Dynamics of Aerial Robots — Intuitive guide

Same equations, but explained like a human being

1. What Are We Even Studying?

We study **rigid bodies**. A rigid body is an object that does *not deform*. Distances between points never change.

For aerial robots, this is a very good approximation: the drone moves, rotates, but does not bend.

To describe a rigid body in space, we must answer two questions:

- Where is it?
- How is it oriented?

That is the entire subject.

2. Position, Orientation, and Frames

Position: We track one special point: the **center of mass** G. Why? Because Newton's laws are simplest there.

Orientation: We attach a **body frame** to the robot. This frame rotates with the robot.

Two frames always exist:

- Space (inertial) frame: gravity lives here.
- Body frame: inertia and motors live here.

Confusion usually comes from mixing these two.

3. Rotation Is Hard — So We Encode It

Rotations are not like translations. You cannot add angles like vectors.

So we encode orientation using:

- rotation matrices, or
- Euler / Yaw–Pitch–Roll angles.

Important idea: Angles describe *orientation*, not motion.

Motion is described by something else: **angular velocity**.

4. Angular Velocity — The Key Concept

Angular velocity answers one question:

> "How is the orientation changing right now?"

It is a vector:

- direction = axis of rotation,
- magnitude = speed of rotation.

This is why even if you use angles, dynamics is always written with $\boldsymbol{\omega}$.

Golden rule: Never differentiate angles blindly. Always convert to angular velocity.

5. How Every Point Moves

A miracle of rigid-body mechanics:

> If you know how one point moves and how the body rotates, you know how *every* point moves.

So the velocity of any point =

- motion of the center,
- plus rotation around the center.

This is why all velocity formulas look the same.

6. Mass, Center of Mass, Inertia

Mass answers:

> "How hard is it to move this object?"

Inertia answers:

> "How hard is it to rotate this object?"

The center of mass is chosen so that:

- translation and rotation separate cleanly,
- equations become readable.

Inertia tensor: Not just a number, but a matrix, because rotation depends on direction.

7. Momentum and Energy — Why We Care

Momentum describes how much motion the body wants to keep. Angular momentum describes how much rotation it wants to keep.

We group both into the **kinetic wrench**.

Energy gives a scalar measure of motion, but dynamics uses momentum because forces act on it directly.

8. Newton–Euler: The Heart of the Course

Everything reduces to this idea:

> Forces change motion. Torques change rotation.

For a rigid body, this becomes:

- sum of forces = mass $\times$ acceleration,
- sum of torques = change of angular momentum.

The extra term that scares everyone comes from the fact that the body is already rotating.

It is not magic — it is geometry.

9. Forces, Torques, and Flying Robots

Flying robots are special because:

- they are not constrained by joints,
- all forces are external.

Gravity always acts in the space frame. Motors always act in the body frame.

Understanding how these interact is the core difficulty — and the core skill.