



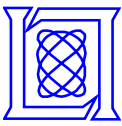
Airspace Encounter Models for Conventional and Unconventional Aircraft

**Matthew W. Edwards, Mykel J. Kochenderfer,
Leo P. Espindle, James K. Kuchar, and J. Daniel Griffith**

**Eighth USA/Europe Air Traffic Management
Research and Development Seminar
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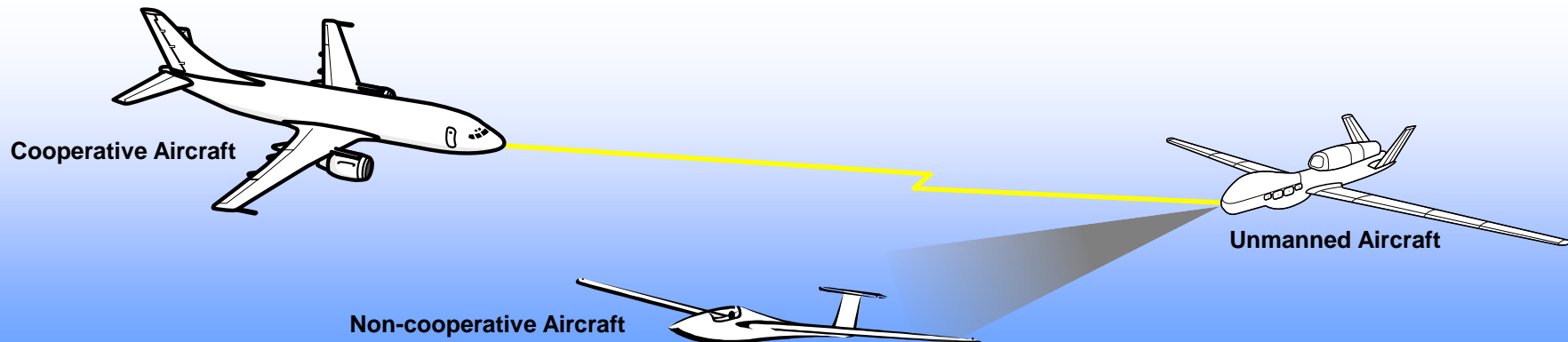
Future Needs for Collision Avoidance

Collision avoidance systems have an important role in the future of aviation

- **Integration of unmanned aircraft into the airspace will require sense and avoid capability with proven target level of safety**
- **Next generation of air traffic control concepts will require enhancement of existing collision avoidance system onboard manned aircraft (TCAS)**

Before deployment of new systems, rigorous safety analysis is required

- **Determine required surveillance performance**
- **Evaluation of performance on different categories of aircraft**
- **Assessment of interoperability with existing systems**





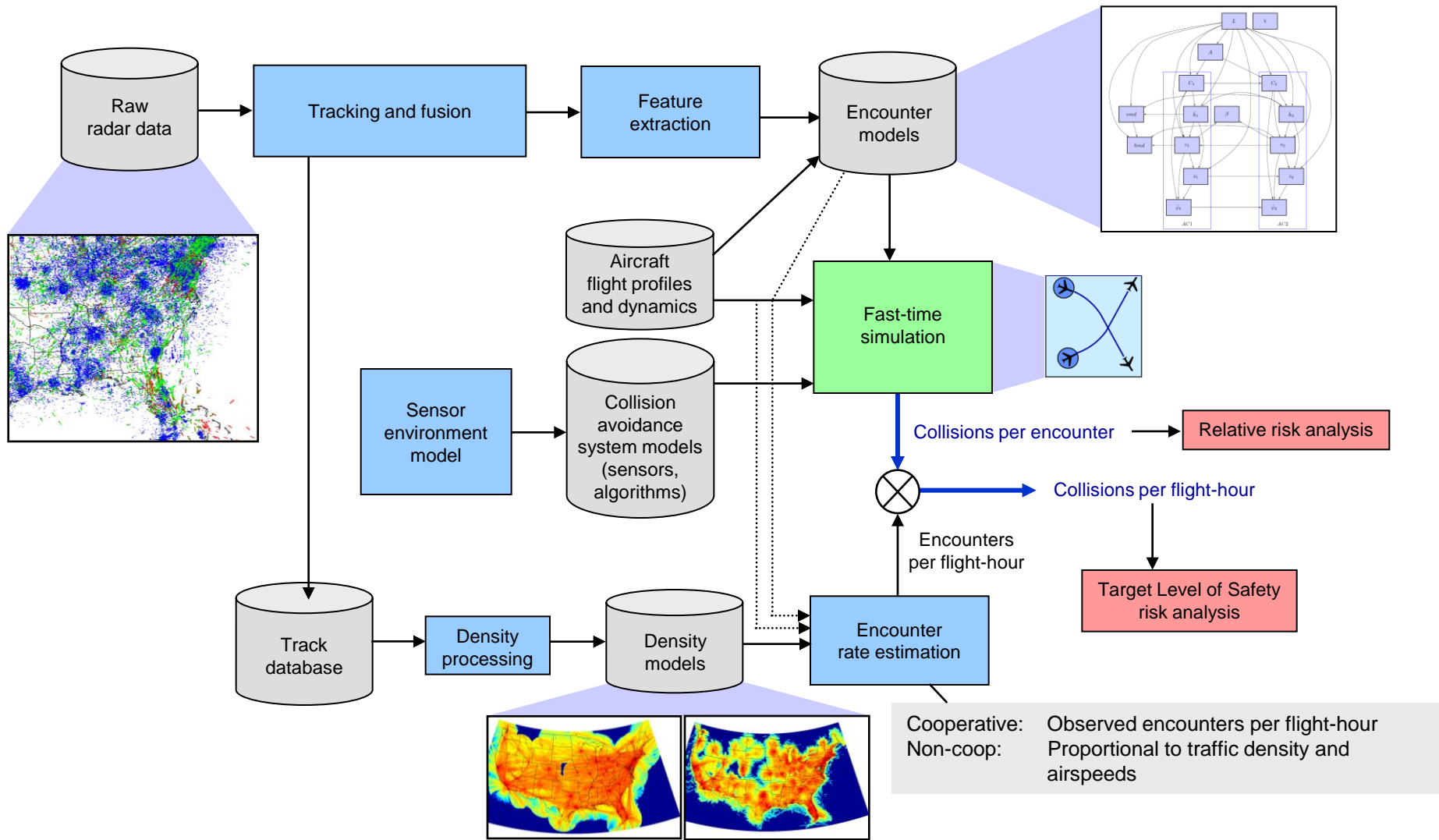
Problem Statement and Requirements

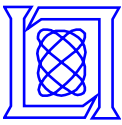
What are the encounter geometries that a collision avoidance system needs to resolve in the airspace?

- **Statistically-representative of actual encounters**
 - Approx. 1 minute window near point of closest approach
 - Provide realistic mix of encounter geometries and situations
- **Physically-realistic dynamics**
 - Aircraft equations of motion
 - Three-dimensional, able to handle multiple maneuvers / accelerations
 - Derived from operational data
- **Cooperative and non-cooperative intruder characteristics**
 - Cooperative situations may include ATC intervention
 - Wide range of possible aircraft performance characteristics
- **Support fast-time simulation**

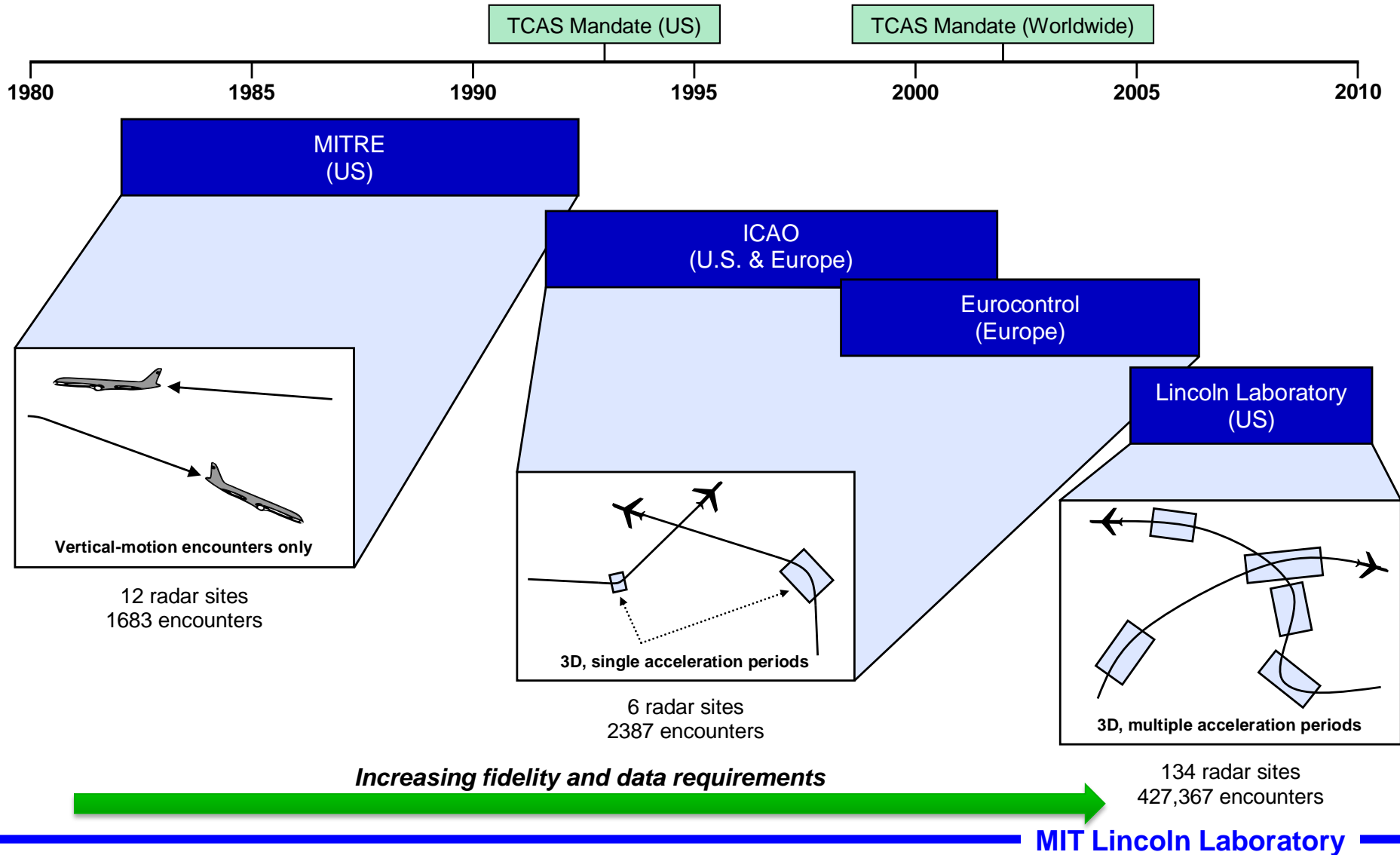


Safety Assessment Simulation Framework



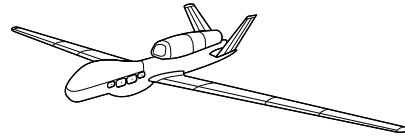


Encounter Model Development History





Encounter Model Categories



Aircraft of interest



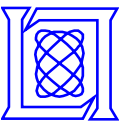
Intruder aircraft

	Discrete code	1200/VFR
Discrete code		
1200/VFR		
Non-cooperative Conventional		
Non-cooperative Unconventional		

Appropriate Model

- Correlated (cooperative)**
 - Prior U.S. model needed to be updated, captures RVSM
 - Assumes ATC involvement
- Uncorrelated 1200-code (non-cooperative surrogate)**
 - First model to capture encounters between VFR aircraft
 - Assumes no ATC involvement
- Uncorrelated (unconventional aircraft)**
 - Models vehicles unlikely to carry transponders
 - Assumes no ATC involvement

Conventional: General Aviation typical of 1200-code aircraft
 Unconventional: balloons, gliders, ultralights,...



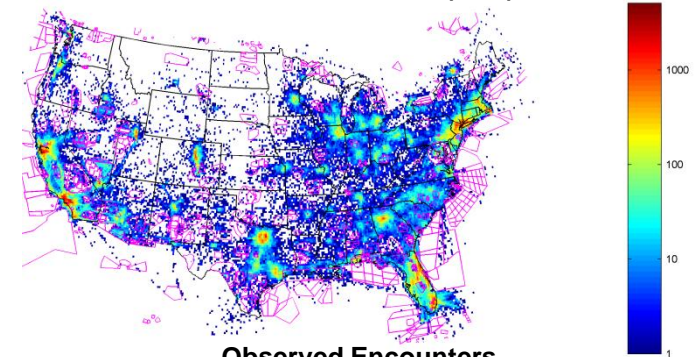
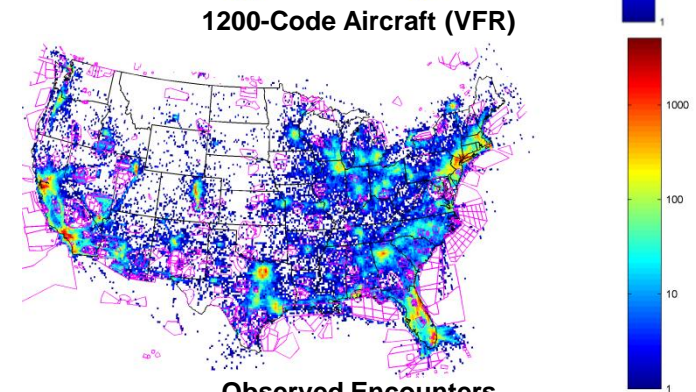
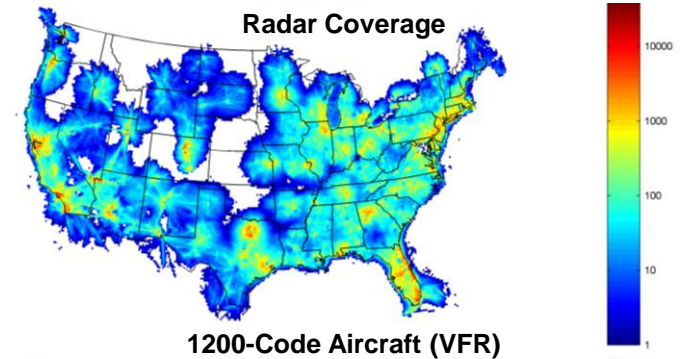
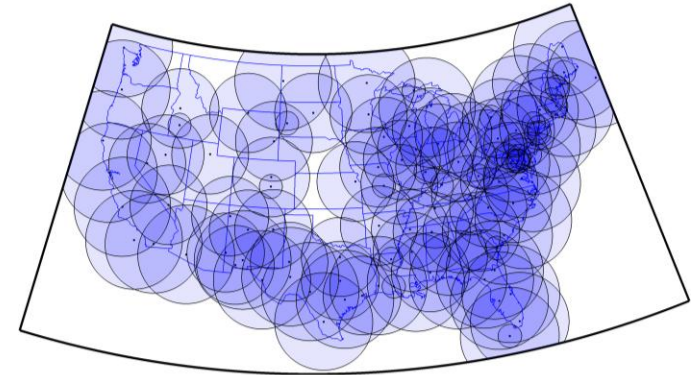
Data Sources

Models based on continuous, real-time radar data from Air Force 84th Radar Evaluation Squadron (RADES)

- Includes raw and unprocessed data for both cooperative and non-cooperative aircraft
- 134 ASR and ARSR sensors used in model
- Total airspace coverage results in traffic density characterization

Difficult to create an encounter model using primary only tracks

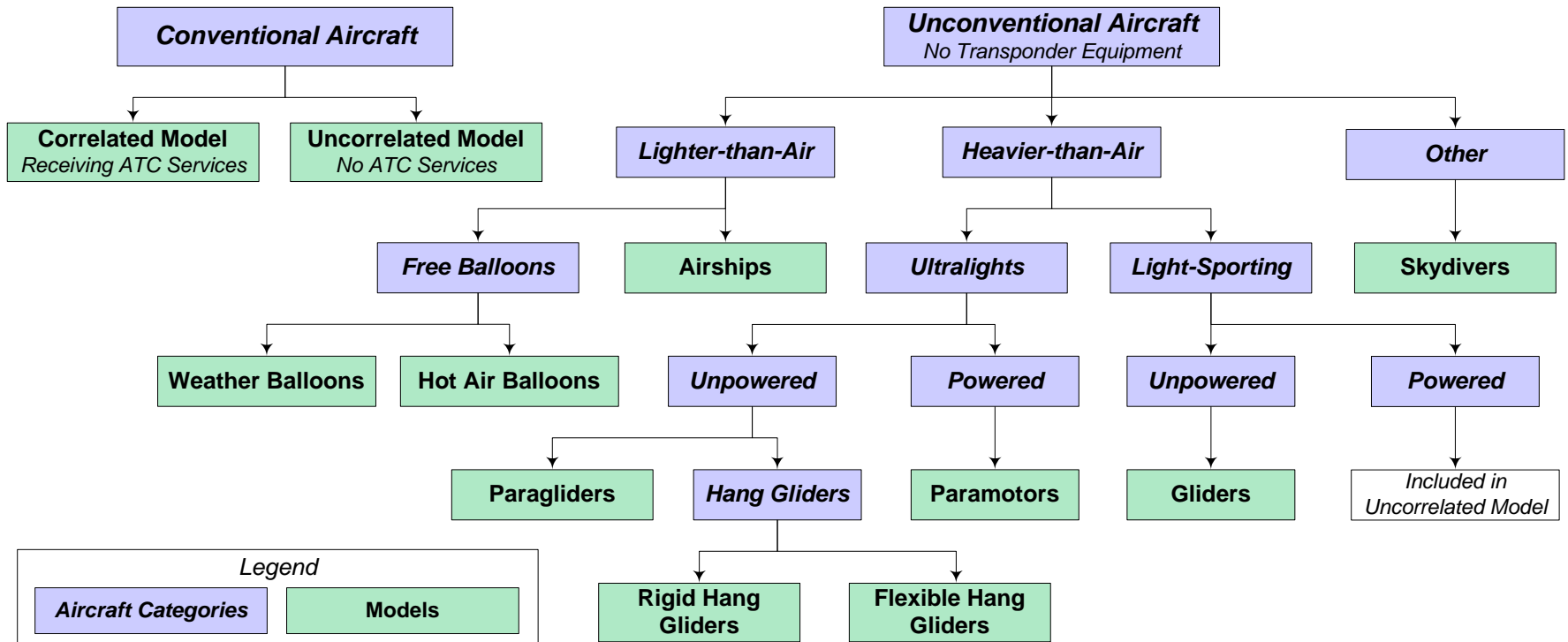
- Unconventional models created using pilot-uploaded GNSS data



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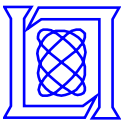


Encounter Model Taxonomy

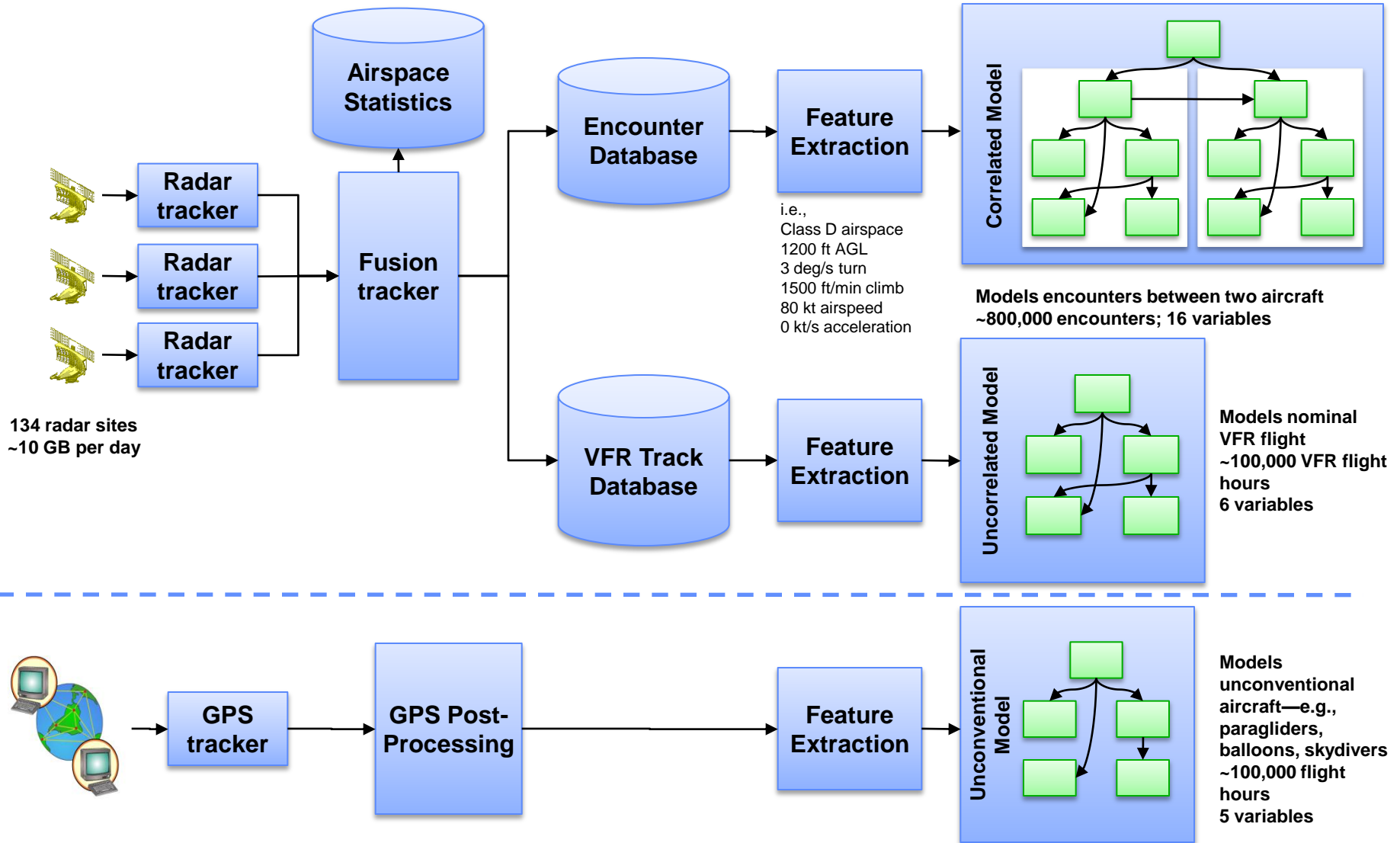


Unconventional model composed of 9 individual models

- Need to simulate against each type to determine specific system deficiencies

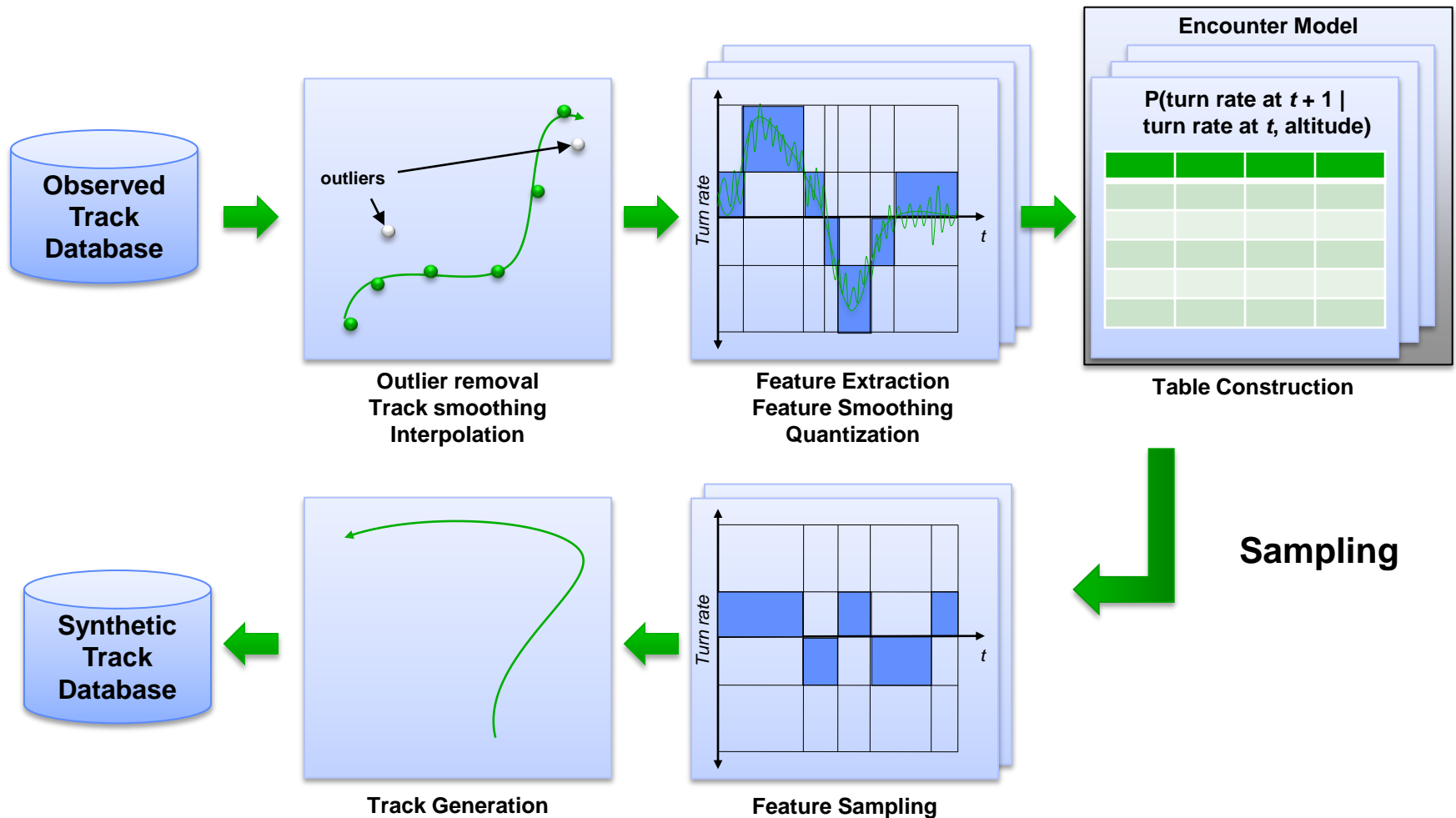


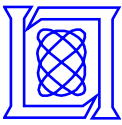
Model Development Overview





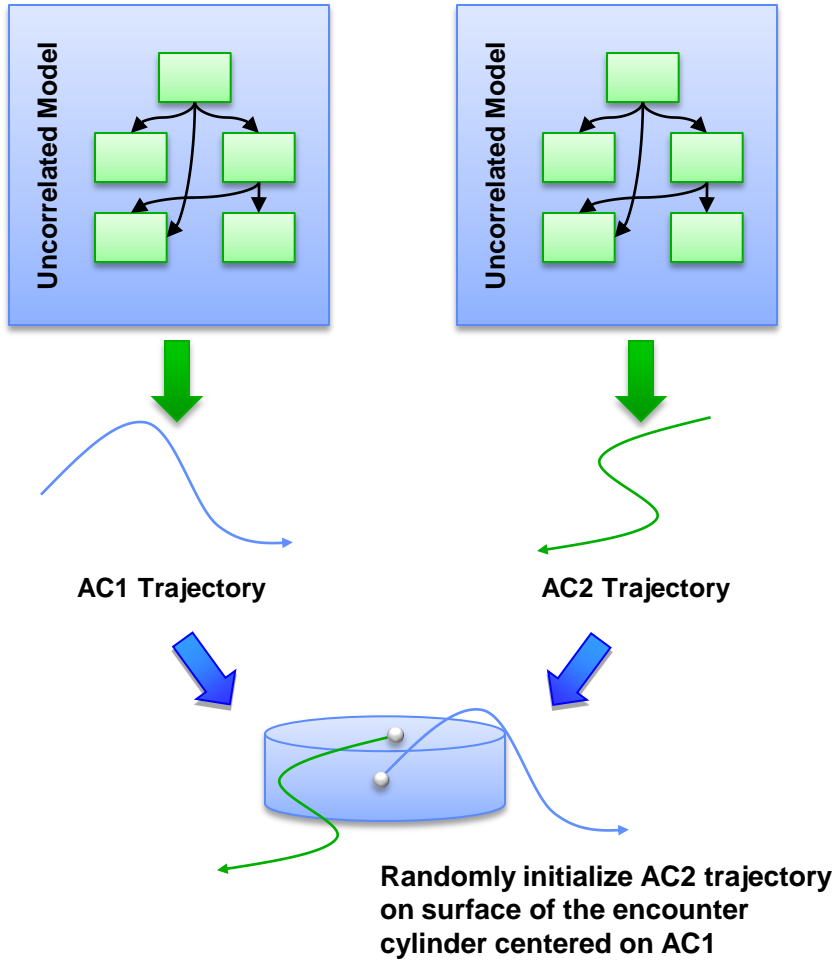
Model Development Process



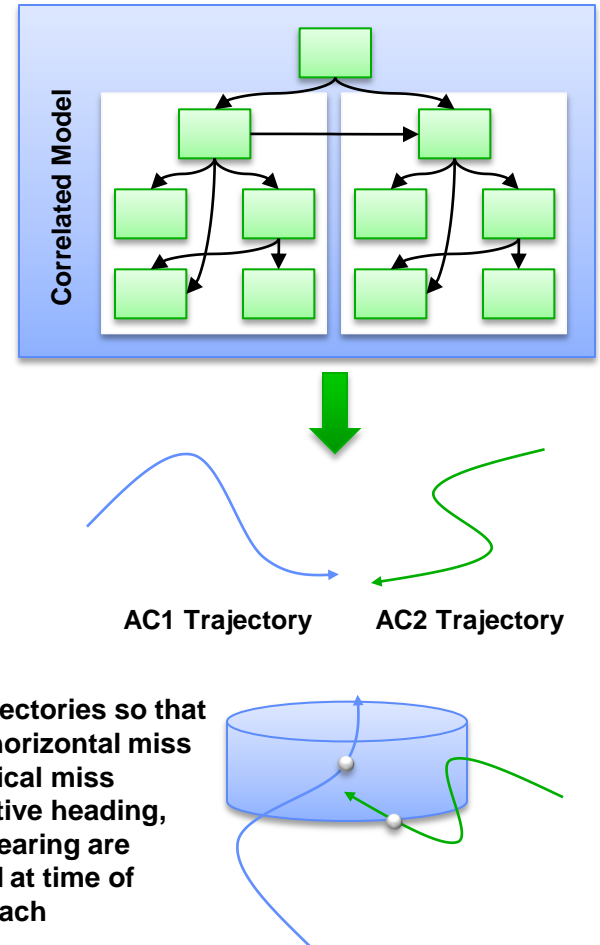


Encounter Construction

Uncorrelated Encounters



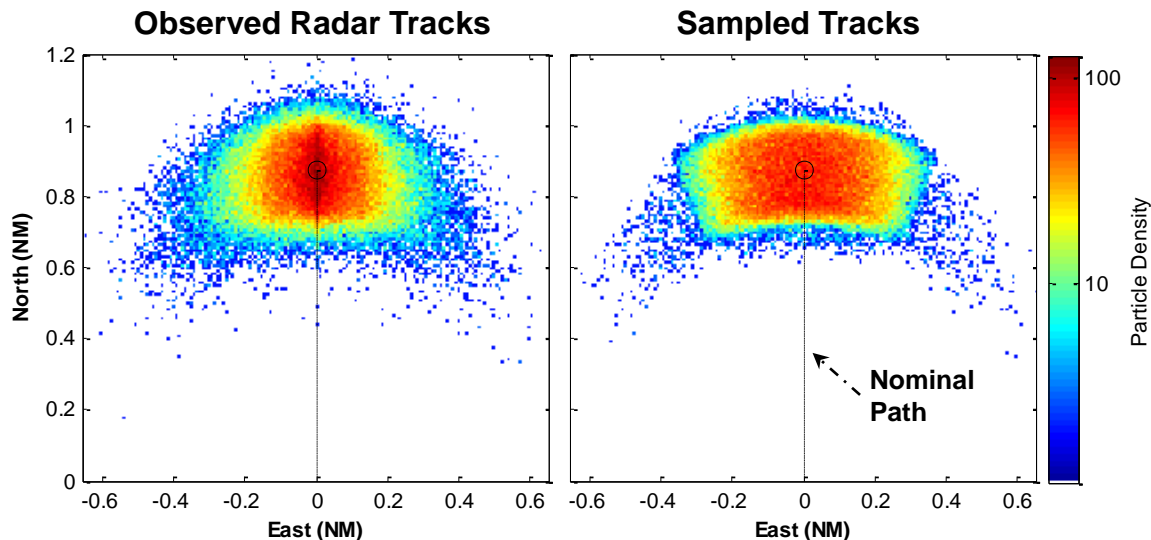
Correlated Encounters

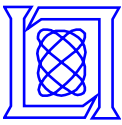




Model Validation

- **Unmodeled features of randomly-generated encounters compared to observed**
 - Altitude crossing and slow closure encounter rates
- **Compared uncorrelated model characteristics against true primary-only tracks**
 - Model characteristics similar to a large class of non-cooperative tracks
 - Other non-cooperative aircraft tracks captured by unconventional model
- **Examined seasonal and regional variations**
 - Densities very sensitive
 - Trajectory characteristics not sensitive





Encounter Model Products

Project Report
ATC-344

**Correlated Encounter Model
for Cooperative Aircraft in the
National Airspace System
Version 1.0**

M.J. Kochenderfer
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J.K. Kuchar
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24 October 2008

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Prepared for the Federal Aviation Administration,
Washington, D.C. 20591

This document is available to the public through
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Springfield, Virginia 22161

Project Report
ATC-345

**Uncorrelated Encounter Model of the
National Airspace System
Version 1.0**

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14 November 2008

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LEXINGTON, MASSACHUSETTS

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Project Report
ATC-348

**Encounter Models for
Unconventional Aircraft
Version 1.0**

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10 April 2009

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- Model description reports
- Data tables
- Software to generate trajectories
- Traffic density database

Current users

- JHU/APL
- MITRE/CAASD
- MTSI
- Northrop Grumman Corp.
- USAF Simulation and Analysis Facility (SIMAF)



Applications

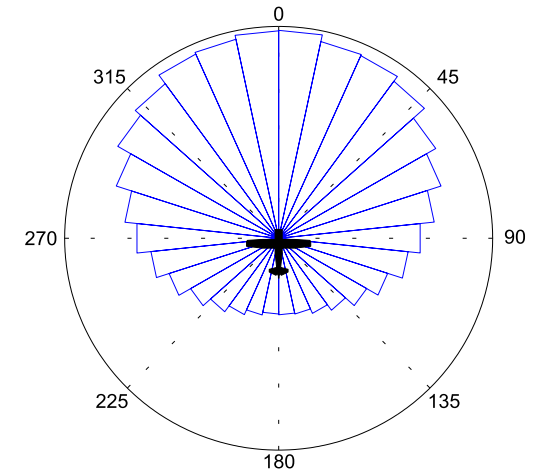
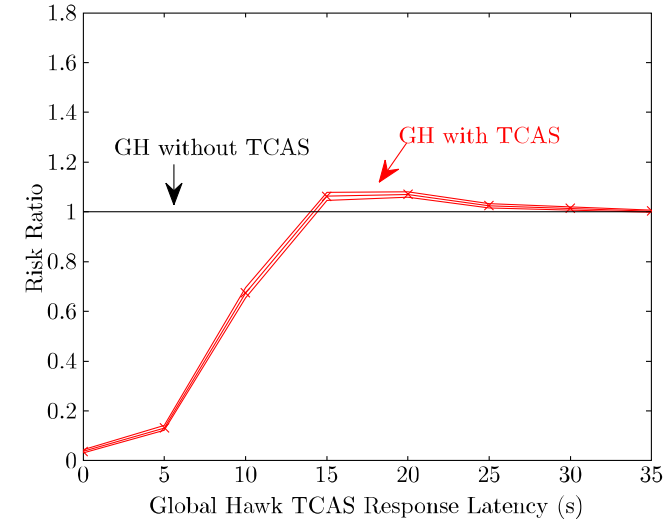
TCAS Safety Analysis

- Re-analyzed the performance of TCAS II versions 7.0 and 7.1
- Used to determine relative benefits of logic and surveillance modifications

Unmanned Collision Avoidance Systems

- Examined the use of TCAS on Global Hawk UAS, focusing on sensitivity to latency
- Models used to analyze candidate systems for Global Hawk and Predator B UAS
- Demonstrated electro-optical field of view and range trade-off study

TCAS Latency Response on Global Hawk*
(Mode S Intruder)

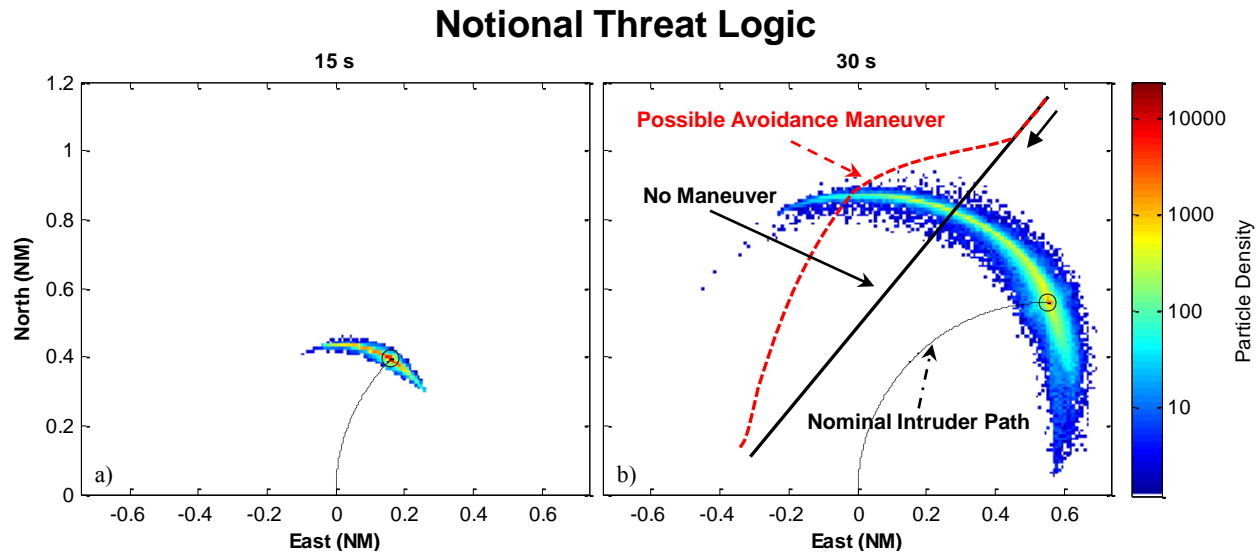


*Risk Ratio = $P(\text{Near Mid-Air Collision with System})/P(\text{Near Mid-Air Collision without System})$



Future Development and Applications

- **Multi-threat encounter model**
 - Encounters between more than two aircraft occur more often than anticipated
- **Update encounter models and density database to reflect future changes in the airspace**
- **Exploit models within future collision avoidance architecture, involving probabilistic intruder trajectory propagation**





Summary

- **Developed a new statistical approach to encounter modeling, optimally leveraging recorded data**
 - **Models validated using several quantitative and qualitative techniques**
- **Created first encounter models that capture non-cooperative aircraft, including conventional and unconventional aircraft**
- **Models are being used by several organizations for manned and unmanned collision avoidance system development and analysis**
 - **Models and software to generate samples are publicly available**