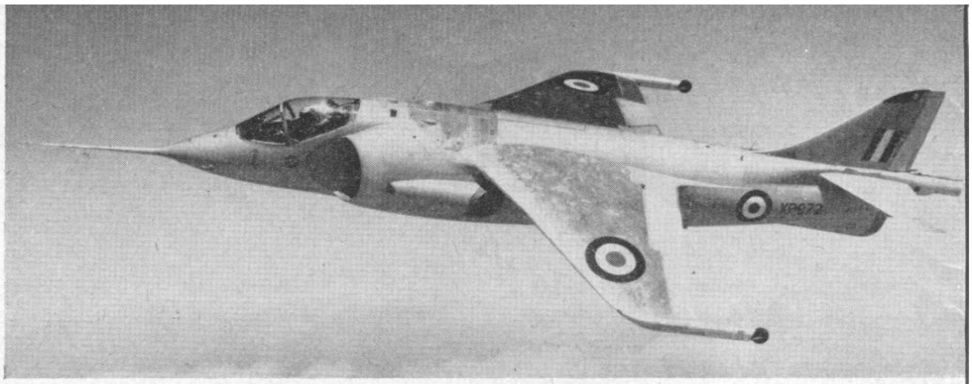
Lift Engines or Vectored Thrust?

by John Fricker



The third prototype P.1127, XP972

JET LIFT IS not an exclusively British idea—the French had a piloted Atar flying around on end as long ago as 1957, and in the same year double transitions to and from vertical flight were successfully completed in the U.S.A. by the Ryan X-13 Vertijet. Both projects, however, were doomed from the long-term point of view by their impractical "tail-sitter" configuration, and it was left to Britain to give a lead to the world with the development of "flat-riser" jet lift.

This was pioneered by Rolls-Royce, who can trace studies on powerplants for vertical take-off as far back as 1941, but practical experiments with jet lift began with the twin-Nene "Flying Bedstead" in 1953. Two examples of this queer rig were built, and covered the whole spectrum of free-flight performance within their design capabilities in a year or so of testing, during which they demonstrated horizontal speeds up to 30 m.p.h., despite their fixed vertical tailpipes. They proved, apart from the basic possibility of jet lift, the practicability of "puff-pipe" control at zero speeds, in conjunction with a suitable auto-stabiliser.

With the parallel development of suitable lift engines, emerging with the RB.108 of 2,200 lb. net thrust for a weight of only 285 lb.—giving a thrust/weight ratio of 8:1—Rolls-Royce were able to take the jet lift idea a stage farther and power a research airframe for "flat-rising" VTOL. With four RB.108s for lift and another for propulsion, the Short S.C.1 first flew conventionally in April 1957, and made a successful initial transition from hovering to wing-borne flight on 6th April 1960.

Continued development of the Rolls-Royce "composite powerplant" concept, with separate lift and thrust engines, has doubled achieved thrust/weight ratios to 16:1 with the introduction of the RB.162 ultra-lightweight unit. This lift engine, which uses plastics and glass fibre in its construction to halve its cost per pound of thrust compared with conventional jets, has received financial backing from the British Government, as well as from France and Germany, and was specified for a large number of entries to the N.A.T.O. BMR-3 and -4 contests for a V/STOL fighter-bomber and transport.

Official backing for the U.K. entry to NBMR-3 was given to a Hawker design, however, using a different system of jet lift, despite the success shown by the S.C.1. The new system was developed by Bristol Siddeley, following experience gained with thrust deflection of the small Viper turbojet in the Bell X-14 VTOL research aircraft in the U.S.A. and from an idea by the French designer Michel Wibault in 1957. He proposed to the M.W.D.P. in Paris a version of the BE.25 Orion with four centrifugal fans having controllable discharge volutes so that their thrust could be angled as required, and designed a fighter round it, the Type 1-4-212 Gyropter.

The Pegasus

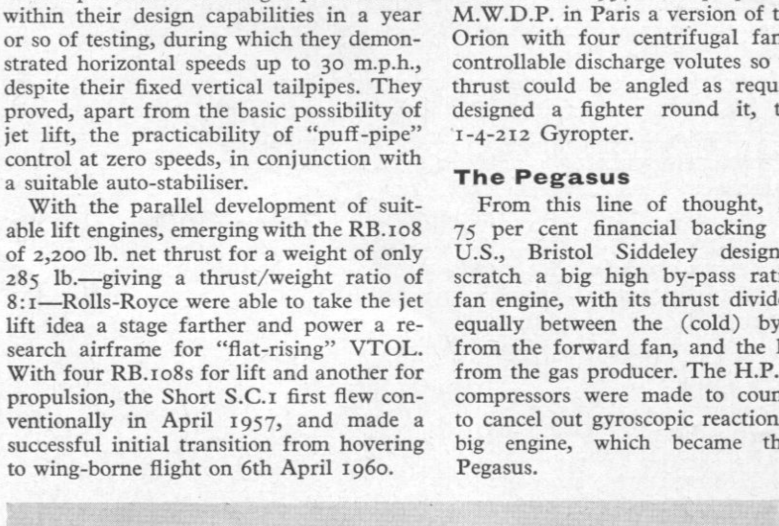
From this line of thought, and with 75 per cent financial backing from the U.S., Bristol Siddeley designed from scratch a big high by-pass ratio ducted fan engine, with its thrust divided almost equally between the (cold) by-pass air from the forward fan, and the hot efflux from the gas producer. The H.P. and L.P. compressors were made to counter-rotate to cancel out gyroscopic reaction from the big engine, which became the BS.53 Pegasus.

Its four "jet" pipes each deliver 25 per cent of the total thrust equidistant from the C.G., and swivel in unison between 0 and 100 degrees to direct all available power at any angle from the horizontal to forward of the vertical. The nozzles are operated by interlinked air motors, and are actuated throughout their complete range in about a second by a simple lever on the throttle quadrant. With a couple of gauges for puff-pipe pressure and nozzle angle, the actuation lever is the sole addition to what is otherwise a normal fighter-bomber cockpit.

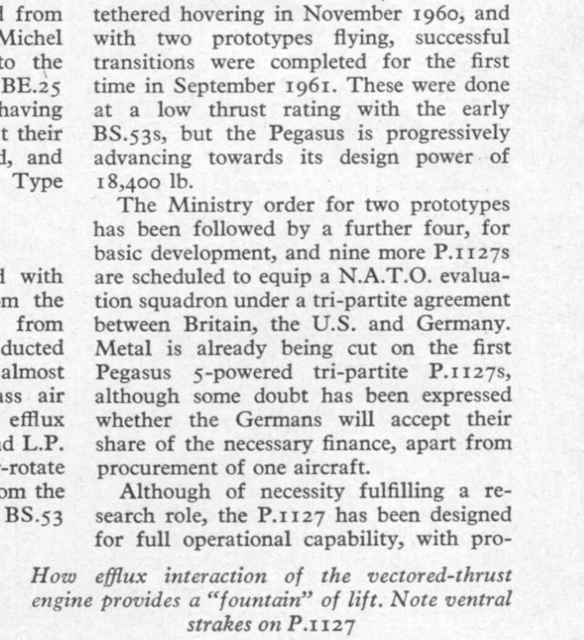
Simplicity is the essence of the Pegasus and its initial airframe, the Hawker P.1127, which are a unique combination of completely untried engine, airframe and VTOL technique. Although the BS.53 has flown in no other aircraft, progress has been remarkable. The P.1127 started untethered hovering in November 1960, and with two prototypes flying, successful transitions were completed for the first time in September 1961. These were done at a low thrust rating with the early BS.53s, but the Pegasus is progressively advancing towards its design power of 18,400 lb.

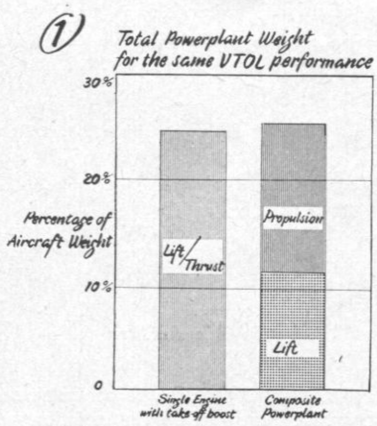
The Ministry order for two prototypes has been followed by a further four, for basic development, and nine more P.1127s are scheduled to equip a N.A.T.O. evaluation squadron under a tri-partite agreement between Britain, the U.S. and Germany. Metal is already being cut on the first Pegasus 5-powered tri-partite P.1127s, although some doubt has been expressed whether the Germans will accept their share of the necessary finance, apart from procurement of one aircraft.

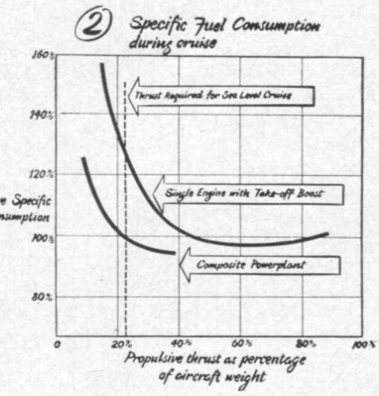
Although of necessity fulfilling a research role, the P.1127 has been designed for full operational capability, with pro-

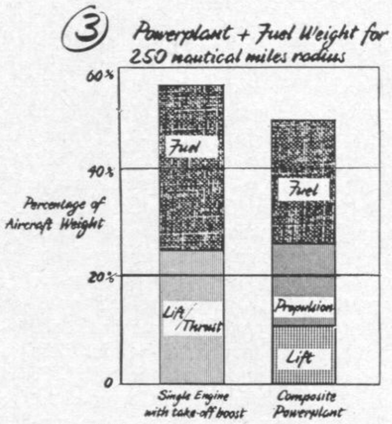


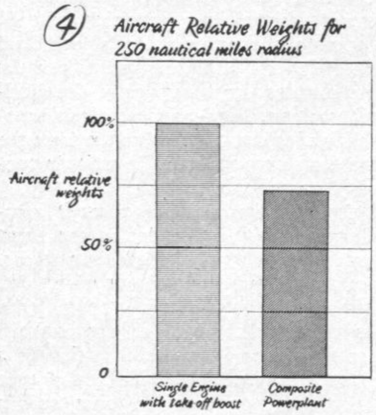
How efflux interaction of the vectored-thrust engine provides a "fountain" of lift. Note ventral strakes on P.1127

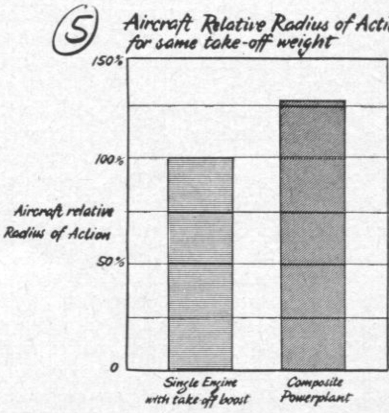












Graphs prepared by Rolls-Royce to compare the composite-powerplant and single-engine vectored-thrust systems for VTOL aircraft performing the same mission. RIGHT: *Balzac during free hovering trials*

vision for internal and external weapons stowage. One prototype has already flown with 500-lb. weights on underwing attachment points to measure inertia in roll, and as the full thrust of the BS.53 becomes available, simulated warloads may be carried. The P.1127's combat capability is classified, but it shows an all-round improvement over the Hunter.

"Composite" claims

Some penalty must always be incurred for VTOL capability, whether it is gained by the Rolls-Royce composite powerplant system or Bristol Siddeley vectored thrust. As the diagrams show, Rolls-Royce claim superiority in relative aircraft weight for a given radius (which happens to be that of NBMR-3), in specific fuel consumption during cruise, and therefore powerplant plus fuel weight. Put another way, in graph 5, for the same take-off weight, Rolls claim a 25 per cent plus increase in relative radius of action for the composite powerplant VTOL fighter, for only a slightly heavier total engine weight, as shown in graph 1.

One of the strongest arguments, in fact, for the composite powerplant is that the use of separate lift engines enables the optimum propulsion unit to be selected, which becomes increasingly important over longer ranges. Rolls-Royce consider that a single vectored thrust powerplant would normally have to be much too large for economical cruise operation, have only a medium pressure ratio for low specific weight, and a high by-pass ratio for minimum fuel consumption.

Another claim made for the composite engine concept—of which second-stage research and development, in the form of the Dassault Balzac V 001, has moved to France—is that of safety. Eight RB.108 lift engines are installed in the Balzac, which has the same configuration as the RB.162-lifted definitive Mirage IIIV, and if one unit fails in the hover, the opposite engine would be cut out to maintain equilibrium. It may then be possible to overboost the remaining lift engines briefly to achieve a soft let-down in the event of an abandoned vertical take-off at full load—the only occasion when maximum lift power would be required. The Mirage IIIV is claimed to be able to complete a VTOL mission with one RB.162 out of action.

With its single powerplant, the vectored thrust (V.T.) aircraft has a danger envelope in case of failure during the hover and early transition, but this is probably no worse than during the take-off of other single-jet fighters such as the F-104. Not being interested in hovering demonstrations, an operational VTOL fighter would normally be extra vulnerable for about 20 seconds between lift-off and transition, during which the new Martin-Baker zero-zero rocket seat should guarantee safety for the pilot. Another point is that R.A.F. statistics show that there are more crashes resulting from systems malfunctions than engine failures, which puts the composite-engined aircraft at a corresponding disadvantage.

With ingestion and re-circulation problems, there is a strong credit balance for the vectored-thrust system. In current composite-powered aircraft, eight closely grouped lift engines, each developing a ton of thrust in the Balzac and twice that in the Mirage IIIV, are mounted vertically pointing at the ground a few feet below. At full power for take-off, the high-velocity and high-temperature efflux from eight powerful turbojets has formidable erosion properties, and even one RB.108 will make a 4 ft. × 9 in. hole in unprotected turf.

Light protection plates and small-area platforms can minimise these effects, for the loss of some operational flexibility. It could be difficult to do a full-power check before lifting off anything except a hard or protected surface, without serious ingestion problems. Small lift engines may be particularly vulnerable, whereas the massive compressor blades of a vectored turbofan have shown more tolerance to ingestion, expelling light particles of material through the cold efflux.

With the Pegasus, all engine checks can be done with the nozzles pointing aft, and these are deflected downwards only immediately before lift-off. Efflux temperatures and pressures are lower with a ducted fan engine, with less blast effect, but for many reasons most take-offs with VTOL fighters

V/STOL Fighters

will involve a short forward run, thus leaving debris and hot air behind. Quite low forward speeds give invaluable lift increases, and the V.T. aircraft has the advantage of having all the installed engine power available for maximum acceleration.

The technique with the P.1127 is to open up to full power with the nozzles pointing aft, and at a predetermined speed, to pull the nozzle position lever back to a computed stop, to leap into the air. This technique was shown at the 1962 S.B.A.C. Show and resulted in a startlingly short take-off from grass with virtually no surface disturbance. The composite aircraft is at a disadvantage in having less than 50 per cent of its total engine output available for V/STOL propulsion, whereas the V.T. machine can also use its considerable thrust excess for sensational climb and acceleration performance — particularly useful in a fighter. There are no worrying and possibly embarrassing problems of re-lighting a battery of lift engines for the V.T. pilot at the end of a sortie, nor a complicated check at an early stage for battle damage in the system in case diversion to a conventional airfield becomes necessary.

Intake momentum drag

Intake momentum drag can rob VTOL aircraft of a great deal of power, and with composite powerplants, as shown by the S.C.1, it helps to be able to tilt the lift engines, despite the additional complication, to gain enough forward thrust for a rapid transition. To ensure the optimum power for hovering flight, the P.1127 requires an inflatable rubber intake lip for the necessary blunt contour, and a more complex variable intake will probably be necessary on higher-speed V.T. fighters.

With its lift engines running, a composite aircraft has an induced flow at right-angles to the line of flight, resulting in a nose-up pitching moment. Another problem is that of cross-coupling control effects arising from the gyroscopic couples of several vertically-mounted turbines all turning in the same direction. These effects have been explored in the S.C.1, and their relative absence in the P.1127, because of its counter-rotating V.T. engine, is one of the main reasons why the Hawker aircraft has found auto-stabilisation unnecessary. Even without this aid, the P.1127 is said to have much better handling qualities in the hover than all current helicopters.

Yet another effect accompanying closely-grouped lift engines which could necessitate retention of a take-off grill, as currently used with the Balzac, is the production of a suction force due to the entrained airflow drawn in along the underside of the wing by the jet efflux. This can offset much of the total lift effect. The V.T. layout is fortunate in that lateral separation of the efflux nozzles provides an aerodynamic interaction against the ground that can actually become favourable, providing a "cushion-craft" effect that can be felt by P.1127 pilots during vertical descents. The ventral "strakes" fitted to the Hawker aircraft are designed to entrap this ground "fountain" (see diagram) and serve no other purpose.

The V.T. principle seems to promise the optimum operational flexibility, although it will be interesting to watch the progress of the French VTOL programme. Very rapid flight development has been achieved with the Balzac during its initial hovering trials, and transitions are planned for the early months of 1963. The Mirage IIIV prototype, with a SNECMA TF-106 and eight 4,400-lb. RB.162s, is due to fly towards the end of next year, and is due in service with L'Armée de l'Air, which is reported to have requested 120 machines, by about 1966.

On this time-scale, the Mirage IIIV will be the first Mach 2 VTOL fighter to become operational, since its rival claimant for first place in NBMR-3, Hawker's P.1154, is not required for several years after that date. To be produced both for the R.A.F. and the R.N., in single- and two-seat versions, the P.1154 requires a completely new V.T. powerplant, the Bristol Siddeley BS.100, developing around 30,000-lb. thrust, on which work has already started.

The BS.100 will use a new technique known as plenum-chamber burning (PCB) to boost its thrust up to 30 per cent for lift-off, and American financial aid is being received for its development programme. PCB involves fuel injection and ignition in the cold nozzles of the ducted fan, rather like afterburning, except for the simpler environmental conditions, and should present no insurmountable technical problems. PCB enables closer tailoring of the powerplant to cruising conditions to be achieved, and the BS.100 was selected for several of the NBMR-3 entries.

Britain's preference

Government support has been proclaimed for the P.1154, which apart from other considerations was the cheapest design to NBMR-3, and so far as the Ministry of Aviation is concerned, official preference on the merits of V.T. versus C.P. for fighters has been made clear.

In the meantime, the British lead in VTOL techniques should be maintained with the P.1127, although at the moment orders from a number of interested countries await a move from the R.A.F. Unfortunately, there is little money to spare for this extremely useful Hunter replacement, and if the R.A.F. has to choose between the 1127 and the 1154, it will naturally settle for the latter. Even a token production batch for the British forces, however, would clear the way for several foreign orders. The U.S. Army alone is reported to want about 300 P.1127s, but even one-tenth of this number for the R.A.F. would also provide invaluable information on the revolutionary tactics which VTOL fighter-bombers will bring to the battlefield.

Flying the P.1127*

by T. P. Frost

(Chief test pilot, Bristol Siddeley Engines Ltd.)

THE HAWKER P.1127 has a conventional stick and rudder which, in addition to operating normal aerodynamic controls, also operate jet reaction controls positioned at the nose, tail and wingtips. When the engine nozzles are away from the horizontal position, high-pressure air is automatically supplied to these valves from the engine compressor to provide attitude control in non-conventional flight.

A simple form of single channel auto-stabilisation is available but in the event of unserviceability transition can readily and comfortably be carried out without it.

Control of the thrust vector is by a single lever alongside a conventional vertically mounted engine throttle. This lever is the only extra cockpit control over and above the conventional ones and is operated backwards to rotate the engine nozzles downwards.

Flight routine

After only the simplest of checks the engine is started up with the nozzles rearwards, to minimise any ground erosion or exhaust gas recirculation effects, and they are only selected down immediately prior to take-off. The aircraft is best lifted off by increasing power fairly rapidly until unstick occurs. Height is then maintained by natural manipulations of the throttle, a suitable handrest being provided to enable precise movements to be made when required.

Compared with a helicopter, very slightly more attention is required for height control since throttle movement gives acceleration rather than a velocity change, since ground effects tend to give a small unstable cushion rather than a stable one, and since the available thrust-to-weight ratios tend to be less. Nevertheless, the crisp response of the Pegasus engine combined with a suitable throttle to engine gearing give the pilot a straightforward task.

As with a helicopter, judgment of height and rates of ascent or descent are made by looking out and around in the normal manner. The view from the conventional fighter-type cockpit of the P.1127 is adequate in this respect, special attention having been given to the provision of good visibility over the nose and sideways.

Position of the aircraft is maintained by suitable adjustment of its attitude, using

* Extract of a paper presented to the Society of Experimental Test Pilots in Los Angeles.