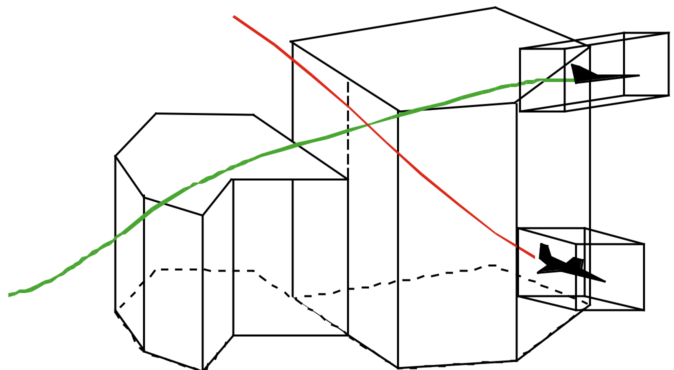
Analysis of Aircraft Separations and Collision Risk Modeling



Dr. H. D. Sherali
C. Smith
Dept. of Industrial and Systems Engineering

Dr. A.A. Trani
S. Sale
Q. Chuanwen
Dept. of Civil Engineering

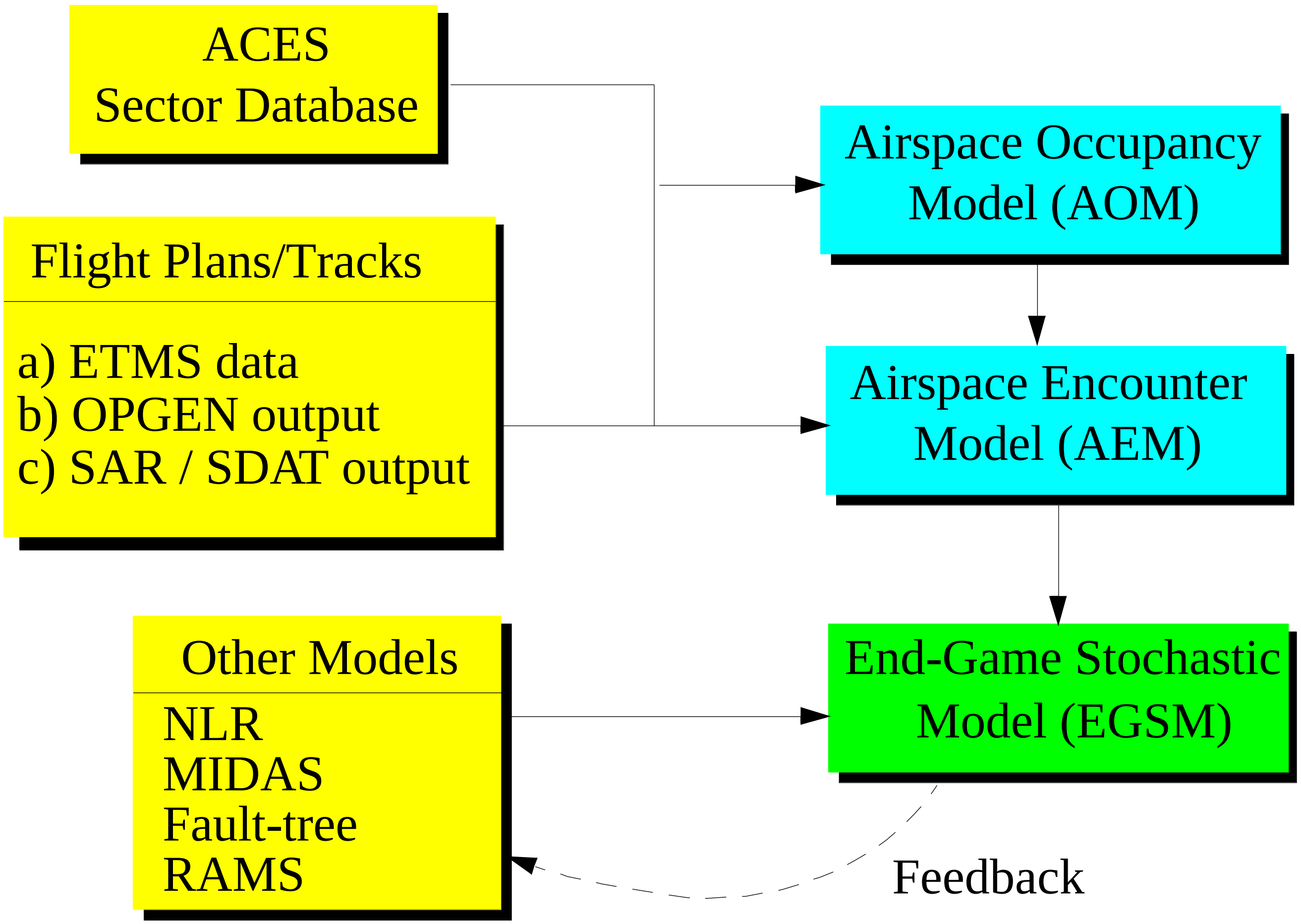
Virginia Polytechnic Institute and State University

FAA Sponsor: Dr. Steven Cohen

Scope of Work

- Participate in a joint FAA/Eurocontrol group assessing development of collision risk models and tools
- Help FAA and Eurocontrol develop collision risk assessment tools
- To identify current and future airspace scenarios to be modeled in detail with collision risk models
- Provide insight on how new FAA Concept of Operations would change the exposure to risk
- Develop a generalized model of airspace / air traffic to help identify collision risk exposure

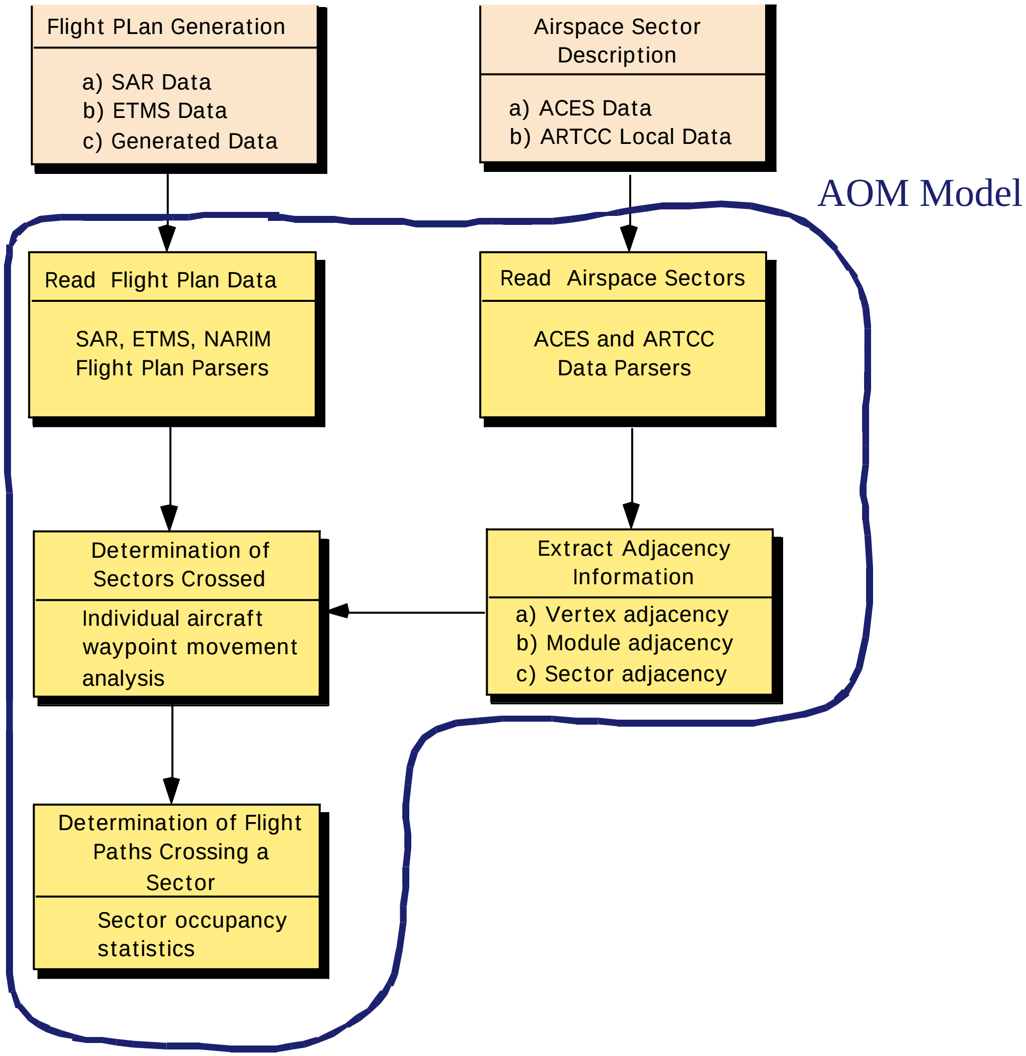
Modeling Framework



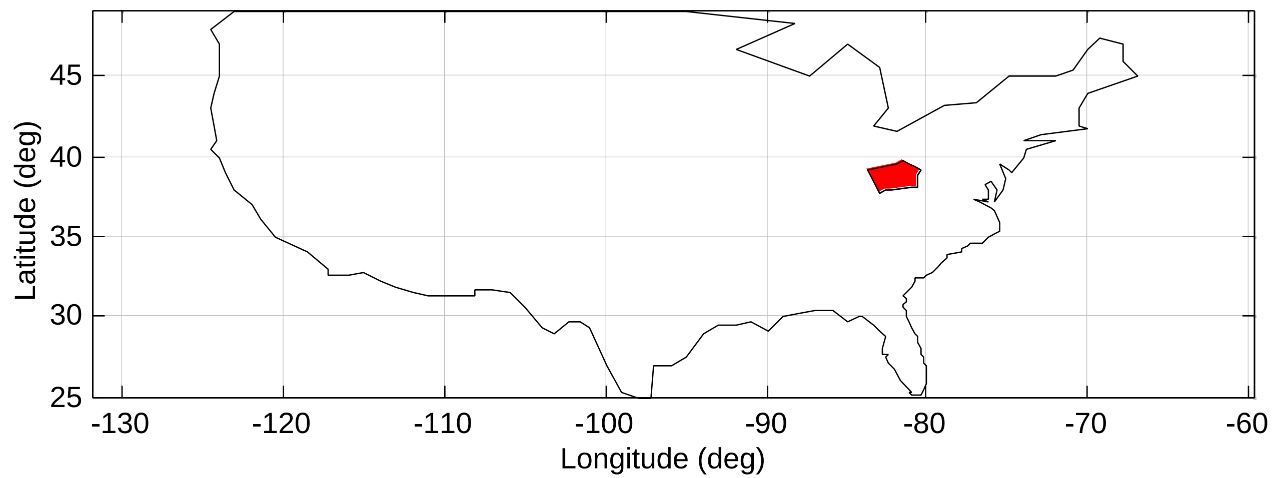
Airspace Occupancy Model (A OM)

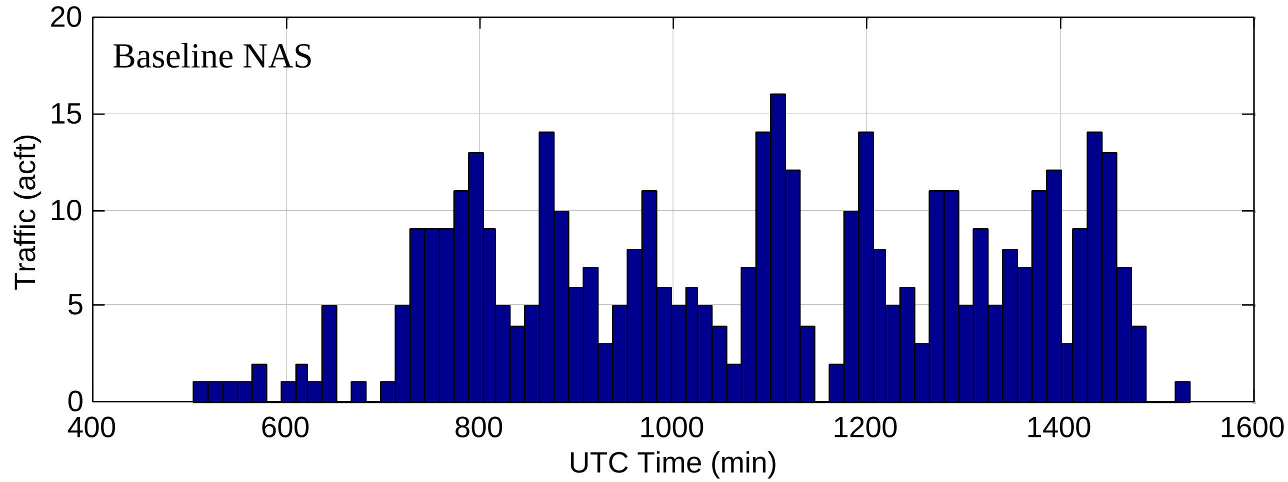
- Parses three types of flight data structures:
  - ETMS (flight plans)
  - SAR (flight tracks)
  - NARIM (optimally generated flight plans)
- Globe-circle route between O-D pairs is also possible
- Estimates entry points to sectors and time occupancy information
- Determines the numbers of aircraft in a sector simultaneously
- Individual airport flow triggers are possible
- Outputs information for AEM

AOM Model Functional Diagram



Sample Traffic Flow Patterns (AOM)

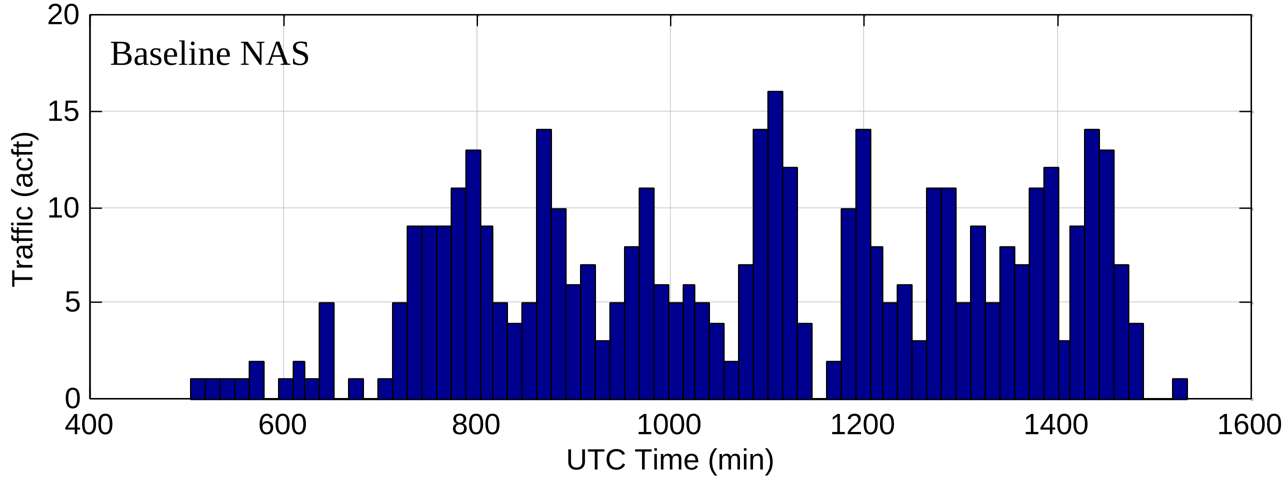


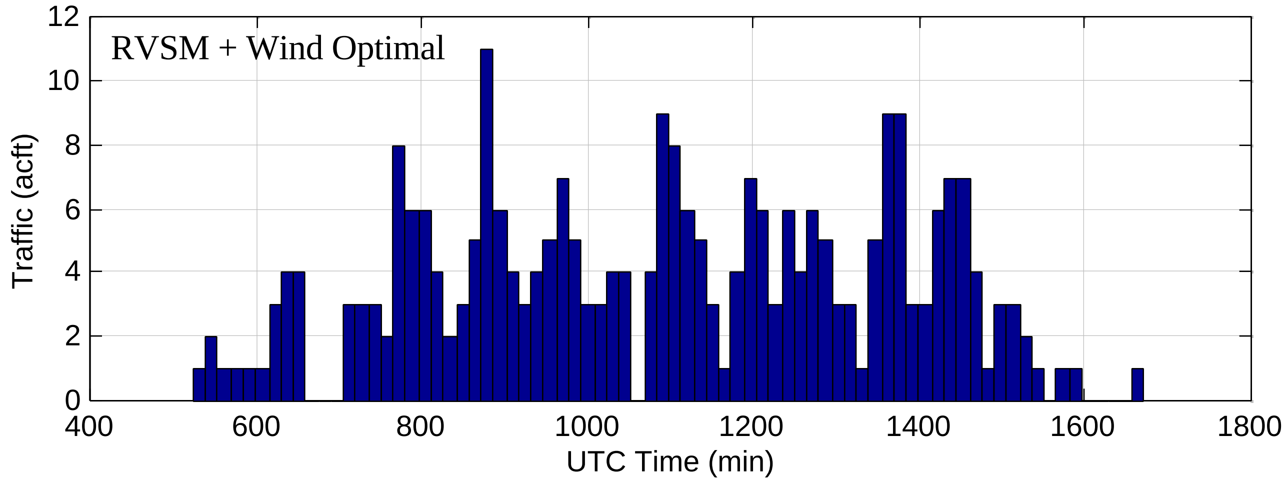


affic (acft)

Latitu

Comparison of Traffic Flow Patterns

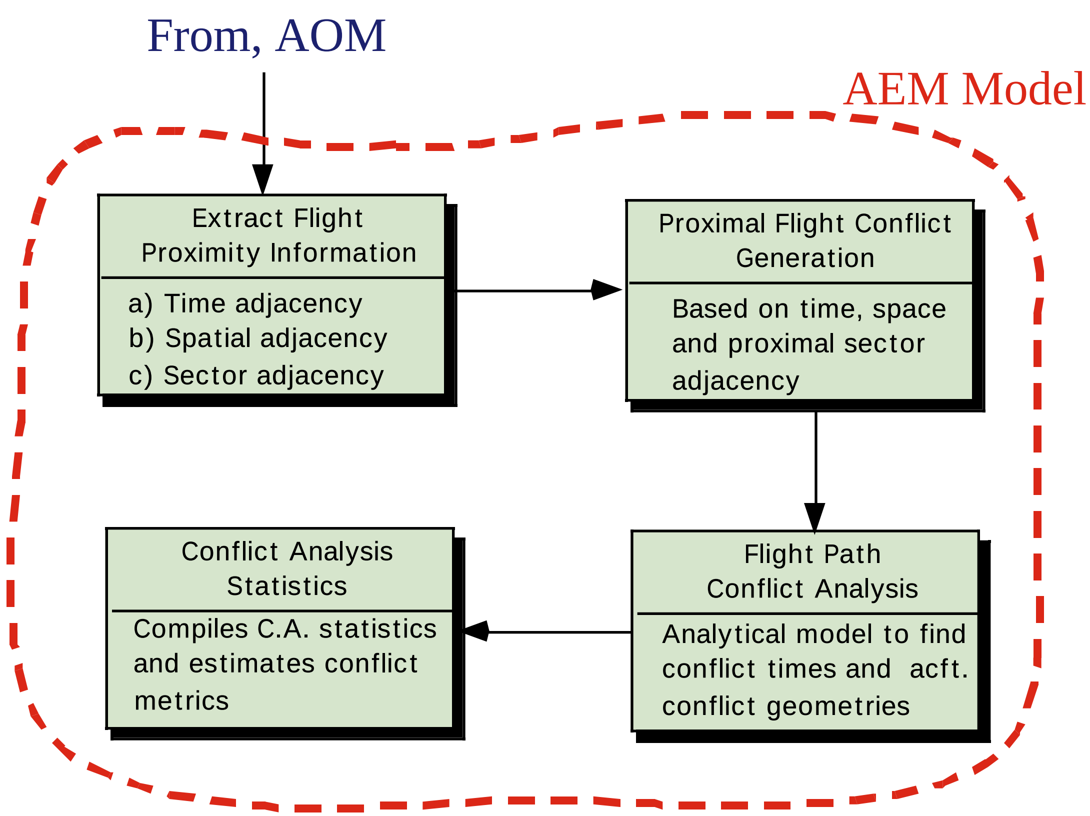




Airspace Encounter Model (AEM)

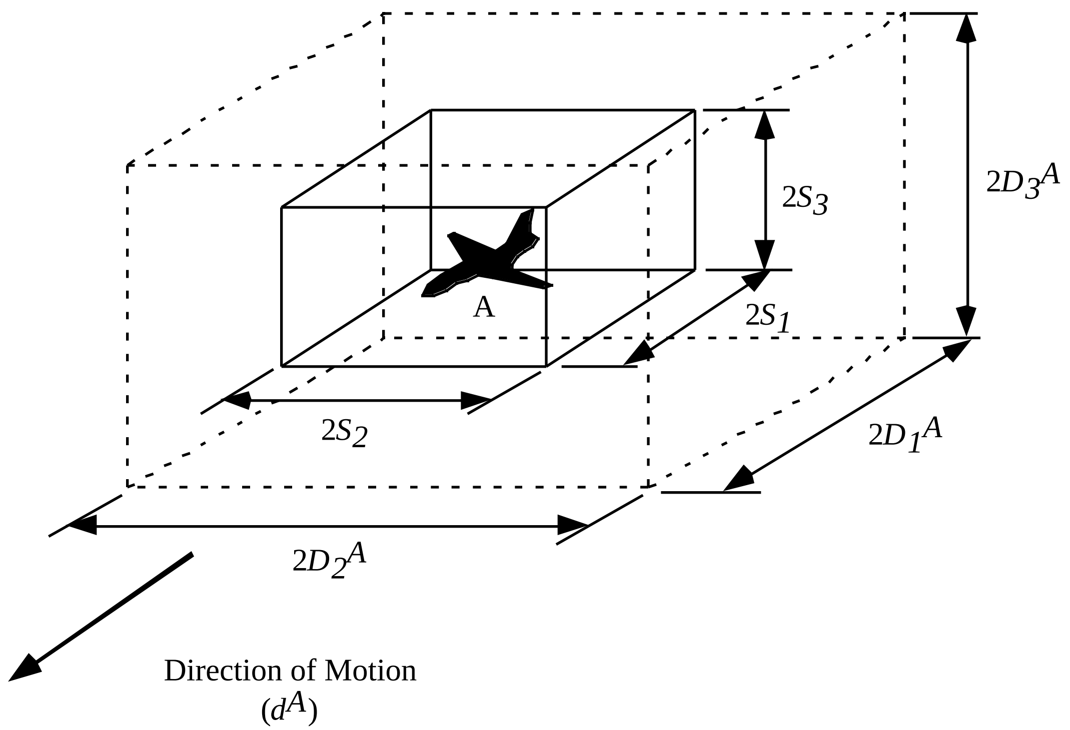
- Determines the type of aircraft conflicts likely to occur in every airspace sector
- Detailed geometry of each conflict pair is determined using analytic equations (waypoint structure used)
- This information is used to assess the number of flights in conflict at every sector and the complexity of the ATM task in hand
- Can be used to investigate future ATC sector scenarios to be modeled using man-in-the-loop simulations

AEM Model Functional Diagram



Conflict Detection Levels

Three conflict levels are defined around each aircraft as shown in the following figure (can be changed to any values and shapes)



Air craft Confl ict Detection

Currently a box model is built around the aircraft to predict conflicts

An analytic model is used to establish the geometry of the conflict and related parameters:

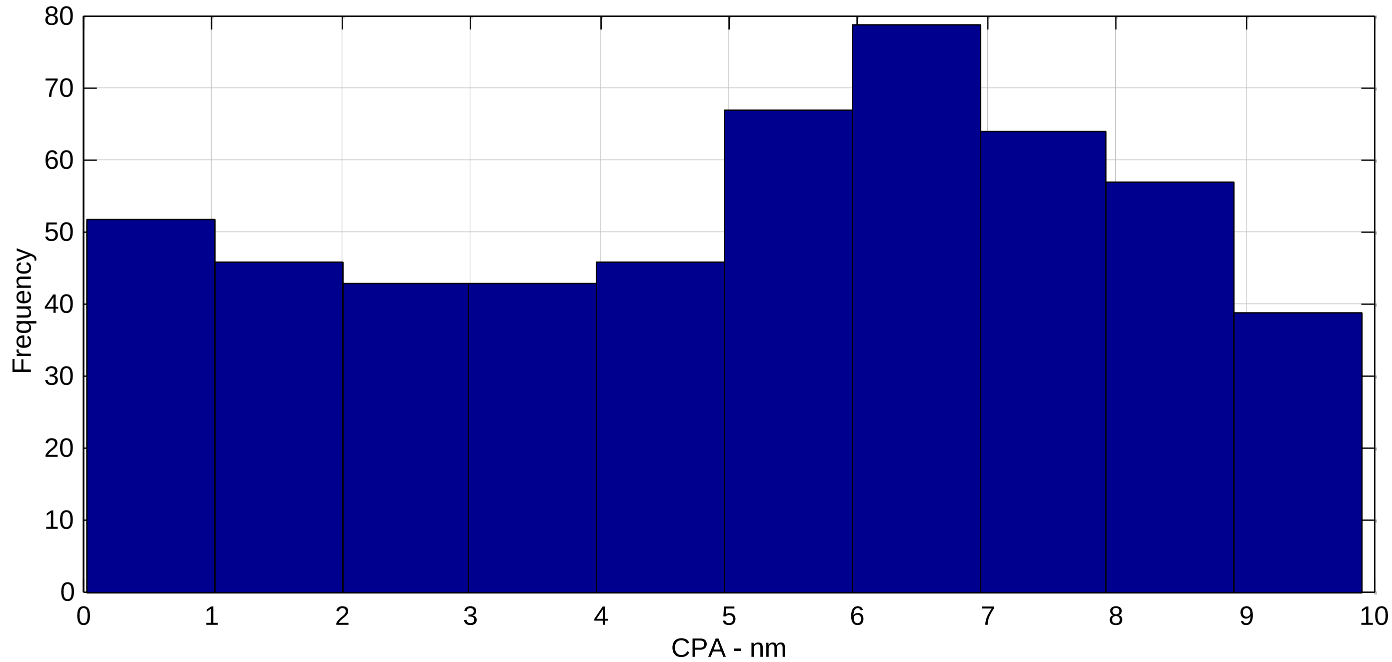
- geometry of the encounter (heading, transitions, etc.)
- duration of each conflict (includes multiple instance conflicts)
- speeds and altitudes of aircraft involved
- sector piercing (in and out)

- This information can then be used to estimate sector occupancies and collision risk exposure densities without intervention

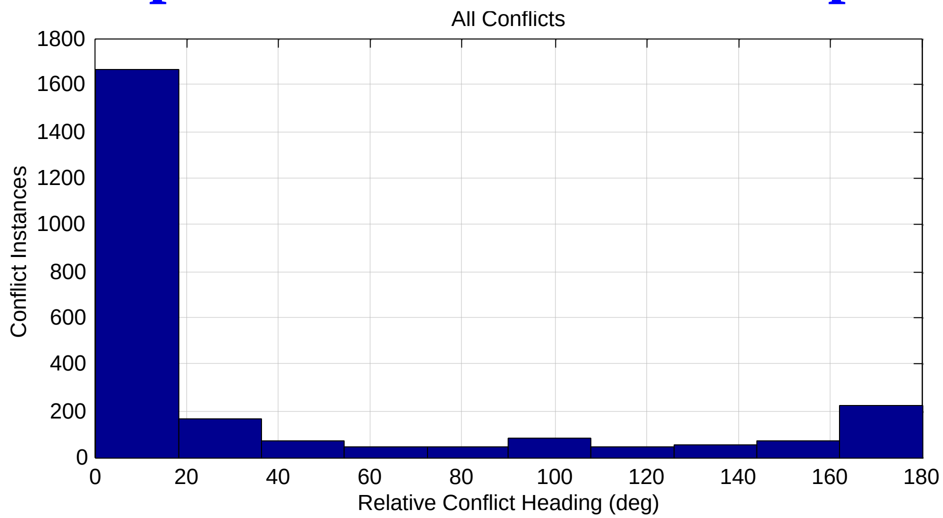
Sample AEM Output

The following histogram illustrates the Closest Point of Approach (CPA) of all 536 blind conflicts detected

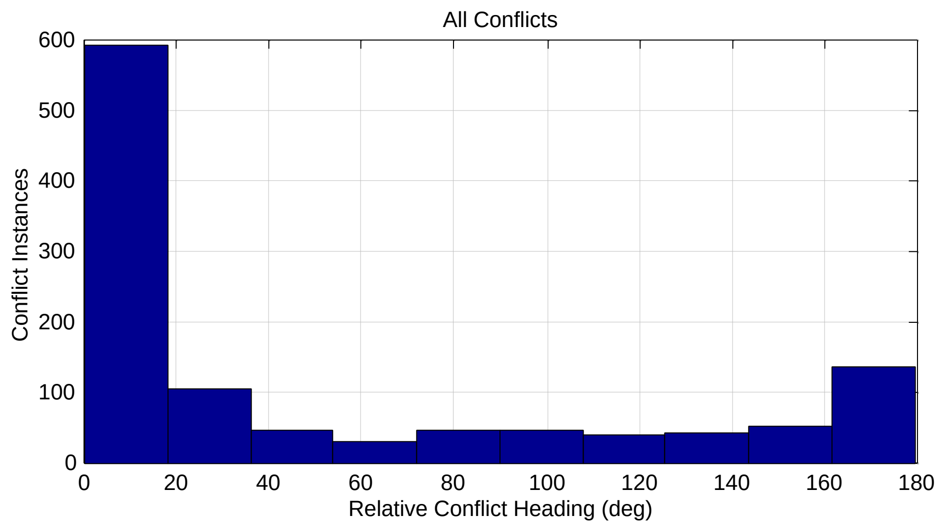
Includes altitude change conflicts



Sample AEM Conflict Output



Current



Cruise-Climb

AOM and AEM Model Validation

- The models have been ‘validated’ using actual SAR data from ZMA and ZJX ARTCC (August 17, 1997)

Blind Aircraft Encounter Type	No.of Total Conflicts	No.of Enroute Conflicts
Severity 1	462	6
Severity 2	70	2
Severity 3	2	0
Total	536	8

- Severity 2 conflicts were manually checked and both aircraft would have violated the middle protection zone of at least one aircraft assuming 3D linear segments between waypoints
- Limited sampling rate of streamlined SAR data (explains possible aircraft deviations from assumed path)

AEM and AOM Model Application

- These models have been applied to the following scenarios

	Concept of Operations		
ARTCC Center	Baseline (1996 Traffic)	RVSM (1996 Traffic)	Cruise Climb (1996 Traffic)
ZTL[a]	✓	✓	✓
ZID	✓	✓	✓
ZMA[b]	✓	✓	✓
ZJX	✓	✓	✓

a. 6,000 flights used of 18,000 daily flights
b. 8,000 flights used of 18,000 daily flights

- All flights have consistency across scenarios (i.e., same flights in each database)

Changes in Traffic Patterns under *Free Flight* Modes of Operation

	Number of Sectors in Center	Number of Sectors with Dissimilar Traffic Flows (RVSM / CC)	Average Difference Between Baseline and RVSM / CC Traffic Flows (%)
ZMA	37	8/9	11.2 / 13.8
ZJX	33	1/1	19.8 / 21.5
ZTL	58	5/5	35.2 / 34.9
ZID[a]	32	10/8	102.5 / 86.3

a. Using 6000 flights

Sample Blind Conflict Results (ZJX)

Scenario	Conflict Type	Vertical Transition Conflicts	Enroute Conflicts
Baseline (1996 Traffic Data)	Severity 1	127	28
	Severity 2	91	19
	Severity 3	13	9
	Total	231	56
RVSM + Wind Optimal FP (1996 Traffic Data)	Severity 1	104	8
	Severity 2	66	6
	Severity 3	4	2
	Total	174	16

Sector Conflict Results

The time and spatial characteristics of blind conflicts under various NAS Concept of Operations are different (statistically)

ARTCC Center	Scenario	P Values ($\alpha = 0.05$)
ZID/ZTL	Baseline vs. CC (enroute)	0.441
ZID/ZTL	Baseline vs. CC (transition)	0.021
ZID/ZTL	Baseline vs. RVSM (enroute)	0.016
ZID/ZTL	Baseline vs. RVSM (transition)	0.007
ZID/ZTL	RVSM vs. CC (enroute)	0.060
ZID/ZTL	RVSM vs. CC(transition)	0.562
ZMA/ZJX	Baseline vs. CC (enroute)	0.002
ZMA/ZJX	Baseline vs. CC (transition)	0.374

Other Conflict Statistics

Relative heading of the blind conflicts

ARTCC	Baseline Mean (standard dev.) (deg)	RVSM Mean (standard dev.) (deg)	Cruise Climb Mean (standard dev.) (deg)
ZMA/ZJX	36.48 (64.35)	37.91 (65.38)	45.49 (68.87)
ZID/ZTL	36.22 (59.00)	37.57 (53.81)	51.54 (63.88)

Conflict times (vertical transition conflicts)

ARTCC	Baseline Mean (standard dev.) (min)	RVSM Mean (standard dev.) (min)	Cruise Climb Mean (standard dev.) (min)
ZMA/ZJX	4.56 (11.52)	2.85 (9.91)	2.86 (9.89)
ZID/ZTL	3.04 (2.40)	2.40 (5.47)	2.27 (5.18)

More Conflict Statistics

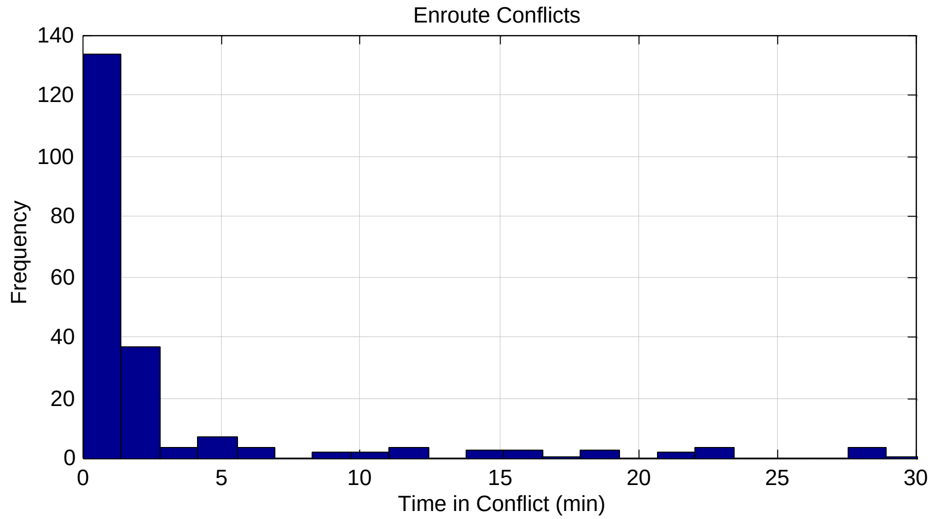
Conflict times (enroute conflicts)

ARTCC	Baseline Mean (stand. dev.) (min)	RVSM Mean (stand. dev.) (min)	Cruise Climb Mean (stand. dev.) (min.)
ZMA/ZJX	5.37 (9.04)	9.18 (11.84)	5.15 (9.42)
ZID/ZTL	6.31 (10.86)	6.21 (10.94)	4.48 (10.30)

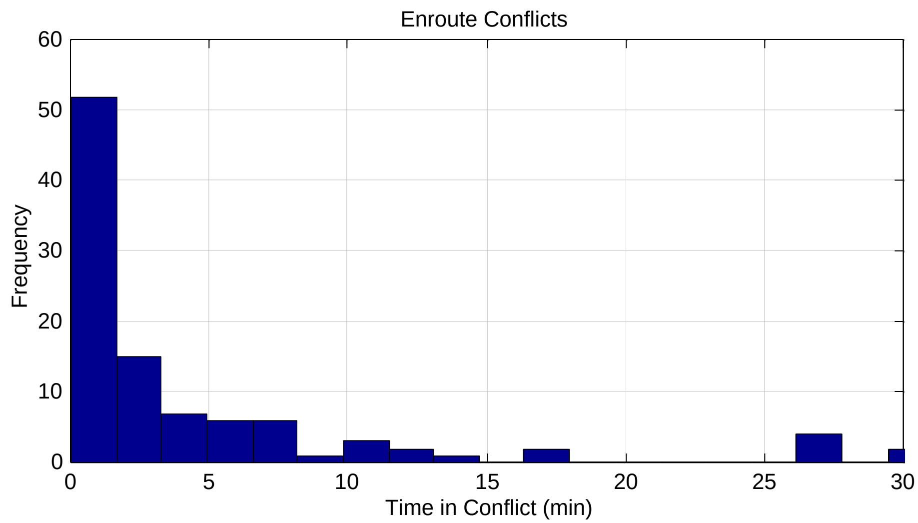
Closest Point of Approach (enroute conflicts)

ARTCC	Baseline Mean (standard dev.) (nm)	RVSM Mean (standard dev.) (nm)	Cruise Climb Mean (standard dev.) (nm)
ZMA/ZJX	3.54 (2.84)	4.68 (3.32)	3.62 (3.02)
ZID/ZTL	3.97 (2.88)	5.09 (2.57)	4.17 (2.30)

Sample Graphical Output

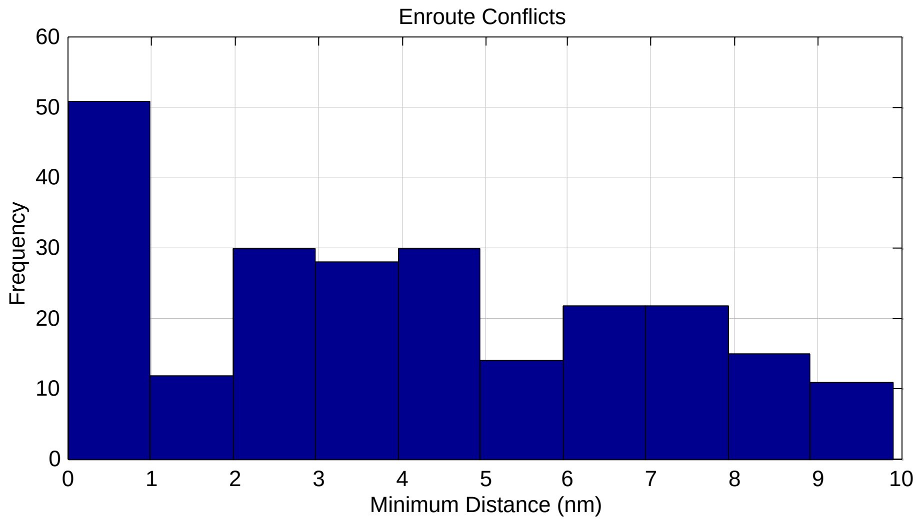


Baseline

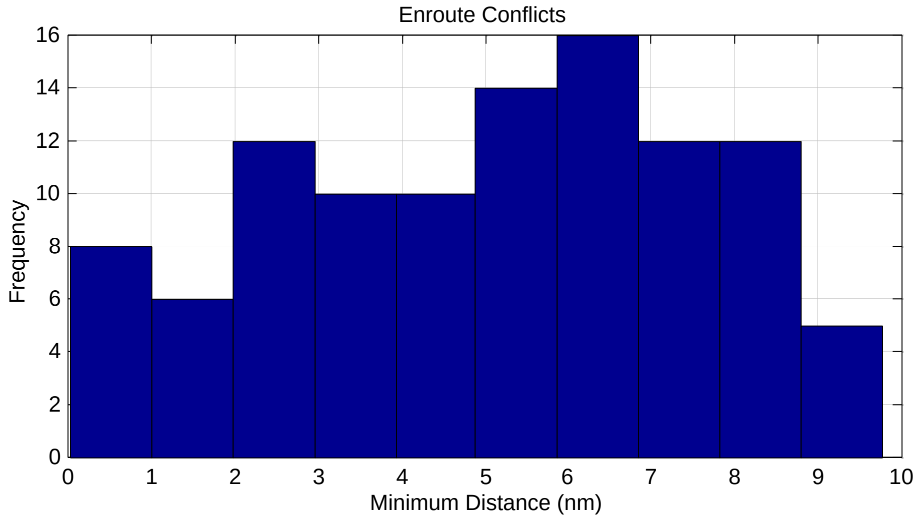


RVSM

Another Sample Output

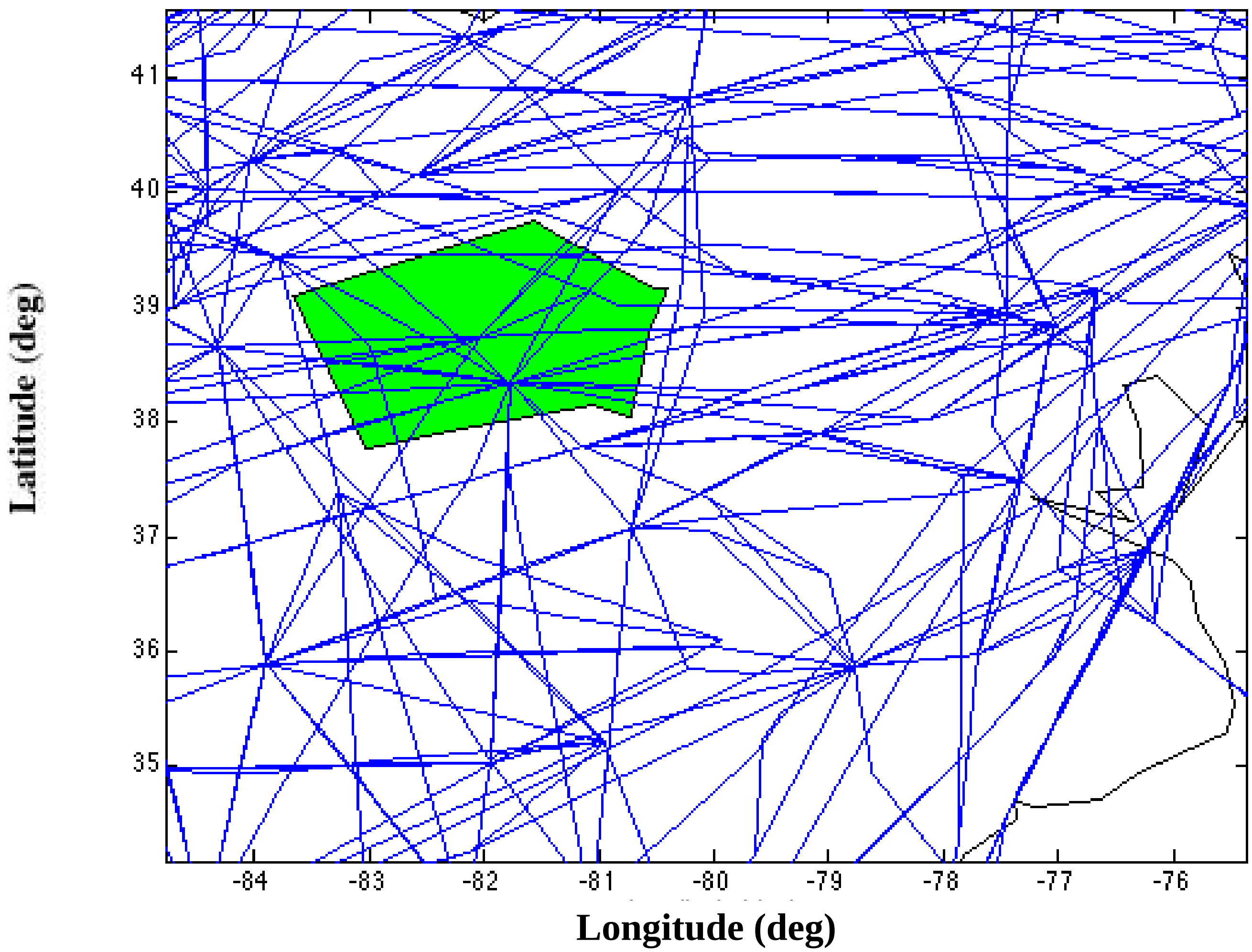


Baseline

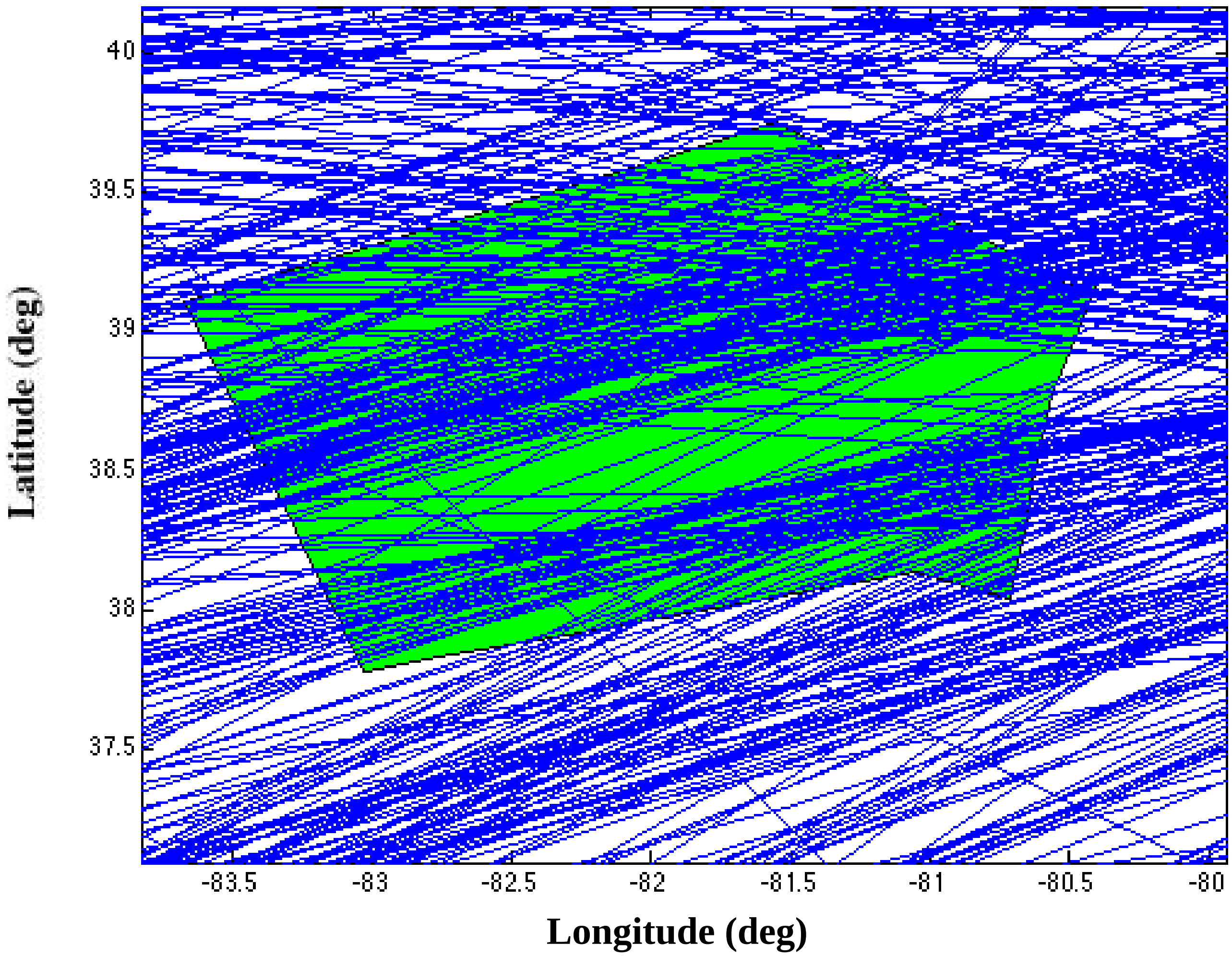


RVSM

Flight Plans (baseline)



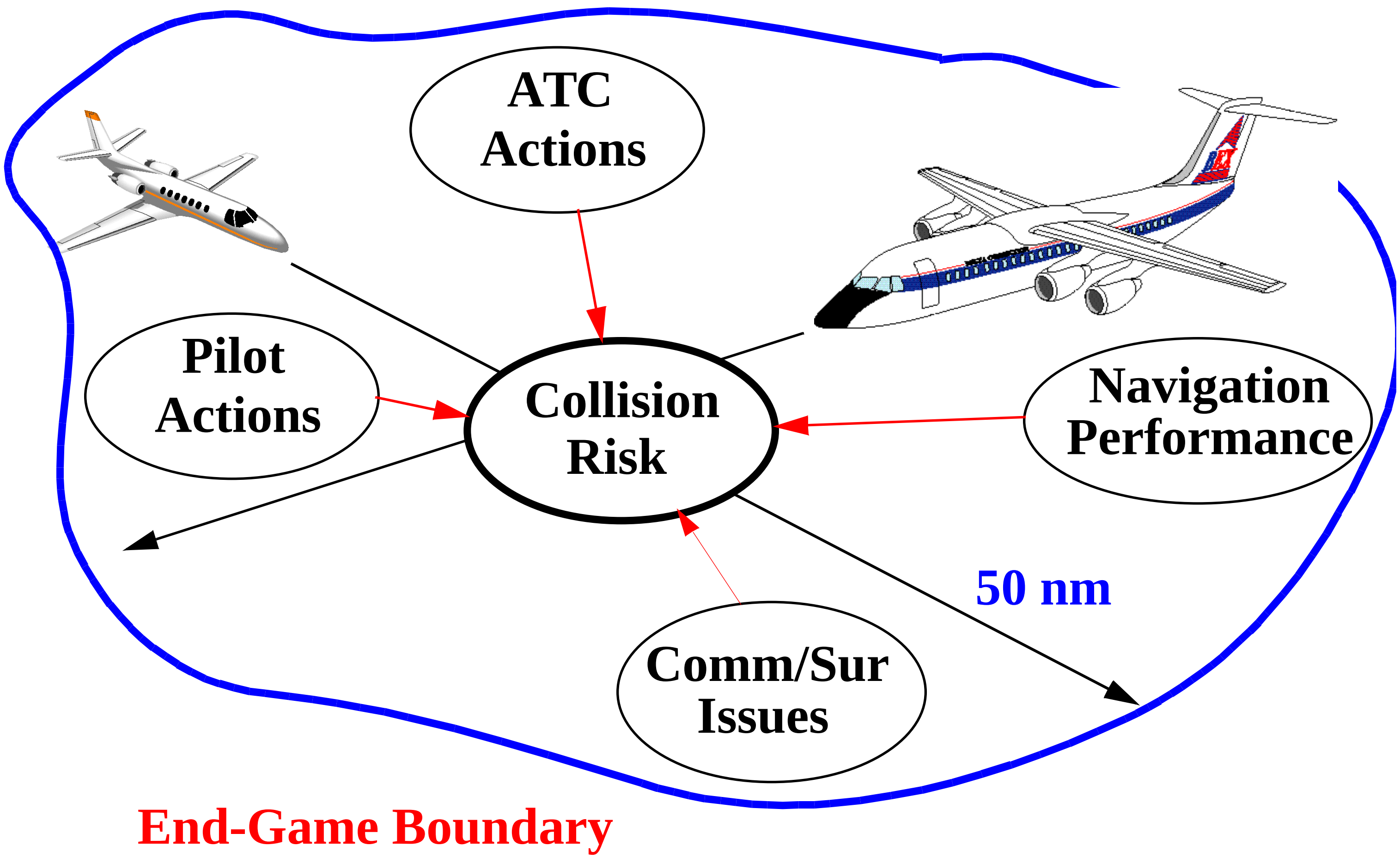
Flight Plans (R   VSM +   Wind Optimal)



Summary of Results

- There would be moderate to substantial variations in traffic flow patterns across various ARTCC sectors in NAS (4 ARTCC tested)
- Reduction in the potential conflicts in the enroute airspace system under Free Flight operations if reduced vertical separation criteria is in place (there is a need to quantify the absolute collision risk)
- Substantial to moderate differences in the time and space distribution of blind conflicts under RVSM and Cruise Climb scenarios
- Moderate changes in the distribution of relative headings of conflicts in the transition to some Free Flight scenarios (i.e., cruise climb)
- Vertical transition conflict times under RVSM and Cruise Climb scenarios are expected to be shorter in duration

Next Step (End Game Modeling)



Future Tasks

a) Analysis of 2005 and 2015 NAS scenarios

b) Introduction of end-game stochastic dynamics to mimic blunders (ATC, pilot, and aircraft related failures)

- Integration of NLR Petri Network model with AEM
- Integration of fault-tree analysis
- Integration of MIDAS-derived results

c) Determine collision risk for various NAS Concept of Operations using the enhanced modeling tools