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Aerodynamic design of an ultra-low rotating speed geared fan

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Abstract

For a geared fan with a high bypass ratio, it is easy to reduce its rotating speed by increasing the gear's reduction ratio without changing the original structure of the turbofan engine. A reduction in the rotating speed can effectively reduce the aerodynamic noise of the engines. In addition, due to the low rotating speed, the requirement for structural strength decreases, thus the blade thickness can be reduced, further effectively reducing the engine's weight. This study presents a new concept of diffusion blade profiles for designing a fan rotor with an ultra-low rotating speed. The blade profiles of the new concept are characterized by large cambers and convergent blade passages in their rear parts. A large camber contributes to an ultra-high load, and a convergent blade passage contributes to the control of the growth of the boundary layers on blade surfaces and reduces the flow losses. Flow field numerical simulations show that the designed fan has nearly the same mass flow rate and total pressure ratio as an existing fan, but its rotating speed is only 2240 RPM, much lower than that of the existing fan (3700 RPM), and its efficiency at design point is 0.964. Research on stacking line sweep indicates that the forward sweep at blade root can effectively reduce the relative Mach number at the outlet, thus reducing the losses from shock waves and increasing the efficiency.

Key words: High bypass ratio fan; Aerodynamic Design; Ultra-low rotating speed; 2D blade profile; Stacking line of sweep

1. Introduction

Noise is a primary technical index of civil aircraft, and the Advisory Council for Aeronautics Research in Europe(ACARE) requested that in the year 2020s environmental indexes, civilian aircraft noise should be reduced by 50% as compared with 2000[1, 2]. As for the power plant of most civil aircraft—the turbofan engine, its noise is the primary source of an aircraft's noise, and the engine noise is mainly generated by the fan and the exhaust nozzle [3–6].

In 1973, the concept of a geared turbofan engine was put forward in the literature [7]. An analysis of the literature and follow-up studies [8-10] showed that compared with a direct-drive turbofan engine, the fuel consumption rate, noise, and maintenance cost of a geared turbofan engine are lower, and its weight is also lower. After more than 30 years of cooperation, P & W, Avio, MTU, VAC, and other advanced international aviation technology research agencies carried out a series of research projects on associated components, assembly, and system technology, which included component rig tests and overall tests of the engines. Demonstrator GTF™ was installed on a Boeing 747 in 2008 to carry out flight tests. Compared with the replaced direct-drive turbofan engine, the noise of the demonstrator was reduced by 50%, and the fuel consumption was reduced by 12% [11]; but its structure becomes a little complex, because it has a speed reducing gear and a lubrication system for the gear.

With regards to a geared turbofan engine, due to the high bypass ratio, low exhaust velocity, and relatively low exhaust noise, the proportion of fan noise in an engine increases [12]. Therefore, a reduction in the fan noise significantly reduces the overall engine's noise.

Fan noise mainly occurs from inlet disturbances spread upstream generated by shock waves in the blade passages and turbulent fluctuations spread downstream generated by boundary layers on the blade surfaces and their wakes [13]. A decrease in the fan rotating speed can reduce the inlet relative Mach number at the blade tip, thus weakening the fan noise (single tone) generated by the shock waves. It can also reduce the relative velocity in the fan blade passages, thus weakening the noise generated by the turbulence of boundary layers, vortex shedding (broadband), and tip clearance leakage flow (broadband). Past research studies [14, 15] have pointed out that the fan noise is proportional to the tip speed of the fan blades to the fourth power. It has also been pointed out that the

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