Current Status and Future Prospects of Jet Engines

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Abstract. Current status and future prospects of Jet engine are described in this paper. Specifically, this paper contains three aspects: the current application of jet engines, the advantages and disadvantages of four major types of jet engines, and its future development trends. The method of the paper is analyze main four types of Jet Engines principle separately, and makes comparisons. Specifically, those four main types of Jet Engines are turbojet, turbofans, turboprops and ramjets. Moreover, if people want to understand Jet Engines, understand how Brayton cycle run is necessary. Brayton cycle is the principle of Jet Engines. Additionally, work and Efficiency of the turbojet engine are important means to make comparison among those four main types. Nowadays, Jet Engines are mainly applied in aircraft, marine power plants, but they still have drawbacks. Since there are many difference among their noise, emissions, maintenance cost and reliability of those four main types, their applications have some tiny difference.

Keywords: Turbojet, turbofans, turboprops, ramjets, Brayton cycle, work and Efficiency of the turbojet engine.

1. Introduction

It was pointed out by the author called Sumit Singh that the jet engine make lots of contributions in human history, it has brought society and opened up new areas for aviation. Frank Whittle was the first person building the jet engine. He added two - stage shafts to a single - side centrifugal compressor. By increasing the absolute velocity of the fluid, the supply pressure is raised, thus improving the normal operation of the rotor passage. After a while, Frank Whittle wanted to improve its efficiency, which means that converting low-mass high-velocity into high-mass low-velocity model. Therefore, he built a system called 'turbofan'. 5 main types of aircraft jet engines are currently used in the world: Turboprop engine, Turbojet engine, Turbo-shaft engine, Turbofan engine and Ramjet Engine. Additionally, in order to analyze them thoroughly, understanding what is Barony cycle and bypass ratio is necessary. Currently, plenty of fields powered by jet engines, such as jet aircraft, cruise missiles, rocket and unmanned aerial vehicles. Different types of engines have their own benefits and drawbacks. To illustrate, turbojet has very high power-to-weight ratio. Turbofans can raise the burner temperature thus improving the whole efficiency. Turboprop is very fuel efficient. And Ram compressor has sufficient initial flight velocity due to self-sustaining. To be more specific, turbojet has high fuel consumption. Turboprop has limitation in airspeed. Turbofan is larger and heavier than other one and perform well only at low altitude, And Ram compression need assisted take-off. Unfortunately, nowadays, although people regard it as one of the most important breakthroughs, few of country are able to use it in practical, because it is too expensive and complex, especially how to properly allocate the fan in take into inner and outer channels. 'Although the jet engine has been around for a long time, we're still managing to develop the technology', as Dr Peter Childs expound, reader in Mechanical Engineering in the Thermo-Fluid Mechanics Research Centre.

2. Mechanism

2.1. Four main types of jet engines

2.1.1 Turboprop engines

Since the velocity of the propeller is not very high, turboprop engines perform more efficient at the speed below 725km/h. But compared with piston engines, these engines are equipped with higher power-to-weight ratio, which contributes to enhanced reliability and shorter takeoff. But turboprop engines also bring us few drawbacks. Their high initial cost, lower power and speed, cause their limit in a lower ceiling.

2.1.2 Turbojets

Compared with Turboprop engines, turbojets have lower frontal area and produce higher exhaust speed, which enables them to fly at high altitude with better speed and fuel efficiency. In this case, turbojets are commonly used to drive medium range cruise missiles. These engines produce lots of jet noise, but turbojets perform much better than turbofans in this index.

2.1.3 Turbofans

Turbofans have smaller nozzles and larger turbines, which makes them have more pressure and temperature drops. These engines can increase the inlets of air and fuel, results to higher power and better efficiency in cylinders. Full combustion is more eco-friendly and qualifies this type of engine the capacity of sonic flight in the mean time.The fan does not increase the exhaust speed due to the increase in thrust, thus improving the overall efficiency of the engine.

2.1.4 Ramjets

Ramjets are much lighter, with the help of simpler structure, enable to produce higher power-to-weight ratio and lower cost. Ramjets are particularly useful in applications requiring a small and simple mechanism for the use in a much higher speed, such as the missiles. The US, UK, and Canada had widespread ramjet powered missile defenses during the 1960s. The new generations of ramjets are mainly called scramjets. Ramjets also have drawbacks, they can’t move an aircraft from a standstill [1], and they also require an assisted take-off.

Since the problems of environment being much severer, with the idea of making the applications more adaptable with human beings, modern jet engines are seeking a more efficient improvement to reduce the cost and fuel consumption. Meanwhile, the jet noise can also be an important factor.

2.2. The thermal cycle of the turbine jet engine is the Brayton cycle

2.2.1 The figure of Brayton cycle

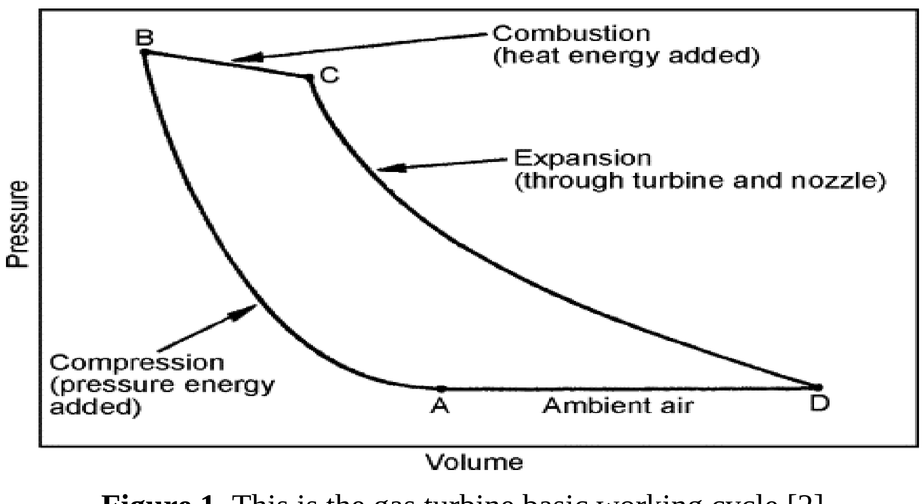

Figure 1. This is the gas turbine basic working cycle [2]

The process includes 4 steps, (1) an adiabatic compression process (A-B), (2) a constant-pressure heat-addition process (B-C), (3) an isentropic expansion process through the turbine and nozzle (C-D), (4) a constant-pressure cooling process (D-A). Each of the step is reversible.

2.2.2 Work and Efficiency of the turbojet engine

In the figure1 (P-V diagram), the net work is the area of quadrangle ABCD, so the net work of the turbojet is:

Where q1 and q2 are defined as heat received by the system.

According to the change of the enthaple:

$$q_1 = h_a - h_d = C_p(T_a - T_d) \tag{1}$$

$$q_2 = h_c - h_b = C_p(T_c - T_b)$$

Therefore, $W_{net} = C_p(T_a + T_c - T_b - T_d)$

Where cp is specific heat capacity, T is the enthalpy of the state.

So, the thermal efficiency :

$$\eta_{th,Brayton} = \frac{\text{Net Work}}{\text{Heat addition}} = \frac{C_p(T_a+T_c-T_b-T_d)}{C_p(T_c-T_b)} \tag{2}$$

In ideal brayton cycle, PA=PD, PC=PB

So, $\frac{T_d}{T_a} = \frac{T_c}{T_b}$. Meanwhile, $\eta_{th,Brayton} = 1 - \frac{T_a}{T_b}$

A little more change will get this formula:

$$\eta_{th,Brayton} = 1 - 1/r_p^{(k-1)/k} \tag{3}$$

Where $\eta_{th,Brayton}$ is the thermal efficiency of the Brayton cycle, r_p is the pressure ratio, and k is the specific-heat ratio.

$$\text{Bypass ratio: } B = \frac{W_{all}}{W_{al}} \tag{4}$$

Here B is the bypass ratio, W_{all} is the mass flow rate of the bypass stream, W_{al} is the mass flow rate entering the core.

The bypass ratio is an important design parameter of the turbofan engine, which has a great influence on the engine oil consumption rate and thrust-weight ratio. High bypass turbofan engines may be considered to be those with bypass ratio B > 4 or 5; current engines have B values up to 10 [3].

2.3. The formula of the thrust

As the thrust equation shows:

$$F_n = \dot{m}_e v_{he} - \dot{m}_0 v_0 + BPR(\dot{m}_c v_f) \tag{5}$$

Here is the mass rate of hot combustion exhaust flow from the core engine, is the mass rate of total air flow entering the turbofan (is the mass rate of intake air that flows to the core engine, is the mass rate of intake air that bypasses the core engine, is the velocity of the air flow bypassed around the core engine, is the velocity of the hot exhaust gas from the core engine, is the velocity of the total air intake the true airspeed of the aircraft), BPR is the Bypass Ratio.

3. Result

3.1. The future model of the jet engine

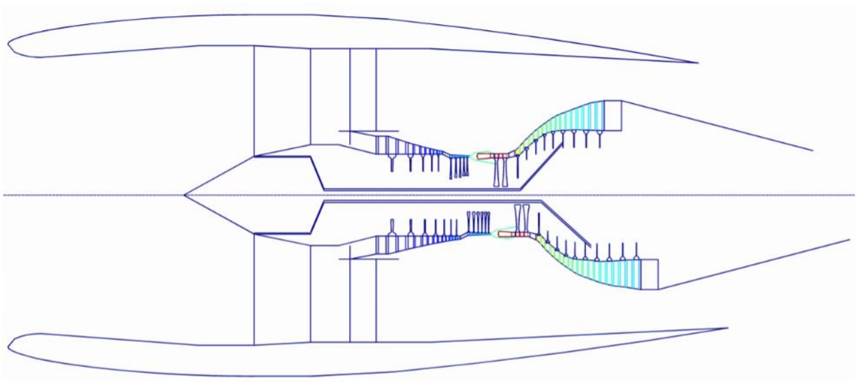

Figure 2. Future ultra high bypass ratio engine designed using year2020 objective technology (upper half) and year2000 technology (lower half) [4]

In this picture, the conventional LPT operates with a stage loading coefficient of 4.5. However, the year 2020 LPT uses a value of 5.2. The aircraft wing and tail geometry as well as the maximum take-off weight are iteratively adjusted to meet the design range. [5].

This design, they have their own advantages in terms of high technical safety improved reliability, and reduced noise and carbon dioxide emissions. These are the factors and conditions needed for the future market, and at the same time, it will not bring about more capital consumption. Therefore, this will be the blueprint for the future development of the turbofan engine.

3.2. Applications of jet engines

Currently, because of it high-efficiency, jet engines are used in lots of field. Because jet engines can ensure to deliver products rapidly, transfer people and push forward artillery, people usually regard it as an necessary invention that changed the world. Through charging in a plenty of air and discharging it quickly, jet engines are powered to move forward. One of the most different characters of current jet engines is that there are huge fans in front, and meanwhile, they are able to pass a second turbine instead of directly shooting the gas out. Compared to the older ones that accelerated themselves by taking less air, the newer ones have to seek more air, which is more effective.

First, aircraft application. A tremendous thrust it produce will causes the plane to fly very fast. Lots of plants, such as jet aircraft, automatic aerial vehicles and cruise missiles, are powered by jet engine. Moreover, people use jet engines as rocket’s generation model, provide force for fireworks, model rocketry, spaceflight, and Second, marine power plants. This is because jet engine are able to electrical generate, thus power for water, fossil fuel, natural gas, also providing propulsion for ships and locomotives.

Unfortunately, nowadays, although people regard it as one of the most important breakthroughs, few of country are able to use it in practical, because it is too expensive and complex, especially how to properly allocate the fan in take into inner and outer channels.

In order to improve metrics, specifically to higher fuel efficiency and lower cost, and decrease noise and emissions, jet engines’ sponsors are constantly searching for higher-edged concepts. One promising concept having been investigated for two decades is, to apply a speed reduction gear on the low spool of two-shaft engine between the fan. [5] Lower fan speed of Geared turbofan engines guarantees higher bypass ratios, and thus get lower fuel consumption less noise. Even through British Aerospace 146 is a kind of geared turbofans, it is quietest commercial aircraft. Reduced fan tip speeds make it became much quieter than before.

Table 1. In this figure summarizes the major design objectives for the next generation turbofan engine relative to the engines in-service today

Criteria	Existing Engine	Objective
Fuel Burn	Base	>-12%
Noise	-2 to -4dB rel. ICAO stg.4	>-20dB rel ICAO stg.4
Emissions	-40% rel ICAO 96	-60% rel ICAO 96
Maintenance Cost	Base	>-30%
Reliability	Base	Zero Target (no IFSDs)

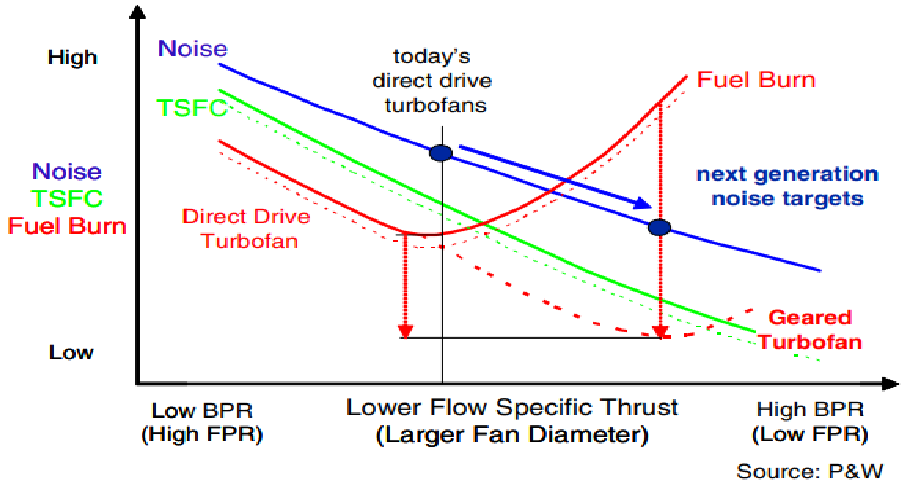

Figure 3. The Geared Turbofan Concept as the Enabler of High Bypass Ratio Turbofan Engines

In contemporary studies, there is a primary design, that analyzed a multilayer fabric reinforcement of a jet engine. To be more specific, a continuum equivalent finite element model that can response to high-speed impact, is cultivated. Decreasing the computational cost of remaining the level of accuracy close to that of mesoscale modeling, is one of the most profound achievement. In the design of large systems, that regard fabric material as components, will be aided by methodology. To achieve this goal, a representative volume element (RVE) model of a common woven Kevlar 29 fabric was created and almost the stretch and shear loads were tested to calculate equivalent macro-mechanical properties. A continuous equivalent model of coupon levels is then built to validate the recommended method. The numerical results of absorption energy and damage expansion are compared with the numerical results of mesoscale and experimental models. In short, the continuous equivalent FE model reduces the computational cost by more than 400 times and the accuracy loss is less than 6%. Finally, the traditional metal engine sealing device and fabric enhancement device are simulated by verification modeling method to fan the blade load. [6]

3.3. Thermal efficiency and energy saving

As for the thermal efficiency of jet engines, the fuel temperature can improve remarkably in this index. Merchandisers can improve their dependence of fuel as a heat sink and air, owing to high thermal stability, and save energy from compression or adding aircraft drag. Imagine that increasing the maximum fuel temperature from 160°C to 127°C, although it can be more efficiency because waste heat recovery can become an energy savings of 0.2%, the influence on other kind of generators are more profound. [7] Therefore, there are 0.5% or more will be saved in this work, and 60% of them are from leveraging the high thermal stability that synthetic fuels can afford. To build such models that for predict engine performance and fuel systems, and previously used in predicting fuel properties, like in a sequence of Monte Carlo simulations to analysis different ingredients' different impact on engine efficiency. Predicted efficiency increases by 0.17% or 0.25% at high and low power, respectively. This work establishes a way to incorporate jet engine efficiency as an objective function into algorithms designed to optimize the composition of sustainable alternative fuels. [8]

3.4. Shock-wave structures of prospective combined jet engine

Due to the chemical reaction downstream of the Mach stem, the heat energy flow leads to three points of height, total pressure loss and changes in the shape of the Maher stem. In order to analyze the effect of thermal energy flow on Mach reflective structure, it is necessary to elaborate the engineering analysis model used to simulate Mach reflection and pulse energy release. The results obtained in this study can be used as a newly created approximate analysis model and its application benchmark in simulating the flow of stamping jets and combined jet engines. [9]

3.5. Gas-turbine combust-or's performance of under high-altitude relight conditions

A physics-based, low-order ignition model is used to assess the ignition performance of a kerosene-fueled gas-turbine combust-or under high-altitude relight conditions. In this study used the ignition model is based on the motion of virtual flame particles and their extinction according to a Karlovitz number criterion, and a stochastic procedure is used to account for the effects of spray polydispersity on the behavior of the flame's extinction. The effects of large droplets rising from the poor fuel atomization at sub-idle conditions are then investigated in the model parameters' context and the ignition behavior of the combust-or. For that, the cold flow of a Reynolds-averaged Navier-Stokes simulation in the combust-or was performed and used as an input for the ignition model. Ignition was possibly with a Sauter mean diameter (SMD) of 50μm, and was enhanced by increasing the spark volume. Although the doubling of spark volume at larger SMDs (75 and 100μm) resulted to the suppression of short-mode failure events, ignition was not achieved due to a reduction of the effective flammable volume in the combust-or. Overall, a lower ignition probability is obtained when it come with the use of the spray's stochastic procedure, which is expected due to the additional detrimental effects associated with poor spray atomization and high polydispersity.

3.6. The unsteady magneto hydrodynamic fluid flow along the porous parallel plates

With a proper choice of the stream function, velocity components can be obtained in exact solution. Emissions of the pollutants from the aviation sectors are doubled compared with the figure in 2000. There are so many recent developments which are actively developed to combat the emission by increasing the performance of the Jet engines. The role of the computational fluid dynamics and the numerical approaches are crucial in terms of research and development. The exact solutions have been solved by many different transformation method. The analytical solutions in closed form are obtained for the stream function, axial and radial velocities and the flow velocity. The effects of Darcy parameter, magnetic parameter, Suction Reynolds number and frequency parameter on lower and upper plates are discussed through graphs.

4. Conclusion

There are mainly four types of jet engines: turboprop engines, turbojet engines, turbofan engines and Ramjet engines. For turboprops, their initial cost is high, and both speed and power are low, which means that they are limited in a lower ceiling. For turbojets, they produce higher exhaust speed, and can fly at high altitude with better speed and fuel efficiency than turboprops. For turbofans, they have higher power and better efficiency in cylinders, which means that they can exhaust lower velocity while give much thrust per unit energy. For Ramjets, they are lighter, have lower cost and can produce higher power-to-weight ratio. But they have to be powered by assisted take-off. Jet engines mainly apply in aircraft, marine power plants, but they still have drawbacks. As time goes on, worldwide researchers are focus on improve jet engines' metrics, mainly on how to lower fuel consumption, weight and cost, to be more quiet, and decline emissions. Since fan tip speed account for its noise, geared turbofan engines, such as the British Aerospace 146, can reduce noise effectively. Additionally, the fuel temperature can improve the whole processes' thermal efficiency.

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