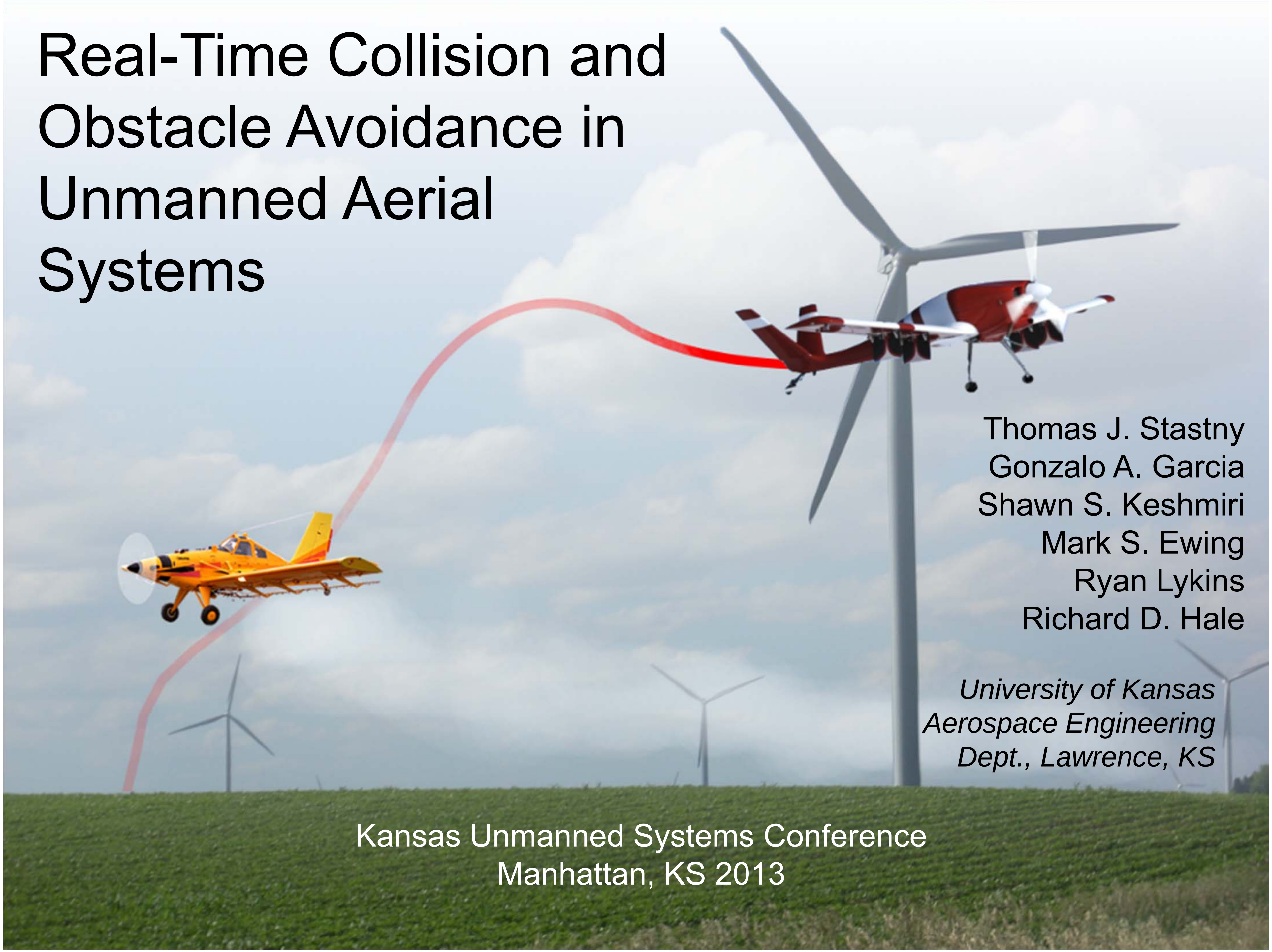

Real-Time Collision and Obstacle Avoidance in Unmanned Aerial Systems

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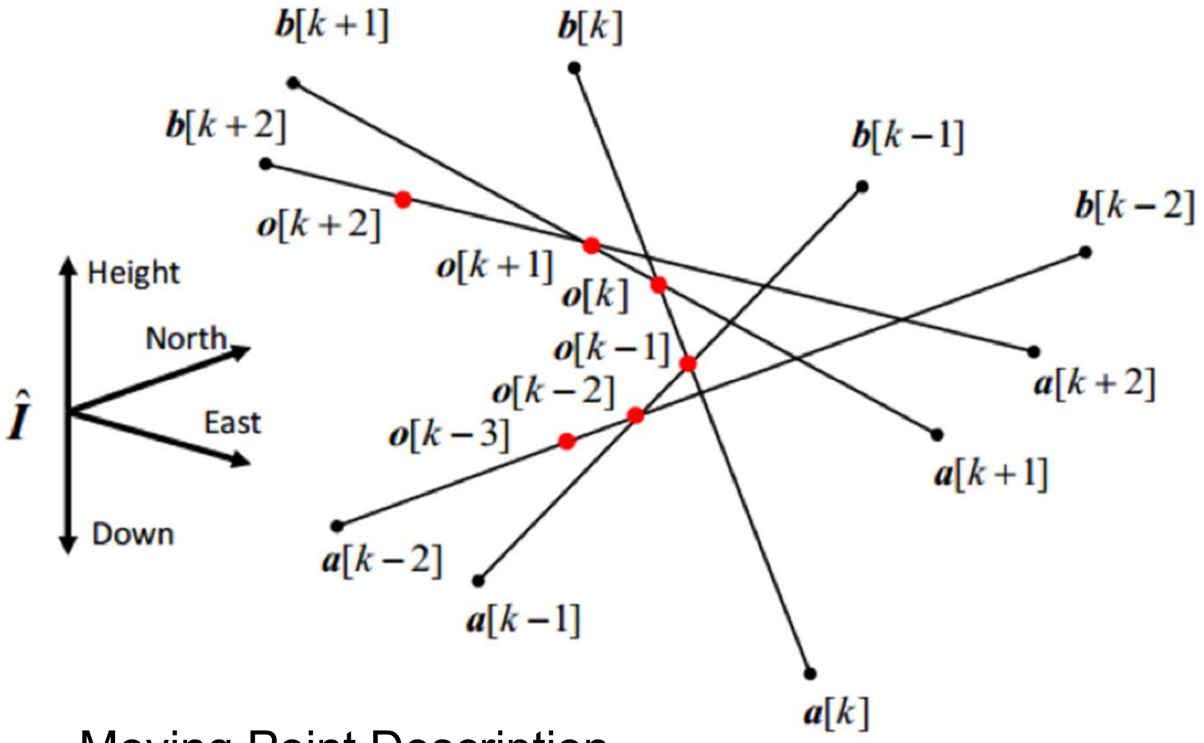
Core Research Focus Areas

1. **UAS Modeling and Flight Dynamics Analysis**
   I. System and Parameter Identification
   II. Collision Avoidance Algorithms
   III. Trajectory Optimization Methods
2. **UAS Flight Control**
   I. Nonlinear and Robust Controllers
      I. Collision Avoidance of Cooperative and Noncooperative Agents
3. **UAS Flight Testing**
   I. Small & Large UAS Flight tests
4. **Hardware & Software Development**
   I. KUASF Autopilot System
   II. See-Detect-Avoid Radar
   III. Autolanding Laser Based sensor

UAS Program @ KUAE

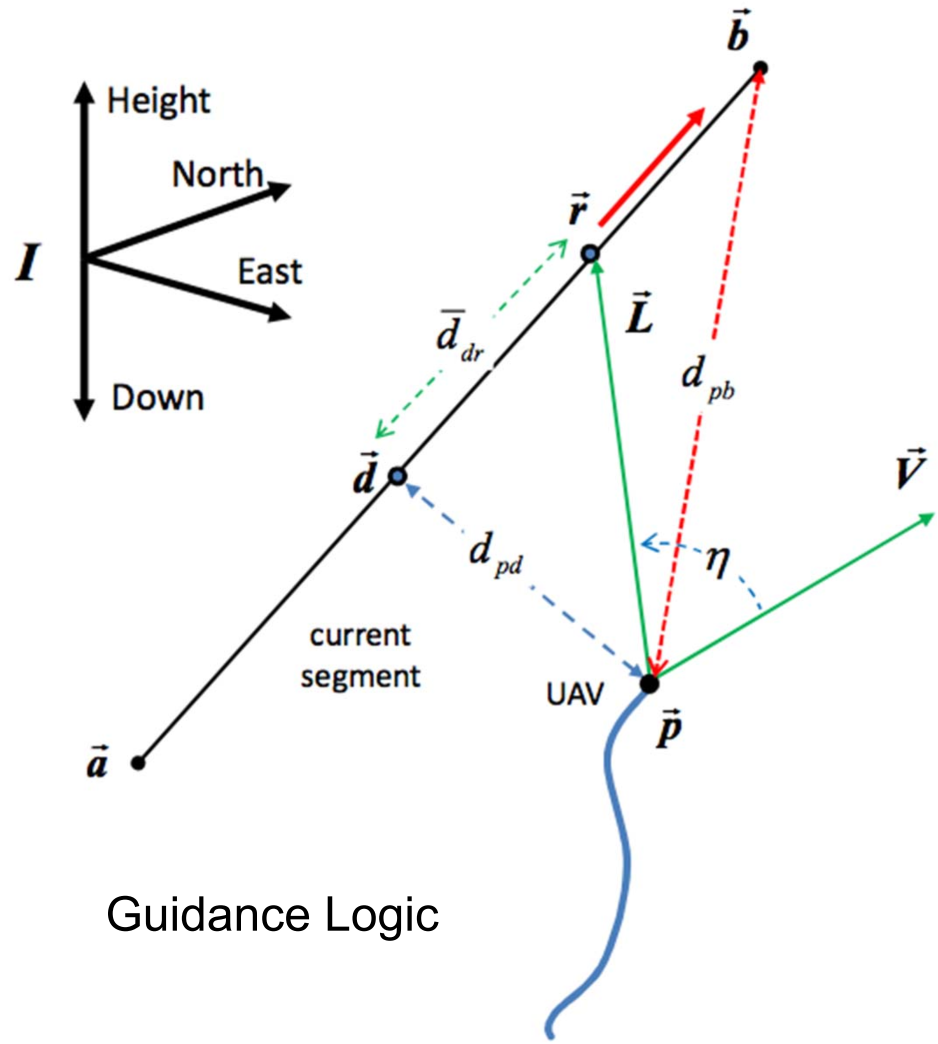
GUIDANCE

To improve tracking of complex trajectories, the aircraft is commanded to follow time-varying waypoints (moving points) characterized by a position and velocity.



Moving Point Description

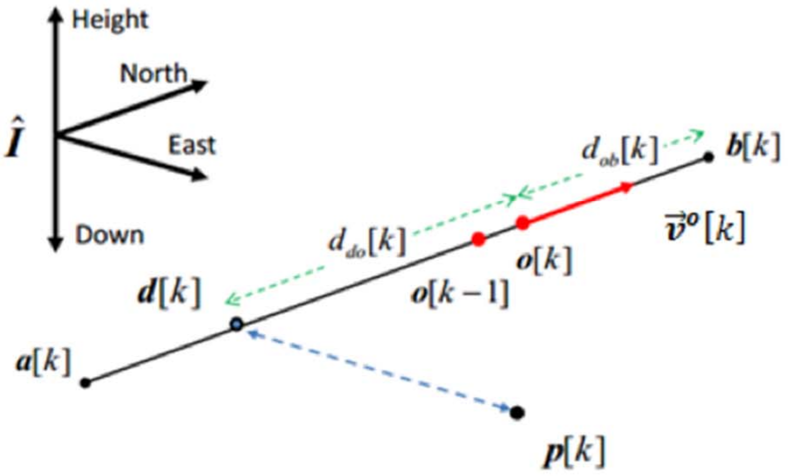
At any given time [k], the guidance logic considers the current waypoint segment defined between two points **a**[k] and **b**[k], extremum of the line created by two consecutive moving points **o**[k] and **o**[k-1].

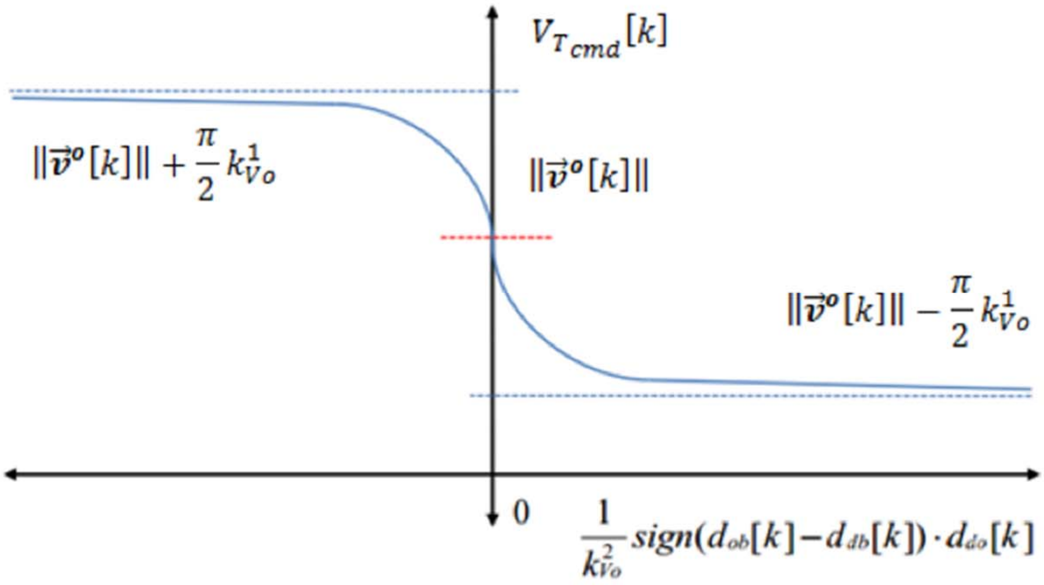


Guidance Logic

With a current waypoint segment defined, the guidance logic places a point **r** a fixed distance in front of the nearest point on the track **d** from the aircraft. The vector **L** and velocity **V** then create the angular error η which should be minimized by the NMPC (indirectly) to ensure a tight trajectory following.

GUIDANCE





To ensure the aircraft does not fall behind or get too far ahead of the current moving point, another logic is implemented to retain proximity to the desired moving point through the arctangent function shown above. Velocity increments are added or subtracted from the desired velocity when the aircraft is forward or behind the desired location.

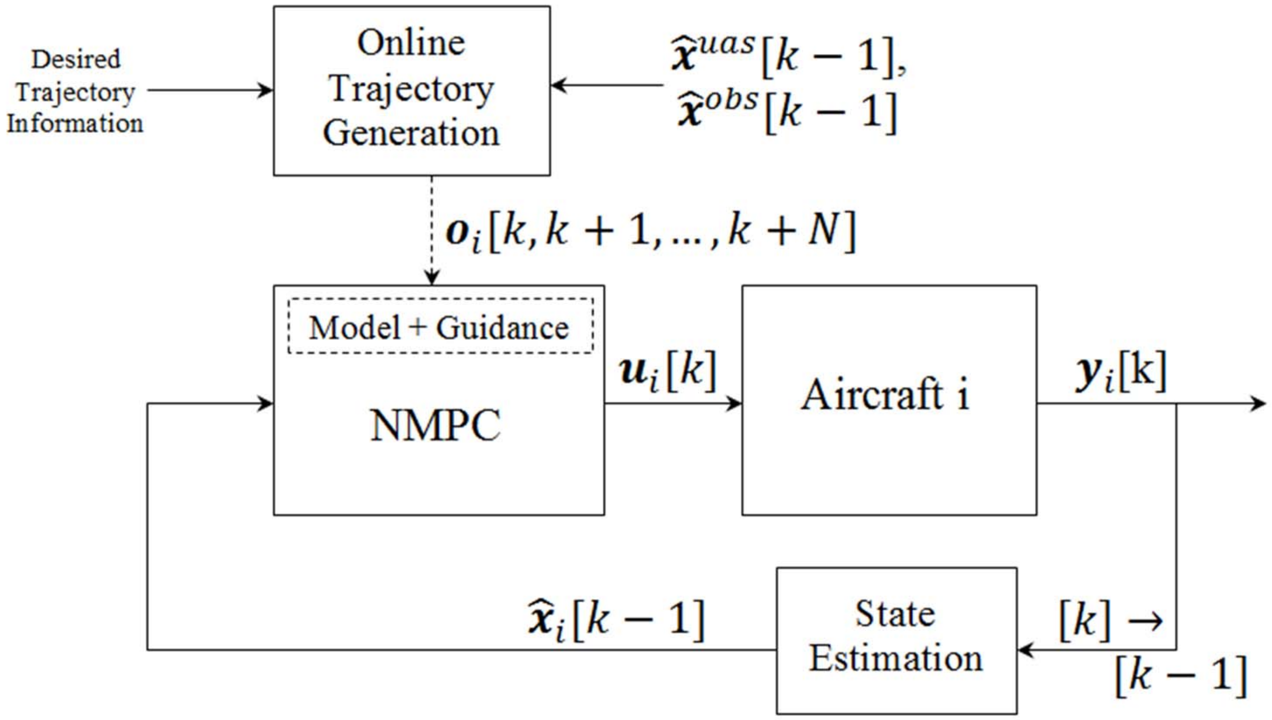
CONTROL

The control task has been given to a nonlinear model predictive controller (NMPC). As opposed to linear methods, the NMPC is capable of considering a time-varying, fully nonlinear 6DOF description of the aircraft model while maintaining state and input constraints. A step towards minimizing the typical NMPC cost function (shown below) is made each time step for a control sequence forecast through a finite horizon.

$$J(\boldsymbol{e},\boldsymbol{u}) = \sum_{k=1}^{N} \boldsymbol{e}_{k+1}{}^{T}\boldsymbol{Q}_{k}\boldsymbol{e}_{k+1} + \boldsymbol{u}_{k}{}^{T}\boldsymbol{R}_{k}\boldsymbol{u}_{k}$$

Error vectors **e** are comprised of roll, pitch, total velocity, and sideslip commands. As the commands are integrated in terms of errors (actual minus commanded), the control problem is simplified to a regulating problem removing the need for more complex reference tracking.

CONTROL



Control Problem

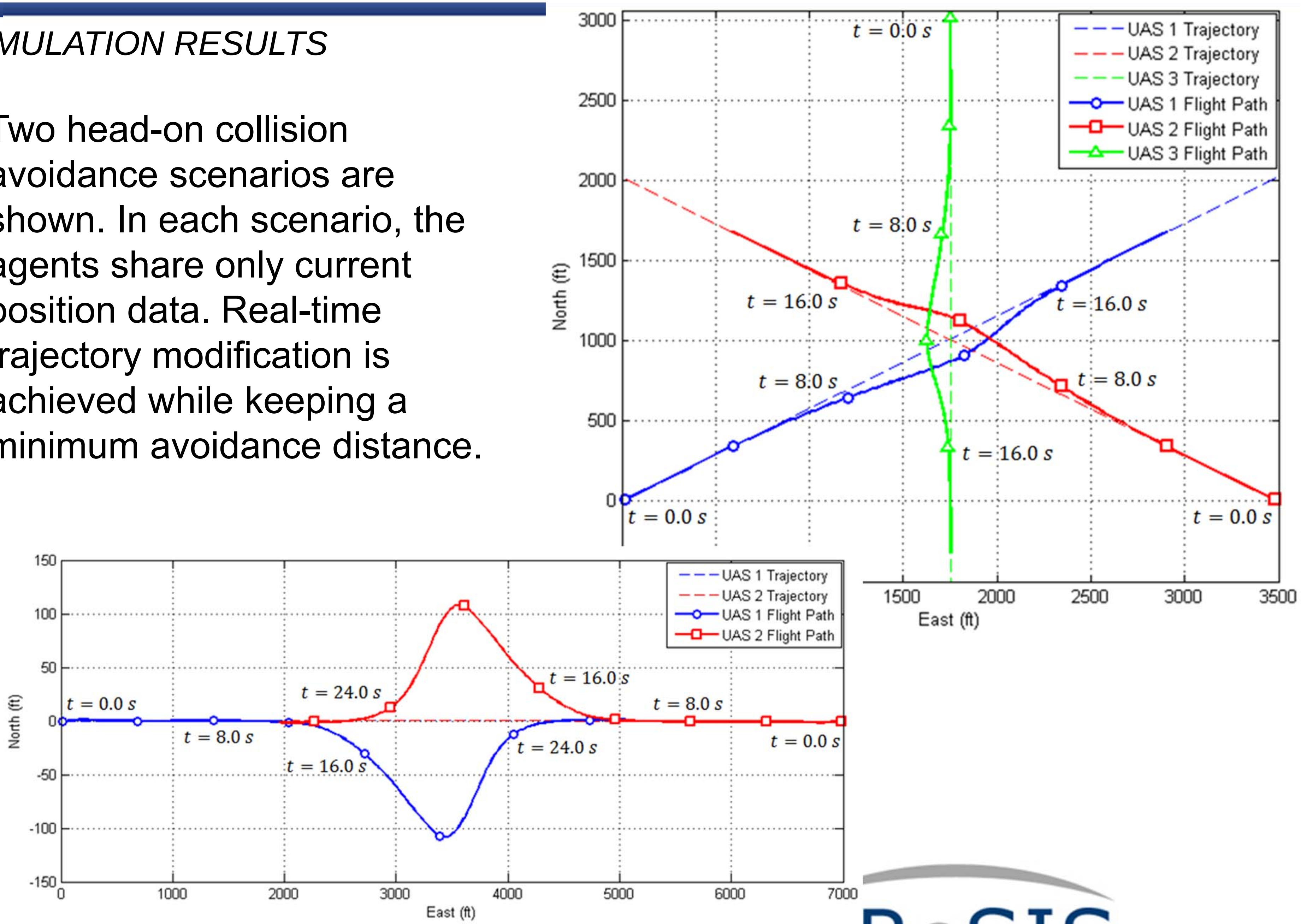
To reduce cross coupling between imbedded inner and outer loops, the trajectory information (described in the guidance logic) and aircraft model are imbedded into the NMPC. This allows control sequence generation for tight trajectory tracking over the horizon all in a single nonlinear loop.

Details of *COLLISION & OBSTACLE AVOIDANCE* logic can be found in the submitted Journal Article to the ASME Journal of DSMC.

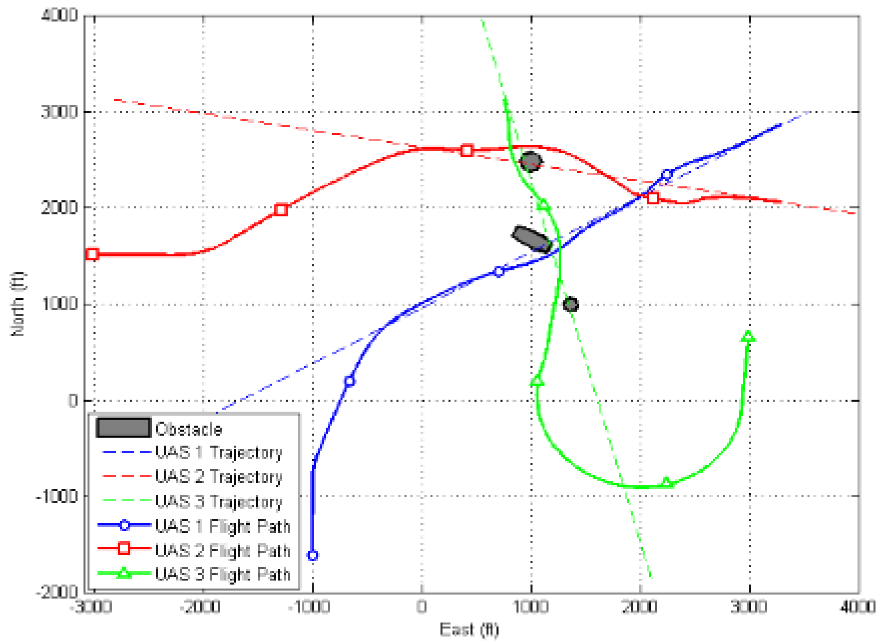
Stastny, T.J., Garcia, G., Keshmiri, S., “Collision and Obstacle Avoidance in Unmanned Aerial Systems Using Morphing Potential Field Navigation and Nonlinear Model Predictive Control ,” Under Review, ASME Journal of Dynamic Systems, Measurement and Control, 2013.

SIMULATION RESULTS

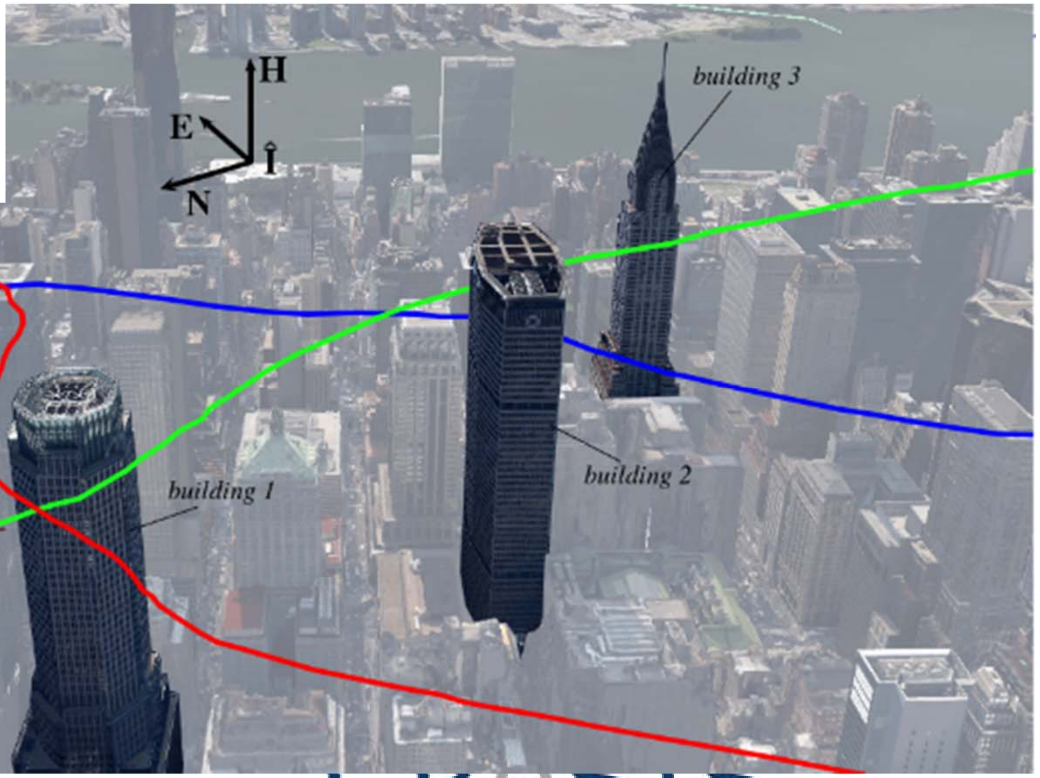
Two head-on collision avoidance scenarios are shown. In each scenario, the agents share only current position data. Real-time trajectory modification is achieved while keeping a minimum avoidance distance.



SIMULATION RESULTS



A simulation showing collision and obstacle avoidance in an urban environment is shown. Three UAS are commanded to follow displayed straight trajectories and autonomously adjust their tracks to avoid three buildings as well as inter-vehicle collision.



The NMPC is able to generate feasible control solutions in real-time and retain tight tracking of complex (modified) trajectories.

Questions?