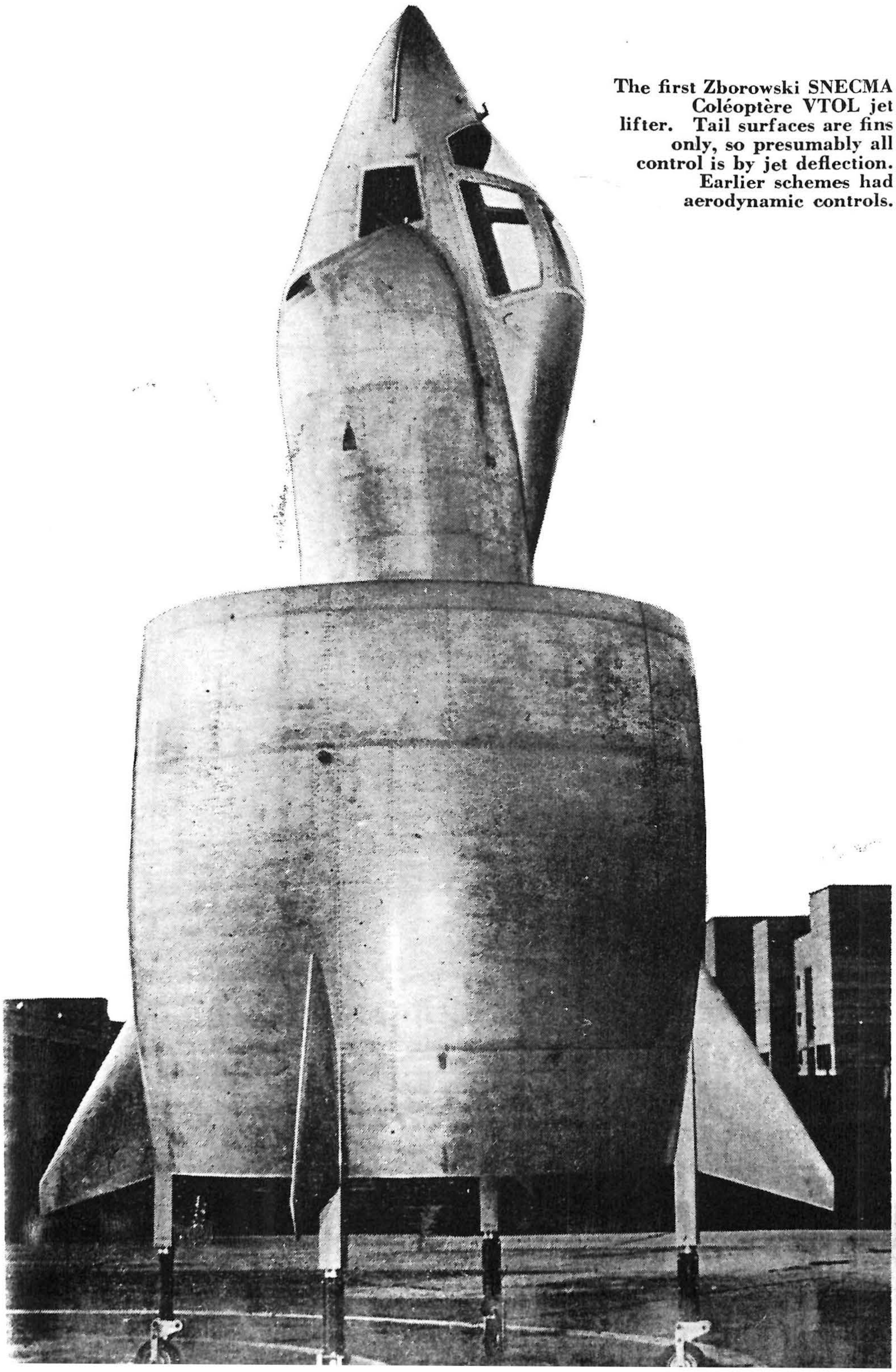
Some Thoughts on VTOL

By JAMES HAY STEVENS



The first Zborowski SNECMA Coléoptère VTOL jet lifter. Tail surfaces are fins only, so presumably all control is by jet deflection. Earlier schemes had aerodynamic controls.

WHEN THE Editor asked me to do a round-up on VTOL and STOL activities, I first had it in mind to try to survey the whole varied range of projects. However, it soon became obvious that, at the very least, one entire issue of AIRCRAFT would be required, so in the end we compromised on a two-part treatment, each section to be of readable proportions.

There has been much muddled thinking on VTOL, even among technical types, so that even the interpretation of the initials has been distorted. *Vertical take-off and landing* is with us now, and has been with us in a practical form for almost a generation — ever since Igor Sikorsky got airborne in his homburg hat in the VS-1 on April 15, 1941 and stayed that way, under full control, for 65 minutes. Even before that, the latest of the Autogiros invented by Juan de la Cierva had been brought to a pitch where skilled pilots could achieve genuine VTOL.

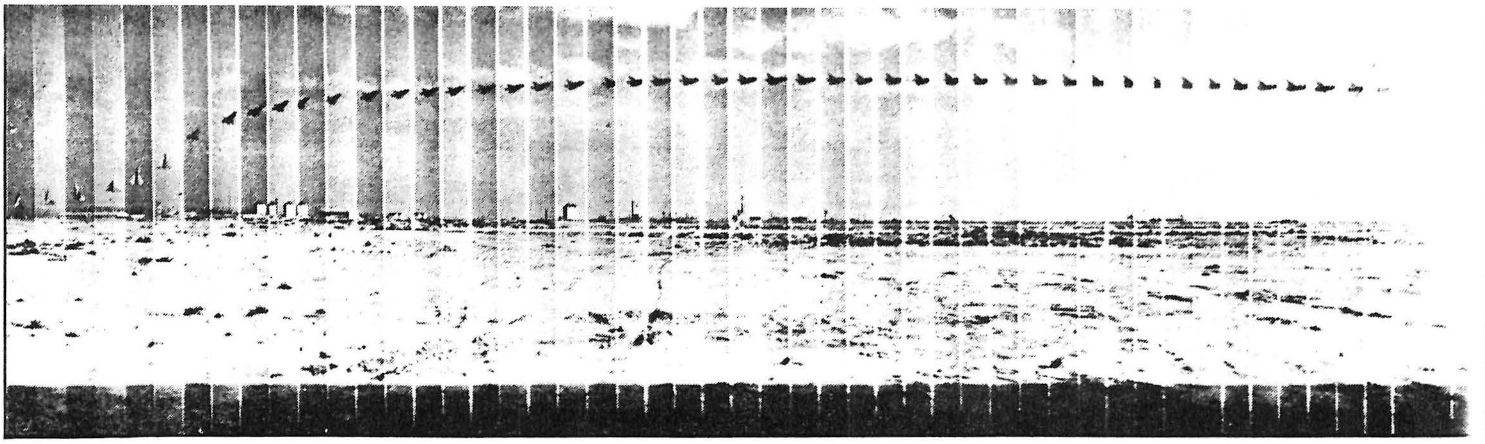
Built-in Headwind: The helicopter has many limitations: its mechanisms are cumbersome and heavy, it has plenty of built-in headwind, the very nature of the beast — that is the stalling of the retreating blade — limits its maximum speed. Nevertheless, it is likely to remain the most efficient method of plain vertical flight and of hovering — at least until antigravitics materialize. The sheer efficiency of the helicopter for its fundamental task is often obscured by its poor payload and ampg as a transport.

Here I would like to make the point that all heavier-than-air flight is closely related and, moreover, it is straight Newton: Third Law, "to every action there is an equal and opposite reaction." In each and every case of aerofoil is the device which is used to accelerate a mass of air downward and so produce a reaction that will overcome the acceleration of gravity. The resultant lift is in direct proportion to the aerodynamic efficiency of the aerofoil and the net amount of energy supplied to the system.

At the other extreme, the sailplane is of the highest aerodynamic efficiency and spins out the initial potential energy of its launching height by the tortuous use of upcurrents of air bringing heat (solar) energy reinforcements from the ground — a little fuel goes a very long way.

The reaction of an airplane wing

Dec/58 Aircraft 236



Series of photos made by sequence camera shows Ryan Vertijet transition from vertical to horizontal flight.

arises from the forward motion imparted by engine thrust and the designers' compromises wring an infinite number of changes out of the basic formula. The general picture, however, is that most lift is obtained from each pound of fuel by accelerating a large mass of air slowly—e.g. a high aspect ratio with a heavily-cambered wing section.

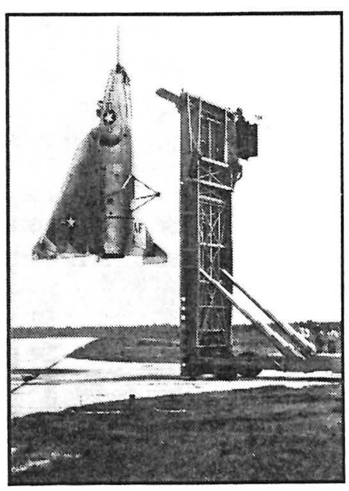
Rotating Wing: The helicopter is, of course, simply a specialized wing that is rotated to give a relative airflow without moving the aircraft. Rotor downwash is the same as that from a wing, save that it is highly concentrated. It is important in this context to remember that an aerofoil reacts upward from its downwash, rather than to think of the suction above the upper surface, for it is then easy to see the direct link with jet propulsion.

The extreme form of VTOL is, of course, jet lift; as exemplified by the Ryan X-13 and X-14, the Rolls-Royce "Flying Bedstead", the Russian ditto, the SNECMA "Flying Atar" and *coléoptère,* the Short SC-1, etc. The ultra-rapid, hot jet efflux replaces the rotor or wing downwash and, be it noted, this gas stream is provided by the hundreds of tiny aerofoils in the compressors(s). True, the heat energy released by combustion of the fuel accelerates the jet, but part of it drives the compressor, the essential aerodynamic device in the cycle — a VTOL ramjet is a physical impossibility.

Jet lift is probably the most extravagant method of using fuel yet devised — certainly it is in subsonic flight. Although it can be achieved experimentally with almost any good modern turbojet, a thrust weight ratio of at least 5 or 6 is necessary to obtain a sufficient weight margin for airframe and fuel. Such an engine weight ratio is only attainable with a low pressure ratio, which permits the use of lightweight materials throughout the engine. However, low pressure ratio means a relatively high specific fuel consumption, of the order of 1.2 lb./lb. thrust/hr.

The Hard Way: The back of an envelope and a stub of pencil soon show that, for example, 7,000 lb. of jet thrust will require 140 lb. of fuel a minute, while a modern piston-engined helicopter of 7000 lb. weight might use 5 lb. a minute. Efficiencies and installations would vary widely, but the crossover point where jet lift fuel weight exceeds the weight of a rotor installation is of the order of four minutes — thus jet lift is only tolerable where rotor drag in cruising flight is not.

An essential difference between jet lift and that of a rotor is that while the latter has a certain pendulum stability, the former is completely unstable because as soon as the thrust line and the c.g. do not coincide an upsetting couple is created. In order to preserve balance a "black box" is required; that is an auto-stabilizer based upon rate-sensing gyros to detect any tilt and the angular velocity of it. The information from these gyros is computed electronically and is fed to control mechanisms which, in the Rolls-Royce/Short concept, actuate outrigger balancing jets, and, in the SNECMA one, main-jet deflectors. Pilot control is in the form of a graduated displacement override that upsets the balancing function to the desired degree.



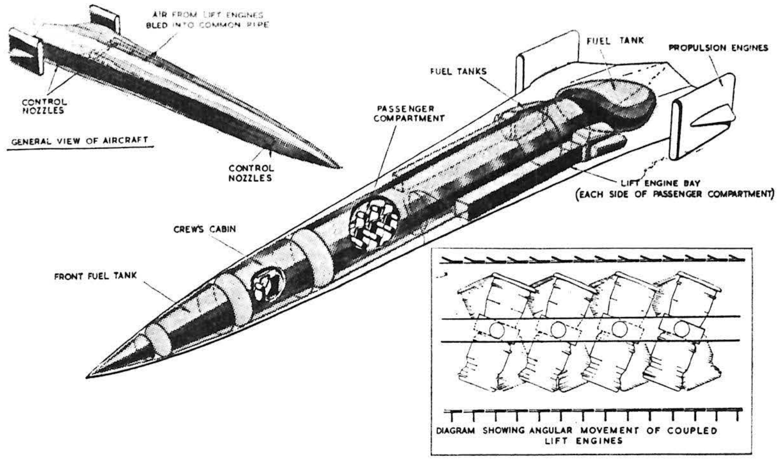
Vertijet lifts off trailer suspension cable, then "backs" clear before transition on level flight.

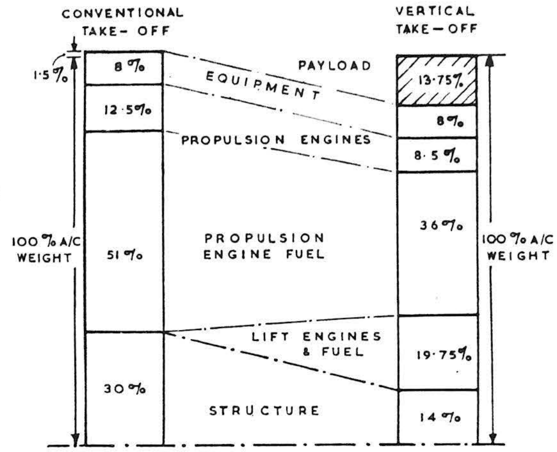
Now that the balance and control of jet-lift flight systems have been satisfactorily proved in Britain, France, Russia and the U.S., it remains but to apply them in one of the several forms tested, these are: tail-sitters, flat-risers and tilt-thrusters. Each has its own particular virtues and vices, or rewards and their prices, which must be weighed against what is required — in other words it is compromise once again.

• **Tail-Sitters:** These are a pretty obvious breed and were in fact among the earliest studies — the Fairey FD 1, a rumoured Polish design, the Zborowski *coléoptères,* the Ryan Vertijet and the defunct airscrew-driven Convair and Lockheed designs are familiar examples.

Essentially, this is a fighter application, since gimbal-mounted passengers, although seriously postulated by a few long-haired scientists, are quite unthinkable. However, with modern interceptors having engines of static thrusts approaching their weights it could be a practical proposition where space is restricted to a small platform, as on a ship, or where the defence must be completely camouflaged. Of course it further strait-laces the designer, who must keep down structure weight, while accommodating additional black boxes, a secondary set of controls and a tricky cockpit layout — and he is always hard put to it on the weight question.

A disadvantage of the tail-sitter is





Above L, diagram showing essential features of Griffith flat riser; R, percentage comparison of conventional and Griffith supersonic airliner weights; below R, supersonic VTOL flight plans for take-off and landing.

the "windage" of its upended wing surfaces. This is one reason for the "mounting board" of the Ryan. It is claimed that the almost symmetrical shape of the *coléoptère's* annular wing does much to reduce the toppling force of a surface wind.

The SNECMA Zborowski *coléoptère* layout is approaching the flight stage, which will prove (or disprove) its feasibility. The principal advantage claimed for this curious vehicle is that the inherent stiffness of a cylinder makes this a very light wing structure. There is ample fuel volume, well-disposed relative to the c.g., and the L/D ratio is not much lower than that of a delta wing of equivalent lift. The annular wing does not, according to its inventor, sensibly increase thrust by induced flow, but it can, he claims, be used as a ramjet, or contain a ducted fan.

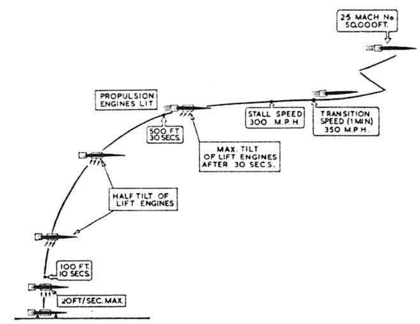
"Backward" landing while literally looking over the shoulder is evidently less tricky than one would think and can be aided by an auto-pilot giving a controlled descent rate. With the high fuel consumption of a supersonic fighter, the difference between take-off and landing weight is so great that main engine thrust may well give an ample margin (110 to 125% aircraft weight are the extremes of different pundits) for control of vertical descent after a sortie. On the other hand, at take-off weight boosting might be needed, possibly by rocket, to achieve transition speed. Again, it might well prove simpler and more practical to use zero take-off ramp technique.

A word must be said about the interesting, if anachronistic, U.S. Navy airscrew-driven tail-sitters. If these, with their counter-rotating, large-diameter fans had been developed before combat speeds passed the 500 mph mark they could have been useful interceptors. This layout had, of course, the advantage of some pendulum stability and a slipstream which obviated the need for separate low-speed control devices.

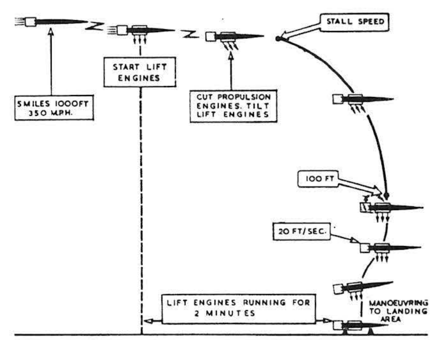
•**Flat-Risers:** In this form of VTOL system the airplane is a near-wingless supersonic vehicle which would have an impossible stalling speed — say 350 mph at take-off and 300 mph empty. The inventor of the scheme is Dr. A. A. Griffith of Rolls-Royce and he has done a great deal of thinking and experimenting with his fearsome looking "darts".

The whole point here is that an optimum supersonic aerodyne form has first been designed. This is practically a stone-age spearhead with wings that are little more than "cutting edges" blended with the main core. For this shape, the inventor claims far better values of L/D in supersonic flight than are obtainable with any conventional wing-fuselage-tail formula. This, in turn, means lower thrust requirements, fewer (or smaller) engines and much less fuel — so the weight spiral is unwound considerably.

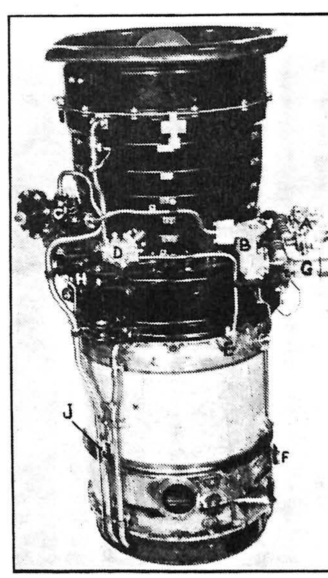
Next the structure itself is unconventional because of its high volumetric form; a girder construction is envisaged in which a (windowless) pressurized container is used for the personnel and fuel tanks are of good volu-



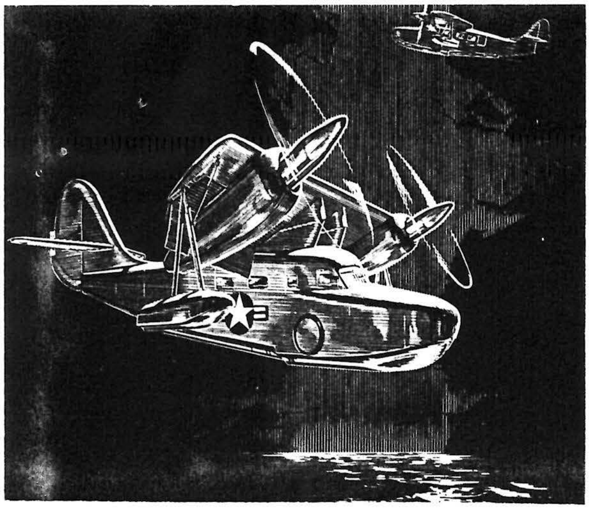
Take-off Sequence.



Landing Sequence.

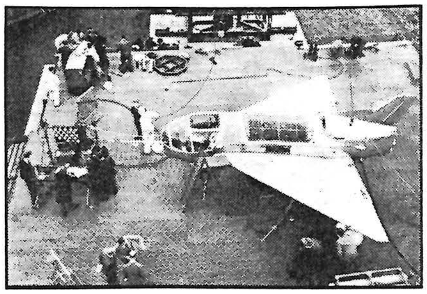


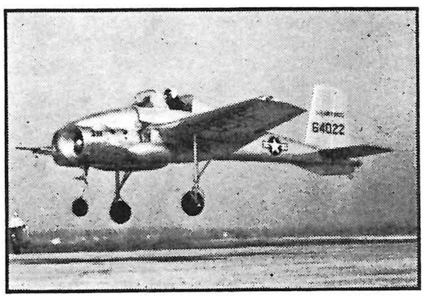
Right, Rolls-Royce RB-108, first jet lift engine. Legend: A—flexible fuel couplings to permit tilt; B—fuel junction unit; C—Hobson fuel control unit; D—fuel distributor; E—fuel manifold on combustion chamber; F—combustion chamber fuel drain; G—mounting trunnion; H—lugs for coupling bolts; J—bearing oil drains; K—air bleed sleeve for control jets.



Kaman K-16B VTOL/STOL aircraft utilizes a tilt-wing and propeller-rotors. It is being developed for the U.S. Navy.

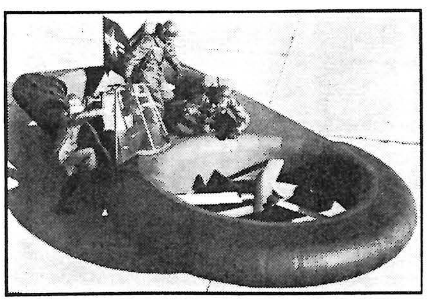
Short SC. 1 VTOL research aircraft is shown on the specially built test platform from which all early trials are being conducted.

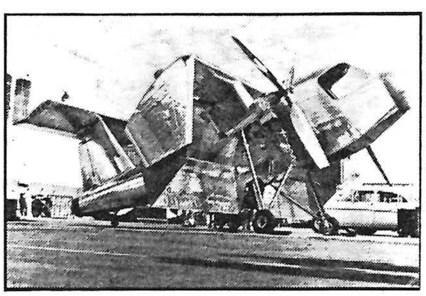




Bell X-14 experimental VTOL aircraft for U.S. Air Force has successfully completed full transitional cycles in flight.

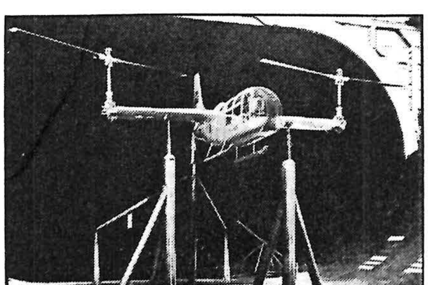
Piasecki 59K, being developed under U.S. Army contract as a general purpose high utility vehicle, has two submerged rotors.





Ryan Vertiplane uses the deflected slipstream principle to achieve VTOL. Production version is to be built for U.S. Army.

Bell XV-3 convertiplane, shown here during full scale wind tunnel tests, has tilting rotor propellers for vertical take-off and landing.



metric shape. The outer surface is unstressed, other than by direct aerodynamic loads, and so can be of light alloy even for endurance flights — two hours for the Atlantic — at Mach 2.5. Problems of differential thermal expansion are solved by passing hot air through the tubular structure. Propulsion engines, turbojets with afterburners, are disposed in two "cigarette packets" at the rear ("wing" tips), where they can operate at high efficiency, cannot subject the structure to sound-wave battering, and comprise fin area for directional stability. Small aerodynamic surfaces give control in horizontal flight.

Having designed what he considers to be an idealized load-carrying supersonic shape, Dr. Griffith had to devise a means of getting it on and off the ground — here I am not quite sure whether the supersonic egg or jet-lift chicken came first, but in the result it is immaterial. So great has been the saving in structure weight that it is now within the realms of possibility to provide the jet thrust to levitate it — even with the added weight of the jet-lift engines and their fuel. What has been done is simply to swap wing, landing gear, and supersonic engine/fuel weight (due to the greater aircraft drag) for the weight of the jet-lift equipment. Fortunately, the shape of the aerodyne is well suited to containing the tanks of small vertically-mounted engines and the associated ducting for the controlling air jets.

Dr. C. T. Hewson of Rolls-Royce gave an outline of the system to The Royal Aeronautical Society in London last spring and his diagram summarizes the flight plan. The Rolls-Royce RB. 108 lightweight turbojets are mounted in pairs on trunnions and are tilted fore-and-aft to aid acceleration into, and to decelerate before, transition. Compressor-bleed air is used to provide lateral and nose balancing jets. Autostabilization would include completely automatic descent and landing. Running time for the lift jets is brief, perhaps three minutes a flight and every effort would be made to keep this to the absolute minimum because of the high fuel consumption — and this means rapid ground and in-flight starting techniques. Dr. Hewson's comparative diagram for the Griffith aerodyne and a conventional supersonic

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VTOL Research in Canada

The pre-production stage is nearing for a Canadian multi-engined transport aircraft capable of taking off and landing vertically with big payloads.

By next spring research may reach the point where it will be possible to conduct air tests of some of the complex equipment, such an aircraft will require to lift itself vertically 10,000 feet off the ground and then fly in level flight at speeds of some 500 mph.

The present speculation is that a VTOL aircraft will fly in Canada in three to eight years. The designers hope they will be able to develop an aircraft capable of carrying a payload of at least 5000 lbs., and probably much more.

Work on the design of a VTOL aircraft in Canada started in 1955, and now is progressing in laboratories of the National Aeronautical Establishment and the National Research Council.

The obvious area for operation of a VTOL plane is the Canadian north, where airfields are expensive and difficult to build and maintain. And the Conservative Government has continually stressed its interest in development of the Canadian north country.

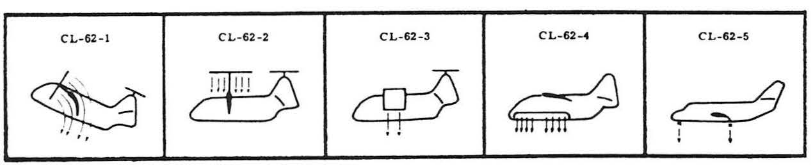
Under present plans, NRC envisages a VTOL aircraft with four turbine engines. These would drive fans embedded in the wings to lift the plane vertically. Once the aircraft was at a safe flying height, the jet blasts from the engines would be switched from the fans to conventional exhausts pointing rearward to give forward flight. This type of powerplant design is expected to win out over other proposals.

One major problem, of course, is what will happen when the plane is in transition from vertical to forward flight. Tests in this connection are being made at Uplands airport at Ottawa, with a station wagon which runs components of future VTOL aircraft up and down the long runways.

While research is still in the preliminary stages, NRC hopes to be able to make some air tests early next year. The present plan is to conduct these tests with a small aircraft, into which will be incorporated some vertical lift equipment. Performance of lifting fans in the wings will be among the first components tested. At the moment, a special 12-inch fan of the type which might be used in a VTOL plane, is under test at the NRC engine laboratory. It is expected that a test fan for a full-size VTOL aircraft will be built within a year or 18 months. It would be three feet in diameter.

Research into optimum configuration of VTOL power plants has involved both theoretical studies and experimental tests. The theoretical studies first entailed a comparison of several gas generator thermodynamic cycles, a comparison of fan drives, and, finally, a comparison of fans. A disc loading of about 200 lb./sq. ft. was attained by a model fan, and then a fan of about 500 lb./sq. ft. disc loading, with a new driving turbine to match, was designed and built. Speed and thrust measurements have been accurately obtained, but a torquemeter capable of operating at speeds up to 15,000 rpm has been installed for the purpose of determining the efficiency of the thrust-producing fans under study.

Construction of balance mechanisms and other equipment is in hand. The smaller of two test rigs is designed to accommodate models having a span of five feet. The larger rig is intended initially for slipstream deflection experiments on wings up to 12 feet in span. The slipstream is provided by propellers driven by four hydraulic motors of approximately 50 horsepower, each fed from a central power plant and mounted independently of the wing.



During the past two years, Canadair has been conducting, on behalf of the DRB, a design study in which the five VTOL aircraft configurations illustrated above were investigated. Briefly, these were:

- **CL 62-1 Slipstream Deflection:** Four shaft turbine-driven propellers, used for normal propulsion, would also be used in hovering. Slipstream would be deflected vertically by very powerful flap system, and resulting reaction would provide lift.
- **CL 62-2 Tilting Wing:** Four shaft turbine-driven propellers would supply thrust for propulsion; would also supply lift in VTOL operation, for which wing and nacelles would be rotated into vertical position.
- **CL 62-3 Tilting Ducted Propeller:** Shaft turbines would drive ducted propellers mounted on wing tips. In normal flight, system would provide thrust for propulsion; in VTOL operation, ducted propellers would rotate 90° to supply lift.
- **CL 62-4 Jet Lift Turboprop:** Turboprop forward propulsion would be used, but for VTOL operation, a series of small, lightweight turbojets, mounted vertically along fuselage sides, would furnish lift.
- **CL 62-5 Turbojet Propulsive Wing:** VTOL lift would be provided by series of turbojets contained in wing aft portion, which would be deflected vertically, and by several jet engines in the forward fuselage. Some of wing-mounted engines would be used for propulsion.

airliner show on a percentage basis the claims for the device.

High Support: The other side of the penny may be briefly summarized. Although the aerodyne requires no landing gear, it has to be supported high off the ground on a special VTOL cradle because below about 1.25 x chord the downward jets generate ground suction instead of lift — since the dart shape has no wing chord as such, the critical dimension would be the span. The Short SC-1 will solve the simple transition problems — it has as yet proved easier than anticipated with all convertiplane configurations — but cannot give the answer to one critical factor. This is whether or not the mass of air being inhaled and ejected will inhibit the establishment of circulatory flow over the aerodyne, where the jet-lift apertures will occupy much of the embryonic aerofoil. The approach flight path, at first offered as a simple all-weather operation of vertical descent over a beacon, obviously involves a precise parabolic path decelerating from Mach 2.5 and descending from 50,000 ft. Because of the limitations of fuel consumption the "canned" passengers would have to be subjected to decelerations of 1/3 or 1/2 g — most unpleasant. Also, no human pilot could control such a flight path and this means even more reliance upon electronics, with duplication against breakdowns.

Again, Mach 2.5 flight will be no joke because maneuvering at such speeds requires enormous radii and I, personally, feel it would be a hard task feeding the airliners into an airway pattern, with timing into the landing beacons to seconds rather than minutes after a three thousand mile flight. The flight planning and ATC for medium-haul operating makes one dizzy to contemplate.

Tilt-Thrusters: These schemes make a very varied bag. First there came the Bell with tilting engines and now the X-14 with jet deflection; the former was a lash-up with various components of other airplanes and included a wing and swivelling engines. As a testbed, it was passable, but since jet thrust must pass close to the c.g. right through the flight, it is, like the later jet deflection, a constricting configuration unlikely to have practical applications.

The other forms of tilt-thruster all

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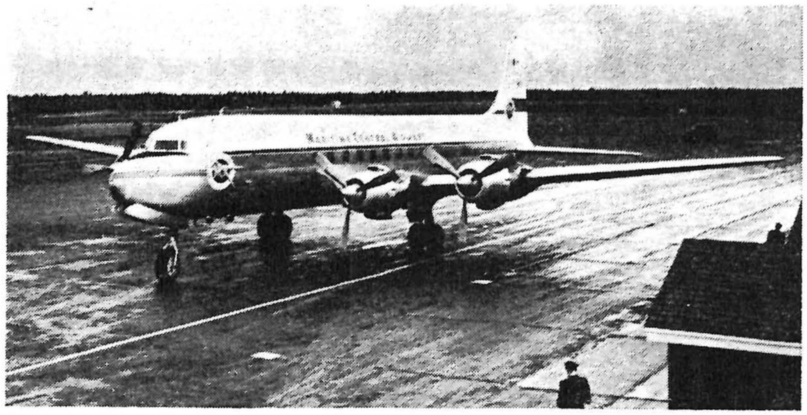
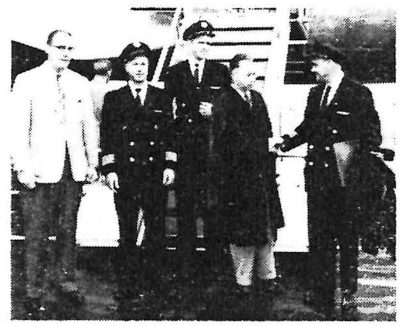
great amount of blue light shining on the red or orange fluorescent pigment is changed and emitted as red or orange light. Bold colors are not achromatic in nature. They do not appear as whites, grays or blacks at extreme distances as ordinary colors do.

As a safety device, fluorescent colors are here to stay. From the published fact that more than 92% of all mid-air accidents happen during daylight conditions of VFR, it is needless to point out the value of "being seen". That the USAF is convinced about the effect of the riotous colors on its air safety program is obvious. In October the U.S. Air Force awarded a contract to Switzer Brothers to furnish 50,000 gallons of Blaze Orange paint and Filteray to safeguard some 13,000 non-tactical aircraft. That's the best kind of testimonial any company can get.





MCA COLLECTS DC-6A: Shown on its arrival at Moncton Airport last month, is Maritime Central Airways' new Douglas DC-6A. The airliner was ordered two years ago at a cost of $1.3 million. It carries 90 passengers, cruises at 330 mph, can can be converted to cargo duty. At right, L to R: R. E. White, chief dispatcher; Capt. C. E. Blair, check pilot; First Officer J. S. Steeves; E. P. Watson, flight supt.; Capt. G. J. Godfrey, chief pilot.

THOUGHTS ON VTOL

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have airscrews: the Hiller X-18 tilt-wing, the Bell XV-3 and Vertol 76. Thus they are essentially low-speed aircraft and have combination rotor/propellers — rather undersize as rotors and pretty overgrown as propellers. They are all of twin-screw configuration. Where the screws are rotated they are at the wing tips to facilitate rotation of the axes. They are related to the Rotodyne in that they are helicopters at take-off and landing and airplanes when cruising. It is simply that the designers have decided that the mechanical complexity of transverse shaft drives in the wing and the headaches of a dual-purpose airscrew have the best potential—weight and reliability wise, that is.

Of the conversion systems, the Hiller and Vertol tilt-wings look most sensible, for the rotors do not have to batter their downwash on to the wing in vertical flight and yet the slipstream helps build up wing lift during transition. It is generally considered to be a layout offering a good payload potential with high cruising speed.

Other Formulae

THE FAIREY Rotodyne was recently fully described (See AIRCRAFT, August, 1958, "Centre to Centre Airliner") and its fundamental design principles outlined. Recapitulating briefly, it is a helicopter for VTOL, with torqueless tip-jet rotor drive, and when cruising is an autogiro with a stub wing carrying 60% of the weight. Rotor off-loading permits a cruising speed of 160 kts. Dr. G. S. Hislop's view is that "gas" drive is superior to a shaft and that the efficiency of true propellers for traction overcomes rotor drag.

The McDonnell XV-1 configuration is similar in principle to the Rotodyne and is claimed to have been the first rotary-wing aircraft to reach 200 mph. Because the XV-1 has a single propeller it requires small tail airscrews for control while hovering.

Most mysterious of vertical flight systems is the shrouded fan. Nobody, to my knowledge, has given any data or simple arithmetic on the thrust-weight ratios attainable. I have heard Igor Sikorsky say that the weight of a tip shroud is about the same as that of the blade tips which it replaces — as a parallel on a weight efficiency basis, endplates usually lose out compared with extended wingtips. Undoubtedly a shroud will increase rotor efficiency and where compactness — such as in the Hiller Flying Platform — is required, the formula has attractions. Equally certainly, though, the relative velocity of the downwash is greater, that is the air requires more acceleration and, therefore, more power to do it — so another figure comes into the comparison. However, I feel that, like the "Flying Atar", its appeal is mainly the psychological one of novelty. With the thrust below the c.g. there is a strictly limited degree of tilt, for traction, before an upsetting couple is formed and the contraption topples.

Double and triple shrouded fan devices will be stable and capable of better traction, but the new U.S. Army projects are decidedly low-speed vehicles. It is somewhat ironical that a "rotor" unaffected by blade stall — for it is really a vertical-axis propeller — is being used for a slow-speed aircraft.

The Bréguet company in France, with a long history of rotating-wing interest, has patented a scheme for rotating fans submerged in the wings of a sleek monoplane — and there is our old friend the Avro Omega. These schemes are theoretically possible, but most of them, when one looks at the complex mechanisms and/or does a few simple sums, are disillusioning. It all comes back to the late Bill Stout's immortal phrase "Simplicate and add more lightness" — for that, after all, is the basic axiom of aviation.