Scottish Contributions to Rotary Wing Flight

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Abstract

This paper charts the history of rotorcraft development in Scotland. Beginning with the early efforts of Mumford to achieve rotor-borne flight, through the major technology advances of G&J Weir in the 30s and 40s up to present day activities. The paper shows that despite being a relatively small country, Scotland's traditional expertise in engineering when applied to the development of rotorcraft, generated significant technological advances.

Introduction

In the very early years of the Twentieth Century the City of Glasgow and its extensive shipbuilding and engineering industries on the River Clyde and its hinterland provided a considerable percentage of the world's requirements for ships, associated and other heavy engineering capital goods. It's not surprising therefore that some aspects of its technology became a basis for early experiments in aviation at the hands of one or two creative and practical thinkers.

Denny/Mumford Helicopter 1905 - 1914

In early 1905, Edwin Mumford, head of the Experimental Tank at the Denny shipyard constructed a prototype Helicopter, Figure 1. As the main business of Denny's was of course shipbuilding, experiments on the helicopter were of low priority, and development was an extended process. The ship building heritage of the machine is also evident from the design of the "rotors" which more resemble ship screws than rotary wings. Initial experiments used one "lifting screw", but the final version of the vehicle had six. Each screw was 24ft in diameter and was constructed of fabric stretched over a wooden rim, wiring bracing being used to provide structural stiffness. It was calculated that the screws would have to be rotated at 45rpm to generate sufficient lift for flight. The design was very much governed by the lack of availability of a light weight powerplant. In the end a single 4 cylinder, 2-stroke engine providing 40 h.p. was sufficient to lift the 1600lb vehicle. Tethered flights were eventually successfully made, versions mounted on skis and floats built. Development of this vehicle ceased in 1914 due to the onset of WW1, and the much more spectacular successes of fixed wing pioneers such as the Wright Brothers.

Figure 1: The Denny/Mumford Helicopter (1905 – 1914)
(*Artist Impression: Dugald Cameron*)

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James Weir and the Cierva Autogyro Company

G&J Weir was (and still is) a prominent heavy engineering company based in the Cathcart area of Glasgow. In the early part of the 20th century the company was run by the brothers George and James Weir. George, the first Lord Weir, was Director General of Aircraft Production during World War One. Both had an interest in aviation, and their Cathcart works had been turned over to aircraft production during the First World War. It was James, a pioneer flyer, who became seriously interested in the work of Juan de la Cierva during the 1920s. After Cierva demonstrated his C6 autogyro, Figure 2 to the Air Ministry at Farnborough, in October 1925, G&J Weir, along with James Weir himself became Cierva's main financial backer, establishing the Cierva Autogyro Company in the U.K.. James Weir become Chairman of the company in 1928, a position he held well into the 1960s long after Weir's interest in rotorcraft ceased.

Figure 2: A Replica of the Cierva C6 in the Curato Vientos Air Museum, Madrid, Spain
(*Photo: Diego Dabrio*)

Figure 3: The Cierva C30A (Avro 671 Rota Mk. 1) in the Imperial War Museum, Duxford, U.K
(*Photo: Asterion*)

Cierva focused on the design of the rotor system and relied on existing aircraft manufacturers (principally A.V Roe & Co. – Avro) to supply airframes. The most successful example of this is the Cierva C.30A, Figure 3, with 143 being built under license during the 1930s. Avro built 78 of these aircraft (designated Avro 671 Rota) whilst 40 were built in Germany by Focke Wulf (designated Fw C30). Intrestingly both of these aircraft were still in use (in small numbers) by the RAF and Luftwaffe at the outset of WW2. A number of examples of these aircraft survive in Museums today.

The Early Weir Autogyros

James Weir himself was an autogyro enthusiast already owning one of Cierva's C6 aircraft, Figure 2. It's no surprise then that Weir's themselves got into the business of designing and building their own aircraft, producing a number of prototype autogyros during the 1930s, the first being the W.1 first flown by Cierva in May 1933, Figure 4. This aircraft had a 28ft diameter rotor and was powered by a 40 h.p. Douglas-Dryad two cylinder air cooled engine in the nose. This was followed by the W.2, Figures 5 and 6, which first flew in March 1934 with Weirs test pilot, Alan Marsh at the controls. The 28ft rotor was slightly modified from the W.1, it had a more powerful engine (the 50h.p. Weir Dryad II) and the fuselage was give a sleeker, more aerodynamic shape. This was a serious venture by Weirs in an attempt to enter into the aircraft manufacturing business and it is clear that significant contemporary expertise and technology was applied to the task. Consider for example the fin and tailplane configuration of the W.2 in Figure 5. This was modified after stability issues were encountered in flight tests, the tailplane (featuring endplates) for the new prototype W3, Figure 7, being retrofitted to the W2 (see Figure 6 for the W2 in its final configuration with the W.3 tailplane fitted). It is also known that Weirs carried out wind tunnel tests of autogyro shapes.

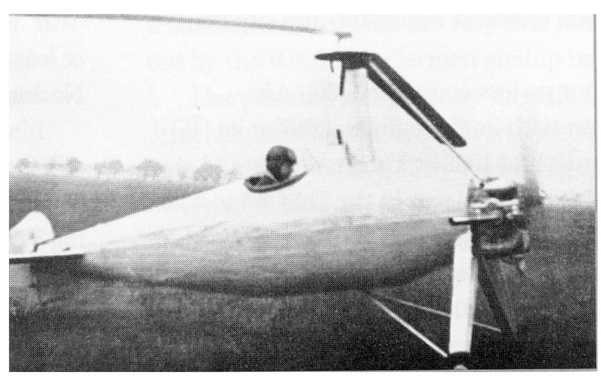

Figure 4: The Weir W.1 Autogyro at Abbotsinch (now Glasgow Airport) with Juan de la Cierva at the Controls

Although these aircraft were experimental prototypes they were very successful. It is reported that James Weir himself used the W.2 to commute from his home in Dalrymple, Ayrshire (taking off from the walled garden of his mansion) traveling the 40 miles to Weirs Cathcart factory in the south of Glasgow! The success of the W.1 and W.2 provided Weirs with the expertise required to go ahead with development of a production vehicle, the W.3.

Figure 5: The Weir W2 Autogyro Conducting a Demonstration Flight (1934)
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Figure 6: The Weir W2 Autogyro in the Museum of Flight, East Fortune, Scotland
(Photo: Malcolm Clarke)

<u>The "Autodynamic" Rotor Head</u>

Although Weirs and the Cierva Autogyro Company developed autogyros independently there was significant collaboration, and the most notable outcome of this was the "autodynamic" rotor head, which allowed the "jump take-off" to be performed. From the very early days, autogyros used pre-rotation to achieve take-off. This often involved a rope being wound around a drum attached to the rotor shaft. Several men would then run with the rope to rotate the rotor. A long taxi, often around the airfield for several minutes, was then required to get the rotor to a speed sufficient for flight. The introduction of direct drive of the rotor from the engine via a clutch was a big improvement, however a lengthy ground run was still required once the clutch was disengaged, in order to achieve flight. The autodynamic rotor allowed mechanical pre-rotation and a jump take-off. The Cierva and Weir autogyros used three bladed, "direct control" rotor heads. Essentially the whole rotor head could be oriented in the required direction to give pitch or roll control. The blades had a flap degree of freedom (developed by Cierva in his early years of autogyro development to alleviate root bending) and so also required drag hinges with friction dampers to counter Coriolis effects (and to improve ground resonance characteristics). The blades were however of fixed pitch.

Cierva tried a number of different rotor head designs to improve take-off capability until finally, along with Weirs, he developed the "autodynamic" rotor head. By orienting the drag hinge slightly from the perpendicular to the disc plane, under pre-rotation the blades "lagged" the hub and rested against the drag stops. This reduced the blade angle of attack, Figure 7, and hence drag, greatly improving the effectiveness of the pre-rotator. The blades could then be spun up to an r.p.m. well above that necessary for flight, storing substantial kinetic energy. When the pre-rotator was disengaged, and the driving torque removed from the shaft, the blade "over ran" the hub adopting a positive incidence, and generating sufficient lift to "jump" the aircraft into the air. A height of as much as 15ft could be achieved, thrust from the propeller accelerating the aircraft forward into conventional autorotative flight. Although a relatively simple idea, bringing such a system from concept to flight no doubt required all of Weirs design expertise and manufacturing skills. Intuitively this sounds like quite a tricky piloting task however the literature of the time suggests that this type of take off was a simple and safe operation.

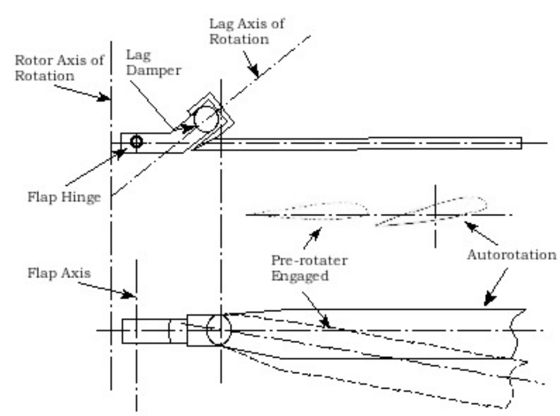

Figure 7: The Principle of the Autodynamic Rotor Head

Heading for Production: The Weir W.3 & W.4 Autogyros

The ability to perform a jump take off vastly increased the appeal of the autogyro to potential users. It is known that Cierva demonstrated this technology to Pitcairn in the early 1930s and it is likely that he adapted this for use in his autogyros which became extremely popular for mail flights, amongst other applications. Cierva himself fitted the autodynamic rotor to the C30, Figure 3, which was then a successful vehicle, 178 examples being constructed under license. Weirs themselves realized the potential of this device and began designing their own production autogyro, the W.3 (which was based on the W.2) with the aim of putting it into production. The W.3, Figure 8, first flew on the 9th of July 1936 and had a 2 bladed rotor which was powered by the new Weir Pixie I a four cylinder in-line, air cooled engine developing 50 h.p. A more robust landing gear than the W.2 was fitted, and the ineffective ventral fin of the W.2 was replaced by a more conventional design. So successful was this aircraft that a few weeks later it was demonstrated publicly during the August Holiday motor racing meeting at Brooklands.

Figure 8: The Weir W.3 Autogyro

During 1937 further refinements to the design were made and a new type, the W.4 was launched, Figure 9. This aircraft was powered by an uprated Pixie engine (developing 68 h.p.) and refinements included a faired rotor pylon, improved under carriage, and an improved transmission. The first flight was on the 6th of January 1938 but unfortunately this aircraft was destroyed during early trials, when during an attempted jump take-off the aircraft rolled on its side. The test pilot, Alan Marsh escaped unhurt. Although the W.4 represented a distinct improvement on the W.3, the time of the autogyro was rapidly coming to an end as progress around the world in the development of helicopters began to have an impact. Weirs also turned their attention to the powered rotor vehicle.

Figure 9: The Weir W4 Autogyro
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It is interesting to note that although within industry it had become clear that the helicopter would supercede the autogyro, the public still held a great fascination for the autogyro, and were it not for the advent of the second world war, there may indeed have been a market place for vehicles such as the W.4. The simplicity and ease of operation of these jump take-off capable vehicles would undoubtedly have been attractive to a public who still viewed the fledgling world of aviation as glamorous and exciting. Mass production could have reduced the unit cost sufficiently to bring the autogyro into the reach of many individuals and small operators, and as the advertising copy of the time said: "*Jump starts make almost any field a 'Gyrodome'*". Indeed quoting from the July 23rd, 1936, issue of *Flight* : "*The £100 autogyro which certain newspapers glibly announced a year or two ago is obviously sheer moonshine. Unless and until the machine is produced at the same rate as one of the popular motor cars, such a price is of course quite ridiculous. It is thought, however, that before long it may be possible to buy a W.3 for something in the neignbourhood of £500. Compared with aeroplane prices this cannot be considered as excessive.*"

There is a certain resonance in this statement. The 1930s was a golden era of flight where aviation was at the forefront of technological advance, and very much grabbed the public interest. Today we live in the information age where advances computing and communications technology grasp the attention of the public at large. Today's equivalent of the "£100 autogyro" is the "$100 laptop".

Weir Pre-war Helicopter Developments

Weirs success in building autogyros, had not gone un-noticed and led in 1937 to a request from the Ministry of Aircraft, to design and build a helicopter. The Bregeut-

Dorand helicopter in Germany and the Focke-Achgelis Fa-61 had both flown and proven that the concept of powered rotor flight was possible. Weirs first helicopter was the W.5, Figure 10, and this design owed much to the proven configuration of the Fa-61, Figure 11. Work on the design of the W.5 began in November 1937, and its first flight was from Dalrymple in June 1938 at the hands of Raymond Pullin, son of Weirs chief designer, C.G. Pullin, (third from left in Figure 12). The W.5 was powered by the Pixie I engine and had a maximum weight of 840lb and was capable of a maximum forward speed of 78m.p.h.

Figure 10: The Weir W5 Helicopter (1938)

Figure 11: The Focke-Achgelis Fa-61 (1936)

The outriggers were of plywood box construction and carried 15ft diameter twin wooden bladed rotors, Figure 13. The blades, along with many of the other components came from the W.3 and W.4 autogyros. The rotors were fully articulated with flap and lag hinges, and a swashplate arrangement for cyclic pitch input. The"direct control" of the rotor used in the early autogyros was retained for pitch and yaw control, however roll control was by differential thrust. As there was no collective, thrust was controlled by varying rotor r.p.m. The engine was mounted with drive shaft facing aft to facilitate the design of the gearing to take power to the rotors. Figure 12 shows clearly a blower cooling fan placed to the front of the engine. The W5 was the first helicopter to be flown in the U.K., and the third in the world, and made over 100 successful flights by July 1939. It is worth mentioning that the first untethered flight of the Vought-Sikorsky 300 was on the 26th of May 1940, almost 2 years after the W.5 made its first untethered flight.

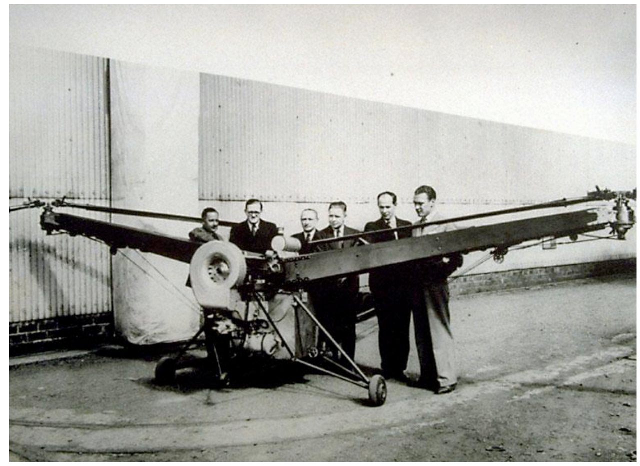

Figure 12: The Weir W.5 Design Team (1939)
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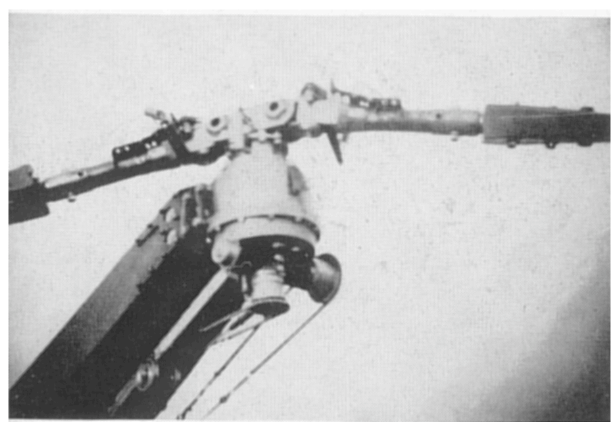

Figure 13: The W.5 Rotor Head

Design of a larger helicopter, the W.6, began in October 1938, a few months in advance of the Air Ministry placing a contract for such a vehicle. The W.6 made its maiden flight 1 year later on the 26th of October 1939 with R.A. Pullin at the controls, Figure 14. The following day it was flown again with 2 passengers on board – the first time a helicopter had ever carried passengers. The W.6 was constructed using a tubular framework carrying two, 25ft diameter, three bladed rotors on elevated outriggers, Figures 15 & 16. It was powered by a DH Gipsy Six II engine developing 200 h.p. The possibility of using autorotation in the event of engine failure was first demonstrated by the Weir W.6 which had been designed with the ability to declutch the engine from the rotors.

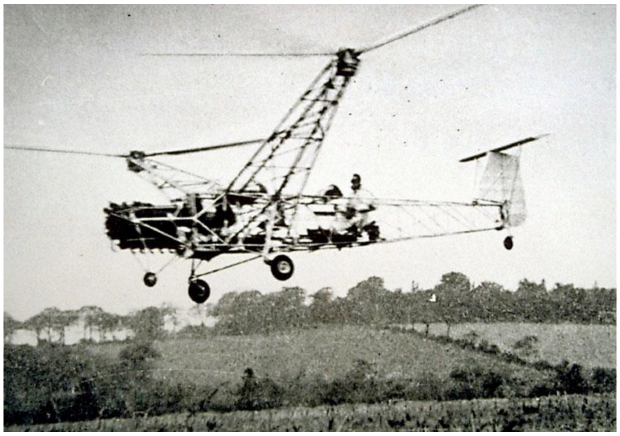

Figure 14: The W.6 in Flight
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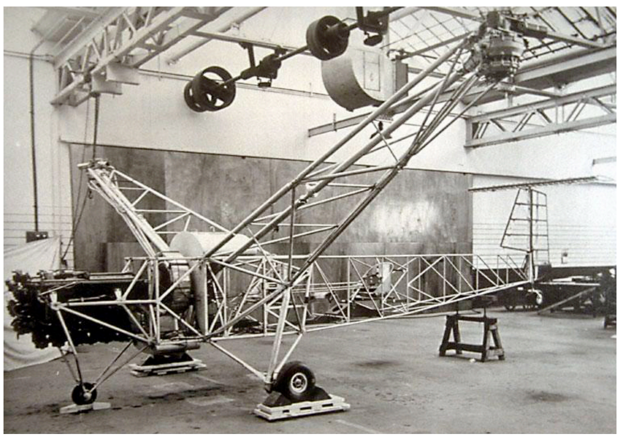

Figure 15: The W.6 Under Construction at the Argus Foundry, Thornliebank, Glasgow, 1939
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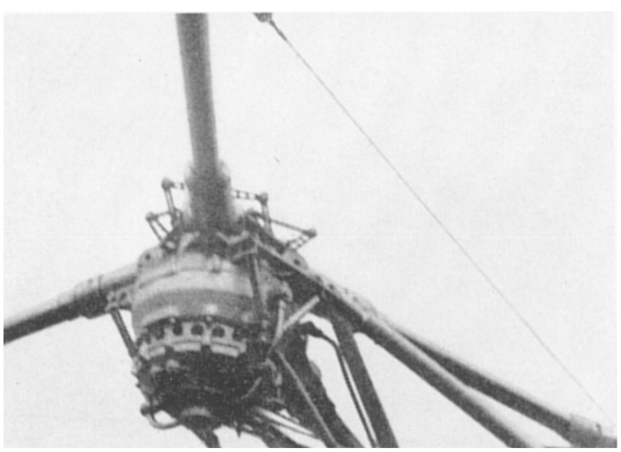

Figure 16: The W.6 Rotor Head

Advances were also made in the controllability of the helicopter by the inclusion of a rotor speed governor and hydraulically operated controls. The rotor hub itself was improved upon mid-way through development after the failure of one of the blades. A new gimballed hub was designed featuring a delta 3 hinge and was referred to as Aerodynamically Stabilized Rotor. The W.6 was flown extensively over the next 10 months, logging 79 hours of flight, carrying many passengers.

The War Years

In early 1940 Air Vice Marshal Tedder was given a demonstration flight in the W.6. No doubt he would have been impressed by its capabilities however, due to the pressure of the war on resources, the Air Ministry cancelled the helicopter project in July 1940. From this point on aircraft manufacturers were very much obliged to follow the directives of government (through the Air Ministry), and all research and development of helicopters in the U.K. was effectively halted. It was said that Weir's had at that time, the largest helicopter design team there was. Had the success of the W.5 and W.6 been exploited, it is very likely that Weirs would have become the world's first major helicopter manufacturer of production aircraft.

In 1940, a larger version of the W.6, the W.7, a 3-seat naval "Fleet Shadower" was designed to meet requirements for an anti-submarine aircraft for the Royal Navy, but the Air Ministry's ban on helicopter work meant that it never left the drawing board. In 1943 the Air Ministry lifted its ban on helicopter development having viewed with great interest the progress made by Sikorsky whose R-5 helicopter was nearing production status. Weir proposed the W.8 which was a single rotor helicopter driven by tip-jets. As with the W.7, this aircraft never left the drawing board, and later that year the aircraft department of Weirs was disbanded. Much of Wiers design activity went to the Cierva Company, as did many of Weirs engineers and designers.

The Post-war Years: Cierva-Weir Helicopters

By 1945 the Cierva company had taken over all of Weirs helicopter business (forming the company Cierva-Weir) and so inherited a number of projects. The first of these was the W.9, Figure 17, which was developed in response to an Air Ministry specification for an experimental helicopter. This aircraft had a loaded weight of 2647lb and was powered by the same DH Gypsy Six engine as the W.6. Air from the engine cooling fan was mixed with hot engine exhaust gas, then ducted down the length of the tail boom and discharged from a port facing duct. This provided anti-torque and directional control by means of horizontal slats controlled by pedal inputs. The W.9 underwent a short and very promising test programme from 1945, until the only prototype was destroyed in an accident in 1946.

Figure 17: The Cierva-Weir W.9 Helicopter

The W.10 was to be a 4/5 seat single engine helicopter, but it never passed the concept stage. The W.11 “Air Horse”, Figure 18, was a large 3-rotor helicopter designed to carry up to 24 passengers. It was the largest helicopter in the world when it first flew in December 1948 and was powered by a single R-R Merlin 24 engine generating 1620 h.p. mounted just aft of the pilot’s cockpit. The rotors were of 47ft diameter and were mounted on out-riggers, anti-torque being provided by lateral tilt of the rotor discs. One of the roles considered for the aircraft was as a crop-duster, and this possibility attracted considerable funding for development. A payload of 6720lb of insecticide would have been possible, and such was the promise of the first prototype W.11, that a second aircraft was commissioned. Unfortunately the first aircraft crashed on the 13th of June 1950 killing all 3 flight test crew including Alan Marsh, who had been involved in most of Weirs earlier developments. Although the second prototype was completed, it never flew, and was scrapped in 1960.

Figure 18: The Cierva-Weir W.11 “Air Horse” (c 1950)

The W.11T was to have been a larger twin engined version of the W.11 but was cancelled after the crash of the first prototype W.11. The W.12 was to have been a freighter utilizing the R-R Dart engine but again this didn’t advance beyond the concept stage. The designation W.13 was never used, but the final Weirs inspired aircraft was the W.14 Skeeter, Figure 19. This was a small 2-seat helicopter of gross weight 1500lb which first flew towards the end of 1948. Ground resonance problems delayed the development, which, along with the cancellation of the W.11, led to the ultimate demise of the Cierva company. The helicopter technology developed by Cierva (much of which had originally come from Weirs) was then acquired by Saunders-Roe who took over Cierva in January 1951. They completed the development of the Skeeter, taking it into production, with 88 examples being built for the British and German armies. Production ceased in 1960 when Saunders-Roe’s helicopter business was acquired by Westlands. Design features of the W.14 were retained in the much more successful Westland Wasp/Scout aircraft. One example of the W.14 remains in flying condition with the British Army Historic Aircraft Flight, Figure 19.

Figure 19: The W14 (Saunders-Roe Skeeter) of the British Army Historic Aircraft Flight

The Kay Autogyro

A short-lived but nonetheless significant achievement was made by David Kay in the 1930s. He designed and built the Kay Type 33/1 autogyro, Figure 20, in Perth in 1934. This aircraft was the first rotorcraft to feature a variable incidence rotor whereby the blade pitch could be varied in flight collectively. The aircraft was tested by the Air Ministry, however it was not developed any further. It now resides in the Museum of Flight in East Fortune, Scotland.

Figure 20: The Kay Autogyro

The Current Picture

The University of Glasgow, has had a long interest in rotary wing flight, stretching back to the early 1980s. The two main themes are flight dynamics and aerodynamics. There has been much experimental research in the area of unsteady aerodynamics with a series of programmes looking at blade vortex interaction and dynamic stall. More recently computational aerodynamics have been as much of a feature of the Department's research output as the experimental work. In flight dynamics the Department has developed expertise in the area of rotorcraft mathematical modeling and simulation techniques. By the mid-1990s sufficient rotorcraft expertise had been gained in the Department to bid for a major project on autogyro safety. After a series of fatal accidents, the UK Civil Aviation Authority requested tenders to undertake a major study aimed at supporting the updating of the UK Airworthiness Requirements for autogyros. This has been an on-going process which has involved simulation, wind tunnel testing and flight testing. Autogyro mathematical modeling (and the modeling of autorotative flight generally) is now a major component of the Department's research, and in the late 1990s the Department acquired its own autogyro for flight test purposes, Figure 21. This is a converted two place Montgomerie-Bensen autogyro (registration G-UNIV), with the rear seat removed to make space for instrumentation. The aircraft itself was built by Montgomerie Autogyros, manufacturer of the popular Merlin Autogyro. Montgomerie still manufactures kits for autogyros from their factory in Ayrshire and is the latest in the line of organizations in Scotland with an interest in rotorcraft technology.

Figure 21: Montgomerie Autogyro G-UNIV

Concluding Remarks

This paper has highlighted a number of important contributions made by Scots companies, institutions and individuals in the field of rotorcraft technology. Most notable were the achievements of G&J Weir, the advances they made in the late 1930s giving them the world lead in helicopter design. As is often the case, the opportunity to exploit this lead was not taken. But for the priorities set by wartime aircraft production, it is possible that Weirs may well have been the first to bring the helicopter in to mass production. Nonetheless, the advances made by Weirs were influential, and hopefully, the part they played in the development of the helicopter will become more widely recognized in the future. Today Scotland's interest in rotorcraft technology is in the form of the research carried out by the University of Glasgow, and in the manufacture of autogyros. Both of these ventures continue to flourish and are likely to give Scotland a role in the world of rotorcraft for some time yet.

Bibliography

"The Illustrated Encyclopedia of Aircraft (Part Work 1982 – 1985), Orbis Publishing

Leishman, J.G., "The Weir W-5 and W-6 Helicopters", Vertiflite, Vol. 48, No. 4, 2002

Leishman, J.G., "The Cierva W-11 "Air Horse", Vertiflite Vol. 49, No. 1, 2003

Leishman, J.G., "Principles of Helicopter Aerodynamics", Cambridge University Press, 2nd Edition, 2006, ISBN 0-321-85860-7