ANALYSIS OF DIFFERENT PROPULSION SYSTEMS FOR TIP JET ROTOR SYSTEM

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الملخص

تقدم هذه الورِقة دراسة نظريه على نوع مطور من أنظمة الدفع وهو النفث الذاتي لنهاية المروحة المبني أساسا على الهواء المضغوط الناتج من قوة الطرد المركزي لدوران المروحة. تمت المقارنة بين أداء هذا النظام مع بعض انظمه الدفع التقليدية مثل المحرك الصاروخي و المحرك النفاث. علما بأن المقارنة تمت من ناحية القدره المتوفرة وكذلك زمن الطيران وتبين من هذه الدراسة إمكانية تطبيق هذا النوع من الدفع على طائرات صغيرة الحجم مثل طائرات بدون طيار أو طائرات الإقلاع العمودي.

ABSTRACT

Theoretical investigation of tip jet propulsion based on compressed air due to rotor blade rotation has been presented. Performances were compared in case of rocket, ramjet and pressure-jet engine. Rocket and ramjet engine had practical application in middle of 20^{th} century, while third way of propulsion is based on turbojet thermodynamic cycle. Comparison has been performed according to available and required power, and to flight duration. The present investigation shows the possible application of pressure power system as propulsion unit for unmanned helicopters or VTOL vehicles.

KEYWORDS: Rotor; Helicopter; Flying vehicle; Rocket engine; Ramjet engine; Pressure jet.

INTRODUCTION

In order to rotate the main rotor, conventional helicopters utilize a piston engine or a turbo shaft engine having a rotating shaft mechanically linked to the rotor. The power is transmitted from the engine to the main rotor as a driving torque. This driving torque induces a fuselage torque that has the same magnitude as the driving torque, but in the opposite direction. To compensate for the induced fuselage torque, a compensation torque, created by the tail rotor of the helicopter, is applied to the fuselage of conventional mechanical helicopters. The compensation torque produced by this tail rotor is a function of the speed of rotation of the tail rotor, pitch and the distance between the shafts of the main rotor and tail rotor.

Differing from the conventional driven system, tip jet driven helicopter uses the power of gases discharged through the tip of the blades of the rotor to impart rotating motion to the rotor. No torque is transferred from the fuselage to the rotor. Therefore the tail rotor may not be needed and drive system has a considerably simpler construction. Indeed, the tail rotor is a major cause of accidents and it adds complexity to the helicopter drive system. As a consequence helicopter is lighter. On the other hand, some disadvantages arise from the utilization of tip jet. One major shortcoming is the low efficiency of its drive system. However, the lightened weight compensates this deficiency.

Under the designation WNF 342, the world's first jet-driven helicopters were built by the Wiener Neustadter Flugzeugwerke (WNF) in the suburbs of Vienna, four machines being built representing progressive experimental steps in a research program instituted in October 1942. This program was directed by Friedrich von Doblhoff, who had decided to develop a jet-driven helicopter in preference to a mechanically-driven one because of the attraction of simplicity, lack of rotor torque and transmission gear [1]. The WNF-342 shown in Figure (1). Ref [2] addresses a power system for a reduced scale tip-jet rotor by using a small turbo-jet engine which is designed and tested on a UAV (Unmanned Aerial Vehicle).

Figure 1: The WNF-342 helicopter

MODEL DESCRIPTION

Rocket motor:

In the rocket motor used for the helicopter rotor tip jet, the liquid hydrogen peroxide is fed with high pressure from a tank to a chamber filled with a decomposition catalyst. The processes occur as following;

- The decomposition catalyst causes the hydrogen peroxide to decompose into water steam and oxygen. Heat is released by the reaction. The temperature of the formed gas mixture is about 650^{o}C.
- After passing through the catalyst chamber the hot, high pressure gas mixture is released through a rocket nozzle.
- The velocity of the gas flow after the nozzle becomes well over 1000 m/s and gives the rocket a considerable reaction force thrust.

Figure (2) shows rocket motor uses liquid hydrogen - peroxide that operate helicopter Intora Firebird IF -2. Thrust generated in the rotor tip due to rocket motor is [3],

$$F = m_e \cdot V_e \tag{1}$$

Thrust power generated by two rocket motors in the rotor tip jet system is obtained by;

$$N = 2 \cdot F \cdot V_t = 2 \cdot m_e \cdot V_e \cdot V_t \tag{2}$$

Specific power and, specific fuel consumption for the two rocket motor are obtained by:

$$N_{sp} = \frac{N}{2 \cdot m_e} = V_e \cdot V_t \tag{3}$$

$$SFC = \frac{2 \cdot m_e}{N} = \frac{1}{N_{sp}} = \frac{1}{V_e \cdot V_t} \tag{4}$$

In the above equations m_e masseurs combustion chamber hot gases mass flow, V_e nozzle outlet velocity, and V_t is rotor blade tip speed.

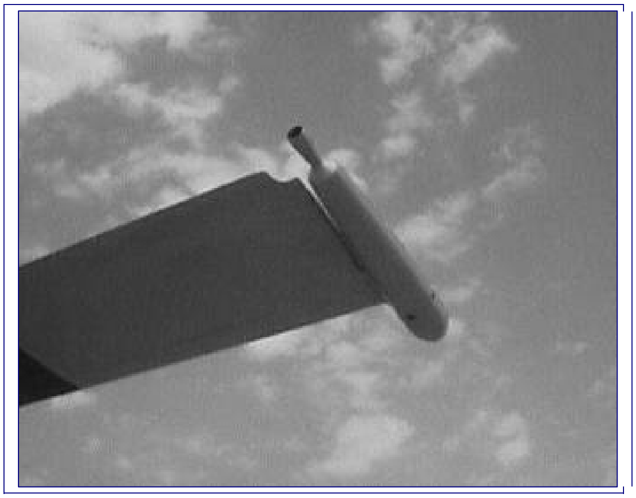

Figure 2: rocket motor uses for tip jet helicopter Intora Firebird IF -2

Ram jet engine

In applying the ram jets to the helicopter, a two bladed rotor configuration has been assumed. The rotor performance for the helicopter is calculated and the thrust required from each ramjet evaluated. The thrust equation is

$$F = m_a \cdot (V_e - V_t) \tag{5}$$

The power produced by the two engines is evaluated as:

$$N = 2 \cdot F \cdot V_t = 2 \cdot m_a \cdot (V_e - V_t) \cdot V_t \tag{6}$$

The specific power and specific fuel consumption are computed as:

$$N_{sp} = \frac{N}{2 \cdot m_a} = (V_e - V_t) \cdot V_t \tag{7}$$

$$SFC = \frac{2 \cdot m_f}{N} = \frac{m_f / m_a}{N_{sp}} = \frac{f}{(V_e - V_t) \cdot V_t} \tag{8}$$

In equations (5) to (8), m_a and m_f measure inlet air flow rate, and engine fuel mass flow rate respectively. Thus unlike rocket engine driver system, ram jet engine has lower fuel consumption.

Tip mounted ram jets has not proven to be very useful because the ram jet is inefficient at the speeds that can be achieved at the tip of the rotor blades. The speed is limited from the blades strength and shockwave standpoints. The problem is that the ram compression has not enough impact pressure.

A hybrid engine where the combination of ram compression and compressed air is provided by centrifugal compression is used in a helicopter rotor tip jet or for other applications. As a small two-seated ram jet power helicopter, Hiller model HJ-1 Hornet (shown in figure 3), became the first ram jet power unit to be certified in the United States and also the first C.A.A. (Civil Aviation Authority) approved tip mounted power plant.

Figure 3: Hiller Hj-1

Present proposed pressure power system

In the pressure combustion system, air is compressed through the blade rotor due to centrifugal force generated during blade rotation. What characterizes this method is that, no air compressor unit is used. Incoming air is compressed in the rotor and directed to 2-D combustion chamber located at the end of the rotor, and then ejected through the nozzle to produce thrust force. This thermodynamic cycle is identical to that of turbojet engine. The hollow blade rotor is functioning in the same way as radial compressor, heat is generated in the two dimensional combustion chamber, and the rotor blades work as a turbine [4]. The present designed rotor and 2-dimensional combustion chamber plus the complete proposed rotor system are shown in Figure (4).

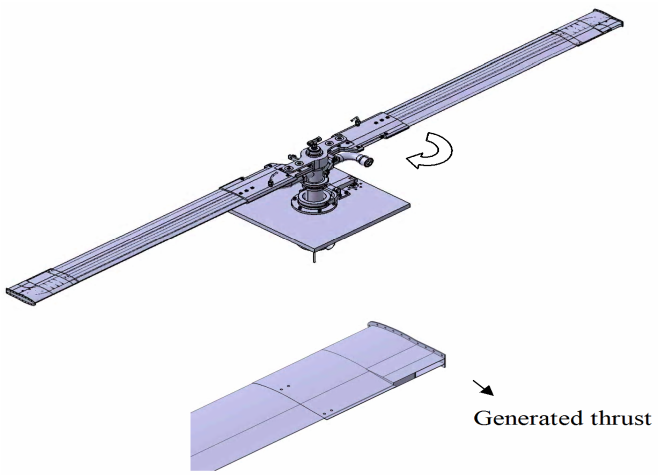

Figure 4: proposed rotor system and 2-D combustion chamber)

The specific power, fuel consumption and optimum operating conditions for the pressure Jet system were estimated by the following method;

$$F = m_a \cdot V_e \tag{9}$$

Power generated due to rotor tip jet is:

$$N = 2 \cdot F \cdot V_t - N_{drag} = 2 \cdot m_a \cdot V_e \cdot V_t - 2 \cdot m_a \cdot V_t^2 \tag{10}$$

$$N = 2 \cdot m_a \cdot (V_e - V_t) \cdot V_t \tag{11}$$

Thus the rotor useful power

$$N_{ROT} = n \cdot m_a \cdot \{[V_e \cdot V_t] - [V_t]^2 - [W_b]\} \tag{12}$$

Where W_b is the work used for compression through rotor blades.

$$W_b = c_{pa}(T) \cdot T_a \cdot \left(\frac{\pi_k^{\frac{\gamma-1}{\gamma}-1}}{\eta_k} \right) \tag{13}$$

Specific useful power

$$N_{sp} = \frac{N_{ROT}}{m_a} \tag{14}$$

Specific fuel consumption

$$SFC = \frac{m_f}{N_{ROT}} \tag{15}$$

The pressure in the combustion chamber is determined from the pressure rise in the air compressor due to rotor centrifugal action in the blades, the pressure loss due to friction in the blade, and the pressure loss in the combustion chamber.

RESULTS AND COMPARISON

In comparing the payload endurance characteristics for the different types of helicopter power systems, the optimum conditions for all types are considered. A value of v_{tip} =280 m/s is taken, and it forms a reasonable basis for comparison for pressure jet system.

The comparison curves of payload endurance for configurations of 300 kg, and 100kg and Specific fuel consumption are given in Figure (5) and Figure (6). These graphs show the general implications of present pressure jet power system and rocket power system. The rocket jet rotor helicopter can carry a considerably greater payload but can only operate for very short time that is because the engine has higher fuel consumption than a pressure combustion engine or a jet engine. Pressure combustion power system is much better than rocket power system; because of its lower specific consumption.

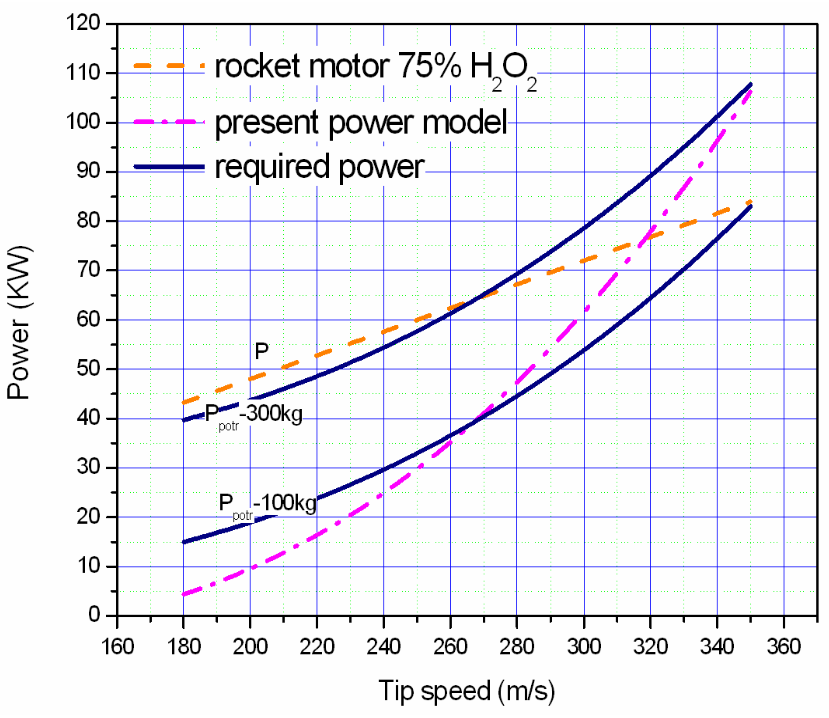

Figure 5: Comparisons curves of payload endurance for configurations of 300 and 100 kg

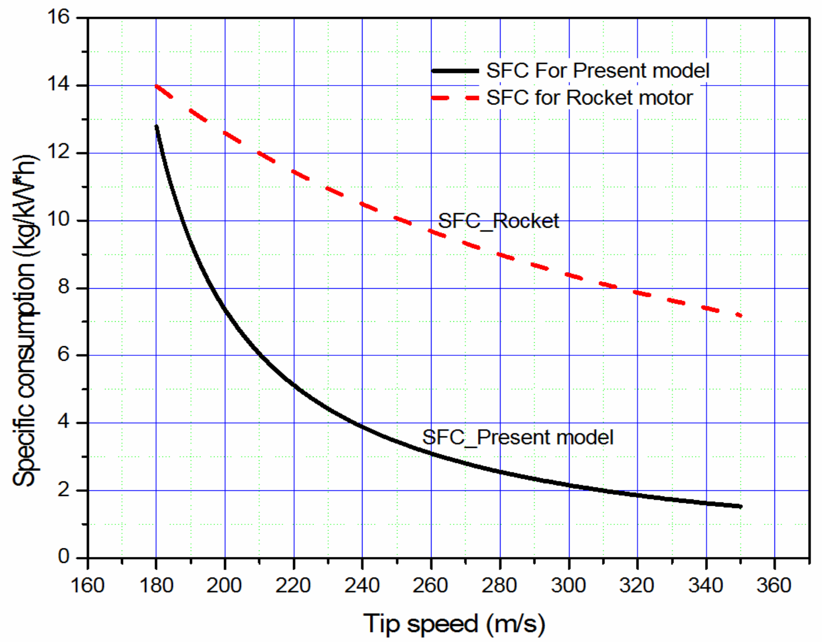

Figure 6: Comparisons curves of SFC between rocket motor and present pressure model.

CONCLUSION

It has been shown that, for a helicopter of a given gross weight, the rocket jet rotor configurations is capable of a considerably higher payload for flight of very short time, but that only short missions are possible. What characterizes a rocket engine is that it can develop a high power despite being light weighted, and the drawback is that the engine has higher fuel consumption than a pressure combustion engine. Therefor, the rocket engine is best suited for applications where low weight is important and high power is needed for a shorter period of time. Thus, the rocket jet rotor system helicopter will therefore have only limited specialized application.

The present pressure combustion power system operates mush better than the rocket system if saving in fuel consumption is considered with the simplicity of the unit design. In general view the results of this work can only be taken as giving guide to the payload and endurance relationships of the various configurations.

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NOMENCLATURE

m_a	Air inlet mass flow rate (kg/sec)
m_f	Fuel mass flow rate (kg/sec)
m_e	exit mass flow rate (kg/sec)
c_{pa}	Specific heat (J/kg. K)
Ta	Ambient temperature (K)
SFC	specific fuel consumption (kg/Nh)
γ	Specific heat ratio
π_k	pressure ratio of the rotor blade.
η_k	efficiency of the rotor
n	number of rotor blades
f	fuel – air mixture ratio
N	Power (w)
N_{ROT}	Rotor useful power (w)
N_{drag}	drag power (w)
F	Thrust (N)
V_e	Nozzle exit Velocity (m/sec)
V_t	rotor blade tip velocity (m/sec)