2003 Cierva lecture

The Fairey Rotodyne – technology before its time?

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THE LEGACY OF JUAN DE LA CIERVA

It cannot have escaped notice, that in two months time we will celebrate the centenary of the first flight of a powered aircraft carrying a man. We rightfully acclaim 'The miracle at Kitty Hawk' for all that it has meant to our chosen profession, albeit outside our remit as a rotorcraft section.

There is however a significant 80th anniversary, which we can add to this centenary year. On 9 January 1923, a Cierva C-4 autogyro piloted by Lt Alejandro Gomez Spencer made an officially observed circular flight of over 4km (2·5 miles) in Madrid.

This important event brought the name of Juan de la Cierva to the fore on the International scene, and was subsequently to prove to be the key to the modern helicopter, an interesting lesson in technology in that, Cierva never set out to invent the helicopter, and never produced one himself.

Of equal significance is the fact that the Rotodyne represented an innovative application of the technology that Cierva began. Many would claim that the gyroplane has never been exploited to it's full potential; maybe the Rotodyne gave us a foretaste of what was possible.

There is a further irony in the fact that Cierva died in 1936, in the crash of a DC-2 airliner taking off from Croydon, all the more poignant for a man whose life's work was dedicated to the creation of a safe aircraft.

1.0 INTRODUCTION

Rotodyne was a large compound helicopter, designed and built by the Fairey Aviation Company in the late 1950s. It was a bold concept intended for production, in the form of a 53,500lb/65-seat, VTOL airliner, which combined helicopter and gyroplane technology to achieve forward speeds in excess of 200mph.

The most significant innovation in its design was the use of tip jets. This paper traces the origins of the Fairey interest in the use of tip jet drive and the development of the successful 33,000lb/40-seat demonstrator, which flew in 1957 and which in the course of a four-year programme, proved the feasibility of the concept.

When the Rotodyne project was terminated in 1962, work was well advanced on the design of the production aircraft and metal had been cut.

Some of the technical reasons for not proceeding with the project are discussed, and the question is raised as to whether the concept could or should be revisited over forty years on, in the light of new technology now available.

2.0 THE ORIGINS OF TIP JET DRIVE

The process whereby a helicopter rotor is driven by means of power units attached to the blade tips has always attracted rotorcraft designers, as early as 1842, W.H. Phillips is reported to have flown a 2lb (1kg) model helicopter driven by steam effluxes from the blade tips with limited success. In 1925, Louis Brennon (UK) successfully flew a large helicopter test vehicle, in which the rotor was driven by propellers at the blade tips (Fig. 1). During the same period, similar experiments were flown by Isaaco (Italy) and Bleeker (USA).

The advantages are obvious, by driving the rotor from the blade tips there was no resultant torque generated by a driven shaft, dispensing with the need for a gearbox between engine and rotor or any anti-torque system, such as a tail rotor.

In the event, the main stream of helicopter development progressed along entirely different paths. The most familiar being the single main rotor, with torque offset by a smaller tail rotor that also provides yaw control. Considerable success has also been achieved with twin rotor arrangements. By the outbreak of WW2, practical helicopters were emerging in Europe and the USA, by the end of hostilities, several were in production and the dream of a flying machine capable of sustained and controlled hover had been achieved.

It is perhaps interesting to observe that many of the features that led

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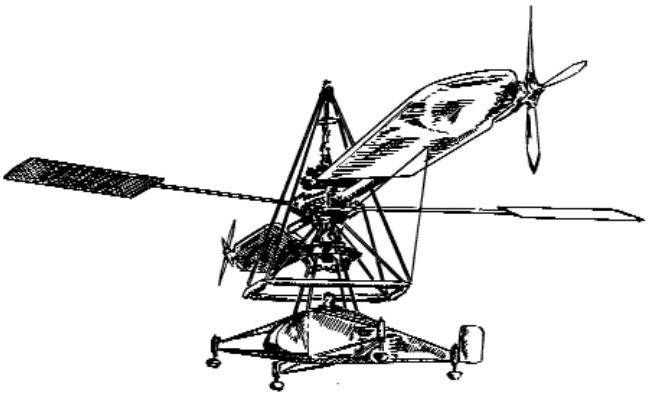


Figure 1. Brennon's helicopter 1924, an early example of a tip-driven rotor.

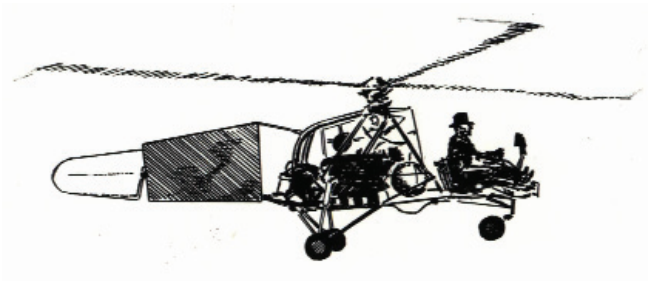


Figure 2. Doblhoff WNF 342 V2 1943. The first helicopter to use tip-jet drive successfully.

to the evolution of the successful helicopter, were brought about during the creation of a vehicle, which was never intended to hover.

In the early 1920s, Juan de la Cierva was working in Spain to create an aircraft that could fly at low speed without the risk of stalling; the stall was seen as the biggest single cause of aircraft accidents.

In order to achieve his objective, Cierva turned to the autorotative rotor as the primary source of lift and control. Before success could be achieved it was necessary to conceive many of the features which are part of all rotor systems, and which were to prove to be the key to the emergence of the helicopter as we know it. But what Cierva had created was the Gyroplane, a rotorcraft but not a helicopter, it was indeed safe from the stall, and it is one life's ironies that Cierva himself died in an airliner accident when it stalled on take-off from Croydon.

For the purpose of this study, it is necessary to look to Germany, where the potential of the helicopter was recognised long before the solution was realised. Several practical rotorcraft were flown in Germany during the years 1936-1945. The work of Anton Flettner is of special interest. When Flettner first turned his interest to helicopters in 1930, he designed an aircraft with a single torqueless rotor driven by two 30hp Anzani engines driving two small propellers attached to the blades, unfortunately the prototype was destroyed while undergoing tethered testing.

Flettner successfully flew a very elegant gyroplane in 1936, but the sole prototype was lost as result of an in-flight fire. Interest was then directed towards a rotorcraft designed to operate as a helicopter when the rotor was powered or to fly as a gyroplane with the rotor in autorotation in forward flight. To achieve this, propellers were mounted on outriggers, operating in opposite directions to counteract torque in the helicopter regime. Once in forward flight the rotor was allowed to autorotate and both propellers re-adjusted to provide forward thrust. A production version was ordered and six prototypes were completed.



Figure 3. Gyrodyne 1947.

Flettner continued his work on helicopters and his Fl 282 Kolibri with its ingenious intermeshing rotor system was ordered into full production in 1944, but never came about due to Allied bombing and the end of hostilities.

Freidrich von Doblhoff, who from the outset favoured tip jet drive was working at the Weiner Neustadter Flugzeugwerke (WNF) in Vienna, the Doblhoff team built and flew the world's first jet driven helicopters, only a few years after the flight of the first successful turbojet powered flight, with the Heinkel He178.

The Doblhoff helicopter was designated WNF342; four development prototypes were constructed (V1, V2, V3 and V4) (Fig. 2). Each one, although similar in general principal, differed considerably, gaining sophistication as the Doblhoff team progressed up the learning curve. One of the key figures in the Doblhoff group was the young aerodynamicist and thermodynamicist, August Stepan, as the first aircraft progressed towards flight, it was Stepan who was to become the chief test pilot.

The first three aircraft were controlled and powered for forward flight in the familiar fashion, by tilting the rotor disc, with an aerodynamic rudder for yaw control, but V4 incorporated a pusher propeller to provide forward thrust, with this it was possible to extinguish the tip jets and maintain the rotor in autorotation, offering the potential of high forward speeds. The full capability of the Doblhoff machines was never to be demonstrated, tests with V4 had barely commenced when the end of hostilities terminated the programme.

The hardware and the personnel were dispersed, with Doblhoff going to the USA, where he was later responsible for the McDonnell XV-1, convertiplane, which also utilised tip jets. Stepan came to the UK, to join the Fairey Company, which was actively working on design studies for tip jet driven helicopters.

3.0 THE FAIREY AVIATION COMPANY

The Fairey Aviation Company was one of many aircraft manufacturing groups that came into being to meet the demand for aircraft during WW1.

Richard Fairey, who was then chief engineer at Short Brothers, formed the company in 1915. He established his works at Hayes in Middlesex, not far from what is now the site of Heathrow Airport. The company grew during the years between the wars to become a major manufacturer, responsible for many famous aircraft. The Fairey Aviation Company established a fine reputation as the manufacturer of naval aircraft, including such famous types as the Swordfish, Fulmar, Firefly and Gannet.

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Figure 4. Jet Gyrodyne 1954.



Figure 5. Ultra-Light 1955.

In the uncertain peacetime years that followed WW2, the decision was made to move into the helicopter market. A strong helicopter design team was formed, under the leadership of Dr J.A.J. Bennet, and it was decided to concentrate on original designs rather than follow the safer path to build established types under licence.

From the outset the Fairey team followed an innovative approach, their first project was the Gyrodyne (Fig. 3), which utilised an offset forward thrusting propeller to counteract torque, rather than the familiar tail rotor. Some success was achieved with the Gyrodyne, which established a world speed record, achieving 124·3mph (200km/hr). The Gyrodyne project was finally halted by a fatal accident caused by a rotor head fatigue failure.

By this time the tip-jet research group, strongly reinforced by the German team were well advanced with their proposals, the surviving Gyrodyne was extensively modified to incorporate tip-jet drive as a test bed and demonstrator for future activities. The Jet Gyrodyne as it became known, incorporated twin pusher propellers, and relied upon kerosene burning pressure jets as the sole power for the rotor (Fig. 4). By September 1956 the Jet Gyrodyne had been used to establish a technique to achieve transition into autogyro regime, having completed 190 transitions, opening the way for the Rotodyne Fairey produced a further tip-jet driven helicopter in the form of its diminutive Ultra-Light, this was a small two-seat helicopter which relied solely on tip-jets to power the rotor and was intended for ship-borne use and battlefield observation (Fig. 5).

The flight experience gained with the Jet-Gyrodyne and the Ultra-Light; coupled with the extensive test rig facility at White-Waltham established the technological base for the massive Rotodyne.

4.0 THE ROTODYNE PROJECT

The decade, which followed WW2, offered an unprecedented opportunity for growth in air transportation. The advance in technology that invariably accompanies war promised better standards in safety and comfort, coupled with an increase in demand. Throughout the world, airliner projects were under development to fill the needs of a world at peace.

The Fairey Company looked to the inter-city routes in Europe and North America, the stage lengths were generally short and in most cases the journey between the city centre and the airport at either end took longer than the flight itself. This was clearly an application for which the helicopter could be used to advantage.

Any reduction in the ground transportation time could only be achieved by the use of heliports sited in the city centres, such helicopters as were available, were too small, too slow, unreliable and fearfully expensive to operate. A possible solution to many of the problems lay in the compound helicopter, with this in mind the Fairey team had already started a programme of work with the Jet Gyrodyne to develop tipjet drive and were experimenting in flight tests with the rotor off-loaded.

The origins of the Rotodyne can be traced back to a study by Dr J.A.J. Bennett and Capt A.G. Forsyth, which resulted in British Patent No 673870 entitled: ‘Improvements relating to Rotorcraft’.

In the years that followed the Fairey Project Office produced a number of design studies in response to perceived demand and also to meet stated requirements from British European Airways (BEA). The proposed aircraft varied in capacity from 20 to 40 seats, all of which were to be capable of speeds greater than 150mph, well above that achievable by the helicopters then in being. The Fairey response to a BEA requirement for a 30/40-seat short haul airliner, resulted in the award of a Ministry of Supply research contract in 1953, which was to become the Rotodyne.

As early as 1950 the Fairey team had concluded that the pressure jet was the only suitable means for powering large tip-jet rotors.

4.1 Airframe and structure

The basic configuration of the Rotodyne was similar to any medium airliner, the fuselage cross section was rectangular 8ft wide with 6ft headroom (2·44m × 1·82m) (Fig. 6). The construction was a simple stressed skin box structure and because there was no necessity to pressurize the cabin, it was possible to include a line of large passenger windows along the length of the fuselage. The passenger cabin was 33ft (10m) long, laid out to take 40 passenger seats mounted in pairs with a single centre aisle.

A toilet facility was included and provision for light refreshments was available, baggage space was situated forward and aft to accommodate an allowance of 40lb (18kg) per passenger. Entrance was gained via an airstair door on the forward port side. Upon boarding the Rotodyne the passenger would be confronted with a comfortable, well appointed airliner with ample headroom, access to the cabin for freight which was to include wheeled vehicles in the transport role, was achievable through twin clamshell doors in the rear fuselage.

Twin Napier Eland NEL7 Turboprops were mounted on the high wing 46ft 6in (14·17m) span, a conventional tailplane with twin fins was fitted, giving the basic aircraft the appearance of a truncated airliner, similar to that of its fixed wing counterparts. The fuel load, 756 gallons, was carried in four tanks situated in the wings, feeding a single 30-gallon collector tank in the pylon.

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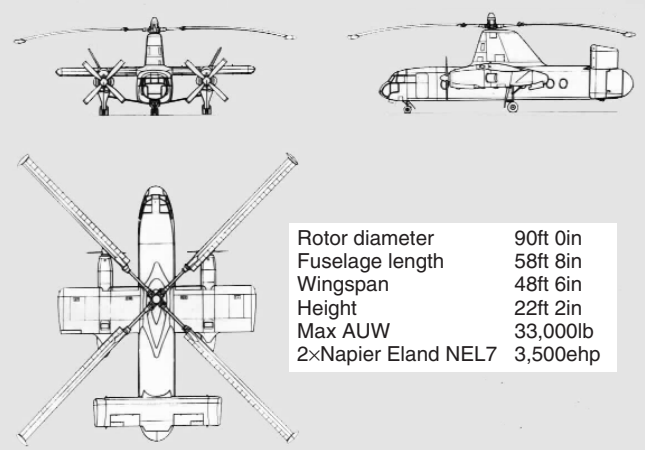


Figure 6. Rotodyne type 'Y' general arrangement.

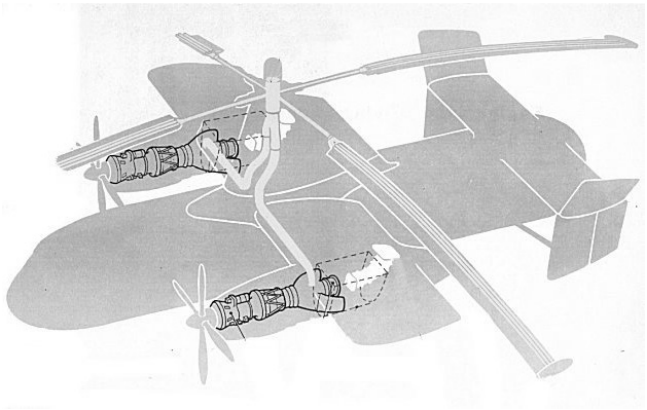


Figure 7. Rotodyne type 'Y' power systems.

The rotorcraft component of the aircraft took the form of a tall pylon mounted centrally above the wing, carrying a 90ft (27·43m) diameter four bladed rotor. A retractable tricycle landing gear was included.

4.2 Rotor head and blades

The rotor head was constructed from steel forgings, consisting of a central hub, to which were attached four box beams carrying the flapping lugs with the feathering hinges outboard, there were no drag hinges in the design, the swash plate through which cyclic and collective pitch was applied to the blades, was situated above the rotor head. The control mechanism, fuel and electrical services passed through the centre of the head, surrounded by concentric air ducts terminating in a cast trouser leg base to accept air from the two engines (Fig. 7).

The requirement to duct compressed air to the blades resulted in a unique rotor head structure, which was further complicated by the need to allow for an engine failure in the helicopter regime. This was achieved by arranging that each engine/auxiliary compressor fed air to diametrically opposed pairs of blades.

The port engine fed blades 1 and 3 while the starboard engine fed blades 2 and 4. In the event of an engine failure, the good engine took up power with thrust increased on one pair of blades driving the rotor.

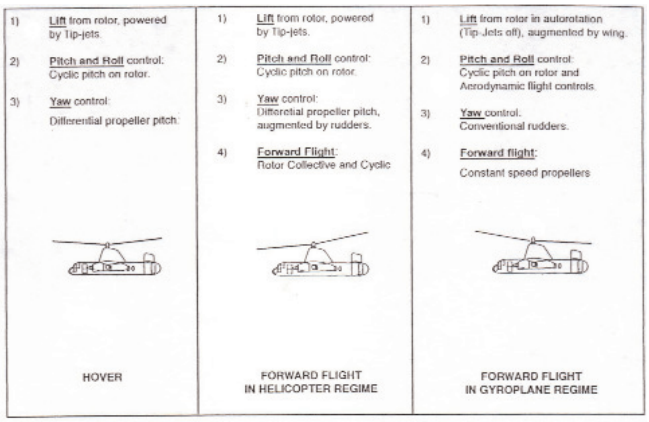


Figure 8. Rotodyne control in hover and forward flight.

The main rotor blade consisted of an aerofoil shaped leading edge torsion box structure, comprising two steel spars with stainless steel top and bottom skins. The trailing edge sections were made up of floating light alloy segments. Compressed air for the tip-jets was ducted through the leading edge torsion box structure via three thin walled stainless steel tubes.

4.3 Operation

Being a convertiplane, the Rotodyne had two distinctive regimes of flight. The aircraft took off to the hover, with direct lift from the rotor, operating as a conventional helicopter, using cyclic pitch for roll and pitch control. Yaw control was achieved through differential pitch applied to the propellers (Fig. 8).

Transition into forward flight continued in the helicopter regime by application of forward cyclic and collective pitch to achieve a steady climb at 60-80kt. Yaw control was maintained through differential propeller pitch but as forward speed increased the available range of differential pitch reduced. However, with the increase the aerodynamic rudders began to take effect and controlled flight to the transition speed of 110kt was maintainable with the rotor powered by the tip-jets.

Transition into the autogyro regime was achieved by increasing propeller pitch and reducing power on the rotor until the tip-jets were at idling power and the propellers providing practically all the forward thrust. At this stage fuel to the rotor was switched off and the auxiliary compressor providing tip-jet air was de-clutched.

The rotor speed was then allowed to settle in autorotation with approximately 2º of collective pitch. With the rotor off-loaded in this fashion forward speeds up to 160kt could be easily achieved. It should be noted that forty years ago this was a very high speed for any rotorcraft. Control in the autogyro regime was maintained through a combination of cyclic pitch on the rotor and conventional aerodynamic control surfaces.

Transition back into helicopter fight was essentially a reversal of the procedure, reducing speed to 110kt and engaging the auxiliary compressor to provide air to the tip-jets, fuel and ignition was selected, usually helicopter flight was re-established within 4-5 seconds.

4.4 Tip-jets

The tip-jets were elegant in their simplicity, consisting of a bullet shaped single jet unit mounted tangentially at the tip of each blade (Fig. 9). The chamber was built up of forgings and sheet metal in Nimonic 80A, with a liner manufactured in Nimonic 75.

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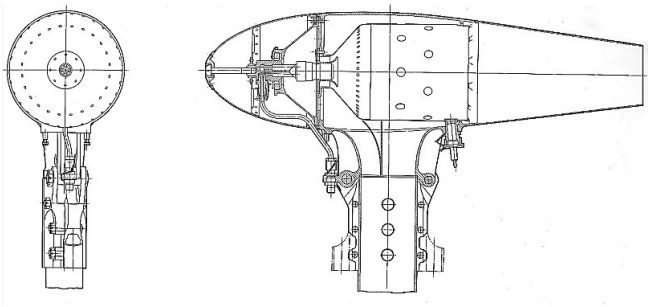




Figure 9. Rotodyne tip-jet.

Air entered from the blade through the side of the chamber to mix with atomised fuel, which was ignited by means of duplicated high-energy igniters. Once ignition was achieved, combustion was self-sustaining until fuel was cut off.

Initial flying was carried out with plain jet nozzles and as might be expected the noise levels under full power were extremely high. A considerable amount of effort was put into silencer development with more than 40 different efflux configurations tested, reductions of as much as 25% were achieved.

Much has been said of the excessive noise generated in the hover when experienced at the landing pad, but it should be noted that, on the two occasions the Rotodyne flew into Battersea Heliport (Fig. 10), which is situated less than 1km from Westminster, with an approach path which entailed light-up adjacent to the Houses of Parliament. The whole operation passed unnoticed by the general public and the noise levels on Westminster Bridge, directly under light up, could not be measured above the London traffic noise.

4.5 The development programme

The Rotodyne flew for the first time on 6 November 1957. Development work leading up to this had been in hand for six years. Test rigs had already been established at the test airfield at White Waltham for Gyrodyne and Ultra-light, consisting of a single test stand and a rotating rig. Specially modified Rolls-Royce Dart engines provided air for these rigs, as the programme expanded, a larger spinning rig



Figure 10. Landing at Battersea in central London.

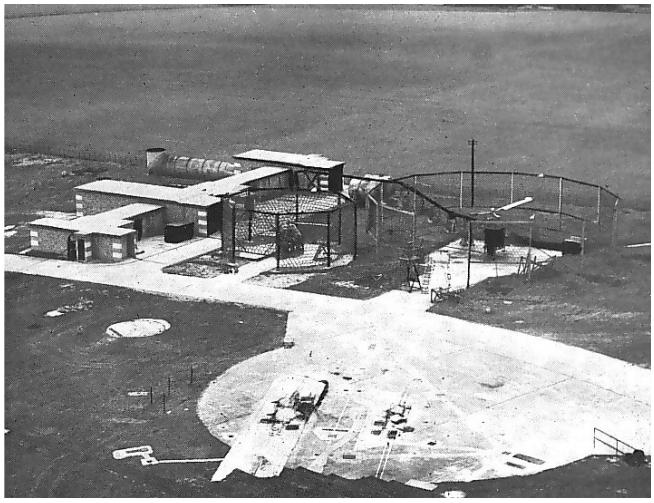


Figure 11. Test rigs at White Waltham.

was installed capable of running the Rotodyne units and further test cells were added. Rolls-Royce Avons replaced the Darts.

Fairey had also undertaken extensive wind tunnel testing with 1/6th and 1/15th scale models in their own wind-tunnel facility at Hayes.

Resonance was of special concern in the case of the Rotodyne, which was not only breaking new ground in terms of size, but also had a wide dynamic profile brought about by the broad rotor speed range and the propellers.

The potential problems were studied in advance by the use of a specially constructed 1:15 scale dynamic model. This was followed up by full-scale tests on a specially prepared ground-running rig situated at White Waltham (Fig. 11).

Initially comprehensive shake tests were carried out with the aircraft suspended from a large crane. For ground resonance tests, the aircraft was placed on a specially prepared running rig, with four cables attached to a collar situated directly under the main rotor head. The cables ran over support arms to hydraulic jacks set in the ground.

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Figure 12. Rotor rig at Boscombe Down.



Figure 14. Bridge laying demonstration.



Figure 13. First flight configuration.



Figure 15. The mature aircraft in 1962.

It was possible for the aircraft to run in a freestanding state with tension off the cables. The whole airframe and rotor was comprehensively instrumented with read out within the aircraft and repeated in a control cabin well clear of the rotor disc.

Ground running was carried out covering the full spectrum of engine, propeller and rotor speeds. At any time during the ground runs, if a potential problem was experienced the controller could tension the cables and the aircraft shut down.

The most ambitious ground installation of all was established at the A&AEE Boscombe Down (Fig. 12). This was a full representation of the aircraft, consisting of rotor, powerplants and controls and was used for endurance testing, systems development and pilot familiarisation. The rig was operated to full aircraft maintenance standards and procedures and could accept flight standard components with full instrumentation.

Initial running with the rig commenced early in 1957, and it was fully operational by the following August to provide support and confidence well in advance of the first flight. The methodical approach to the initial running phase and resonance problem was typical of the Fairey design philosophy.

4.6 The flight programme

The first flight took place on 6 November 1957 (Fig. 13). Initial flying was all undertaken operating in the helicopter regime achieving a total of 70 flights over five months.

The first transition was undertaken on 10 April 1958, over the ensuing six-month period the transition process was fully developed and the flight envelope extended, by the end of this phase transitions were being completed with confidence at 300ft.

On 5 January 1959 the Rotodyne established a world speed record over a 100km closed circuit at 190mph (307km/hr), this was 30mph higher than the absolute speed record for a conventional helicopter at the time.

The following summer the aircraft was demonstrated at Paris and gave further demonstrations in Brussels before returning to Heathrow. The programme continued to investigate single engine operation, running landings in the autogyro regime and the development of a rotor governor (Figs 14 and 15).

During this period, design work had started on a larger aircraft intended for production. Designated Type ‘Z’, this was to be powered by two Rolls-Royce Tynes and was to carry 57 passengers.

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As the full potential of the concept became apparent, serious overseas interest was being shown, most significantly from The Kaman Aircraft Corporation that negotiated a licensing agreement for sales and possible manufacture in the USA. Letters of intent were received from Okenagen Helicopters of Canada and New York Airways. Japan Airlines declared an interest for their domestic operations and there was also considerable military interest.

Encouraged by this interest, the Fairey team started work in earnest on the design of the larger Type Z. The test rigs at White Waltham were modified and enlarged to accept the bigger units, while work commenced on a full-scale mock-up of the proposed production aircraft.

Times were changing; in early 1960s there were over twenty major aircraft manufacturers in the UK. In the course of one year these had contracted to three by a process of amalgamation and absorption, primarily in response to a Government-led re-structuring of the industry.

The incentive to take part in the re-grouping process was the clear indication that the main bulk of Government support for future projects and orders would be placed with those companies which had complied with Government's wishes.

The aircraft and helicopter activities of Fairey Aviation Company were merged with Westland in February 1960. Westland had already absorbed Bristol and Saunders-Roe and with the acquisition of Fairey, Westland became the sole helicopter manufacturer in the UK.

There was as a consequence, a promise of further Government support for the Rotodyne project, a crucial factor in this support was the expectation of an order from BEA but it was also important that the military interest took the form of a firm order.

The process of re-organisation had its impact on the programme and effectively slowed progress. There was increasing concern that the high noise levels would exceed the mandatory minima and an all-out effort was made to demonstrate that these could be met. The flight into Battersea Heliport, in the heart of London, was mounted to help dispel some of the official doubts.

It has often been suggested that Westland failed to pursue the Rotodyne project with any commitment, but in fact they continued the programme with vigour and even shelved their own Westminster helicopter project in favour of Rotodyne.

There was however, a major difficulty. In order to achieve single-engine operation in the helicopter regime (i.e. one pair of blades delivering power), it was necessary to enrich the fuel/air ratio that could result in efflux temperatures as high as 1,400ºC.

The quest for a suitable material for silencer construction was extensive, among the materials tested were platinum and ceramic coated molybdenum. Silencer configurations capable of achieving the noise levels then acceptable had been tested and demonstrated on the test rigs.

Another important factor was that from the outset Fairey had taken a very careful and methodical approach to the design and development, allowing no corner cutting to speed the programme along. It was largely due to this that such an ambitious project proceeded without any serious mishaps, but such an approach did not come cheaply, the development costs were high and progress slower than would be acceptable to modern programme management expectations. The proposed 57-seat Z model was to all intents and purposes a new aircraft and it was clear that it would take several more years to see the new aircraft into service.

The eventual unit cost of the vehicle would have been high, and the operating costs would probably have been unacceptable to the airlines.

The end came when Okenagen and BEA withdrew their interest and it became obvious that a military order was not forthcoming. Westland were already working to capacity on conventional helicopters for the Royal Navy and the Army, backed up by healthy overseas orders.

Official interest in the Rotodyne programme was finally withdrawn in February 1962. The sad thing is that the hardware was destroyed so promptly and so little was done to preserve the technical records, no one has openly admitted responsibility for this act of technological vandalism. All that remains of the prototype is a small section of fuselage approximately 2m (6·5ft) long, the rotor head and pylon internal structure, a test specimen rotor blade and a few tip-jets. These are all held at the Helicopter Museum at Weston-Super-Mare in Somerset (Fig. 16)



Figure 16. All that remains in 2003.

In the course of its five-year flight programme the Rotodyne completed 430 test flights and over 300 hours flying. The programme effectively demonstrated a practical solution to VTOL short/medium range transport of a size comparable with the largest of helicopters, there was confidence that the concept could be extended in size and performance to meet future requirements.

5.0 THE TYPE 'Z' ROTODYNE

The Rotodyne that could have been is worthy of comment. By mid 1959 Rotodyne was attracting worldwide interest, New York Airways and BEA having expressed their interest by indicating they might purchase at least 12 and possibly up to 50 machines. In parallel with the civil version an almost identical aircraft suitable for military use was under consideration.

As discussions developed, it became clear that the Eland-powered Type Y would be too small and that the production aircraft would have to be redesigned to incorporate two Rolls-Royce Tyne engines, which would permit the gross weight to be increased to 58,500lb (see Table 1 and Figs 17-19).

The proposed aircraft while retaining the familiar shape of the Rotodyne would be approximately 20% larger.

The new aircraft represented a substantial re-design of the original concept in many areas.

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Table 1
Type Y and Z Rotodynes

	Type Y	Type Z
Wing span	46ft 6in	75ft 0in
Wing area	475sq ft	898sq ft
Fuselage length	58ft 8in	69ft 5in
Rotor diameter	90ft 0in	109ft 0in
Cabin internal:		
Length	46ft 0in	52ft 9in
Width	8ft 0in	9ft 8½in
Height	6ft 0in	7ft 0in
Max take-off weight	33,000lb	Civil: 58,500lb/ Military: 68,300lb
Power units:	2×Napier Eland NEL7 Rated 2,800shp	2×Rolls-Royce Tyne Rated 5,725shp
	Aux compressor for tipjets 22·7lb/sec	2×Rolls-Royce RB176 44·95lb/sec

Rotor diameter: 109ft 0in
Fuselage length: 69ft 5in
Wingspan: 75ft 0in
Overall height: 27ft 3in
Maximum take-off weight: 58,500lb
54 –70 passengers

2×Rolls-Royce Tyne Mk 22 turboprops
6,330 shp
2×Rolls-Royce RB-176 gas generators

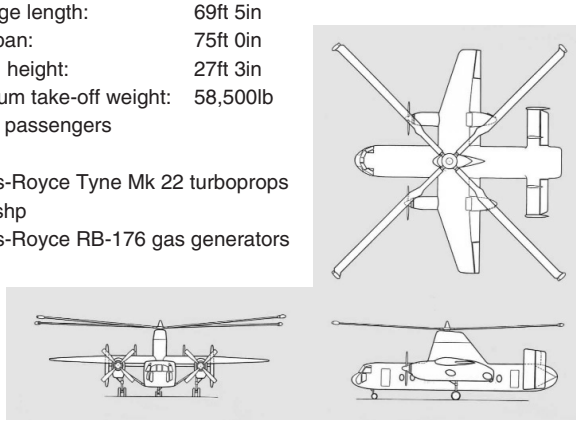


Figure 17. Rotodyne Type 'Z' general arrangement.

- Air for the tip-jets was to be provided by two RB176 gas generators, which would only be run for take-off, transition and landing/hover phases.
- The wing area was doubled.
- The cabin floor area was increased by more than 40%.
- The design included electrical rotor blade de-icing.
- The civil variant was to include a tip-jet silencer system based on the multi-nozzle nine-jet units ground tested during the original test programme.

6.0 FORTY YEARS ON

Since the events discussed in this paper occurred, air transport has advanced at an unbelievable rate, to the point where the available airspace, air traffic control and airfield facilities are stretched to the limits.

The use of VTOL has frequently been proposed as a means of alleviating the runway congestion, which the short haul provincial airlines generate. This is indeed one of the objectives of the tilt rotor programmes such as: Civil V-22 and Eurofar.

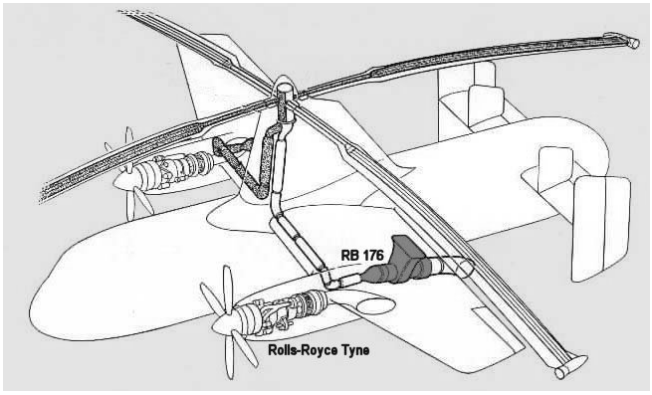


Figure 18. Type 'Z' power systems.

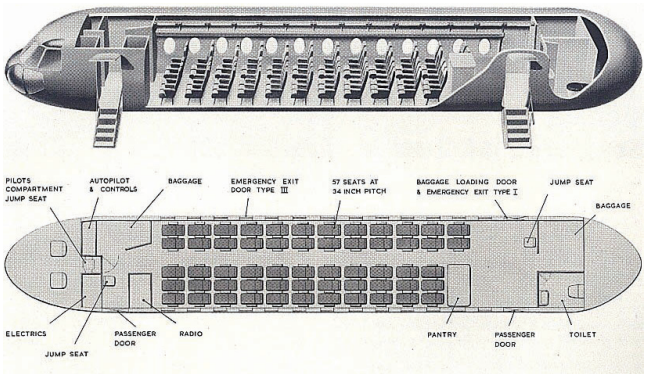


Figure 19. Type 'Z' cabin layout.

Military requirements and expectations have also advanced, calling for performance well beyond the capability of conventional helicopters and this has brought the convertiplane to the fore as a possible solution.

The V-22 Osprey programme is a prime example. The V-22 concept dates back to 1982, and is currently ongoing. It represents the only large convertiplane technology programme with any production prospects and has deeply committed the two major companies concerned. As such the V-22 represents the only medium lift rotorcraft with high-speed capability.

These comments should not be construed as criticism of what has evolved into a very fine aircraft, but it does suggest that we have placed all our very expensive eggs in one basket.

The Rotodyne technology has been neglected for forty years. In the period that has elapsed, there have been advances, which would affect a New Generation Rotodyne:

- Reliable and properly substantiated composite structures are now commonplace.
- Main rotor blade design and construction has led to a marked improvement in rotor efficiency and component life.
- Gas generators and turboprops have improved in efficiency, which would allow tip-jets to operate at lower temperatures and may even allow cold cycle operation.
- The physics of noise generation and suppression are much more clearly understood, coupled with advances in materials, this should result improved silencer performance and durability at high temperatures.
- Automatic flight control and rotor governing were high-risk technology at the time when the Rotodyne was under development.

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- Propeller technology has advanced, offering improved performance and efficiency.
- The materials and dynamic design of rotor heads has advanced.
- Glass cockpits, health usage monitoring, active vibration control, integrated systems and fly-by-wire, can now be considered.

It must be appreciated that although the above features may well provide solutions in many areas of the design. New problems would almost certainly become apparent:

- The noise levels acceptable for certification will be very stringent, and even if achievable they will not necessarily be accepted by the environmental lobby.
- The integration of rotorcraft into the air traffic control system is an ongoing problem. Any solution may well negate perceived advantages of VTOL.
- Public perception of rotorcraft is that they are less safe than fixed-wing!
- Vibration levels acceptable for certification are probably still too high from the average passenger's viewpoint.
- Even forty years on, the technology is still cutting edge. The programme will have to be managed with care. This may well lead to prolonged development and high costs.
- It will be difficult to keep the unit costs and operating costs down to an acceptable level.
- Such a programme would extend the resources of even a large corporation. Simultaneous civil and military interest and International collaboration are probably prerequisites.

7.0 RENAISSANCE

During the forty years or so that have elapsed since the demise of the Rotodyne conventional helicopters have progressed, gaining as they would from the technical advances, which have affected all forms of aviation.

Helicopters operating in the heavy lift role at weights comparable with that envisaged for Rotodyne are in regular use throughout the world.

There is however a demand for even greater capacity and performance which may only be achievable by the convertiplane or compound helicopter. It is in this area that the technology developed for the Rotodyne may yet come into its own.

At least two groups in the United States are considering projects to meet US government requirements for the next generation of heavy lift rotorcraft, and perhaps continue the quest for the VTOL airliner that can take its place in the transport network.

7.1 Carter Aviation Technologies (Carter)

Essentially a design, research and development office, the company is mainly concerned with the development of a unique gyroplane, which combines a high efficiency autorotative rotor system, off-loaded by a wing. The primary aim with this combination is to achieve a high rotor tip speed ratio (exceeding $\mu = 1$) thereby opening the way to higher forward speeds through reduced rotor drag.

Led by Jay Carter, the small dedicated team has overseen the construction of a technology demonstrator, the CarterCopter (CCTD), which has been flying since September 1998.

The development vehicle has a gross vertical take off weight of 4,500lb and has achieved a tip speed ratio of $\mu = 0{\cdot}87$ and a forward speed of 173mph. The CCTD incorporates composite construction, a high aspect ratio wing with a span of 32ft; a Carter-designed 8ft diameter high-efficiency propeller and a 45ft diameter high-energy rotor system. The US Defence Advanced Research Projects Agency (DARPA) is helping to fund the next generation Carter propeller and rotor.

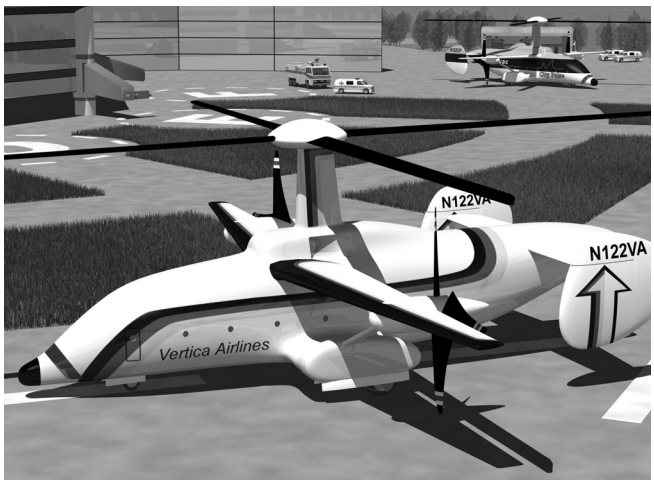


Figure 20. Carter Heliplane Transport (CHT).

Table 2
Carter Heliplane Transport (CHT)

Wing span	150ft
Fuselage length	106ft
Rotor diameter	150ft
Propeller diameter	24ft
Max all-up weight	155,000lb (VTOL mode)

Carter intends to explore the potential of the system in flight at high μ values, and to progress to high altitude flight at higher speeds (350mph at 45,000ft). The use of a wing to off-load the rotor in autorotation has a relationship to Rotodyne and the company has completed preliminary design studies for a large VTOL transport, the Carter Heliplane Transport (CHT) (Fig. 20).

The aim with the CHT would be to produce a heavy-lift VTOL transport exceeding the payload and flight performance of the C-130 Hercules and able to carry 130 passengers. The US Army named the CHT a 'slowed-rotor/compound helicopter' and has recognised it as a possible candidate for their proposed air-manoeuvre transport programme.

The CHT will be a gyroplane like the CCTD, but will include the pilot option to take-off, hover and land like a conventional helicopter, with its rotor in direct drive, using its twin pusher propellers to counteract torque by the application of differential pitch. In forward flight it will convert to a gyroplane, offloading the rotor by means of its high aspect ratio, high efficiency wing. Carter claim that during this process rotor speed will be reduced to minimise profile drag and maximize flight efficiency, applying the technology demonstrated with the CCTD. The scale of the CHT is impressive (see Table 2).

The CHT will be designed to cruise at 208mph at mean sea level; the fuselage will be pressurised to operate at 40,000ft. At 32,500ft MSL, its cruise speed at best L/D should exceed 400mph.

7.2 Groen Brothers Aviation

Groen Brothers Aviation (GBA) is a company dedicated to the design and production of gyroplanes. The main activity over the past sixteen years has been devoted to the design and development of the Hawk 4, four seat gyroplane, which holds the distinction of being the world's first turbine powered gyroplane.

With the development, certification and production planning for the Hawk 4 well in hand, GBA have turned their interest to convertiplane technology and have expressed an interest in the development of commercial Gyrodyne platforms using the features established with the Rotodyne.

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Figure 21. GBA Heavy Lift Gyrodyne.

Table 3
GBA Heavy Lift Gyrodyne

Wing span	100ft
Fuselage length	110ft
Rotor diameter	112ft
Max all-up weight	132,000lb

Part of the GBA philosophy is the concept that existing aircraft airframes can be adapted to accept rotor systems, and to this end they have successfully modified and flown a Cessna 337 Skymaster airframe powered by a single propeller turbine to operate as a gyroplane to demonstrate viability.

The next phase of the programme is to produce a larger demonstrator vehicle by adapting an Antonev An-28 airframe (19-seat commuter) under the name GBA Gyroliner. The Gyroliner will incorporate all the features of the Rotodyne including tipjet drive for the rotor. It must be appreciated that the Gyroliner is currently at the project study stage and an ITP (intention to proceed) has not been declared.

Groen Brothers Aviation has responded to an invitation from the US Defence Advanced Research Projects Agency (DARPA), to submit a study for a heavy lift rotorcraft. The GBA proposal sets out to adapt the C-130 airframe to accept a tipjet drive rotor system, but the design of a purpose built airframe of similar dimensions is also under consideration.

The GBA Heavy Lift Gyrodyne (HLG) would be in every sense a 'New Generation Rotodyne', operating in a similar fashion, but incorporating many of the technological features that have evolved in the forty years that have elapsed since the original Rotodyne programme.

The HLG proposal allows for a four turboprop 'Hercules look-alike' arrangement, but an alternative version powered by two turbofans has been proposed. The arrangements to provide air for the tipjets are still under review.

It has been fully appreciated by GBA, that it is not a question of simply 'cobbling' together a heavy lift rotorcraft from a C-130 airframe. The programme would call for new airframes, modified at build, and may in fact call for a purpose-designed structure. The dimensions of the HLG are listed in Table 3.

Both the above proposals are to say the least ambitious. Neither has progressed beyond the 'project pefinition' stage, and would call for participation from one of the major aerospace companies and official support, to progress further.

7.3 Mathematical modelling for Fairey Rotodyne

During the post lecture discussion, Professor David Balmford pointed out that Fairey had undertaken some innovative work to study the dynamics aspects of the Rotodyne.

It is considered that his summary of this work is worthy of inclusion in this paper.

In the mid 1950s, the Dynamics Department was set up at Hayes as part of the Technical office, the purpose of which was to mathematically model the dynamic behaviour of the Fairey Rotodyne in four main areas. These were:

1. Prediction of the rotor blade natural frequencies and mode shapes in flap, lag and torsion.
2. Prediction of the response of the complete rotor system in the plane of rotation due to non-simultaneous light-up of the tip-jets, leading to lag plane oscillations of individual blades.
3. Minimisation of the forced response of the airframe due to rotor system vibratory forcing at four per-rev frequency. The airframe was represented as an assembly of beams of defined stiffness characteristics, with point masses positioned at the beam junctions, as required. It was fully realised that confidence could not be placed in the absolute values of predicted natural frequencies, but the method was valuable in indicating the trends of changes in natural frequencies with changes in structural stiffness in various regions of the airframe. The results from this analysis guided the design change consisting of the introduction pitching flexibility into the rotor pylon, which significantly reduced the four per-rev frequency vibration in flight.
4. Prediction ofground resonance behaviour in order to provide design guidance in the areas of undercarriage stiffness and damping characteristics, and rotor blade lag plane stiffness and damping requirements. It was considered that a fundamental analysis was required in order to gain basic insight into the problem, and also to avoid the approximation that would have to be made in order to apply the Coleman criteria for avoidance of instability. Since the application of ground resonance theory that ground resonance would occur within the rotor speed range during ground operation, a physical ground resonance model was designed, built and tested, which confirmed the predicted instability. This established confidence in the use of the mathematical model to guide the design modifications to the undercarriage characteristics and the rotor lag plane dynamics, to completely eliminate any tendency to ground resonance throughout the full range of ground operating conditions.

It is believed that the mathematical approaches that were developed for the four problem areas described above were unique in the industry at that time, and in fact formed the basis for further developments in analytical techniques which were successfully applied to later designs of helicopters.

8.0 CONCLUSION

To re-visit Rotodyne technology would be a major undertaking, much of the baseline data has been lost, and the key players in the original programme have long since retired. The resources required and the expenditure involved is such that anything other than success could spell ruination for the participants.

In the current environment, the success or failure of large corporations rests on the outcome of a single major project. Product responsibility and the litigation it generates tend to limit innovation.

Perhaps we are not ready to cut metal or lay up composites, but maybe the concept should be re-visited in the form of a project study to determine the promise of the Rotodyne and who knows?

Maybe the time has at last come, and perhaps the technology is not before its time!

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