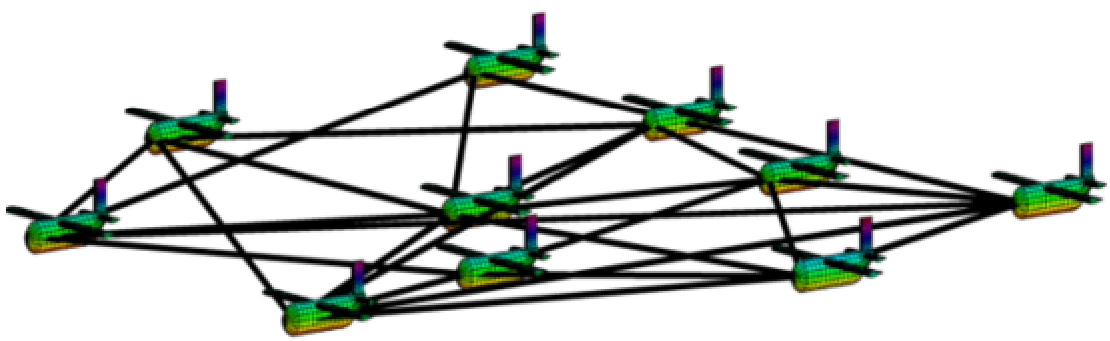
Flight dynamics and control is one of the cornerstones of aerospace engineering. This discipline aims is to understand the dynamics of the aircraft, quantify various notions of stability and performance for distinct flight conditions, and then design control and estimation algorithms that lead to satisfying various notions of performance and stability criteria.

In our group, we examine flight dynamics and control particularly as it relates to optimized and high performance flight systems for various aerial vehicles, including commerical airplanes such as Boeing 787 and unmanned aerial vehicles that can support such missions as search and rescue, fire fighting, and medical services. Our approach aims to provide a systematic means of designing highly efficient and constrained systems that are not amenable to design by traditional methods. In this venue, we provide efficient algorithmic tools for satisfying design criteria both in time and frequency domains for a wide range of high performance platforms.

**Funding Aknowledgements: AFOSR, Boeing**

Some of our ongoing projects include:

## Gust Load Alleviation for UAV Swarming



Dynamics network redesign provides and approach to improve the effectiveness of the human controllers' signal in reducing a wind gust perturbing the UAV swarm. Specifically, by rewiring the interaction network topology, we are able to amplify the human controllers' signals, to more effectively dampen the perturbation.

References:

[1] A. Chapman and M. Mesbahi, "UAV Swarms: Models and Effective Interfaces," In Handbook of Unmanned Aerial Vehicles, Springer, 2013 (to appear).

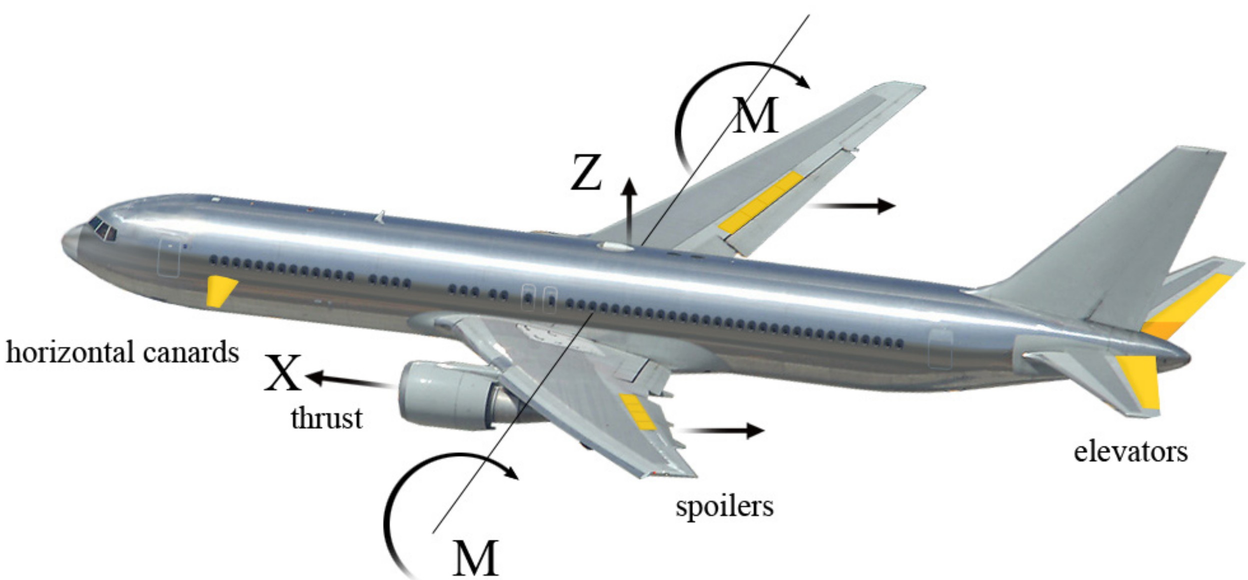
[2] A. Chapman, R. Dai, and M. Mesbahi, "Network Topology Design for UAV Flocking with Wind Gusts," In Proc. of the AIAA Guidance, Navigation, and Control Conference, 2011. (Slide)

[3] A. Chapman and M. Mesbahi, " UAV Flocking with Wind Gusts: Adaptive Topology abd Model Reduction," 1045-1050, In Proc. of the American Control Conference, 2011 (Best Session Presentation Award). (Slide)

## H2/Hinf Optimal Load Alleviation for Modern Aircraft

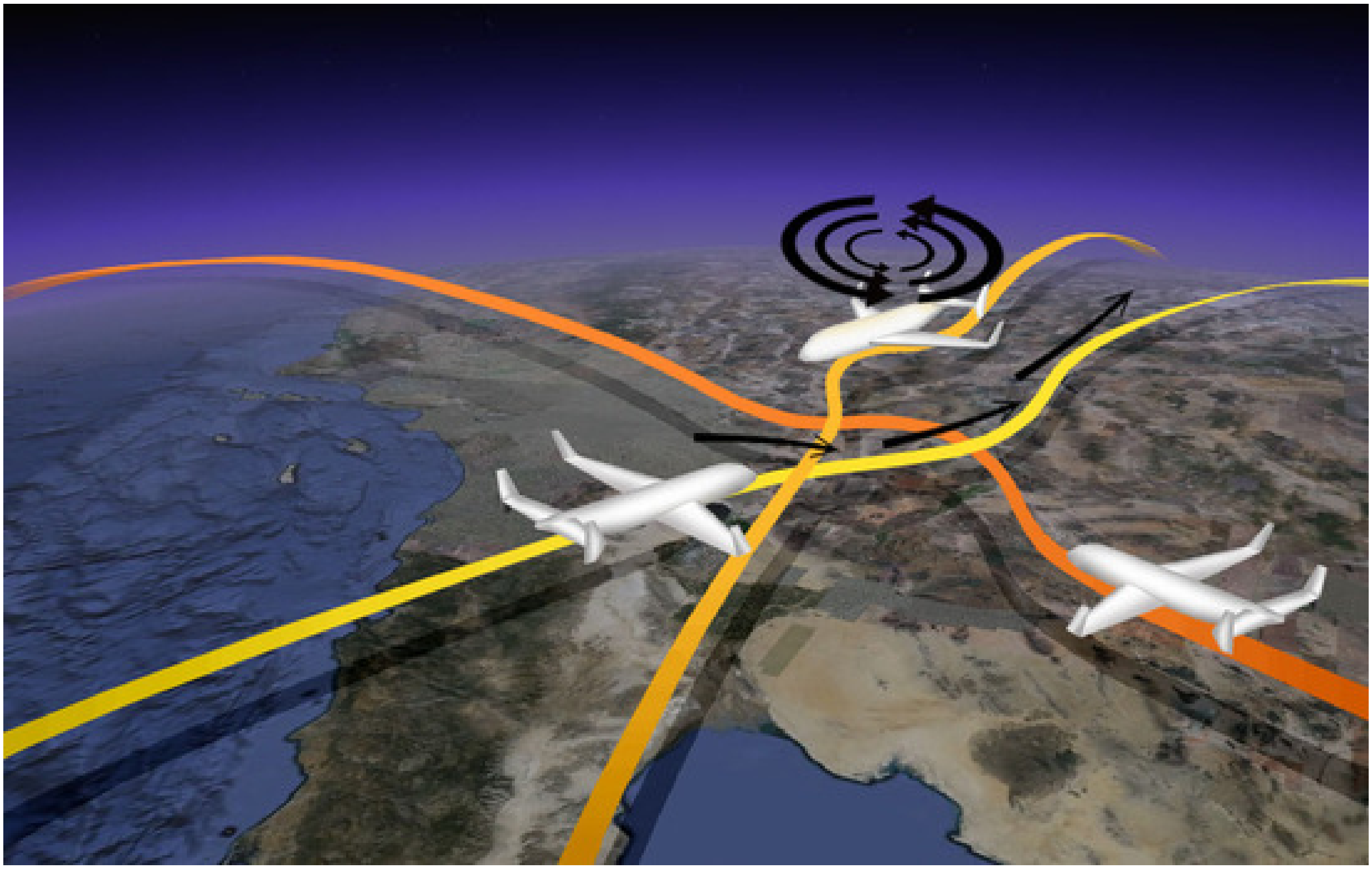
Wind gusts cause additional fuel expenditure, metal fatique, structural deformation, as well as reduction in flight comfort. By using controlled deflections of tail and wing control surfaces, it is possible to minimize the amplitude and the number of transient bending cycles to which the structure maybe subjected in flight.

Gust Load Alleviaton (GLA) systems are used to reduce the effects of the gust turbulence on the vertical (and side) motion of an aircraft to decrease airframe load and improve passenger comfort. New designing technology for modern aircraft allows us to introduce new type of control surfaces and implement the latest control theory and optimiation framework, for example H-2 and H-inf optimal control techniques are considered. The future works includes the use of L1-system norm and model predictive control to view the problem from the time-domain perspective.



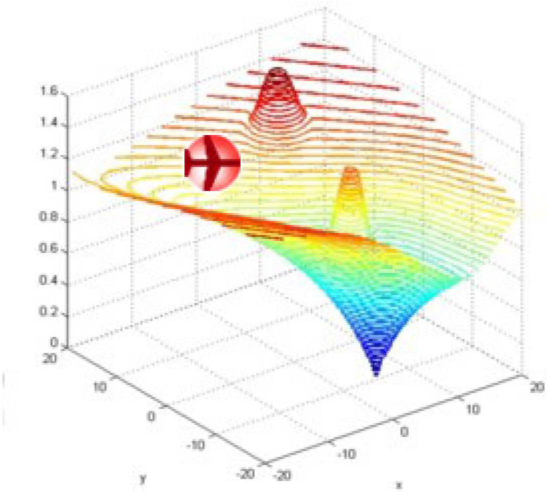
The control surfaces involve in longitudinal GLA controller are elevators, spoilers, and horizontal canards. In some case, ailerons may be used.

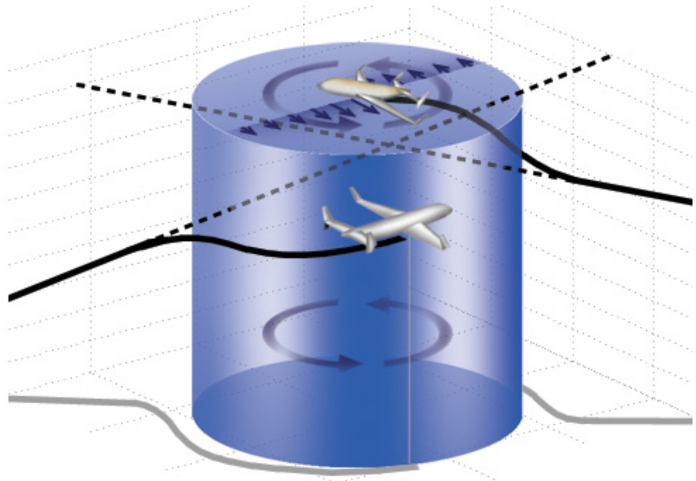
## Collision Avoidance Algorithm for UAVs

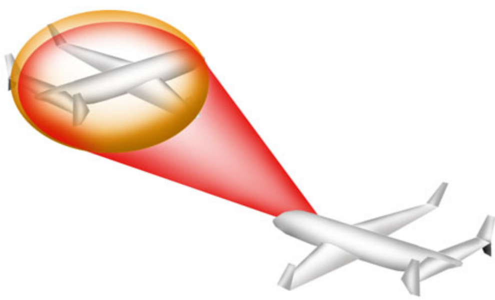


Collision Avoidance and deconfliction become of importance when UAVs are required to operate in close proximity of each other. The deconfliction algorithm is designed to gaurantee the collision-free convergence to the final desired destination for each UAV in the presence of static and moving obstacles. The performance of the algorithm are restricted by the aircraft maximum turn-rate during the avoidance maneuver. It is also preferrable to have the least deviation from the nominal path. The Unicycle model is chosen to represent the nonholonomic property of UAVs and is suitable for the turn-rate study. The algorithm is developed from the 3 main concepts:

- Navigation function to help directing the UAV to he destination by avoid static obstacles
- Swirling function (virual vortex vector field) to help stiring the UAVs counter-clockwise avoiding collision with other moving obstables
- Collision cones with safety angles to help adjusting the performance (Minimize nominal path deviation , reduce trajectores overshoot, etc.)







Navigation Function Swirling Function for 2 conflicting UAVs Collision Cone

The guarantee collision avoidance came from the swirling effects that always put the aircraft in the detection range into the limit cycle until vehicles are safe from the collision courses. This is proved using Lasalle Invariance Principle. The performance of the algorthm such as turn-rate or trajectories overshoot is managed by adjusting design parameters in Navigation function, swiring function, and safety angles.

Simulation 5 UAVs.jpg

Simulation example for 5 UAVs flying through the same location

Simulation Groups UAVs.jpg

Simulation example for 2 groups of UAVs flying cross path

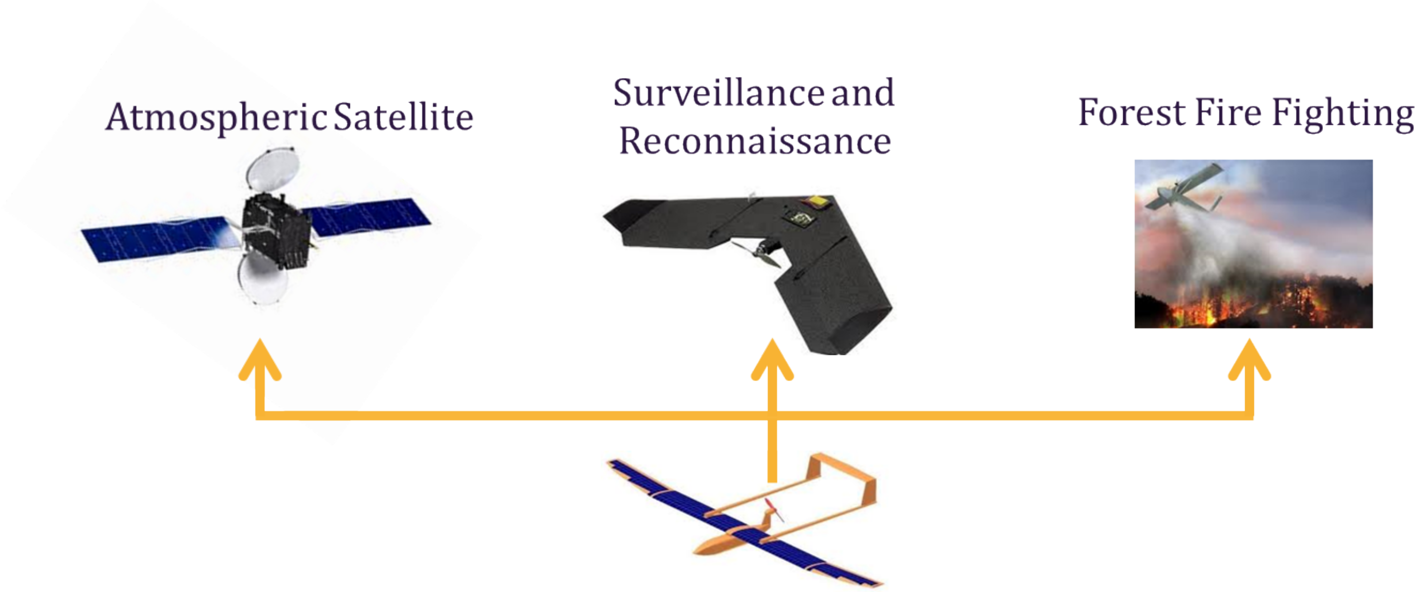
Reference:

[1] P. Panyakeow and M. Mesbahi, "Deconfliction Algorithm for a pair of Constant Speed Unmanned Aerial Vehicles," IEEE Transaction on Aerospace and Electronics Systems, January 2014.

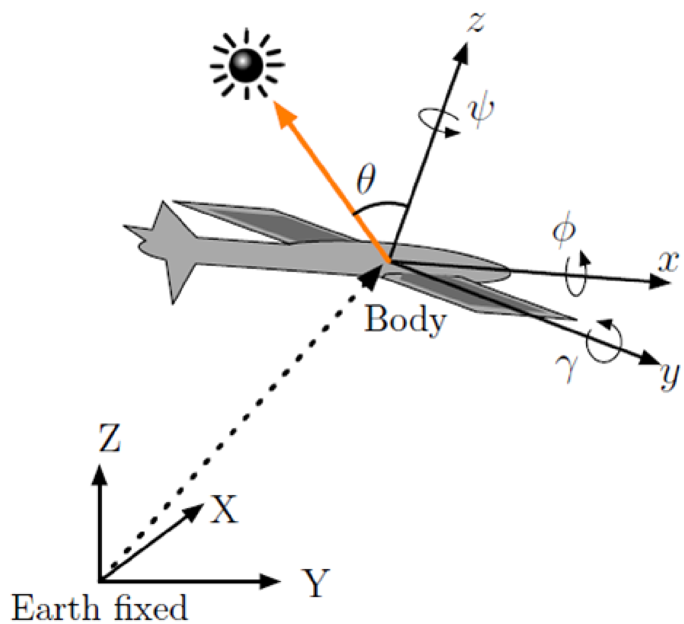
[2] P. Panyakeow and M. Mesbahi, "Decentralized Deconfliction Algorithm for Unicyce UAVs," in Proc. of the IEEE American Control Conference, June 2010.

[3] A. Rahmani, K. Kosuge, T Tsukamaki, and M Mesbahi, "Multiple UAV Deconfition via Navigation Functions," in Proc. of the AIAA Guidance Navigation and Control Conference, August 2008.

## Solar Powered UAVs




In this project the problem of optimal path planning and power allocation for Unmaned Aerial Vehicles (UAVs) is explored. The UAVs are equipped with photovoltaic cell on top of their wings and their energy sources are solar power and rechargeable batteries. The Sun incidence angle on the photovoltaic cells, which substantially affects energy harvesting, is determined by the attitude of the UAV and the sun position.



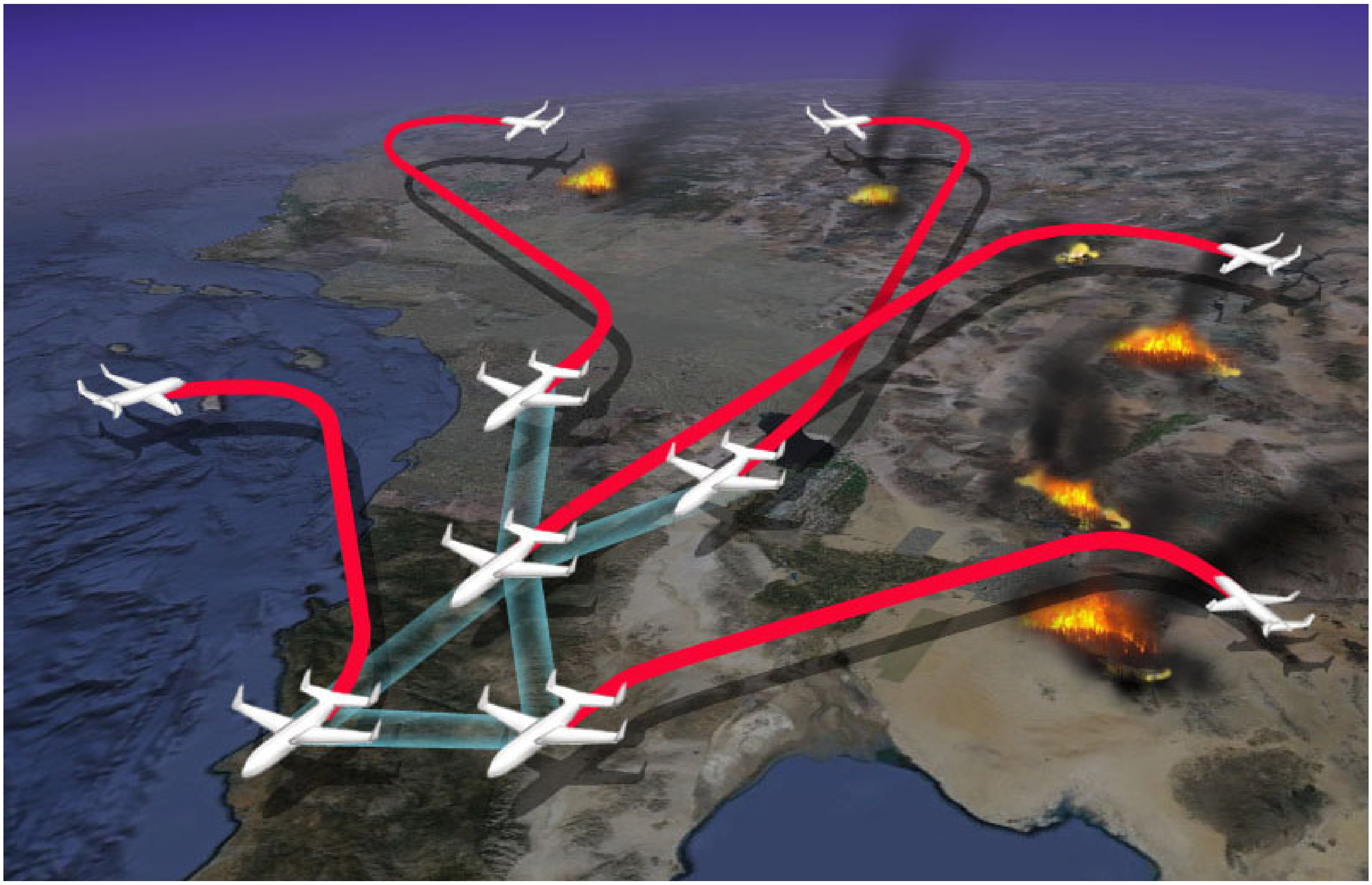

References:

[1] S. Hosseini and M. Mesbahi, "Energy Aware Aerial Surveillance for Long Endurance Solar-Powered UAV, " In Proc. of The AIAA Guidance Navigation and Control Conference, 2013.

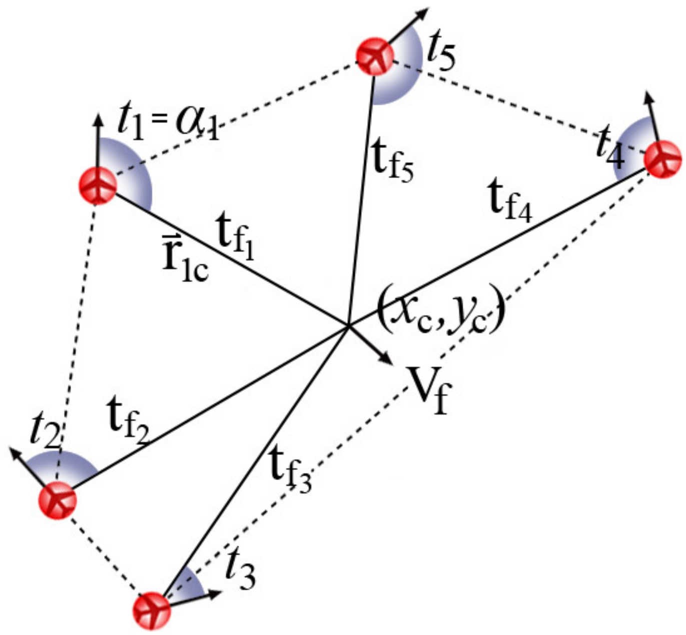
[2] S. Hosseini, R. Dai, and M. Mesbahi,"Optimal Path Planning and Power Allocation for a Long Endurance Solar-Powered UAV," In Proc. of the IEEE American Control Conference, 2013. (Slides)

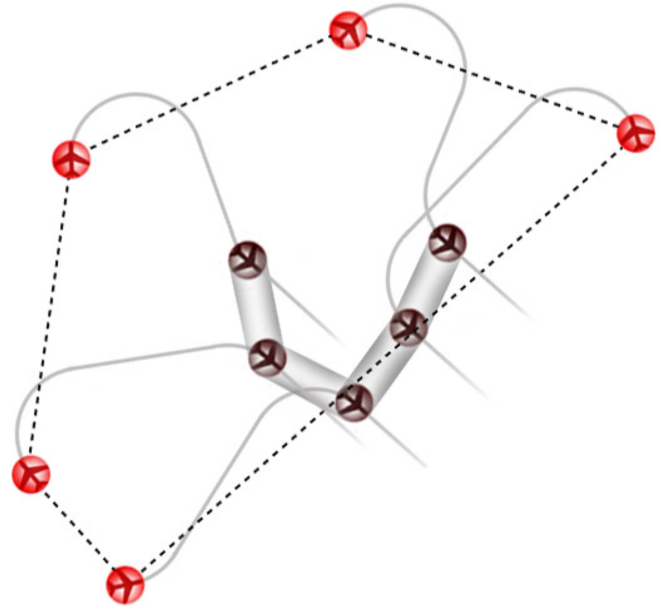
[3] R. Dai, U. Lee, S. Hosseini, and M. Mesbahi, "Optimnal Path Planning for Solar-Powered UAVs Based on Unit Quarternions," 3104-3109, In Proc. of the 51st IEEE Conference of Decision and Control, 2012

## Optimal Trajectories Planning for Network Establishment of UAVs



This research involves the application when UAVs are required to disperse to perform a task such as monitoring, imaging, reconnaisance, data-processing, etc., the relative dstances between vehicles may exceed their maximum communication range creating uncertan netwok connectivity maintenance. In order to reestablish network connectiviy for data exchange and to resume mission opration as a group, the problem of controlling vehicles that are initially out of range of detection to an area where they can sense eah other thus becomes important.



Optimization and Nonlinear-Programming methods are used to determine the shortest trajectories that bring the UAVs to a connected formation where they are in range of detection of one another and oriented in th same direction to maintain the connectivity. The methods are designed base from the fundamental concept of Pontryagin Minimum Principle (PMP) and bang-bang control.

NAQ2.jpg

Figures above show the optimal network aquisition path-planning algorithm. The left picture show the exact global minimal time solution form nonlinear optimal control while the figure to the right shows the result from nonlinear-programming method.

References:

[1] P. Panyakeow, R Dai, and M. Mesbahi, "Optimal Trajectory for Network Establishment of Remote UAVs" In Proc. of The IEEE American Control Conference, 2013. (Slides)

[2] R. Dai, J. Maximoff, and M. Mesbahi, "Formation of Connected Network for Fractionated Spacecraft," In Proc. of The AIAA Guidance Navigation and Control Conference, 2012

[3] Y. Kim and M. Mesbahi, "On Maximizing the Second Smallest Eigenvalue of a State-Dependent Graph Laplacian," IEEE Transactions on Automatic Control, Vol.51, No.1, 116-120, 2006