Influence of Degraded Environment on Airspace Safety (IDEAS) NNX08AY52A

Eric Feron, Georgia Tech
Emilio Frazzoli, MIT

Program review
July 24, 2009

Project Overview

- National Airspace System is largest man-made dynamical system.
- System has evolved from “blue sky” situation to today’s busier environment.
- NextGen constitutes the core concept for the future evolution of the NAS, and NASA is in charge of engineering development of the system.
  - Involves evolution of CNS infrastructure and air traffic operations.
  - Improved economic benefits contingent on improved safety record.

Plan

- Team
  - PI, students, other relevant personnel
  - Partnerships outside of NASA
  - Collaborations with NASA
- Objectives of research
  - Hypothesis being pursued
  - Relevance to IVHM
  - Progress to date
  - Publications
- Finances, Issues, Risks, and Concerns

Team Feron

- PI: Eric Feron, Professor, Georgia Tech, Decision and Control Laboratory and Air Transportation Laboratory. Areas of interest: Control systems, software implementation of control systems, air transportation, high agility flight vehicles.
- Co-PI: John-Paul Clarke, Associate Professor, Georgia Tech, Air Transportation Laboratory. Areas of interest: Application of operations research and guidance algorithms to important problems in air transportation, incl. airports, airspace management. Many ATM “firsts”.
- Erwan Salaun, Post-Doc. Areas of interest: Nonlinear filtering, UAVs, Ground robots, Air Transportation.
- Maxime Gariel, PhD Candidate. Areas of interest: Anything that flies, incl. parachutes, avionics, air transportation.
- Adan Vela, PhD Candidate. Areas of interest: Application of optimization and control to air transportation problems.
- Hang Gao, BS Candidate and rising ~~senior~~ junior. Many research interests. Currently focusing on machine learning for data classification.

Team Frazzoli

- Co-PI: Emilio Frazzolli, Associate Professor of Aeronautics and Astronautics, Laboratory for Information and Decision Systems, MIT. Areas of interest: Air and space operations, control systems, multi-vehicle systems, air transportation.
- Dimos Dimarogonas, Post-doctoral Associate, Laboratory for Information and Decision Systems, MIT. Areas of interest: Decentralized control of multi-agent systems, robot navigation, networked control and control of hybrid systems
- Kevin Spieser, PhD student, Laboratory for Information and Decision Systems, MIT. Areas of interest: air-traffic control, airspace safety, formation flying, flight-path planning, free flight schemes, multi-agent and reconfigurable systems, coordinated decision making, distributed control, modeling of social and psychological dynamics, crowd control strategies.

Partnerships outside NASA

- FAA/Steve Bradford (NextGen Chief Scientist)
- ENAC and European Air Navigation Authorities (Air traffic complexity)
- WPAFB (Frazzoli)

Partnerships inside NASA

- NASA-Ames: Integrated Vehicle Health Management (Bdg 269)
- NASA-Ames: Airspace Systems Program (Bdg 210)

- NASA-Langley (Cesar Munoz)

Plan

- Team
  - PI, students, other relevant personnel
  - Partnerships outside of NASA
  - Collaborations with NASA
- Objectives of research
  - Objectives
  - Relevance to IVHM
  - Progress to date
  - Publications
- Finances, Issues, Risks, and Concerns

Objectives

- **Phase I: Fundamental theory**
  - Task 1: Framing the notion of system health degradation
  - Task 2: Choosing baseline system dynamics
  - Task 3: Listing perturbations/exogenous inputs to the system
  - Task 4: Metrics and system outputs
  - Task 5: Thinking ahead: Time considerations
- **Phase II: Metrics and health monitoring system development**
  - Task 6: Analytical approach to system health monitoring: Fundamental limits on system health
  - Task 7: Probing traffic configurations for sensitivity to perturbations
  - Task 8: Generating environmental degradations
  - Task 9: Developing a comprehensive health monitoring and prediction tool
  - Task 10: Feeding back traffic health evaluation tool onto traffic magagement: Traffic flow management

Research approach

- Begin with a relatively unstructured, *n*-pronged approach
  - Give everybody the opportunity to experiment with various ideas
  - Enable relative decoupling of Georgia Tech and MIT efforts
  - Flavor of today's presentations
- Will eventually converge to a more structured, end-to-end process that leverages all individual efforts and follows logical flow of proposal
- "Do it, then do it right" (Dave Miller, MIT)

Relevance to IVHM project

(From http://www.aeronautics.nasa.gov/nra_pdf/ivhm_tech_plan_c1.pdf)

- Safety assurance of advanced safety critical technologies for the National Airspace System (NAS), NextGen, N+1, N+2, etc
- Airspace Systems Program (ASP) – Collaboration with ASP on an IVHM NRA study on health monitoring of airspace will provide the IVHM project with a better understanding of airspace safety issues, and will stimulate broader development and application of IVHM technologies.
- **IVHM 3.2.4** "An automated capability to diagnose the causal factors of anomalous operations in real or emulated data of large, fleet-wide or airspace heterogeneous data sources."
- **IVHM 3.3** [...] At Level 3, this element includes integration of information from the various systems in the aircraft as well as examination of fleet-wide or airspace-wide data to predict anomalies pertaining to the National Airspace System.
- **IVHM 1.3 Advanced Analytics and Complex Systems** The fulfillment of the IVHM project's goal requires the ability to transform the vast amount of data produced by the aircraft and associated systems and people into actionable knowledge that will aid in detection, diagnosis, prognosis, and mitigation at levels ranging from the aircraft-level, to the fleet-level, and ultimately to the level of the national airspace.
- **IVHM 1.3.5.1** Implement two prototype computer tools to evaluate airspace system health (WAYPOINT) .

From Decadal Survey of Civil Aeronautics: Foundation for the Future

- “Using a common set of safety metrics (see R&T Challenge E16), this Challenge would develop methods both for monitoring the current system through ongoing analysis of operational and maintenance data and for predicting potential safety problems associated with proposed changes to the air transportation system.”
- “The system would also disseminate relevant information to agents in the air transportation system that might be affected, with the goal of rapidly initiating analysis and intervention systems to identify and resolve near- and long-term conflicts or hazards. To be useful, flight monitoring technologies will need to avoid false alarms associated with routine deviations to adjust spacing between aircraft or in response to local weather conditions. Technologies developed in response to this Challenge could also be used to better predict the near-term consequences of flight plan deviations. Data generated by onboard systems could be combined with data provided by ground systems to extend the time horizon of the predictive capabilities to more than just a few minutes”

From 2010 NASA budget

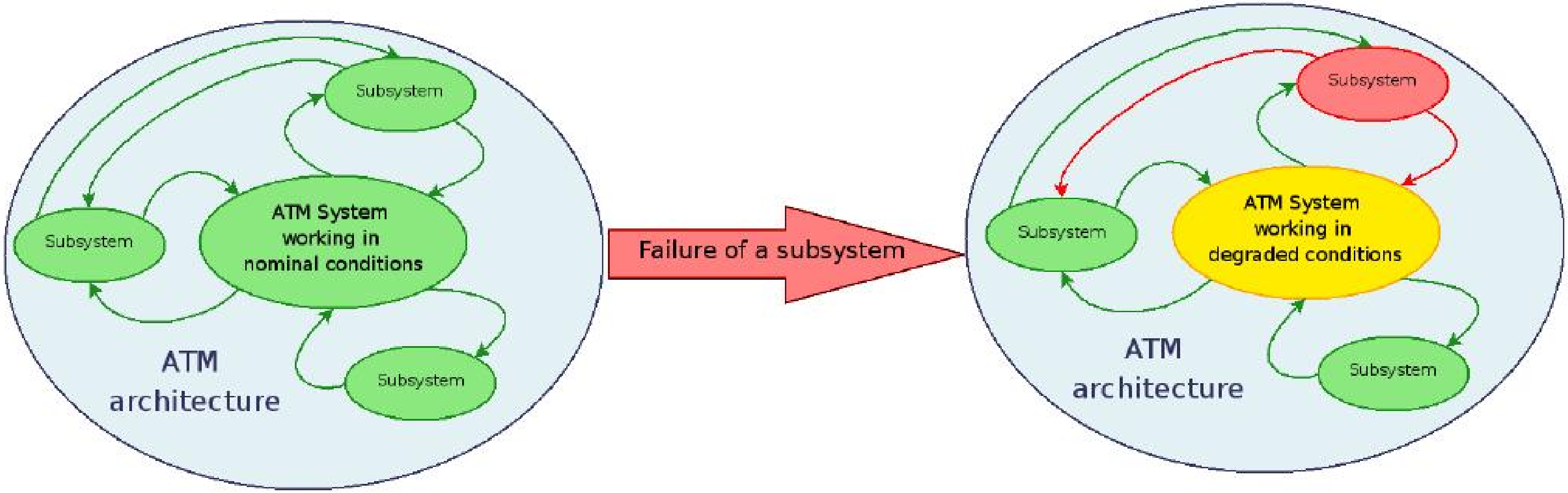
"A key enabling technology will be the ability for sharing and processing large amounts of information among the various vehicle subsystems to more accurately diagnose the system health state and execute the logic to self-correct any critical anomalies detected. This data mining capability can also be applied to operational data about both aircraft and airspace."

Graceful Degradation
of Air Traffic Management Systems

Maxime Gariel

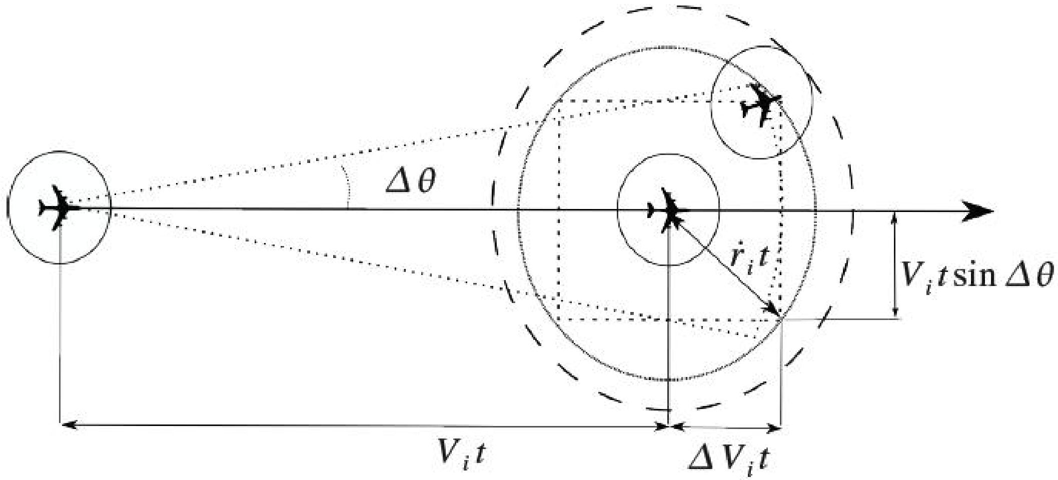
Possible failure/degradations affecting ATMS

- ATM Computational infrastructure
- Communications
- Surveillance
- Operations
- Vehicles
- Airport closure

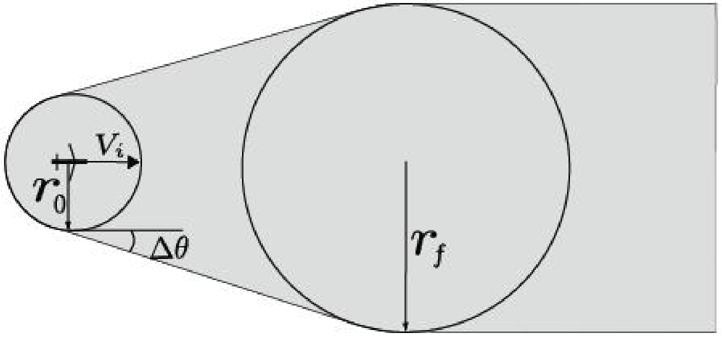


➡ A graceful degradation occurs when the transition from a nominal mode of operation to a degraded mode of operation is smooth and with no catastrophic event

New model of uncertainties : on the heading and the speed



➡ Separation distance as a function of the prediction time



Radius of avoidance:

$$r(t) = \begin{cases} r_0, & t < 0 \\ r_0 + \dot{r}_i t, & 0 \le t < t_g \\ r_f, & t \ge t_g \end{cases}$$

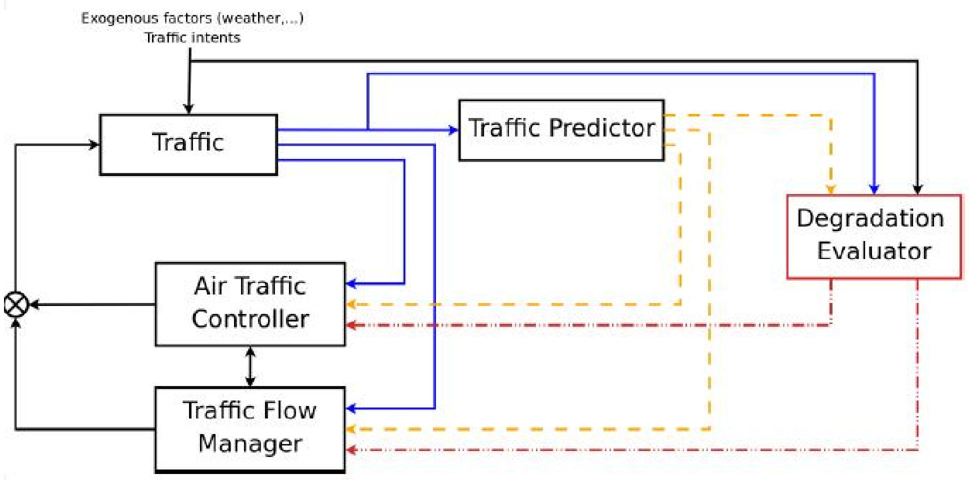
Degradation evaluator architecture

Based on

- current traffic
- predicted traffic
- weather forecast

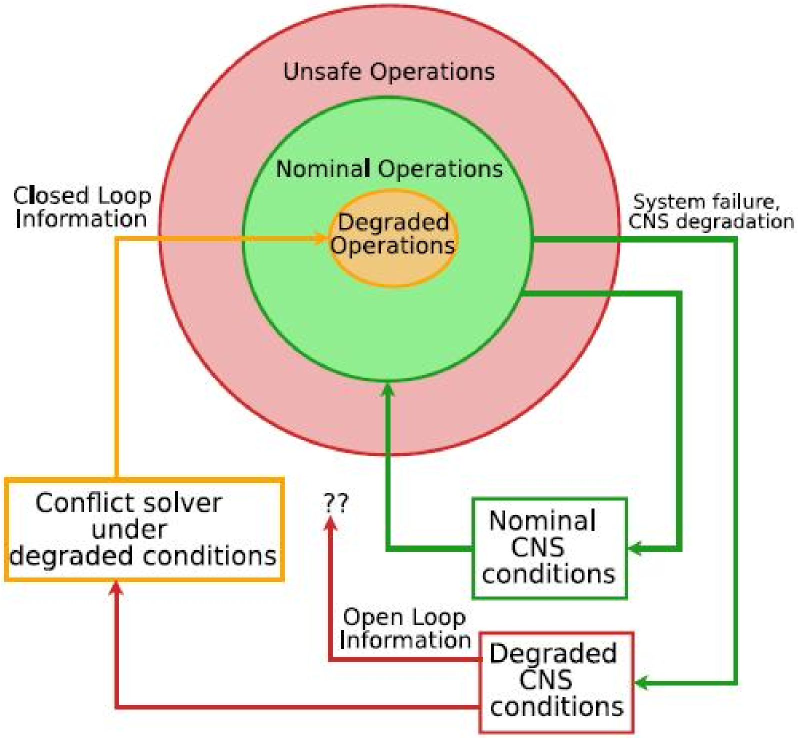
Purpose

- identify hazardous situations
- evaluate severity of situations
- propose solutions



➡ Use of complexity maps based on CNS degradation

Open and closed-loop information



Open-loop information

- number of potential conflicts
- localization of potential conflicts
- time to potential conflicts
- cluster

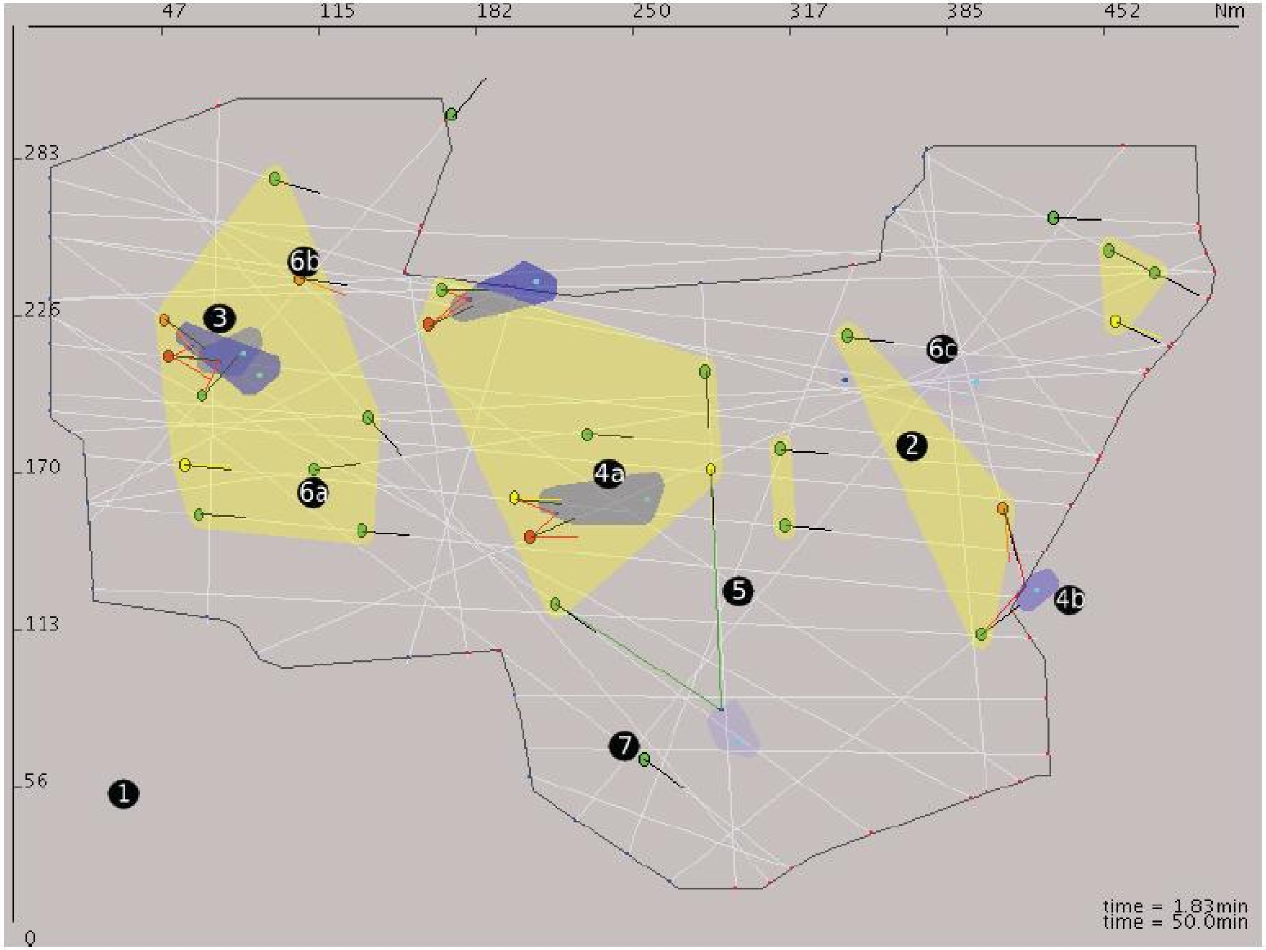
➡ *Measure of the spread of the degradation*

Closed-loop information

- heading or speed change required
- number of maneuvers
- magnitude of maneuvers
- aircraft indirectly involved

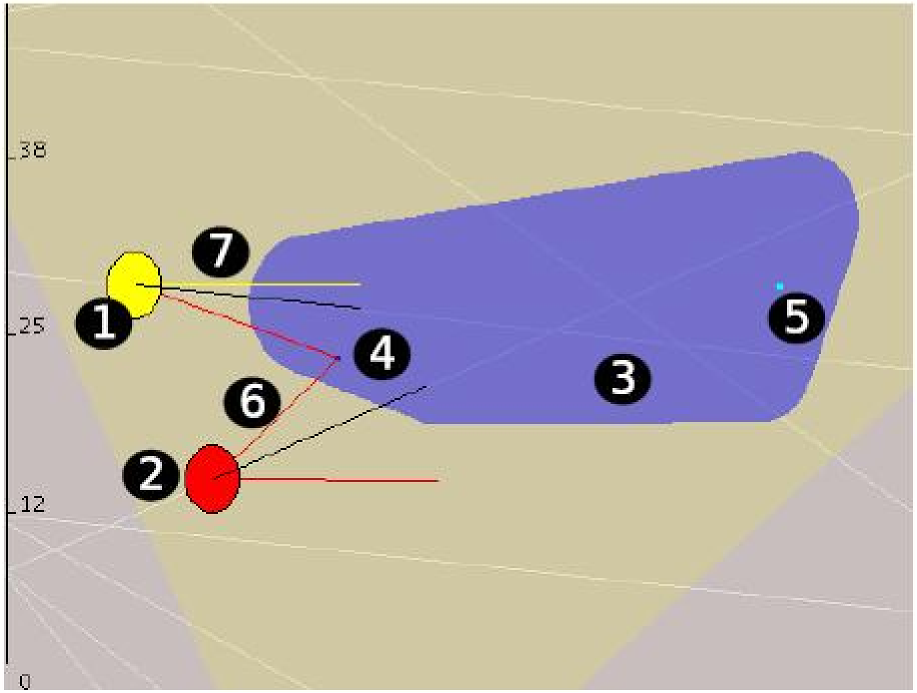
➡ *Measure of the severity of the degradation*

Complexity map for one flight level of Cleveland center



+ VIDEO!

Characterization of the degradation complexity



2 aircraft potential conflict

- ❶ aircraft represented by their circle of avoidance
- ❷ initial velocity vector (black line)
- ❸ conflict area
- ❹ location of conflict's beginning
- ❺ location of conflict's end
- ❻ identification of involved aircraft and time to conflict
- ❼ required avoidance maneuver

RaGeCoM
- Rapidly Generated Complexity Maps -
An easy-to-use support tool for airspace health prediction

Erwan Salaün
Adan Vela

Georgia Tech

Tasks 1 throough 9 – an (incomplete) end-to-end approach

Rapidly Generated Complexity Map

- Complexity map based on vector input

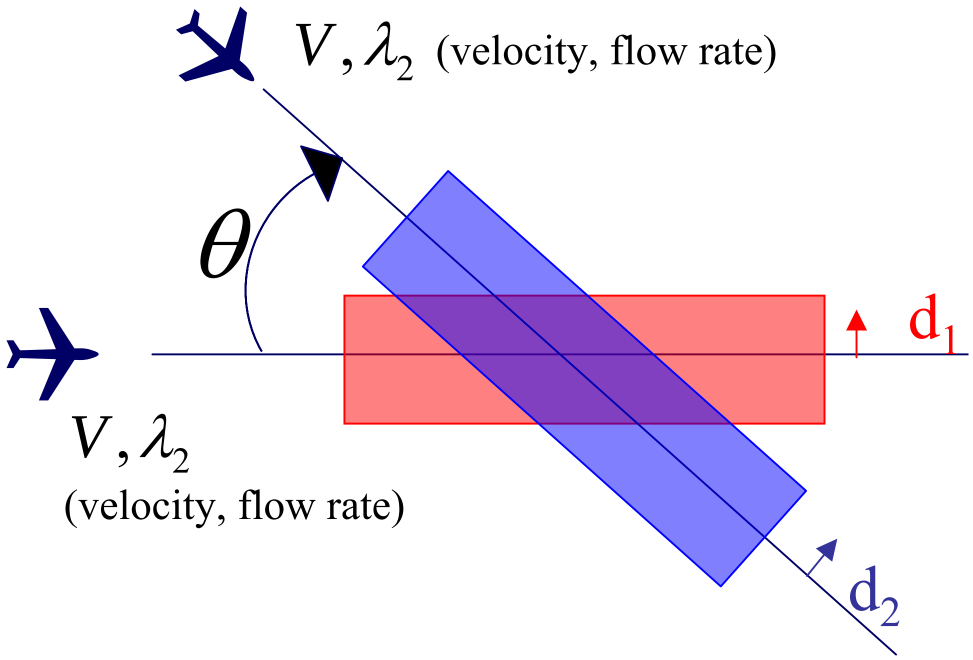
- Map is a temporal and spatial probabilistic measure of complexity (current and future)

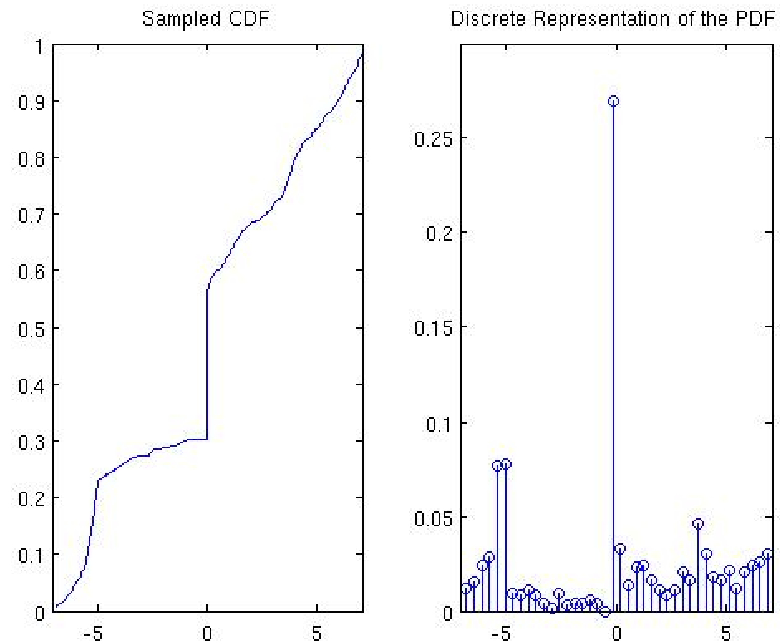
- *RaGeCoM* is based on two main ideas:

  - Analyzing the behavior of a single and pairwise flows of aircraft to a set of base inputs (e.g. flow rates, crossing angles, rogue aircraft, convective weather) and synthesizing the results to the sector level with multiple flows.

  - Defining the complexity of an airspace as the likelihood that controllers need to deconflict more than 2 aircraft at the same time in a given area.

A single intersection





CDF and PDF of lateral deviation of flow1 (θ, λ_2 fixed)

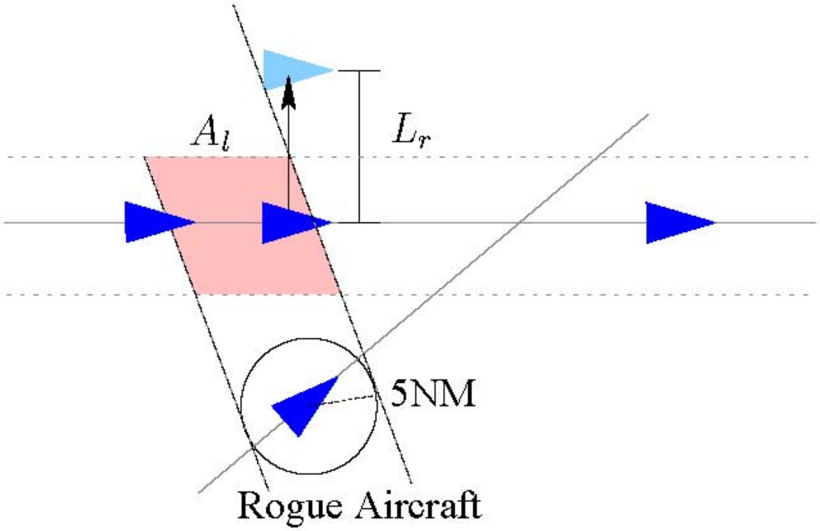
$$P(d_1 \le d) = F_{d_1}(\lambda_1, \lambda_2, \theta)$$

$$P(d_2 \le d) = F_{d_2}(\lambda_1, \lambda_2, \theta)$$

Generation of probabilistic function through simulations and analytical approach

Rogue aircraft

Aircraft (from an « usual flow ») prevents conflict with an external rogue aircraft

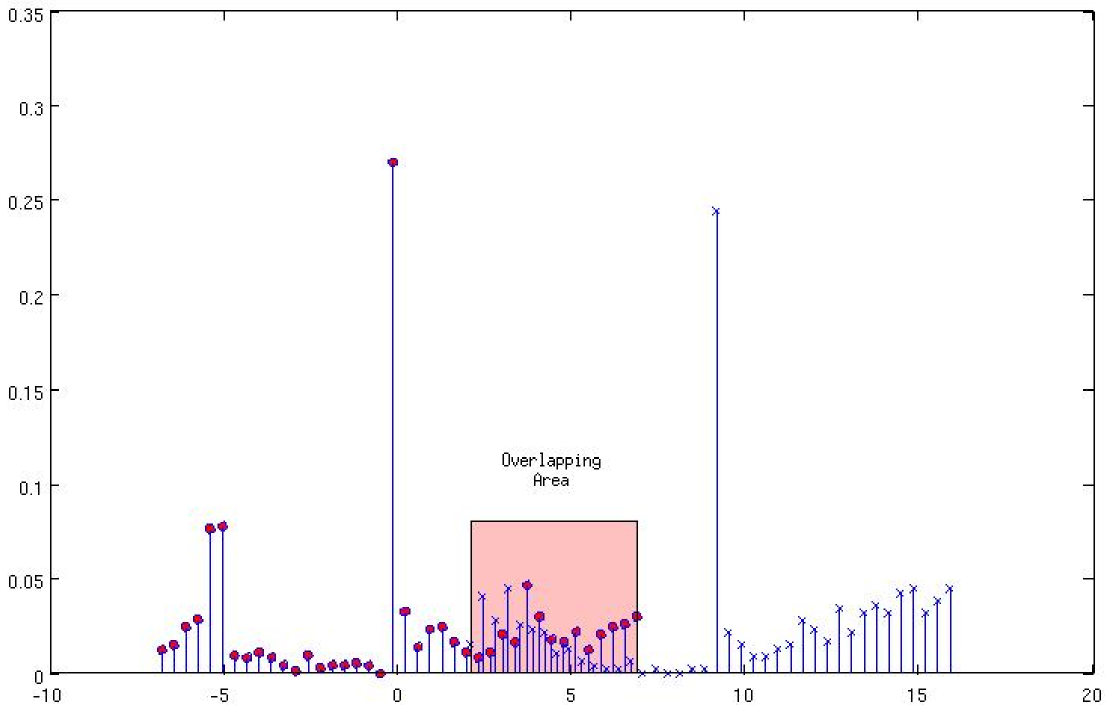


Determination of the necessary avoidance maneuver as a function of θ (crossing angle) and λ (flow rate)

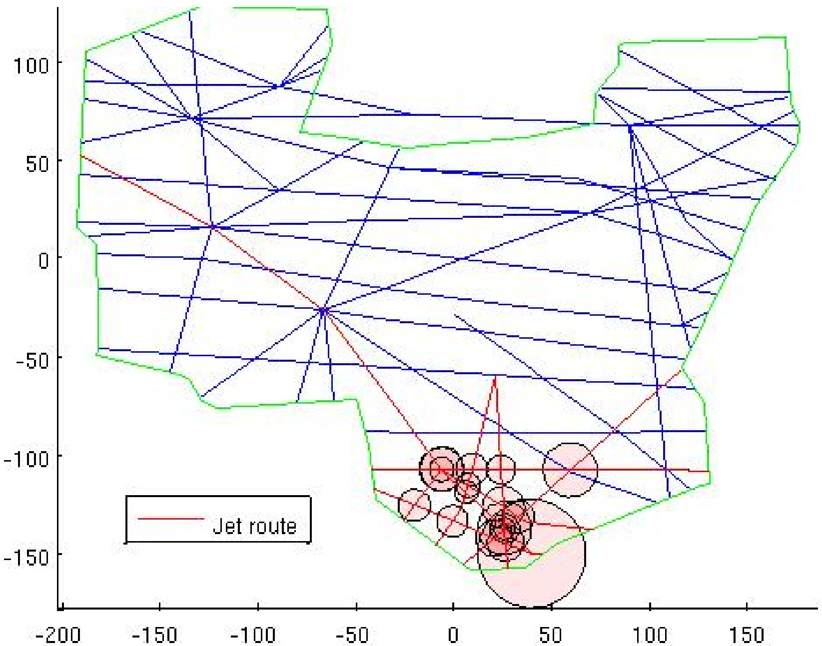
Rapidly Generated Complexity Maps

• Done: spatial and temporal avoidance maneuver distribution for several cases (flows intersection and rogue aircraft) as a function of the traffic configuration (flow rates, crossing angle)

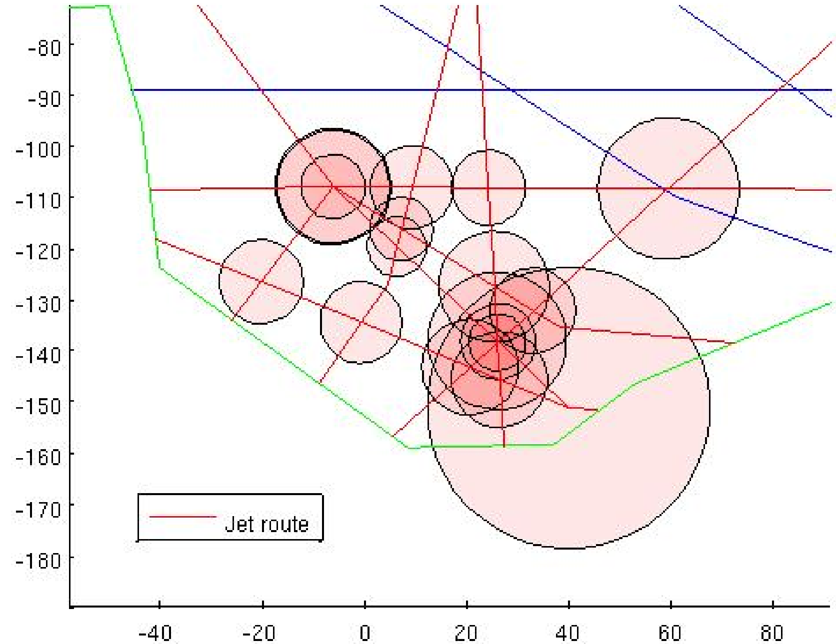
• Key point for RaGeCoM: overlapping areas of these distributions
<-> controllers need to deconflict more than 2 aircraft at the same time in a given area



RaGeCoM – Aircraft flows

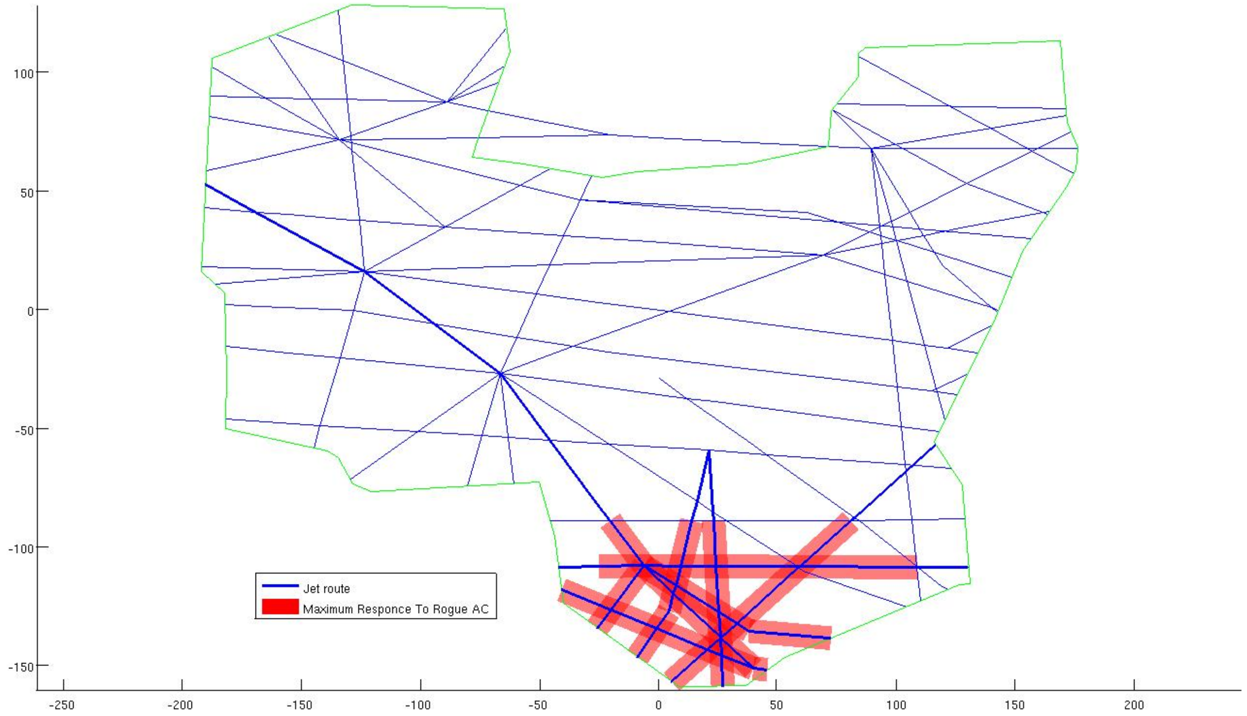


Cleveland center



- For a given route configuration, this complexity map related to aircraft flows is a function of the arrival rate -> current or future
- The consequences of new route configurations can be evaluated

RaGeCoM – Rogue aircraft



• For a given route configuration, this complexity map related to rogue aircraft is a function of the arrival rate -> current or future
• The consequences of new route configurations can be evaluated

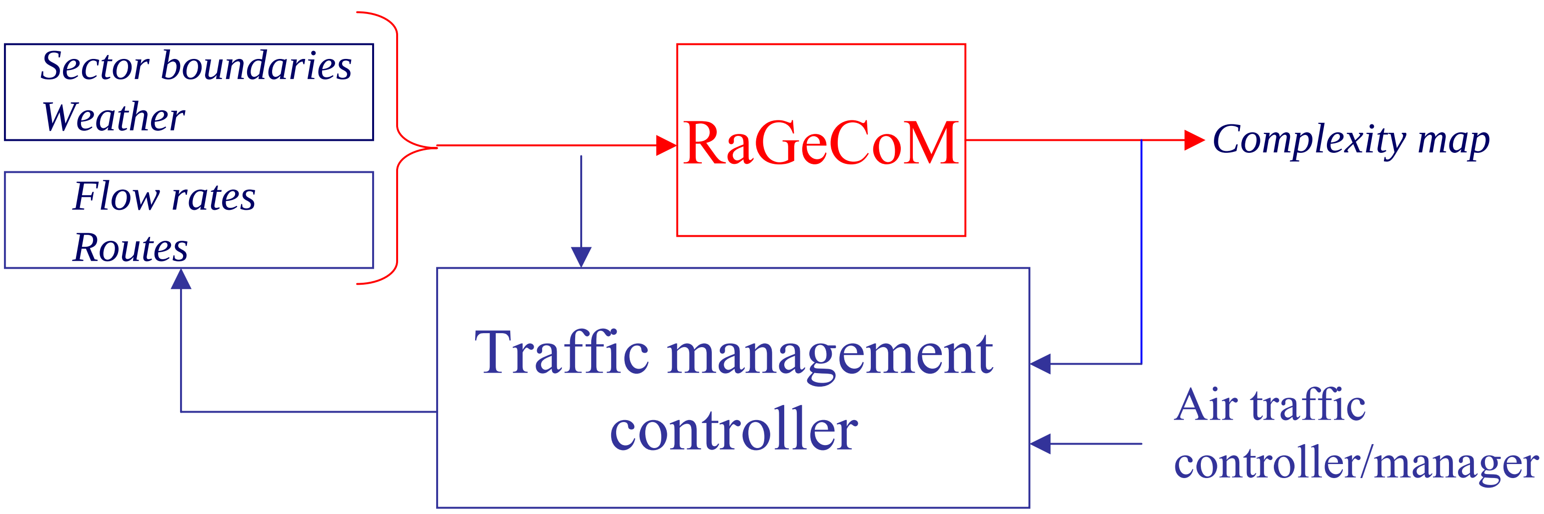
Next steps and further works

Next steps:

• Develop new complexity maps (e.g. weather)
• Validate this approach with real data
• Use of a human controller model instead of the automated conflict resolution

Further works:

• Develop (semi-)automated mechanisms to balance and plan traffic across several sectors to increase capacity of an airspace while avoiding high-complexity areas



Controller model development

Hang Gao and AdanVela

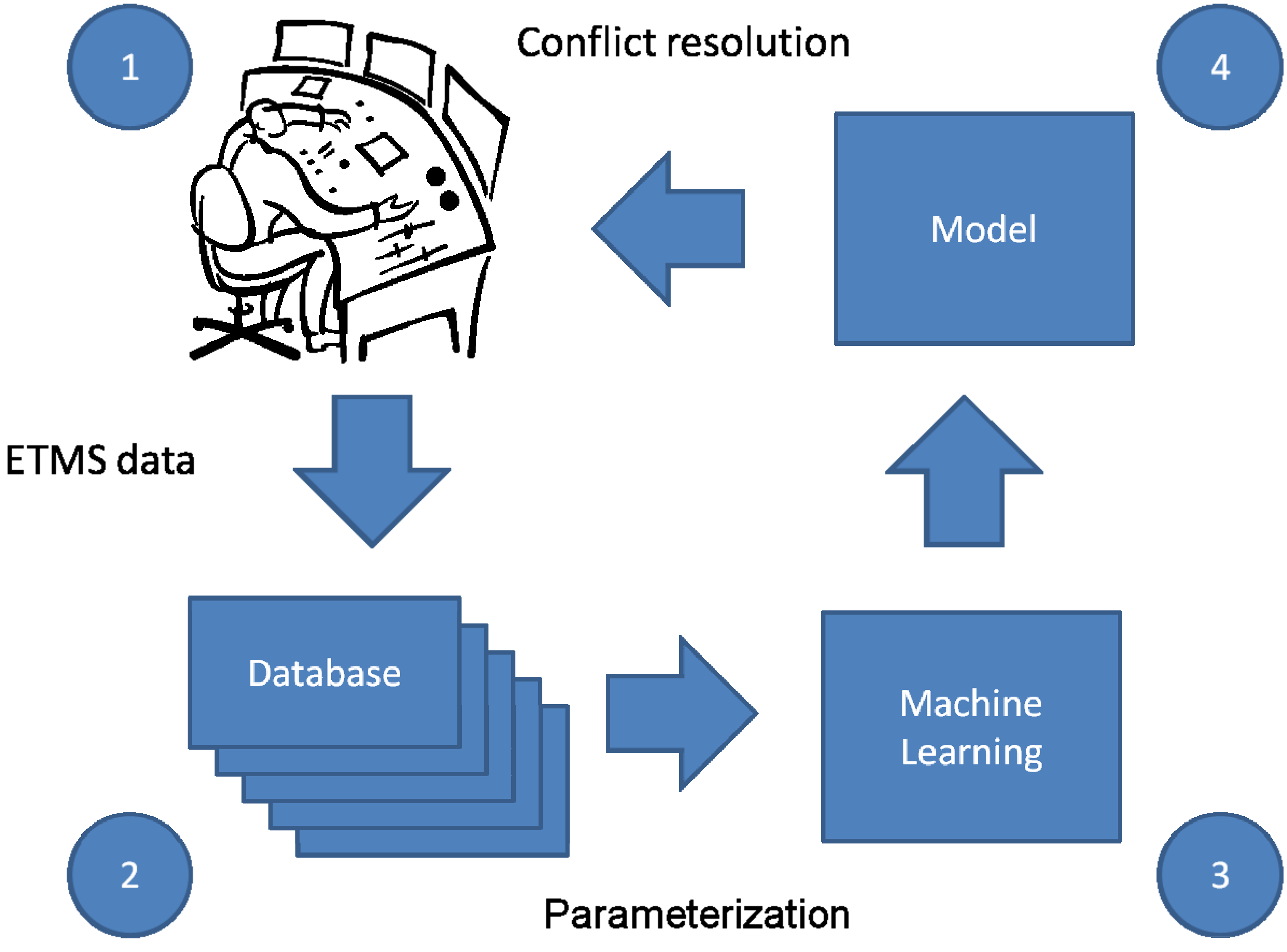
Project Outline

- Objective:

  To model human air traffic controllers (ATC) by machine learning.

- Approach:
  - Mastering Enhanced Traffic Management System (ETMS), a real-time aircraft tracking system used by ATC, data.
  - Classifying the conflict cases(inputs) and the resolution cases(outputs).
  - Implementing a method of classification and machine learning to generate model.

Roadmap of Project



Database

ETMS Data Tables:

- –**Airline**
- –**Block_alt**
- –**Bndxing**
- –**Cancel**
- –**Control**
- –**Flight**
- –**Position**
- –**Time**

–**Route:** **route information of all flights**

–**Tz:** **one-minute interval radar reports for all flights**

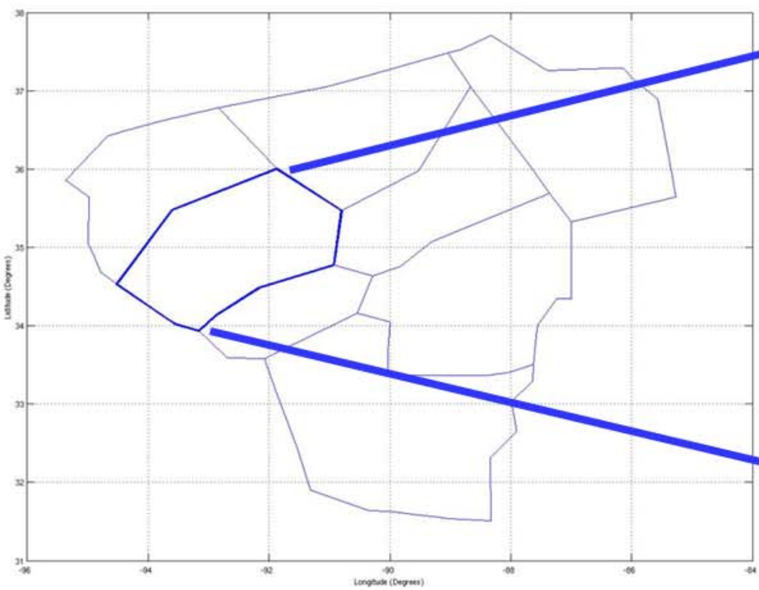
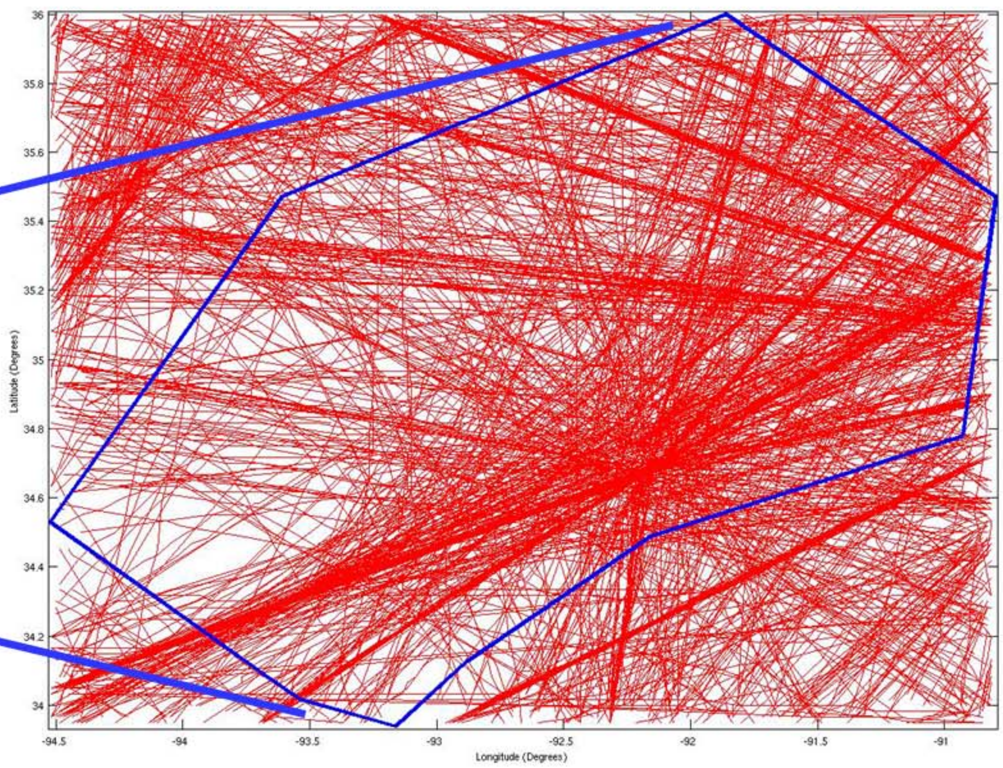


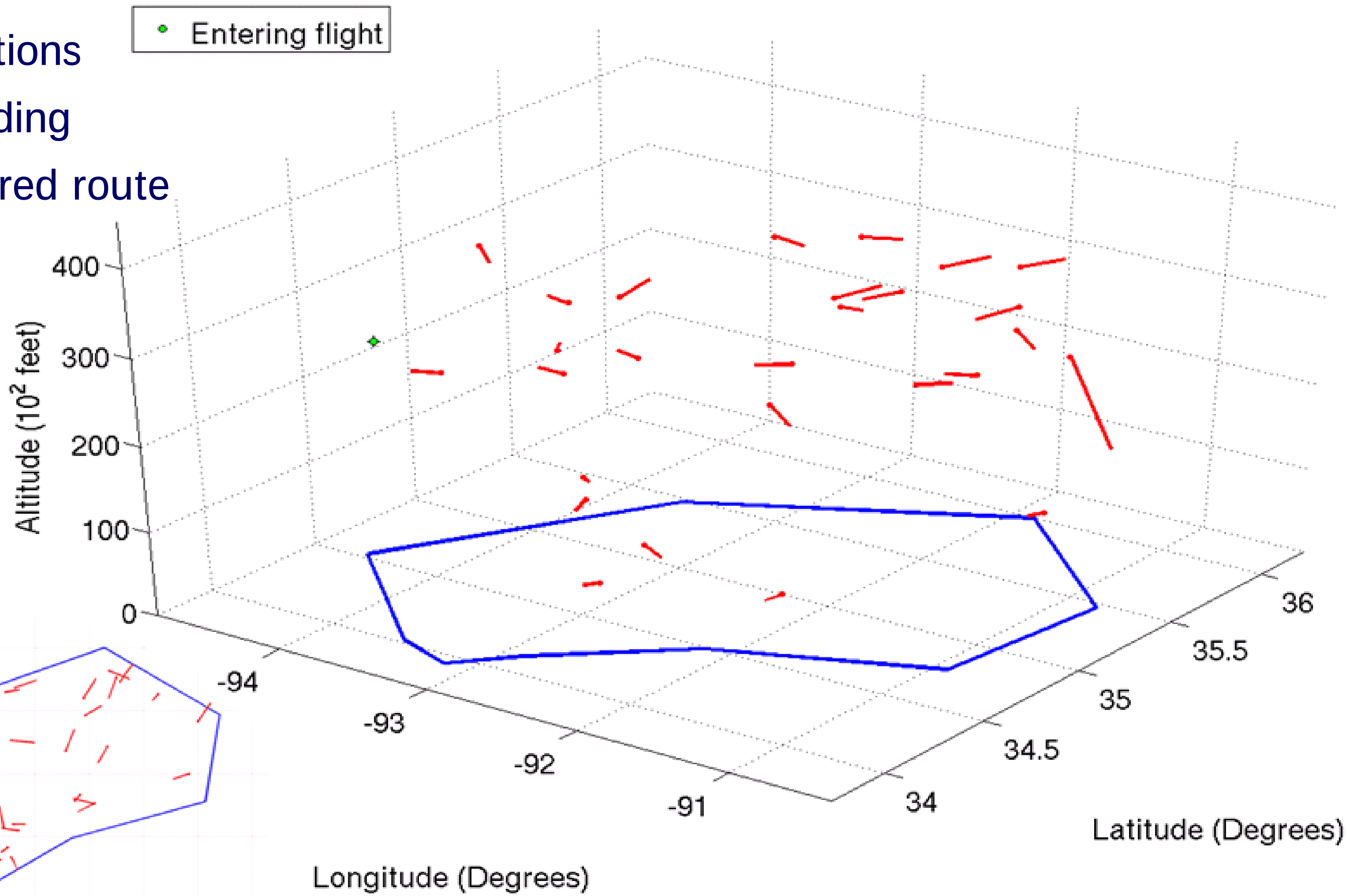
Figure 1. ZME(Memphis)



Sector ZME20 (Little Rock, Memphis)

Database: Input

- Data point contains flight characteristics for a fixed-frame sector situation.
  - Positions
  - Heading
  - Desired route
  - Etc.



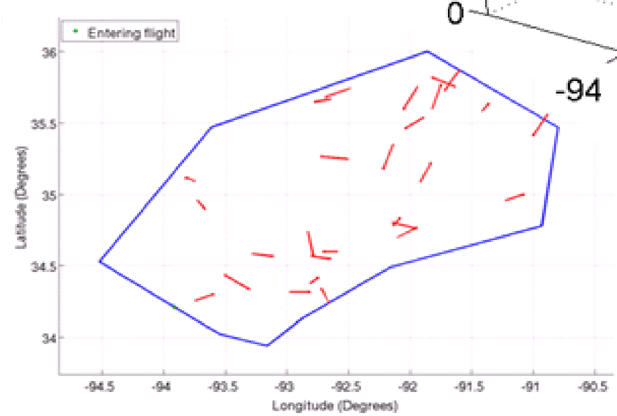


Figure 2. 2D & 3D Plot of Input (AAL1821,10/04/2004,ZME20)

Database: Output

- Historic solution to input
  - Actual route
  - Actual velocity

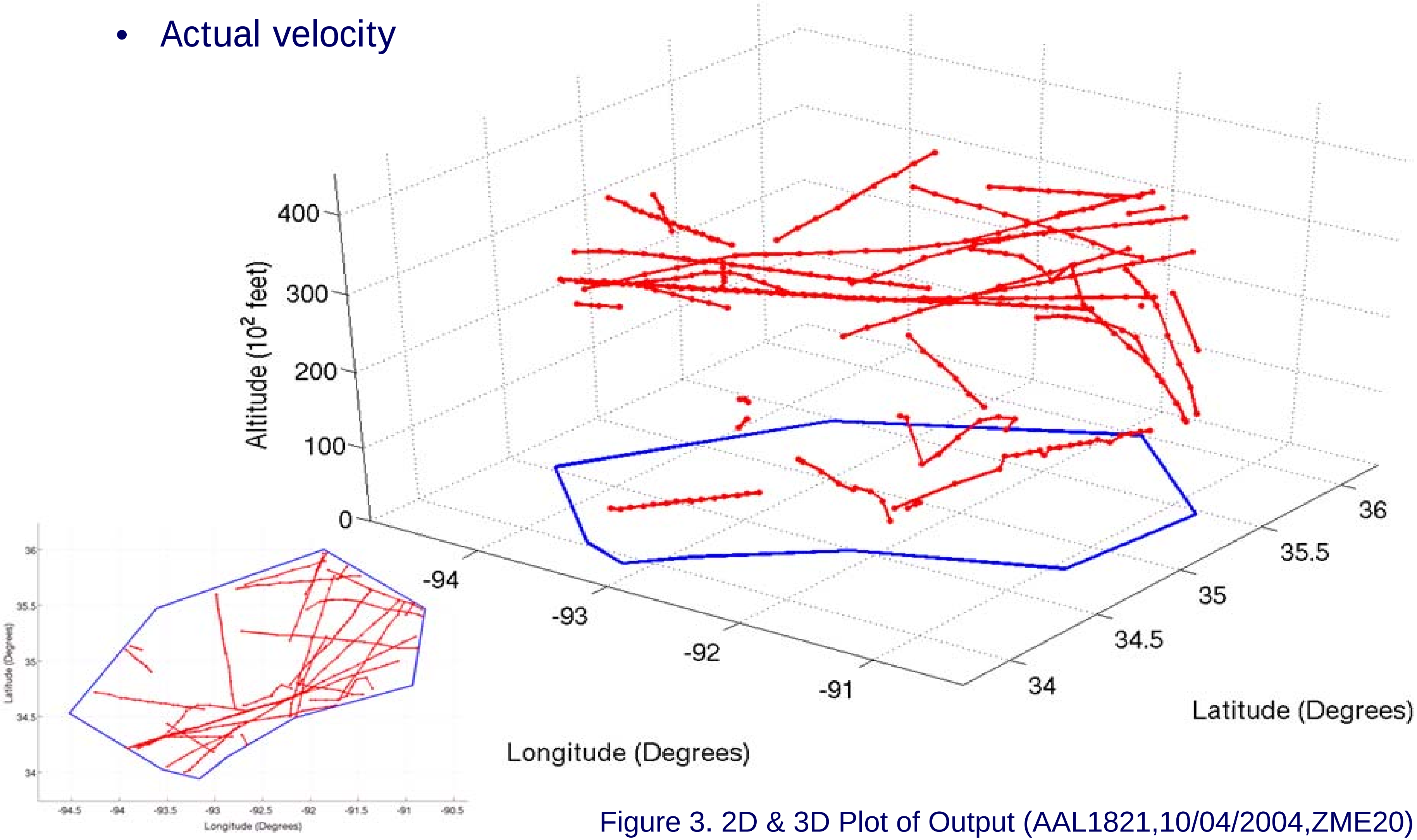


Figure 3. 2D & 3D Plot of Output (AAL1821,10/04/2004,ZME20)

Current Standing

- Data extraction and analysis codes with time and memory efficiency.

- Systematic approach to the acquisition of input, with a progressive vector of variables.
    - *flt* – flight entering sector
    - *sec* – sector of airspace (Z__)

$$f_{input}(flt, sec) = Lat, Lon, Alt, H, dsR, \ldots$$

- Defining real-life ATC parameters through studying the historic flight data from ETMS.

Dimensional reduction and solution mapping

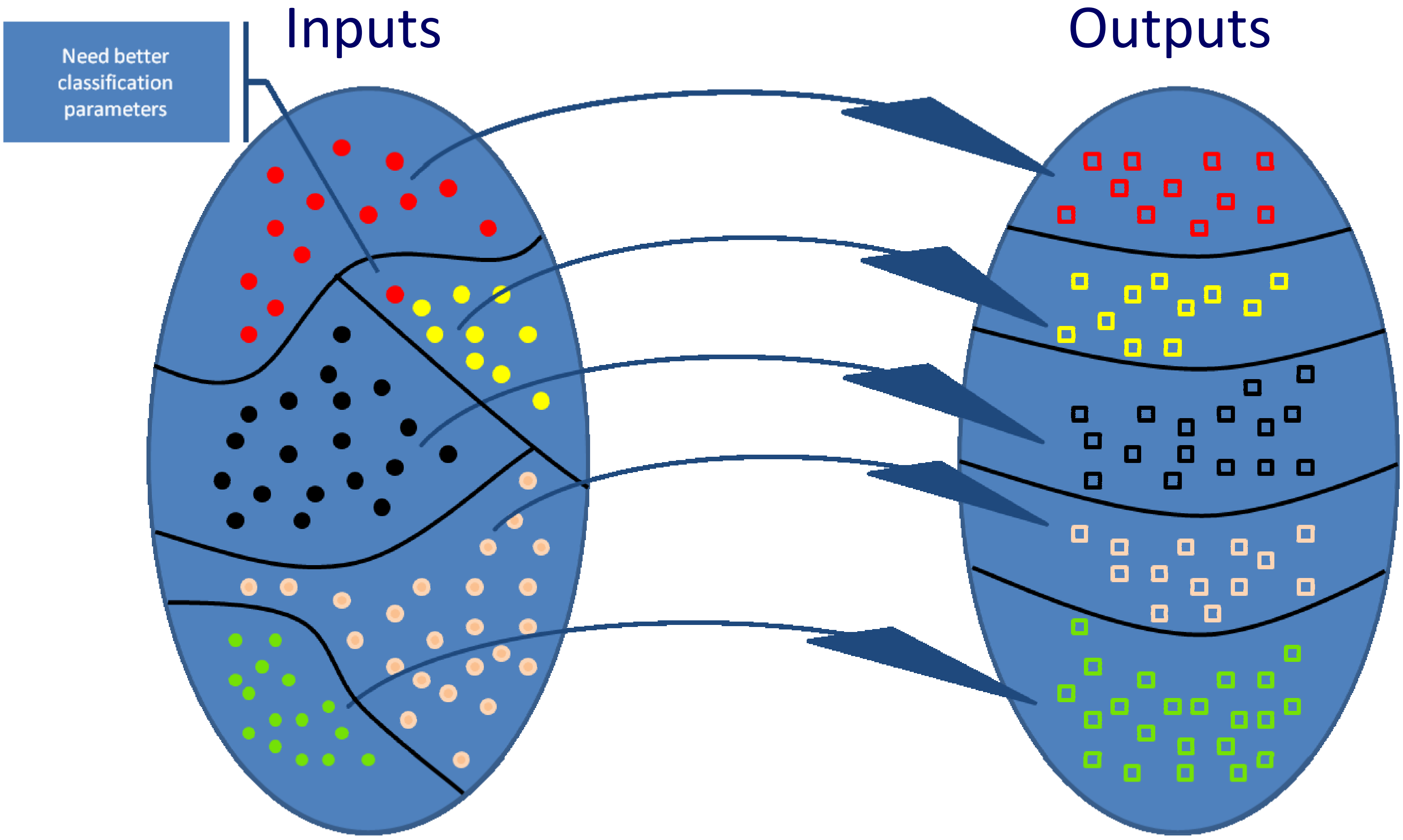


Figure 4. Input-Output pairing

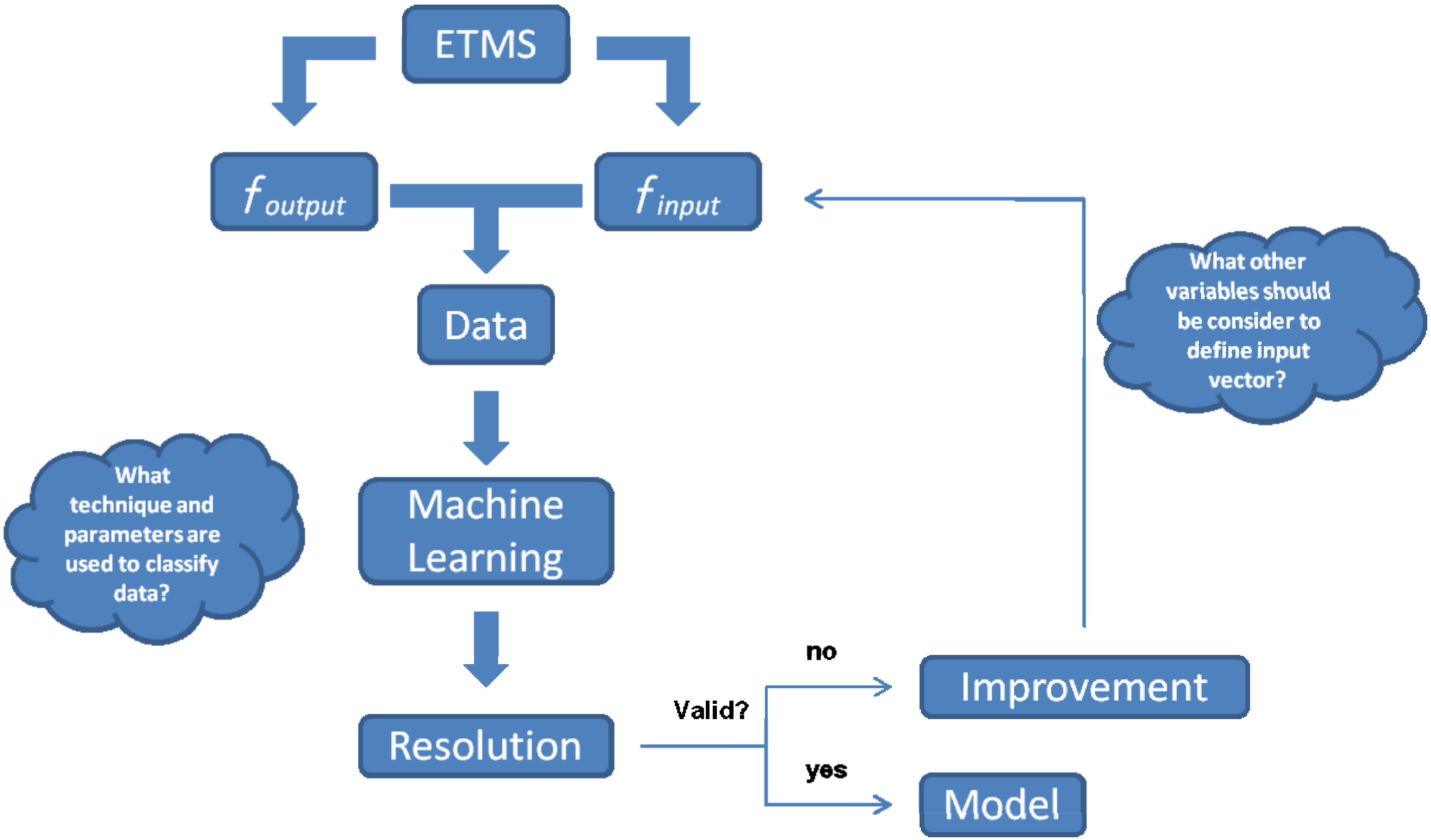
Future Work

- Determining a method of classification and solution mapping.

- Possible candidates:
  - Cluster analysis
  - Kernel Principal Component Analysis
  - Support vector machine

- Obtaining a viable model with valid conflict and resolution pairs.

Flowchart


ETMS
f output
f input
Data
Machine Learning
Resolution
Valid?
no
yes
Improvement
Model
What technique and parameters are used to classify data?
What other variables should be consider to define input vector?

Airspace Monitoring:
A data driven approach

Maxime Gariel

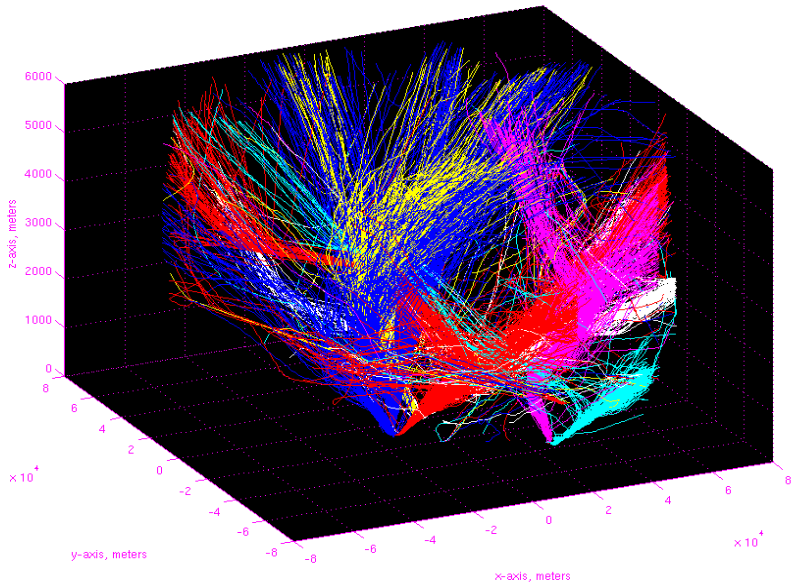
Objectives

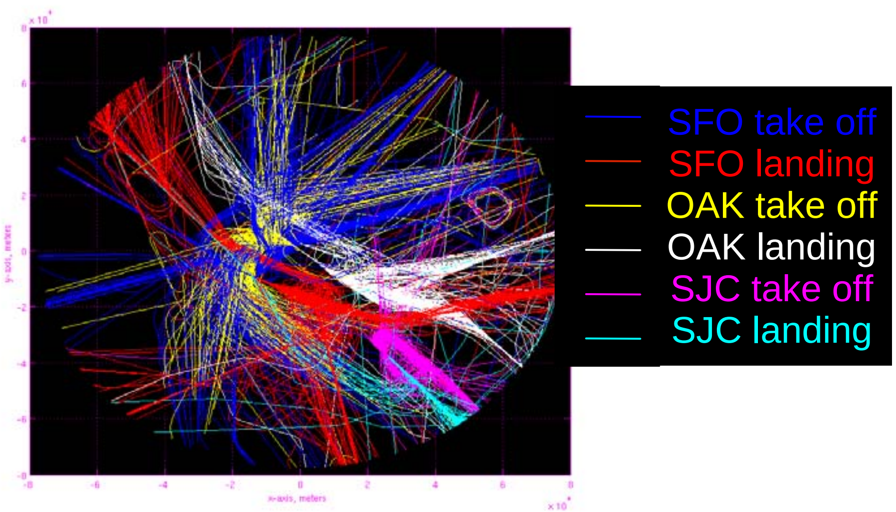
- Learn nominal operations from available data: identification of the system

- Detection of non-nominal situations/outliers in current traffic

- Have a non location specific algorithm to monitor the airspace

Learning phase





__Available data:__

Aircraft tracks for the Bay area TRACON.
9 month of data: January to September 2006.

Generation of nominal/standard path using trajectory clustering : use of a new trajectory clustering method.

Traffic is split by airport and then by departing or landing and treat each group of trajectory independently.

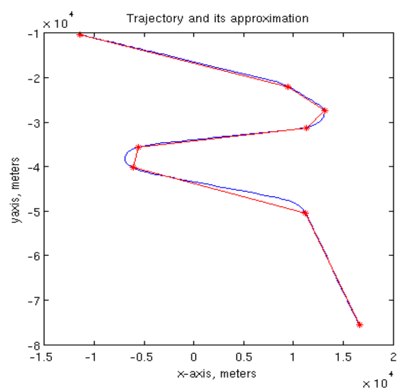
Only (x,y,z) position of aircraft is used to cluster trajectories.

Clustering methodology

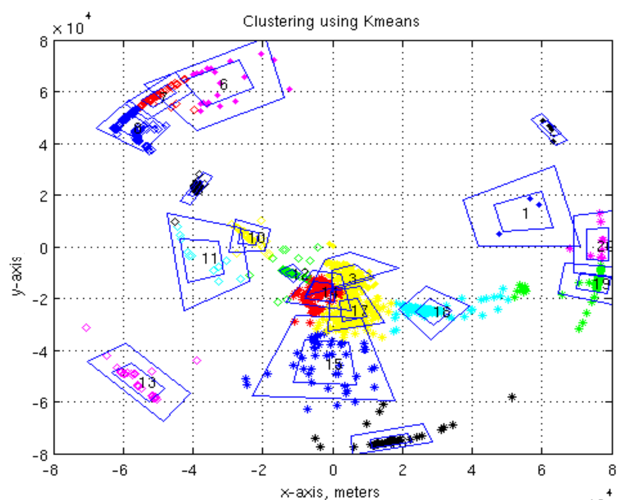
Issues to cluster trajectories:
- 3D time series
- various length

Some methods already exists, but not satisfying for our purpose (deal with very noisy and random trajectories)
Available trajectories are smooth and with very little noise.
We want to exploit the features of flight path: straight legs with identifiable turns.

① Identification of trajectory features: turning points.



② Cluster all the turning points of all the trajectories to generate "waypoints" (use of Kmeans and IMS algorithms)

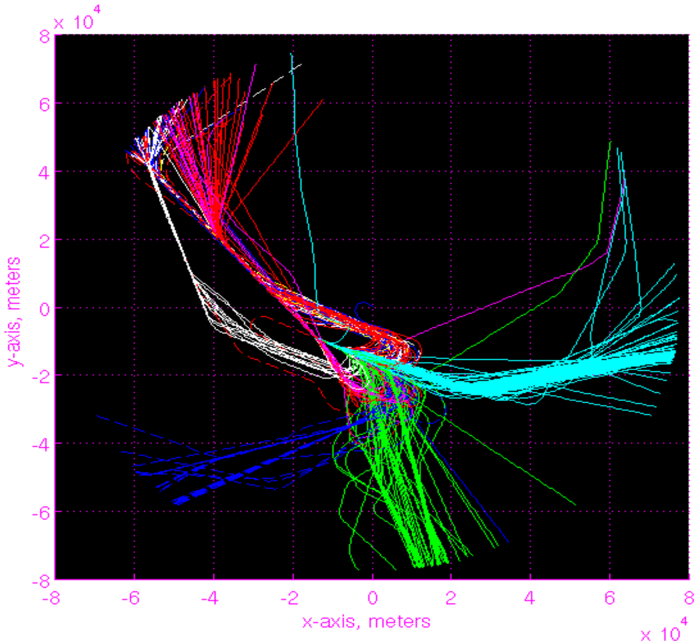


Clusters of turning points and corresponding waypoints

③ Represent trajectories as a sequence of waypoint. The number of waypoints is finite.

④ Cluster the sequences using sequenceminer (find the longest common sub sequen symbolsce). SequenceMiner allows use to compare symbol sequences of various length.

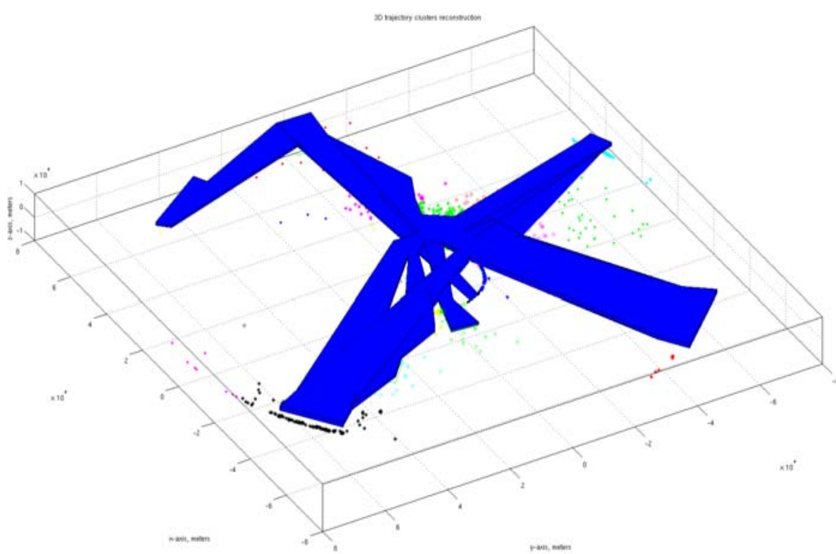
Clustering results. Airspace reconstruction



Clustering for one day
of landings at SFO

Enables us to reconstruct 3D “pipes” for aircraft. This idea was: if an aircraft flies inside the pipe, it is doing what it is supposed to do. If exiting the pipe, it is not anymore.
Pipes are generated by joining in 3D the “waypoints” previously determined. For each cluster, a representative trajectory is determined. It is the longest common subsequence.

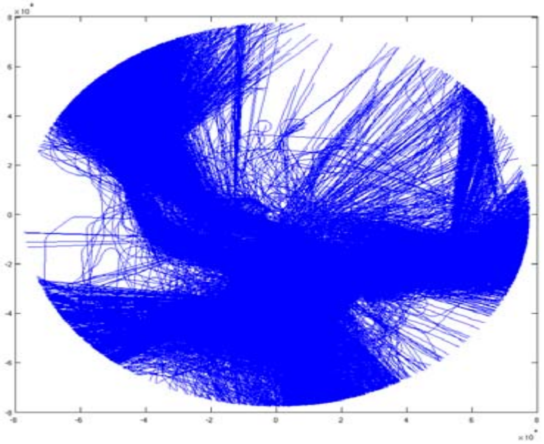
The methodology presented gives good result for a limited number of trajectories.



Reconstruction of 3D operations

Issues with this methodology

The previous methodology gives good results over a day, but if extended to a larger data set, there exists a large variability over time. This generates pipes too wide and no monitoring can be achieved from them.



Trajectories of landings on runways 28R/L at SFO for 3 month

Future work: cluster trajectories using more data and metadata, such as heading, speed, time of the year/ time of the day, TRACON density, aircraft type...

Markov model generation

We present another approach for airspace monitoring: Use of transition matrix between waypoints.

Operation modeling:

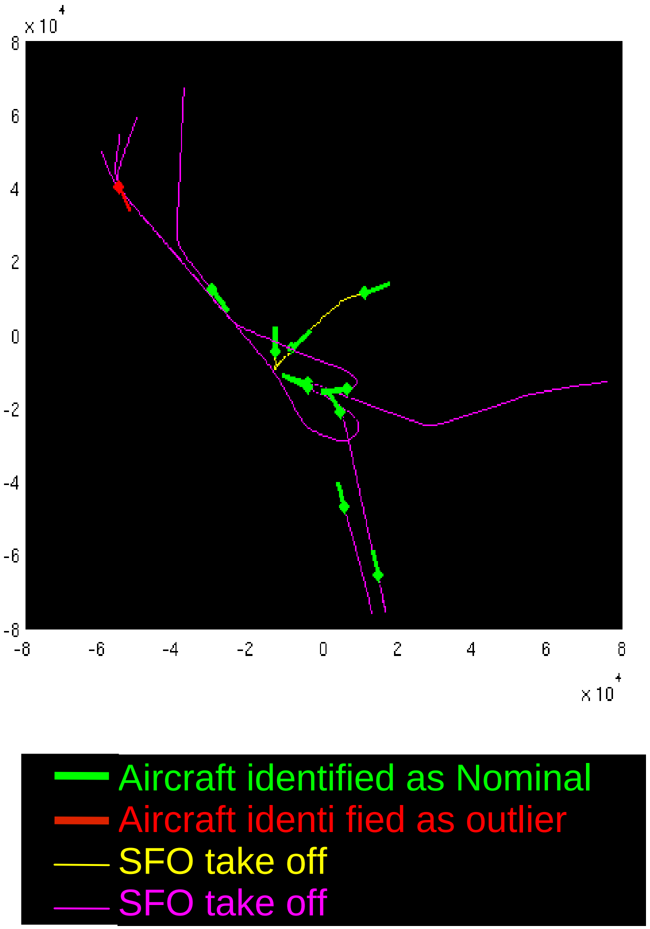
From step ③ of the trajectory clustering, we generate a transition matrix *T* for the waypoints. T_{ij} is the probability of an aircraft flying over way point *i* to head towards waypoint *j*

A transition matrix for each type of operation (airport - departure / landing) is generated.

Airspace monitoring:

At each time step, for each aircraft, the closest waypoint is identified. Then, using the transition matrix, possible headings for the aircraft are identified. If the aircraft does not follow one of the possible headings,
it is identified as an outlier.

Airspace monitoring: Markov model



Conclusions: false alarm rate still too high…

This is due to high variability in the size of the waypoints. Aircraft don't always turn exactly over the physical waypoint.

working on it

Influence of Degraded Environment on Airspace Safety (IDEAS):

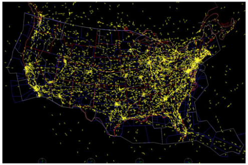
Understanding Fundamental Limits for NextGen Air Traffic in a Degraded Environment

Emilio Frazzoli,
Kevin Spieser, Dimos Dimarogonas

Laboratory for Information and Decision Systems,
Aeronautics and Astronautics Department,
Massachusetts Institute of Technology

July 24, 2009

Introduction



- Current Air Transportation System (ATS)
  - Highest safety standards
  - large, complex, and loosely connected
- Lacks the operational scalability to effectively meet projected increases in the demand for air travel.
  - two- to three-fold increase forecasted by 2025.
- The NextGen project addresses this need for sweeping change in the operation of the ATS.
  - less centralized
  - leverages technological and computational advancements
  - employs abstract reasoning skills to deliver a user-based experience

NextGen and IDEAS

- Key Characteristics and Capabilities of the NextGen ATS
  - distributed decision making
  - scalability and robustness
  - weather assimilation in route planning
  - super-density operations
  - trajectory- and performance-based operations
  - integrated safety management
- IDEAS Project:
  - Develop a health monitoring tool for a next-generation ATS to prevent severe declines in system health despite possible degradations in the environment.
  - Close alignment between IDEAS goals and approach, NextGen objectives, and NASA roles.

Understanding Fundamental Limitations on Traffic Health

- To evaluate the efficiency of a next-generation ATS, we must have a precise understanding of what is and is not possible, through analytical, quantitative, characterization of the effects of (nominal/degraded, current/NextGen):
  - Traffic volume
  - Technologies and infrastructures
  - Policies and protocols
  - Environmental parameters (weather, etc.)

  on system-level (or local) metrics such as delays, throughput, safety, "complexity".
- **Objective:** Formally determine fundamental limitations on performance of large-scale, decentralized, mobile systems, in nominal and off-nominal situations, to:
  - Provide a benchmark for practical ATM approaches
  - Asess proposed technologies and achievable objectives.
  - Steer policy and infrastructure development.

Overview of proposed approach

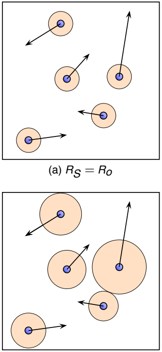
- Network of ATS (aircraft+ground infrastructure) in a control volume, subject to
  - dynamics constraints
  - communication constraints
  - sensing limitations
  - regulatory constraints
  - computational (and cognitive) constraints
- Inputs:
  - Aircraft arrival rate,
  - Source/destination distribution
  - "Safety degradation"—weather, etc.
- Outputs (local/global):
  - Throughput/Delay
  - Safety margins and/or probability of violations
  - Operator workload
- use tools from operations research, queuing theory, distributed computation, and robot motion planning/control.
- Analyze for large numbers of aircraft

The Transfer Problem

- Problem setup:
  - n autonomous agents, $A_1, \ldots, A_n$.
    e.g., a fleet of aircraft
  - Agents can move with bounded speed within a worskpace $\mathcal{Q}$ of area A.
    e.g., a control volume/region, or the whole NAS
  - Each agent is assigned an Origin and a Destination point (O-D pair).
    e.g., airplanes traveling between airports
- Questions:
  - What is the minimum time $T^*(n)$, necessary to safely transfer all agents from their Origin to their Destination point, without causing conflicts?
  - How does such minimum time scale as the number of aircraft n becomes large?
- *The answer depends on the definition of conflict, which in turns is tied to interactions between aircraft.*

Previous results

- Conflict definition
  - assign each agent a safety disc, $M_S\left(t\right)$, of radius R_S
  - System is conflict-free if $M_i\left(t\right) \cap M_j\left(t\right) = \emptyset$, $i, j = 1, \ldots, n, \ \forall t$
- How to model R_S?
  - constant i.e., $R_S = R_0$
  - Affine dependence on speed i.e., $R_S = R_0 + \kappa|v|, \ \kappa > 0$



(a) $R_S = R_o$

(b) $R_S = R_o + \kappa|v|$

Sharma et al. [2007]

Let $R_S = R_0 + \kappa|v|$. Then:

1. If R_0 is bounded away from zero (e.g., a constant), $T^* = \Theta\left(\frac{\bar{L}n}{AV_{\max}}\right)$.
2. If $R_0 = O\left(1/\sqrt{n}\right)$, then $T^* = \Theta\left(\kappa\bar{L}\sqrt{n/A}\right)$.

Some remarks

- Current regulations: $R_0 = 2.5\mathrm{nm} = \mathit{constant}$
- "Sensor-based" routing: agents can slow down to reduce congestion
  Direct applicability to ground-based traffic, application to air traffic on mean motion.
- Key parameters:
  - R_0: physical dimensions, uncertainty, maneuvering, ...
  - κ: communication/processing delays, reaction time, ...
  - A: Area of available region
- Capture degradation through effects on R_0, κ, A, e.g.:
  - Navigation sensor failure $\leftrightarrow$ R_0.
  - Communication network failure $\leftrightarrow$ κ
  - Weather $\leftrightarrow$ A

Towards super-density operations

- **Idea:** Assuming some form of coordination is possible among agents (e.g., as in NextGen), the dimension of the safety buffer should be related to the relative, rather than the absolute, velocity of the agents.

(a) safe (b) unsafe

- New definition of conflict:
  - system is conflict-free if for each pair of active agents, A_i, A_j,

$$|p_i(t) - p_j(t)| \geq \kappa |\dot{p}_i(t) - \dot{p}_j(t)|, \qquad \kappa > 0, \forall t$$

- Stresses relationship between separation distance and relative velocity.
- How much does allowing "super-density" through coordination affect delays/congestion?

Time complexity of cooperative routing

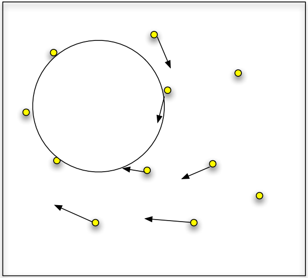
Theorem

Under the relative-velocity conflict model, for any set of n O-D pairs,

$$T^* = O(\kappa \log n).$$

Proof outline: The following algorithm achieves the bound:

- Let c be the center of the largest disk not containing any source/destination node. Note that the radius of this disk, also known as the dispersion of the node point set, is $\Omega(\sqrt{A/n})$
- Two phases: All active mobile units move at an angular offset α (resp., $\pi - \alpha$) wrt to the radial direction, with speed proportional to their distance from c.
- Activation/deactivation (takeoff/landing) times computed in such a way that the boundary conditions are matched.



Some remarks

- Inter-agent coordination yields a substantial improvement on delays ($O(\log n)$ vs $O(\sqrt{n})$).
- Exact scaling not yet clear:
  - There exist arrangements of O-D pairs such that $T^* = \Omega(\log n)$, but also arrangements such that $T^* = 0(1)$.
- Unrealistic assumptions about speed (linear scaling with distance from center).
- However, the algorithm establishes the existence of an algorithm achieving superior performance.
- Also, the algorithm indicates that clever use of a common flow field can yield major performance improvements (NextGen theme).

A dynamic version of the transfer problem

A Queueing-Based Formulation of Traffic Analysis

- model the arrival of source and destination points stochastically, e.g., spatio-temporal Poisson point process, time parameter λ, and spatial density f.
- how do traffic densities and arrival rates affect metrics such as wait time, system time, queue length, etc?
- what is the effect of “shutting down” a portion of the workspace (e.g., to model a no-fly zone or severe weather system) have on system performance?
- Under what conditions does the system go unstable?

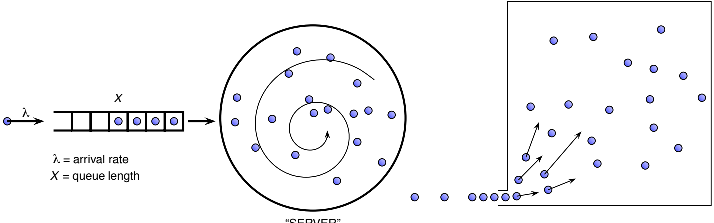
Preliminary queueing results

Simple batching policies yield:

- Queue instability in the "standard" case ($R_0 = const > 0$), for $\lambda > \lambda_{\max}$
- Stable operation for *any* λ for $R_0 = O(1/\sqrt{n})$, delays increase linearly with λ

$$T^* = O(\kappa^2 \overline{L}^2 \lambda / A).$$

- Stable operation for *any* λ for cooperating agents, sub-linear increase in delays with λ.

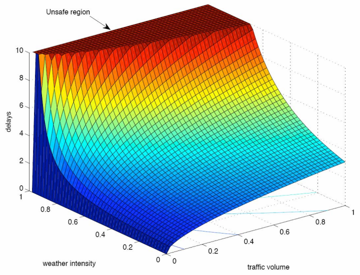


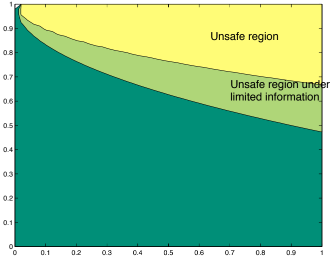
(a) batch transfer scenario

(b) zero wait time scenario

A path to unsafety

- The system's performance may be extremely sensitive to "degraded" conditions
- Excessive (not necessarily infinite) local load on the system can cause safety violations.
- Limited-information policies will result in smaller safety margins.
- Understand trade-offs between information/computation and safety.





Current/future work

- Transition cooperative routing algorithms to more realistic super-density operations scenarios
  - Decentralized computation, speed and acceleration bounds, non-convex environment, etc.
- Develop theory for the dynamic case (queueing models)
  - Assess precisely how weather, failures, etc., affect queue load factor, delays, etc.
- Address other metrics in addition to delays, e.g., Georgia Tech complexity models.

Risks

- Methodological risk: tools and techniques well understood in their original domain (e.g., queueing theory), but extension to problems involving dynamical systems are needed

- Gap between tractable abstractions and real-world applicability.

- Include numerical/simulation analysis (of our and/or others' approaches) and approximation techniques

Publications

- A. Vela and E. Salaün, “A two-stage stochastic program for air traffic conflict resolution under wind uncertainty”, 28th Digital Avionics Systems Conference, October 2009, *To be published*.
- A. Vela and E. Salaün, “A simplified approach for determining airspace capacity under automated conflict resolution”, 28th Digital Avionics Systems Conference, October 2009, *To be published*
- J-P.B. Clarke, S. Solak, Y-H. Chang, L. Ren, and A.E. Vela, “Air Traffic Flow Management in the Presence of Uncertainty”, USA-Europe ATM R&D Seminar, 2009.
- M. Gariel and E. Feron, “Algorithm of avoidance under uncertainties for a 3D airspace”, 28th Digital Avionics Systems Conference, October 2009, *To be published*.
- M. Gariel and E. Feron, “Graceful degradation of air traffic operations: airspace sensitivity to degraded surveillance systems”, IEEE, vol. 96, no. 12 , pp. 2028-2039, December 2008.

Plan

- Team
  - PI, students, other relevant personnel
  - Partnerships outside of NASA
  - Collaborations with NASA
- Objectives of research
  - Hypothesis being pursued
  - Relevance to IVHM
  - Progress to date
  - Publications
- Finances, Issues, Risks, and Concerns

Finances

- Project spending started with a time delay:
  Georgia Tech – spending initiated January ’09

  MIT – spending initiated March ‘09

Institution	budget	Remaining funds as of 08/1/09
Gatech	$136,000	~$45,000
MIT	$100,000	~$44,040.

Risks

- Late start caused by search for talent.
- Data is scarce, data containing incidents is more than scarce.
- Dealing with not only today's but also tomorrow's NAS ➔ emphasis on engineering analysis