

The background of the cover is a vibrant blue with a subtle, grainy texture. A large, black silhouette of a helicopter is positioned diagonally from the top right towards the bottom left. The helicopter is shown in a dynamic pose, with its main rotor blades blurred to indicate motion. The tail boom and tail rotor are also visible. The overall composition is clean and modern.

The Art of the **Helicopter**

John Watkinson

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For Liza

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Preface

The modern helicopter is a sophisticated device that merges a surprising number of technologies together. This wide range of disciplines is one of the fascinations of the helicopter, but it also makes a complete understanding difficult. The very ability to hover, which sets the helicopter apart, also dooms it forever to vibration, poor performance and economy in forward flight, and thus restricts its numbers.

The unique capabilities, complexity and inherent limitations are part of a helicopter's charm, and have given rise to some wonderful definitions and descriptions, which generally contain more than a grain of truth:

A helicopter is a mechanical engineer's dream and an aerodynamicist's nightmare.

A helicopter is a collection of ball-races flying in close formation.

A helicopter is a collection of vibrations held together by differential equations.

My own search for an understanding of the helicopter was hampered by the huge gap between books containing beautiful photographs but little information and advanced textbooks full of equations.

This, then, is the book that I couldn't buy when I wanted to learn all this; it could not be a conventional book because I have had such difficulty with them. It combines theory and practice of how helicopters are made, how they fly, how they are powered and how they are controlled. It would be impossible to consider all of that without at least some reference to flying techniques.

Most technical books assume an existing level of knowledge, but the wide readership and wide range of disciplines make that inappropriate here. Instead of making incorrect assumptions about the reader, this book approaches every subject from first principles, and builds up in a clearly explained logical sequence using plain English and clear diagrams, avoiding unnecessary mathematics.

Technical terms and buzzwords are all defined, and acronyms are spelled out. Misnomers, myths and old wives' tales (for these are plentiful) are disposed of wherever they arise. Whilst the contents of this book are expressed in straightforward language there is no oversimplification and all of the content is based on established physics and accepted theory. The student of technology or aerodynamics will find here a concise introduction, leading naturally to the more advanced textbooks on the subject.

The would-be pilot will find clear explanations of the principles to act as a perfect complement to the instruction itself. The experienced pilot will find the detailed descriptions of the characteristics of helicopters an aid to safety. This book covers the theory of the helicopter in more than sufficient depth to enable the reader to pass the helicopter theory examination. There is enough practical information to allow the

reader to make sense of the machine's flight manual and to prepare for the helicopter type examination.

The rotary wing flying machine is just part of the larger subject of general aviation. Related subjects such as human factors, meteorology, air law and navigation scarcely differ with the type of flying machine, and are not repeated here save for differences specific to helicopters.

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Much material was obtained from the International Helicopter Museum in Weston-super-Mare, UK, The Fleet Air Arm Museum in Yeovilton, UK, The Museum of Flight in Seattle, Washington, The Igor I. Sikorsky Historical Archives in Stratford, Connecticut, The Hiller Aviation Museum in San Carlos, California and the American Helicopter Museum and Education Center in Brandywine, Pennsylvania. The kindness and helpfulness of the staff of all of these was exceptional and deeply appreciated.

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Reg Austin did a superb job of checking my words for technical accuracy. Mikael Reichel advised on the pedagogical aspects of the text and many of my explanations are the better for that. I would not have obtained all of the necessary photographs and permissions without the assistance of Liza Marshall. I am indebted to Steve Coates for allowing me access to his collection of wartime German helicopter material.

Individuals who have helped include Fred Ballam, Oliver Dearden, Margaret Denley, George Done, David Gibbings, Nick Gribble, Bruce Holben, Russell H. Jones, Bill Kidd, Dan Libertino, Bo Maggs, Tim Price, Renée Renaud, Trevor Scantlebury, Eric Schulzinger, Tom Shenton, Jonathan Simpson, Jay P. Spenser, David Steel, North E. West and Katharine Williams.

Introduction to rotorcraft

1.1 Applications of the helicopter

Although helicopters must all follow the same laws of physics, the forms that practical machines take vary tremendously due to the range of tasks to which they can be put. To avoid confusion, this book takes the view that an aircraft is any man-made aerial machine capable of climbing out of ground effect. Thus a helicopter must be an aircraft. Neglecting aerostats (balloons etc.) any aircraft that is not a helicopter will be an aeroplane (USA: airplane).

It will be seen later in this book that the slower an aircraft goes, the more power it needs to maintain height. Hovering is the ultimate case of slow flight, suggesting that helicopters must have a high power to weight ratio. This will require heavy engines and a corresponding fuel capacity. These factors limit load carrying capability and range.

The mechanical complexity of the helicopter and the inevitable vibration demand a lot of maintenance. The airspeed of the true helicopter is forever restricted by fundamental limits. It will generally be more expensive to move a given load by helicopter than by almost any other means, and so if a suitable airstrip exists, a fixed-wing aircraft can do the job at lower cost, and generally at a higher airspeed. In most cases helicopters cannot compete economically with aeroplanes, and so their use is restricted to applications for which aeroplanes, or other forms of transport, are unsuitable.

In remote areas, there will be no airstrips; in wartime, runways are conspicuous targets, and, with the exception of the aircraft carrier, are fixed. The helicopter's ability to hover means that it can land almost anywhere a fairly flat firm surface exists. Some are genuinely amphibious, landing with equal aplomb on water or land. If the ground is unsuitable (or if the waves are too high) many helicopters can transfer goods and passengers whilst in the hover.

This ability makes the helicopter the ideal rescue vehicle. Many lives have been saved because the helicopter can get to places that would otherwise be difficult or impossible to reach. War casualties, the victims of shipwrecks, mountain climbing accidents and natural disasters such as earthquake or flood today have significantly higher chances of survival because a helicopter can get them rapid treatment.

The accounts of helicopter rescues make more thrilling reading than novels because they are true. Helicopters have flown far out of range of the shore by taking fuel from oilrigs and ships, sometimes taking fuel in the hover if a landing was impossible. This would be remarkable in good weather, but emergencies occur in all weather conditions and the helicopter has evolved to handle the worst.

Despite their life-saving ability, most of today's helicopters were originally designed for military use. As military fixed-wing aircraft became faster and faster, they found

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it harder to attack ground targets or to support ground troops. During the Vietnam War, it was found that the helicopter had a major role. Transport helicopters excelled inserting and withdrawing troops, delivering ammunition and food, evacuating the wounded, recovering the crews of downed planes and even the planes themselves.

Armed helicopters proved to be ideal for attacking ground targets. At first these were general-purpose machines hurriedly fitted with weapons, but later dedicated attack helicopters evolved, complete with armour plating and redundant systems to allow them to withstand ground fire. As their load carrying capability has increased, these machines have virtually rendered the tank obsolete.

Although ideal against ground targets, the helicopter is slow and vulnerable to attack from the air. Fixed-wing planes are necessary to provide the air superiority in which the helicopters operate. As an alternative, helicopters can operate under stealth conditions, avoiding detection by using terrain.

Large military helicopters are very expensive to operate, and armed forces found it worthwhile to have simpler machines specifically for training purposes. A small number of helicopters have been designed specifically for the civil market and these are popular with large companies for executive transport.

For the average private owner, the sheer cost of running helicopters precludes all but the smallest machines with aeroplane-derived piston engines. Virtually all other helicopters are now turbine powered.

1.2 A short technical helicopter history

This is not a history book and this section must necessarily be brief. The reader interested in the US history of the helicopter is recommended to the comprehensive yet highly readable works of Jay Spenser.^{1,2} The recent book by Steve Coates, *Helicopters of the Third Reich*,³ is essential reading to the historian as it shows how far ahead of the rest of the world German helicopter engineers were at that time. For those who read French, two more fascinating volumes are available. *L'Histoire de l'Hélicoptère* by Jean Boulet⁴ contains the words of helicopter pioneers themselves. *Les Hélicoptères Florine 1920–1950* by Alphonse DuMoulin⁵ recounts the pioneering work of Nicolas Florine.

The history of the helicopter has been very short indeed. In comparison with fixed-wing aircraft, helicopters need more power, have to withstand higher stresses, are harder to understand and control and have more moving parts. It is hardly surprising that the development of the helicopter took place well after that of the fixed-wing aircraft.

Early helicopters lacked enough power to fly. Once helicopters were powerful enough to leave the ground, they were found to be uncontrollable. Once the principles of control were understood, they were found to vibrate and to need a lot of maintenance and so on. Today's helicopters represent the sum of a tremendous number of achievements in overcoming one obstacle after another.

Before World War II helicopters were in an experimental phase. This was the heyday of the gyroplane, invented by the Spaniard Juan de la Cierva and technically refined by Raoul Hafner, an Austrian working in England who would later contribute much to the development of the helicopter.⁶

The first practical helicopter was the Focke-Wulf Fw-61 of 1938 (Figure 1.1), followed in the same year by the Weir W-5 (Figure 1.2) that flew two years before Sikorsky's VS-300 (Figure 1.3). The urgencies of war accelerated all technical development with the emergence of production helicopters, where the work of Anton Flettner (Figure 1.4) and Heinrich Focke was far in advance of anything taking place elsewhere.



Fig. 1.1 The Focke-Wulf Fw-61 was the first helicopter to move beyond the experimental stage and was capable of extended flights. The hull was based on that of an Fw Stieglitz aeroplane. Note the vestigial airscrew that simply cools the engine. (Steve Coates)



Fig. 1.2 The Weir W-5 flew extensively, but development of all helicopters was suspended in the UK during World War II. (AugustaWestland)

The Focke-Achgelis Fa-223 shown in Figure 1.5 became, on 6 September 1945, the first helicopter to cross the English Channel when a captured machine was flown to England by Hans Gerstenhauer. This machine had a payload of 2000 kg.⁷

Helicopter development in the UK was halted by government order during World War II and, being an Austrian, Hafner was locked up, but fortunately not for long.

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Fig. 1.3 The Sikorsky VS-300 had an extended development period during most of which cyclic control was not understood and unwieldy auxiliary rotors were used instead. (Igor I. Sikorsky Historical Archives Inc.)



Fig. 1.4 The Flettner Kolibri (Hummingbird) was the first synchropter and was an advanced and capable machine. Kaman developed the concept and produced the successful Husky and K-Max models. (Steve Coates)

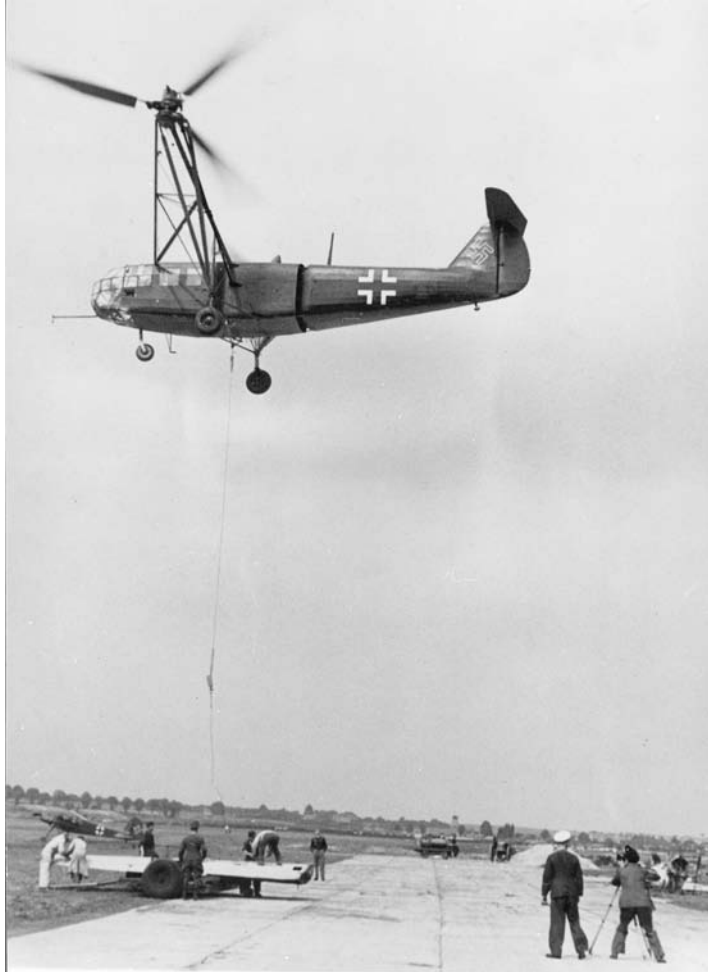


Fig. 1.5 The Focke-Achgelis Fa-223 was a large and capable machine that was in production during World War II. Few were produced due to Allied bombing. The machine was far ahead of anything else in the world at the time. (Steve Coates)

In Germany, production was hampered by Allied bombing, whereas US helicopters were unrefined. The result was the same: helicopters made little contribution to the war itself.

After World War II great progress was made in the understanding of helicopter dynamics and stability. This led directly to machines that were less stressful to fly and correspondingly safer. The Bell 47 (Figure 1.6) based on the research of Arthur Young was in 1946 the first helicopter to be certified. The Sycamore of 1952 (Figure 1.7) designed by Hafner, was the first British helicopter to be certified and was noted not just for its performance, but also for its light control forces which needed no power assistance.⁸

Advances in constructional techniques and materials continued to improve the service life of components, especially blades. Possibly the most significant single step

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Fig. 1.6 The legendary Bell 47 was based on Arthur Young's research and was the first helicopter to be certified in the USA. Larry Bell never liked the utilitarian appearance, but it outsold all of the more stylish models. The flybar stabilization system was adopted extensively in later Bell machines. (Bell Helicopter Textron)



Fig. 1.7 The attractive Sycamore was Hafner's masterpiece and the first helicopter to be certified in the UK. (AugustaWestland)