A. V. ROE CANADA PROJECT 'Y'
NOTE ON THE PROJECT IN VIEW OF THE ASSESSMENTS CARRIED OUT BY THE RAE AND NGTE

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RAE Tech. Memo No. Aero 316 - "Preliminary Comments on a Proposal for an Aircraft powered by a Radial Flow Jet Turbine Engine" by J. R. Collingbourne and A. L. Thorpe; and NGTE Note No. NT 52 "Project 'Y' - an Assessment of Power Plant" by P. F. Ashwood and D. G. Higgins, have now been received by the firm. These reports have contributed much to the successful evaluation of the Project and the trouble that has been taken is much appreciated. This present note seeks to expand and comment on certain important detail points in the RAE and NGTE memos largely in view of further work which has been carried out since the firm's statement was published. This statement was used as the basis of the RAE and NGTE memo. It will be convenient to raise these points as a review of the latter.

THE RAE TECH. MEMO AERO 316

<u>Performance</u>

The performance as quoted by the RAE is not very seriously different from that claimed by the firm except in respect of the endurance; which is given as 20 minutes. This is very much a "specification endurance" and ought to be scrutinized rather closely.

The firm's statement on Project 'Y' Sept. '52 (p.42) exampled a comparative high speed mission profile worked according to another specification. This broke the fuel down into allowances for all phases of the specified flight, allowing 5 min. combat at M = 1.5 at high altitude. An endurance of nearly one hour and a range of over 800 miles resulted.

It should be realized that the requirement for 10 min. at maximum rpm at 45,000 ft. completely dominates the fuel used picture, absorbing over 60% of the total fuel on board. We assume that this requirement is an "omnibus" taking care of descent, landing and reserve but we point out that for the type of machine being proposed it certainly takes care of it good and proper. With over 60% of the fuel taken care of in this way the endurance figure becomes rather meaningless: furthermore, the relative effect is very different for different aircraft and the requirement for "max. rpm" puts a high top speed at a discount. This is illustrated by Figures 1 and 2 attached.

On the RAE NGTE figures the maximum rpm speed is 2.2M and at this speed the jet is producing 41,500 horsepower (Fig. 1) If this is reduced by 10,000 horsepower this speed only falls to 1.94M which is probably the top speed of the comparative Project in the RAE note. Fig. 2 shows how much fuel this 10,000 H.P. represents in 10 min. and that it would give the aircraft 50% more endurance at M = 0.9 at 45,000 ft. - or the same figure as the comparative RAE Project shows.

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Performance (continued)

In actual fact if the thrust of the engine were scaled down 25%, the aircraft would get thinner so the drag and perhaps the weight also would be reduced. The possibility of actually doing this was briefly looked into by the firm some time ago but the results were inconclusive and the work involved in redesigning to get an accurate idea of the effect is not thought worthwhile at this stage.

It is suggested that a more appropriate specification attack technique for this type of aircraft where combat may be envisaged at 45,000 ft. is to dive from cruising altitude and allow say 5 min. combat at M = 1.5 at 45,000 ft. Looking at Fig. 2 it is seen that this would release 4,100 lb. of fuel (or nearly 30 min. at M = 0.9, at 45,000 ft.) towards endurance. A small extra climb fuel allowance would come out of this.

It is of course obvious that such a large engine is capable of consuming fuel at a very great rate, indeed the fuel system is envisaged as allowing for a maximum fuel flow of about 60,000 lb./hr. whereas not more than 9,000 lb. can be stowed internally - or enough for a total of 6½ min. at the maximum rate. It is suggested, however, that in practice high fuel flows will be used with discretion and it has been pointed out that the fuel used in getting to high altitude - where the fuel flow at high rpm is quite moderate; and where quite reasonable economy in air miles per lb. is obtained at supersonic speed, due to the high thermal and propulsive engine efficiencies - is principally a function of the work done in lifting the gross weight to the altitude; being only moderately affected by the efficiency of the process.

Stability and Control

It is considered that the complete analysis of stability undertaken by the firm represents a correct view of the likely characteristics. It has proved possible to considerably simplify the calculations for manual computation and although we agree with the RAE that the aerodynamic assumptions are subject to considerable error it has also been shown that very large error in the doubtful derivatives will not affect the general conclusions on stability and control. Broadly speaking we are dealing with the reactions of a gyroscope to applied loads, and modifying these with aerodynamic effects.

It is believed that the typical stability modes have been identified fairly clearly. Rates of roll and control angles per g at supersonic speeds have also been evaluated.

The work which has been done on stability and control is being prepared in some half a dozen reports which will shortly be available.

Our equations show disagreement with the RAE opinion that there is no great margin of stability; indeed our calculations show that the rotor rpm could be halved without introducing any rapid instabilities. With regard to the normal typical lateral oscillation mentioned by the RAE we find that this has been eliminated by the gyroscope. There is no Dutch roll.

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THE NGTE NOTE NO. 52

Weight

It has been stated that the engine airframe structure integration will give a considerable weight saving and the NGTE say that the claim for low aircraft weight is based on this. We now feel that this view is too superficial. It is clear that a large percentage of the wing area comes right with the engine because of its shape but there are other factors which must have a considerable influence.

The weight of a conventional axial of 40,000 lb. thrust can be estimated by empirical methods. If the curves given by Moyes and Pennington in their paper "The Influence of Size on the Performance of Turbo-Jet Engines" (given before the 1951 Brighton conference) are extrapolated to this figure, a weight of about 30,000 lb. results.

Considering the proposed single disc flat engine, in the first place it seems to offer an economy of parts: comparing it with the axial we find no counterpart for the compressor discs, the extra bearings (including thrust race), the engine backbone or the main shaft and hub. Secondly it seems possible to design for low tip speed; the outer edge of the disc is travelling at less than 800 ft./sec., and since the disc stress will vary as the square of the tip speed this in itself should result in a considerable weight reduction. Thirdly, it is noteworthy that the large flow areas in the engine are obtained with quite small blades. Centrifugal force on a blade varies directly with the weight and also as the speed times the RPM. In the proposed engine the rpm is of the order of one tenth, the compressor blade weight per unit circumference is less than half and the blade root speed is less than three quarters of the equivalent values on a conventional present day 6,000 - 7,000 lb. axial. It is clear that were the disc of similar thickness the stress imparted to it by one blade row would be of the order of one thirtieth of that added to its disc by a conventional blade set. It is suggested that this is a good reason why six rows of blades (half-supported by shrouds and having the centrifugal loads to some extent balanced by gas loads) can additionally be hung on to one disc without adding appreciably to its weight.

It is considered that these other factors have a principal influence in bringing out an engine weight (with scantlings) of the order of one-half the empirical figure. With regard to specific weight the NGTE point out that the figures quoted are not outstanding when compared with conventional figures but we feel they would regard them as outstanding for a conventional engine of this thrust capacity, and do not seem bad when compared with a few present day engines on makers' figures (not of course including development, but nor do our figures) as shown by the diagram on Fig. 3

In view of the above it does seem that direct weight analogy between the flat engine proposed and the conventional axial is difficult and likely to be spurious.

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Weight (continued)

Nevertheless, it seems a possible view that the proposed engine consists mainly of a turbine wheel, compressor blading and a combustion system arguing that:

1. The compressor discs become unnecessary because of the large diameter - flow area effect. Effective hub/tip ratio is greater than 0.95.

2. The engine backbone and some of the outer casing weight is absorbed into the aircraft structure.

3. The main shaft and one or two bearings is avoided by the layout.

4. The turbine disc itself is light and has a large hole in the middle, because it is well cooled and has a low tip speed.

Exhaust Duct Loss

It is considered that a loss of 7% of the turbine exit pressure is perhaps rather high. It is pointed out that 2/5 of the jet is exhausting substantially rearwardly through a short length of pipe. The 7% is an overall figure presumably representing a much greater loss on the forward exhaustors; moreover the turbine leaving velocity has been held to a maximum of 1,150 ft./sec. (M = 0.58) and some considerable diffusion from this figure before turning the "high aspect ratio" jet round the corner is envisaged.

Non-Axial Discharge

The RAE mention the tendency which the side exhaust gases will have to follow the direction of the tip. We think that some credit should be taken for this and that it is possible that the loss due to the "non-axial" exhaust and the use of a convergent nozzle may be offset to a considerable extent by designing the forward propelling nozzles in such a way that a Prandtl-Meyer expansion will take place to develop the full velocity in a direction close to the line of flight. The expansion round the corner will of course produce a pressure gradient across the jet in favour of a forward reaction on the forward facing part of the jet nozzles. It is probable that there will be losses associated with this process (although the Prandtl-Meyer expansion is isentropic) and some loss should be counted. However, since the pressure ratio across the final nozzle increases with speed and the margin for pressure gradient across the jet also, due to compressibility, we suggest that a loss of 8% of the net, rather than the gross thrust would be a reasonable approximation at this stage. If 8% is deducted from the net thrust only, the lines plotted by the NGTE in their Fig. 2 will be altered to approximate to the dotted line which corresponds to the firm's predictions.

Axial Velocity at Inlet

The 580 ft./sec. axial velocity is not considered high in view of the low

Axial Velocity at Inlet (continued

tangential blade speed, and the design value gives a Mach No. of 0.72 at the first blade. We feel that the factors taken into account by NGTE in assessing stage temperature rise ought to be stated as we see no objection in using $\alpha_2 = 2^\circ$ through the compressor which, combined with a high radial velocity gives a ΔT of 21°C/stage.

It is considered that this low stagger design and unusual layout is very different from the RA14 and it is suggested that compromising considerations such as low hub/tip ratio with twisted blades may have enforced a somewhat low ΔT for this engine. It is pointed out that over 20°C per stage is not the least unusual.

Blade Root Stresses

It is considered that the shrouds will have an important effect on blade root stresses particularly on the earlier stages. At only 450 ft./sec. a good material will support considerably more than its own weight. We find the stress on the high aspect ratio first rotor blade can be brought down by something of the order of 50,000 psi by the shroud. They will be fully effective on all stators also. NGTE have neglected this effect.

Mechanical Design

It should be made clear that the design of the rotor as a cantilever from one central bearing envisages deflections of the rotor up to 0.35" at the rubbing surface near the guide vanes, in the manoeuvring case. It is not practical to make a cantilever rotor so stiff that it will not deflect (in the plane of the disc) past the limit set by considerations of tolerable gap between blade tip outer casing: and it is not at present the intention to design for a small gap in the radial direction between the edge of the shroud and the body: therefore a seal has to be designed to overcome leakage and this should not be excessively difficult in view of the practicability of shrouding the rotor blades. Several likely schemes are being considered. A test rig has been constructed and preliminary tests have been started.

As far as the bearing is concerned the design so far shown should be regarded as dedidedly interim. It is considered that a satisfactory design should be simply a matter of ingenuity and development time and two qüite promising new schemes which deal with the rotor concentricity are available. The NGTE suggestion does not seem quite practical because the rotor radial stretch under load involves a complicated follow-up gear on bearings mounted at right angles to those shown.

General

With regard to the NGTE's conclusions:

The design philosophy has been to design the aeroplane principally for the supersonic regime and its poor subsonic manoeuvrability is not

General (continued)

regarded as very important. The endurance is what you make it as has been pointed out earlier. Vulnerability is an imponderable but the servicing problem is not expected to be severe in view of the simplicity of the design and the ease with which it can be taken to pieces. This is demonstrated in an exploded view contained with the most recent statement on the Project. The efforts which have been made to verify the weight are also explained in this statement and further explanation for the low weight has been attempted herein.

One method of dealing with rotor deflection has now been explained and in general it is not considered that the proposal incorporates a very great number of untried mechanical design features. Efforts have been made to keep the design as conventional as possible within the proposed layout and the untried design features do not appear unduly formidable.

Finally if a reasonable developed thrust figure of 50,000 lb. is combined with the bare engine weight of the latest designed engine the specific weight becomes 0.19 lb./lb. and if this thrust figure is applied to the bare aircraft (i.e. without disposable load) the aircraft specific weight is 0.35 lb./lb. The latter figure compares with some present day bare engines.

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T. D. Earl - cs