Vectored Thrust Engines for Single and Multiengined Aircraft

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Many important advances have been made in recent years in the development of engines for V/STOL aircraft. In this paper, the application of V/STOL power plants currently being developed by Bristol Siddeley Engines is discussed, including the Pegasus vectored thrust engine that has been undergoing bench and flight development in the Hawker P.1127 strike/reconnaissance aircraft for four years and advanced developments designed to power V/STOL strike aircraft. The Pegasus engine is also suited to power V/STOL transport aircraft and the final section of the paper is devoted to this topic. First, the STOL transport aircraft is considered, where the combination of the deflected thrust capability of the Pegasus-type engine with wing/flap boundary-layer control gives extremely short airfield performance. The VTOL transport is then discussed including the development of lightweight lift engines for this application, and finally future vectored thrust engines are considered.

Introduction

THERE can be little doubt that V/STOL is the greatest advance in aeronautical engineering since the Wright Brothers first launched their airplane. Those of us who have been fortunate enough to land and take off high-speed modern aircraft, large or small, military or civil, in marginal conditions of visibility on wet and slippery runways will be the first to appreciate its benefits. In time, this appreciation of its advantages will spread until military commanders and civil passengers demand its use on all types of aircraft to increase their utilization, flexibility, and safety.

The purpose of this paper is to describe, somewhat broadly, the application of the Bristol Siddeley vectored thrust engines in aircraft varying from the single-engined tactical fighter to the four engined military transport. For this reason, the paper is divided into four sections: 1) Bristol Siddeley Pegasus development, 2) the Hawker P.1127 aircraft, 3) supersonic vectored thrust engines, and 4) V/STOL transport aircraft.

Excellent original papers on the Pegasus engine and Hawker P.1127 have been given by Hooker,[1] Young,[2] and Denning[3] of Bristol Siddeley, and Bedford[4] and Merewether[5] of Hawkers, but a quick resumé of leading particulars here will make a more complete picture.

1. Bristol Siddeley Pegasus development

A very useful background to the design of the Pegasus engine is given in Ref. 2 and only a brief description is necessary. The Pegasus engine is a two-spool, ducted fan, turbojet and the layout is shown in Fig. 1. Approximately 60% of the air from the front fan is ducted through the forward (cold) nozzles; the remainder passes through the high-pressure compressor and turbines to exit through the rear (hot) nozzles. A two-stage turbine drives the fan and a two-stage turbine drives the high-pressure compressor. Fan and high-pressure compressor contrarotate to eliminate gyroscopic couples.

The four nozzles are rotatable through at least 100°, which gives the pilot control of the direction of thrust he requires by actuation of the nozzle lever and the amount of thrust by actuation of a throttle lever. The nozzles are driven by a dual Plessey air motor through a simple robust mechanical system. Figure 2 shows the arrangement of the nozzle actuator system for the Hawker P.1127 in which the nozzle selector lever is the only additional control in the cockpit.

Air for reaction control systems is fed from the combustion chamber casing. The air bleed valve opens automatically as nozzles are rotated down from the horizontal, no additional control being required.

The main advantages of the turbofan vectored thrust systems are listed for ease of reference.

1) Single engine installation possible.
2) Fully controlled thrust angle.
3) Total thrust available for vertical, transition, and normal flight.
4) Greater thrust available for acceleration and climb.
5) Starts, checks, and taxying with nozzles horizontal. No ground erosion, recirculation, or debris ingestion.
6) Considerable overload possible for short takeoff.
7) Resultant thrust passes through point near aircraft c.g.
8) Simple control systems. Autostabilizers not essential.
9) Contrarotating low-pressure/high-pressure compressor eliminates gyroscopic couple.
10) Low exhaust velocity and temperature.

The Pegasus is installed and currently flying in the Hawker P.1127.

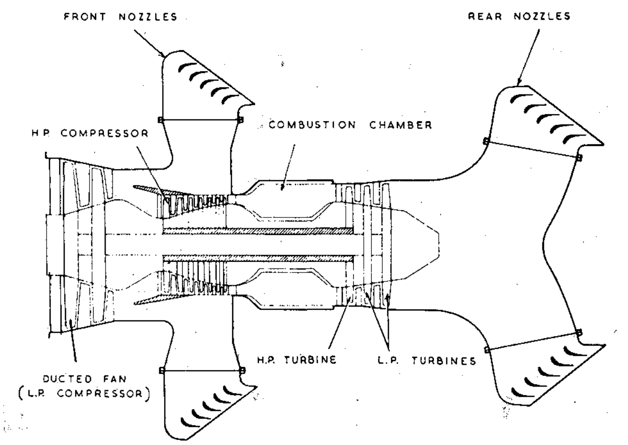

Fig. 1 General arrangement of Pegasus.

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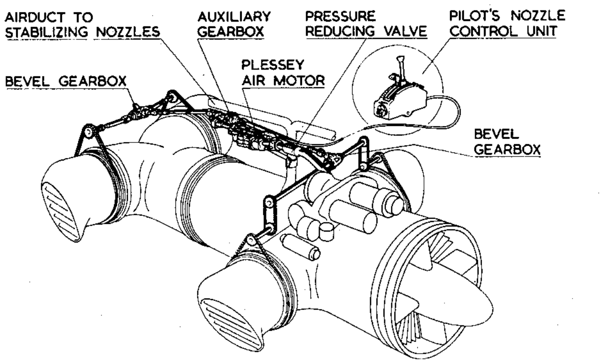


Fig. 2 Typical installation of jet nozzle actuator system.

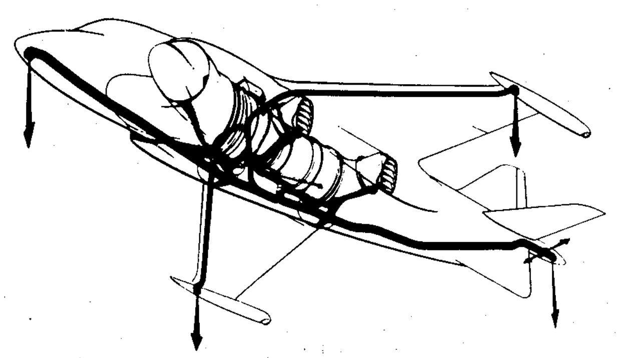


Fig. 4 Air bleed to reaction controls.

2. The Hawker P.1127

This aircraft was designed as a single-engined tactical strike fighter. Figure 3 illustrates the aircraft in hovering flight. It is transonic and, aided by a thrust/weight ratio in excess of unity, has a formidable rate of climb. Added to this, it takes off vertically without autostabilization and with only the simplest control system.

Reaction controls are situated at the nose, tail, and wing tips of the aircraft, and the disposition of the air ducts and control nozzles is shown in Fig. 4. Each reaction control valve is linked mechanically to its relevant control surface, i.e., rudder for yaw, aileron for roll, elevator for pitch as in Fig. 5. Air from the combustion chamber casing is fed automatically to the reaction control once the nozzles are selected down from the horizontal.

A. Vertical Takeoff and Landing

To takeoff vertically, the pilot has only to start and taxi to the takeoff position in the normal manner, with nozzles horizontal. The nozzles are then selected to the vertical position and the throttle opened fully. Once airborne, if hovering is desired, position over the ground is maintained by small natural movements of stick and rudder. When the nose is depressed by a small forward movement of the stick, the thrust line is inclined backward and the aircraft moves forward. Similar reaction follows other control movements. During this phase, the nozzles remain fixed in the vertical position and height is maintained by small movements of the throttle.

Transitions from the hover are simply achieved by moving the nozzles aft. The aircraft accelerates rapidly, the increasing aerodynamic lift compensating for decreasing jet lift. Speeds well in excess of stalling speeds are obtained with only 45° nozzle angle selected and the only evidence of a completed transition is the rapidly increasing air speed and the nozzle angle indicator at zero. Decelerating transitions are obviously carried out by moving the nozzles down and increasing jet lift as aerodynamic lift is reduced. Deceleration of $\frac{1}{2}\,g$ can be achieved by selecting nozzles forward 10° from the vertical and utilizing the combined effects of the braking thrust and intake drag. The nozzles are moved back to the hover position just before zero speed is reached, otherwise the aircraft hovers 10° nose down. This variable nozzle angle was used to advantage during recent carrier trials, when the aircraft hovering attitude was some 5° nose down because of wind speed over the deck. The nozzles were selected 5° aft and normal attitude was resumed.

Fig. 3. P.1127 hovering.

B. Short Takeoff and Landing

It is the author's opinion that STOL will be the normal operational role of the aircraft and VTOL only resorted to under extreme operational conditions. Vast overloads are possible by accepting field lengths of 300 yd. Takeoff technique is to accelerate the aircraft initially with the nozzles fully aft and to rotate the nozzles to an intermediate position at a precalculated speed for a given overload condition. The time to nozzle rotating speed, say 50 knots approximately, is extremely short, but the Hawker nozzle control has a preselector device that enables the correct angle to be applied rapidly without the pilot having to look into the cockpit, as seen in Fig. 6.

Undoubtedly the Hawker P.1127 is the simplest V/STOL aircraft possible. Easier and safer to fly than a comparable jet fighter, with no electronics or autostabilization in its control system, an operational squadron in the most remote areas could be maintained at readiness with the minimum of preparation and logistical support.

3. Supersonic Vectored Thrust Engine

It is not proposed here to discuss the optimization of the powerplant configuration for the V/STOL strike aircraft. In Ref. 3, a detailed study has been made of various engine/airframe configurations for the supersonic V/STOL aircraft. In this paper by Denning, the choice of thermodynamic cycle was examined in some detail and the conclusions of this study were that the following thermodynamic characteristics should be chosen: 1) the engine should be a turbofan with a bypass ratio of unity, 2) the over-all pressure ratio should be at least 14:1, 3) turbine entry temperature of 1400°K, and 4) plenum chamber burning temperature 1200°K.

The main cycle characteristics for supersonic application different from the Pegasus engine are the higher cycle pressure ratio and the addition of plenum chamber burning. The major development effort during the last two years has been on the evolution of the plenum chamber burning system,

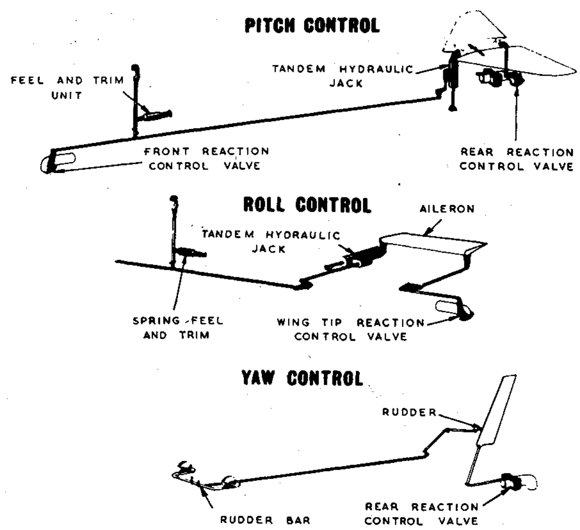


Fig. 5. Flying control system.

which has now been successfully demonstrated on a Pegasus engine, and by full-scale rig testing. A brief reference is made to the evolution of the BS.100 engine, Fig. 7, for supersonic V/STOL strike aircraft.

During the course of the development of the Pegasus engine and the Hawker P.1127 aircraft, requirements had emerged in the United Kingdom, in Europe, and in the United States for V/STOL tactical strike aircraft having a supersonic speed capacity. It was apparent from initial project studies that the range of aircraft which satisfied these requirements was substantially larger than the Hawker P.1127 and for the United Kingdom and European requirements, which were very similar, the resulting aircraft was approximately twice the gross weight of the P.1127, and hence the engine required was roughly twice the gross thrust of the Pegasus. The takeoff thrust requirements and thrust required at supersonic speeds at altitude showed the need for thrust boost to avoid grossly overengining the aircraft during other parts of the flight plan.

The background that had been obtained in the design and development of the Pegasus engine had confirmed the advantages originally claimed with regard to the simplicity and installational advantages of the four-nozzle configuration, and the confidence was such that it was always felt that the layout should be retained in advanced developments of the Pegasus. However, during the course of the project studies and investigations of the critical thrust requirements for VTOL takeoff and high Mach number at altitude, a number of schemes were studied. The addition of a conventional reheat system to the hot end of the engine was considered, where the Pegasus trouser-piece rear hot nozzles were replaced by a straight-through jet pipe that diverted the hot gas downward for takeoff through a single nozzle and allowed normal rearward exhaust in forward flight. A separate reheat system was added to the deflector nozzle to boost thrust for takeoff. This scheme was shown to be particularly unattractive because of the aggravation of the inherent c.g. problem in the aircraft. This type of layout without thrust boost is considered again later in this paper in connection with thrust deflection configurations for the V/STOL transport.

Further investigations of thrust boosting led to the study of Pegasus-type nozzle configurations employing burning in the cold nozzles and hot nozzles; the temperature in the cold nozzles was limited to 800°K. Detailed consideration of the design of an engine where, from initial development, burning in the hot and cold nozzles was employed, suggested that the complexity of three combustion or burning systems would give added development problems. It was shown that, by raising the temperature of the cold burning system to 1200°K

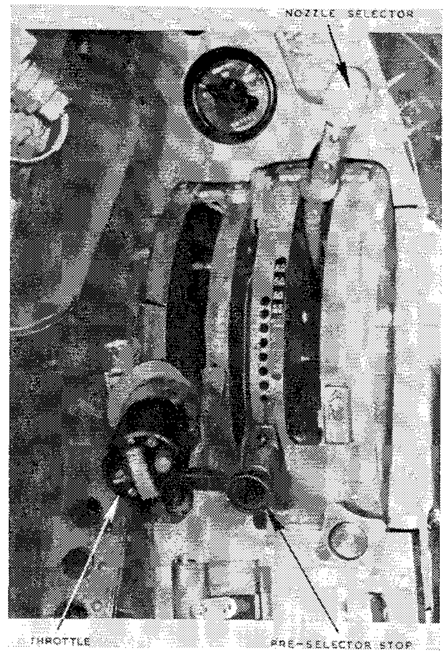


Fig. 6 Engine control box.

and using cold burning only, the same thrust level could be achieved as obtained with the combination of lower temperature cold burning together with the rear hot nozzle burning. Some of the early studies were carried out in close cooperation with the Republic Aviation Company. Subsequently, the BS.100 engine design has proceeded for the Hawker P.1154 aircraft.

4. V/STOL Transport Aircraft

The tubofan vectored thrust engine has an equally important application in V/STOL military transport aircraft in addition to its primary application to the single engined strike aircraft, Fig. 8. The ability to deflect the total installed propulsive thrust gives very short takeoff distance for STOL applications and, by use of the thrust deflection as reverse thrust, gives equally short landing distances. First, a brief statement is given of the STOL performance achieved using vectored thrust; then the particular aspects of this type of engine will be considered as applied to the STOL transport.

A. STOL Transport Aircraft

A1. Consideration of airfield performance

Current military tactical transport aircraft require fields of at least 1000 yd from which to operate and, with the increasing need for mobility in military operations, the new military transport aircraft are required to operate from very short fields, i.e., 500 yd, and from semiprepared surfaces. The

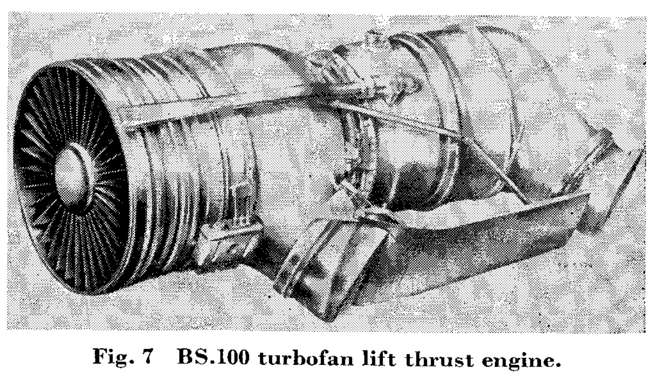


Fig. 7 BS.100 turbofan lift thrust engine.

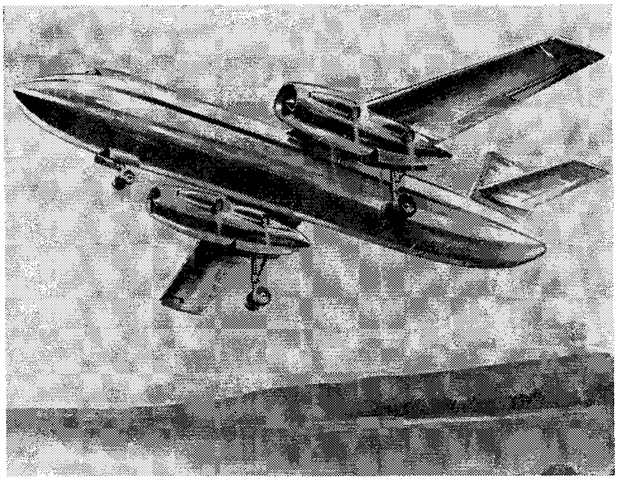


Fig. 8 Twin engine STOL transport aircraft.

takeoff distances are shown in Fig. 9 for a conventional transport aircraft (i.e. turbofan powered, medium range, cruising at 450 knots), and the reductions in takeoff distance are shown using thrust deflection and applying boundary-layer control to the wing flaps.

The first graph shows the takeoff distances calculated at a wing loading of 90 psf which represents takeoff at maximum all-up weight (AUW). The second graph is computed for a wing loading of 60 psf and is representative of a midmission condition.

It is shown that a transport aircraft having a wing loading of 90 psf and using normal flap configurations and deflections requires field lengths of around 3000 ft even when using very large installed thrust/weight ratios as high as 0.8. At the midpoint, with a wing loading $W/S = 60$, the takeoff distance is still about 2000 ft. The reductions in takeoff distance achieved using thrust deflection can be seen and are of the order of 22%, and the reductions gained by applying boundary-layer control are a further 33%. For a moderately swept wing aircraft designed to cruise at a Mach number of about 0.7, the wing maximum lift coefficient would be between 2 and 2.20, but this can be increased to a value between 3 and 3.5 using flap blowing.

It has been demonstrated that the application of thrust deflection and boundary-layer control to tactical transport aircraft gives an extremely short field length capability, without penalizing the aircraft by installing a large excess of thrust and adopting extremely large wing areas. The penalty of excess thrust and wing area would be very significant in giving poor cruise efficiency.

The mission requirements for military tactical transport aircraft call for very short field performance at the forward base after takeoff at maximum mission weight from a conventional base. It is seen that at the maximum AUW at the start of the mission, for a wing loading $W/S = 90$ and

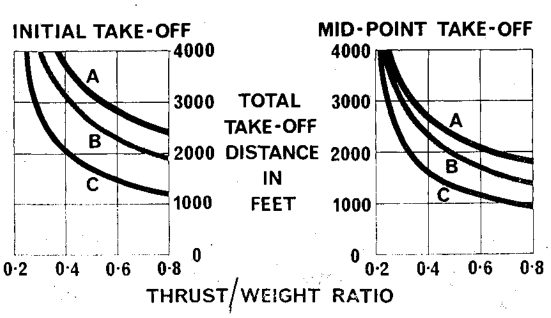


Fig. 9 Takeoff performance of tactical transport: *A*, conventional aircraft; *B*, with thrust deflection; *C*, with thrust deflection and flap blowing.

thrust/weight ratio $T/W = 0.40$ (these represent design values chosen as a compromise between the cruise and short takeoff requirements), the takeoff distance is just under 2100 ft but is only 1100 ft at the forward base, where the reduced weight conditions give $W/S = 60$ and $T/W = 0.60$.

A2. Comments on thrust deflection arrangements

Before considering the general aspects of the application of vectored thrust engines to transport aircraft, some remarks are made on ways of achieving thrust deflection. In the takeoff performance analysis, the simple assumption has been made that the installed thrust can be fully deflected without defining precisely how this is achieved. The configuration of the Pegasus engine leads to the simplest and most effective means of full thrust deflection. Other means can be devised for deflecting the engine thrust, and reference has already been made to this in discussing the problems of thrust deflection and thrust boosting for the supersonic V/STOL engine. However, in a recent *Flight* article,[6] one particular scheme has been proposed called the "switch-in deflector." In this scheme a pair of clamshell doors, normally forming part of the inner jet pipe wall, blank off the jet pipe during thrust deflection and divert the exhaust through two side mounted deflection nozzles. Also described is the "twin-elbow deflector" that is similar to the rear "trouser-piece" nozzle arrangement of the Pegasus engine.

A number of performance and installational aspects need to be considered in comparing different thrust deflection systems and these can be briefly listed: 1) engine performance losses due to the thrust deflection mechanism, 2) total installed drag of engine pod configuration, and 3) total installed weight of engine pod unit. Now we can consider the importance of these factors for these schemes.

Engine performance losses. Losses result in the Pegasus "four-nozzle arrangement" and with the "twin-elbow" deflector due to turning the gases and due to the cascades; these losses will be present during the whole flight regime and will be of importance during the cruise. With the "switch-in" deflector, losses due to the "egg-box" deflector and thrust splay will be experienced during takeoff; in the cruise there will be leaking of the exhaust gases through the nozzle system.

Pod drag. The Pegasus-type and twin-elbow arrangements will have profile drag and skin-friction contributions due to the nozzle configurations, and these items will be minimum with the "switch-in" deflector. The base drag components that may be associated with such nozzle arrangements can be lessened by covering the backward facing areas with small fairings appropriately shaped. It could be expected that the greater over-all pod drag would be associated with the "switch-in" deflector where, because of the rearward location of the nozzle arrangement and extended jet pipe, the cowl would tend to retain maximum diameter toward the rear and have a large wetted area.

Installed pod weight. In comparisons that have been made of Pegasus-type engines and "straight through" arrangements (i.e., the conventional bypass engine), the weight of the nozzles and associated mechanism was of the same order as the weight of the bypass duct. The extension of the jet pipe and "egg-box" deflector installation would add weight to the basic bypass configuration, and thus the switch-in deflection system would give the largest engine-change-unit (ECU) weight. With regard to the pod installation as mounted on the aircraft, further installation weight penalties would result with the twin-elbow or "switch-in" deflection schemes in the pod attachments, where the nonalignment of the structural and thrust loads would require strengthening of the pod-stalk spar attachments.

From studies made of the application of these various systems to V/STOL transport aircraft, it has been concluded that the Pegasus four-nozzle configuration leads to the simplest installation of engine into the airframe. When the over-all mission requirements are studied in detail, and the performances achieved with the thrust deflection schemes are compared, the resulting aircraft AUW's are very similar. It is only in extreme long range missions that fuel weight penalties occur with deflecting nozzle systems. However, detailed design studies of the particular installation problems in V/STOL transports do suggest that the simplicity of the Pegasus nozzle configuration in obtaining full thrust deflection for short takeoff and landing, while incurring small inherent penalties in other parts of the flight regime, will be significant in endowing the aircraft with the specified airfield performance.

A3. Engine performance and installation aspects

The application of the deflected thrust engine to the STOL transport aircraft involves consideration of a number of engine performance and installation aspects. First, the particular requirements of short-field performance leads to the demand for high thrust ratings for utilizations shorter than the normal 5-min period associated with takeoff ratings for a conventional transport aircraft. Additionally, "emergency ratings" must be declared and probably "short-life" ratings; also, restoration of thrust on a hot day is usually demanded. The life of an engine for a STOL transport aircraft is determined by the same criteria as for a conventional transport aircraft, by the level of takeoff rating declared and hence by the turbine entry temperature chosen. This in turn determines the creep life of the turbine blades, which is the generally used design factor. The pattern of utilization will be similar for both aircraft.

In the application envisaged here, high-pressure bleed air is supplied for flap blowing purposes and, as this is used continuously, the rating quoted for bleed-on must be lower than for the zero-bleed case so as to maintain constant turbine entry temperature in order to avoid reducing the overhaul life. However, a schedule of short life ratings can be declared with "bleed-on," where the nominal engine thrust is maintained, and for "bleed-off," where the thrust is actually boosted. Here, because of the short duration (i.e., for periods varying from 1 to 10 sec) that the thrust and hence turbine entry temperature is increased, the blade temperature is not raised to the gas temperature, and hence the creep life of the blade is not correspondingly reduced.

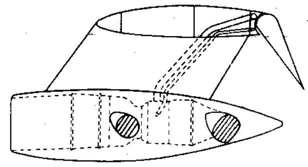
The provision of emergency ratings must lead to a direct decrease in engine life, since this higher thrust rating will be required for a significant period (i.e., up to 1 min), possibly after an engine failure, while any change in aircraft attitude or speed is corrected. It may be necessary to inspect engines after use of the "emergency-rating"; life recorders may help in assessing this. The use of water injection for thrust restoration on a "hot day" involves mechanical overspeed of the engine but no effective temperature rise as the turbine blades are cooled to the nominal entry temperature. The particular installation aspects of the deflected thrust engine are associated primarily with the provision of high-pressure air for flap blowing, nozzle rotations up to 180° to give reverse thrust for landing, and the installation of pumps and associated equipment for the water-injection system. In Fig. 10 a simple representation is shown of the bleed air ducting system to the wing flaps. The third diagram of the figure shows the nozzles rotated to a forward position for reverse thrust, and movable fairings are represented which are designed to reduce nozzle profile drag and which must necessarily be rotated with the nozzle. The equipment for water injection can be installed in available space in the pod behind the engine rear trouser-piece unit.

B. VTOL Development and Applications

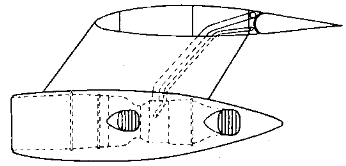
B1. Lift engine development

The full awareness of the advantages to the military and civil operator of V/STOL aircraft will become readily ap-

a) Takeoff: flaps at takeoff setting; intermediate nozzle deflection



b) In-flight: zero flap deflection; zero nozzle deflection



c) Landing: full flap deflection; full reverse thrust

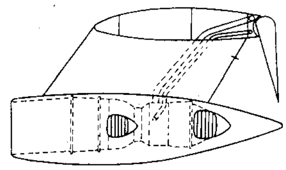


Fig. 10 Nozzle and wing-flap configurations.

parent when such short-field performance aircraft enter service. A view is widely held that, before pure VTOL transport aircraft are developed, a full evaluation should be made of the operating problems of such aircraft and the lessons obtained from STOL transport aircraft, currently under development, should be applied to these proposed VTOL developments. The early development of lightweight lifting engines is discussed in the paper by Moore,[7] and we would like to mention here the work that has been proceeding at Bristol Siddeley in this field. In 1958, studies were initiated of the design and performance assessment of lightweight lift engines for transport applications. The requirements of low exhaust velocity to give reduced noise and general ground disturbance and low fuel consumption to minimize the fuel carried for the VTOL mission dictate the choice of a bypass engine. However, consideration must be given to the installed weight of the complete system of lift engine pod unit and the fuel carried, besides the actual bulk of the unit. In Fig. 11, the results are given of some calculations of the thrust/weight ratio for a turbojet and a ducted fan lift engine against a base of fuel carried (or burned) in minutes. First the bare-engine case is considered, and in the left-hand figure it is seen that above 1 min of fuel the ducted fan engine is superior, and at 5 min the T/W is 30% higher. This comparison is only for the uninstalled engine. The two lower curves (shown in dashed lines) compare installed thrust/weight ratios assuming the installed weight is equal to twice the bare-engine weight

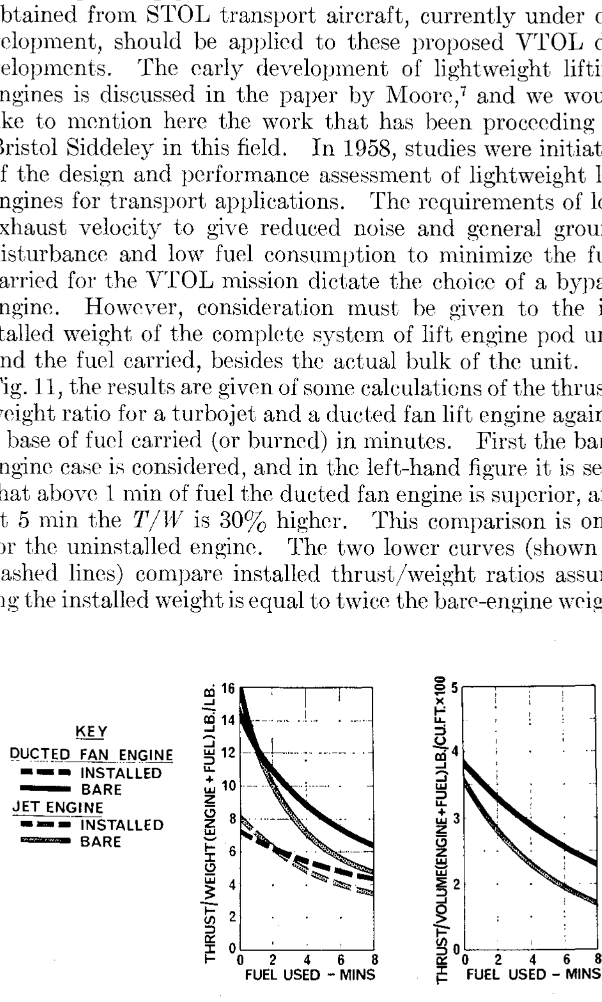


Fig. 11 Comparison of lift engines.

(i.e., assuming an installation weight factor of 2), and at 5 min of fuel the ducted fan engine has an installed thrust/weight ratio some 20% higher than the turbojet lift engine. The volume or space occupied by the lift engine unit and necessary fuel must be kept to a minimum, and in the second diagram, the thrust per cubic foot of engine plus fuel is shown, illustrating the lower total volume associated with the ducted fan engine, allowing for fuel carried.

In the studies made of lightweight lift engine, front and aft fan configurations were studied and the choice of thermodynamic cycle involved consideration of bypass ratio, compression ratio and turbine entry temperature. Consideration of all the design and performance factors in the choice of lift engines led to the decision to proceed with the development of a front fan engine, as shown in Fig. 12, on the grounds of simplicity of layout and installation. Also, the front fan engine is less vulnerable to damage from foreign matter that would be expelled directly through the cold duct, as opposed to being contained in the gas generator system of an aft fan engine. Development of the front fan lift engine has been proceeding, rig testing of components has already begun, and target performance is being achieved.

B2. VTOL lift engine intake research

For the VTOL transport aircraft, the arrangement of multilift engine pod configuration leads to intake design difficulties and a wind-tunnel test program was initiated to investigate intake problems and optimum intake configurations. The program of tests was carried out to investigate the velocity distribution and total pressure recovery at various axial positions in the duct when the intake duct centerlines were nearly normal to the freestream direction. At the start of transition for landing, during lift engine start-up, the freestream/intake velocity ratio will be abnormally high [$V_0/V_1 = 0$ (10)], and high pressure losses and severe maldistribution will be experienced in the intakes. It is thus necessary to find some means of minimizing these effects without incurring weight penalties or compromising the hover conditions (where $V_0/V_1 = 0$), in order that engine starting may be carried out easily and safely in flight.

The wind-tunnel model is shown in Fig. 13 as mounted in the working section of the low-speed tunnel. Five intakes are represented and the fixing wires that were used to attach various intake covering doors and devices to improve the performance can be seen. The intake flow was simulated by attaching the intake duct to the suction side of compressors outside the tunnel. The purpose of the tests was to investigate the effect on performance of the following geometrical parameters: 1) lip shape and compressor hub shape; 2) intake length by studying flow conditions at various distances below the surface of the pod; 3) cover door shape and position when open; 4) incidence; and 5) splitters and cascades.

The test program was concentrated at first on general investigations on intakes 1, 3, and 5 (from the leading edge) with equal inlet flows. The results showed that at low velocity ratios (takeoff), the performance of all intakes was high, but as the velocity ratio was increased (forward speed increased), the performance of the intake was reduced, and the first intake always had a lower performance than any other. Consequently, the test program was biased toward a study of the first intake only at high freestream inlet velocity ratios, since it was argued that any devices used to improve the performance of the first intake could be used, if necessary, on the subsequent ones. On Fig. 14, the pressure loss coefficients of the first intake are shown. The basic loss curve shown is that for the intake in its original form with no cover doors and this geometry had the highest pressure loss. The performance was improved by building up the leading edge lip to give a radius of 19% of the intake diameter. This reduced local pressure gradients and delayed separation of the flow. The losses at high velocity ratios were still excessive.

Within the range of positions studied, the length of the intake duct had little effect on the flow separation. The losses measured, using side doors or doors that were raised from the top surface of the pod, were greater in both cases than the intake basic loss. Model incidence was varied over ±10° and had little effect on intake performance. Splitter vanes in the intake, with subtended angles of 90°, 150°, 210°, and 270°, were investigated. Configurations with 1–3 vanes were studied. The 210° angle splitter gave promising results with three blades, although high losses were present at zero velocity ratio due to blockage effects. A vertical cascade was tested with similar results to the splitter. However, by inclining a cascade at 45° with variable blade pitch/chord ratio, the loss compared to the basic intake was reduced considerably.

Further, to these investigations of basic intake performance and study of certain devices, a series of tests was initiated using blowing at the intake lip. This configuration gave the lowest intake loss and was superior to any other device studied, partly because of intake pressurization by the blowing air. Major improvements to the intake distributions have also been achieved.

C. Future V/STOL Transports

The development of a ducted fan lift engine led to consideration of the application to VTOL developments of existing military tactical transport aircraft. Also, serious design proposals were made for a VTOL conversion of a NATO strike/fighter aircraft. Many projected V/STOL transport aircraft have specified the Bristol Siddeley BS.59 ducted fan lift engine and design studies have been made of complete engine pod units including engine control and fuel systems. In connection with possible civil applications, studies were

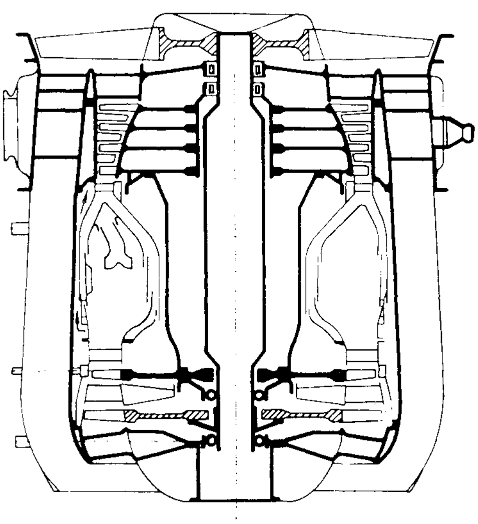


Fig. 12 Front fan ducted lift engine.

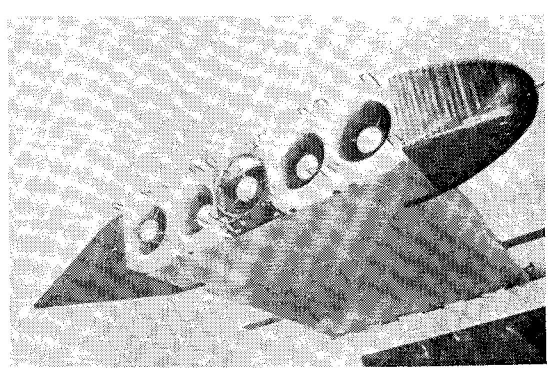


Fig. 13 Pod intake model.

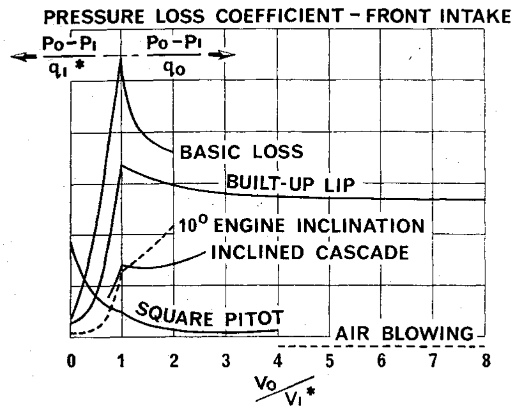


Fig. 14 Lift engine intake tests.

carried out of developments of the BS.59 engine with higher bypass ratios to give noise levels acceptable for airline operations. Further work has now been concentrated on proposals for future pure lift and vectored thrust engines of moderately high bypass ratio where a basic engine configuration is used to derive a lightweight lift engine and vectored thrust engine.

Optimum VTOL transport aircraft should necessarily be based on a single engine type for simplicity of installation and from powerplant cost considerations. The studies that have been made of possible future VTOL transports have been primarily concerned with short range military and civil aircraft. For such applications, powerplant weight is of prime importance and the cruise s.f.c. may be compromised in favor of achieving low engine weight and low initial cost. Optimum cruise is at a Mach number of 0.6 to 0.7, and the moderately high bypass ratio engine (i.e., bypass ratio 2) is ideally matched to these requirements when considering the takeoff and cruise regimes.

Figure 15 shows a possible design of a short range military assault transport, having four wing-mounted pod units. The lift/thrust engine is mounted forward in a composite pod arrangement. This contributes to the vertical takeoff by use of the deflection nozzles shown. Two lift engines are mounted vertically in each pod and each lift/thrust and lift engine provides basically the same thrust. Roll control is achieved by differential throttling of the lift engines, pitch and yaw control is provided by swiveling control jets at the nose and tail of the aircraft, and additional yaw control can be obtained by rotating nozzles on the lift engines. The design of suitable intakes for the under-wing pods requires detailed investigation as does the general pod wing interference problem. The performance and installation studies that have been made of the combined lift thrust and lift engine proposed here suggest that a truly economic and operationally acceptable turbofan powered, pure VTOL transport aircraft can be designed and constitutes a real advance in high speed V/STOL transport design.

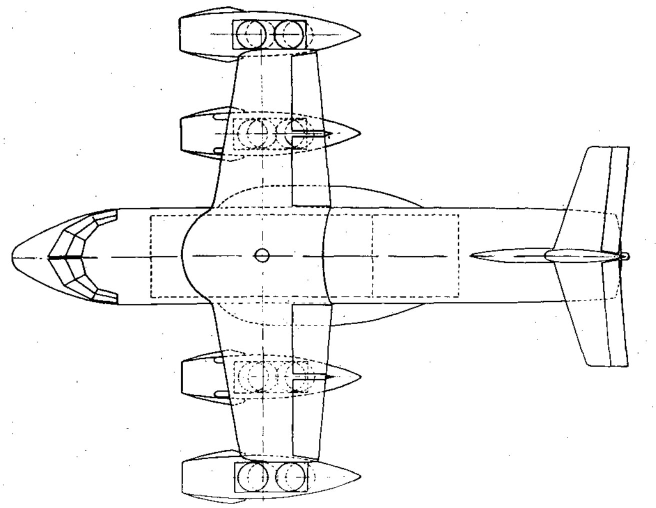


Fig. 15 Future VTOL transport aircraft.

Concluding Remarks

An attempt has been made in this paper to review the developments that have been proceeding in the V/STOL powerplant field at Bristol Siddeley Engines. The development of the Pegasus engine has presented the usual development problems but these have not been significantly increased by the novel and revolutionary vectored thrust capability. The experience gained in operating the Hawker P.1127 aircraft has confirmed the claims made originally for the advantages of the turbofan vectored thrust engine. The contribution of the Pegasus concept to the simple design of aircraft and ease of operation in the takeoff and landing transition is well understood and appreciated as significant in producing a very flexible aircraft that operates over a very wide speed range.

The successful development of the Pegasus engine and Hawker P.1127 single-engined V/STOL strike aircraft is now to be followed by the development of a single-engined supersonic V/STOL strike aircraft based on the BS.100 engine designed specifically for such aircraft. This engine retains the turbofan and four rotating nozzle concepts of the Pegasus engine, and thus the powerplant and airframe of the supersonic V/STOL strike aircraft will benefit directly from the considerable experience accumulated here.

The turbofan vectored thrust engine has equally important applications to the V/STOL transport aircraft and extremely short field performance can be achieved by using thrust deflection, especially if this is combined with wing/flap boundary-layer control in the aircraft. The evolution of VTOL transport aircraft necessitates the development of lightweight lift engines, which must be of the bypass type to minimize the installed engine weight and fuel penalty associated with VTOL aircraft application. The optimum VTOL civil and military transport aircraft, having high forward speed, must be turbofan powered and, to achieve an acceptable level of economy in design, a common engine type of moderately high bypass ratio must be evolved for the vectored thrust and direct lift engines.

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