Payload release dynamics with UAV not moving in the direction of wind.

The following documentation describes the payload trajectory when the payload is dropped from moving UAV. This documentation assumes that the UAV is not moving along the direction of wind.

The data we know beforehand:

- Velocity of wind in north direction
- Velocity of wind in east direction
- Current coordinate of UAV
- Target coordinate of UAV

Coordinate calculation:

When the UAV is moving along the path to drop the payload and the payload dropping point lies in a straight line, the calculation of where the payload is to open to reach that point starts.

Let the current coordinate be (current_n,current_e) and target of where payload should be released be (target_n, target_e).

If theta θ is the angle in which the UAV is moving then,

$$\theta = tan^{-1}\left(\frac{target_e - current_e}{target - current_n}\right)$$

Let the wind blowing in the east be WindSpeedEast, and the wind blowing in the west be WindSpeedNorth then, If phi φ is the angle in which the wind is blowing then,

$$\varphi = tan^{-1}\left(\frac{windSpeedEast}{WindSpeedNorth}\right)$$

To calculate the relative direction in which the payload will drop, the relative velocity vector of wind velocity and UAV velocity should be taken.

To find the relative velocity of wind and UAV, law of cosines is used.

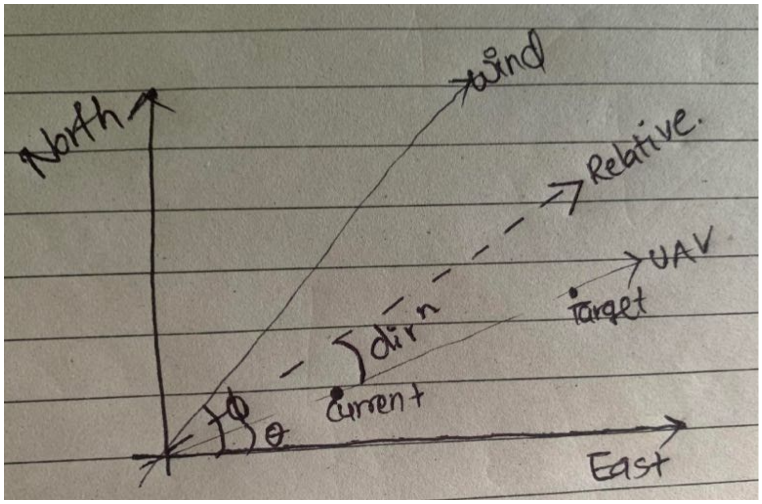
$$relative = \sqrt{uav_{speed}^{\ 2} + wind_{speed}^{\ 2} - 2 * uav_{speed} * wind_{speed} * cos(c)}$$

Where, c = π - (θ - φ)

And,

$$dirn = cos^{-1}\left(\frac{relative^2 + uav_{speed}^{\ 2} - wind_{speed}^{\ 2}}{2 * relative * uav_{speed}}\right)$$

Now, To calculate the releasing point if target point is (target_n,target_e) then,



if the relative payload path is same as plane path

$$RP_n = target_n - x * cos(dirn)$$

$$RP_e = target_e - x * sin(dirn)$$

if the relative payload path is above the plane path

$$RP_n = target_n - x * cos(\theta + a * dirn)$$

$$RP_e = target_e - x * sin(\theta + a * dirn)$$

if the relative payload path is below the plane path or no wind is blowing

$$RP_n = target_n - x * cos(\theta - a * dirn)$$

$$RP_e = target_e - x * sin(\theta - a * dirn)$$

Where (RP_n, RP_e) denotes the Release point in the north, and Release point in the east. This is the point where payload should be released in order for payload to reach the target destination.

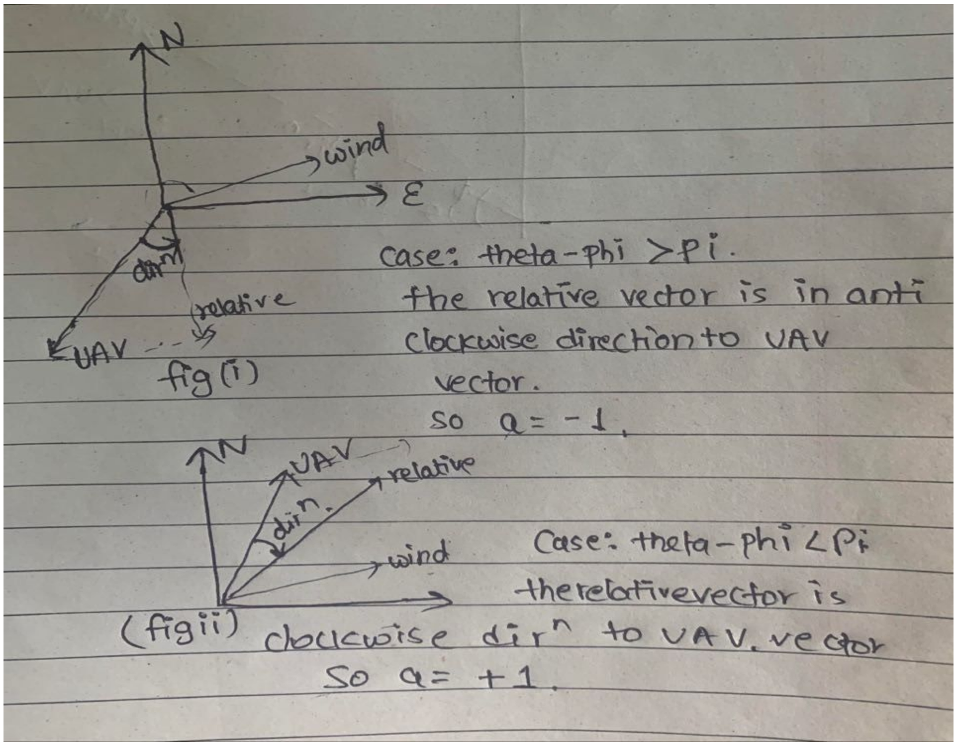
Where a is variable whose value is 1. This value changes to -1 whenever the difference in angle between theta and phi exceeds pi.

IN NORMAL CASE

whenever theta > phi then the resultant vector of direction 'dirn' is below the UAV velocity vector (below means '-' in 1st and 2nd quadrant),

BUT

when the difference between theta and phi is greater than 180 degree then the resultant vector of direction 'dirn' is still below the UAV velocity trajectory but is in 3rd and 4th quadrant (and here below means ' + '). So to change this direction of + to - and - to + 'a' is used.



The figure above shows the use of variable a.

Dynamics calculation.

Let,
g = acceleration due to gravity
M = mass of payload
A = cross sectional area of payload
Rho = air density
dt = free fall prediction time stamp
Cd = coefficient of drag
Z_0 = surface roughness, where the payload is to be dropped

And,
Vz = velocity in z direction
Az = acceleration in z direction
z = intermediate height calculated
H = height over target,
Vw = wind speed
Vx = velocity in x direction

Ax = acceleration in x direction
X = displacement in NE plane in NED frame
Vrx = velocity in x direction wrt wind velocity
V = relative speed vector
Fd = drag force
Fdx = drag force in x direction
Fdz = drag force in z direction

Then, Calculation of intermediate height in Z direction is given by,

$$V_z = V_z + a_z * dt$$
$$Z = Z + V_z * dt$$
$$h = h - z$$

As we know that, the wind velocity varies with the height, then the velocity of wind according to height is given by formula below

$$V_w = V_w * \frac{log(\frac{total\ height - z}{z_0})}{log(\frac{total\ height}{z_0})}$$

Then, for calculation of range along x direction, i.e along NE plane in NED frame

$$V_x = V_x + a_x * dt$$
$$X = X + V_x * dt$$
$$V_{rx} = V_x + V_w$$

Since the acceleration is unknown in the above equation, we have to calculate acceleration. To calculate acceleration, drag force should be known. For drag force,

$$V = \sqrt{V_z^2 + V_{rx}^2}$$
$$F_d = \frac{1}{2} * rho * C_d * A * V^2$$
$$F_{dx} = F_d * \frac{V_{rx}}{V}$$
$$F_{dz} = F_d * \frac{V_z}{V}$$

Now, acceleration can be written as,

$$A_z = g - \frac{F_{dz}}{M}$$
$$A_x = -\frac{F_{dx}}{M}$$

These dynamics equation should be run in loop in the program until the difference between intermediate height(z) and total height(h) reaches 0.