DESCRIPTION AND THOUGHTS ON THE TURBO DISC

Introduction

This document briefly describes a simple form of gas turbine engine which it is felt, forms a half way step between the ram jet engine and the centrifugal engine as originally conceived by Whittle.

Its principal aims are as follows:

(1) A thrust weight ratio of at least 9 to 1.
(2) The development of high thrust and comparative efficiency with no forward speed.
(3) The attainment of moderate to high compression ratios with low centrifugal stresses.
(4) The elimination of turbine discs and blades.
(5) The use of simple materials and manufacturing processes.

Description

The engine has the appearance of a hollow disc 24" in diameter and 2" thick, rotating on a central bearing arrangement.

Air is drawn into the disc through a central air intake and is burnt internally and expelled around the circumference from six equally pitched tangential nozzles, (See Figure #1).

The disc is made up of two main parts:

(1) An inner disc rotating clockwise with the central eye intake as an integral part and carrying twelve (12) straight radial vanes sandwiched between the two walls of the disc.

(2) An outer disc positioned about the inner disc but rotating counter-clockwise on a common centre with the inner disc carrying on its circumference the six equally spaced nozzles pointing tangentially rearwards relative to the direction of rotation.

Immediately inside the circumference of the outer disc and adjoining the six nozzles is the annular combustion space. Positioned radially inside the combustion chamber and sandwiched between the walls of the disc, are eighteen (18) radial vanes, curved in such a way as to receive the air thrown off the inner disc with the minimum of shock and deliver it to the combustion chamber. The inner and outer discs are connected together by a simple set of internal and external spur gears so that, when the outer disc is driven round by its six nozzles at a rim velocity of 600 feet per second, the inner disc is driven in the opposite direction at a rim velocity of 700 feet per second.

Description and Thoughts on the Turbo Disc

The action of the engine is as follows:

An element of air entering the central intake is centrifugally thrown out to the circumference of the central disc where it realizes a rim velocity of 700 feet per second and a small amount of compression due to the centrifugal force. It leaves the centre disc and at 700 feet per second is picked up by the inner edge of the outer disc which is rotating in the opposite direction at 600 feet per second. The element, therefore, experiences a change in momentum, due to the change in velocity of 700 + 600 = 1,300 feet per second. The force due to this sudden change in momentum can only be absorbed by the element itself in the form of pressure and consequent heat; added to this is the pressure due to the centrifugal force of the outer disc rotating with a velocity of 600 feet per second. The sum of these momentum changes produces at the most conservative reckoning, a compression ratio of 3.4 to 1 and at the most optimistic, a compression ratio of 8 to 1. The compressed element, therefore, arrives in the annular combustion chamber where fuel is injected and burnt - the products of combustion escape from the six tangential nozzles which are of the convergent divergent type sized conservatively to a pressure ratio of 4 to 1. These nozzles drive the outer disc which in turn drives the inner disc in the opposite direction.

The Advantages Claimed for this Configuration as Compared with the Conventional Centrifugal Type are as follows:

(1) A high compression ratio is obtained for low rim velocities. A plain ring will safely support itself at 600 feet per second rim speed whereas, to achieve the same compression ratio with a conventional centrifugal impeller 1,500 feet per second would have to be realized. 1,500 feet per second tip speed is about the safe limit of rotation for any disc made of known materials even when specially designed with a thick centre portion tapering to a thin circumference, the result is usually a heavy component and the limiting compression ratio for such an impeller is just over 4 to 1. It is believed that ratios as high as 8 to 1 are quite possible with a counter-rotating unit similar to that described above. No Yes No

(2) The elimination of the turbine resulting in the ability to use much higher combustion temperatures and smaller combustion chamber volumes (the necessity to properly cool the combustion gases with excess air to bring the mixture below the limiting temperature which the turbine blades can stand to a very great extent dictates the length and volume of the conventional combustion can).

(3) The nozzle is a more efficient way to convert pressure into work than the turbine blade. No, the nozzle does not convert

(4) The higher combustion temperature permits smaller mass flows to be used for generating the same thrust which enables higher compression ratios to be realized.

Description and Thoughts on the Turbo Disc

The Advantages Claimed for this Configuration as Compared with the Conventional Centrifugal Type are as follows: (continued)

(5) The elimination of turbine blades and the low centrifugal stresses involved permit the use of simple manufacturing processes such as spinning, sheet metal work, etc. Making the whole venture a comparatively cheap undertaking.

Engine Leading Particulars

Outside diameter - 24" not counting nozzles.
Rim Speed of outer disc - 600 feet per second.
Rim Speed of inner disc - 700 feet per second.
Compression ratio at least 3.40 to 1, possibly 8 to 1.
Mass flow 4.6 lb. of air per second at compression ratio of 3.4 and 10 lb. per second at compression ratio of 8 to 1.
Available thrust - 119 lb. at compression ratio of 3.4 to 1 and 320 lb. at 8 to 1.
Weight 25 lb.

Torque available to do useful work and drive the compressor = the nozzle area 9 sq. inches x pressure rise 35.5 sq. inch = 319.5 x the radius 13" = 4,153 lb. inches.

The greatest contribution to the efficiency of the engine, will be made by the compressor and since this is of unconventional design, there is no experimental data on which to base a theory. One very simple approach would be to assume that the outside disc was stationary and the centre disc rotated with the whole rim velocity of 1,300 feet per second and use existing curves for an impeller at this rim speed. The results obtained by doing this give a compression ratio of 3.4 to 1 which is felt to be very pessimistic as it does not take into account all momentum change, (See Figure #8). However, assuming this to be correct, the torque required to drive the compressor is equal to the change of angular momentum per second experienced by the air. If the angular momentum of the air entering the disc is zero, then the total torque on the compressor is given by T ....

$$\text{Where } T = \frac{UR}{g} \text{ lb. ft. per lb. of Mass Flow}$$

and U = Whirl Velocity
R = Radius of Impeller Tip

$$= T = \frac{1300 \times 7 \times 4.6}{32.2 \quad 12}$$

$$= 108.3 \text{ ft. lb.}$$

which when subtracted from the available nozzle thrust torque of 4,153 lb. inches and multiplied by 2 on account of the gear ratio gives a useful torque of 1553.8 lb. inches or a useful thrust of 119.5 lb.

Engine Leading Particulars (continued)

The other more realistic way would be to take the pressure stage-by-stage on a change of momentum basis.

The curve shown on Figure 7 represents the pressure experienced by a pitot tube at all speeds up to a Mach Number of 2.0 compressible q_c

The points plotted along the curve and circled are derived from the formula below, for the plain disc of (Figure #7)

$$\frac{P_T}{P_e} = \left[1 + \frac{\gamma - 1}{2g} \frac{\rho_e W^2}{P_e} \left(R_T^2 - R_e^2 \right) \right]^{\frac{\gamma}{\gamma - 1}}$$

Where P_T = Tip pressure and P_e = eye pressure
R_T = Tip radius and R_e = eye radius
W = Rotational velocity in radians
γ = Ratio of specific heats for gas used
ρ_e = Density of gas used at impeller eye

it will be seen that they fall almost exactly along the curve for compressible q.

The above formula is an expression for the compression ratio experienced at the rim of a hollow disc in which the internal gas is rotating with the disc but there is no radial flow - it will be seen that for a given rim Mach Number, the centrifugal pressure of the gas inside the disc at the rim is equal to thepressure on a pitot tube traveling at the same velocity.

If the radial flow is very small compared with the tangential flow or whirl, the curve given on Figure 7 will very closely portray the truth. This is to a very large extent true of the above engine. Consider the element entering the intake of the central disc; it will eventually arrive at the rim of the centre disc where it will have a whirl velocity of 700 feet per second and a pressure as given by the point marked (a) on the curve of Figure 7 - the element then leaves the rim of the centre disc at a pressure equal to that at point (a) on the curve and a velocity of 700 feet per second and is picked up by the outer disc where it eventually arrives at the circumference with a velocity of 600 feet per second in the opposite direction. The element, therefore, experiences after leaving the rim of the inner disc, a momentum change due to the change in velocity of 1,300 feet per second. This takes you to point (b) on the curve, however, this would be the pressure if the outer disc were a receptacle moving on a straight patch. This is not so. The path of movement of the outer disc is a radius and there will, therefore, be some centrifugal force exerted - this will take us to point (c) on the curve; point (c) represents a compression ratio of approximately 10 to 1. This figure

Engine Leading Particulars (continued)

is admittedly a little too high to be easily accepted. However, it is felt that the reasoning is correct, particularly when considering the momentum change indicated on the curve of Figure 8 and it is proposed to use this as the top limit of what might be expected, only reduced to 80% as an efficiency factor for adiabatic compression. This permits us to use a compression ratio of 8 to 1.

Referring back to the curves on Figure 6 and using the same combustion temperature of 1800° Kelvin, also the same nozzle area of 9 sq. inches, a thrust of 930 lb. is available at the nozzles and requires a mass flow of 10 lb. per second.

The torque to drive the compressor

$$T = \text{the torque on the outer disc } \frac{(1300 \times 12 \times 10)}{(32.2 \times 12)}$$

$$+ \text{ twice the torque on the inner disc}$$

$$= 2\ \frac{(700 \times 7 \times 10)}{(32.2 \times 12)}$$

$$= 658 \text{ ft. lb. (by slide rule)}$$

$$= 7{,}890 \text{ inch lb.}$$

the torque available at the nozzle = 930 x 13 lb. inches = 12,090 inch lb. the useful torque is, therefore, 4,200 inch lb. which is an available thrust of 320 lb.

Description of a Plain Rotating "Disc"

The steps in the thinking which have led up to the design study of the counter-rotating disc just described are well portrayed in the following description of a single piece rotating disc which has actually been made and run successfully (See Sketch #2).

.....A hollow disc 10" in diameter and 1" thick was made from two circular mild steel spinning, .040" thick and welded together around the circumference (See Drawing #2). Equally positioned around the circumference were four nozzles all pointing tangentially in the same direction. Inside the disc and eight inches in diameter was an aluminum boundary wall with 300 3/32" diameter holes drilled radially through it forming a type of coarse mesh sieve; the boundary wall was 1" deep and 1/4" thick being held in position with 1/8" rivets. On the inside of the boundary were equally positioned eight radial vanes also 1" deep, 1/4" thick and held in position with 1/8" rivets. At the very centre of the top disc was housed a self-aligning ball race and at the centre of the bottom disc was a 1 1/2" diameter hole. Facing this hole axially and abutting it with a sliding gland was a 1 1/2" diameter pipe. Fed into this 1 1/2" diameter pipe are two other pipes, one 1" diameter and the other 1/4" diameter. The 1" diameter pipe is to feed air to the

Description of a Plain Rotating "Disc" (continued)

disc and is to be connected to the plant main air pressure line - it has in its length a sliding port which enables it to be opened to the atmosphere.

The 1/4" diameter pipe is to feed propane gas to the disc. The propane and the air mix in the 1 1/2" abutting pipe and enter the disc as a combustible mixture. This mixture flows radially outwards in the disc and penetrates the boundary wall through the 300 1/32" diameter holes entering the 1" wide annular space between the boundary wall and the perimeter of the disc - this area shall be known as the combustion chamber. The mixture is ignited in this area by means of a blow lamp pointed in through one of the four radial nozzles. The burnt gases escape through the four nozzles.

To start the engine the disc is held from rotating and the air is turned on to a small extent with the sliding port in the air line closed. Next, the propane gas is turned on slowly and the blow lamp is lit and pointed down one of the nozzles. The gas will then light on the outside only of the boundary wall - the boundary wall acting as the gauze in a Davy safety lamp. When the gas is well lit the blow lamp may be taken away and the disc left free to rotate which it will immediately do. The air and the propane gas may then be steadily turned on being careful to keep the mixture right by watching the colour of the exhaust flame from the four nozzles. The disc will accelerate very rapidly and at some figure above 4,000 RPM the port in the air line may be opened and the air slowly turned off. When the disc will be running and pumping its own air. All you then have to do is control the propane.

Limitations Experienced with Single Piece Rotating Disc

The first trouble experienced when running the single disc, was due to overheating of the combustion chamber; this was due to the lack of mixture control due to pre-mixing the propane and air before the combustion chamber.

A very simple modification was carried out which make it possible to feed the propane gas direct to the combustion chamber through a gallery pipe and an extra rotating gland. This completely overcame the overheating trouble; it was found that the hot gases of combustion which were lighter than the cold incoming air were displaced from the wall of the combustion chamber by a layer of cool incoming air - this kept the chamber wall cool.

The main limitation to this simple disc was that as the combustion chamber was rotating, the only compression ratio to be experienced before combustion was that due to the centrifugal force, the kinetic energy of the tangential or whirl velocity is not recovered in the form of pressure, therefore, to achieve a reasonable compression ratio, very high rim velocities have to be realized.

Limitations Experienced with Single Piece Rotating Disc (continued)

The disc described above would burst at about 900 ft. per second which would only produce a compression ratio of 1.3 to 1 on the most optimistic reckoning. However, that the disc ran at all spoke well for the other efficiencies involved and proved the principle. It would be just possible to make such a unit which would run at a tip speed of 1,500 ft. per second with a compression ratio of 2.5 to 1, but that would be about the limit.

Application

What use could be made of such an engine .... is of course, the first thought that enters one's mind. It could be used to develop shaft horsepower, but as the rim velocity is comparatively low and the efflux gas velocity is very high the losses due to slip would be large.

It is the writer's opinion that the engine's most natural role is that of a pure jet unit delivering thrust.

It has been suggested that a unit 24" in diameter could produce a useful thrust of from 119 to 320 lb. for a weight of 25 lb. or a lift weight ratio of from 4.75 to 1 up to 13 to 1. It is also felt that should the size of the disc increase this weight, lift ratio would become even more favourable. A disc could easily have more than one stage of counter-rotation which could either result in a reduced rim velocity or if possible, increased compression ratio. Even if conditions did not improve a disc delivering 5,000 lb. of useful thrust might be expected to weigh 500 lb. This thrust could be obtained from the disc by turning all the jet nozzles downwards from the plane of the disc so that there is a component of velocity parallel to the plane of the disc and one perpendicular to it. The angle through which the jet nozzles are turned will depend on the amount of work which is required to do the pumping as against that which is left over for useful thrust, (See Figure #3).

The result is that the whole disc will experience a vertical lift perpendicular to the plane of rotation. If we were to consider the 5,000 lb. thrust unit which weighed 500 lb. we could fit that into a purely experimental flying machine in which .....

The pilot weighs	200 lb.
The airframe weighs..............................	1000 lb.
The fuel (200 Imperial Gallons) weighs	1600 lb.
The engine weighs................................	500 lb.
TOTAL	3300 lb.

Application (continued)

The thrust, however, is 5,000 lb; the aircraft (See Figure #4), will lift vertically off the ground and will accelerate from a force of 1,700 lb. or half a "g". It will very quickly pick up speed and the ram rise will improve the compression ratio until, when the aircraft is traveling at a Mach Number of 2, if the pilot is not already cooked, the compressor can be thrown away (presumably by means of a by-pass) and the engine will operate as a pure ram jet. All this is allowing one's imagination to run very far ahead of our present achievements.

February 7, 1952. J. C. M. Frost

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