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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.

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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.

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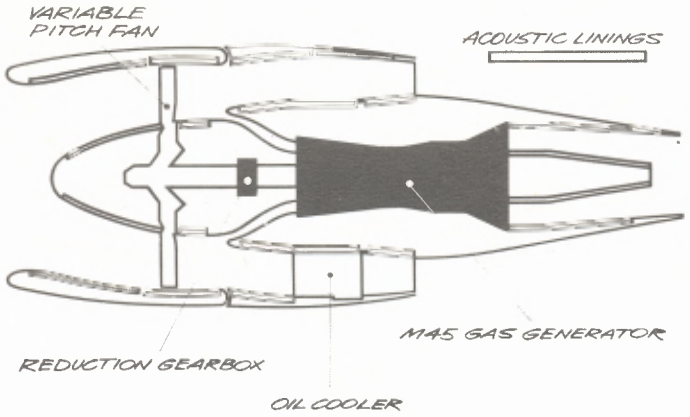


Fig.1 M45S (RB.410) basic engine layout

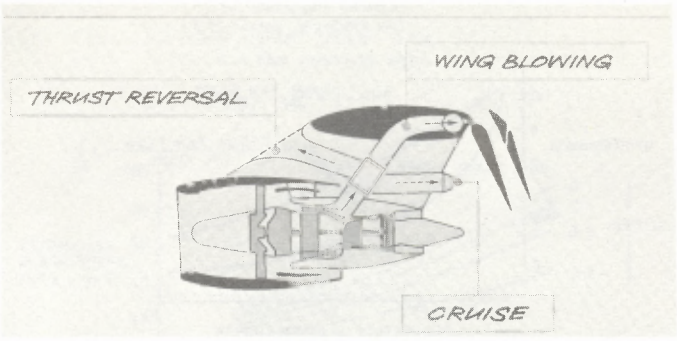


Fig.2 Blow fan air distribution modes

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

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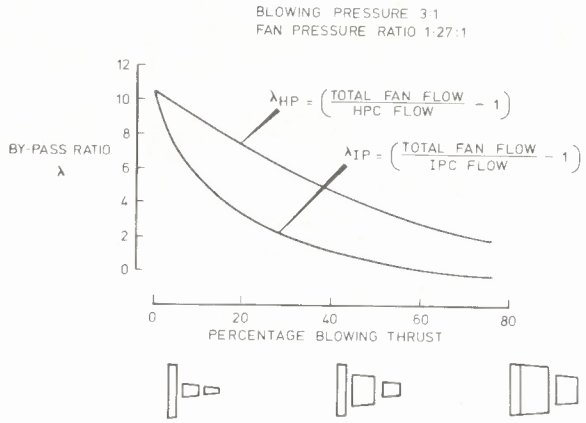


Fig.3 Blow fan — bypass ratios

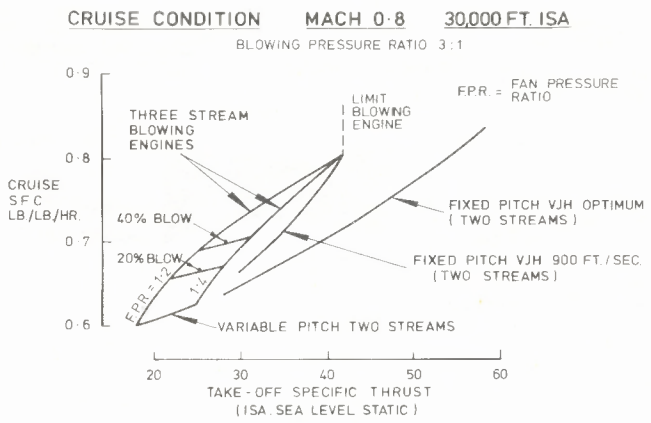


Fig.5 Blow fan cruise performance — SFC

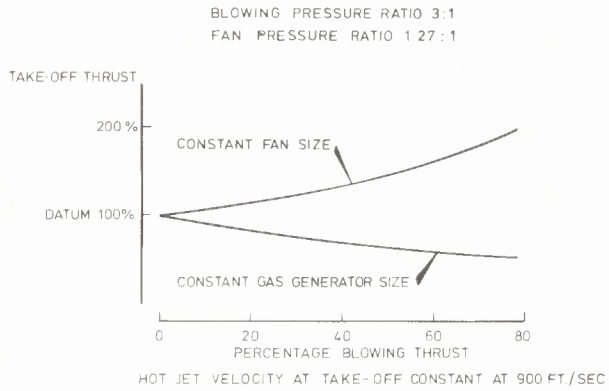


Fig.4 Blow fan — thrust sizing

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

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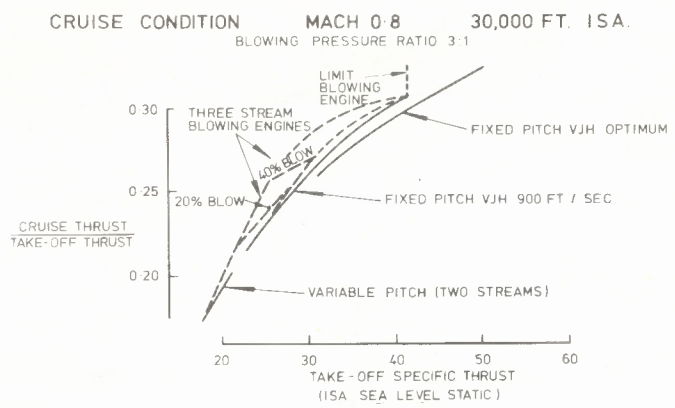


Fig.6 Blow fan cruise performance — cruise thrust/T.O. thrust

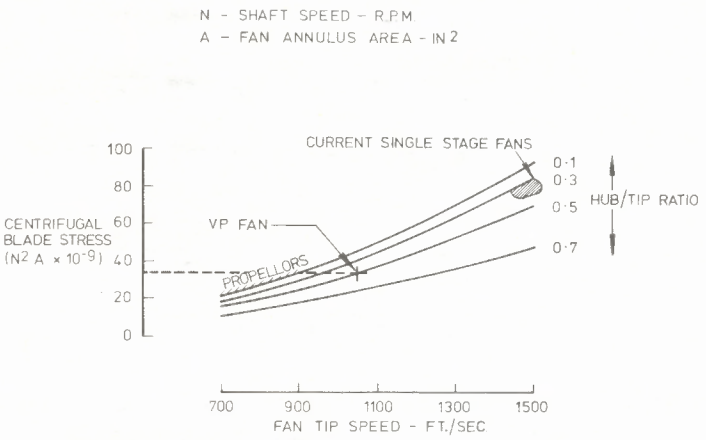


Fig.7 Propellers and variable pitch fans — hub stress comparison

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.

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.

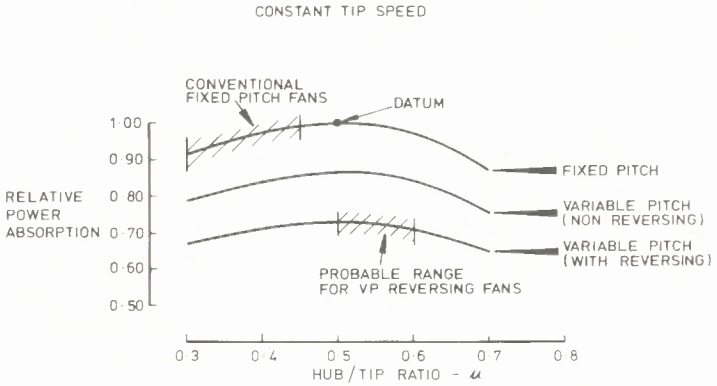


Fig.8 Comparison of fan performance, fixed pitch and variable pitch — power absorbtion

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

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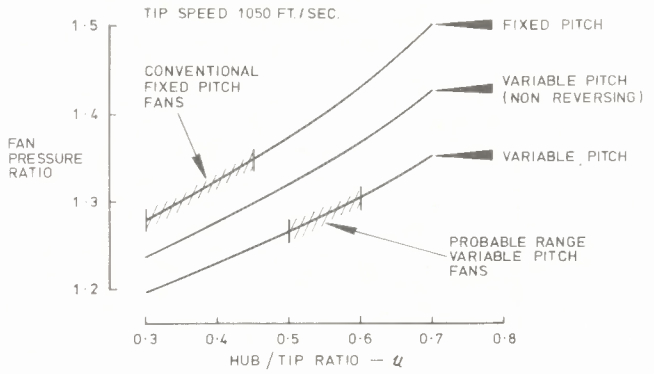


Fig.9 Comparison of fan performance, fixed pitch and variable pitch — fan pressure ratio

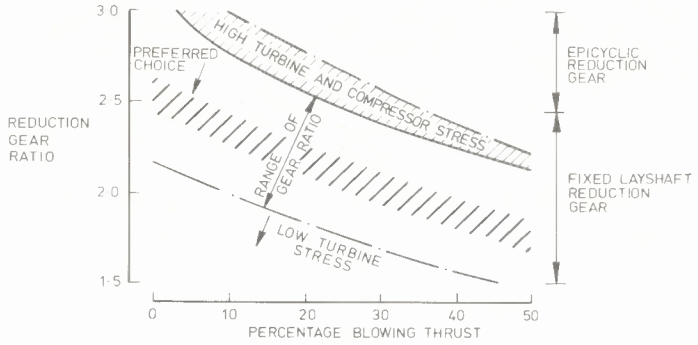


Fig.10 Reduction gear ratio versus percentage blowing thrust

fan compared with 1.32 for the non-reversing fan and 1.37 for the fixed pitch fan. At a given power absorption fan casing diameters are 17 percent greater for the reversing fan and 7 percent greater for the non-reversing fan at a hub:tip ratio of 0.5, although these differences would be reduced if the fixed pitch fan had a lower hub:tip ratio. The choice of hub:tip ratio of 0.5 or more becomes inevitable on the variable pitch fan when blade taper ratio and tip pitch:chord considerations are allowed for. This implies a more difficult entry duct design for the gas generator similar to that which arises on a propeller turbine.

It has been assumed that reverse thrust is achieved by turning the blade through fine pitch. This results in the camber and twist on the blade being in the wrong sense and implies that the outer portions of the blade must produce most of the reverse thrust. This also requires that the blade tip should have minimum camber to reduce negative camber in reverse. Reversing through feather pitch would avoid these particular difficulties but requires the blade to pass through the stall and flutter regions and is undesirable from the thrust modulation viewpoint.

MECHANICAL DESIGN — BASIC CONSIDERATIONS

The variable pitch fan engine both simplifies and complicates the work of the designer. On the one hand, it re-introduces the gearbox, cooler, and variable pitch mechanism, and on the other hand, it allows freedom to design the fan and power turbine system separately without imposing the constraints of one upon the other.

The Fan Unit

This can be designed as a module consisting of the fan and its pitch change mechanism. The favored method of driving the mechanism is by oil pressure in a vane motor system. A high hub:tip ratio is preferred to reduce blade taper ratio to lower stress and produce the best hub and blade root form compromise.

The modern propeller is designed on an integrity basis, rather than for containment as on the fan engine. This is, of course, forced on the propeller designer by the nature of the propeller, but it does raise the question whether this design philosophy can be applied to the variable pitch fan. The fundamental differences, which might justify such an approach, are the lower stress levels in the blade and the better round shank root form of the variable pitch blade. Additionally, the variable blades tend to be of larger chord due to higher bypass ratio and smaller blade numbers and, hence, should be less liable to foreign object damage. The elimination of blade containment would make a significant reduction in engine weight of the order of 5 percent.

A further consideration where variable pitch has a possible advantage over conventional fans is in the optimum employment of composite materials for blading. Again, the stress levels, root form, and large chord blades are the justification. The large reduction in blade weight, up to 60 percent, and the nature of the probable blade failure would reduce the blade containment problem to relative unimportance.

Reduction Gear

The difference between the variable pitch fan and the propeller is well illustrated by the differing gearbox requirements. The propeller normally requires a step down ratio of between 10:1 and 14:1 to achieve its tip speeds of about 850 fps, whereas the variable pitch fan is likely to require a step down ratio of between 2.5 and 3.0 for the zero-blow design.

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As the percentage bleed thrust is increased, the size of I.P. compressor increases, and some reduction in its shaft speed may be necessary if compressor stress level is critical. At the same time, the fan size reduces, and to maintain its tip speed, it is necessary to increase its shaft speed in inverse ratio to fan diameter. Both these effects tend to reduce the required gear ratio. Fig. 10 illustrates this effect and shows the constraints imposed by various stress limitations. This shows that the preferred ratio drops from about 2.5 at zero bleed down to 1.8 at about 40 percent blowing thrust.

There are a number of different types of gear design which have been considered for these types of engine. For the zero-blow engine, the epicyclic is still a contender, but is close to the limits of practicability from the planet gear centrifugal stress viewpoint. Below a ratio of 2.5:1, the rotating annulus or a "Star" gear becomes an attractive solution. An alternative to the Star gear is the bevel gear of the piston engine era. For a consistent gear box policy covering all blow-fan engines, the latter types are clearly to be preferred.

As power is increased, then the gear becomes more difficult to design on a weight and heat dissipation basis. While gears in the range 10,000 to 25,000 hp would seem to be feasible, some upper limits on size may emerge on closer study.

The Gas Generator

The design of the gas generator presents few new problems and is, in general, simplified. The requirement for the low-speed fan shaft has been eliminated by the gearbox, and this avoids the major problem of passing such a shaft through the middle of the gas generator which is itself shrinking in relative size as flame temperatures rise progressively.

The Turbine System

The freedom to select the turbine shaft speeds to optimize the gas generator and bleed compressor system in isolation leads to the minimum number of turbine stages, i.e., 4 or 5, as on a propeller turbine. References (4) and (6) indicated that at a bypass ratio of 10, the ungeared engine would require around 12 stages of turbine. This should lead to significant reduction in cost and weight.

APPROACH THRUST DESIGN CONSIDERATIONS

It appears probable that STOL aircraft will progressively develop by maximizing aerodynamic lift at specified approach speeds which will be

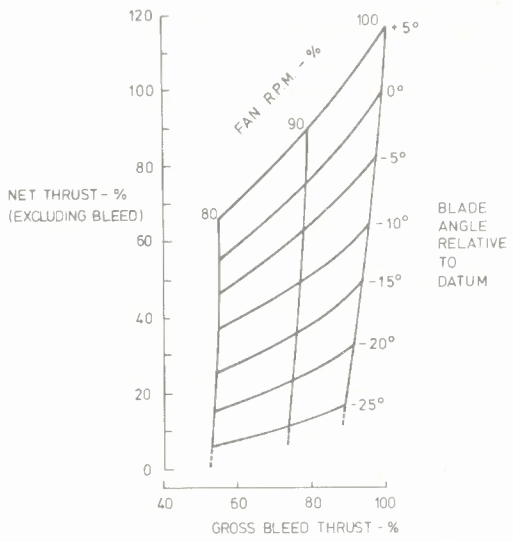


Fig.11 Blow fan performance approach to land

set by runway retardation limits and cross-wind landing requirements. The likelihood of air bleed being required, at least on approach, should, therefore, increase with time. Residual propulsive thrust requirements are of the order of 0 ~ 10 percent of the total engine thrust, and these have to be provided and modulated while the bleed air supply is at its maximum requirement.

The process of moving the fan blades into fine pitch very rapidly reduces fan thrust and also decreases core engine exhaust thrust. The bleed air thrust is unaltered, except for the loss of supercharging due to the reduced fan pitch, and this can be offset to some degree by designing the bleed system to absorb the excess flow not required by the gas generator in the fine pitch condition. Fig. 11 indicates a typical variation of engine thrust, less bleed thrust, with change in fan pitch angle. An important implication is that the fan still has a significant positive tip setting at approach thrust setting.

PERFORMANCE OPTIMIZATION

The presence of variable geometry, in the form of variable fan pitch, can be used to optimize engine performance. There are two particular regimes where this advantage might be taken. These are:

1 To maximize cruise thrust
2 To optimize part-load fuel consumption.

The variable pitch mechanism would be used to select the appropriate fan and intermediate pressure speeds, while the fuel throttle controls

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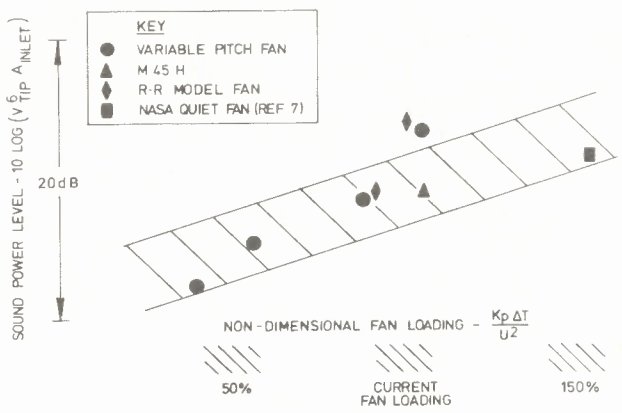


Fig.12 Variation of single-stage fan intake noise levels with loading

the gas generator high-pressure spool speed.

The results to be obtained will depend very much on the engine component characteristics and the resultant matching achieved in the various parts of the speed range. On a particular design using semi-empirical component data, it has been shown that maximum cruise is always obtained when the fan speed is set to the maximum design limit and the turbine entry temperature is treated in like manner. It should be remembered that on a fixed pitch fan engine, the components are generally matched to achieve a given maximum thrust and the part-load performance is the result of the consequent arbitrary combination of part-load characteristics which, in any case, presents a difficult performance prediction problem at low engine speeds. Hence, no general proposition can be stated regarding the magnitude of any part-load performance improvement.

Again, the Development Engineer has, in effect, an infinite set of fans at his disposal as he works to achieve his performance and reliability goals. The choice of the final geometry can be made during the test bed running phase on the basis of a measured optimum combination of fan blade angle and compressor speeds. In addition, it is likely that the fan pressure ratio and flow can be developed to higher power absorption during the later thrust improvement phase, possibly even without change in blade geometry.

NOISE

Current single-stage fan engines have jet noise levels which are close to those generated by the fan; hence, the employment of large amounts of sound absorbant duct lining will produce limited returns since they would leave the jet noise obtruding. The higher bypass ratio, lower jet velocity STOL engine enables linings to be used to maximum advantage and holds out the prospect of achieving the STOL noise target levels of 95 PNdB or EPNdB at 500 ft from the aircraft.

At its design blade setting, the variable pitch fan should have noise characteristics which follow similar laws to those of fixed pitch fans, since conventional design rules have been applied and the blades have similar aerodynamic loading. The overall noise levels for the engine should be reduced because of the lower blade speeds and lower jet velocities, but these are not necessarily peculiar to the variable pitch fan.

Fan blading noise could be expected to be dependent on the parameters — local dynamic head, local velocity, and blade lift coefficients. As blade incidence is reduced, then the steady-state pressure loads reduce and the fluctuating local pressures also should follow suit. Hence, it might be expected that noise created by unsteady flow over the blading at constant tip speed will also reduce. At the same time, the flow through the fan disk will be lower and the incident velocity onto the stator row will reduce substantially. Hence, overall noise may be expected to reduce for a number of reasons. In reference (4), it was shown that forward arc noise of a variable pitch fan does, in fact, drop rapidly at a rate of about 1 PNdB per 2 deg of pitch change. The total pitch change from the design value on approach to land may be of the order of 30 deg. This is further illustrated by Fig. 12 which plots fan forward arc total sound power, corrected for the effects of tip speed and compressor size, as a function of fan nondimensional power loading. This shows that variable pitch noise data exhibits significant downward trend with blade loading which is consistent with the results from fixed pitch fan designs. Hence, the philosophy for minimizing approach noise for a blow-fan engine would be to tune absorbent linings to the frequencies associated with the higher engine speeds and reduced pitch settings.

CONTROL SYSTEM CONSIDERATIONS

The fan variable geometry creates a new degree of freedom similar to that obtained with a variable area exhaust nozzle. To use that freedom to the best advantage requires a further element of complexity in the engine control. The two basic elements of the system are blade angle and fuel flow. These control fan speed together with associated compressor rpm and turbine entry temperature together with independent high pressure compressor rpm, respectively. The essence of

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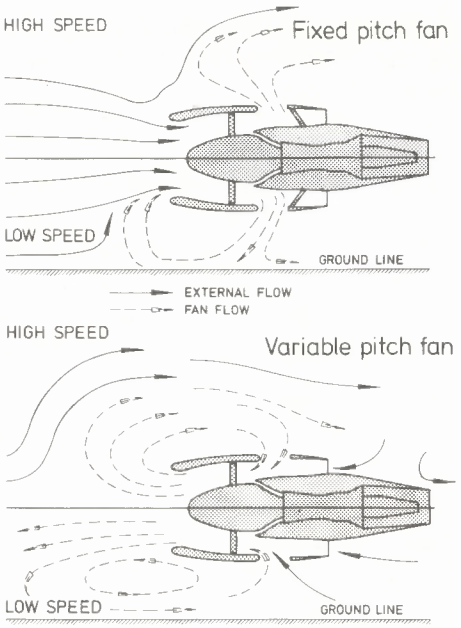


Fig.13 Reverse thrust flow patterns

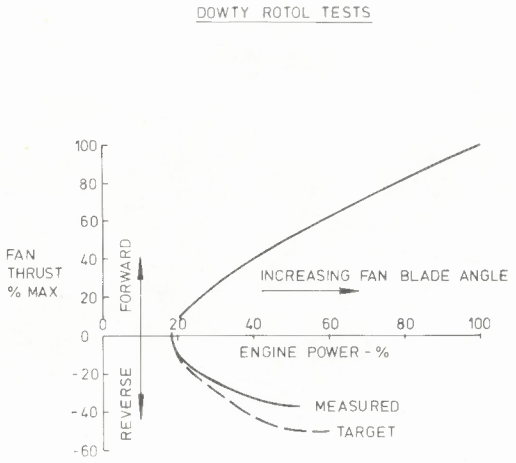


Fig.14 Variable pitch reversing fan typical power — thrust relationship

any such control system for a compound compressor engine reduces to an attempt to schedule low-pressure shaft speed as a function of high-pressure shaft speed or vice versa.

The different modes of steady-state operation, optimum performance, minimum noise, and approach with bleed may require several different schedules of compressor speed. The Olympus 593 in the Concorde already has such a system for use with its variable nozzle employing an analog electrical control. Alternatively, this is perhaps where the new digital control systems might be employed to maximum advantage both for steady-state and transient operation. The Rolls-Royce Tyne Propeller turbine engine has, for many years, operated with a hydromechanical system with broadly similar control requirements.

REVERSE THRUST

The constant speeding propeller was developed to produce reverse thrust during the landing ground roll by allowing the blades to pass through zero pitch into negative pitch or, less ambitiously, to produce drag by "disking" in fine pitch. The airflow in these conditions is certainly not well ordered, and circulatory flows occur at the tips under forward speed conditions. Both blade camber and twist are in the wrong sense for maximum performance. A typical propeller result would be a maximum reverse thrust of 30 percent.

The use of a ducted variable pitch fan to produce reverse thrust by passing through zero pitch in the manner of the propeller leads to a somewhat similar situation. The airflow is entrained into what is normally the fan nozzle, with the assistance of supplementary intakes to reduce intake loss, and is ejected forward out of the normal intake duct. The flow through the fan is again not well ordered and, hence, is difficult to predict. The blade camber and twist are in the wrong sense, and this leads to a situation where the blade root is at or near zero pitch presenting a barrier to the flow, while the outer portion of the blade is at a progressively increasing negative angle of attack; hence, the flow is separated and the process of the impulse type. Outside the nacelle, the momentum flux in the forward direction has a relatively simple external flow field in the static case which becomes progressively more complex as forward speed is applied. The reverse jet flow mixes and is then turned back on itself by the forward motion as shown diagrammatically in Fig. 13. Some of this mixed flow may then be re-entrained by the rear intakes. At some forward speed, the reverse flow may well behave more like a mathematical source than a detached jet and attach itself to the cowl.

The fact that the reverse jet is directed straightforward without directly impinging on the ground or the aircraft structure should ensure that hot gas and foreign object ingestion are minimized. The presence of the cowl should make the variable pitch fan less susceptible than the propeller to damage due to blade tip recircularly flows. Summarizing, it may be said that the conventional fixed pitch fan and reverser has a well-ordered internal flow but a bad external flow

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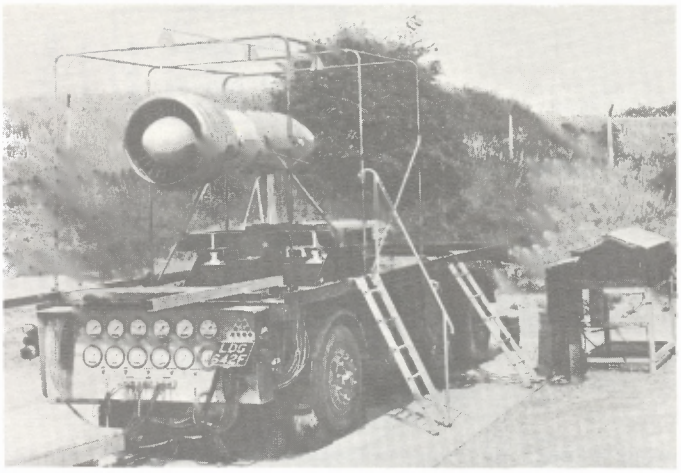


Fig.15 Astazou variable pitch fan

field which makes its use at lower speeds progressively more difficult. On the other hand, the variable pitch fan has a complex internal flow system and a good external flow field which is modified by forward speed to make its use at higher speeds progressively more difficult.

Clearly, the maximum power absorption of the fan in reverse will be lower than in forward pitch because of the adverse twist and camber. At the same time, the gas generator loses the supercharging effect of the fan, and these two effects will tend to offset one another. A typical reverse thrust performance is illustrated in Fig. 14.

The need for a reversing capability is fairly clear for the zero-blow engine, but, as the amount of blowing thrust is increased, progressively more attention has to be given to the control of the blowing component and less to the gas generator and fan residual thrust. In the limit of the 80 percent blow engine, clearly the reverse capability has to be applied to the blowing thrust with perhaps a spoiler on the hot jet. Hence, at some intermediate blowing thrust ratio, the requirement for significant reverse thrust on the variable pitch fan disappears, and the design does not require the constraint that the blades must pass each other at the root. This allows more freedom in choice of design fan pressure ratio as shown in Fig. 9 and favors the high-speed aircraft by decreasing nacelle frontal area and increasing cruise thrust relative to takeoff thrust.

DEMONSTRATION OF FEASIBILITY

Work aimed at demonstrating the concept feasibility has been proceeding for a number of years, particularly the U.K. and France. This can be categorized under the headings:

1 Establishment of theoretical performance roles where such engines would show to advantage
2 Mechanical design evaluation
3 Rig or engine demonstration of critical features of the overall systems.

Project evaluation and mechanical design work begun several years ago at the Bristol Engine Division of Rolls-Royce is being actively pursued in collaboration with SNECMA in France. Pioneering work by the Dowty Rotol Propeller Manufacturers on reversing fans has been proceeding for a number of years in the U.K. using an Astazou engine, Fig. 15, and a Gnome compressor rig. This latter work has, in part, been sponsored by the British Government and has had the technical assistance of Rolls-Royce on fan aerodynamics and the measurement and analysis of noise. In France, the Turbomeca Company has successfully produced and flown the Astafan, a non-reversing fan based on its Astazou single-shaft engine.

The application to larger higher performance engines with compound compressor systems and more advanced high-pressure-ratio fan design calls for a new phase of demonstration using larger gas generators of the type considered for ultimate commercial application. It is hoped that such a European program will be funded, in the first instance, in the form of a ground demonstrator engine. It is, however, clear that many of the new features of such engines will finally require evaluation in flight, and it is to be hoped that such a program will be undertaken as a result of the many STOL aircraft studies now in progress in both the U.S.A. and Europe. The acceptance by the highly industrialized countries of a new form of air transport involving many new systems would best be done on a common agreed basis, and the achievement of such agreement is facilitated by such International collaboration in choice and development of the system components. It is to be hoped that this will occur and that the total cost may thus be substantially reduced.

CONCLUSIONS

1 The high-performance STOL aircraft has a number of engine requirements which make the use of variable fan geometry attractive.

2 Where there is a requirement for bleed air thrust for a high lift system, the variable pitch fan has the particular attractions of decoupling the propulsive and blowing thrust components, thus simplifying the aircraft control particularly on approach to land.

3 The variable geometry may have other at-

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tractions in allowing the optimizing of both performance and noise, particularly at part-load conditions.

4 Thrust reversal, if achieved with reverse pitch, produces more difficult engine internal flow problems but a more favorable installation situation relative to the conventional fan engine. Reversing pitch fans are not a necessary requirement on the blow fan engine.

5 Constraints on fan blade geometry and tip speed imposed by variable pitch restrict the level of fan pressure ratio and result in high bypass ratio, non-blowing engines. The blow-fan suffers much less from this restraint and makes it more suitable for high-speed, swept wing aircraft requiring augmented lift.

6 While a substantial amount of the feasibility of the variable pitch fan system has been demonstrated by small-scale engine running, further work remains to be done on larger scale demonstrator engines before a valid assessment of the potential of the variable pitch ducted fan can be made.

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