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PROPOSAL AND REALISATION OF A MODIFICATION TO AL-9 ENGINE FOR INSTALLING A FREE GAS TURBINE

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Abstract

This paper focuses on the creation of a prototype connection of the AI-9 engine with a free turbine for creation of an experimental turboshaft engine. We go through theoretical knowledge about the issue in which we work on the basis of which we created solutions. We worked with the teaching aids of the Department of Aviation at the airport in Žilina. We prepared these tools for work in the workshop and we made minor adjustments to the engine to make it possible to carry out our work. In our work, we used a procedure called high-fidelity prototyping. This means that we created a digital model on which we applied solutions. We decided to transfer our prototype to the digital environment due to low financial and time costs. We faced several design problems, including the need for a stator, the gap between the guide tunnel and the rotor, or how to connect to other components. We managed to find preliminary solutions for these problems and created a digital prototype of the resulting assembly. Subsequently, we presented the positives of our results and the method of their application in practice.

Keywords

turboshaft engine, free turbine, modification, proposal, connector

1. INTRODUCTION

This paper presents a solution for attaching a free turbine to an AI-9 engine. The AI-9 is an auxilary power unit used in the former Warsaw pact military helicopters like Mi-8 and Mi-24 and Jak-40 aircraft. It is a turboshaft type gas turbine engine with a power of 56 kW. It is manufactured by Ivchenko Progress and Motor Sich, corporations of Ukrainian origin, in three different variations. The base model and AI9-3B are used as starters by supplying compressed air to the main engines for startup. The AI-9V variant is used as an electrical generator to supply electricity to onboard systems.[1][2]

Figure 1 - AI-9 Engine

2. ENGINE CHARACTERISTICS

Table 1: General characteristics [1][2]

Type	Auxiliary power unit
Lenght	740 mm
Diameter	500 mm
Dry weight	45 kg

Table 2: Components [1][2]

Compressor	1-stage centrifugal
Combustors	Annular combustion chamber with 6 fuel injectors
Turbine	1-stage axial
Fuel type	JP-4

Table 3: Performance [1][2]

Maximum power output	56 kW
Overall presure ratio	2:8:1
Air mass flow	1.5 kg/s
Fuel consumption	120 kg/h max
Power to weight ratio	1.23 kW/kg

3. TURBOSHAFT ENGINES

A turboshaft engine is a variant of a jet engine that has been optimized to produce shaft power to drive machinery instead of creating thrust. Turboshaft engines are most commonly used in applications that require a small but powerful engine with low weight, including helicopters and auxiliary propulsion units. A turboshaft engine uses the same principles as a jet engine to produce power, that is, it contains a compressor, a combustion chamber and a turbine in the engine's gas generator. The main difference between a turboshaft and jet engine is that an additional power part consisting of turbines and an output shaft has been incorporated into the design. In most cases, the power turbine is not mechanically connected to the gas generator. Referred to as a 'free turbine', this design allows the power turbine speed to be optimized for the machinery it will power without the need for an additional reduction gearbox within the engine. The power turbine takes almost all the energy from the exhaust gas stream and transfers it through the output shaft to the machinery it is supposed to drive.A turboshaft engine is very similar to a turboprop, and many engines are available in both variants. The main difference between the two is that the turboprop version must be designed to support the load of the attached propeller, while the turboshaft engine does not need to be as robust as it normally drives a gearbox that is structurally supported by the vehicle rather than the engine itself. [5][6][7][10]

4. FREE TURBINES

In a free turbine engine, the propeller is driven by a separate turbine through a reducer. The blower is not on the same shaft as the basic engine turbine and compressor. Unlike a fixed shaft motor, with a split shaft motor we can change the pitch angle of the fan blades in flight or on the ground while the motor is on. The free turbine design allows the pilot to select blower speed regardless of engine speed. A typical free turbine engine design has two independent turbines that rotate in opposite directions. One turbine drives the compressor, while the other drives the blower through a reducer. In the diagram [Figure 2], the compressor is composed of three axial stages combined with one centrifugal stage. Axial and centrifugal stages are assembled on one shaft and work as one machine. Intake air enters the engine through the intake system at the rear of the engine and flows forward through the compressor. The flow is directed to the engine periphery by the centrifugal compressor stage through radial diffusers before entering the combustion chamber where the flow direction is reversed. The gases produced by combustion are reversed again and expand through the stages of the turbine. After exiting the turbine, the gases exit the engine to the atmosphere through an outlet at the front of the engine. Unlike conventional jet engines, exhaust gases are not used to create additional thrust. A pneumatic fuel control system adjusts the fuel flow to provide the desired power level. The speed of the blower remains constant at any position of the control lever using the propeller governor. The accessory drive at the rear of the engine supplies electrical current to the fuel pumps, fuel valves, oil pumps, starter/generator, and tachometer transmitter. [4][7]

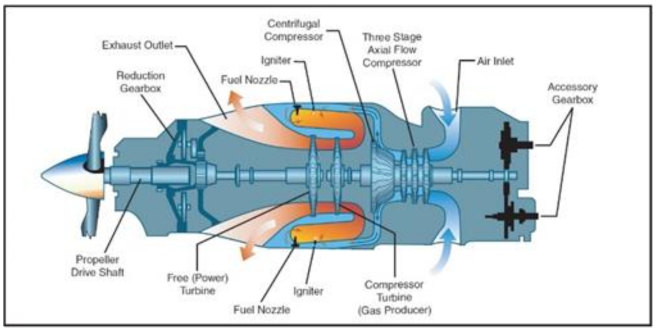

Figure 2 - Free turbine design

5. FREE TURBINE USAGE

Helicopters are a big market for turboshaft engines. When turboshaft engines became available in the 1950s, they were quickly adapted to new designs as a replacement for piston engines. They offered more power and much better power-to-weight ratios. The piston helicopters of that time barely had enough power. The transition to turbine engines made it possible to reduce engine weight and increase cargo capacity. Free turbine engines have proven to be a very good choice for helicopters. They do not need a clutch because the generator can be started while the drive shaft remains stationary. The resulting advantage is a quick start and take-off with a cold engine. By locking the main rotor with the rotor brake, the engine can be started and then, with the gas generator running at 10,500 rpm, the brake is released allowing the turbine to drive the rotor and reach its operating speed in 15 seconds and the time from engine start to take-off is 30 seconds.Another advantage of free turbine designs is the ease with which an opposing engine can be constructed, just turn the drive turbine. This made it possible to construct engines in pairs if necessary. It also allowed opposed engines, where having the turbine rotate in the opposite direction caused a reduction in overall torque and increased stability of the helicopter in flight. The flexibility of these engines allowed easy replacement of piston engines in existing designs where no emphasis was placed on engine layout. However, over time, a parallel horizontal layout placed above the cab became standard. Turboprop aircraft are also powered by a range of free or fixed turbine engines. Larger engines have mostly retained the fixed turbine design, although in many cases this is a twin-shaft arrangement where the main turbine drives the blower and low-pressure compressor, and the high-pressure compressor has its own turbine. Some large turboprops such as the Bristol Proteus or the more modern TP400 have free turbines. The TP400 is a three-shaft design, with two compressor turbines and a separate drive turbine. When the turbine is located at the rear of the engine, the turboprop engine requires a long shaft that leads to the front of the reducer to drive the blower. Such long shafts often pose a problem for designers, as it is necessary to pay close attention to limiting the removal of this shaft.For small turboprops, the free-turbine design has become dominant in modern times, and these designs are essentially all-round, where the intake is located on the front of the engine, driving air forward through the compressor to the combustor and then to the turbine at the front of the engine. This enables a substantial shortening of the shaft driving the propeller, as the turbine is placed much closer to the reducer. Such engines are easily recognizable due to their curved output gear. [4]

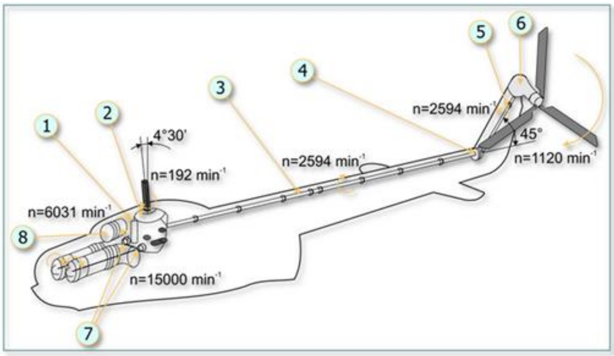

Figure 3: Engine placement in a helicopter

6. HIGH FIDELITY PROTOTYPING

Prototyping is an experimental process where design teams implement ideas into tangible forms from paper to digital. Teams create prototypes of varying degrees of fidelity to capture design concepts and test them.As the main goal of the paper, we set the creation of a digital prototype of the intermediate part that will connect the AI-9 engine and the free gas turbine. The essence of this goal determined the work techniques that we subsequently used in our work [11]

Advantages of prototyping:

- The existence of a solid foundation on which to test ideas and improvements.
- The possibility of rapid adaptation - it is possible to avoid investing too much in one idea, which, if it turns out to be wrong, can slow down or completely stop the development process and cause large expenses.
- Sample target product can be discussed with experts and target customers who can give us feedback
- The prototype is an ideal target for the application of new technologies and procedures that are not established in practice
- Reducing the time required to eliminate errors

Fidelity refers to the level of detail and functionality incorporated into the prototype. It may depend on the level of development in which the product is located and also on the purposes for which we are creating this prototype.

Low fidelity – An example of low fidelity prototypes are paper prototypes. They are fast and cheap, they are expendable, while allowing the rapid application of changes and new designs. However, the downside is the lack of realism, which can make delivering feedback problematic. We must also not forget that complex problems can look simple on paper and will not be given enough attention.

High accuracy – Examples of high-fidelity prototypes are digital models created using software such as SketchUp or Adobe XD. The advantage of digital models is that working with them is more reliable and the development team can better focus on the problems that need to be solved. Testing on these prototypes will produce more accurate results. The disadvantage is that they may take longer to produce and after a long production process the design team may look negatively at the need to make major changes to the prototype and choose a shorter but less perfect solution

When dealing with the creation of a new solution in a field such as aviation or other similar field, as well as for example rocket engineering, space engineering and aerospace technology, it is a common procedure to create several successive physical prototypes, which subsequently improve the errors of the previous prototype. For our situation, however, this is an unattractive approach, because creating individual prototypes is time- and material-consuming. It would also be financially demanding, because we would need the assistance of a third party, as we did not have the capacity to create such parts in the workshop at Žilina Airport. That's why we decided to transfer the entire problem to the digital environment. We achieved this by creating a 3D model, on which we applied solutions from a theoretical environment and evaluated their applicability and discussed the necessary adjustments without the time and material demands of classic prototyping. [11]

7. PART PREPARATION

Both the engine and the free turbine were available in storage at the Žilina Aerodrome, but they had to undergo a preparation before a solution could be contemplated. The free turbine did not require a mechanical adjustment, although the same could not be said about the engine. Free turbines are mounted after the propulsion turbine without being mechanically bound to it. However, this space was occupied by the exhaust apparatus, which neccesitated it´s removal, before anything could be attached. The removal of the engine exhaust did not neccesitate any special equipment and was succesfully removed with basic tools. After the exhaust was removed, the power turbine was exposed and the next phase of the preparation could begin.

Figure 4 - Exposed power turbine of the AI-9 engine

The next phase of the preparation consisted of taking measurements and considering possible theoretical problems and solutions. The flanges on both ends of the future conection part were very similar in size, being only 1cm different in diameter, however the number of holes on each side was different and incompatible with each other, meaning that it was impossible to create a connector with only a single flange, neccesitating a desing with two flanges, which meant that the connector design had to be longer to allow acces to screws during assembly process.

Figure 5 -Free turbine with flange

8. CONNECTOR PART REQUIREMENTS AND DESIGN

One of the questions we encountered during the theoretical part of the design was the need for the static vanes. The rotors of the turbines rotate in opposite directions, which under normal conditions, would eliminate a need for static vanes in the flow of air before the free turbine rotor, but the distance between both rotors proved a challenge as the counter rotating turbine rotors need to be close to each other to provide the functionality of static vanes. The distance between the rotors would at best be 95 mm apart and that is if the two main components would be directly attached to each other, which, as was established earlier, was not possible due to the incompatibility of the flanges. This distance would be increased further by reasons of the flange desing, wich required both engine and free turbine to have it´s own attachment flange and because access directions to both flanges were opposite to each other, distance between both flanges had to be sufficient to grant access to tool required to securely attach both flanges to it´s counterparts. It was deemed that the theoretical distance was too great, and the connector part had to include static vanes on the side that would be attached to the free turbine. This had positive sideffect of providing structural support for a tunnel shaped connector and providing means of attaching a core of the tunnel to the outer shell. The next design requirement for the connector part was it´s abillity to direct the flow of air between the two main components without creating vortexes wich would radically diminsh efficiency and thus viability of the design. One side of the directive apparatus would be the central core in the tunnel between the rotors. It´s need arose from the fact that turbine rotors consist of a wheel surrounded by vanes, thus air flows only on the edges of the tunnel. This needs to be maintained in the tunnel as air flow impacting thecenter part of the free turbine rotor, which you can see in [Figure 5], would diminish the amount of energy the air flow would be able to transfer on to the rotor itself. Thus, the connector part would contain a central core of a conical shape with the top of the cone cut off to match the diameter of the central wheel of the free turbine. The base of the cone would match the diameter of the central wheel of the power turbine. Conical shape of the central core would be a result of a different diameter of the two rotors, the power turbine diameter being bigger, thus the conical core would be pointing from the power turbine to the free turbine. The second part of the flow directing shape would be the outer shell. It also would be of a similar shape as a core, the difference being the shell would be hollow. It would be dirrectly attached to the flanges and connected with the core through the static vanes. Both the core and the shell would pertrude beyound the flanges connecting them to the two main components of the assembly because the flow direction needs to be performed as close to the rotor of the free turbine as possible, the outer shell even petruding beyond the rotor of the free turbine. This is allowed by a gap bethween the rotor and the shell of a free turbine, which could be seen in [Figure 5]. This gap was measured to be between 7 mm and 8 mm, which is sufficient to insert a steel outer shell which could be thick enough to contain hot expanding gases powering the turbines. The flow directing core would need to be as close to the rotors as possible without touching them, ideally no more than one millimeter, to minimize efficiency losses. This however runs into a problem on the side of the engine, as the power turbine is attached by the means of four screws, as seen in [Figure 4]. Theese screws pertrude around 15 mm beyond the rotor. This means that the base of the core needs to have a dip in its center wich would be more than 15 mm deep and its outer diameter would be 30 mm or less smaller than the outer diameter of the cone base, thus allowing the power turbine rotor to rotate freely without being obstructed by the connetor part, yet thou outer diameter of the cone base would still be as little as 1 mm from the power turbine rotor, minizing efficiency loses due to air escaping into the gap. Attachment of the outer shell to the engine side is problematic as the transition on this side has to be smooth to prevent interuptions to the flow of the air and vortex formations. Problem arises in the fact that the width of the shell cannot decrease indefinitely to allow for a completely smooth transition, as material too thin would be susceptible to melting by hot gases passing through the turbine. Also, some losses are expected due to a small gap between the engine flange and the outer shell of the tunnel. It could not be filled by insulating materials as those are also susceptible to the high temperatures present.

9. VISUALISING THE PROBLEM AND SOLUTION

For visualising all the components in a framework where we could apply theoretical solutions, we chose to create a 3D model of individual components and the assembly as a whole in a 3d modeling software. This method of creating results is preferrable, as creating physical prototypes would be costly and time consuming, since we are working with heavy materials such as steel. It would not only take a long time to make changes and apply them, it would also prove costly. For theese purposes, software chosen was Google SketchUp. Reasons for this choice of software in face of existence of more advanced 3D modeling tools were ease of access and ease of use, while being more than adequate for our purposes. First, we started by modeling the free turbine. It consisted of two comnponents in itself, which were the shell in which the turbine was placed, and the rotor.

The shell is a big cavity through which hot gasses travel to spin the rotor and then are directed outwards. The rotor consists of a metal wheel with 26 blades.

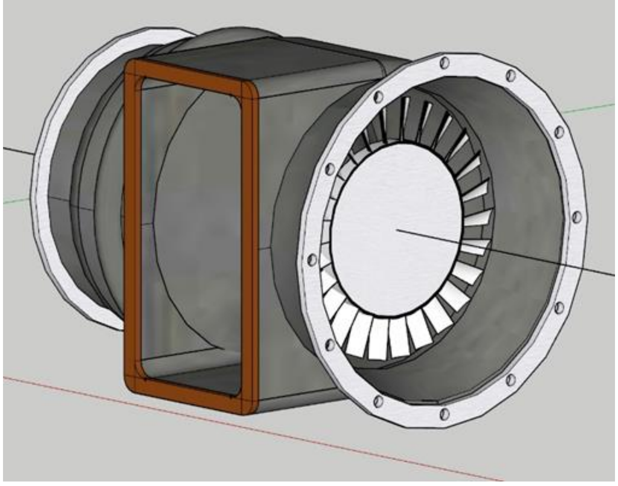

Figure 6 - 3D model of free turbine

Next up was the engine, we decided to model the outer shell and the contour, leaving out all the exterior accessories as it would only clutter the model. However, it was decided to model the most importand interior components for purposes of visualising flows of air in the engine.

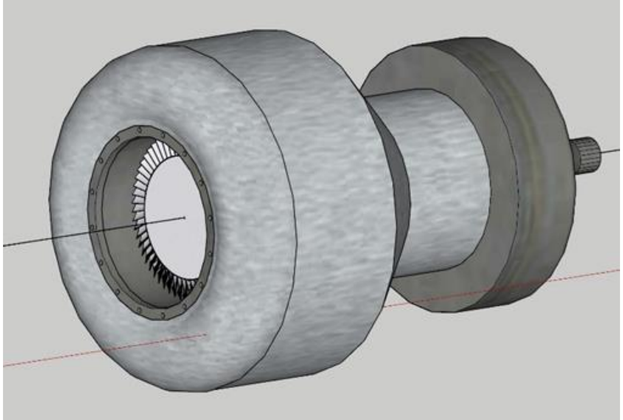

Figure 7 - 3D model of engine

10. RESULTS

The result of our effort was a model of a connector able to be attached to both engine and the free turbine, providing an abillity to use hot gasses that exit the engine for generating power with a free turbine. Connector part is of a peculiar shape as it´s inner parts pertrude beyond and into other parts. It consists of two flanges, one 5mm in lenght, second 10 mm lenght, connected with 50 mm long metal ring. In this ring, an air flow directing tunnel is located. This tunnel is of a conical shape, it´s base being on the side of the engine with a cutout to allow for rotation of the screws that attach the power turbine. The shape of the cone is cut off at the point where it´s diameter matches that of the rotor wheel seen in [figure 6]. On that side, the stator is located, consisting of 16 individual blades to guide hot gasses onto the blades of the rotor.

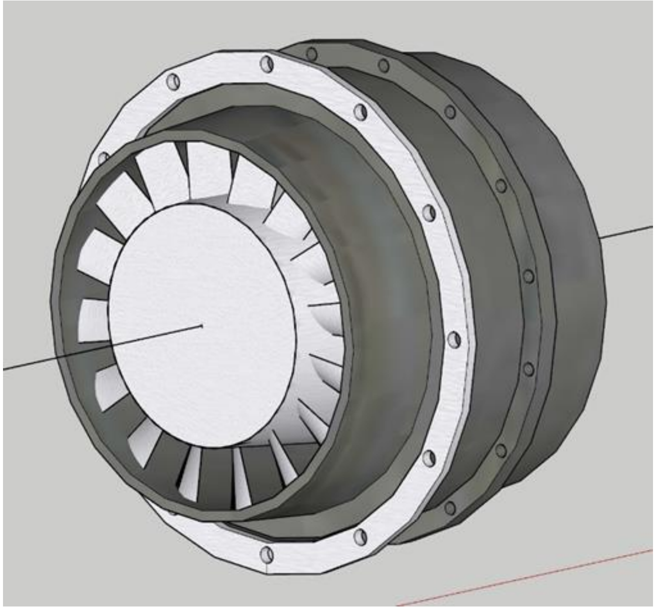

Figure 8 - Connetor part

11. ASSEMBLY

After the connector part was modelled, it was decidet to add all three pieces together and make an interior point of view to visualise how individual parts connect together on the inside and to help visualise how hot gasses flow through the resulting assembly

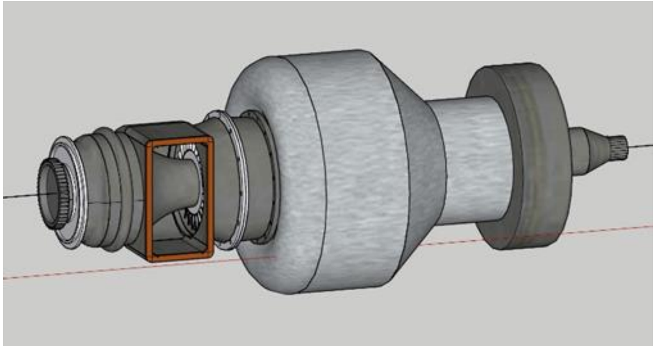

Figure 9 - Assembly

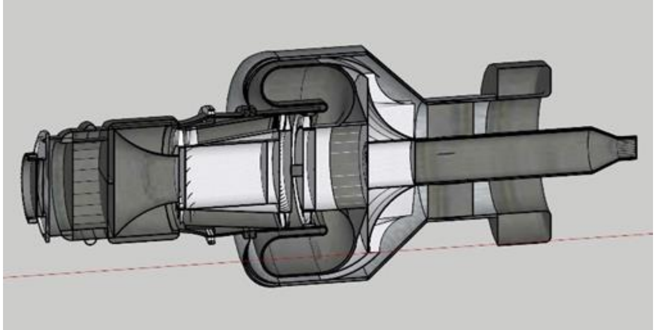

Figure 10 - Assembly interior

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