Innovative Design and Fast Iterative Manufacturing of Micro-Turbojet Engines at Low Cost

Yiding Zhang [1, *], Yitong Zhang [2]

[1] Beijing No.80 high school, Beijing, China

[2] Hajim School of Engineering, University of Rochester, Rochester, the United States

* Corresponding author: David1821029@163.com

Abstract. The turbojet is the foundation of the gas turbine engine, which combines knowledge of fluid dynamics, thermodynamics, heat transfer, mechanical design, manufacturing, and jet propulsion. This paper describes in detail the inspiration source, design process, fluid dynamics analysis, manufacturing steps, ignition test method and test process of small jet engines. 3D modeling software SolidWorks was used for the preliminary modeling and fluid simulation was performed to optimize the design. Part of the model was produced by 3D resin printing technology, and the turbine engine model was driven by compressed air for no-load testing to verify the feasibility and structural stability of the resin model. Subsequently, some parts were printed with metal materials, combined with traditional machining techniques to complete production and assembly, and finally successfully carried out static ignition tests. The micro turbojet engine designed in this paper has successfully achieved static ignition test and demonstrated the feasibility of efficient development with limited resources and low manufacturing cost. This exploration proves the feasibility of rapid iteration technology route. The market prospect and manufacturing cost of micro turbojet are also analyzed.

Keywords: Micro turbojet engine, manufacture, finite element analysis, ignition testing.

1. Introduction

SpaceX, Elon Musk's space exploration technology company, applied first-principles thinking to the development of Falcon 1, returning to basic physics and materials science, by analyzing the application environment and requirements of rocket components, selecting manufacturing materials and processes, and considering costs, and designing and manufacturing many key components from scratch. Inspired by this, the authors adopted a similar approach in the design and manufacture of micro-turbojet engines. The authors combined the previously accumulated basic knowledge of fluid mechanics, returned to the essence of the problem, reconstructed concept design idea, and referred to a YouTube blogger's successful experience (Игорь Негода) in making a turbojet engine, in limited time and budget, successfully designed and carried out the ignition test.

The turbojet engine first appeared in the 1940s and quickly became one of the main propulsion systems for aircraft. With the development of technology, turbo engines have gradually moved towards miniaturization, and the concept of Microbo has also emerged. In recent years, due to the rapid growth of UAV technology and personal model aircraft market, the demand for micro-turbojet engines is increasing. This type of engine can provide efficient power output while maintaining a small size and weight, making it a huge application potential in micro-drones and model aircraft.

Microjet engines are difficult to design and manufacture, so traditional manufacturing methods often involve complex machining processes and the use of expensive materials, which makes research and development costs high. In recent years, with the development of rapid prototyping, 3D printing and simulation technology, low-cost development of micro-turbojet engines has become possible. For example, 3D printing technology can significantly shorten the design and test cycle, while computer simulation technology can optimize the design process and reduce material cost.

When independently designing a micro-turbojet engine, the author referred to the structure and design ideas of individual parts shown in the self-made turbojet engine video. For example, the authors took the rotor shaft of a family car turbocharger already on the market, combined it with

SolidWorks modeling, and made a preliminary model using 3D resin printing technology. The authors then used metal 3D printing and traditional machining processes to fabricate and assemble the final parts. This technical route not only ensured the functionality and reliability of the engine, but also greatly reduced the production cost and project time.

Through this low-cost and rapid iterative method combining first-principles design thinking and advanced manufacturing technology, the authors successfully developed a micro turbojet engine and achieved ignition test. This result demonstrated the possibility of efficient development within a limited budget and time, providing an advanced engine and proposition solution for micro-UAV and model aircraft. Low-cost rapid prototyping and commercial production are expected to accelerate the popularity of micro-turbojet engines in various applications, bringing important impact to model aircraft enthusiasts and related industries.

Based on the accumulated knowledge of fluid mechanics, thermodynamics, and mechanical design, driven by the authors' strong interest in turbojet, the authors drew lessons from other turbojet practices and used Solidwork software to independently design the engine and successfully completed the production of the engine.

2. Turbojet engine system design and optimization

2.1. System working principle

Along the axial direction of the engine, the air flow successively passes through the engine: from front fairing then enter the diffuser after the centrifugal impeller single stage diffuser. After being compressed, the gas enters the combustion chamber and is mixed with the fuel to burn and is ignited by the spark. The high-temperature and high-pressure gas is rectified, expanded and accelerated by the turbine guide, which drives the single-stage axial flow turbine to rotate. After the gas enters the tail nozzle, the pressure is reduced, the growth rate is increased, and the thrust is generated. The shaft sleeve acts as a bearing seat outside the rotating shaft for heat insulation, support and force transmission.

2.2. Flow simulation analysis

In the initial design model of the deflector, the deflector blade was designed to radiate from the center. However, when Solidwork's flow simulation module simulated the gas flow field here, the results were not satisfactory: most of the rotating gas was concentrated on the wall of the deflector. In this case, the gas cannot effectively drive the turbine to rotate, and the gas discharged through the nozzle will tend to diverge outwards. This reduces rotor shaft speed, engine thrust, and deflector life.

Using the fluid simulation function of Solidwork flow simulation module, the authors carried out the second optimization design of the deflector: the deflector blade was designed in arc. This design allows the gas to experience a centripetal force as it passes through the deflector. Under the action of centripetal force, the gas was more focused after passing through the guide blade rather than sticking to the wall. This solved all the problems mentioned above.

2.3. Design, manufacture and sourcing of each component

Table 1. Component preparation

Components	Sourcing and production method
Front deflector, diffuser	3D resin printing, while meeting the accuracy requirements, but also saves the time and cost of production.
Compressor impeller, shaft, turbine	Impeller removed from the turbocharger of a used car model 44VW (purchased from e-commerce website)
Front bearing, rear bearing	High speed precision bearings (e-commerce website purchase)
Spring hold	PA12 nylon 3D printing, both to meet the accuracy requirements and save production time and cost
Combustion chamber, tail nozzle	2520 stainless steel sheet, laser cutting and welding finished
Current deflector	316L stainless steel particles, 3D printed with SLM technology, meet the accuracy requirements
Shell	304 stainless steel sheets, laser cutting and welding completed

3. Prototype manufacturing

3.1. Parts manufacturing

Table 2. Parts manufacturing

3D printing resin parts	Air inlet	The air intake was printed in 3D light cured resin. Printing with resin ensured the accuracy of the air intake, reduced unnecessary pressure loss, and greatly reduced production costs.
	Diffuser	3D light cured resin printed
	Guide	3D light curing resin printing ensured a certain degree of accuracy
	Shaft and kit	Because the purchased turbine had its own shaft, it only needed to add the shaft collar, which could be fixed on the shaft sleeve with bearings. The shaft sleeve was provided with a cavity in which a spring can be placed. The spring gave the turbine a downward force by pushing against the collar. The spring could counteract some of the vibration generated by the turbine, while keeping the turbine in a relatively stable position.
Parts purchased directly	Compressor	The shaft sleeve connected the guide and diffuser and was fixed with screws to ensure the stability of the structure.
	Combustion chamber rear turbine	Due to the complex structure of compressed air turbine, five-axis CNC machining was required, and small batch production would greatly increase the cost. Therefore, the required type of centrifugal pressure turbine was purchased directly in the production of this engine. Centrifugal gas turbine was characterized by small air flow and low efficiency, but the single stage compression ratio was high, so it could meet the needs of small turbojet engines.
	Bearing	Because the structure of the turbine was too complicated, a turbine that matched the pressure turbine was bought online.

3.2. Model verification and preparation

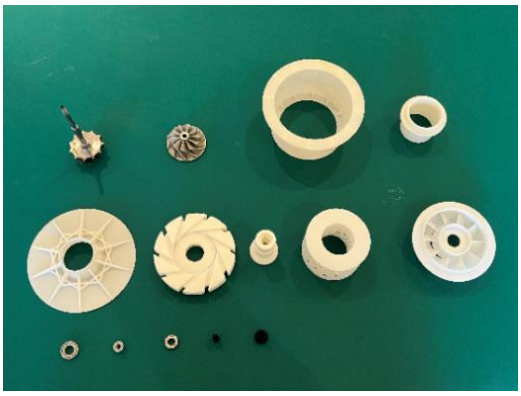

Figure 1. Model Verification

3.3. 3D resin model assembly and testing

The authors assembled the 3D resin model using screws, nuts and other simple fixtures (Figure 2). Then manually turned the turbine to verify the matching between the components and confirm the reasonable clearance between the models.

Then the turbine was driven by compressed air for no-load motion test, which proves the stability of the structure, and the turbine rotor ran well. It was verified that the whole model could run stably at high speed for a period.

Figure 2. 3D resin turbojet model

3.4. System component optimization design

The authors modified some unreasonable designs that appeared in the assembly process. For example, due to the unreasonable clearance between the diffuser and the compressor turbine, there was often a problem in manual testing because of the friction between the turbocharger and the compressor shell, resulting in stalling. Therefore, the gap of 0.2 mm was increased when the 3D drawing was improved.

4. Manufacture of finished model metal parts

Since some of the resin parts could not stand high working temperature and strength requirements, the finished model continued to use these parts, and the other remaining parts were replaced by stainless steel parts.

4.1. Preparation of metal parts

Table 3. Component preparation method

Shell	The shell, which didn't require high machining precision, was made from sheet metal through laser cutting, bending, and welding.
nozzle	The nozzle did not interact with any moving parts, so the precision requirements were low; it was made using laser-cut sheet metal, followed by bending and welding.
Guide	The guide structure was complex and couldn't be machined with a regular lathe, so it was made using 3D metal printing.
Fuel tube	Made from brass tube through heating with a burner and bent, cut and punched
Combustion chamber	Made of 2520 stainless steel sheet, through laser cutting and welding

Table 4. Finished engine parameter

Profile diameter	12.99 cm
Overall length	14.75 cm
Engine mass	1202 g

4.2. Problem solving and innovation in model assembly process

When connecting the deflector to the housing and the tail nozzle to the deflector, the authors used screws and exhaust pipe sealant to seal the gaps instead of connection with traditional flanges. This simplified the structure on the premise of ensuring air tightness and avoided the problem that the sealing ring in the traditional flange was easy to fail due to high temperature. (Figure 3)

Figure 3. Finished turbo jet engine model

5. Ignition test

5.1. Preparation for ignition test

The authors used a stainless-steel folding table as a test bed for the ignition and held the engine in place with pliers and plastic pipe clamps. The engine was then mounted on the test bench (Figure 4).

The authors connected the engine's copper fuel pipe with PVC hose and sealed it with a metal pipe clamp. Then the PVC hose was connected to the butane tank and connected a check valve in the middle of the hose to prevent backflow.

Safety measures: Tie the mobile jaws of the pliers with a rope to assist in fixing; Place fire extinguishers near the test stand; Wear fireproof gloves; Wear a plastic blast mask.

Figure 4. Test bench construction

5.2. Ignition

The authors first used compressed air to drive the impeller to rotate, reached a certain speed, opened the butane tank valve, injected butane into the combustion chamber, and then used butane spray gun for ignition. The turbojet ran continuously without any problem.

5.3. 5.3 Successful ignition

Turbojet engine successfully ran continuously at idle speed as indicated. (Figure 5)

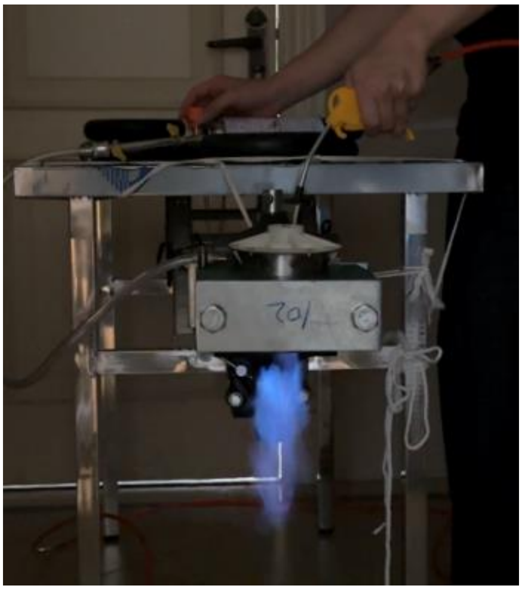

Figure 5. Successful ignition of the engine

6. Commercial value and future prospect of micro turbojet

The authors are very optimistic about the application prospects of micro-turbojet engines in the drone technology and aircraft model market, with the growing demand for small and efficient power systems. Because of its small size, light weight and high-power density, micro turbojet engine is especially suitable for these fields. Compared with traditional power systems, such as lithium batteries, turbojet engines also have advantages in endurance, while they are lighter in weight and higher in energy density. Therefore, it can improve the use of drones in complex environments, to bring more possibilities to its application. With the continuous development of UAV model technology, it is certain that the development prospect in this field will be very broad under the promotion of micro-turbojet.

In addition, the cost and large-scale production potential of micro-turbojet engines are described and demonstrated in detail. Optimized design and low-cost manufacturing process are the key to effectively reduce the development cost. This has laid a good foundation for the commercial application of micro turbojet engine, so that it is expected to play a pivotal role in the field of military UAV civil UAV high-end model aircraft.

To sum up, the fast iterative design route has brought about a significant improvement in the R&D efficiency of Micro-Turbo jet engine. This not only provides a new path for technological innovation, but also injects a strong driving force for the development of relevant markets in the future, which is the current relevant market in China with the continuous improvement of technology and the expansion of application scenarios, in the future field of aviation power, the role of micro-turbojet engines will be more significant.

7. Summary

Through the design, manufacture and testing of the Micro-Turbo engine, the feasibility and superiority of low cost and rapid iteration of technological route have been demonstrated. Using modern technologies such as SolidWorks modeling, fluid simulation and 3D printing, combined with the previously accumulated basic knowledge of fluid mechanics, the authors completed the design optimization and prototype manufacturing of the engine in a short amount of time. In this process, the low-cost 3D resin printing technology not only significantly shortens the manufacturing cycle, but also provides effective development cost reduction and help for the rapid iteration of complex parts.

The experiment not only ensures the accuracy of the product, but also achieves good results in cost control through the combination of resin and metal parts. The flexibility of 3D printing technology brings more possibilities for design, and the cycle from design to test is significantly compressed, which is compared to traditional machining. Through this rapid iterative development path, the authors prove the success and prospect of this technical route, and the prototype manufacturing of complex turbojet engines can be successfully completed under limited budget and time conditions.

The low-cost and rapid iterative technology method has laid the foundation for the commercialization of micro turbojet engines. With the further maturity of the technology, this efficient design process is not only expected to promote the development of the UAV and aircraft model market, but also may open new application directions in the field of aviation power technology, in the case of limited resources, with the help of advanced manufacturing technology to achieve efficient development of complex engineering design, to further promote the development of aviation.

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