manufacturing methods use a removable medium such as wax, sand, metal shot, or low-melting-point metal alloys to fill the gap between the tubes and provide support during bending.

When developing a double-wall tube-bending system for launch customer



Wolfbend technology is used throughout the Bombardier RJ700 regional jet for fuel supply lines (top two photos) and fuel vent lines (bottom).



Wolfbend tube-bending technology relies on polytetrafluoroethylene because the material is flexible and can be extruded in special profiles and at close tolerance.

Bombardier Aerospace, the main objective of **Wolfbend** President Larry Wolf was to improve on an existing manufacturing process. Bombardier was using a polyolefin heat-shrink sleeve to fill the gap between tubes. It was doing the job, but scrap rates during bending were high. The sleeve could not be removed, which was beneficial in supporting both tubes once in service, but it obstructed most of the leak-draining capacity. The goal was to find and test a material that would remain between the tubes, but could also be extruded in a shape that had built-in drainage channels.

Testing began in Bombardier's Montreal tube shop using heat-shrinkable PTFE (polytetrafluoroethylene), a material that had good potential for bendability and could be extruded in special profiles to close tolerances. The heat-shrink process proved very good for fixing the sleeve in place before bending, but there were two problems: 1) the heat gun subjected the tubing to temperatures above 400°F, which affected the aluminum's strength characteristics; 2) the heat-shrinkage rate also varied, which made it impossible to maintain the sleeve thickness tolerances needed to fill the gap between tubes completely. Too thick and the tubes could not be assembled, too thin and scrap rates during bending would be significant.

The second series of tests began using a standard non-shrinkable PTFE. This ma-

terial proved to be workable for manufacturing tolerances, and test results were also promising for bend quality and repeatability. The next step was to fine-tune the dimensions and tolerances, and optimize the size and number of drainage channels in the sleeve. Sizing the channels was a challenge because they affected the bend-supporting integrity of the sleeve. Ten different sleeve profiles were tested, including a spiral-cut version before arriving at the final shape.

The final step in testing was to improve on the bending characteristics of the sleeve material. This was also critical because it had to flow, but not crush or crack under extremely high bending loads. The material settled on was a proprietary PTFE formulation that improved on the bending characteristics of standard PTFE without significantly impacting cost.

The entire testing and development process took 10 months, and also provided a few unexpected benefits. "A positive and surprising result from testing of the new material was that bend defects such as wrinkles on the inner tube always transferred to the outer tube," Wolf said. "This was not true of the previous polyolefin method. Now we only needed to do a visual inspection, totally eliminating the costly X-ray inspection step."

In addition to improving manufacturability, "We found we could also bend thinner-walled tubing," Wolf continued. "We were producing double-wall tube that could do the same job and was 47% lighter. We also were able to develop a simple assembly process that used our existing bending machinery and tooling. The entire job could be done in-house."

Wolfbend became Bombardier's shrouded fuel line design standard, and has been used on all subsequent Bombardier aircraft designs. It has recently been adopted for use by **Cessna** on the Mustang, which falls into the relatively new category of very light jets.

Airbus is currently working with Wolfbend on evaluation tests to verify leak drainage capacity, and has already successfully completed Wolfbend bending tests using titanium tubing. **Embraer** also is conducting tests to verify the Wolfbend process for in-house manufacturing and elimination of their X-ray inspection process for double-wall tubing.

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Single test article does the job for Falcon 7X

For the first time, **Dassault Aviation** relied on a single test article to complete static and fatigue testing of a civil aircraft. Engineers recently wrapped up 16 months of testing for the Falcon 7X in Toulouse, France. It was subjected to the equivalent of 40,000 cycles—two times the design life of the airframe.



The Falcon 7X's wings are pulled up as much as 2.5 m at the tips as part of the plane's static and fatigue testing regime.

As required by the **FAA** and **EASA** (European Aviation Safety Agency), the test article reached 150% of design limit load on the wings, cabin, and fuel tank. The wings of the aircraft were bent 2.5 m as measured at the wing tips and at 150% design limit load. To date, 20 production wing sets have been fully assembled.

"This is not only a great accomplishment for the program, but it speaks volumes about how the Falcon 7X was designed and built," said Charles Edelstenne, Chairman and CEO of Dassault Aviation. "For one test article to be subjected to the grueling nature of both the static and fatigue testing further validates the advanced design features Dassault has incorporated into the Falcon 7X."

During the entire test program, CEAT used the same jigs and test equipment developed with CATIA. This helped engineers complete testing on the schedule established three years ago. The test equipment included 64 computer-controlled actuators, 2000 strain gauges, and four pressurization systems.



Wind-tunnel testing is another key tool for proving out the Falcon 7X.

The flight-test program for the Falcon 7X has surpassed 850 hours covering 275 flights. Flight testing and certification are expected to wrap by early next year, with deliveries beginning in the second quarter.

About 40 aircraft are now in various stages of production at the company's plant in Bordeaux, France. More than 92 copies of the world's first purpose-built fly-by-wire business jet have been sold.

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