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A VARIABLE PITCH FAN FOR AN ULTRA QUIET DEMONSTRATOR ENGINE

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A VARIABLE PITCH FAN FOR AN ULTRA QUIET DEMONSTRATOR ENGINE

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1. INTRODUCTION

A little over five years ago aircraft designers on both sides of the Atlantic were engaged on a new breed of civil aircraft for operation close to city centres. For a variety of reasons, environmental pressures being far from the least, Downtown STOL, per se, did not prove to be just round the corner, despite some encouraging experiences for example in Canada with the twin Otter between Ottawa and Montreal. However the arguments for such a system still exist, (albeit so do some of the objections) but furthermore there is also a need for a new quiet aircraft to replace the ageing types engaged on intercity routes, which are mainly turboprop powered. Such an aircraft must have a field performance equal to that of the turboprop, and be able to satisfy the environmentalists, and so before STOL in the 1990's we can reasonably expect Q.R.T.O.L. in the 1980's.

The engine requirement for a short field (short or reduced is only a question of degree) is a higher ratio of take-off to cruise thrust than that associated with present day fan engines. A quiet engine requires a low hot jet velocity for low rear arc noise, and a low fan tip speed for forward arc noise. Both noise and thrust requirements may be achieved with cycles of high by-pass ratio and low fan pressure ratio. These cycles also have a low s.f.c. and so they are therefore highly suitable for engines for RTOL and STOL. For low pressure ratios below about 1.4:1, efficient operation over all of the speed range of the aircraft requires some variability, which in the case of a fixed pitch fan could be effected by a variable area exhaust nozzle. If however a variable pitch fan is employed to take advantage of the flexibility of control and other features, that it confers on aircraft operation, it can itself provide this adjustment for efficient operation and eliminates the need for a variable nozzle.

2. JUSTIFICATION OF VARIABLE PITCH

The variable pitch fan about which this paper is concerned has many claims of merit. The principal one of these is that it provides propulsion characteristics, that allow aircraft to operate safely and quietly within an ATC system, involving steep approach and climb out. In fact it is difficult to envisage an alternative system that fulfills

The achievement of near zero thrust levels is a requirement for 6-7^{o} approaches and this must be associated with an ability to modulate the thrust rapidly in order to fly accurately down a prescribed path. Further, to ensure safety and to enable landings in the worst visibility categories, a very fast response to full take-off thrust is essential.

Under these approach conditions, the V.P. fan, when driven by a two spool engine having an I.P. compressor, can result in the achievement of near zero thrust with almost instantaneous modulation response and restoration of full take-off thrust in an emergency in about 1 second. The low thrust is achieved by adopting fine pitch of the fan at high fan RPM, when the I.P. compressor acts as a "brake" to enable the use of stable H.P. spool speeds. Further the high speed of the Fan/I.P. compressor heavily supercharges the H.P. spool, leading to the fast acceleration capability for restoration of full thrust. Variable I.P. compressor bleed is used in conjunction with fan blade pitch angle to preserve the best I.P. compressor running conditions.

There are very many other advantages of V.P., which collectively are very attractive, particularly when associated with the above main feature.

These are:-

a) Elimination of the need for variable fan duct nozzles to compensate for the effect of forward speed on fan operating line.

b) Fine tuning of engine running for optimum power and SFC at different atmospheric temperatures.

c) Reverse thrust without special reversers; though the ability with V.P. to achieve reverse thrust down to zero forward speed should not be overlooked, or the value of that under-estimated.

d) Rapid achievement of reverse thrust for normal landing and aborted take-off.

e) Acoustic advantages by selection of particular fan speed for any part thrust setting.

f) "Free" air for wing blowing under all part thrust conditions.

g) Others involve topics such as water injection, engine adjustment to increase TBO, cabin conditioning, anti-icing cross wind immunity etc.

On single spool High Bypass engines V.P. might be essential for engine starting (too much load on starter unless fan in fine pitch) and low speed running, and because idle thrusts are otherwise too high for aircraft ground handling. The Turbomeca Astafan is an example.

Many of the above features are also very attractive

High bypass ratio cycles normally require highly loaded L.P. turbines, but the use of a reduction gear enables the low speed variable pitch fan to be driven with a high speed shaft; thus allowing the number of turbine stages to be kept low. This together with the elimination of a separate reverser system has significant weight advantages.

Having briefly surveyed the applicability and characteristics of the V.P. fan engine, we will now move on to describe the V.P. fan of a demonstrator engine, called M45SD-02, its design philosophy both aerodynamic and mechanical, its construction, its performance, its functioning, and some early test results from the engine running. The basic parameters of the demonstrator engine and its proposed fully rated production successor the M45S-11 are shown in the following table.

3. ENGINE DEFINITION

The basis of the demonstrator engine is the M45H-01, which is currently in service on the VFW.614 feeder airliner. Changes are minimal to incorporate a variable pitch geared fan, but includes the addition of a 4th stage to the L.P. turbine, to transfer more shaft power to drive the fan with the consequential lowering of hot jet velocity, which is a requirement for the achievement of low noise.

	M45SD-02	M45S-11	M45H-01
Thrust lb (KN)	10027(44·6)	14370(63·9)	7600(33·8)
By-Pass Ratio	8·73	9·8	2·85
Fan Outer P.R.	1·27	1·31	1·60
Fan Inner P.R.	1·18	1·20	1·50
Hot Jet Velocity f/s (m/s)	900 (274)	900 (274)	1377 (420)
Fan Tip Speed f/s (m/s)	1027 (313)	1133 (345)	1495 (456)
Noise Predicted PNdB at 500 ft. (170 m)	95	96	105·5 (Unsilenced)
Reduction Gear Ratio	2·38:1	2·38:1	-
SFC SLS lb/hr/lb (mg/N/sec)	0·32 (9·1)	0·31 (8·8)	0·46 (13·1)

The precise choice of pressure ratio for technology demonstration fan design is not particularly important. It is not proposed to justify the choice herein because it is firmly believed that the overall experiment is not sensitive to the design variables and that there will be an adequate read across from the M45SD-02 to a comparatively large range of fan pressure ratios and therefore to any particular requirement dictated by a Q.R.T.O.L. project. For this reason the aerodynamic considerations discussed below tend to be of a more qualitative nature. It is interesting to note that American Designers have also chosen a similar design point fan pressure for their Q.C.S.E.E. project. The general arrangement of the M45SD-02 engine is shown in

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