Printed in U.S.A.

72-GT-61

an ASME publication

$3.00 PER COPY
$1.00 TO ASME MEMBERS

Variable Pitch Ducted Fans for STOL Transport Aircraft

R. M. DENNING

Chief Engineer—Advanced Projects,
Rolls-Royce (1971) Ltd.,
Bristol Engine Division,
Filton, Bristol, England

The Variable Pitch fan has a number of features which make it attractive as the basis for ultra-high bypass ratio ducted fans designed primarily for STOL aircraft. The variability imposes certain design constraints, particularly on fan pressure ratio, and leads to differences in engine geometry relative to equivalent fixed pitch engines. The merits of such engines are discussed under the headings of Performance, Noise, Engine Control, Thrust Modulation, Provision of Air Bleed for High Lift, Reverse Thrust and Development Flexibility.

Contributed by the Gas Turbine Division of the American Society of Mechanical Engineers for presentation at the Gas Turbine and Fluids Engineering Conference & Products Show, San Francisco, Calif., March 26-30, 1972. Manuscript received at ASME Headquarters, December 20, 1971.

Copies will be available until January 1, 1973.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, UNITED ENGINEERING CENTER, 345 EAST 47th STREET, NEW YORK, N.Y. 10017

Variable Pitch Ducted Fans for STOL Transport Aircraft

R. M. DENNING

INTRODUCTION

With the rapidly diminishing availability of suitable land for new large airports has come the search for new systems of Air Transport which would be less profligate in land use and which might also increase the capacity of existing airports. As a result, the next major advance in air transport seems likely to be a radically new form of Short Haul transport which may well be the STOL aircraft. It almost goes without saying that such aircraft must have a high degree of acceptability to local communities. This will not be made easier by the fact that such aircraft will generally operate closer to such communities. While the reason for STOL is not lower noise, it cannot succeed without achieving major reduction in subjective noise levels. Conventional takeoff and landing commercial transport aircraft are now coming into service with Airline Operators which use aero-engines that, for the first time, are specifically designed to meet Noise Certification legislation.

The fundamental feature, common to these new low noise engines, is the use of the single-stage front fan without inlet guidevanes and with large spacing of rotor and exit stator. By extracting most of the energy from the gas generator flow and reducing the hot jet velocity to around 1400 fps at takeoff, major reductions in noise, coupled with a significant improvement in fuel consumption, have been achieved. Such fans are run at higher tip speeds than has been customary in order to produce a high fan pressure ratio and to minimize the number of low-pressure turbine stages. As a result, the fan unit is highly stressed, difficult to design for blade containment, and more critical to foreign object damage.

Looking beyond the achievements of this new generation of single-stage fan engines, the Aerospace Industry is now seeking to produce engines with noise levels some 10 to 15 PndB lower and which also have the required performance characteristics for short field length aircraft. What these characteristics should be is not yet clear, and it appears likely that several competing designs will be evaluated up to the prototype stage. It is in this context that the variable pitch fan concept is being studied.

STOL POWERPLANT REQUIREMENTS

Although these have been discussed in many papers over the past few years, it is useful to recapitulate them. Summarized, they are as follows:

1. An increased takeoff to cruise thrust ratio
2. Lowest practical noise level
3. Low, near zero, axial thrust component on approach to land to allow steep approach paths combined with good acceleration characteristics
4. Reverse thrust usable down to low forward speeds
5. Ability to provide energy for high lift system if required.

It is the last item which has the most profound effect on the engine philosophy. If, for example, the engine is required to supply bleed air for high-lift wing systems, rather than using separate air supply units, then the thermodynamic cycle is dictated to a major extent by the amount and pressure ratio of such air. Even with the bleed thrust as low as 10 percent of the total thrust, an oversize compressor with permanent bypass is essential for efficient operation. There are a number of different high lift systems requiring bleed air ranging from boundary-layer control via the jet flap, to the Augmentor wing. The Externally Blown Flap is a special case where most of the engine thrust is vectored by the flap which then becomes the primary thrust control. The Augmentor wing has been described in a number of papers by D. C. Whittley (1, 2 inter alia),[1] and it requires the largest amount of bleed air with blowing thrust requirements which range from as low as 30 percent up to 80 percent of the total engine thrust. The concensus of view is that the

[1] Numbers in parentheses designate References at end of paper.

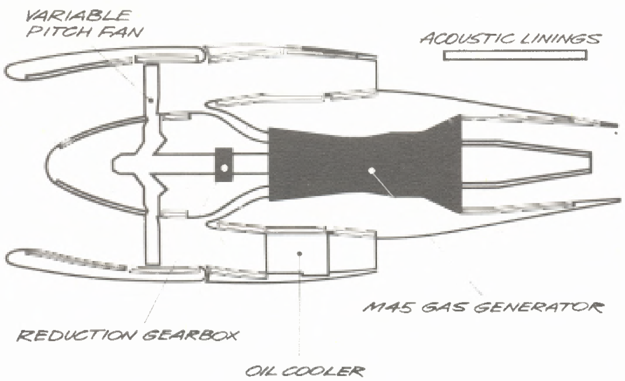

Fig.1 M45S (RB.410) basic engine layout

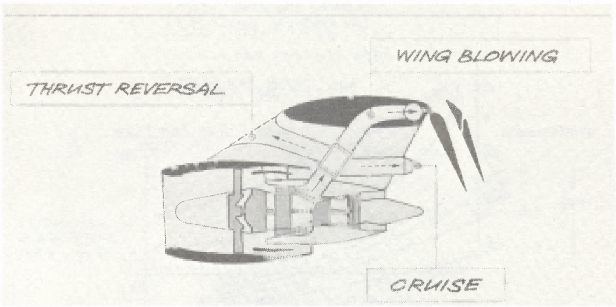

Fig.2 Blow fan air distribution modes

bleed air pressure ratio should be in the range 2:1 to 3:1.

ARGUMENTS FOR AND AGAINST THE USE OF VARIABLE PITCH

Recent papers (4-6) have discussed the use of variable fan geometry.

In its simplest form, the variable pitch fan engine is illustrated in Fig. 1. For noise and stress reasons, the variable pitch fan unit is driven at a low tip speed via a step-down gearbox between it and the gas generator. The gas generator may be of the single shaft type as on the Turbomeca Astafan or be a compound compressor as proposed for the M45S (RB.410) derivative of the M45H engine. Because the variable pitch fan has a fundamentally limited pressure ratio capability, it produces a high bypass ratio which, combined with a low tip speed, leads to a very low-speed, high torque fan shaft. In this situation, the gearbox is essential if very large, low-speed, low-pressure compressor and turbine systems are to be avoided.

The arguments in favor of variable geometry can be summarized as follows:

1 Appraoch thrust modulation — using fine pitch and high rpm values
2 Reverse thrust available down to zero forward speed
3 Optimization of specific fuel consumption
4 Maximization of thrust
5 Improved acceleration control
6 Removes necessity for a variable fan exhaust nozzle
7 Provision of near-constant air bleeds at varying thrusts
8 Optimization of noise characteristics
9 Built-in development potential.

Against these can be set a number of disadvantages which are immediately apparent, e.g.,

1 The low solidity of the fan system which limits the design pressure ratio
2 The mechanical limitations on tip speed set by the variable pitch mechanism which again limit pressure ratio relative to a fixed pitch fan
3 The requirement for a gearbox which almost inevitably arises from the limitations on tip speed
4 The increased control system complexity
5 The more complex reverse thrust engine aerodynamics
6 The general increase in mechanical complexity.

POSSIBLE ENGINE CONFIGURATIONS EMPLOYING VARIABLE PITCH

The subject can be approached from two different viewpoints, that of the Propeller Designer who is offering a "Bolt-on-Augmentor" which is coupled to a shaft power generator or from that of the Engine Designer who is integrating variable geometry into his ducted fan philosophy. The first approach, if genuinely carried through, must result in relatively low-loaded fans which have pressure ratios that do not invalidate, completely, the entry flow conditions for which the gas generator has been cleared. This probably implies fan pressure ratios in the region of 1.1 to 1.2 and is typified by the prop-fan proposals set out by Rosen in reference (3). This paper is concerned with the second approach where the fan is an integral part of the engine and the designer is attempting to maintain the high flight speed characteristics of current short-haul aircraft by minimizing any increase in frontal area for a given cruise thrust.

The variable pitch fan has one particular

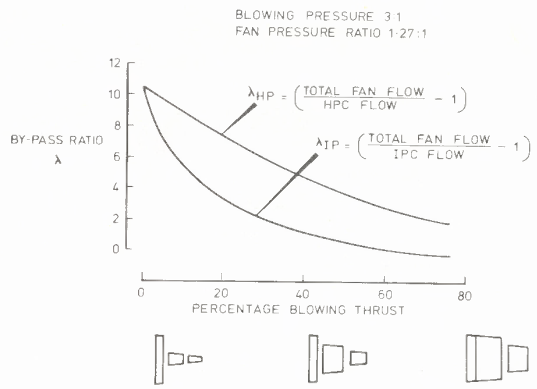

Fig.3 Blow fan — bypass ratios

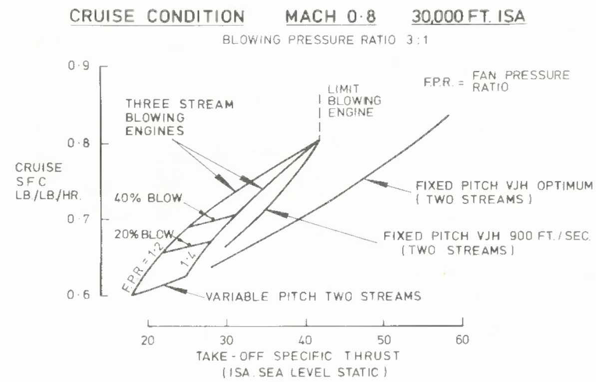

Fig.5 Blow fan cruise performance — SFC

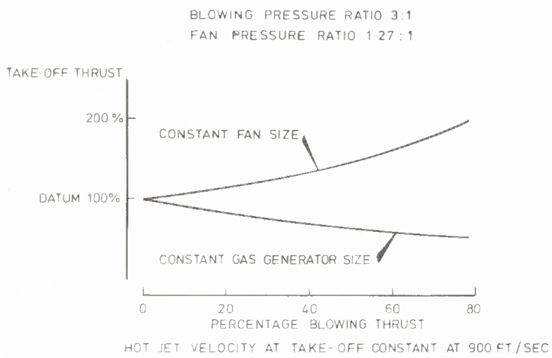

Fig.4 Blow fan — thrust sizing

capability which may in the end turn out to be its raison d'etre. It can maintain high engine speeds and high compressor air bleeds at very low thrust levels, i.e., the approach to land condition. An engine of this "Blow Fan" type is illustrated in Fig. 2. Differing aircraft concepts have requirements for bleed air thrust at takeoff and landing which vary from zero to 80 percent of the installed takeoff thrust. If the gas generator exhaust velocity is specified for noise reasons, then there is a defined energy output of the gas generator which must first be used to produce the required bleed air and then the remainder must be absorbed in a suitable fan system, in this case the variable pitch fan. As the bleed thrust increases, the amount of power remaining for the fan reduces, and, hence, the fan becomes smaller. When the bleed thrust reaches 80 percent of the total thrust, the fan has reduced to the unrealistic point where it becomes the first stage of the bleed air compressor. This is illustrated in Fig. 3 which shows the variation in flow division between bypass duct, bleed air, and gas generator. Looked at from another viewpoint, such blow fans will have varying requirements for core engine size and fan size to produce a given thrust as shown in Fig. 4. Blow fans can be criticized on the grounds that they are special purpose engines. However, if the advantages are great enough and the market big enough, such a criticism is difficult to sustain.

PERFORMANCE OF "BLOW FAN" ENGINES

The use of an engine which must deliver part or all of its bypass airflow at about 3:1 pressure ratio must inevitably produce some performance penalty compared with a fully optimized engine cycle. Probably the simplest method of comparing thermodynamic cycle performance is on a basis of takeoff specific thrust which is a measure of the power plant frontal area and implies similar installation features. Fig. 5 gives SFC at a typical cruise condition for engines having blowing thrusts varying from 0 to 80 percent of total thrust and compares these values with the optimum performance for simple, two-stream ducted fans. Also shown on the graph are the values for two stream engines whose hot jet velocity has been restricted to 900 fps at takeoff for noise reasons. This latter curve links up with blow fans at the extreme point where the variable pitch fan has shrunk to the blowing compressor size and beyond this point would give engines of fan pressure ratio above 3:1.

On a basis of common hot exhaust noise characteristics, it would be unfair to compare the blow fan with the thermodynamic optima but rather with the restricted hot-jet velocity engines. At a given specific thrust, the 40 percent blowing thrust engine is about 6 percent worse on this

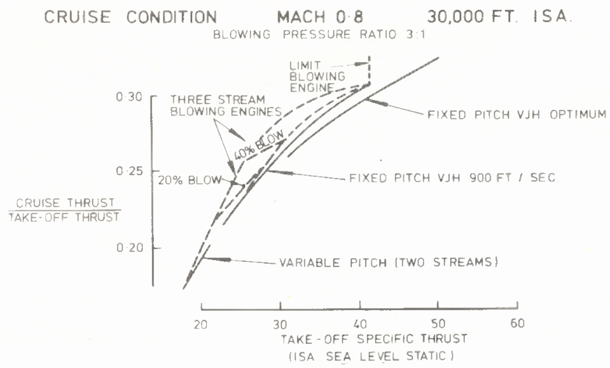

Fig.6 Blow fan cruise performance — cruise thrust/T.O. thrust

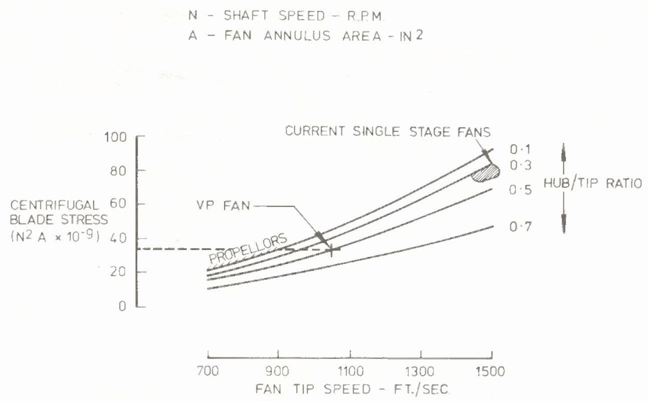

Fig.7 Propellers and variable pitch fans — hub stress comparison

basis, while the 80 percent engine is, of course, equal, as is the zero blow engine. Only the zero blow engine is equal to the thermodynamic optimum, while the 80 percent blow fan is about 13 percent worse.

Fig. 6 shows the associated ratios of cruise to takeoff thrust for these engines, indicating that the blow fans improve in cruise thrust relative to the optimum engines as some compensation for their worse fuel consumption.

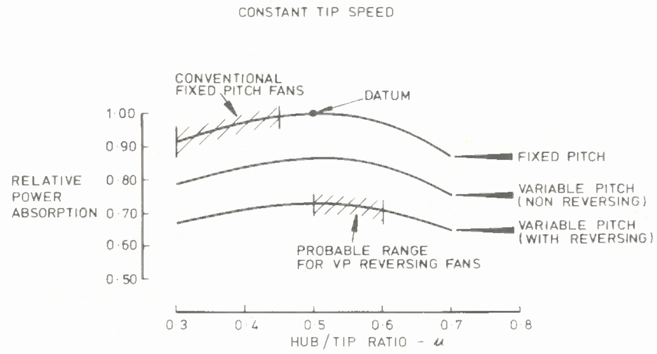

Fig.8 Comparison of fan performance, fixed pitch and variable pitch — power absorbtion

FAN AERODYNAMIC DESIGN

The obvious basis for an initial design of variable pitch fan is to bring together the expertise of the propeller and engine designers. Fig. 7 indicates that if blade root stress levels are to be maintained at propeller values, then a tip speed of around 1000 fps is required at a hub:tip ratio of 0.5. This figure illustrates the beneficient effect of using a high hub:tip ratio and the reduction in stress levels relative to current single-stage fan engines. A further reason for using hub:tip ratios is to provide the space for the variable pitch mechanism. In the past, much of the impetus to lower hub:tip ratios has arisen from requirements to achieve maximum mass flow per unit of frontal area, an important requirement for supersonic aircraft and many military aircraft. On a low noise engine which has a given hot jet velocity, the basic requirement of the fan is to:

1. Absorb a given horsepower
2. Produce a fan pressure ratio compatible with overall performance requirements.

Fig. 8 illustrates relative power absorption obtained with three different philosophies of fan design, all at a given tip speed of 1050 fps.

These are:

1. Conventional tapered annulus, fixed pitch design
2. Variable pitch design which does not allow selection of reverse thrust through fine pitch (i.e., root pitch:chord ratio < 1)
3. Variable pitch design which allows selection of reverse thrust through fine pitch (i.e., root pitch:chord ≥ 1.0).

Designs 2 and 3 require a parallel outer casing for geometrical reasons, while design 3 has the additional constraint on root pitch:chord ratio which tends to dictate the blade root:tip taper ratio. Design 1 is free from these constraints.

It is evident from Fig. 8 that the minimum fan diameter to absorb a given power occurs at a hub:tip ratio of 0.5. This implies a mean fan pressure ratio (Fig. 9) of 1.27 for the reversing

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | **sales@docketalarm.com** | **1-866-77-FASTCASE**

fastcase® Smarter legal research.