Featured Column: ***As the Turbine Turns...***

Focus on Fans

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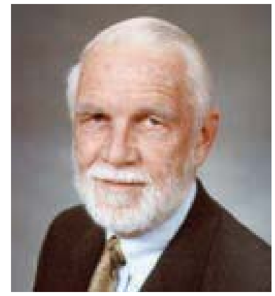

Langston is a former editor of the ASME Journal of Engineering for Gas Turbines and Power and has served on the IGTI Board of Directors as both Chair and Treasurer.

When jet-engined commercial flights first started in the 1950's, aircraft were powered by turbojets – jet engines in which all thrust was provided by gases that went through the engine from inlet to exhaust nozzle, exiting in a single high velocity jet.

Nowadays, almost all commercial aircraft are powered by turbofan jet engines, so-named for a ducted front-mounted fan. Air drawn into the fan is divided into that which flows out of the fan into the jet engine itself and the remainder that bypasses the engine. The lower velocity bypassed air and the higher velocity engine air combine downstream to produce thrust with a larger mass flow at an average velocity lower than the high velocity jet flow.

With a large frontal area, the commercial aircraft turbofan is designed to produce peak thrust at takeoff, with most of the thrust produced by air drawn in by the fan that bypasses the jet engine core itself. Bypass ratios, - the mass of fan air bypassed for every unit mass of air through the engine – can be as high as 8.4:1, as in General Electric's 100,000 pound thrust GE90 engine.

The addition of a fan to a jet engine was first proposed by Frank Whittle (one of the inventors of the jet engine) in a 1930 British patent. He called it a thrust augmenter, because its addition does increase thrust and reduce fuel consumption (that is, has a lower thrust specific fuel consumption (TSFC).

For subsonic flight, the propulsive efficiency, η_p, of a turbofan is also higher than that of a turbojet. This efficiency is defined as the useful propulsive power (the product of thrust and flight velocity, V_o) divided by jet power (rate of change of the kinetic energy of gases through the engine). This simplifies to [1]

Fig. 1

$$\eta_p = \frac{2}{V_e/V_o + 1}$$

where V_e is a suitable average of the lower velocity bypass air and the higher velocity jet exhaust. Equation (1) shows that a turbojet engine with a high value of V_e/V_o has low propulsive efficiency, while a turbofan engine with low values has a corresponding high propulsion efficiency.

Since V_e in Equ. (1) is largely determined by bypass flow in a high bypass engine the fan pressure ratio (which could be 1.6 for a bypass ratio of 8:1) is the key parameter. Lowering it to decrease V_e and increase η_p means increasing the bypass ratio.

New fan technology that has been developed by Pratt and Whitney to increase bypass ratios to 11:l, using a gear box to reduce fan speed and increase fan diameters. The net result is a large reduction in engine noise and as much as a 16 percent improvement in fuel consumption (lower TSFC). Right now P&W geared turbofan engines are being designed, developed and tested in the 18,000 – 30,000 pound thrust range, which represents the biggest and most lucrative part of commercial aviation engine market.[2]

Some have scoffed at the use of a gear box for the fan. At IGTI's TURBO EXPO '05 in Reno, during the keynote session, the president of Pratt & Whitney reported on progress with the geared turbofan. During the keynote discussion period, retired CEOs from GE Aircraft Engines and Rolls-Royce both stated that based on their experience such gear systems were to be avoided.

Recently, I was given a tour of P&W's gear facilities in Middletown Connecticut by Michael McCune, who is the manager of their fan drive gear systems. The company has been developing the fan gear box over a period of twenty years, involving a serious commitment of research, design and gear rig testing. The company has a long history of gear box experience associated with their very popular turboprop gas turbines at Pratt & Whitney Canada.

Field tests have conclusively shown that the geared turbofan has a much lower level of noise. Currently, some airlines have as much as 35-60 percent of their operating costs in jet fuel use. If the geared fan engine does indeed significantly reduce fuel use, this improvement in fan performance will be hard for the competition to beat.

Another way to improve fan performance is to change the pitch of fan blades, during an aircraft flight cycle. For instance, with propeller driven planes, controllable pitch propellers have been in use since the 1920s. During the 1990s jet engine companies tested variable pitch turbofans, but the variable pitch mechanisms used proved to be heavy, bulky and difficult to control.

Recently, Rotating Composite Technologies (RCT), a small firm in Kensington, Conn. has come up with a unique patented design for the variable pitch fan that promises to overcome the deficiencies of those tested in the 1990s[3]. As I write this, two papers on it are scheduled to be presented at our June 14-18, 2010 Turbo Expo in Glasgow. One by John Violette and Eric Loos[4] describes the new RCT variable pitch fan design. The second paper by Robert Mazzawy[5] compares a conventional engine design with one that has the RCT variable pitch fan. Both engines were sized to deliver 30,000 pounds thrust at the operating point. The Mazzawy study shows that an 11 to 16 percent fuel burn improvement for the RCT variable pitch fan design, covering a range of flight profiles.

Stay tuned to see if geared and variable pitch fans will move into the jet engine market, to bring about double digit improvements in airline fuel efficiency! ✲

References

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4. Violette, J.A. and Loos, E.S., 2010, "Mechanical Design of a Variable Pitch Fan for Turbofan Engines", Proc. of ASME TURBO EXPO, June 14-18, 2010, Glasgow, GT2010-22969.
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