



Preliminary Analysis of Separation Standards for Urban Air Mobility using Unmitigated Fast-Time Simulation

Presenter: Seungman Lee

Michael Abramson, James Phillips, Huabin Tang

NASA Ames Research Center

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Urban Air Mobility (UAM)



- UAM is an emerging concept for transporting people and cargo rapidly in and around urban areas using electric Vertical Takeoff and Landing (eVTOL) vehicles
- Compared to conventional flights, UAM vehicles have:
 - Short range
 - Low altitude
 - Low speed
- A key challenge to enable safe integration and operation of UAM flights is to ensure UAM vehicles maintain safe separation from other vehicles



Research Objectives



- To investigate the impact of proposed DFW UAM operations on safety through unmitigated fast-time simulations
- To understand the characteristics of conflicts for establishing separation standards for UAM operations with a set of separation standards
 - Conflicts between UAM flights
 - Conflicts between UAM and conventional IFR/VFR traffic
- To evaluate the sensitivity of a set of separation standards on the safety and operational suitability metrics
- To help the Federal Aviation Administration inform the recommendations of UAM separation standards



Outline



- Risk-based Approach
- Separation Standards and Conditional Collision Risk
- Safety and Operational Suitability Metrics
- DFW UAM Traffic Scenario
- Fast-time Simulation Framework
- Simulation Results
- Conclusions and Future Research



Risk-Based Approach for Separation Standards

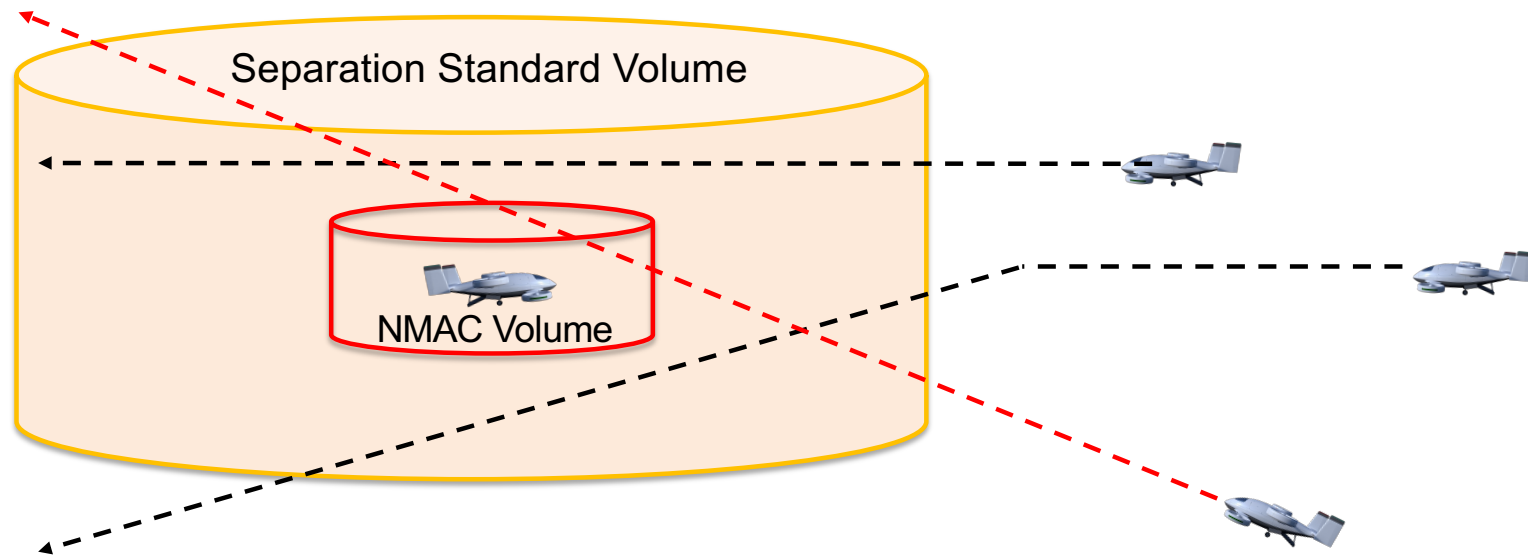
- Separation Minima/Separation Standard
 - “the minimum displacements between an aircraft and a hazard which maintain the risk of collision at an acceptable level of safety” [International Civil Aviation Organization (ICAO)]*
- In risk-based approach, a *separation standard can be framed as a relative state between aircraft for which the risk of collision is acceptable [Weibel, 2011]*
 - A spatial and/or temporal boundary around the aircraft to achieve an acceptable level of safety (collision risk)
- Collision risk can be measured as the conditional probability of a Near Midair Collision (NMAC) given that two aircraft are at a relative state

[Weibel, R. E., Edwards, M. W. M., and Fernandes, C. S., “Establishing a risk-based separation standard for Unmanned Aircraft Self Separation,” Ninth USA/Europe Air Traffic Management Research & Development Seminar, 14-17 June 2011, Berlin, Germany]



Unmitigated Conditional Collision Risk

- Conditional probability of NMACs given defined separation standards have been compromised without any maneuvers to avoid a collision



- RTCA SC-228 Recommended Collision Risk for UAS DAA Well Clear
 - Initial value was **5%** and additional considerations led to **2.2% for TCAS-II equipped aircraft**



Candidate Separation Standards for UAM Operations

- Current large IFR/VFR separation standards will be a critical barrier to enable a high volume of UAM operations in the metropolitan airspace
- New separation standards for UAM operations should be established to accommodate increasing UAM traffic demand without compromising the safety of existing traffic
- As a minimum principle, a separation standard for UAM operations should provide a separation:
 1. Large enough to avoid collision hazards or NMACs and
 2. Small enough to avoid excessive incursions of conflict (i.e., loss of separation) during the flight



Safety and Operational Suitability Metrics

- Safety Metrics

: To measure acceptable collision risk of UAM operations with a set of separation standards

$$\text{Unmitigated conditional collision risk} = P(\text{NMAC}/\text{LoS})$$

- Operational Suitability Metrics

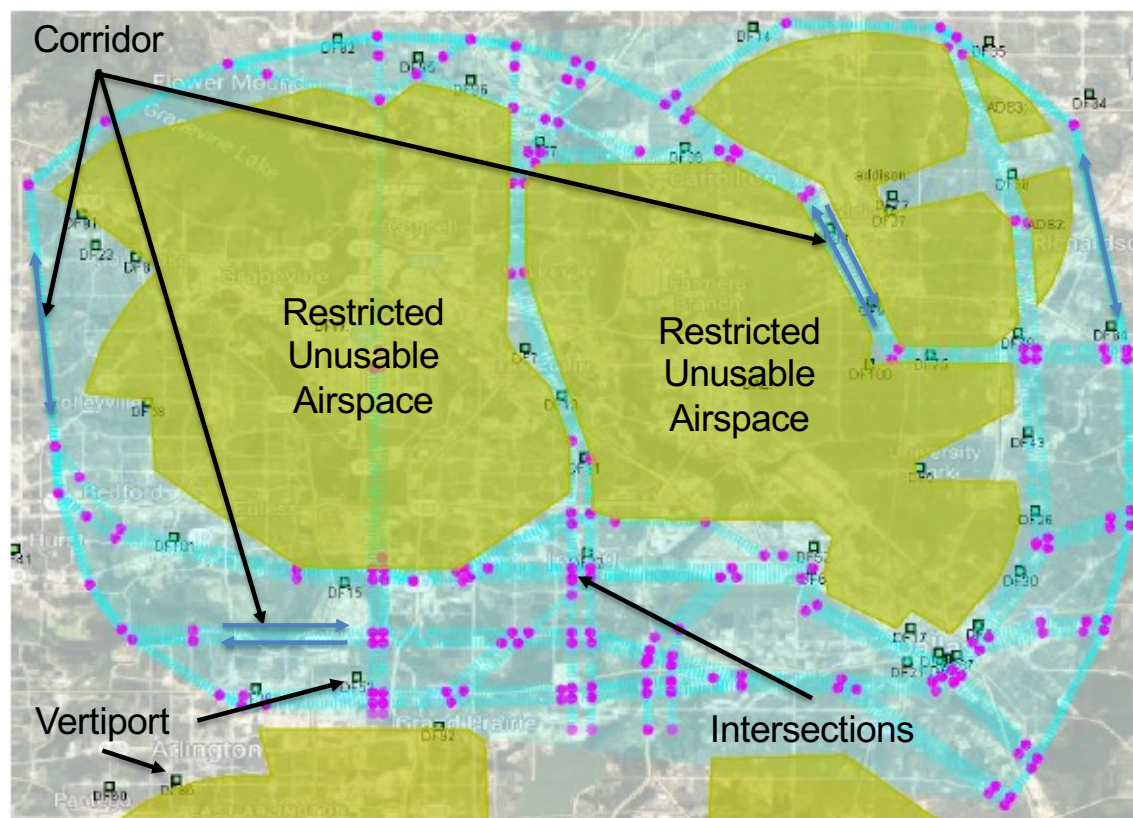
: To measure whether a separation standard is operationally acceptable

$$\begin{aligned} \text{LoS Rate} &= \frac{\text{Total number of LoS}}{\text{Total duration of all UAM flight hours}} \\ &= \text{Number of LoS per UAM flight hour} \end{aligned}$$



DFW UAM Traffic Scenario (Airspace/Route Structure)

- Traffic demand developed by Virginia Tech Air Transportation Systems Laboratory
- UAM route structures including Corridors and tracks at DFW airspace
 - Designed by NASA's UAM Airspace Procedures and Design Team to procedurally deconflict UAM flights from IFR arrival/departure flow
 - 1,500 ft lateral separation between parallel tracks
- UAM flight plan data were generated by NASA's Advanced Trajectory Services – Toolkit for Integrated Ground and Air Research (ATS-TIGAR) tool

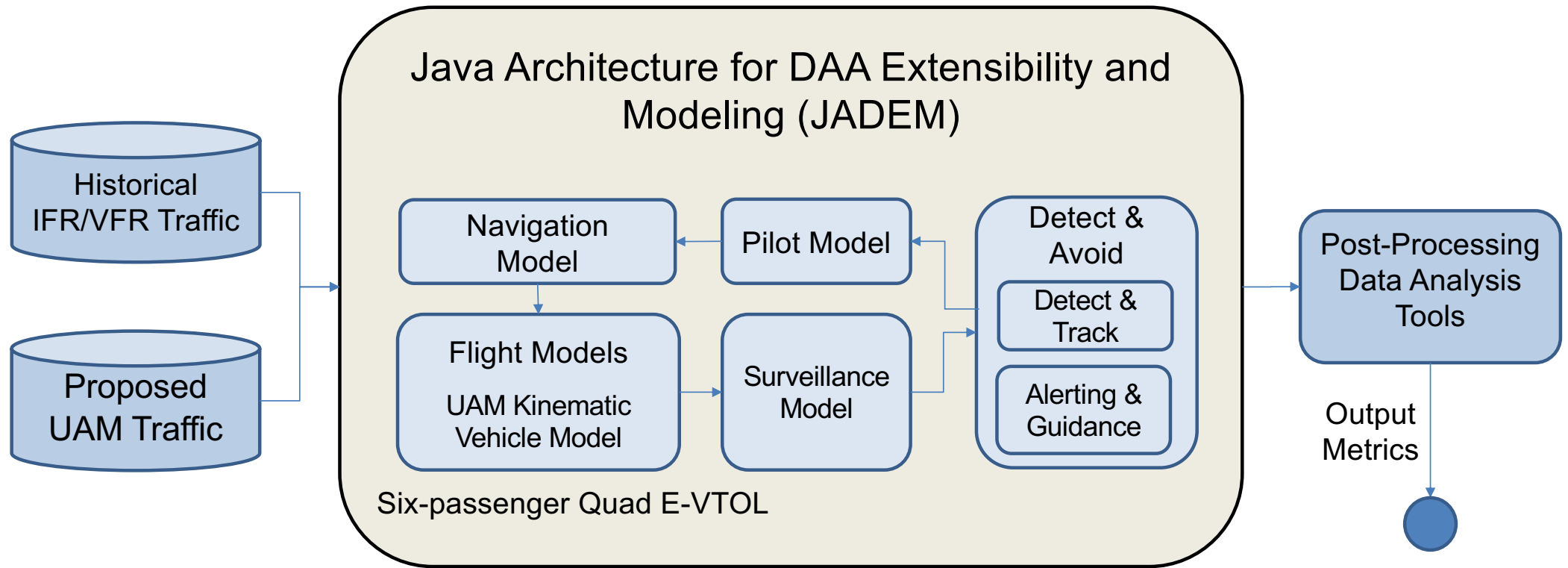




Encounter Set



- A total of 9,986 projected UAM flights for one day were simulated with each of 10 days historical radar-recorded IFR and VFR traffic in the DFW terminal airspace using a fast-time simulation platform
- A typical one-day scenario
 - 7,520 conventional IFR and VFR aircraft per day on average
 - A total of 79,549 unique pairwise encounters between UAM flights
 - A total of 109,536 unique pairwise encounters between UAM and conventional IFR/VFR aircraft for 10 days





Test Matrix (Separation Standard Parameters)

- For conflicts between UAM flights

| Separation Standards | Parameter Space |
|-----------------------------|---|
| Horizontal separation (ft) | 750, 1000, 1250, 1500, 1800, 2200, 3000, 4000, 5000, 6500 |
| Vertical separation (ft) | 150, 300, 450 |

- For conflicts between UAM and non-UAM flights

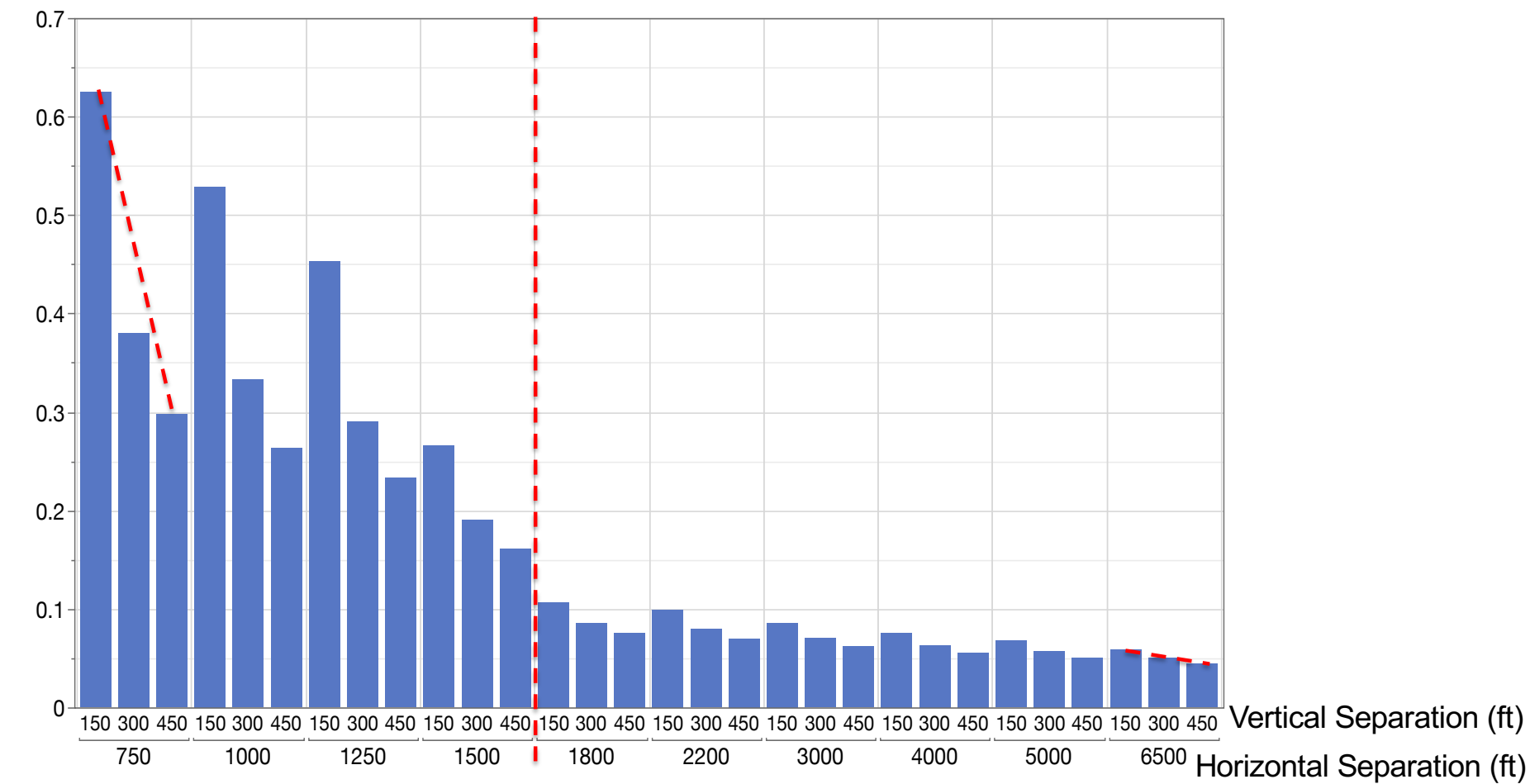
| Separation Standards | Parameter Space |
|-----------------------------|---|
| Horizontal separation | 2500 ft, 3000 ft, 4500 ft, 1.0 nmi, and 1.5 nmi |
| Vertical separation | 500 ft |



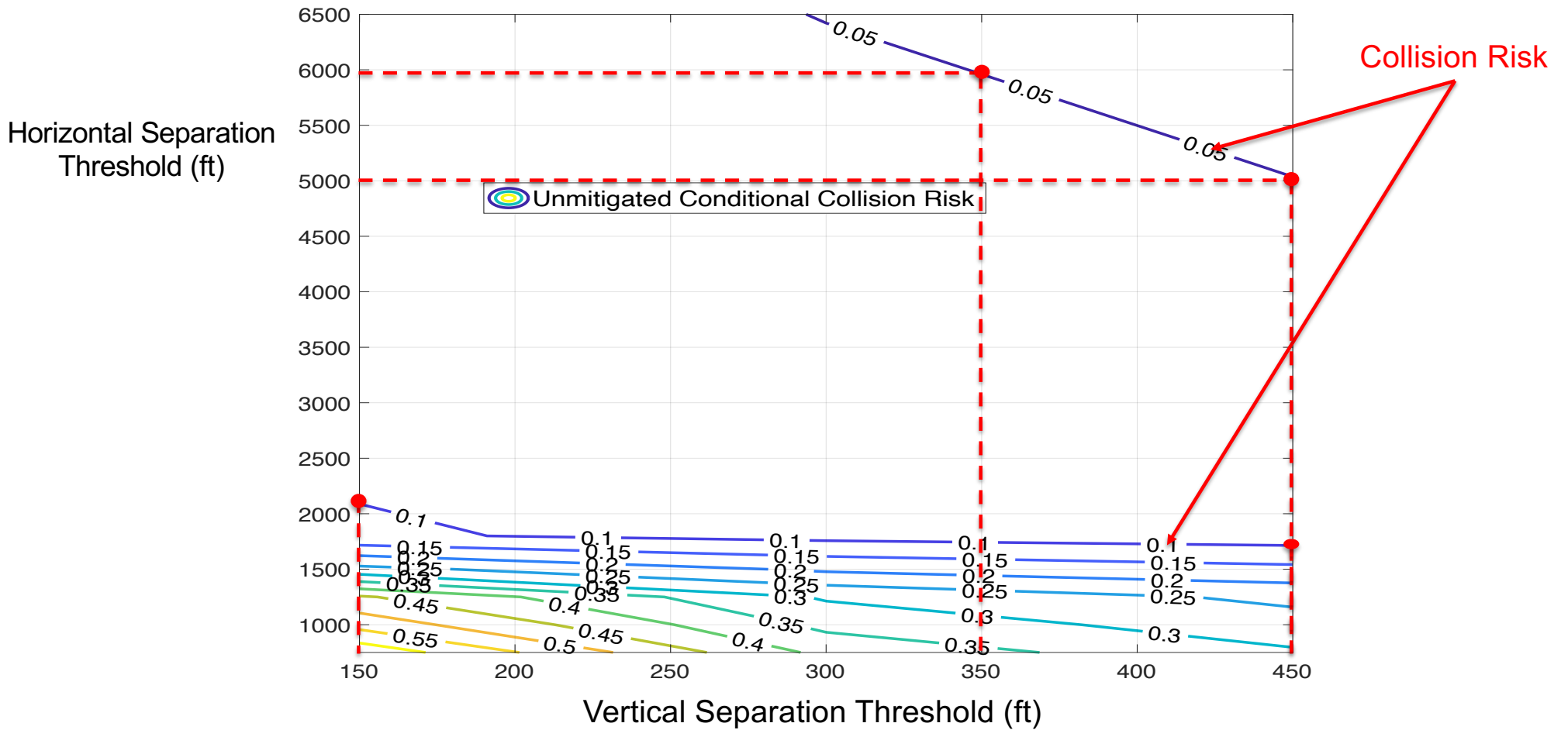
Simulation Results



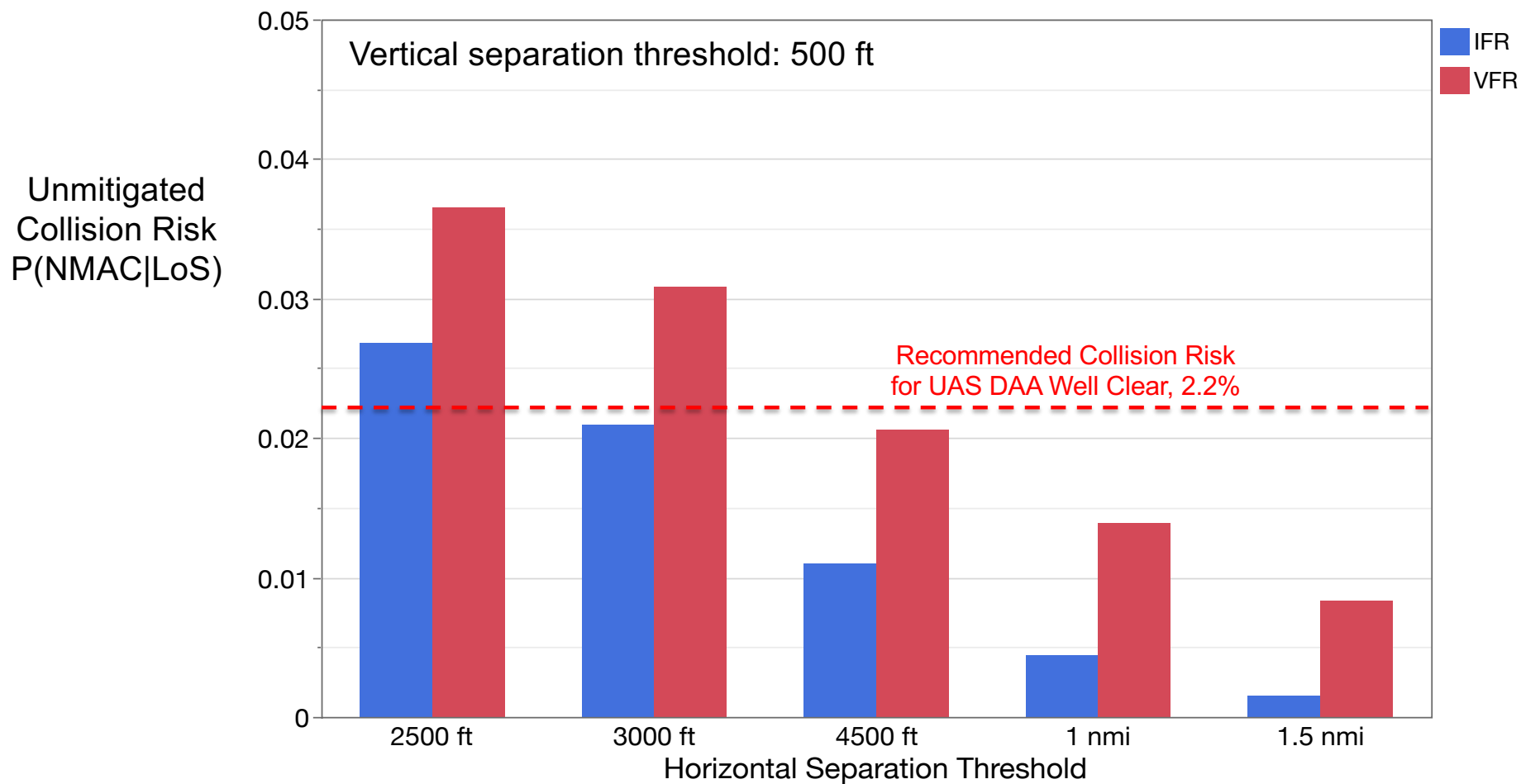
Unmitigated Collision Risk between UAM Flights : Enroute Flight Phase



 **Contour Plot for Unmitigated Collision Risk between UAM flights**



NASA Unmitigated Collision Risk against Conventional IFR/VFR Traffic

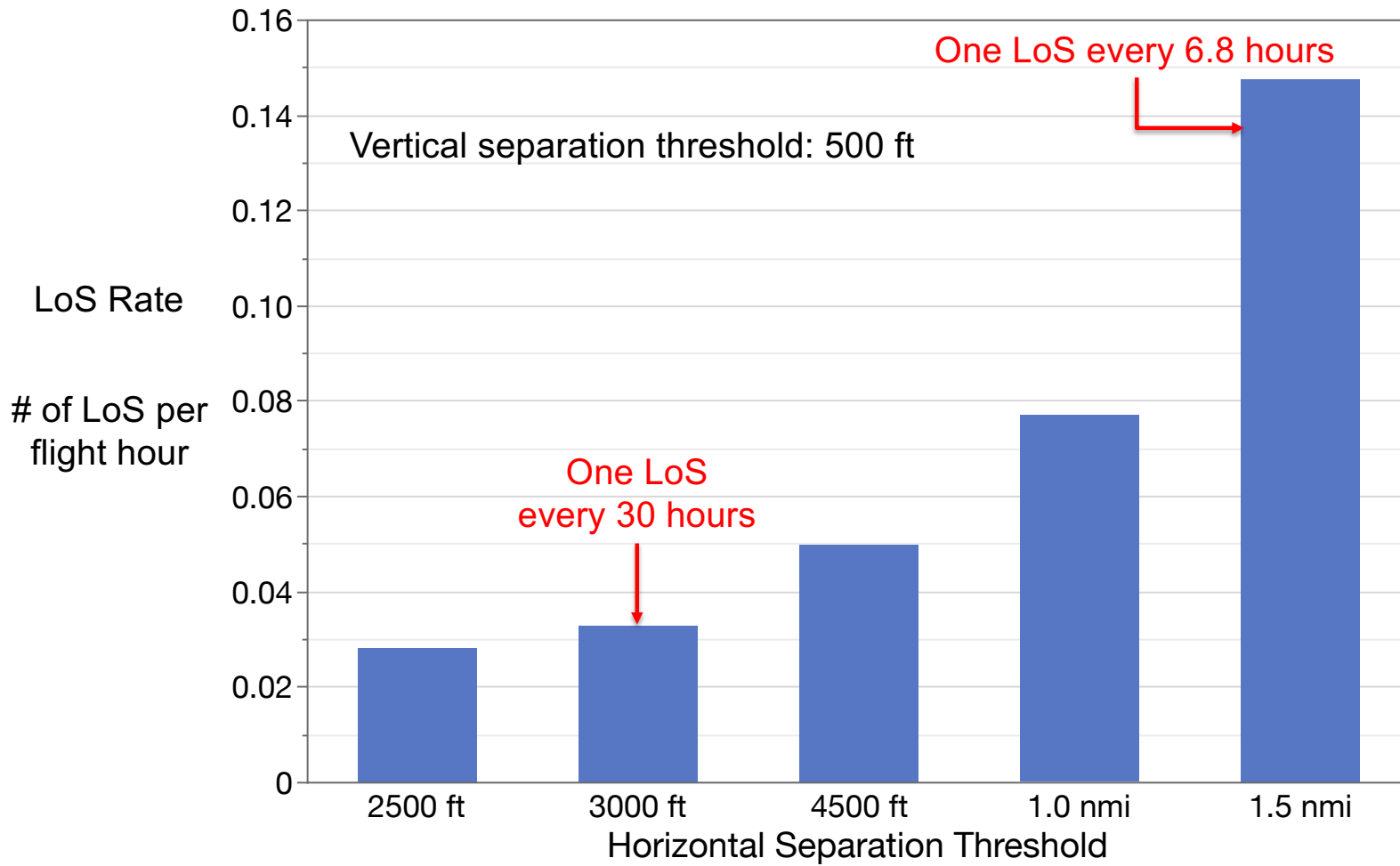




Operational Suitability Analysis (LoS Rate)

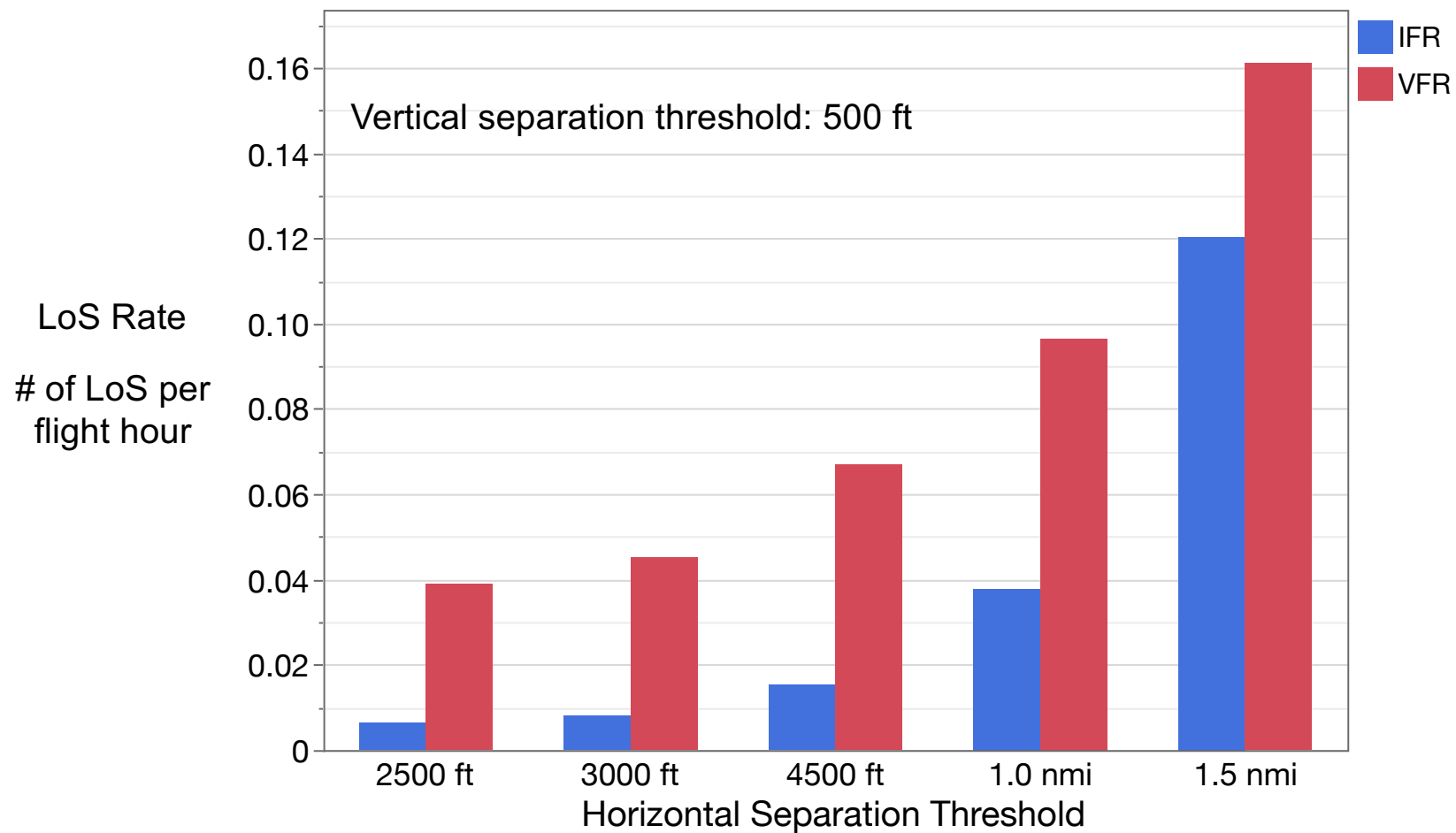


LoS rate with Conventional IFR/VFR Aircraft





LoS Rate during Enroute by Intruder Category





Summary and Conclusions

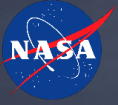


- Trade-off between unmitigated collision risk and LoS rate informs separation standards for UAM operations
 - Larger separation standards provide lower unmitigated collision risk, but higher LoS rate
- Appropriate risk-based and performance-based separation standards should be considered in the design of UAM airspace/route structure
 - Larger lateral separation between UAM tracks than a required horizontal separation standard
- Need of conflict management to reduce high unmitigated collision risk and LoS rate between UAM flights



Future Research Recommendations

- Mitigated fast-time simulation studies
 - To evaluate the impact of mitigation of conflicts on the safety and operational suitability of UAM operations
 - To investigate whether the separation standards can be further reduced while maintaining the same level of safety with resolution maneuvers
- Simulations with various UAM traffic scenarios (various UAM route structures and different traffic densities)
- Human-in-the-loop assessment for evaluating the acceptability of separation standards from UAM pilot and controller's point of view



Seungman Lee
seungman.lee@nasa.gov