simulating the flow distortions at the face of a lift engine. Wind-tunnel tests pointed to the combination of high forward speed and low engine power as causing excessive distortion. A scoop inlet was developed that enabled the flow to turn without separation. For improved pressure recovery in static and near-static operation, longitudinal vanes in the top surface of the scoop were used to augment the inlet area. By opening the vanes at low speed and closing them for engine restart, acceptable inlet performance was obtained over the range of flight conditions tested.

The optimum duct length was found to depend upon the influences of static-pressure gradients caused by flow turning and total-pressure gradients caused by flow separation. In general, increasing the duct length improved static-pressure gradients but increased the extent of any flow separation that might have occurred at the entry lip.

The wind-tunnel data showed that, for a given engine-face velocity, the pressure losses, both with and without scoops, were in good agreement when compared at the same approach velocity. This agreement led to the development of a static-test distortion generator that simulated the total- and static-pressure gradients measured in the wind tunnel. The distortion generator had a bellmouth intake and used blockage plates to change the air flow velocity approaching the engine entry. The distortion-generator data agreed well with wind-tunnel data, which indicated that the generator technique should be useful for engine development testing.

Reference

[1] Tyson, B. I., "Tests of air inlets for jet lift engines," Society of Automotive Engineers-American Society of Mechanical Engineers Air Transport and Space Meeting (April 1964).

SEPT.-OCT. 1965 J. AIRCRAFT VOL. 2, NO. 5

Status Report on Liftjets

C. T. Hewson* and K. R. Davies†
Rolls-Royce, Ltd., Derby, England

A review of 10-yr work on the early RB 108 Liftjet and its derivative, the RB 145, and description of the installation development associated with their respective aircraft are presented in this paper. The lessons learned during this period have proved invaluable to later engine and aircraft designs. The latest Liftjet, the RB 162, which has twice the thrust per unit weight of the early engine, has now been running for two years, and the general design and development are described. The importance of installation from the point of view of installed weight and simplicity of maintenance is discussed. Use of thrust deflection on lift and propulsion jets is possible and has some advantages dependent upon the aircraft reqirements.

I. Experience in VTOL Field

Introduction

WORK at Rolls-Royce on VTOL powerplants and their associated problems has extended over the past ten years. As an introduction to our present and future liftjets, it is interesting to review very briefly these last ten years' work and the lessons learned from this very valuable experience.

We have been involved in several different ways of providing lift thrust for the takeoff of a VTOL aircraft. The Rolls-Royce Avon Engine in the Ryan Verti-Jet provided vertical thrust with the aircraft sitting on its tail. The SC 1 and the Balzac have batteries of pure lift engines to provide all the necessary lift thrust, the propulsion engine being used only for horizontal flight. In between these two extremes comes the deflected propulsive engine thrust for takeoff, which we have achieved by tilting the engine pods as on the German VJ101C, or deflecting the thrust of fixed propulsive engines by means of thrust diverters.

We are actively engaged in reviewing the various methods of thrust deflection in conjunction with several aircraft companies, evolving optimum installations for different aircraft duties.

RB 108 and SC 1 Aircraft

However, by far the major part of our VTOL experience to date has been based on our first design of specialized lifting engine, the RB 108. After a demonstration in 1953 by the "flying bedstead" that a jet-borne vehicle can be stabilized by air jets, the development of the RB 108 was started. Figure 1 is a picture of the "bedstead" during its hover trials.

The RB 108 lift engine, shown in Fig. 2, is a small pure jet engine of low pressure ratio, giving 2200 lb thrust at a thrust weight ratio of 8:1. The engine was designed to power the Short and Harland research aircraft, the SC 1. Four engines provide the lift thrust with high-pressure air bled from each engine compressor to provide aircraft control in roll, pitch, and yaw. The development of the RB 108 installation in the SC 1 has taught us a great deal about the general problems of a pure lift VTO powerplant.

After developing the four-engine system to a satisfactory standard on the test bed, the next big problem that had to be

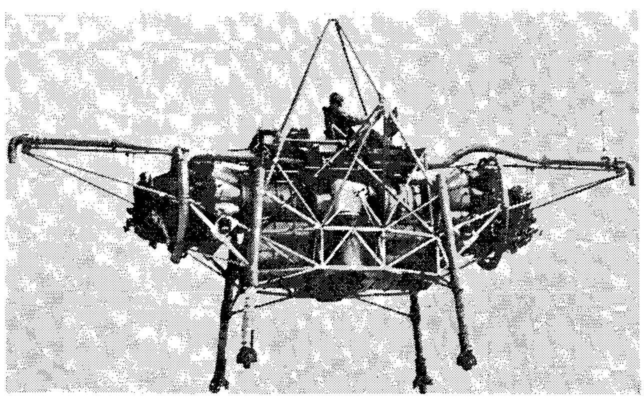

Fig. 1 The flying bedstead.

Presented as Preprint 64-609 at the AIAA Transport Aircraft Design and Operations Meeting, Seattle, Wash., August 10–12, 1964; revision received February 9, 1965.

* Assistant Chief Engineer, Projects.
† Assistant Chief Engineer, Military Engines.

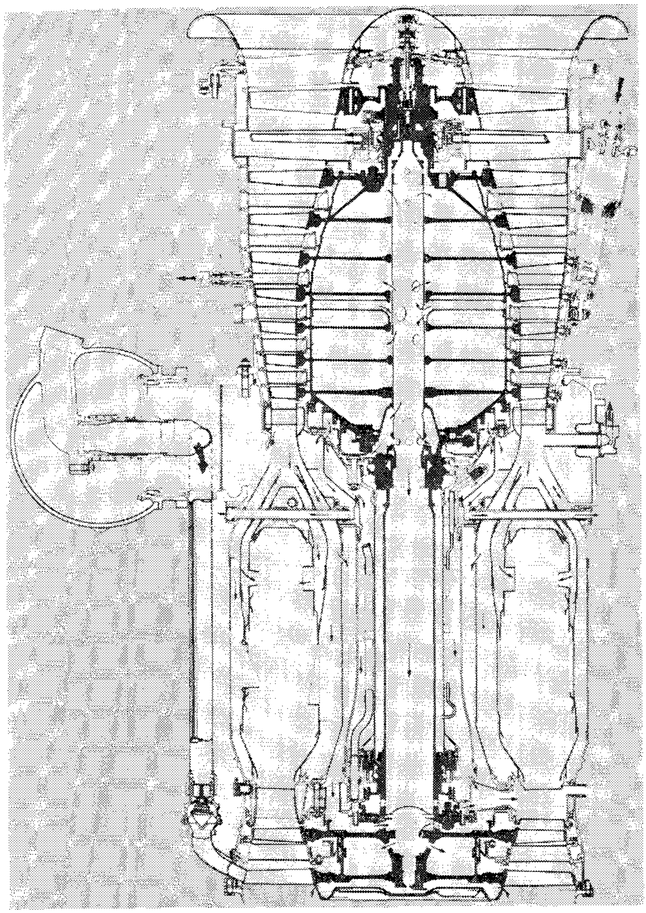

Fig. 2 The RB 108 liftjet.

solved was that of engine functioning in flight, where the substantially vertical installation had several new difficulties. These can be reduced to essentially two problems: that of the pressure difference across the engine from intake to nozzle, and that of the bad velocity distribution at the inlet. A prolonged series of rig tests on models of the SC 1 intake in the wind tunnel was carried out to come to grips with this question. For later installations the engine development work was also done in a wind tunnel; in the early days, we simply installed the RB 108 in the center section of a Meteor aircraft and over a period of flight development evolved the principles of the intake and exhaust configuration which have since been applied to other installations. The broad principles can be stated simply. As shown in Fig. 3, in order to overcome the negative ram inherent in a VTO aircraft of the SC 1 type in flight, "scuttles" were attached to the turbine flange to cause a suction over the jet nozzle. The intake was designed to pump up the intake pressure at low engine speeds, while still allowing free access of air at high engine speeds by means of the spring-loaded slats as shown.

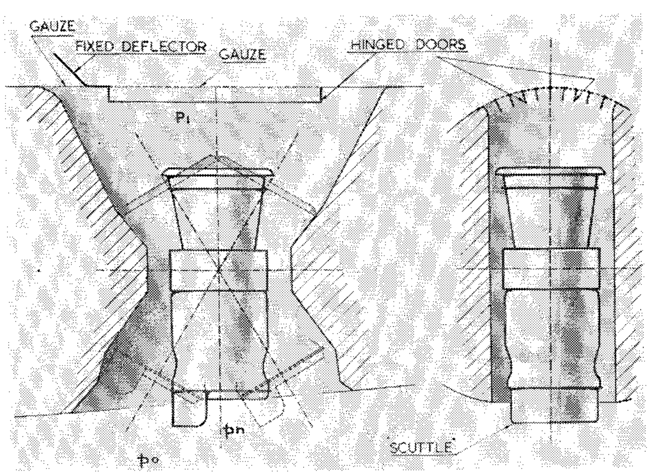

Fig. 3 RB 108 intake and scuttle (Meteor).

The four-engine intake was made up for the SC 1 along similar lines to the single engine development intake and flown in the SC 1. After a period of careful test flying, during which the stall speed was gradually approached from high speed by reducing flight speed in the air and from a low speed by taxiing at increasing speeds along the runway, a full transition was achieved in April 1960. The main part of our SC 1 lift engine development was then completed and the feasibility of transition from jet-borne to wing-borne flight proved beyond doubt.

Balzac Aircraft

The RB 108 has also been used on the Continent to provide lift thrust for several VTO projects. The French Balzac, shown in Fig. 4, is a prototype of the Mirage VTO aicraft and is powered by eight lift engines. The installation development was carried out in a wind tunnel at the Rolls-Royce Flight Establishment at Hucknall. A pair of engines was mounted in a representative portion of the fuselage in the wind tunnel and run over the whole range of flight speeds and engine speeds. The intake, basically similar to the SC 1, was thoroughly tested and developed to a satisfactory standard.

Hover Test Rigs

Other applications of the RB 108 include several hovering rigs, designed to investigate the problems of aircraft control in hover and to help in the development of automatic stabilization systems.

RB 145 and VJ 101C Aircraft

The RB 145 is a developed version of the RB 108, designed to operate up to a Mach number of 1.8 in the stratosphere with and without an afterburner. The engine has been specifically developed to power the German VJ 101C aircraft, illustrated in Fig. 4. Two RB 145 engines are mounted vertically in the forward fuselage and used purely as lift engines for takeoff and transition. Twin engines are installed in each of the wing tip mounted tilting pods and are used with reheat for both takeoff and forward propulsion. The aircraft is controlled in hover by differential engine thrust, not as in the SC 1 and the Balzac by means of air jets. The very fast thrust response of the RB 108 is retained in the RB 145 to give excellent aircraft control in attitude as well as altitude.

The lift engine installation of the VJ 101C is fairly conventional and needed little special installation development. The twin engine pods (Fig. 5), on the other hand, which tilt

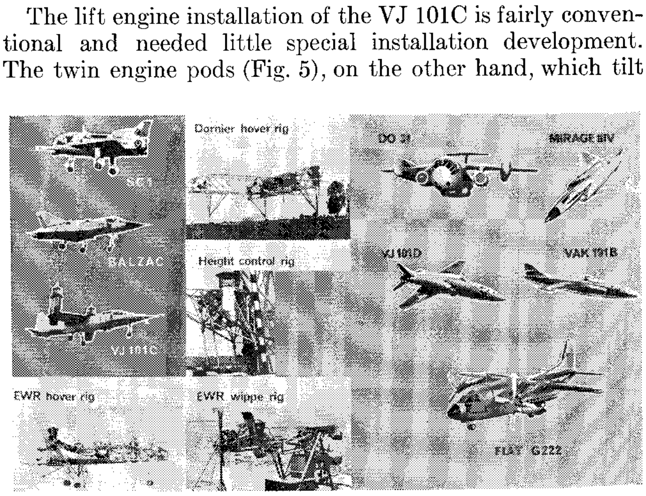

Fig. 4 Liftjet installations.

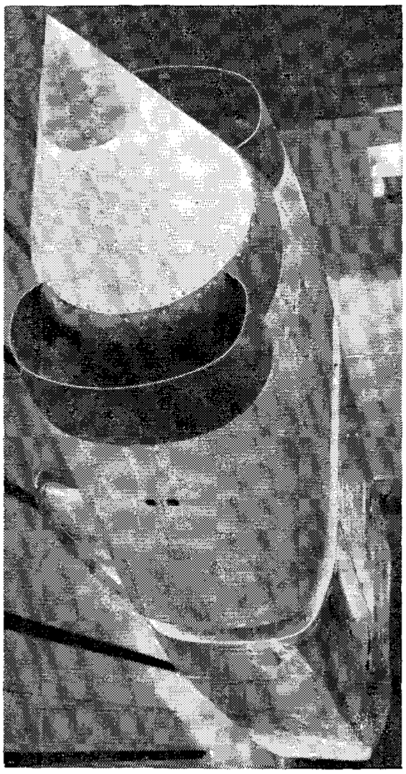

Fig. 5 VJ 101C swiveling pod in wind tunnel.

from vertical to horizontal, were completely new. Rolls-Royce designed and manufactured these pods in close collaboration with the southern German group of companies, EWR-Süd.

The requirements of the engine pods were particularly severe; apart from the main bearing and tilting mechanism, all the services and controls had to be fed in through a small diameter shaft, and of course the design had to be such that there was the very minimum chance of fuel leakage. In addition, the pods were designed to have the minimum frontal area to give low supersonic drag.

The VJ 101C made its first free hover on April 10, 1963, and after a period of control system development completed its first transition on September 20, 1963. Table 1 gives the total bench and flight hours to date for the RB 108 and RB 145 engines. The engine flight hours are total hours, that is, the actual running time of a group of engines multiplied by the number of engines in the group. These figures also include ground running, which is naturally a fairly large proportion of the total for experimental and prototype aircraft.

As well as the specific development of the RB 108 and RB 145 lift powerplants, much work has been done on other aspects of VTO powerplants, notably the problem of takeoff from unprepared surfaces. There are three main problems associated with vertical takeoff from an unprepared surface. These are 1) the ground suction, 2) the possibile ingestion of hot gas into the lift or propulsion engine intakes, and 3) the erosion of the ground surface by the lift engine jets.

Fig. 6 RB 162, lightweight.

II. RB 162 Second Generation Liftjet

Following the encouraging background experience and success on the RB 108, it was realized that it should be possible to achieve a much better thrust-to-weight ratio which could lead to a useful service range coupled with true VTOL capability. For the size of aircraft under consideration, it appeared that a thrust figure in the region of 4000 lb was required. The design had to be as simple as possible with the minimum of components and systems associated with the restricted role of a liftjet which is required to operate at low aircraft speeds only, and over a restricted altitude range.

Our philosophy was to produce a reliable lift unit that would be low in weight and cost, small in volume, and capable of being used in multiple jet pods or banks of engines. If these criteria could be met, the bank of lift units would be comparable to some extent with the cylinders of a piston engine except that in the case of failure of one cylinder the thrust from the remaining cylinders would be unaffected. For added safety under conditions of maximum takeoff load, the thrust of the remaining jets was to be capable of being raised by about 7%, which would maintain a high enough level of total thrust to complete a takeoff transition. The low weight and bulk of this liftjet (Fig. 6) would also ease handling and transportation and the general simplicity result in simple maintenance and, above all, reliability.

Table 1 Total bench and flight hours for RB 108 and RB 145 engines

	Bench development Running		Flight testing			
Engine	Hours	Beginning of test period	Aircraft	Total engine hours	Number of takeoffs	Beginning of test period
RB 108	6362	July 1955	Short SC 1	792	453	September 1957
			Balzac	116	113	July 1962
			Hover Test Rigs	339	137	March 1961
RB 145	3174	July 1961	VJ 101C	202	47	January 1963

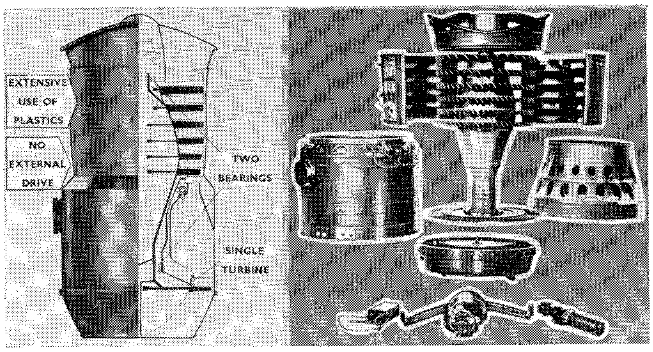

Fig. 7 RB 162 liftjet.

The detailed design concept was evolved in the following way:

1) A single-stage uncooled turbine represented the minimum turbine complexity and cost.

2) A single-stage turbine could drive a compressor of 4.25 compression ratio very efficiently, and this was nearing the maximum compression ratio that could be achieved in a reasonable number of stages without use of variables.

3) The absence of high-altitude requirements permitted a low volume and short length combustion system to be used. By adoption of a single-sided design, it was also possible to meet the fairly large air bleed requirements for aircraft control without introducing complications or high losses.

4) The resulting rotor system was sufficiently short to permit a rigid design supported on two bearings.

5) By strict adherence to the operation requirements for liftjets, simple fuel, oil, and starting systems were achieved. This emphasis on low cost and weight was not to be achieved by relaxation of stressing and reliability standards for the duties required. Certain aspects were certainly different. Long creep life, judged by transport engine standards, was not required, but the number of cycles and starts was likely to be greater. Safety standards, particularly from the point of view of blade containment, were required to be of the same high integrity as other engines produced by our company. This was an exacting requirement when coupled with ultra lightweight constructions.

Details of Construction

The components of the engine can be seen in Fig. 7. Plastic materials have been used extensively in the cooler parts chiefly because of their suitability for large-scale low-cost construction, but also because of a significant weight saving. The front bearing housing is molded in a small number of pieces and bonded together as one assembly.

This casing is bonded at the rear to the two halves of the compressor casing. These half casings, as can be seen in Fig. 7, are themselves fully bonded assemblies of stator blades and casings and are bonded together by axial seams. The complete compressor assembly is bonded to the steel combustion casing that is the main structural component in the engine. This carries the mounting trunnions externally, and the turbine and combustion chamber are carried internally.

The whole bonding process is completed in one operation, and the engine can be dismantled in minutes. There is no limit to the number of bonds that can be made using the latest process.

The single-piece compressor rotor drum is of welded construction and carries the first-stage aluminum rotor blades on pin fixings and the remaining stages of plastic blades in dovetail fixings.

Use of plastics

It may be of interest to review the plastic materials in a little more detail. Much effort has gone into the development of plastics for use in aircraft and engines in the industry, and our company had accumulated a considerable amount of experience on plastics before the decision was finally taken to use it extensively in the RB 162 liftjet. Although a fair amount was generally known about the use of plastic for low stressed components working at low temperatures, little information was available for design of highly stressed and complex components. Our company first began its serious research into the manufacture of engine components about 10 yr ago, and the early examples were in easily molded compounds of the asbestos-reinforced variety. Very soon, however, the full advantages of laminated glass-fiber-reinforced resin systems were realized and a comprehensive program was planned both to develop the material and to learn how to design blades to suit the novel properties.

The obvious design advantages, apart from cost, include the very high strength in the direction of the fibers, the ability to lay the material to suit the duty and the general high strength/weight ratio. In fact, on a weight-for-weight basis the materials are far superior to most others, and on specific stiffness and hot creep strength are comparable over an adequate temperature range. On the debit side, little was known about properties in detail and fatigue properties in particular, and the low Young's modulus meant that deflection under loading would be a problem.

Many new manufacturing problems were present. Control of the basic raw materials, the refrigerated storage necessary to prolong the uncured "shelf life," the design of suitable dies, and many other problems had to be solved before consistent and satisfactory components could be produced.

Fuel system

The RB 108 type of common fuel system for supplying and controlling four engines as used in the Short SC 1 was not considered the best type for installations involving more than four liftjets, and a completely self-contained fuel system was designed for the RB 162. The system had to meet the conflicting requirements of compact size, accurate control over a wide thrust range, acceleration, engine light-up, low weight, and insensitivity to dirty or icy fuel.

Oil system

The present design of system is completely self-contained on each liftjet; the diagram shows its essential features. Based on the fact that the over-all running time was short, it was decided that the simplest system was to inject one shot of oil into the bearings upon each engine startup.

Starting system

Complete dependability was the key requirement for starting since the basic concept of separate liftjets demanded "in-flight" starts on most missions, and a simultaneous start on all units before takeoff. The method finally chosen was by high

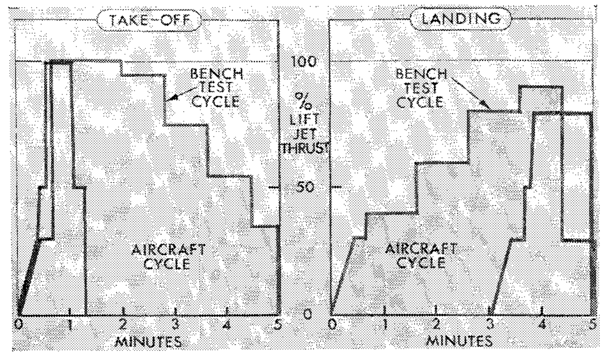

Fig. 8 Liftjet test cycles.

pressure air impingement onto the turbine blades, although as an alternative for certain applications, a hydraulic starter was provided in the nose bullet. Two independent igniters and two atomizer jets fed from the fuel system complete the system. The absence of complication has, so far, paid good dividends, and outstanding reliability has be enachieved during the development period.

Development Highlights

The fundamental operational difference between a liftjet and a conventional propulsion jet engine lies in the running time. Whereas propulsion jets are expected to run thousands of hours between overhauls in commercial transport and hundreds of hours on military fighter aircraft, the liftjet life can be be measured in terms of tens of hours for either duty. The number of takeoffs, however, will be the same whatever the aircraft for both propulsion and liftjets and, in addition, nearly full power is also used on the liftjet for landing. This also means that the number of starts is going to be twice that of the conventional jet and may eventually come to be the factor governing turbine blade life.

Test cycle

For bench testing of liftjets, a new type of test cycle was devised. This test cycle is compared in Fig. 8 with a typical flight takeoff and landing.

The period of operation at maximum power and the total period of running were both more than doubled over the respective flight case to provide a safety margin, and, furthermore, the bench cycle was "stepped" to cover the whole thrust range between idling and full thrust. Each bench cycle simulates a 5-min takeoff and 5-min landing, which is probably three times as long as the transition time.

Development Problems

A number of problems arose during development which were peculiar to a liftjet and its duties. Use of plastics and light metal components and fabrications called for much more tooling during manufacture in the experimental shop than is customary. This carried with it the great advantage that new manufacturing processes could be learned and evaluated in good time before serious production began. Against this advantage costs were much higher and delays unavoidable when modifications were found necessary. Plastic material for compressor blades, for example, introduced a brand new problem during compressor development.

Another mechanical problem particularly associated with the liftjet was the vibration of thin sheet metal walls which lead to some spectacular fatigue failures. This type of problem was not always easy to evaluate as strain gage measurement on sheet metal walls tended to give a wide scatter of resonant frequencies.

A typical example of trouble due to the vibration of sheet metal walls occurred in the front diaphragm of the exhaust unit (the original design of which was 0.018-in.-thick nickel alloy). This wall carries a pressure load due to one surface feeling the pressure of the cooling air being fed up the rear surface of the titanium turbine disk and the other surface being vented to atmosphere.

Persistent failures of this wall were found during early development of the RB 162-1, after anywhere between 1 and 4 hr of bench testing, depending upon the nature of the test. Fatigue cracks originated in several places and propagated to join up, with the result that large patches of the diaphragm wall eventually broke away (Fig. 9).

Several methods were tried to overcome this problem, including redesign to improve the stiffening, local damping, and thickening up of the material. Finally, a completely successful standard was achieved as proved on more than 20 engines and including longer test runs than in a full-type test.

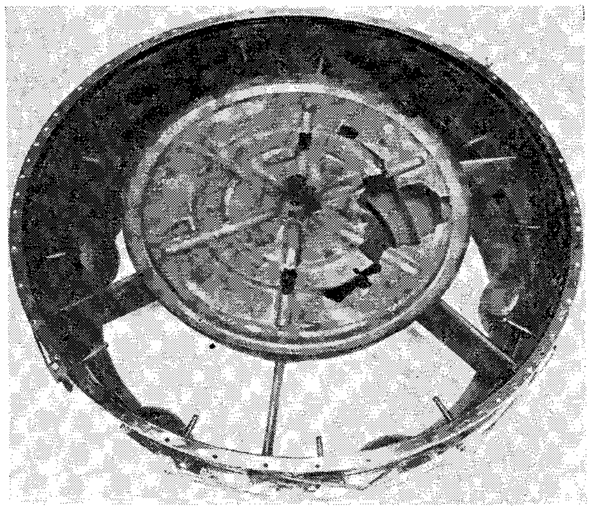

Fig. 9 RB 162 vibration failure.

This and other similar failures in lightweight fabricated components confirmed the suspicion that irrespective of the nominal design requirements, there were certain minimum thicknesses of material below which no degree of refinement in the elimination of local stressing was of any avail.

Intake Testing

Full power was reached within about six months of first running, but the first really important milestone was reached after 15 months, when an engine was installed in the company VTOL wind tunnel. This tunnel was built in order to explore the effect of flight transition conditions on liftjets.

By use of various spoiler flaps in the full-scale tunnel, it was possible to reproduce on the test engine the full range of intake patterns associated with various flight conditions together with the position effect in the fuselage. The most important aspects of the tunnel test were to ensure that the liftjet had sufficient surge margin to operate and handle satisfactorily behind VTOL intakes, and that light-up and pull-away should be possible under windmilling conditions.

During the full-scale tunnel tests, two individual liftjets were separately put through an extensive test series covering all the flight speeds from 30 to 300 knots and over a range of aircraft incidence and yaw.

Aircraft Tunnel Testing

Several months later, a complete "half" aircraft and set of four engines was tested in the French National Wind Tunnel at Modane for engine and airframe compatibility. This tunnel is operated by Office Nationale d'Etudes et de Recherches Aeronautiques and has been successfully used in the past for such tests as the Coleopter. A full-scale macquette, consisting literally of half of a Mirage IIIV split along the longitudinal centerline, was mounted in the eight-meter test section and fitted with two pairs of liftjets. In this tunnel, the effect of multi-engine operation was fully explored under representative flight conditions. In both the Modane and Rolls-Royce tunnels all stages of the compressor were strain-gaged to study intake effect on the blading both aerodynamically and mechanically.

Development to Production

The original choice of engine size at 4400 lb had been made sometime ago to suit various VTOL projects in Europe, and with the passage of time there was a growing realization that more power was going to be needed for production service aircraft. It is particularly obvious from a study of the past history of growth in aircraft weight and matching engine

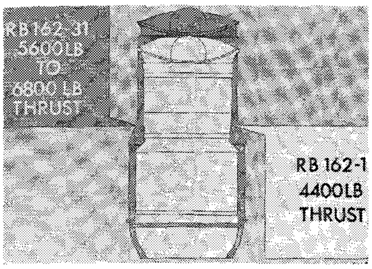

Fig. 10 Comparison of RB 162-1 and RB 162-31.

thrust during the life of most projects that, for VTO in particular, a genuine thrust growth potential would be essential. These factors were not overlooked when the RB 162 was designed, and a fairly generous growth was allowed for. It was becoming evident, however, that the growth factor was going to be absorbed before the engine entered service due to changes in requirements and weapons system. Rather than stretch performance before commencement of production, it was decided that a 30% scaleup was required to avoid eating into the future potential (Fig. 10).

Developments from the RB 162 Liftjet

With a production version in sight, the RB 162 can be considered for other applications and developments. One obvious use is as a booster, since the liftjet is specifically developed for takeoff duty. The self-contained compact design lends itself for use in additional pods, thus requiring the minimum of alteration to existing aircraft, although the small size of the booster would also readily permit a fuselage tail mount.

The booster would be started during taxi-out or just prior to takeoff, and on takeoff, full power would be maintained to the end of the first segment of climb out, or possibly a little beyond. On landing, if fitted with a thrust reverser, the booster could be used to reduce the landing distance. Should a propulsion engine failure have occurred during the flight, the booster could also be used on the approach in readiness for a "go around," thereby increasing the margin of safety.

Size of Liftjets

The present sizes of liftjet under development are in the 4000–6000 lb range and were chosen primarily for military strike aircraft and small VTOL transports. For larger aircraft, it is obviously desirable to keep the number of engines to the minimum consistent with safety, and there is no doubt that larger liftjets with more thrust are possible. However, two problems associated with larger liftjets are 1) worse specific weight for a given standard of engine design or "state of the art," and 2) a slower response rate or time constant.

The effect of a straight geometric scale up from 5000 to 10,000 lb liftjet for a given standard of engine design can be seen in Fig. 11. Obviously the threatened deterioration of 20% in specific weight would be a challenge to the designer,

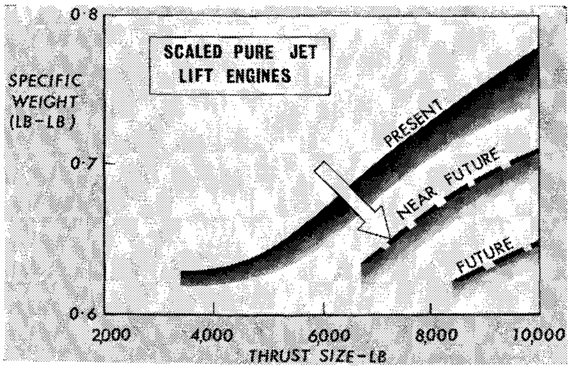

Fig. 11 Variation of engine specific weight with thrust.

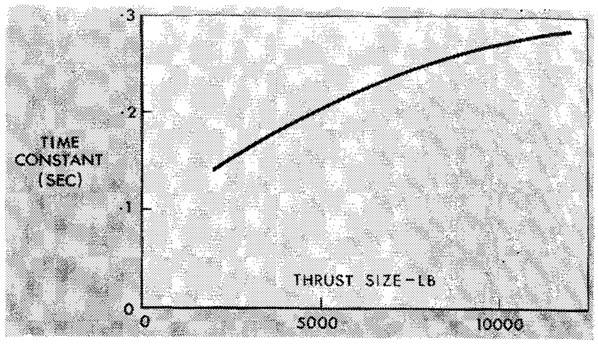

Fig. 12 Variation in time constant against size.

and past experience has shown that time and ingenuity could be expected to defeat the weight law to a large extent.

Thrust response rate with throttle movement for a given type of engine becomes slower with increase in engine size unless complications of variable geometry can be used. This effect is particularly important where differential throttling for aircraft control is employed (Fig. 12).

Safety aspects

Considerations of thrust loss due to a single liftjet failure must also be taken into account when considering size of the liftjet. We cannot convince ourselves of the safety of a transport aircraft unless full lift and control can be maintained with one engine out. Working along these lines, our studies lead us to the conclusion that 8 or 10 liftjets are the minimum for safety under hover conditions. With this number the probability of two or more liftjets failing independently is sufficiently remote to be ignored, being of the order

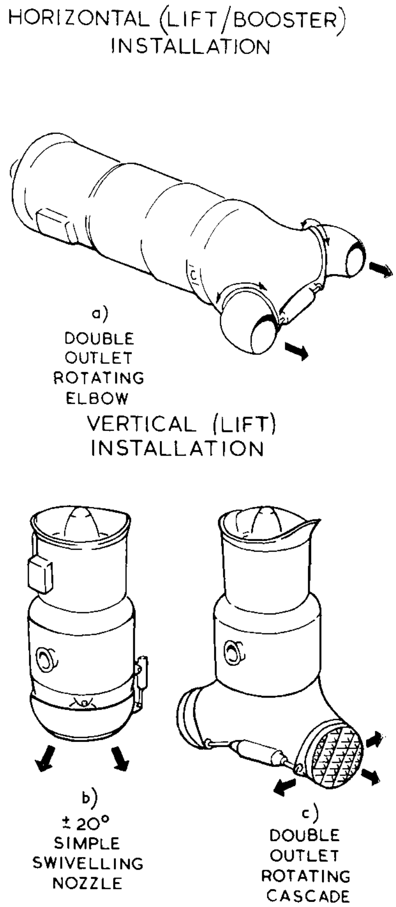

Fig. 13 Liftjet thrust deflectors.

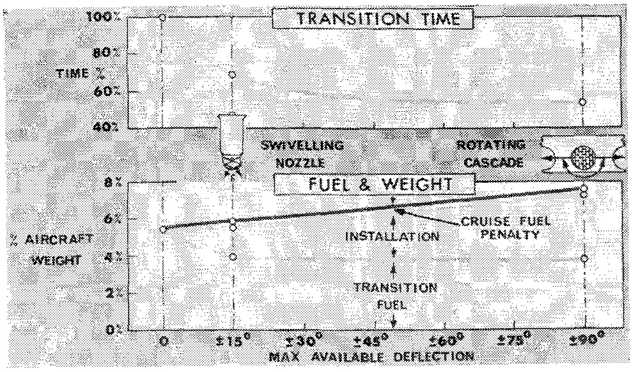

Fig. 14 Transport with lift turbojets, lift thrust deflection.

of one incident per 94 million takeoffs, or one incident in the total airframe lift of a squadron of 10 military aircraft. These probability figures include the optimism given to the simplicity and small number of parts of liftjet compared with a conventional propulsion engine.

Lift Turbo Fans

When VTOL is under consideration for large transport aircraft, it is natural to consider the use of lift turbo fans both to keep down the total number of lift units and for other reasons. The advantages of lift turbo fans are obvious: lower jet noise, lower jet velocity for ground erosion, and low specific fuel consumption. Until detailed studies are carried out the disadvantages are not so obvious. Up until now, aircraft manufacturers have favored the liftjet for its small frontal area and reduced drag during cruise or the remote gas-or mechanical-driven fans rather than lift turbo fans.

Noise

For a military aircraft, noise may not be an overwhelming consideration but the same cannot be said for civil aircraft. Although jet noise will certainly be reduced with increase in fan bypass ratio, blade noise will be increased and methods of silencing this have yet to be developed.

Thrust Deflection

It is impossible to discuss liftjets and lift fans without mentioning jet deflection. Our company has had test and flight experience of many different types of deflection which could be used on liftjets and turbo fans.

Figure 13 shows several methods of thrust deflection which are being developed by the company, in addition to the method of tilting the complete unit as in the Short SC I and the German VJ 101C. On the left of the diagram is shown a double outlet with fully rotating elbows which would be suitable for a lift or booster application, including provision of full thrust reversal on landing. On the right-hand side can be seen the type of swivel nozzle proposed for small deflections (under $\pm 20°$) and also a double-outlet rotating cascade.

The weight penalty is more or less proportionate to the degree of deflection but much shorter transition time reduces the penalty when expressed in terms of engine weight and fuel used during transition (Fig. 14). It is a sobering thought that the thrust-to-weight ratio of the equipment necessary to produce full range thrust deflection is of the same order as a liftjet.

Installation

Achievement of a low engine weight is only part of the task. It is equally important that the installed weight in the aircraft should be as low as possible, that instrumentation and other demands on the aircraft should be kept to a minimum, and that actual unit change and maintenance should be simple and quick.

Early studies predicted that liftjets could be installed for a 50% weight penalty. This has not yet been achieved for the following reasons: 1) the liftjet development itself has not yet progressed sufficiently, and 2) less work has been carried out on the installation aspects than on the engine itself.

The liftjet itself will become smaller and lighter for a given thrust, and this will, in turn, result in dramatic gains in the over-all installation weight. Higher thrusts per unit airflow will also reduce the size and weight of intake doors.

It is possible now to design a simple plug-in installation in which the few connections are made automatically and a unit change can be accomplished in a few minutes. Whether this will prove to be the optimum system, when liftjet "overhaul lives" are so long that engines may only have need to be removed every two or more years, remains to be settled.

Maintenance

The question of maintenance has often been raised as a major problem for the liftjet because of the numbers of units involved. It will perhaps be some time before proof can be provided, but because the problem is an obvious one, a great deal of attention has been paid to it.

Experience on prototype aircraft is not necessarily a true pointer for full service operation. However, judging by a careful analysis of our practical experience on the European prototypes flying with liftjets, compared with the equivalent conventional prototype experience in which maintenance hours were shown to be roughly the same for both, it appears that operational duties should not present a more serious problem than at present.

The following advantages may be set against the "larger number" question: 1) simple prime mover, few parts (Counting all parts, including blades, there are six times as many part numbers in a typical propulsion engine like the Rolls-Royce Spey as compared with the RB 162.), 2) simpler systems on the liftjet, 3) "trouble shooting" easier and quicker, 4) easy access for visual check of compressor and turbine faces, 5) short running time, 6) inherent low creep life utilization because of ability to meet high "emergency rating," 7) very little instrumentation, 8) quick change of liftjet, and 9) quick change of "hot end" parts.

The Future

It has only been possible to touch on some of the more important aspects of design, development, and practical flight experience of the Rolls-Royce liftjets in this paper. Enough may have been said to show that the development of lightweight liftjets is already a practical proposition and the prospects for the future are very exciting. Experience on these lightweight engines will undoubtedly influence future designs of the conventional propulsion engines. Many new uses for the compact low-weight power unit will arise beyond the more obvious ones described in this paper, and greater possibilities will be opened up to the aircraft designer. It is already possible to see that the trend toward lower weight and reduced volume can continue, and revolutionary changes in aircraft layout may not be far off.