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OPEN ROTOR ENGINE CONCEPT IN ULTRA-HIGH BYPASS RATIO ENGINES

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For the jet engine, high engine efficiency can be achieved by improving thermodynamic efficiency and propulsion efficiency, thermodynamic efficiency associated mainly with increased engine pressure ratio (EPR) and turbine inlet temperature (TIT). However, for traditional core engines at this stage, the improvement of thermodynamic efficiency is limited by material properties and cooling technology. Therefore, some research focuses on improving the propulsion efficiency, associated with increased bypass ratios (BPR), and the higher the bypass ratio, the higher the propulsion efficiency. The existing Turbo Fan Engines produce Thrust more than any other engine because of the By-Pass Ratio thrust.

However, propulsive efficiency, highly dependent on the BPR, is currently limited, due to the inherent high BPR of ultra-high bypass ratio engines results in a larger fan diameter, and the blade tip speed increases with the increase in fan size. To avoid reaching the speed of sound, the fan speed needs to be reduced. Therefore, when the BPR exceeds 10, the design goal of the engine is to make the turbine and fan run at their optimal speeds throughout the entire flight phase.

This goal can be achieved through the three-spool engine and the geared turbofan (GTF) structure. However, the weight and drag losses caused by the fan casing of these two engine structures may even exceed the economic benefits brought by the improvement in fuel efficiency. With the development and advancement of technology, if the additional weight and resistance problems caused by the oversized diameter fairing can be overcome, the open rotor structure can be adopted. The open rotor engine concept avoids the negative losses caused by the elimination of the fan casing, and can theoretically achieve a higher bypass ratio.

The European Aviation Safety Agency (EASA) defined it in 2015 as: A turbine engine featuring contra-rotating fan stages not enclosed within a casing. The principle of open rotor is to distribute the power of a power turbine (compressor that does not push core airflow) to two counter-rotating fans through a gearbox. The outer side of this fan also works at circumferential supersonic speeds like the thrust fan of an ultra-wide chord turbofan engine. The open-rotor engine dispenses with the encasement typical of traditional turbofan engines, which increases the flow of cool air, the quantity of air sucked in and expelled by the engine achieving an ultra-high bypass ratio, thus the quantity of moving air can be increased without increasing the plane’s weight.

There are two propulsion modes in open rotor engine: push type and traction type.

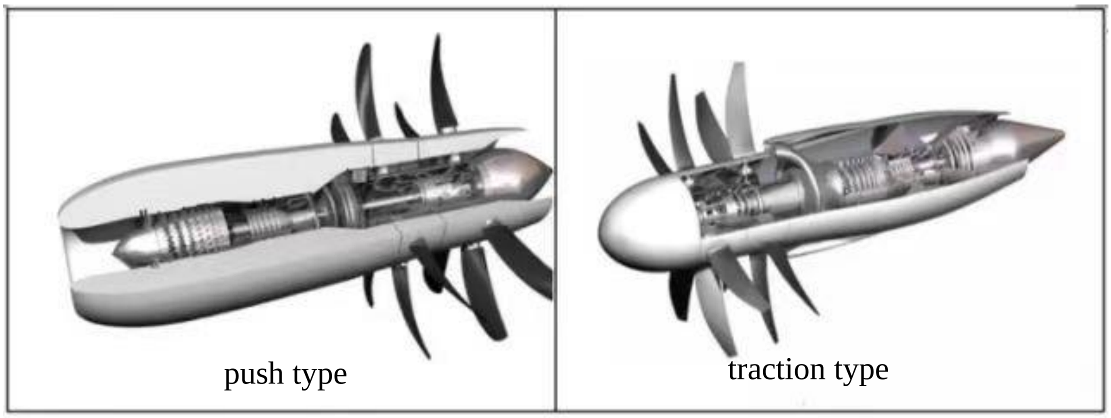

Fig. 1 – Different propulsion modes of open rotor engines

Advantages of open rotor engine:
1) Reduce fan front speed and increase thrust;
2) Improved efficiency;
3) Reduce weight and resistance;
4) High bypass ratio, high efficiency.

Disadvantages of open rotor engine:
1) Large noise caused by the interaction of the blades;
2) Inconvenient installation;
3) The requirements for the structural strength of blade materials are higher.

Methods that scientists have tried to reduce noise

The diameter of the first-stage blades is a little larger than that of the second-stage blades, so that the airflow on the outermost layer accelerated by the first-stage blades will not be torn apart by the second-stage blades. This layer of airflow covers the torn airflow inside and plays a sound insulation role. However, the effect is very unsatisfactory.

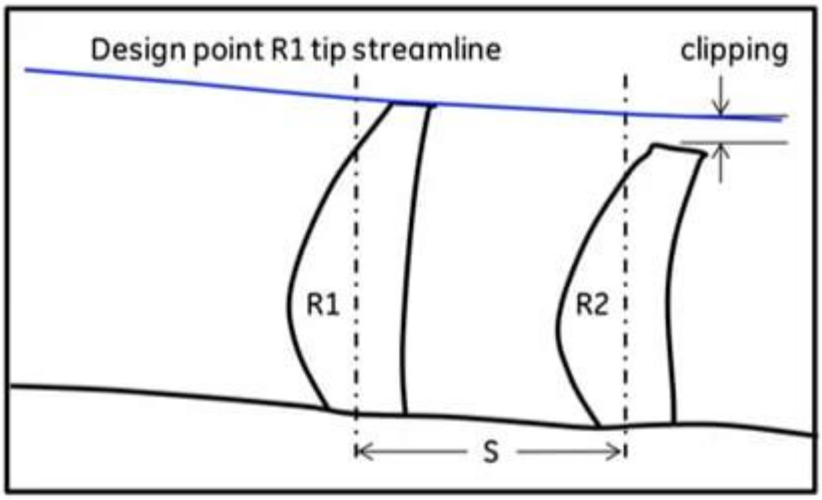

Fig. 2 – Open rotor tip streamline illustrating aft clipping

Creating a brand-new aerodynamic layout for the aircraft, using the main wings and tail wings to wrap the open-rotor engine to reduce noise, but the effect is still not very ideal.

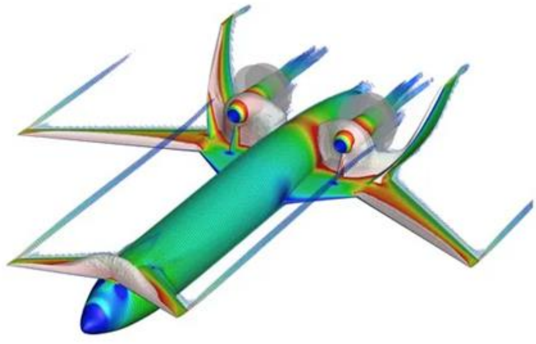

Fig.3 – Open rotor tip streamline illustrating aft clipping

In order to avoid the design and development of brand-new aircraft and reduces research and development costs and delivery cycles, we can just make some change based on the current landing gear structure for installation.

(1) Increase the length of the landing gear;

(2) Increase the distance between the engine and the centerline of the fuselage;

(3) Increase the landing gear retraction trajectory;

(4) Reduce engine diameter through improvements in engine core technology and repositioning of engine equipment (such as flattening of the B737 engine nacelle);

(5) Increase the wing dihedral angle;

(6) Reduce nacelle thickness.

Through this research we can know the main advantage of the open rotor is that the bypass ratio can be greatly increased, thereby effectively reducing fuel consumption. Its propulsion efficiency is significantly higher than that of ordinary turbofan engines, but its maximum cruising speed is slightly lower due to the limitation that the propeller fan tip does not generate excessive shock waves； and the noise and the requirements for material are more difficult to overcome. It is generally believed that this technology may not be adopted unless oil prices increase significantly.