Formation Control System for Multi Autonomous Vehicles

by : Tariq Abdelrahman

CALIFORNIA STATE UNIVERSITY - FULLERTON

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Agenda

- Why flying in a formation ?
- Formation Selection
- Objective
- Technique Methodology
- Formation Construction & Trajectory
- Water Level Technique
- Changing Formation
- Conclusion

Flying in a Formation

Why flying in a formation is important for a fleet?

Because it will maximize the mission results from two points of view:

- **Resources: (fuel, energy, etc)**
- **Tactical: (Safety coverage technique, submission assignment, etc)**

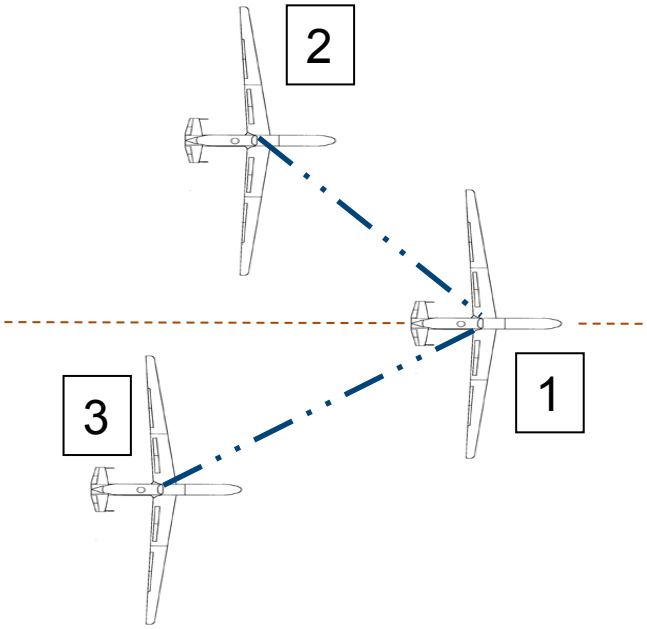
In the normal cases (manned aerial vehicle), maintaining the formation is done by the pilots using visual sight view, in coordinating with the fleet leader.

However, such a thing is difficult to be implemented in a fleet of UAVs

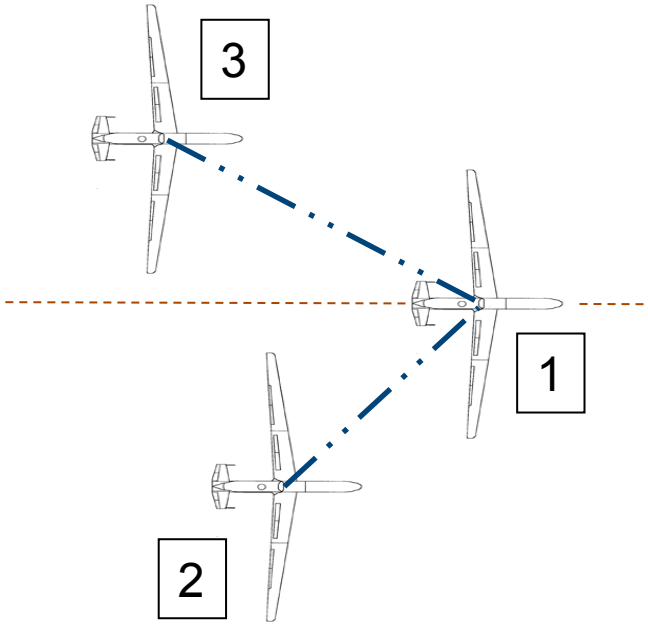
Formation Selection

Selecting formation depends on two variables:

1. **Number of Vehicles**
2. **Formation Pattern**



Left Wing Formation



Right Wing Formation

Objective

Building a formation control system where every vehicle in a fleet should :

1) Maintaining its position in the formation while flying based on assigned plan.

2) Reacting based on any event that affect the formation.
For example loosing one of the vehicle calls for reformatting the group based on new formation.

3) Avoiding the collision with other vehicles in the fleet during any movement.

Technique Methodology

Every vehicle assigned an offset from the leader trajectory to maintain during flying plan.

Then the vehicle changes its velocity and heading relatively based on a proposed technique called "Water level" technique.

The technique methodology:

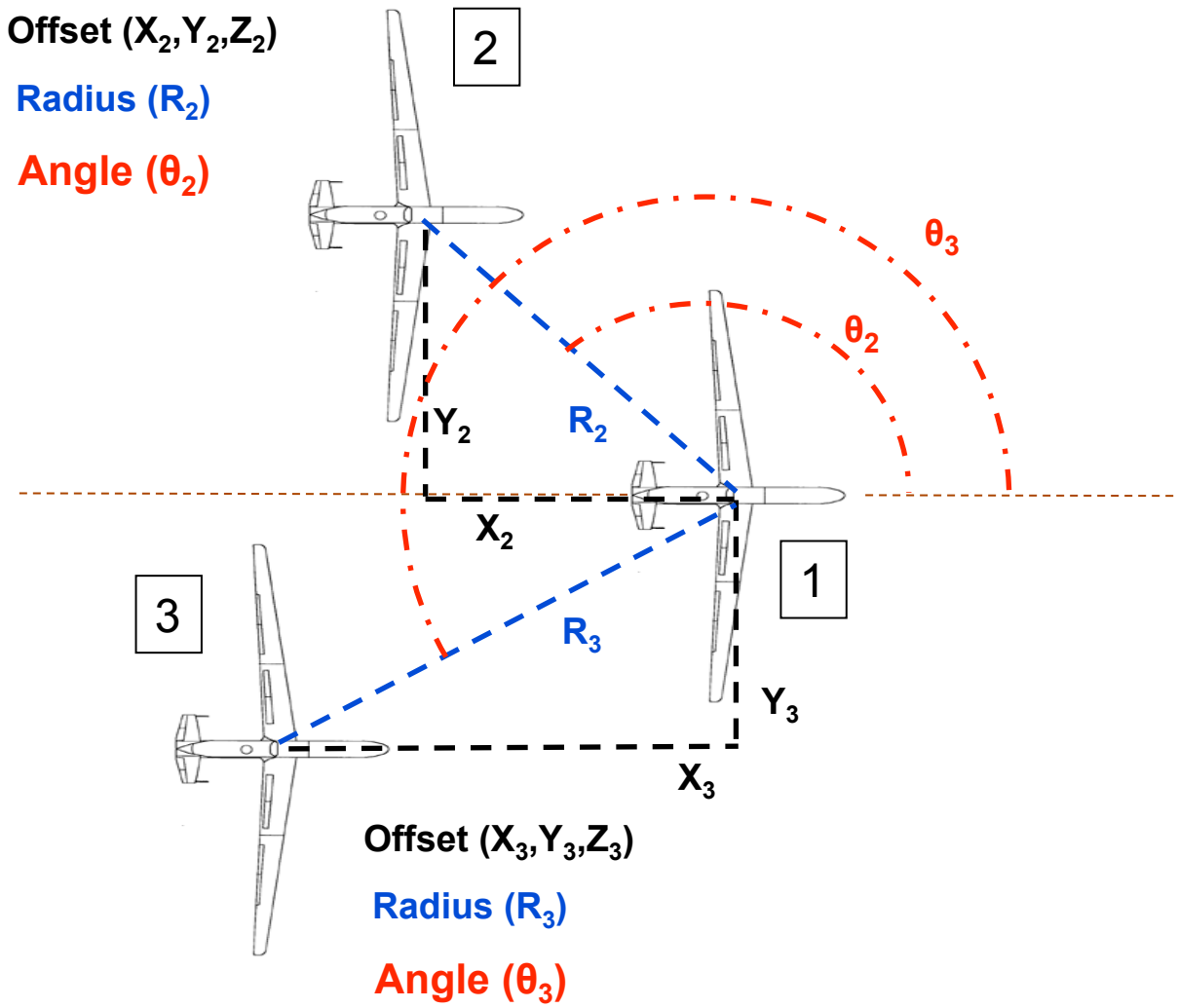
1) Every vehicle has a unique id (Vehicle ID) and formation position number (Vehicle PN) that determine its position in the formation.

2) The vehicles are flying in 3D environment and using passive ranging Global positioning system (GPS) to determine their positions in the globe

3) Every group (fleet) has a communication system that allows their members to exchange messages and information during the flying.

4) A formation structure should be initialized and assigned to the group at the beginning of flight.

Formation Construction



Formation Trajectory

The trajectory of every vehicle is specified by set of waypoints loaded to the vehicle memory. Those waypoints calculated based on every vehicle position in the selected formation.

To calculate the waypoints, first the trajectory of the leader specified based on the flying plan. Then initial waypoint for every vehicle is determined, After that, the coordinates of the rest waypoints are generated using:

1) Transition Operation: for every vehicle, to generate a new waypoint (Xi,Yi,Zi) in the same direction, a (x',y',z') transition applied on the previous waypoint (Xi-1,Yi-1,Zi-1).

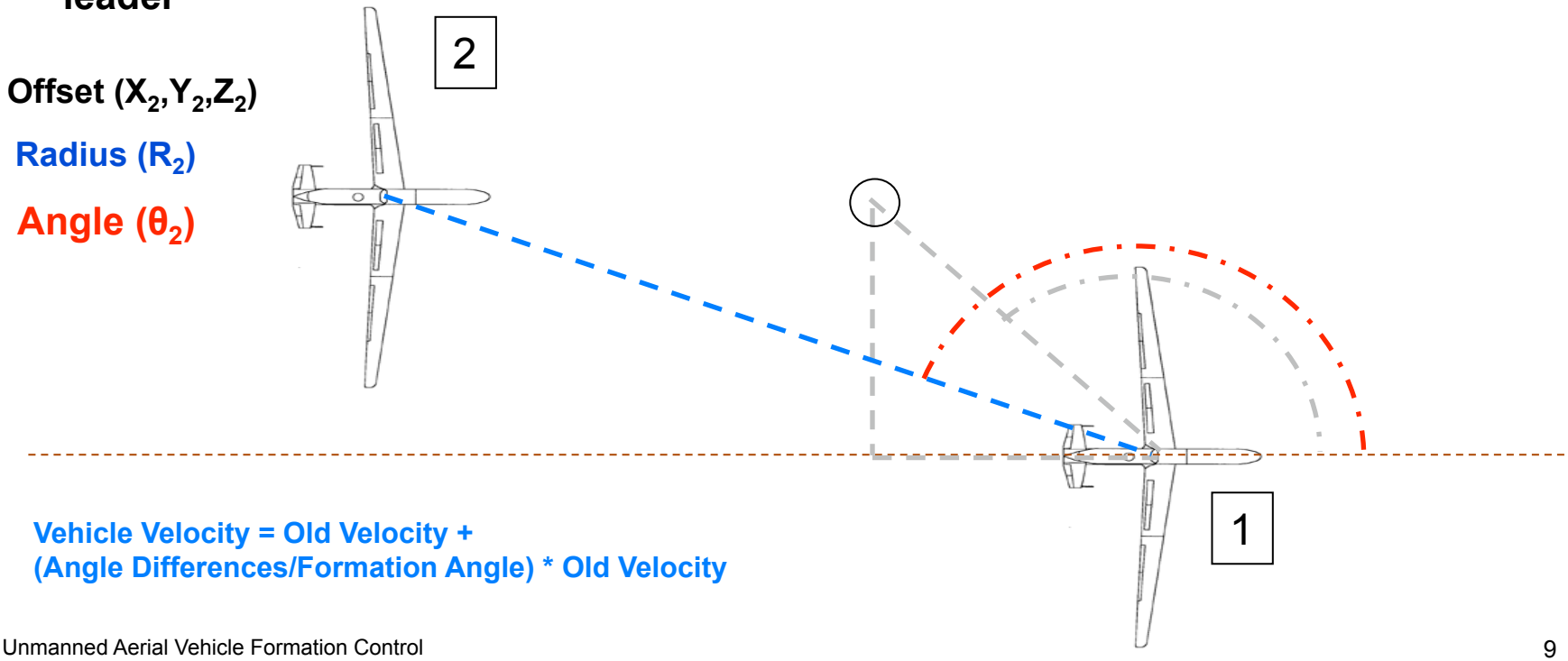
2) Rotation Operation: for every vehicle, to generate a new point (Xi,Yi,Zi) in different direction, a θ' angle rotation is applied on previous (Xi-1,Yi-1,Zi-1) using one fixed (x',y',z') center.

Maintaining Position

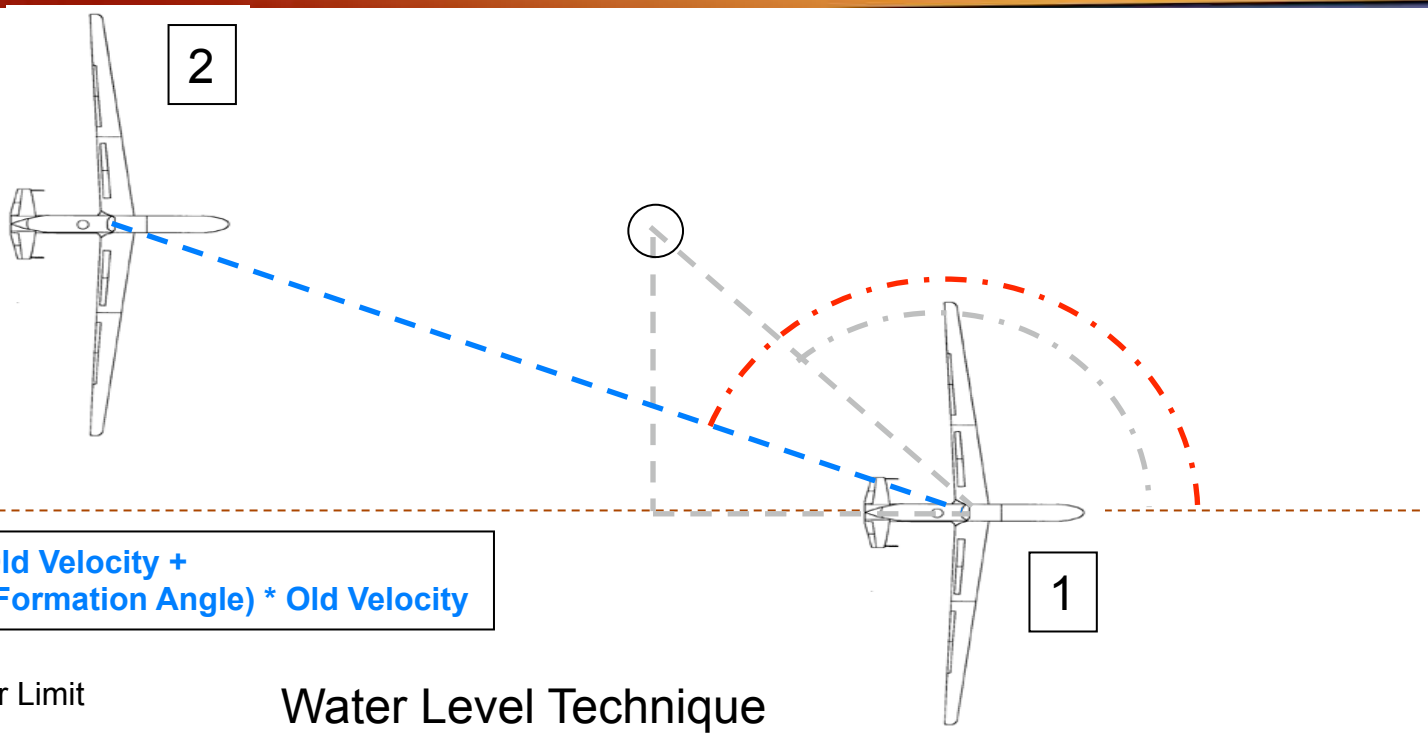
During the flying, the leader vehicle broadcast the following leader data to the rest of vehicles in the fleet:

1. **Coordinates (X,Y,Z)**
2. **Heading Angle**
3. **Velocity**

Based on these information, every vehicle in the groups calculates the position coordinates differences (x,y,z), the distance (r) , and the angle (θ) relative to the leader



Maintaining Position

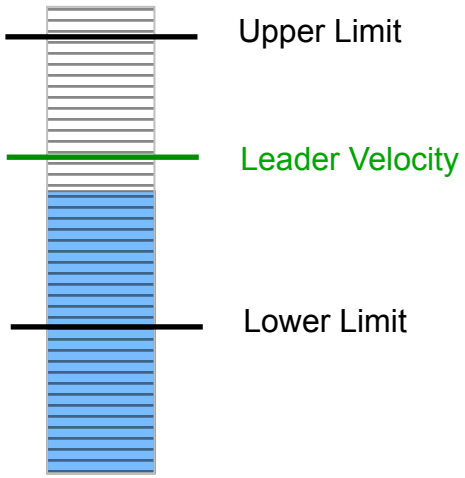


Offset (X_2,Y_2,Z_2)

Radius (R_2)

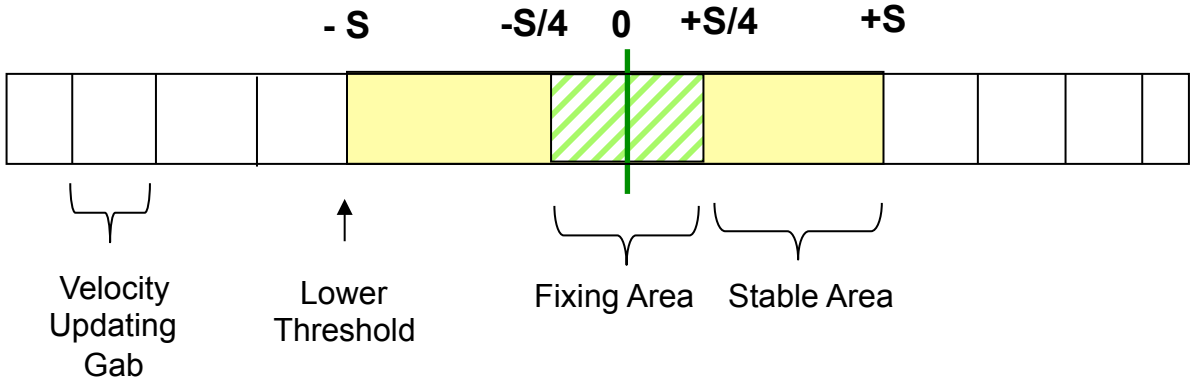
Angle (θ_2)

Vehicle Velocity = Old Velocity +
(Angle Differences/Formation Angle) * Old Velocity



Vehicle Velocity

Water Level Technique



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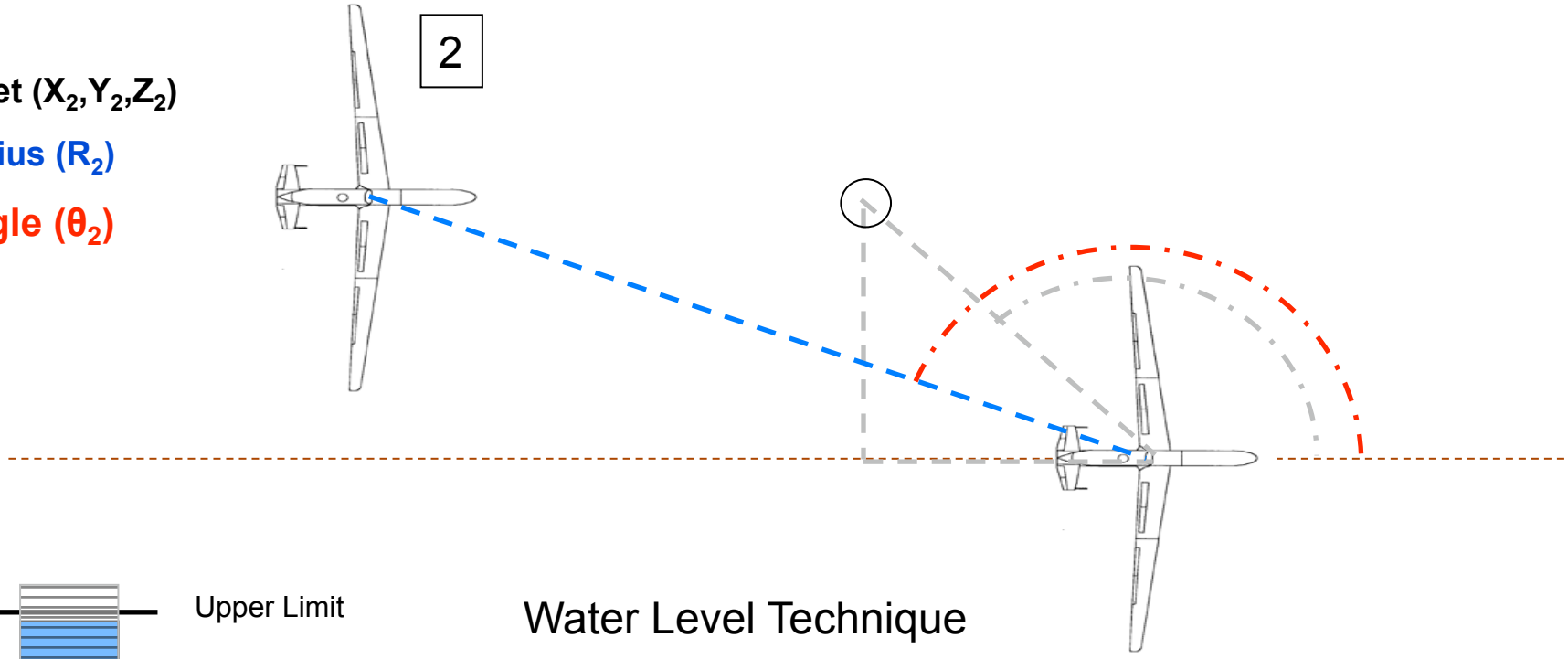

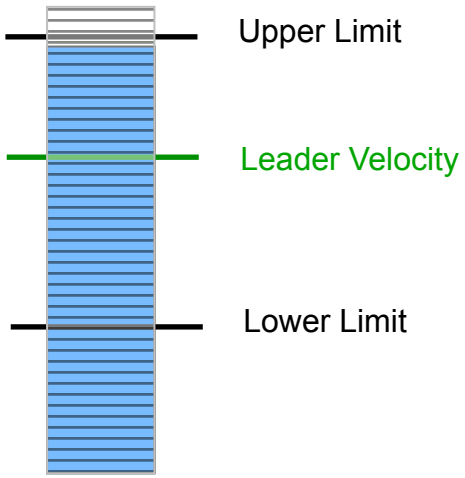

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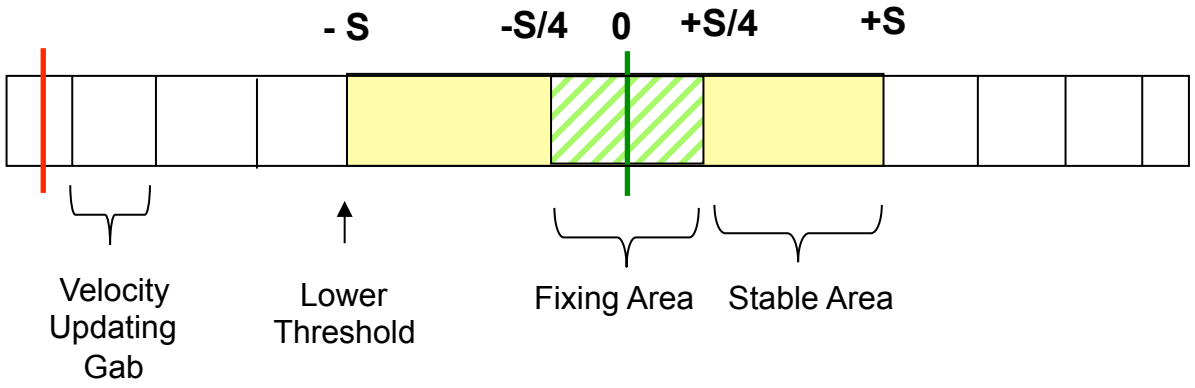

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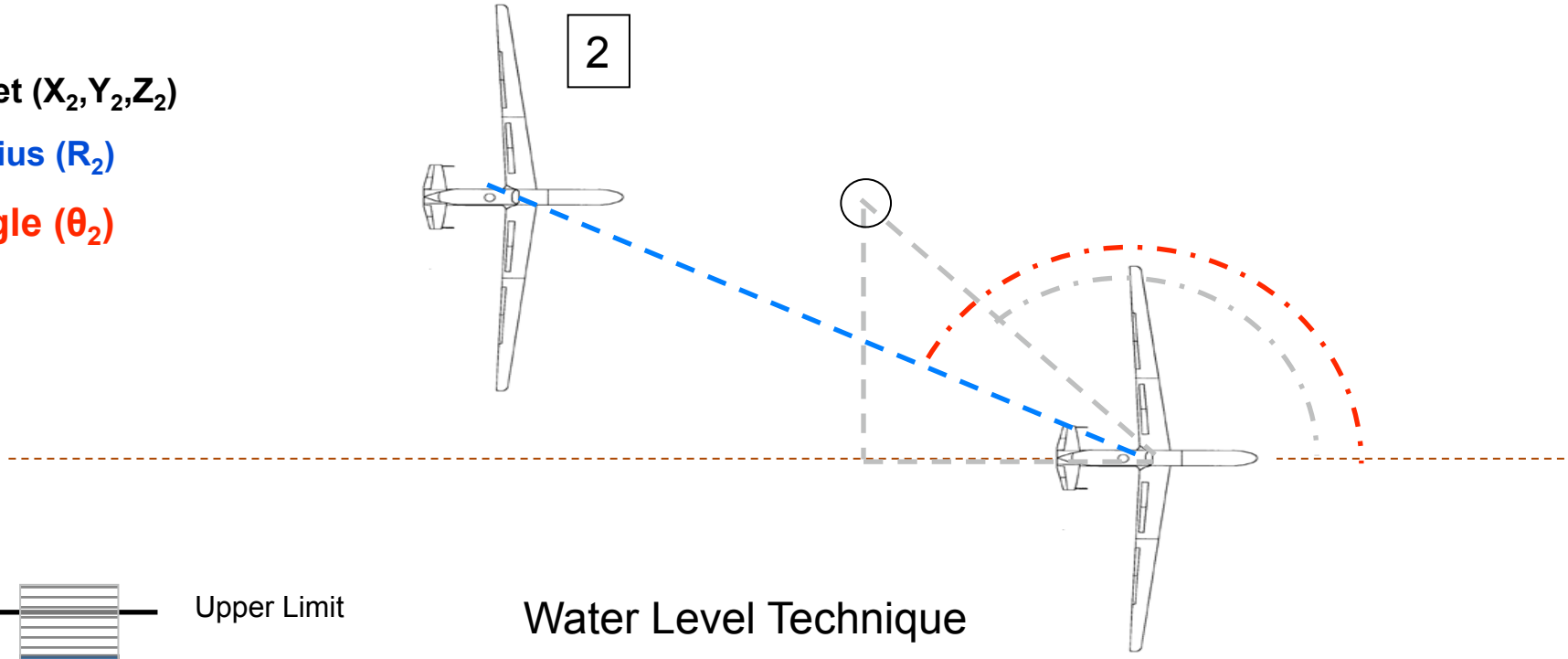

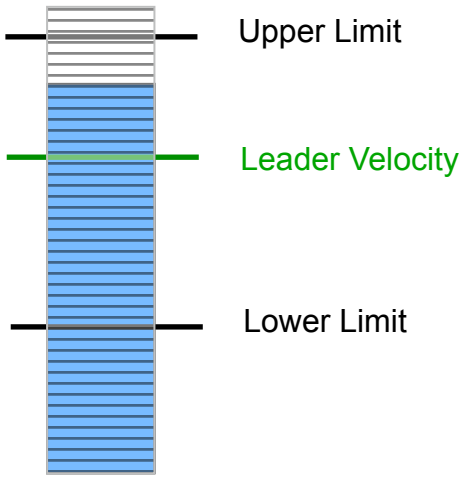

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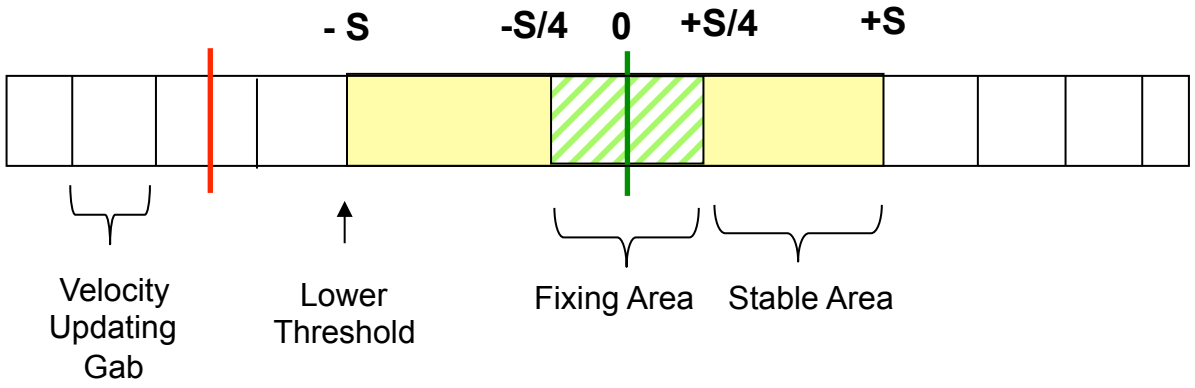

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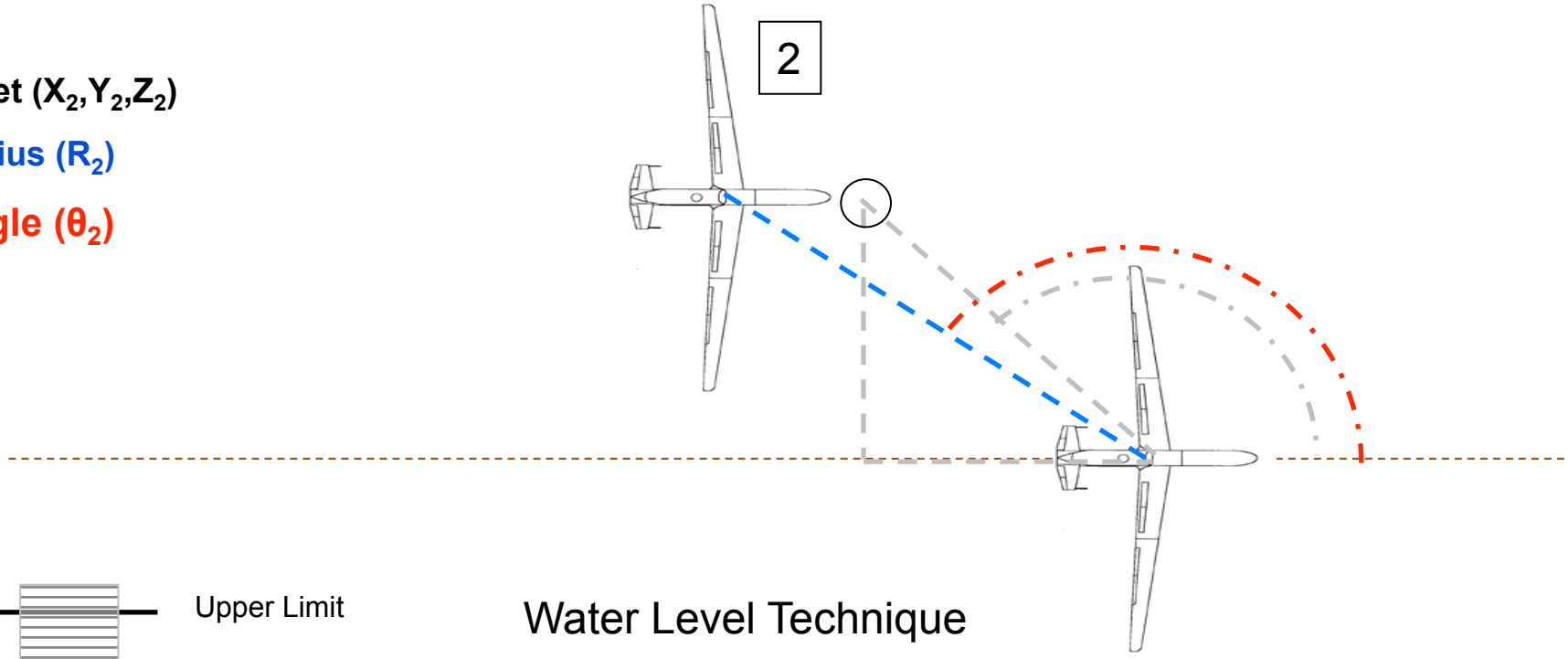

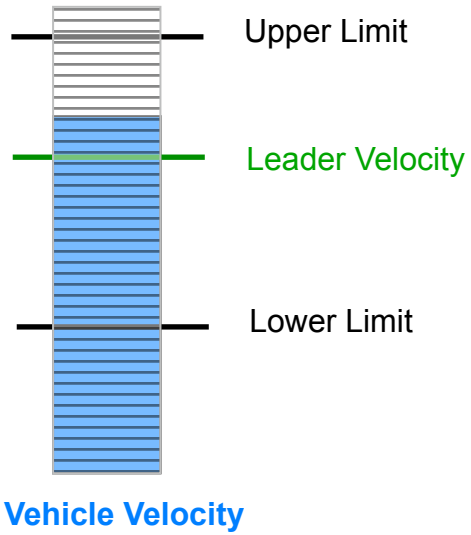

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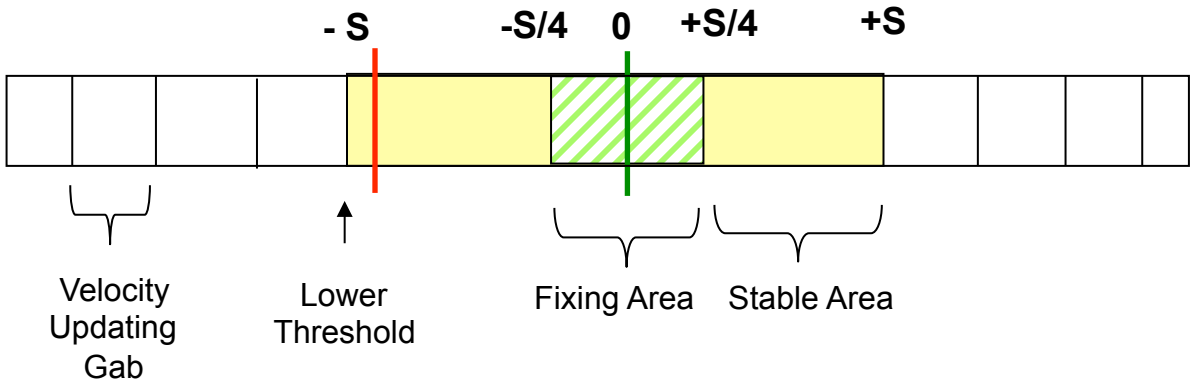

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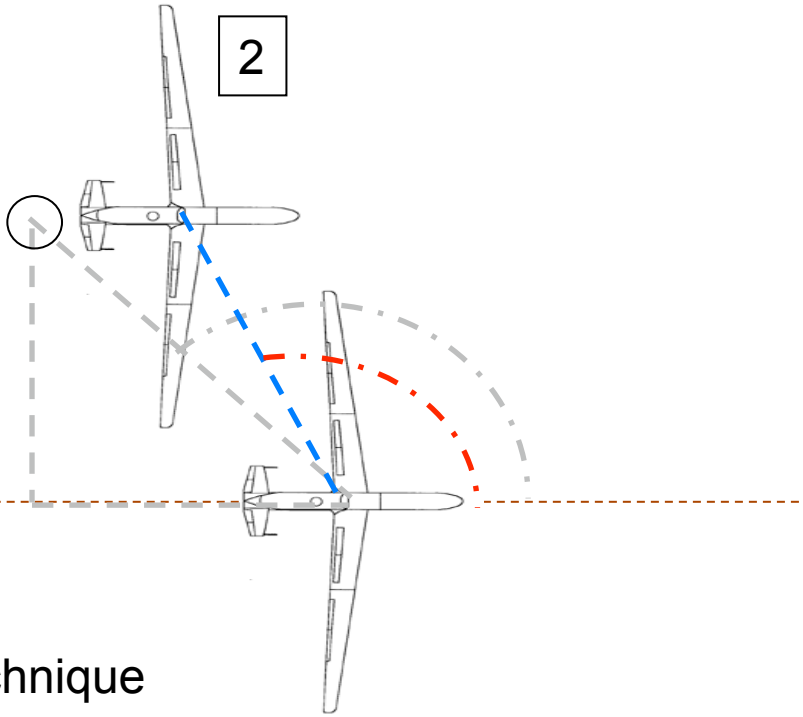

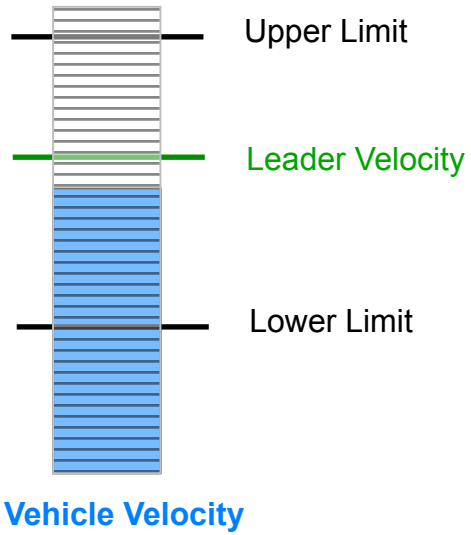

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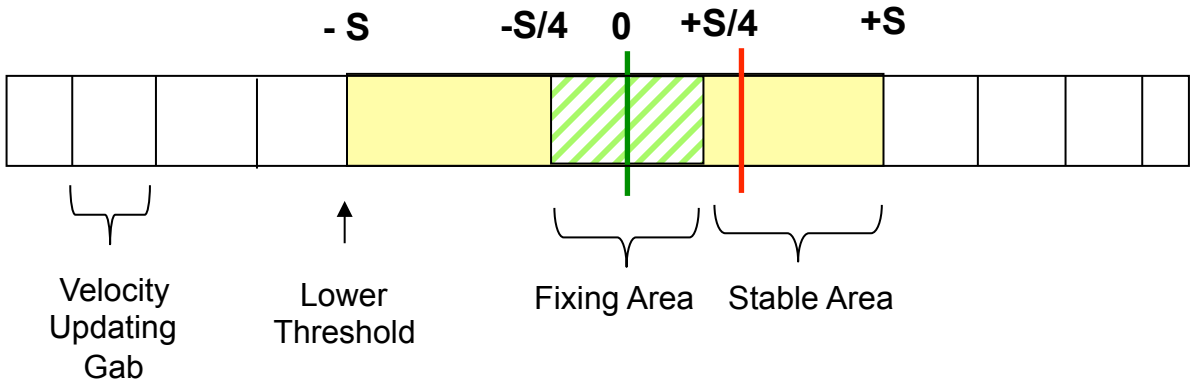

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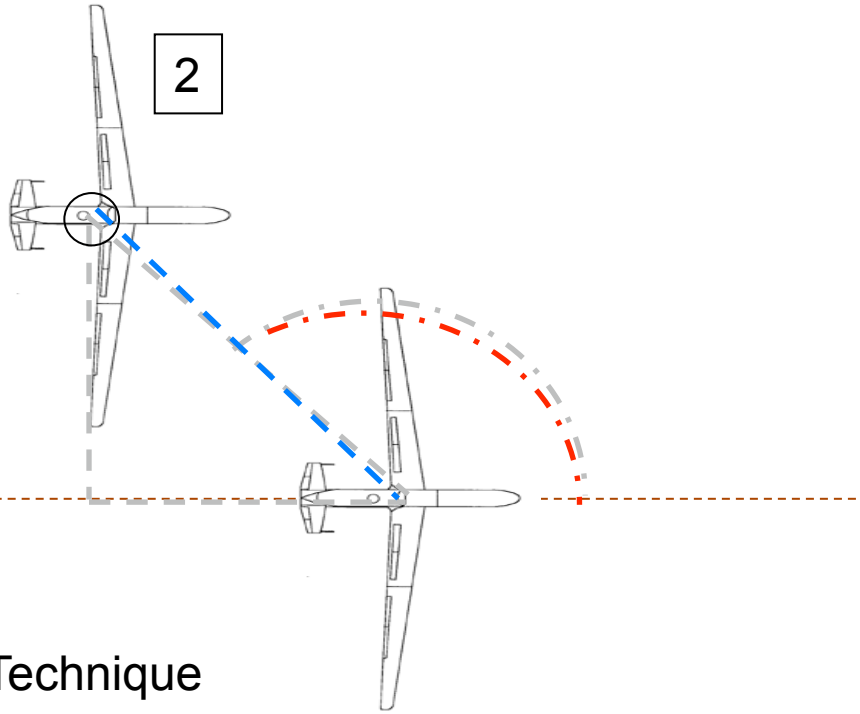

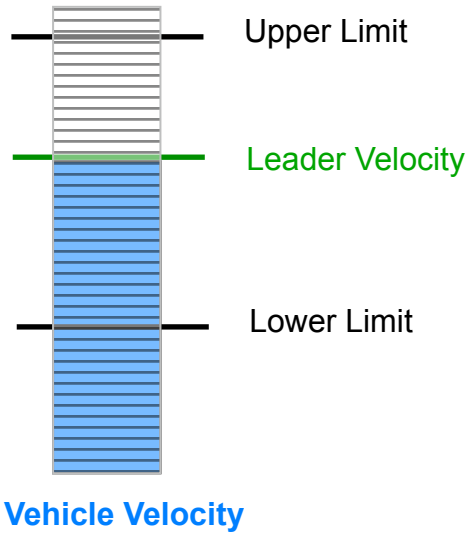

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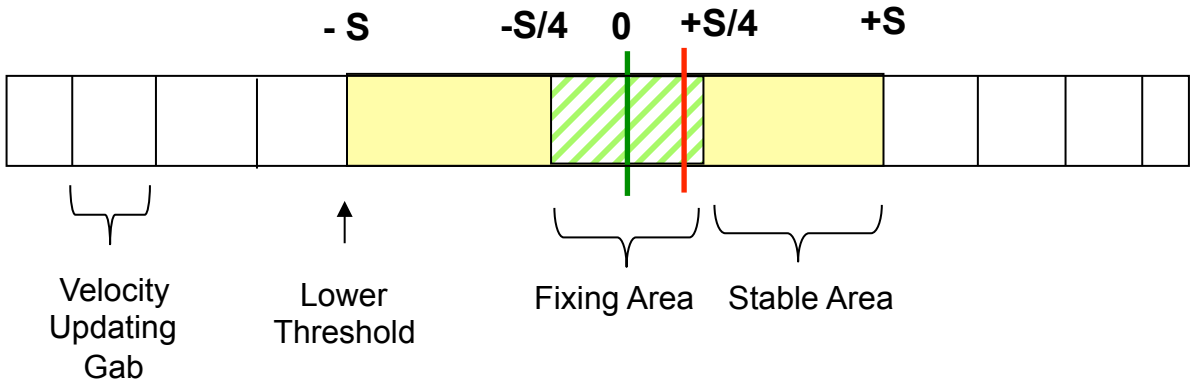


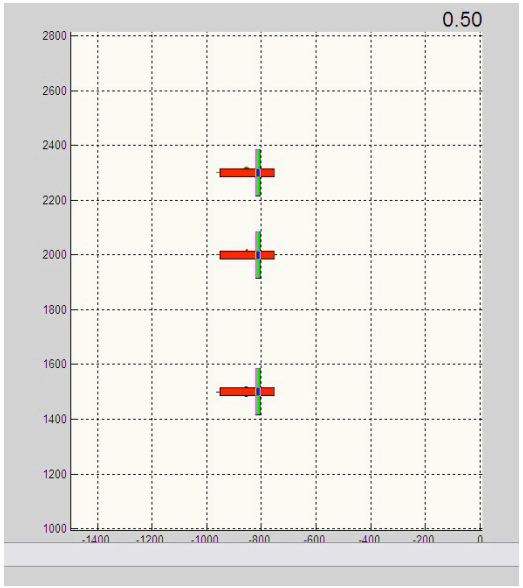
Test Case

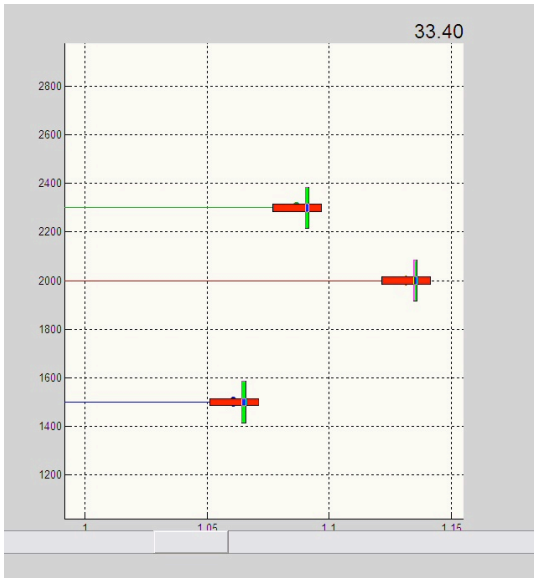
For same number of vehicles that assigned a specific formation, the time varies based on the water level (WT) variable that we set.

If we use the following WT variables to form a 3 vehicle right wing formation:

- Velocity upper limit = 500
- Velocity lower limit = 50
- Upper threshold (S) = 10
- Lower threshold (S) = -10
- Fixing Area (-S/4,S/4) = [-2.5,2.5]
- Velocity Updating Gap = 25

The vehicles will form the left wing formation in 33.4 Seconds as shown in figure.





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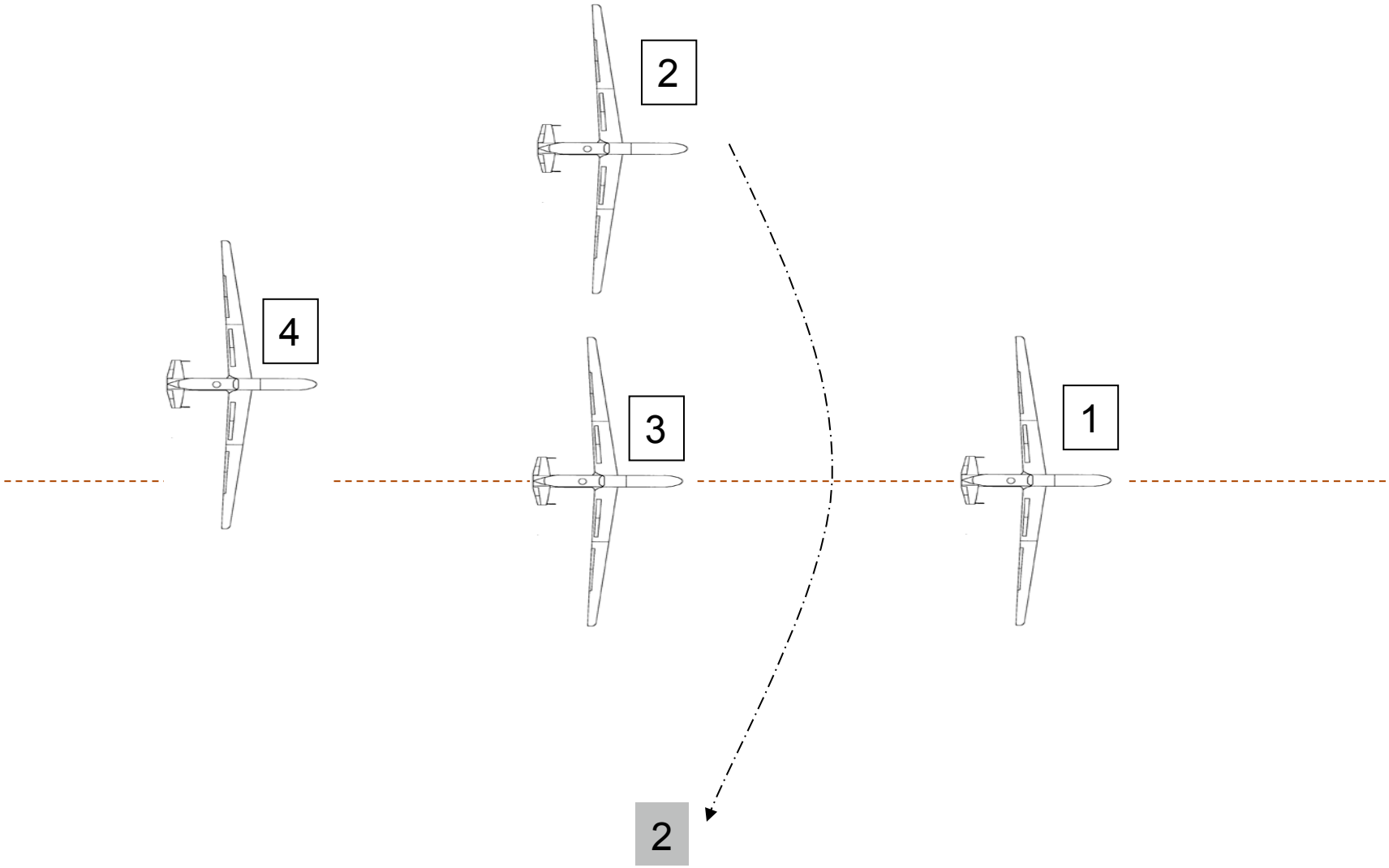
Formation Changing Algorithm

The algorithm will be executed when the leader of the fleet decide to transform from current formation to a new one for any reason, such as new mission has been assigned or new vehicle request to join the fleet.

The algorithm module will go through the following steps:

1) Checking the vehicles positions in the current formation and compare them with the designated positions in the new formation.

Use case 1



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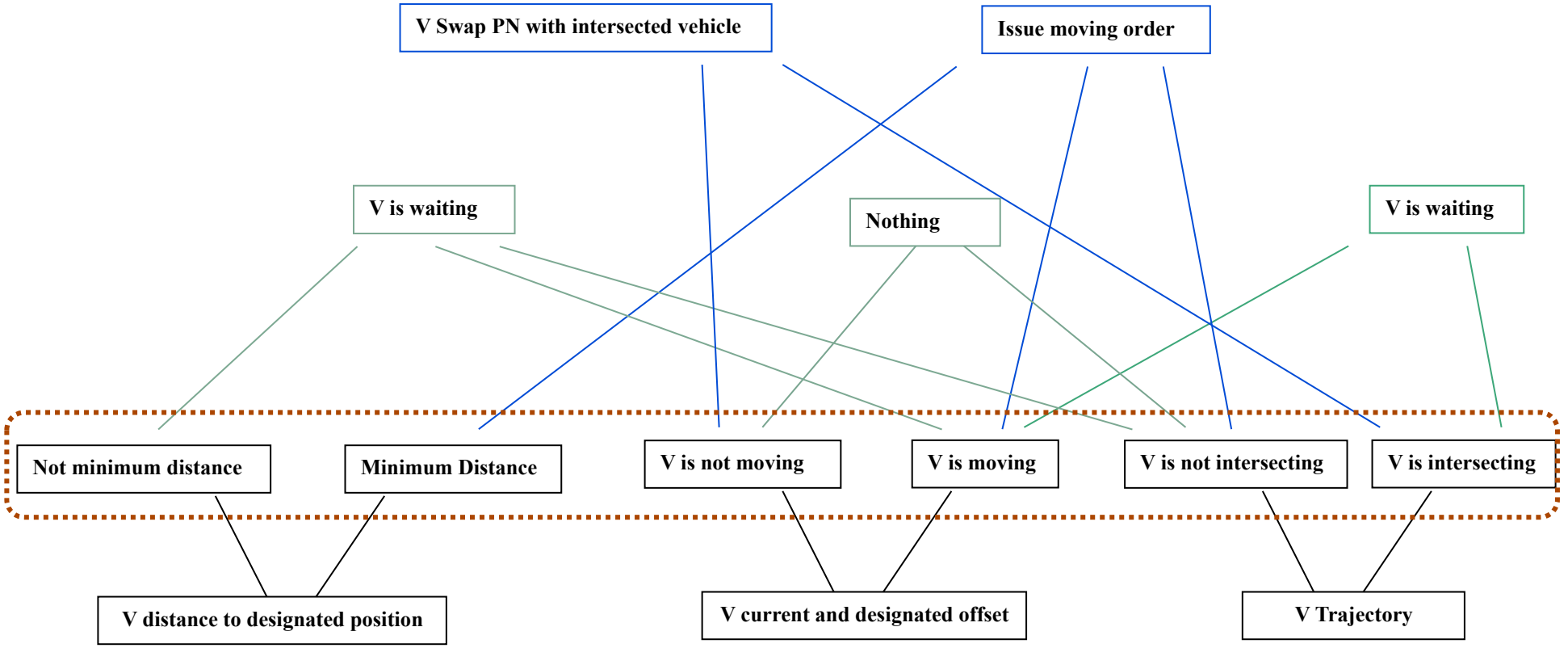
Expert System



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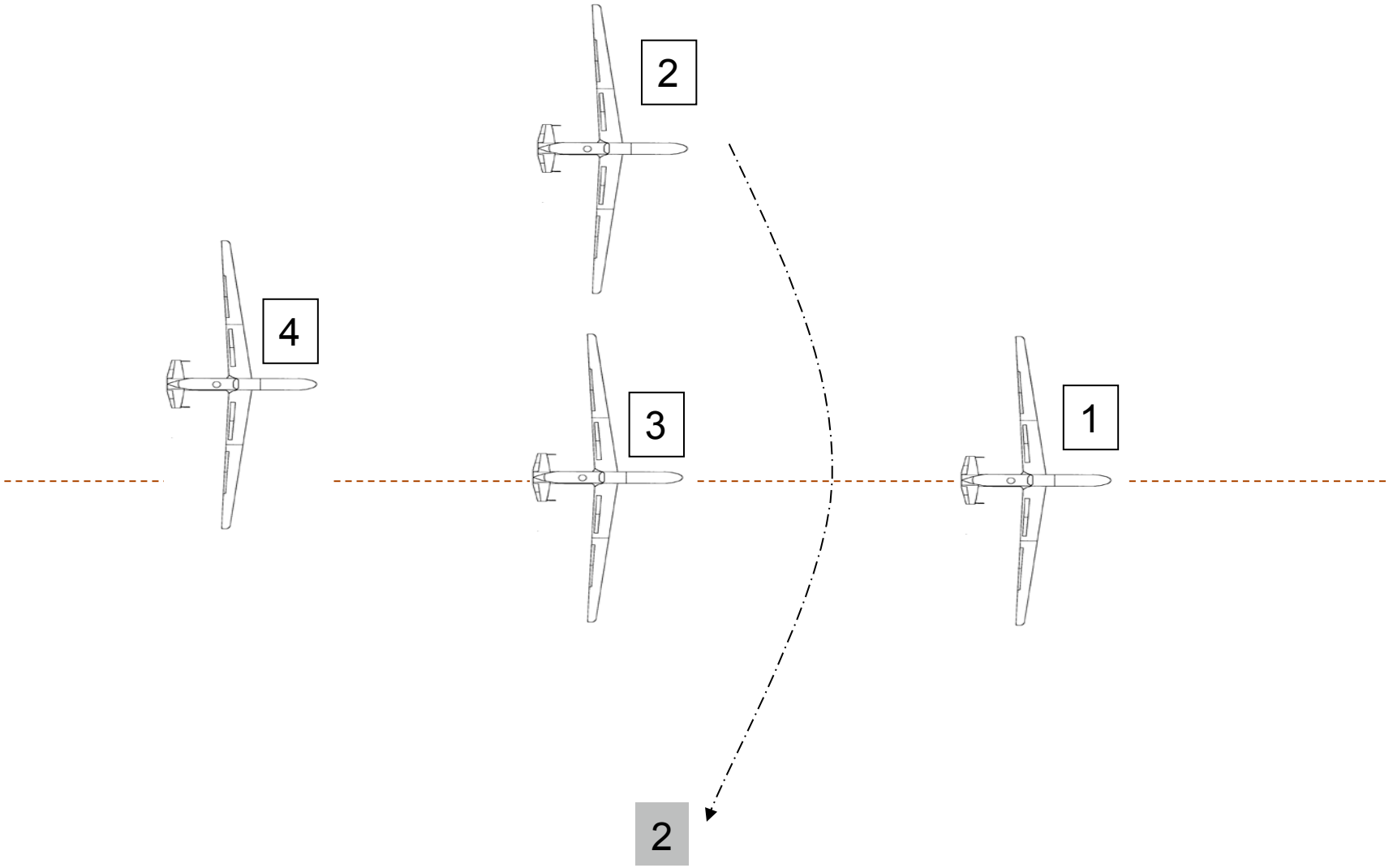
3) Executing the action comes from step 2, which will be one of the following:
   - Swap the position number between two vehicles and their offsets
   - Issue an order for a vehicle to move to its new location on the designated formation

The above steps will be repeated after every action until every vehicle takes its position in the new formation.

Use case 1



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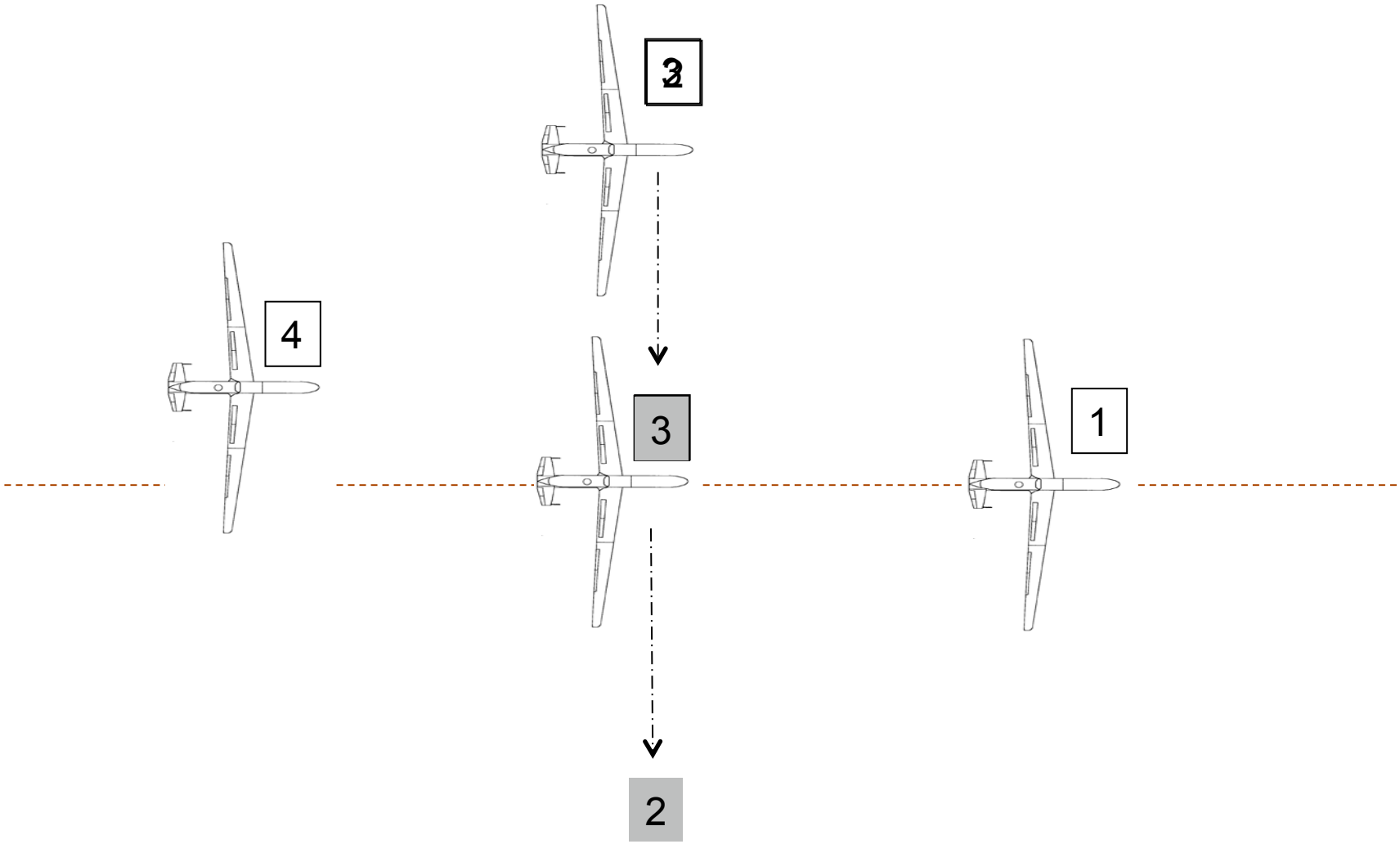
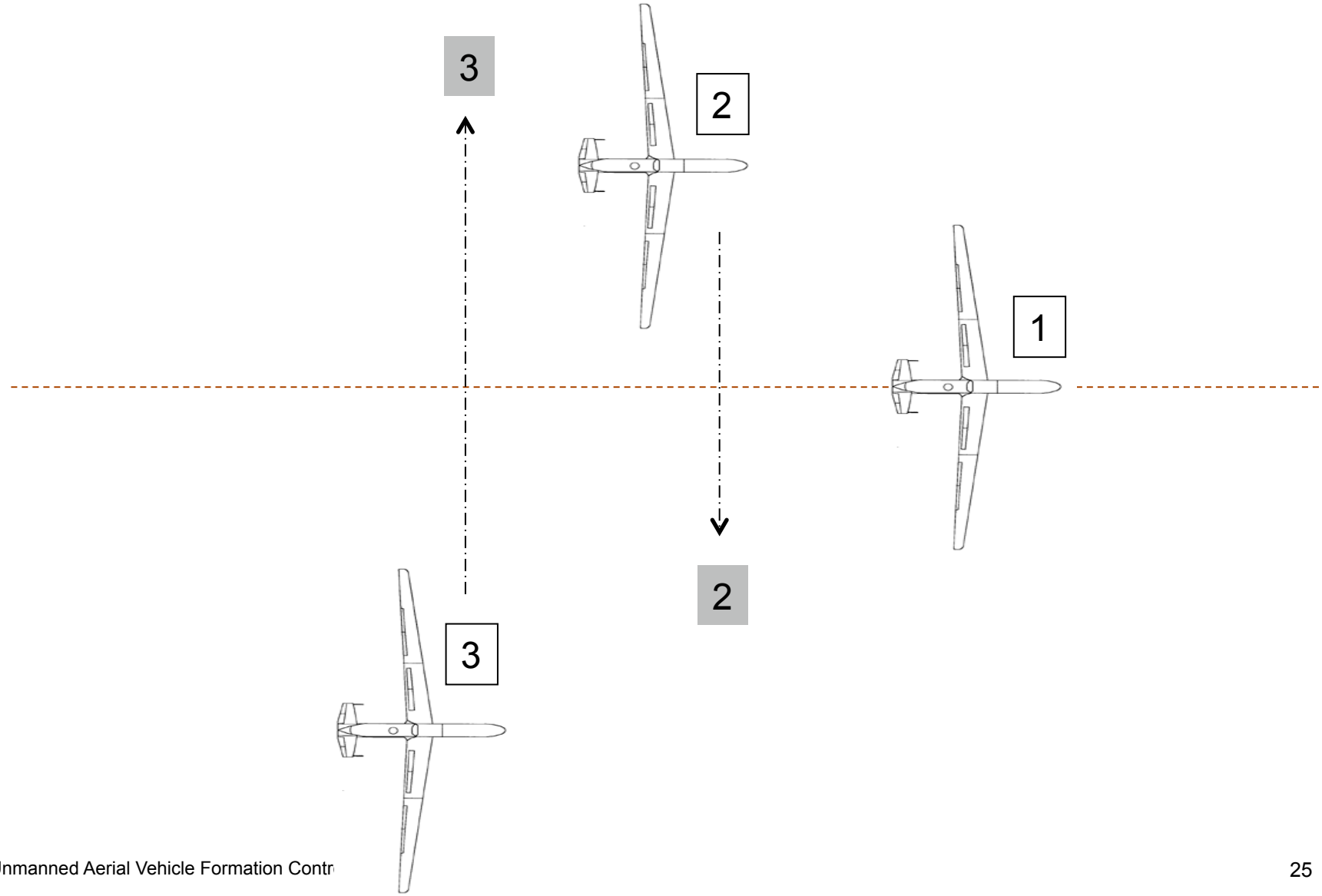


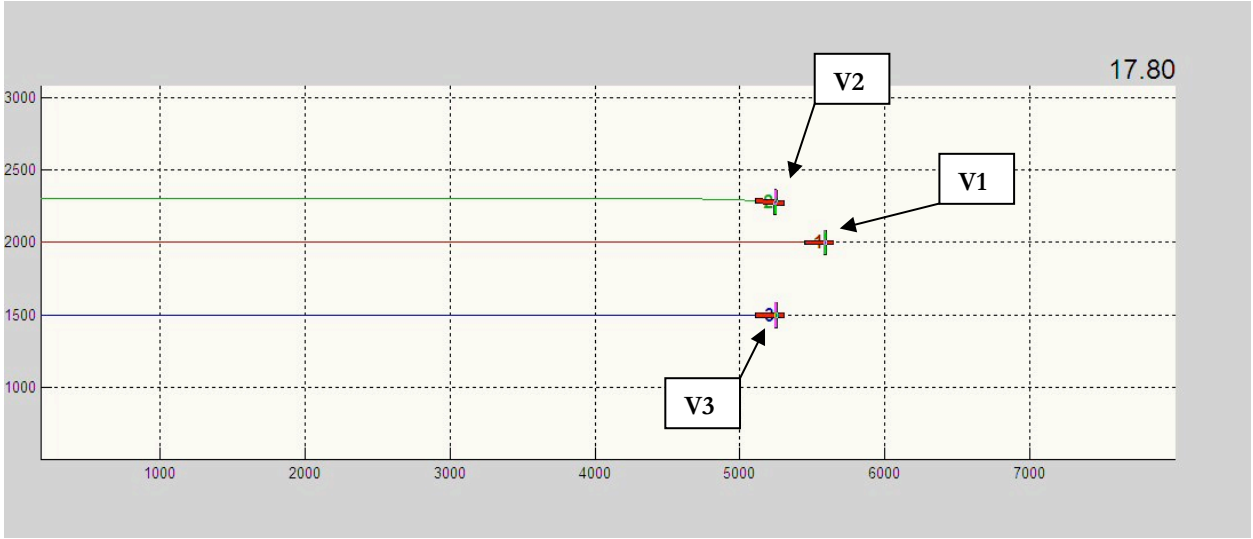
Use Case 2



Test Case

The graph below shows a left wing formation from 3 vehicles:

1.leader V1
2.first wing V2
3.Second wing V3



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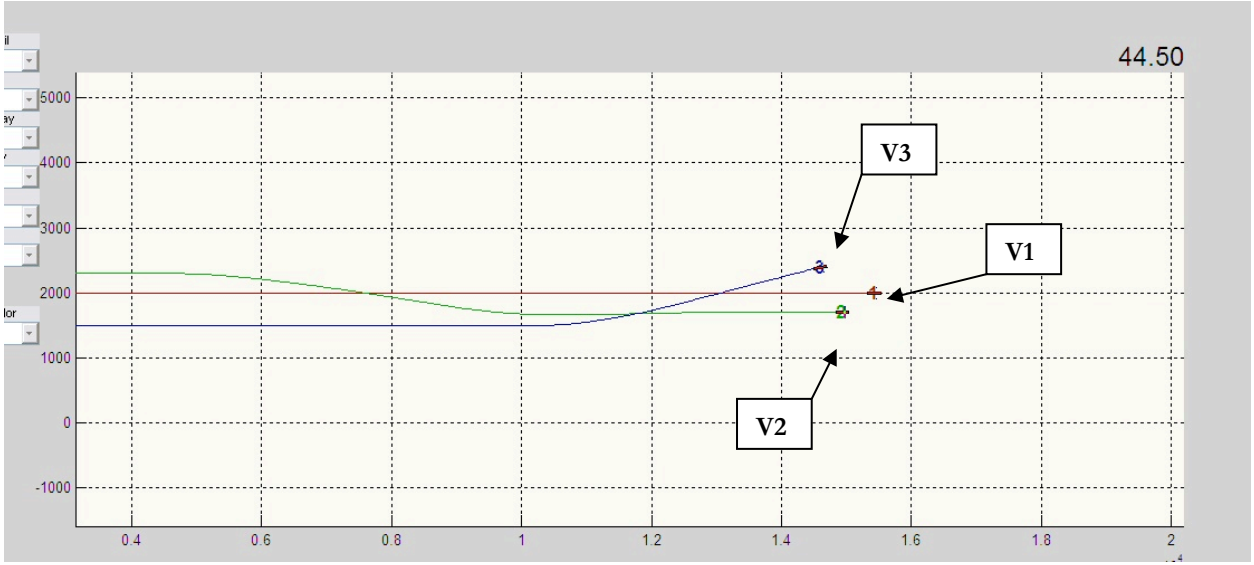

Conclusion

- To increase the performance and the efficiency of the water level technique, the configuration variables should be selected carefully. Taking in the consideration that every environment should has different variables.
- The proposed EM algorithm works by finding the best actions series for vehicles in a fleet to move from one formation to another.
- Water level technique and EM are integrate it with a test bed software that being developed to manage Multi Autonomous Aerial Vehicle formation control.
- Next step will be implementing both the technique and module in real test bed of multi UAVs.

Questions ?