

Define Minimum Safe Operational Volume for Aerial Vehicles in Upper Class E Airspace*

Presented by: **Min Xue**

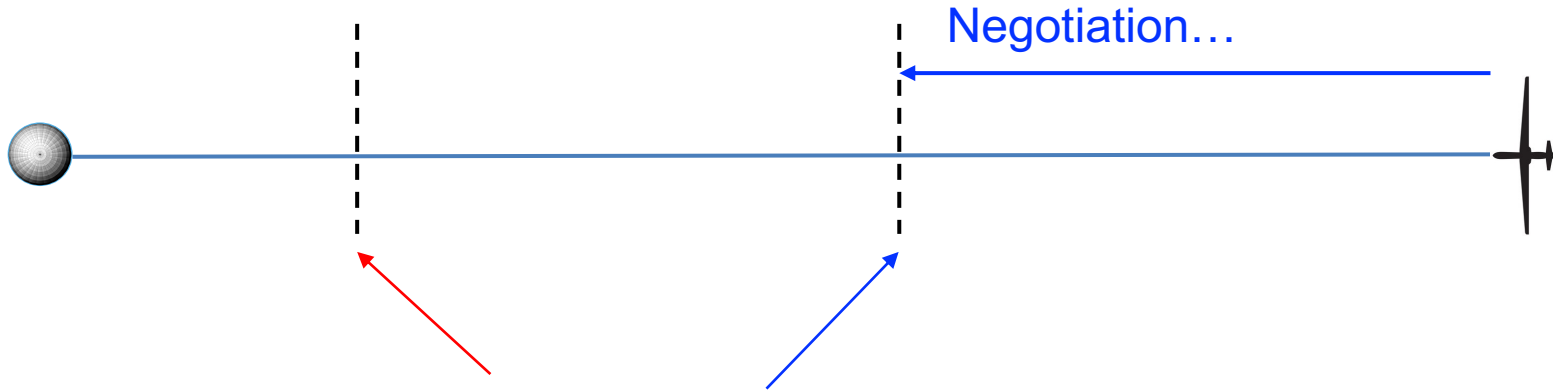
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Motivation

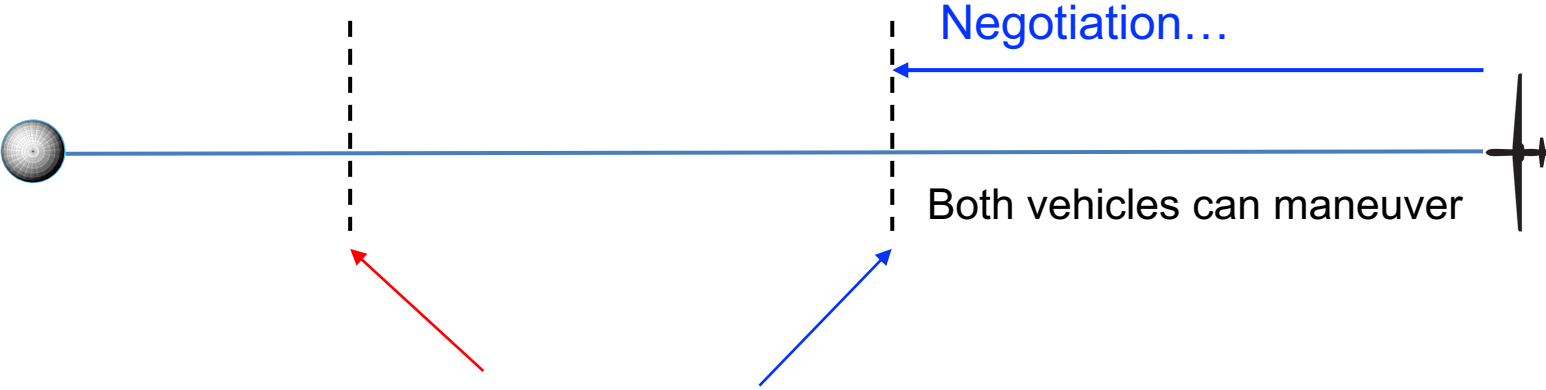


Cooperative operation concept for upper Class E airspace traffic management.



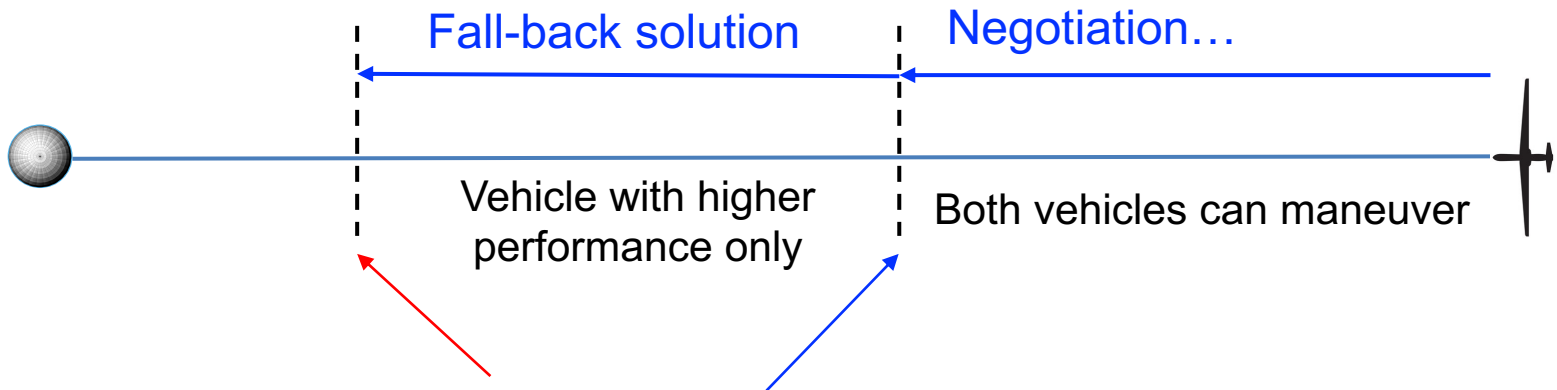
Where is the minimum safe operational boundary?

Cooperative operation concept for upper Class E airspace traffic management.



Where is the minimum safe operational boundary?

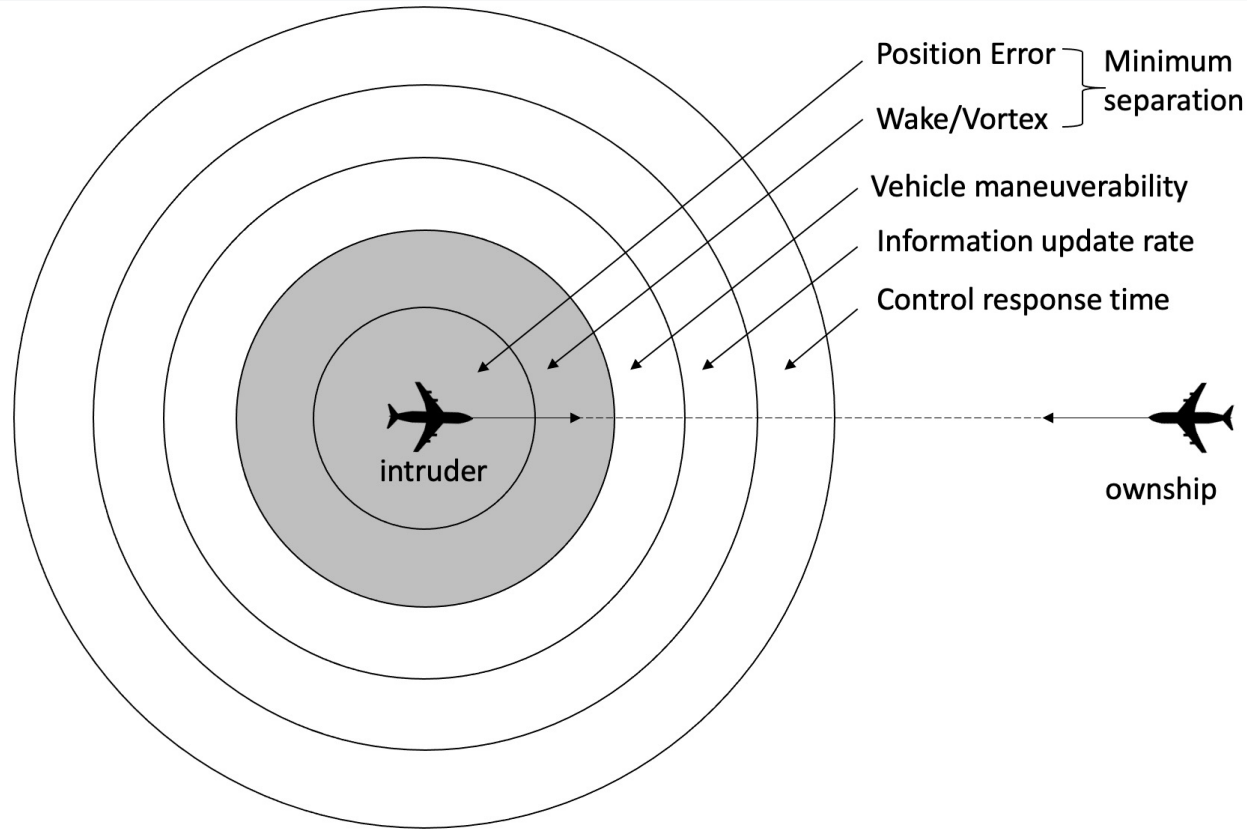
Cooperative operation concept for upper Class E airspace traffic management.



Where is the minimum safe operational boundary?



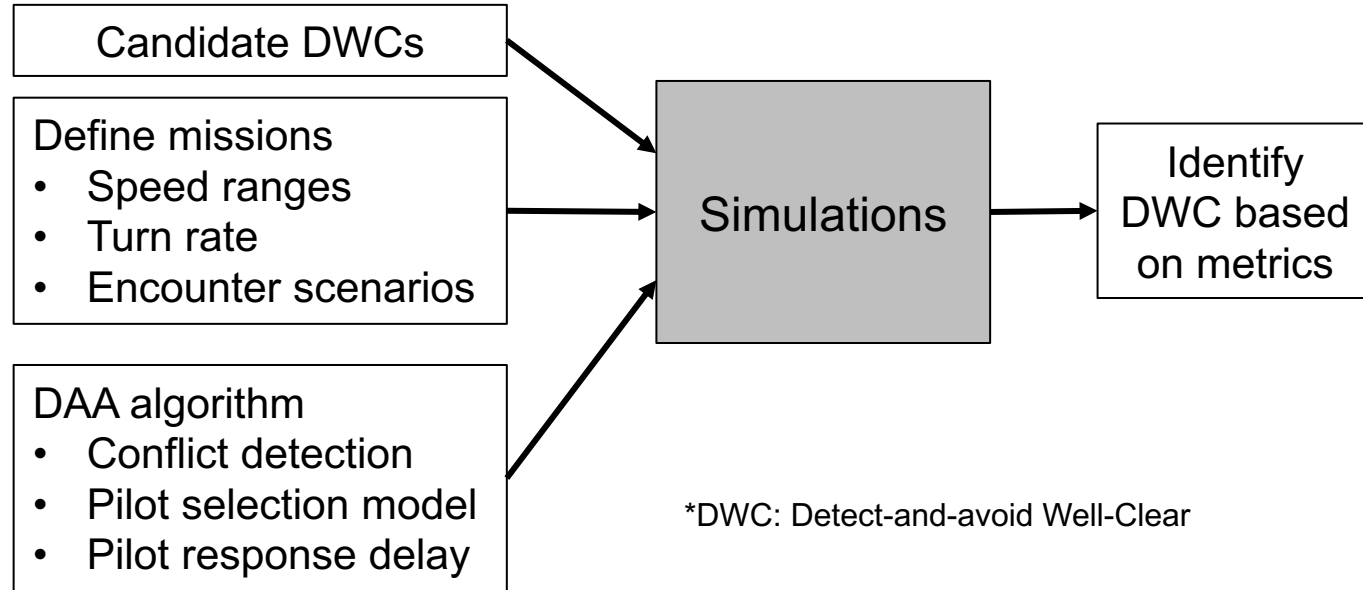
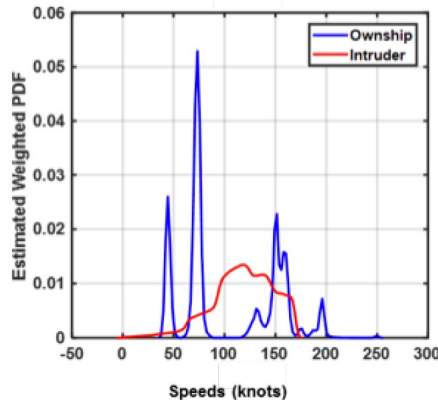
Contributing Factors



Fixed DWC*

Mission dependent

- Speed, altitude
- Turn rate ($7^\circ/\text{s}$)

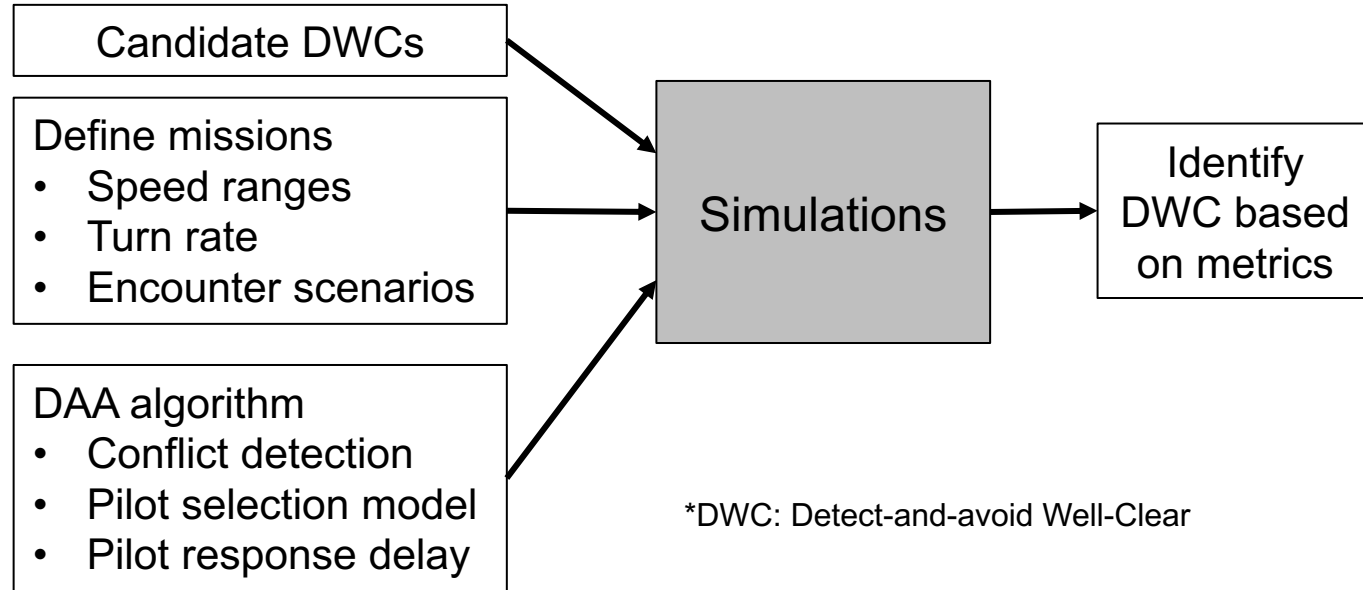
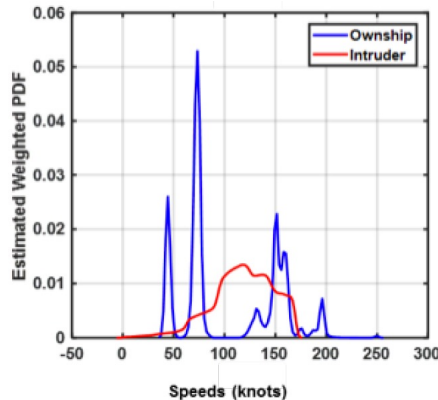


*DWC: Detect-and-avoid Well-Clear

Fixed DWC*

Mission dependent

- Speed, altitude
- Turn rate ($7^\circ/\text{s}$)



*DWC: Detect-and-avoid Well-Clear

- One-size-fits-all
- Mission dependent
- Fundamental understanding
- Initial estimation is needed

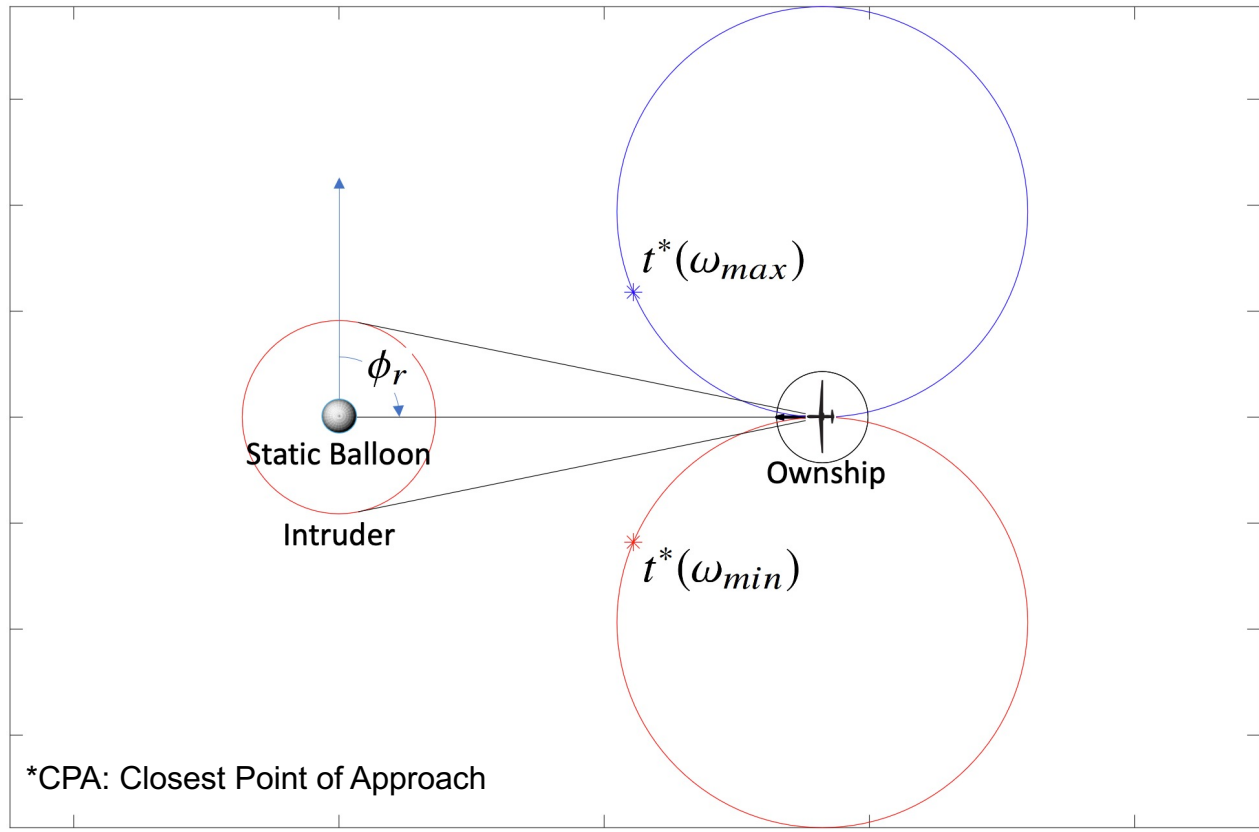


Outline

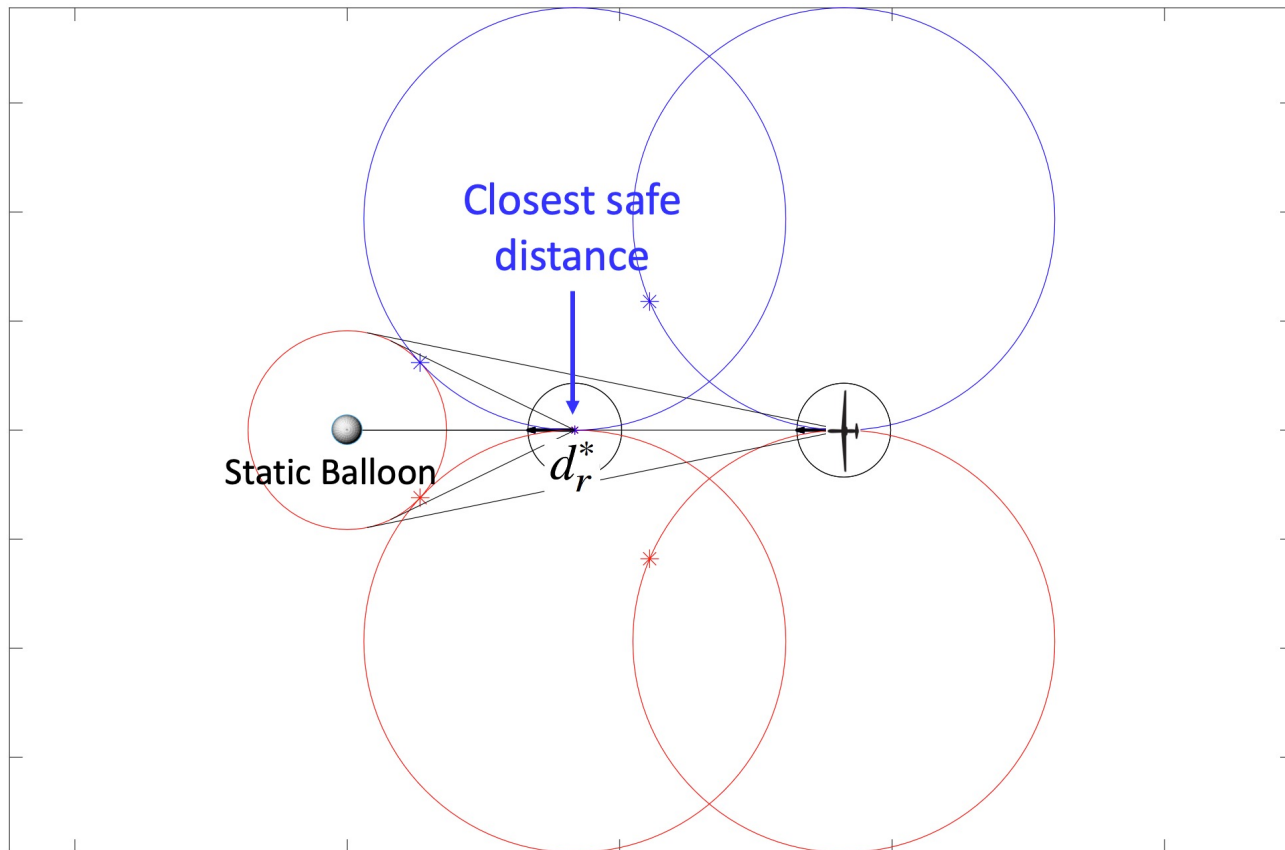


- Algorithm & demonstration:
 - Global Hawk vs. Balloon
 - Global Hawk vs. Aurora Odyssey
 - Quad-rotor vs. Quad-rotor
- Sensitivity study
 - Velocity
 - Bank angle
 - Minimum Separation
 - Delay caused by communication latency and control response
- Simulation verification
- Conclusions

Step I: Find CPA* with the max. and min. turns

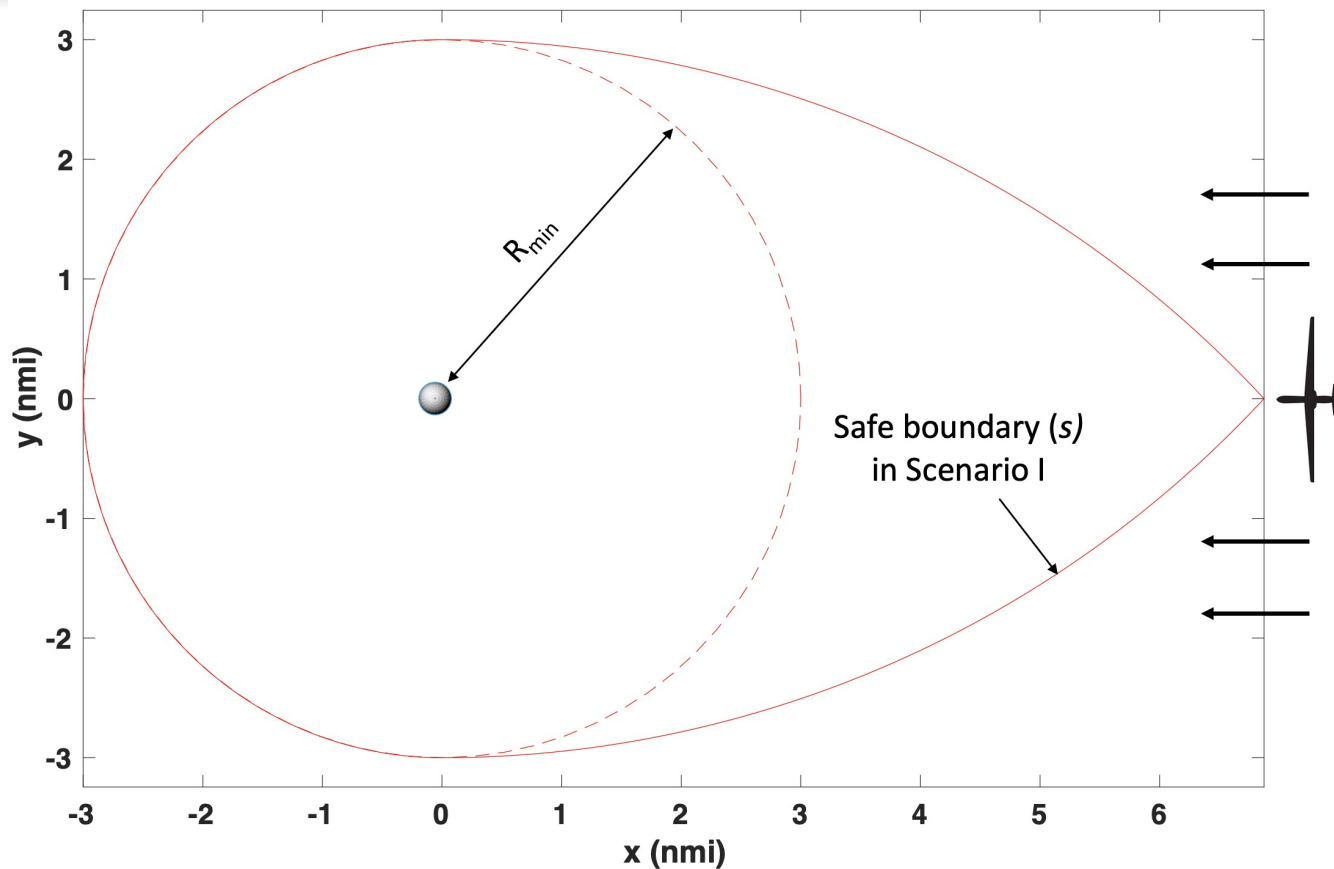


Step II: Find the closest safe distance





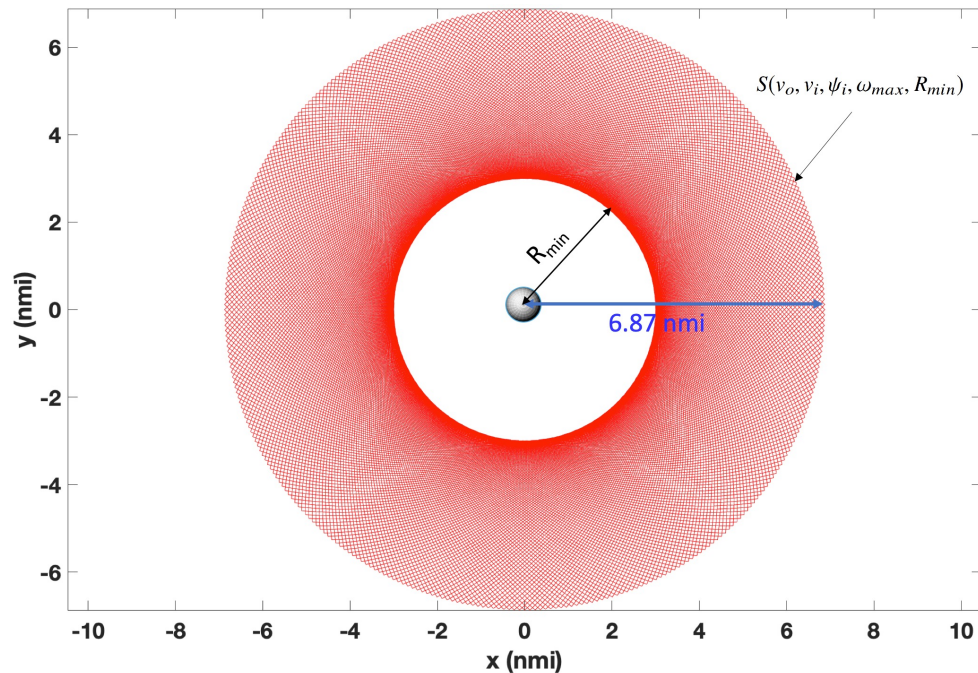
Step III: Safe Operational Boundary for Westbound Aircraft





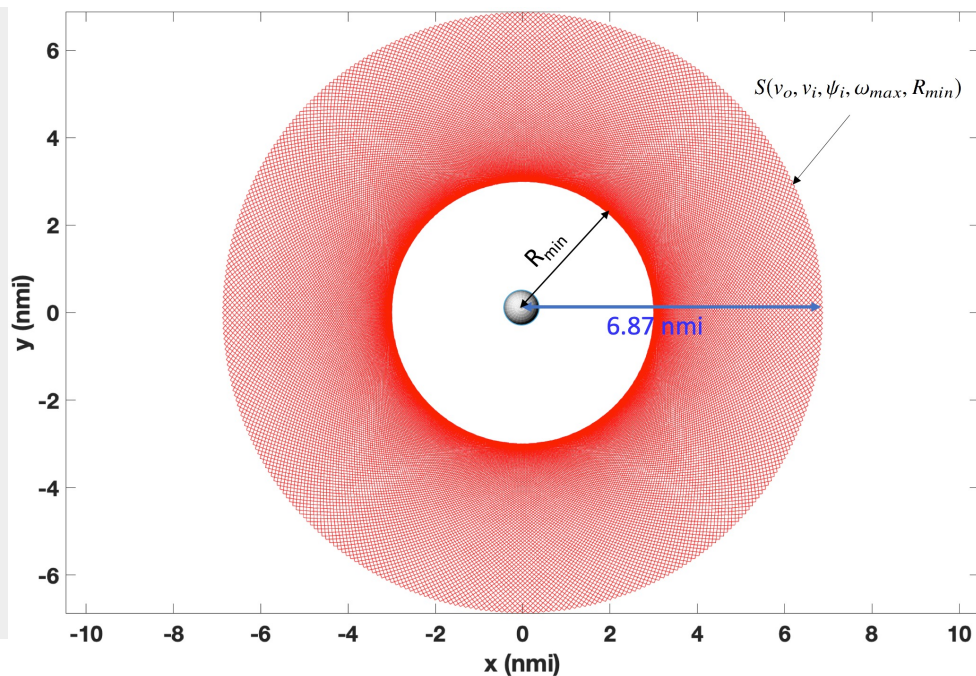
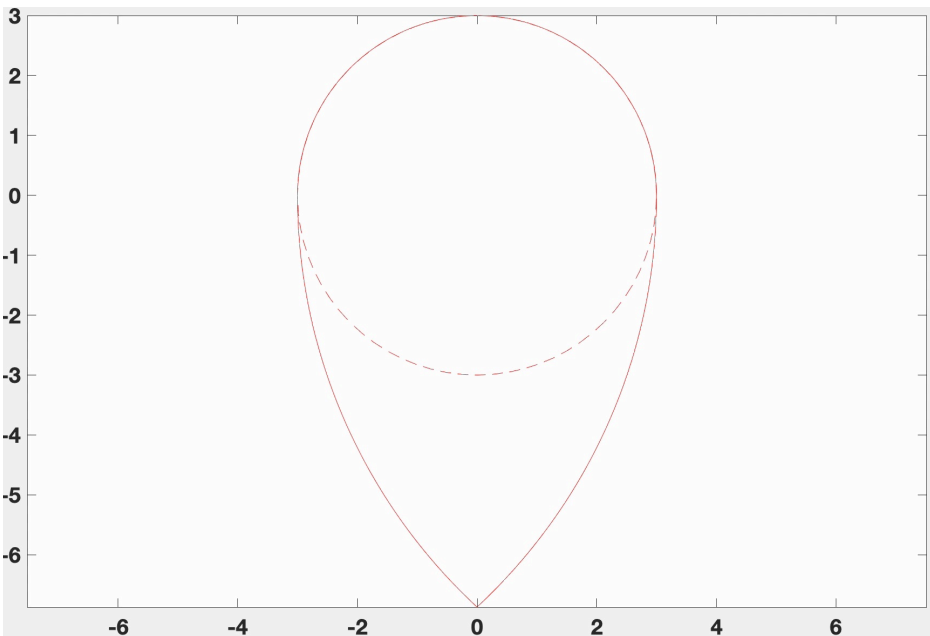
Step IV: Aggregated minimum safe operational boundary

Global Hawk vs. balloon: Global Hawk @340 kts with 14.8° bank; Static balloon



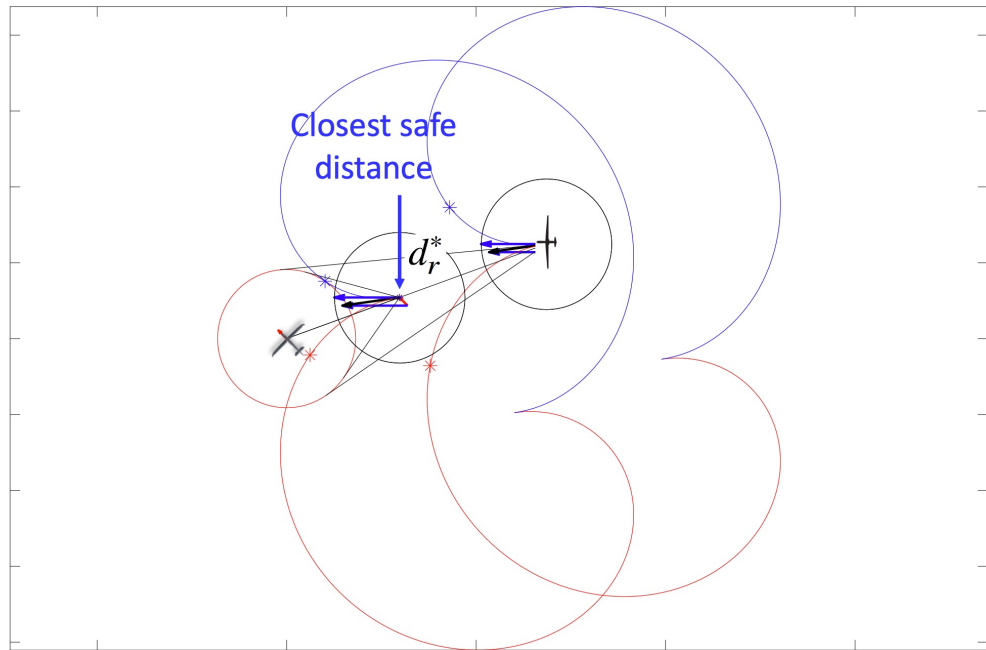
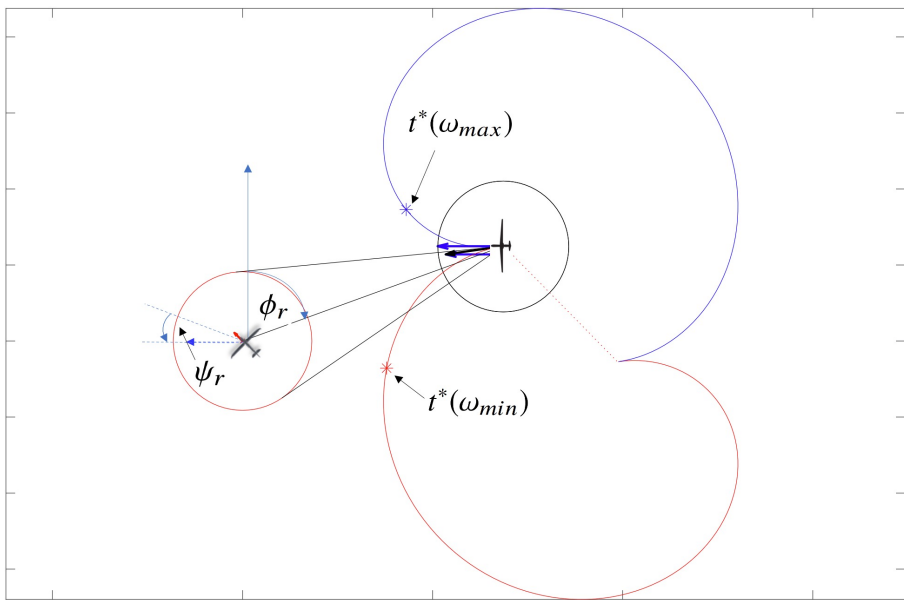
Step IV: Aggregated minimum safe operational boundary

Global Hawk vs. balloon: Global Hawk @340 kts with 14.8° bank; Static balloon



Scenario II: Global Hawk vs. Aurora Odysseus (I & II)

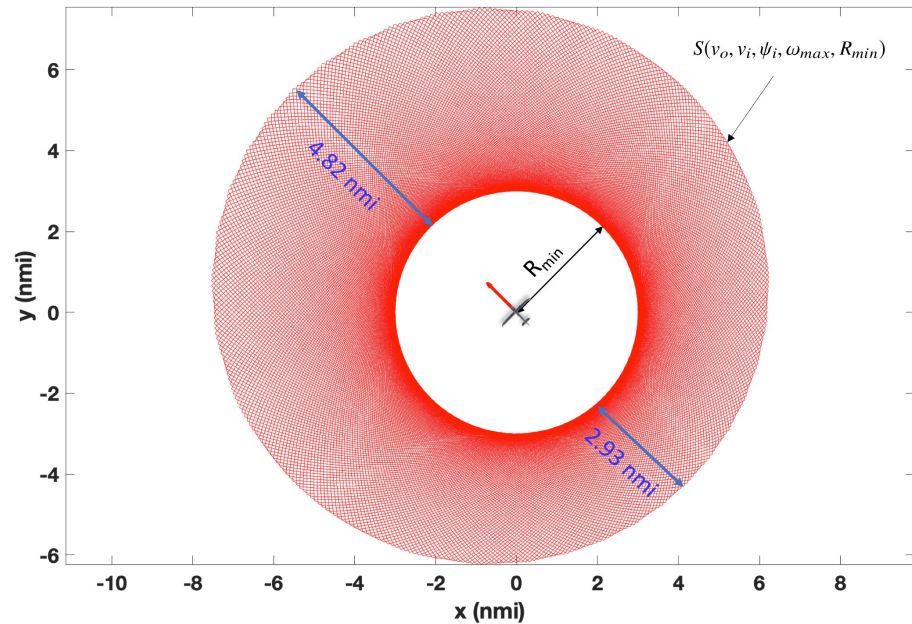
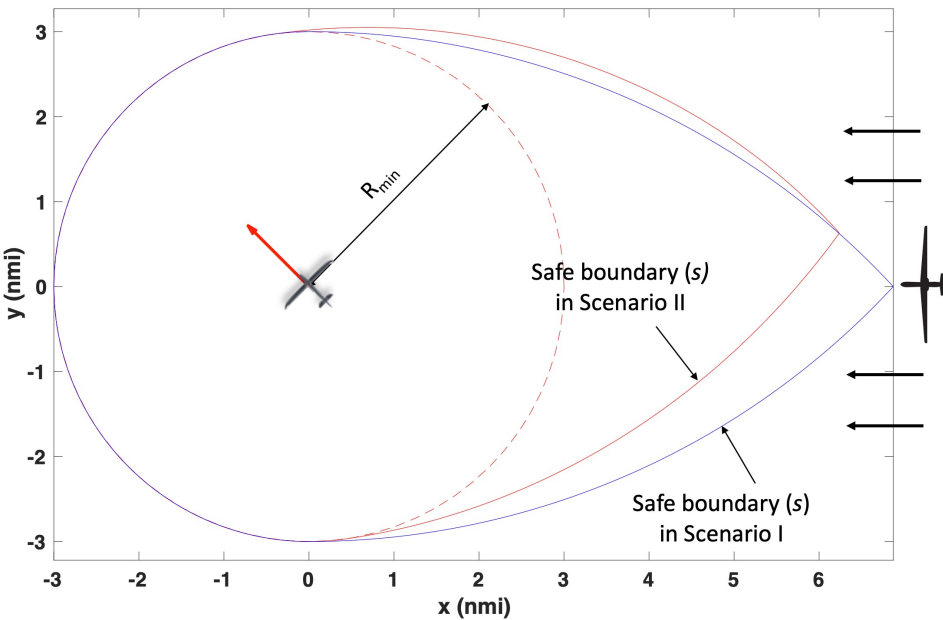
Global Hawk @340 kts with 14.8° bank; Aurora 60 kts





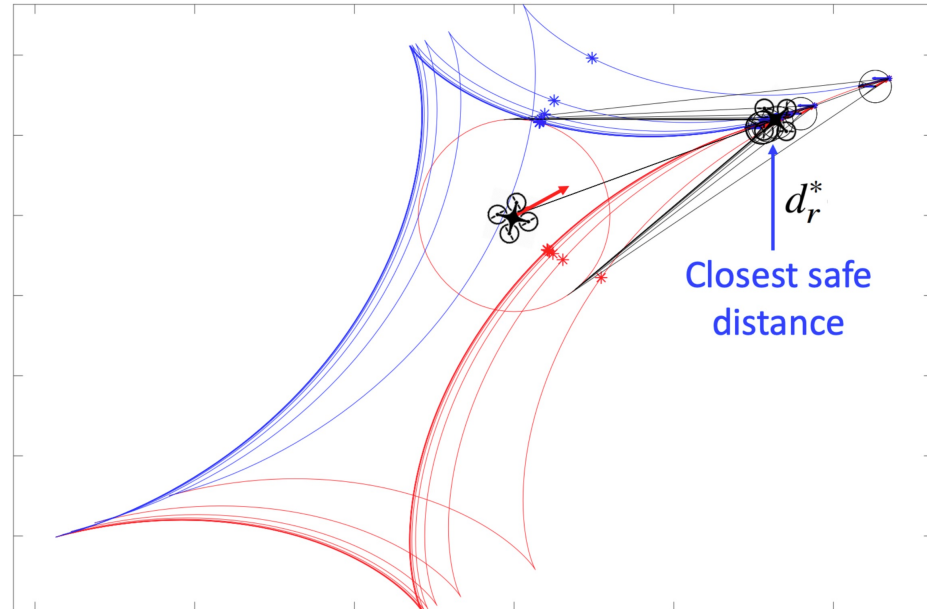
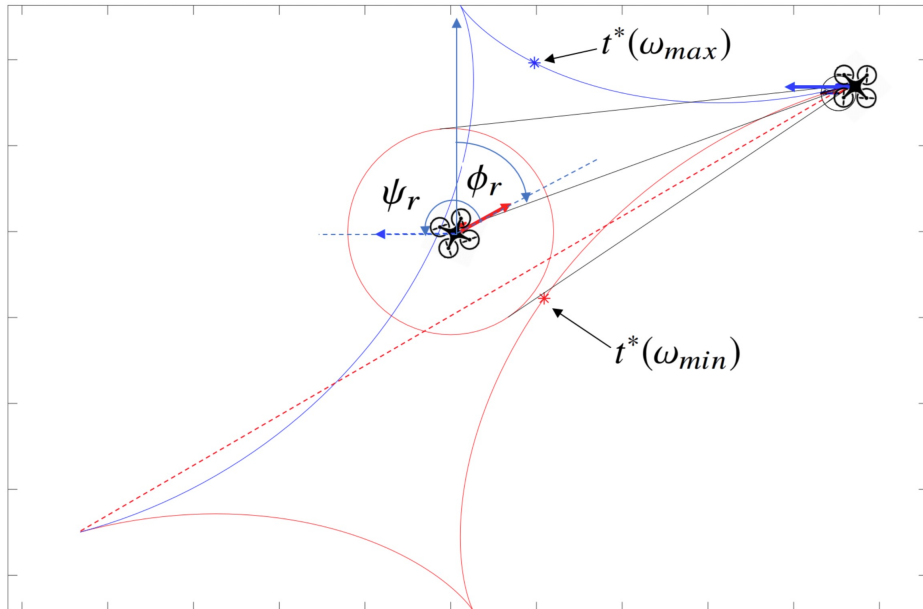
Scenario II: Global Hawk vs. Aurora Odysseus (III & IV)

Global Hawk @340 kts with 14.8° bank; Aurora 60 kts



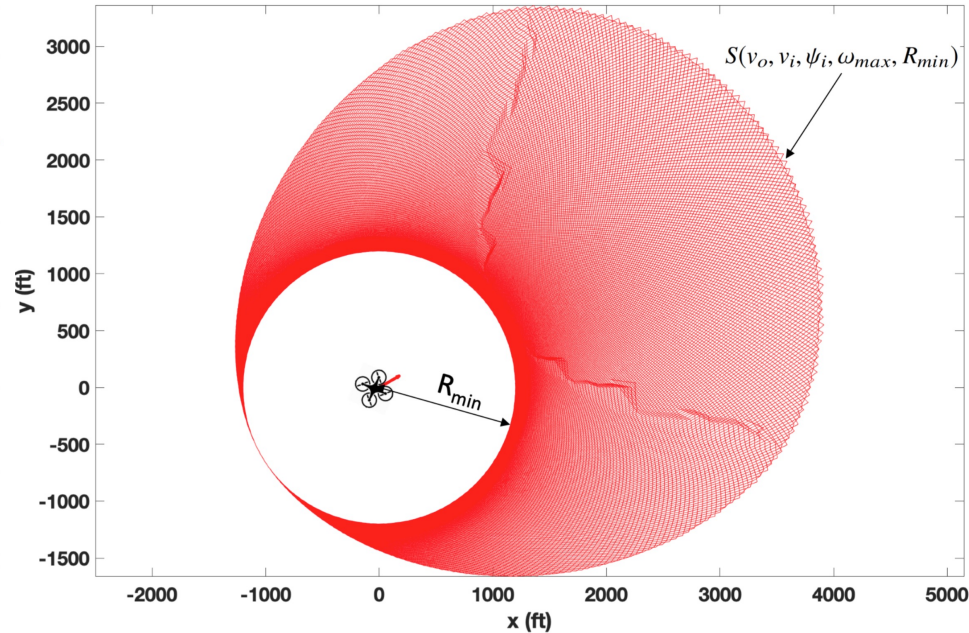
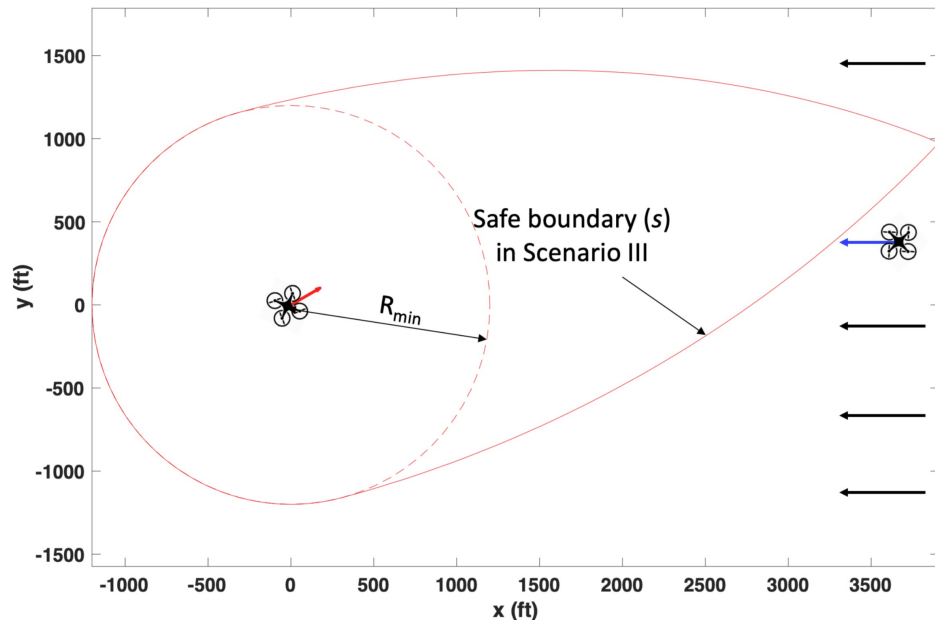
Scenario III: aircraft with the same speed (I & II)

@120 kts with 25° bank



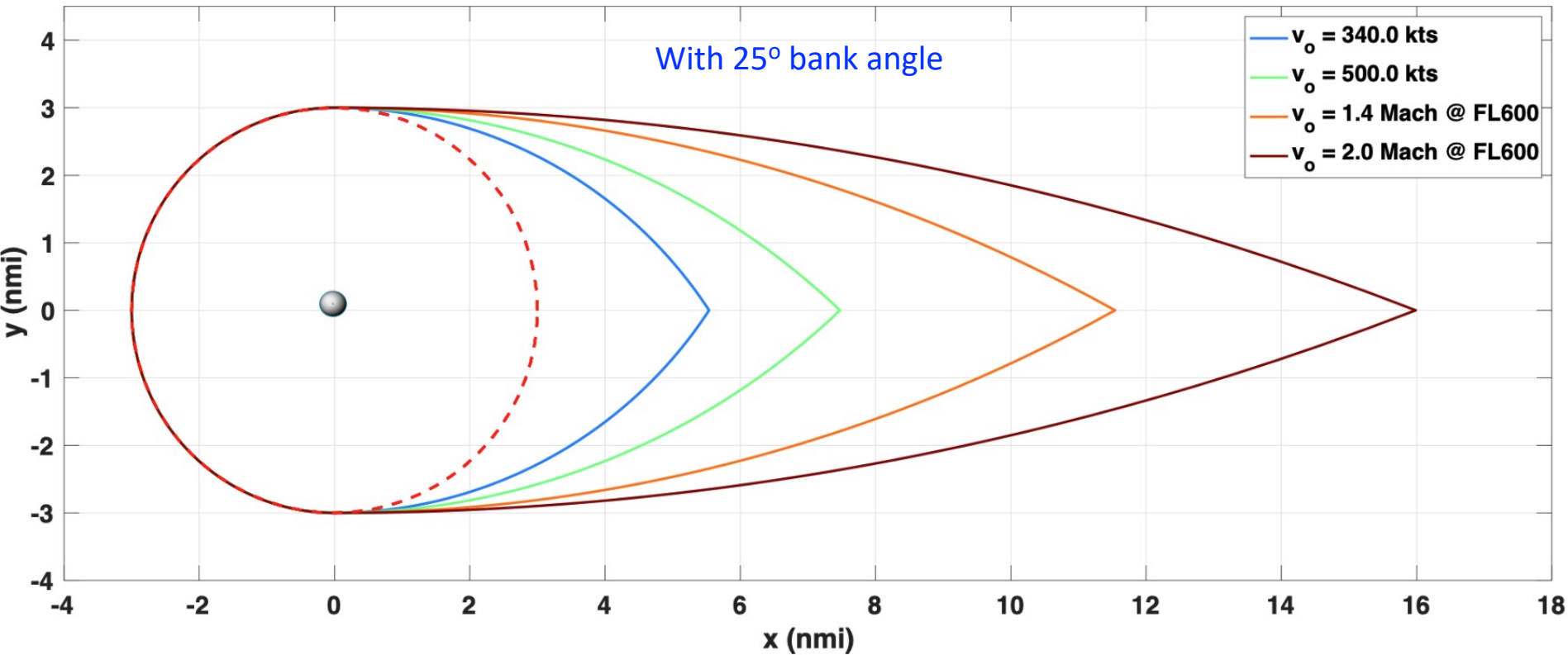
Scenario III: aircraft with the same speed (III & IV)

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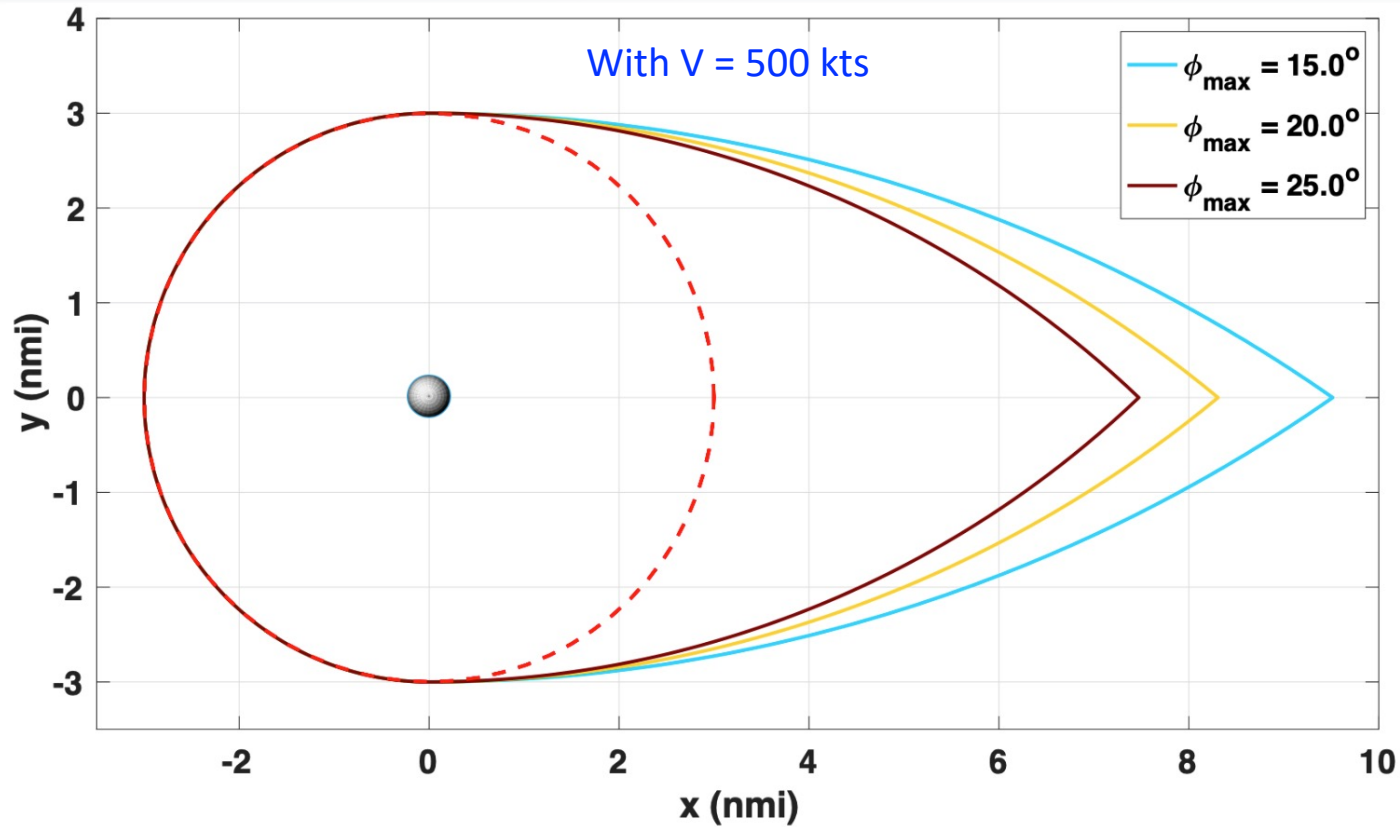


Sensitivity to the velocity



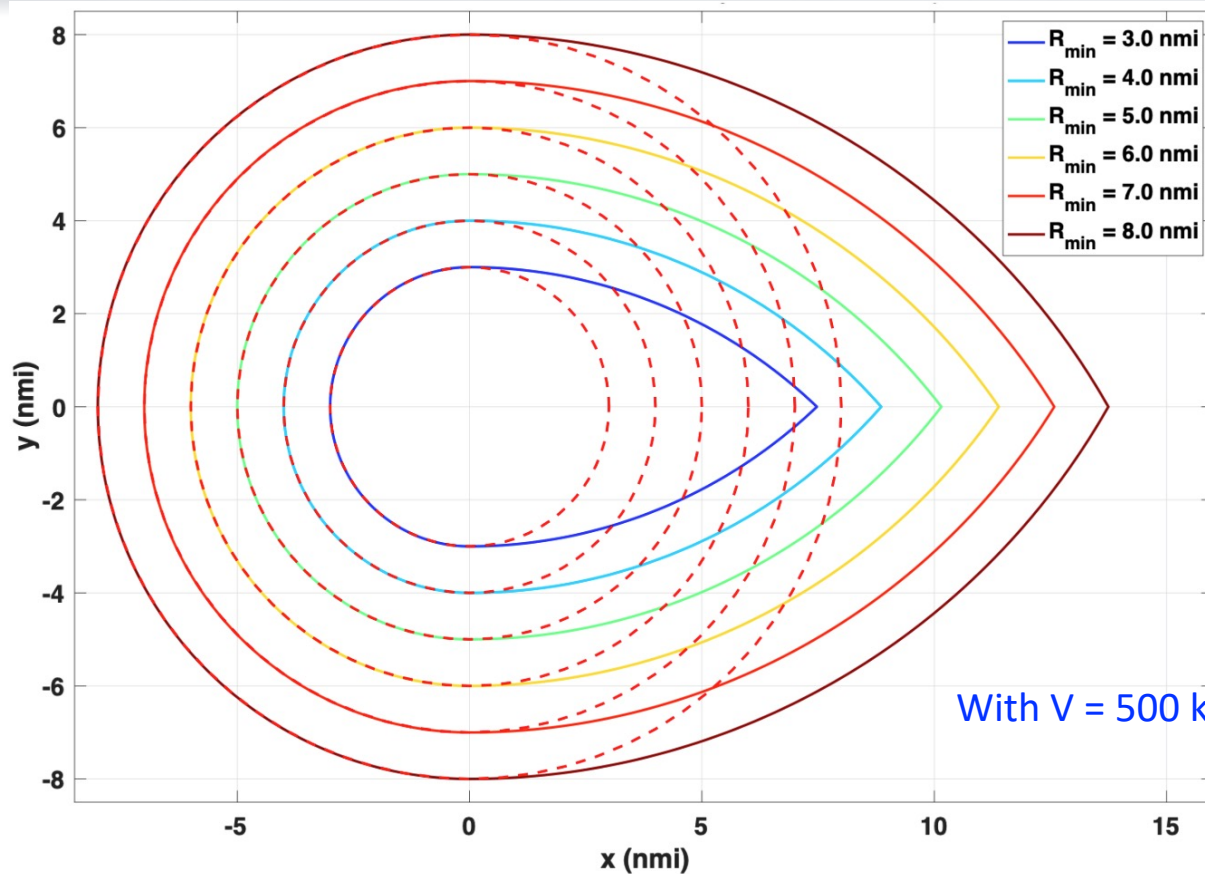


Sensitivity to the bank angle





Sensitivity to $R_{\min}$

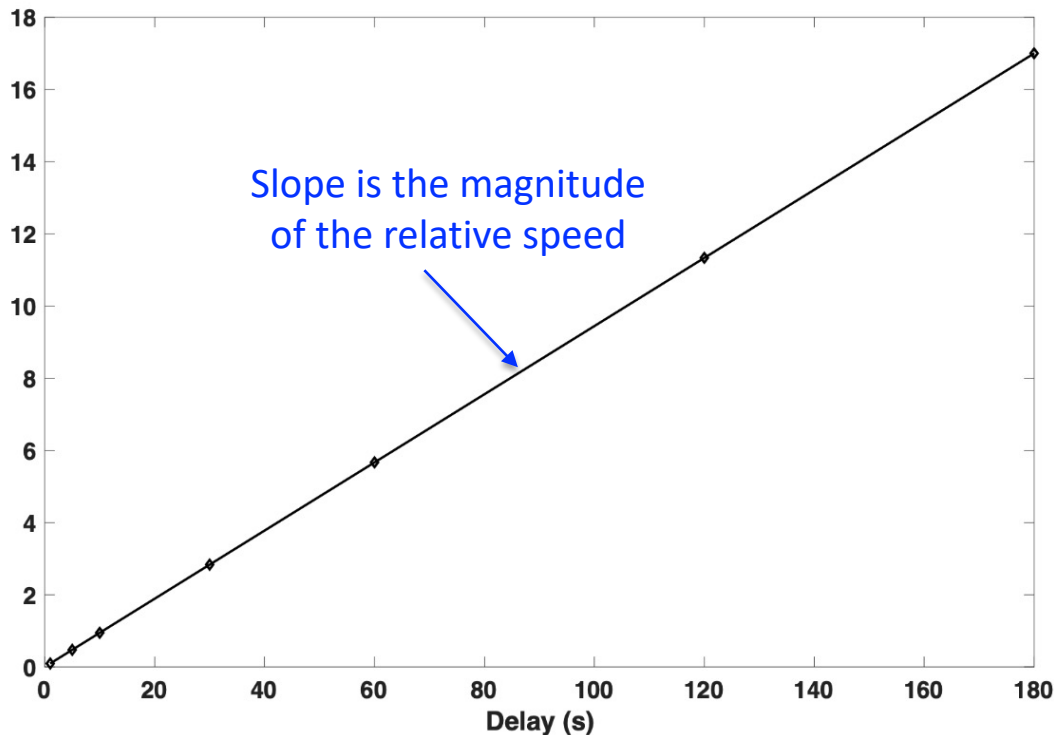


With $V = 500$ kts & 25° bank angle



Sensitivity to the delay caused by latency and control response

Extra distance
required (nmi)

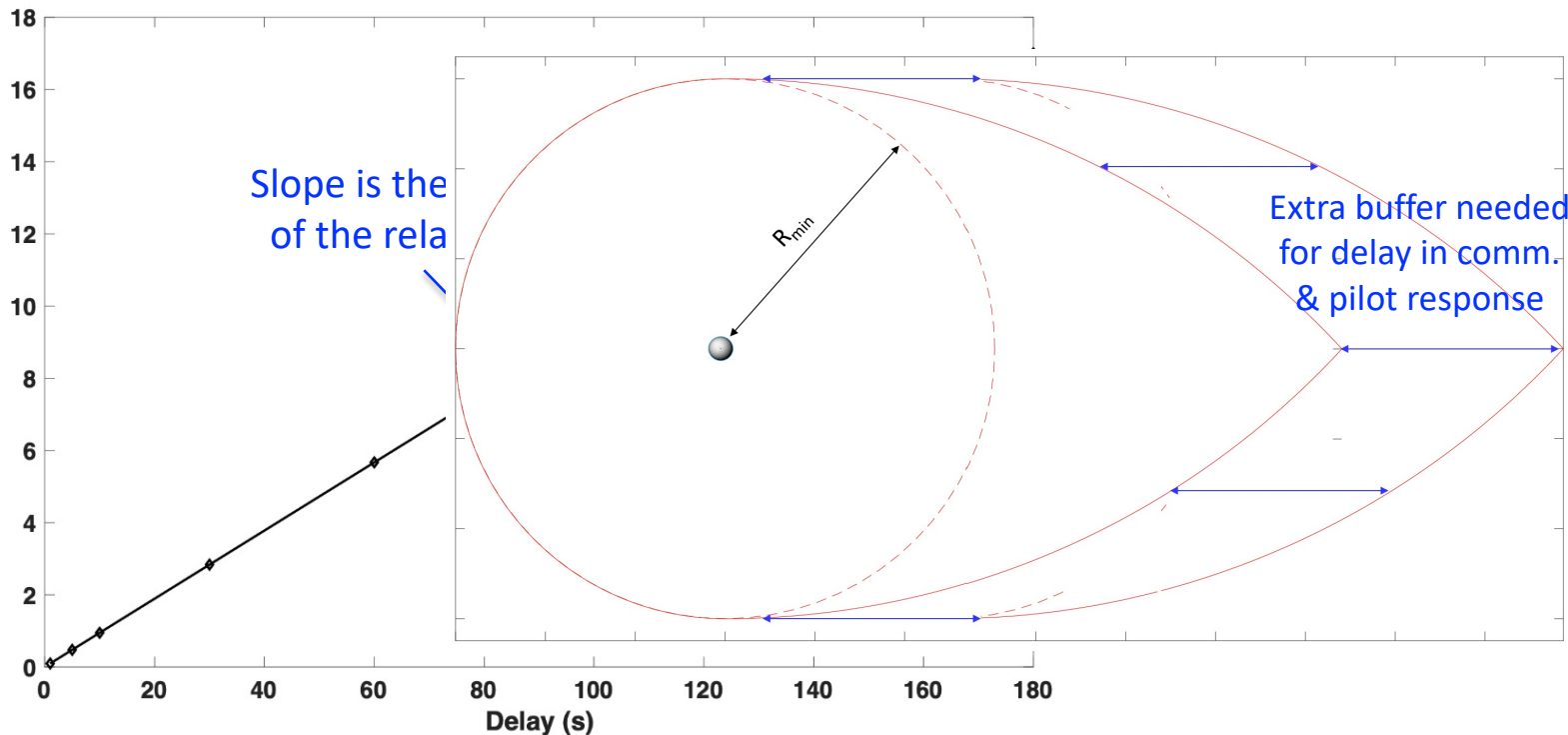


Global Hawk vs. static balloon

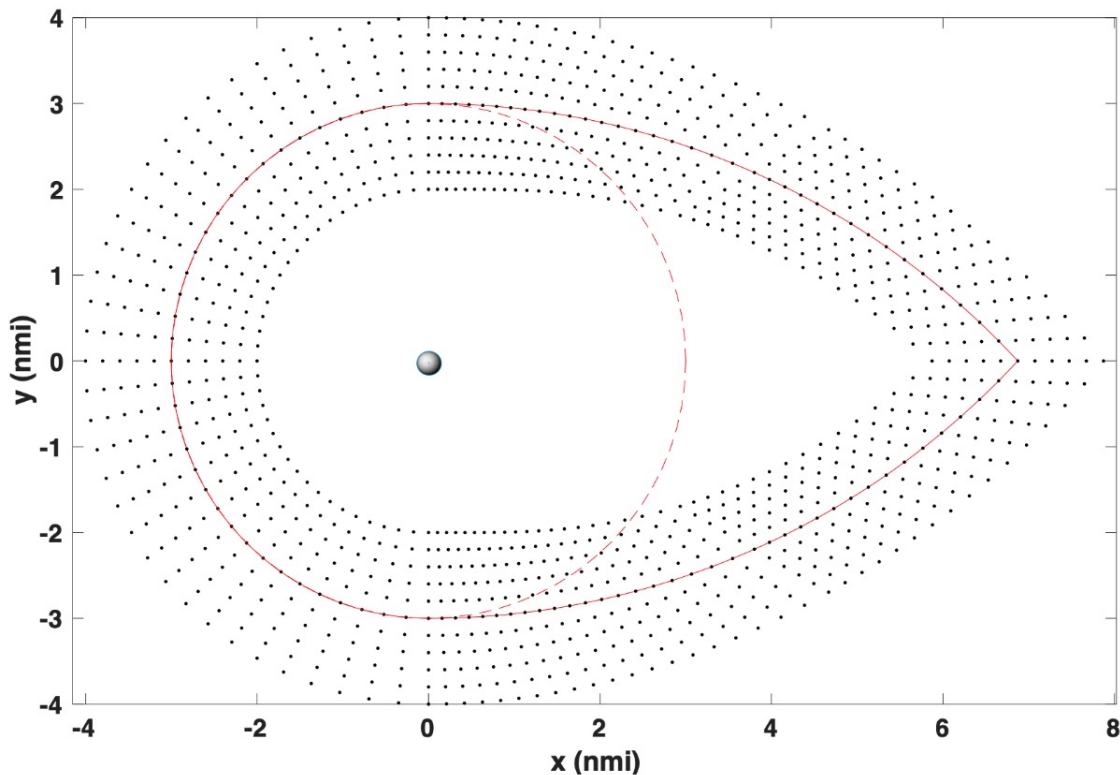


Sensitivity to the delay caused by latency and control response

Extra distance
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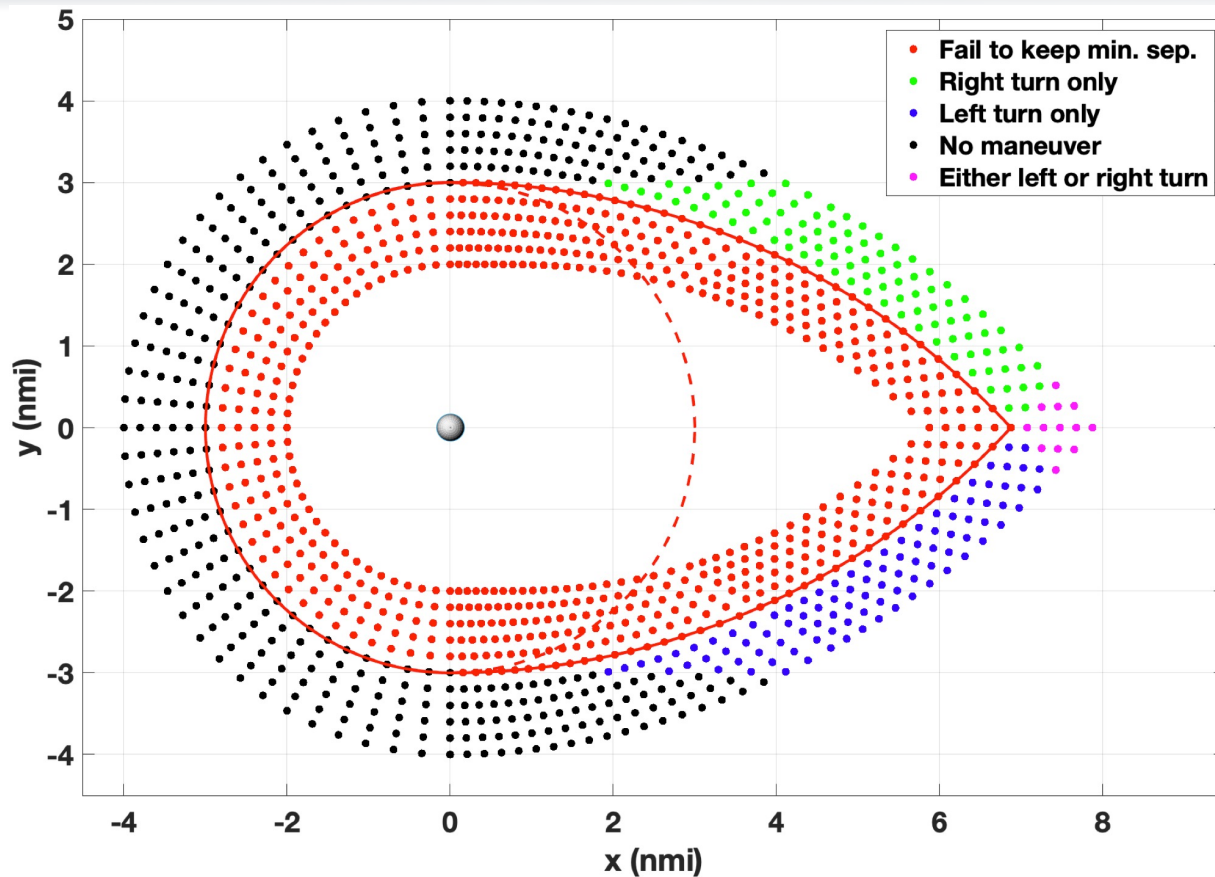
Global Hawk vs. static balloon



- Put the Global Hawk at one grid point
- A total of 1,166 encounter cases
- Let the Global Hawk fly westbound
- Max. allowed bank angle = 14.8°
- Fe³ traffic simulator^[2] is used:
 - Detect and avoid works @ 2Hz
 - Heading angle change only
 - Resolution with min. deviation
 - Kinetic trajectory model for the GH
 - Dynamic model for the balloon

[2] Xue et. al. , "Fe³: An Evaluation Tool for Low-Altitude Air Traffic Operations", AIAA Aviation Forum, 2018.

Verification with simulations: results





Main contribution and potential applications

- An analytical method was developed to define the minimum safe operational boundary driven by maneuverability and delay.
 - Sensitivity analysis shows that the extra separation is dynamically decided by various parameters (speeds, relative position angle, relative heading angle, max. bank angle, delay caused by comm. and control, etc.)
 - Simulation experiments with pairwise encounters verified the analytical results.
- This analytical method will be important to understand and define well-clear type of definition and advance the state of the art.
 - Define reference timelines for cooperative operation concept
 - Used as guidance for tactical avoidance for any pairwise encounter.
 - Support ATC resolve conflict when handling a variety of vehicle performances

