Principles of Helicopter Flight

Second Edition

W.J. Wagtendonk

Principles of Helicopter Flight
Walter J. Wagtendonk OBE

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Nothing in this manual supersedes any operational documents or procedures issued by the Federal Aviation Administration, aircraft and avionics manufacturers, flight schools, or the operators of aircraft.

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Associate Professor W. (Bill) Hopper
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Connie Reeves, Major (ret) US Army,
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McDonnel Douglas
Seattle, Washington

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New Zealand

Flight Lieutenant Phil Murray,
Royal New Zealand Air Force (ret)

John Reid, MBE

Peter Tait
Helicopters NZ Ltd

Colin Bint

Andy Smith
Nelson Aviation College

Keith Broady, Nelson

Bill Conning
Helicopter Operations Ltd

Ann Wagtendonk

Air Commodore Stewart Boys CBE AFC
Royal New Zealand Air Force (ret)

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Physics 1

If you want to fully understand the principles of helicopter aerodynamics, you must understand certain terms, laws and theorems in physics. This chapter deals with principles of physics that have a direct bearing on helicopter flight.

Newton's Laws

Sir Isaac Newton theorized three basic laws, all of which pertain to flying helicopters.

Newton's First Law

All bodies at rest or in uniform motion along a straight line will continue in that state unless acted upon by an outside force.

Newton's first law defines the principle of *inertia*, which means that bodies tend to keep doing what they are doing. If they are "doing" anything at all while in motion, the path the body travels is a straight line. If change is required, then a force must be applied to achieve that change. For example, getting a locomotive moving down a track requires a force which would be greater than the force required to get a small car rolling along a level road. The fundamental physical difference between a locomotive and a compact car is their mass. Mass means the amount (or quantity) of matter in a body; it is directly proportional to inertia. Thus to change the state of rest of any body, a force is required that must be proportional to the mass of that body. The larger the mass and thus the greater its inertia, the greater the force required.

A body's inertia does not change unless its mass changes. A helicopter at sea level or at altitude, flown fast or slow, has the same inertia, provided its mass does not change.

The term inertia is often confused with momentum. Momentum considers not only the mass of the body concerned, but also the velocity at which it travels. Bodies at rest cannot have momentum, although they do have inertia. For a given mass within a body, the faster it travels, the greater its momentum.

Momentum is formulated as:

$$Momentum = m \times V$$

where m represents mass and V represents velocity.

When a helicopter travels faster, its momentum increases and a greater force is required to bring it to a halt. Alternatively, if its velocity stays the same, but there are more people on board, then momentum increases, this time because of the increase in mass and again, a greater force is required to bring the aircraft to a stop.

The greater the mass of a body, the greater its inertia and the greater the force required to change its state of rest or uniform motion along a straight line.

This principle applies no matter where the body is or whether it is moving fast, slow or not at all.

For a given mass, however, if it has velocity it will have momentum as well as inertia.

The greater the velocity, the greater the momentum and the greater the force required to change its state of uniform motion along a straight line.

In short, all bodies have mass and inertia, but not all bodies have momentum. Only those bodies that have velocity have momentum, too.

There are many instances in everyday flying where inertia and momentum play an important part in operating a helicopter. Once you understand their influences you can better anticipate the magnitude of control inputs needed to make required changes within a safe distance or time. For example, if a pilot makes an approach into a confined area when the aircraft is at its maximum gross weight and at a high rate of descent, then the helicopter's inertia is high because of its large mass and its momentum is high because of its high vertical velocity. The pilot must arrest the momentum downward with another force, usually involving power, to prevent the ground impact from being the force that arrests the momentum!

Newton's Second Law

Force is proportional to Mass x Acceleration.

To accelerate a body at a given rate, the force used must be proportional to the mass of that body. Alternatively, if a given mass must be accelerated at a higher rate, then the force required must be greater.

The accelerated air (the induced flow) through a rotor system, which produces the required force for sustained flight, is a good example of this law in action. If the amount of air is increased, then its mass is greater, and as a result the acceleration required can be reduced to provide the same upward force. Alternatively, if the aircraft is heavier and the force required to keep it airborne is greater, then for the same mass of air processed through the rotor disc, its acceleration needs to be greater.

Newton's Third Law

For every action there is an equal and opposite reaction.

Newton's third law is often misused by assuming that the word action means force. One force is not always equally opposed by another. Only when no acceleration takes place, either in terms of speed or direction, could one say that all forces are equal and opposite and only then could one say that to each force there is an equal and opposite force.

When a helicopter hovers at precisely one height, all actions (and in this case "forces") have equal and opposite reactions, but this applies only so long as there is no accelerated movement up/down, left/right or fore/aft.

Conclusion

Newton's laws have a fundamental influence on all aspects of helicopter flight. Throughout this book many of these aspects can be referenced to this chapter and it is therefore important that you have a good understanding of the principles.

Mathematical Terms

In explaining Newton's laws (and those that follow) everyday words are used, such as velocity and acceleration. Although these words appear to be simple and straightforward, in mathematical terms they are somewhat more complex and may require re-learning.

Velocity

Velocity means: speed and direction. The problem here is the inclusion of the term "direction" as an integral part of the word velocity. To say that one's car, traveling at 50 mph, has a velocity of 50 mph is wrong unless a direction value is included. You could only say that a car has a velocity of 50 mph if the vehicle travels at that speed in a given direction, for example, due north. Although this aspect is not of earth-shattering importance on its own merits, the issue is vital when other terms are considered that relate to velocity, such as acceleration.

Acceleration

Acceleration is simply the rate of change of velocity. If the term velocity is understood correctly, it is clear that by changing either the speed part of velocity or the direction part of velocity, one has changed velocity and because of that, acceleration has been established.

Imagine a helicopter maintaining exactly 50 knots in a steady turn to the right. Although the aircraft's speed is unchanged, its direction is not; in fact its direction is constantly changing. The aircraft is accelerating because of this continuous change in direction.

Understand then, that by altering either the speed of an object or its direction, or both, the object is accelerating.

In this context, slowing down (commonly referred to as deceleration) is also acceleration, but in a negative sense.

Equilibrium

Equilibrium means*:* a state of zero-acceleration. When an object travels in a straight line at a constant speed, its velocity is constant (since there is no change in either speed or direction). It can then be said that the object is in equilibrium. If an object travels at a steady 50 mph on a curve, however, it must be accelerating because its direction is constantly changing and it can then not be in equilibrium.

The terms *equilibrium* and *balanced forces* are often confused. Whenever a body travels at a steady speed on a curve, it cannot possibly be in equilibrium because direction is continuously changing. If the curve on which it travels has a perfect and constant radius, however, then all the forces acting on it will be equal and opposite (this assumes there is centrifugal force). Thus it is possible to have balanced forces, yet no equilibrium. To illustrate, a helicopter doing perfect steep turns at a constant altitude, speed and radius is not in equilibrium, but forces acting upon the aircraft are balanced.

Gravitational Forces

Nature's laws dictate that an attractional force exists between all masses. The greater the masses, the greater the force of attraction is between them. In addition to the size of the masses, the distance between them also has an influence: the greater the distance between masses, the less the attractional force.

This law is not always easy to see because any two adjacent masses, or objects, do not always move towards each other. Just because that movement is not evident, however, does not mean that the attractional force isn't there. In most cases, the drag between the objects and the surface they are resting on is greater than the force of attraction between them and so movement is prevented.

The earth is essentially an object of great mass that exerts a large attractional force on any other object in its proximity. The result of this attractional force on any given mass, or object, is called *weight*. The earth's gravitational force originates from its core and acts on the core of any other mass nearby. The farther the object from the earth's core, the less affected it is by the earth's gravity. Since the result of this attraction is called weight, it follows that the mass further removed must have less weight. Indeed, when the distance between earth and a body becomes so large that the attractional force between them becomes negligible, the body is said to be weightless. To say in this instance that it has no weight at all would be technically incorrect because there is still an earth attractional force, but it is now so small as to be unrecognizable.

Earth attractional force has the symbol g, while the mass it acts on has the symbol m. Thus weight can be formulated as:

$$Weight = m \times g$$

This means that the greater the mass for a given "g" the greater the weight or, the greater the distance away from earth for a given m, the less the weight. Remember that mass does not vary if the number of molecules is not altered, but the weight of this mass will change with significant changes in altitude.

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Second Edition

Principles of Helicopter Flight, by Walter J. Wagtendonk, explains the complexities of helicopter flight in clear, easy-to-understand terms. The worldwide helicopter industry has waited a long time to see a manual of this caliber.

This Second Edition adds discussions on the NOTAR system and strakes, as well as the frequently misunderstood principles of airspeed and high altitude operations. Chapter reviews and a concluding practice exam ensure your grasp of the principles learned from this book.

Helicopter pilots need to thoroughly understand the consequences of their actions, and base them upon sound technical knowledge. This textbook provides the background knowledge explaining why the helicopter flies and, more importantly, why it sometimes doesn't. It examines the aerodynamic factors associated with rotor stalls, mast bumping, wind effect, as well as maneuvering flight to include the hover, forward flight, the flare, and autorotation. Helicopter design and components, performance, and weight and balance is covered, along with special techniques such as different types of takeoffs and landings, operating on sloping surfaces, sling operations, mountain flying, and helicopter icing. Technical knowledge and sound handling are the ingredients that make a pilot safe.

For the student learning to fly helicopters in the 21st century, this book is one of the essential keys to flight.

"Wal" Wagtendonk served in the Royal New Zealand Air Force, retiring as an A-2 instructor in 1960. After working with the Nelson Aero Flight Club as Manager and Chief Flight Instructor, Wal, with his wife Ann, formed the Nelson Aviation College in Motueka, which blossomed into one of New Zealand's best known theory and flight training establishments. Nelson Aviation College became the first "approved" school to conduct both fixed-wing and helicopter courses, and many experienced helicopter pilots currently flying all over the world started their basic training under Wal's careful instruction.

Wal was born in The Netherlands, and emigrated to New Zealand at age 20. Having retired in 1990, Wal and Ann now reside in the Bay of Plenty on New Zealand's North Island.

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Aviation Supplies & Academics, Inc.
7005 132nd Place SE
Newcastle, WA 98059-3153
www.asa2fly.com • 1-800-ASA-2-FLY