# Vertical Flight:

**Assumptions:**

* Negligible friction (drag) is experienced by UAV in vertical direction

**Mathematical Model:**

For vertical flight, model is the simplest since drag is neglected. The real-life values will be significantly different but since only take-off and landing is vertical, there would be negligible effect on overall mission time and energy consumption.

Summing all force vectors on UAV,

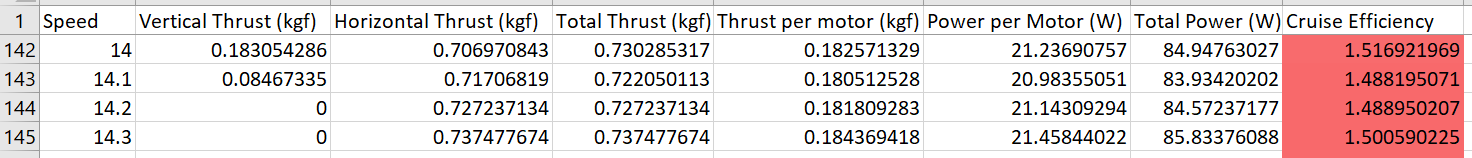
Table

Description automatically generatedUsing the estimated function (thrust as function of power), acceleration can be written as a function of power. Integrating twice w.r.t time, distance travelled can be expressed in terms of total energy consumed. Optimizing the total energy, we find out that 10.5kgf total thrust for UAV gives optimum energy consumption for 30m takeoff

# Horizontal Flight:

For horizontal flight, calculations are simple too. Since the UAV is cruising at constant airspeed and altitude, all vertical components are of no concern. For horizontal components, .

Since lift can be expressed as function of velocity using Fluent Simulations, velocity from comes out to be 14.2ms-1. From this cruise speed, drag can be calculated and hence, required thrust is calculated using that drag. Since power can be written as a close function of thrust for EMAX GT-2826/5, power consumed can be calculated for horizontal cruise. Using this methodology, power consumed during cruise comes out to be 84 Watts.

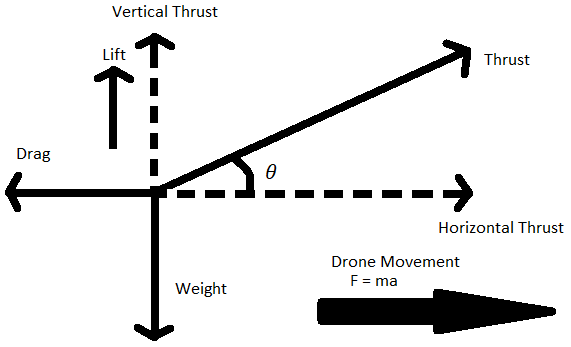


# Rotors Transition State:

**Conventions:**

* Tilt angle in horizontal flight is set as 0o and in vertical flight as 90o.

**Mathematical Model:**

For simplicity, we assume that thrust magnitude during the transition phase remain constant and only the tilt angle changes. Thrust provided by rotors is divided into vertical and horizontal components depending on the instantaneous tilt angle.

Acceleration of UAV is represented as function of tilt angle & drag force. Tilt angle is a function of lift in (i). Fluent simulations show that drag & lift can be written as function of horizontal velocity as:

Hence, using (i) and (iv), θ can be written as function of velocity.

Using (ii), (iii) & (v), acceleration is written as function of velocity. Hence, equation becomes:

Velocity & Speed are given as:

Since the flight controller doesn’t control tilting in a continuous way but in a discrete way, i.e., changing every clock cycle. Which changes the tilt angle every micro-second according to the equations above.

The easiest and most accurate way to calculate the complete spectrum of tilt angle, horizontal & vertical speed, lift, and drag is to distribute time domain into discrete parts of microseconds (Δt) and then, from t = 0s & v = 0ms-1, start calculating lift, drag and acceleration. Use & to calculate distance and next interval velocity.

Using this approach, calculations for transition region are made in excel sheet keeping Δt = 20µs

A picture containing table

Description automatically generated

During transition from 90o to 0o, time taken is 925ms and distance covered is 6.3m.

Note: This calculation assumes that drone acceleration is bottle neck and not the tilting servo speed because tilting servo used in this UAV has a higher angular velocity than that of transition state.

