

# Low NO<sub>x</sub>, Lean Direct Wall Injection Combustor Concept Developed



*Ultra-low-NO<sub>x</sub> combustor concept that injects fuel from the wall of a venturi section (LDWI), counter to the air swirl. The air swirl is generated upstream of the Venturi section. Shown is a module for flame-tube testing with an enclosed pilot burner.*

The low-emissions combustor development at the NASA Glenn Research Center is directed toward advanced high-pressure aircraft gas turbine applications. The emphasis of this research is to reduce nitrogen oxides (NO<sub>x</sub>) at high-power conditions and to maintain carbon monoxide and unburned hydrocarbons at their current low levels at low-power conditions. Low-NO<sub>x</sub> combustors can be classified into rich burn and lean burn concepts. Lean burn combustors can be further classified into lean-premixed-prevaporized (LPP) and lean direct injection (LDI) combustors. In both concepts, all the combustor air, except for liner cooling flow, enters through the combustor dome so that the combustion occurs at the lowest possible flame temperature. The LPP concept has been shown to have the lowest NO<sub>x</sub> emissions, but for advanced high-pressure-ratio engines, the possibility of autoignition or flashback precludes its use. LDI differs from LPP in that the fuel is injected directly into the flame zone and, thus, does not have the potential for autoignition or flashback and should have greater stability. However, since it is not premixed and prevaporized, the key is good atomization and mixing of the fuel quickly and uniformly so that flame temperatures are low and NO<sub>x</sub> formation levels are comparable to those of LPP.

In this LDI concept, the air is swirled upstream of a venturi section and the fuel is injected

radially inward into the airstream from the venturi throat section using six plain-orifice injectors. Important aspects of this technique are (1) a liquid jet should be used (not a thin-film, hollow-cone spray typical of a conventional pressure-swirl atomizer), and (2) the jet should be injected radially inward from the mixer wall toward the approaching swirling airflow at an inclined angle with respect to the radial direction. The advantage of the lean direct wall injection (LDWI) concept is its use of a swirling airflow both for atomizing the injected liquid jets and for mixing the atomized sprays in a short period of time. In the case of coaxially injected sprays, the strong centripetal forces of swirling airflow tend to sustain the liquid droplets (or fuel vapor) inside the core recirculating zones, resulting in a relatively slow mixing process. In the LDWI mode, however, the swirling airflow abruptly breaks the liquid jet into small droplets and the droplets are mixed quickly, within 25-mm downstream of the injection point.

Flame-tube tests were conducted with inlet temperatures up to 810 K, inlet pressures up to 2760 kPa, and flame temperatures up to 2100 K. A correlation was developed relating the NO<sub>x</sub> emissions to the inlet temperature, inlet pressure, fuel-to-air ratio, and pressure drop. If 15 percent of the combustion air would be used for liner cooling and an advanced engine cycle was used, for the best configuration, we estimate that the NO<sub>x</sub> emissions using the correlation would be less than 75 percent of the 1996 International Civil Aviation Organization (ICAO) standard for emissions.

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