Cyclic and Collective

The Art and Science of Flying Helicopters

Forward by Ray Prouty

Shawn Coyle
Eagle Eye Solutions, LLC

AIRCRAFT TECHNICAL BOOK COMPANY

Some Fundamentals 1

Math and Physics Revisited

In order to understand how a helicopter operates, it is necessary to have an understanding of the principles controlling physical objects, as well as the mathematical basis for some of the calculations that are needed.

Not everyone is an engineer, and fewer have studied advanced mathematics or physics. I've made an attempt to simplify the explanations and minimize the equations*, however, some are unavoidable. This chapter should explain the fundamentals of the physical laws important to helicopters.

Vectors

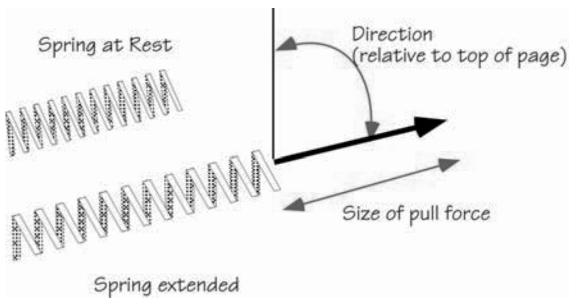


Figure 1-1 Vector Defined

One of the things that isn't easy to immediately grasp is the concept of a *vector*. Since vectors are used a lot in this book, take the time to understand what they mean.

A vector is a way to represent graphically, something with both size and direction. Take a spring for example. It's not possible to pull on a spring without a direction of pull. This gives a force (size) and direction of pull. This can be represented by a vector. Normally the direction of pull is of no importance but it is for us.

Newton's Laws

If you don't remember much from high school physics, you should remember Sir Isaac Newton's three laws†. Helicopters may not have studied physics or law, but they do obey these three.

Newton's First Law

A body tends to stay at rest or in motion in a straight line unless disturbed by some external force.

In simple terms, if you want to change the uniform (steady) motion in a straight line of an object, you need to apply an external force to it. If you want to turn a corner in a car, you have to apply an external force to the car, (the friction of the tires on the road is such a force - try turning a car on ice to show how this is true). If you want to turn a helicopter, or move a helicopter that is hovering, you need to apply an external force to the body of the helicopter.

In steady motion, all the forces are in balance. Throw the forces out of balance or add an external force and the forces attempt to re-balance themselves while the motion is changed to stay in a (new) uniform motion.

* Evidently each equation in a book reduces the number of readers by 50%, and I want to keep both of you.
† What happened before Newton came along is anybody's guess. Things must have been pretty chaotic.

Newton's Second Law

Force is proportional to Mass times Acceleration.

What does this mean? In simple terms it means, with identical acceleration (i.e. the same gravity) a large mass will exert a greater force than a smaller one. Sounds so simple, but remember gravity is an acceleration, so we often confuse mass and weight (weight is a force).

Newton's Third Law

For every action there is an equal and opposite reaction.

Sounds simple enough- if two people are standing on a perfectly smooth, frictionless surface, and one pushes against the other, both will move apart. Since a helicopter in a zero airspeed hover has very little friction acting against it, the action of turning the main rotor tends to want to rotate the fuselage the opposite way. More about this important fact later.

OTHER PHYSICS AND MATHS TERMS

Momentum and Inertia

Momentum is the mass of a body multiplied by its velocity. *Inertia* is the resistance to change (stay at rest, or in uniform motion in a straight line). A body at rest has zero momentum, but it does have inertia. It is still necessary to apply a force to a resting body to make it move (i.e. overcome inertia). Momentum and inertia are important concepts for flying helicopters because a heavy helicopter has a higher inertia than a light one, and requires greater forces to change its flight path.

Speed

Speed is the rate of change of distance per unit of time. For example, a helicopter that travelled 100 nautical miles over the ground in one hour has a ground speed of 100Knots (nautical miles per hour).

Velocity

Velocity is speed *and* direction. Our helicopter with a ground speed of 100Knots must be going somewhere, so we need to say where - for example, a speed of 100Knots on a track of North. Since it's pretty hard to have speed without direction, we often confuse these two terms. When we use velocity (instead of speed) we are using a vector.

Acceleration

Acceleration is not just an increase in speed, as we often think. It is *rate of change of velocity*. Since velocity has speed and direction, acceleration can be either the rate of change of speed or rate of change of direction. Slowing down is an acceleration (typically called negative acceleration). Turning in forward flight is acceleration. Turning in a zero-groundspeed hover is not acceleration of velocity (since you're going nowhere...).

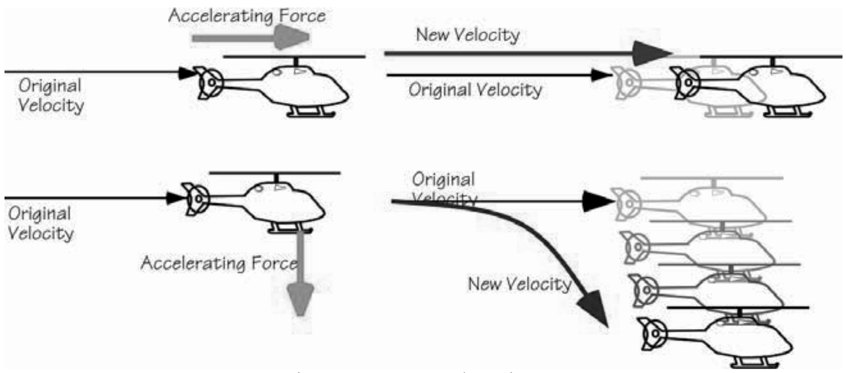


Figure 1-2 Accelerations

Figure 1-2 shows two accelerations - one pushing to change the direction of velocity, and in the other case to change the speed. Thus, acceleration has both magnitude and direction, it too is a vector.

Equilibrium

Derived from the Greek word meaning equal amounts of librium*, it means everything in balance. This implies zero acceleration.

Vectors, Resultants and Resolving

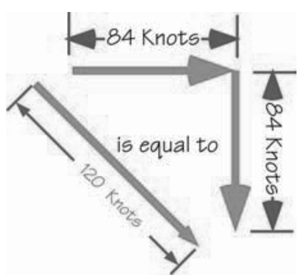


Figure 1-3 Resolving Vectors

Something with both magnitude and direction (such as a velocity) can be considered as a vector. The velocity has both magnitude (speed) and direction. Vectors can be added, multiplied or split apart if appropriate units are used.

For example, a helicopter heading southeast (135°) at an airspeed of 120Knots has a velocity to the east of 84Knots and to the south of 84Knots, as shown in Figure 1-3. This is relatively easy to see, and is called *resolving* the airspeed to two different axes.

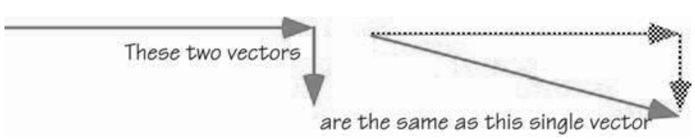


Figure 1-4 Adding Vectors

The opposite of resolving an existing velocity is combining two or more velocities. If two velocities are combined, for example air with both horizontal and vertical velocity, then the resultant is as shown Figure 1-4. Here's a more complex example.

* possibly an early Greek tranquilizer?

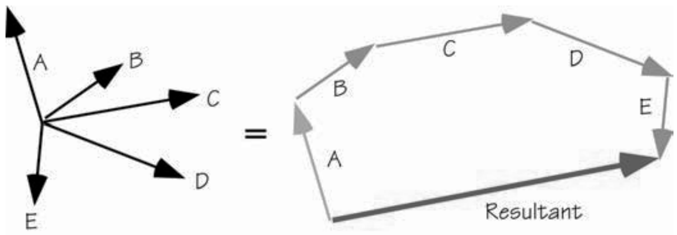


Figure 1-5 Adding More than Two Vector

In the helicopter world, the vectors we most often want to resolve are force vectors.

For example, a thrust vector from a rotor blade will have components that are relevant in both the vertical and horizontal axes.

MOMENTS AND COUPLES

Moments

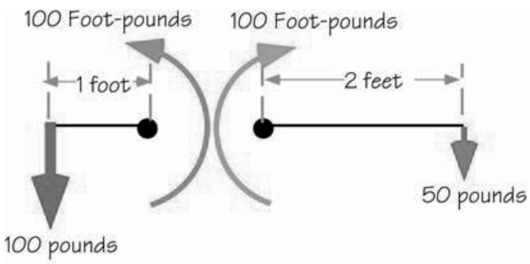


Figure 1-6 Moments Defined

There will be mention later of *moments* and *moment-arms*, and this is as good a time* as any to clarify them. For those who have not encountered a moment before, it is the reaction at a pivot point of a force (e.g. 50 pounds) multiplied by the distance (e.g. 2 feet) from the pivot point that the force acts about, giving units of foot–pounds.

A small force acting at a long distance may have the same moment as a large force acting at a small distance, shown in Figure 1-6. Moments are important in many descriptions of how helicopters work. The symbol for a moment is an circular arrow, as shown Figure 1-6.

A playground teeter-totter is a good example of the use of moments. If you're an adult trying to balance a small child on the other end, you know you'll have to sit close to the center when the child sits at the very end. Your weight multiplied by the distance to the pivot point must equal the weight of the child on the other end multiplied by their distance to the pivot point in order for you to balance each other.

Torque is another word for a moment.

Couple

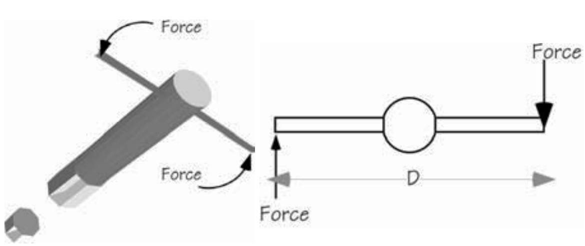


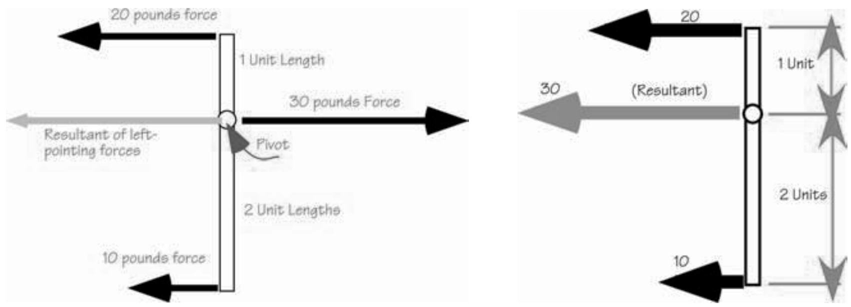
Figure 1-7 Couple Defined

A *Couple* is similar to a moment, except there are two forces acting in equal and opposite parallel directions. The main difference between a moment and a couple is that the couple normally is considered to have two equal forces. Figure 1-7 shows a couple. There is no lateral reaction at the pivot for a couple.

* Sorry about the pun. This is the first of a great many. You've been warned.

BALANCE OF FORCES

It is important to understand how forces balance (or don't balance). Consider the following two examples. In Figure 1-8 a), the forces and moments are in balance- there is no turning moment and no net reaction at the pivot point. In Figure 1-8 b) however, the moments may be in balance, but the forces are not. There is a net sideways reaction at the pivot point of 30 lb.



a) Moments and Forces in balance

b) Moment balanced, forces not in balance

Figure 1-8 Forces and Moments

Dimensional Correctness*

In the world of physics, one of the ways to check to make sure your formulae are correct is to ensure the units work out correctly. This is easy to do when you use consistent units.

Distance and Time

We use units of distance and time quite a bit in aviation. The units we will use in this book for the purposes of talking about physics are L for distance, and T for time.

MASS, FORCE, ENERGY AND WORK

Mass

Mass is not a force. We mortals who spend nearly all our time standing or sitting in an environment with a constant one gravity (1G) environment suffer great confusion over the difference between mass and weight.

Mass has units in the Imperial units system of *slugs*, but we commonly (and incorrectly) use pounds instead. Since most of the time we're only concerned about the effects of mass in a 1G environment† we'll perpetuate the confusion by adopting the simple common term pound (lb.) to describe mass.

In the metric system, mass is in units of Kilograms (kg).

Weight is a force. It has units of pound-force (lbf.) or Newtons (N).

Some books use pounds-force (lbf) or pounds-mass (lbm) to distinguish between mass and weight.The difference between mass and weight may be more clear if you think of two lumps of the same material, one on a weigh scale, and the other on a balance bar, as shown in Figure 1-9 a). In a 1G situation (i.e. sitting still on the earth) both methods of measuring will show the same value. Put them both in a whirling centrifuge, or an

* No, not some new version of political correctness, this has existed for years. And it works.

† helicopters don't do a lot of maneuvering that would increase the G level significantly, and all the performance things we're concerned with happen in a 1G environment, so it's not going to screw things up too much.