National Aeronautics and Space Administration

IDEAS: Influence of Degraded Environment on Airspace Safety

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Introduction

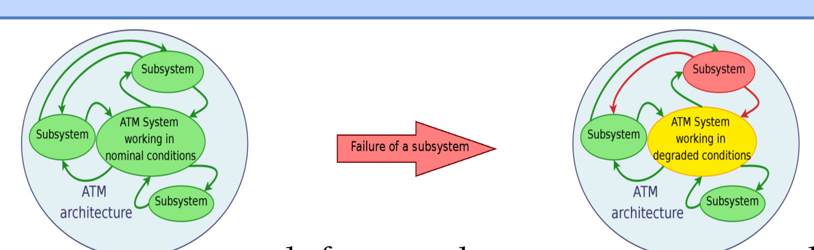
This research is concerned with evaluating the health and safety of current and projected NAS traffic against environmental degradations. Similar to health monitoring systems present in aircraft, our objective is to develop an effective health monitoring system for the air transportation system, whether it operates under current or future concepts of operations.

Our approach is based on developing appropriate input-output models of closed-loop air traffic operations, where the inputs are chosen to be hypothetical system perturbations to air traffic. The outputs represent quantities of interest to evaluate the reaction of the system. They range from how much control amplitude is required to how much communication bandwidth is required to implement and execute the control actions.

This poster presents various methods developed during Year I to evaluate and represent the impact of different parameters on airspace safety: those parameters include equipment failures, increase in traffic volume, compliance to procedures, etc. The diagram on the right hand side shows the integration of the tools in the air traffic management/control system. As the project proceeds into Years II and III, the methods will coalesce into an integrated airspace health monitoring tool.

Airspace Health measured by ability to operate well under nominal and off-nominal conditions:

Computational infrastructure: Computer and network system down.
Communications: Loss of phone lines or radio coverage.
Navigation: FMS failure.
Surveillance: Radar failure.
Operations: Misunderstanding between controller and pilot.
Vehicles: An intruder jeopardizing airspace safety.
Airport closure: A runway closing due to severe weather.
Increase of traffic volume: More aircraft in a limited airspace
Weather: Unexpected pop-up weather.



The ATM system is composed of many subsystems working together, If one fails, the entire system has to work in degraded mode. Health degrades when this is difficult/impossible

Recent publications

E. Salaün, A.E. Vela, E. Feron, J.-P.B. Clarke and S. Solak, **A Simplified Approach to Determine Airspace Complexity Maps under Automated Conflict Resolution,** *Digital Avionics Systems* Conference, October 2009.

A. Vela, S. Solak, E. Feron, K. Feigh, W. Singhose, and J.-P. Clarke, **A Fuel Optimal and Reduced Controller Workload Optimization Model for Conflict Resolution**, *Digital Avionics Systems Conference, October 2009.*

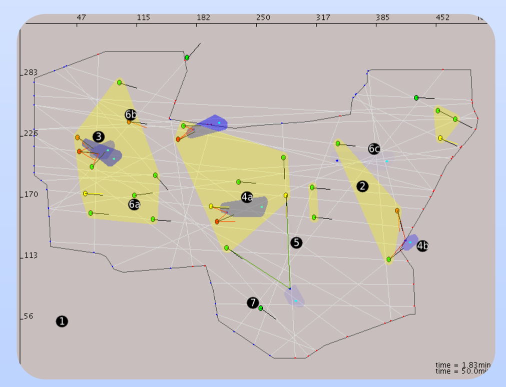
M. Gariel, A. Srivastava and E. Feron , **Aircraft Trajectory Clustering and an Application to Airspace Monitoring,** *Conference on Intelligent Data Understanding, Poster, October 2009.*

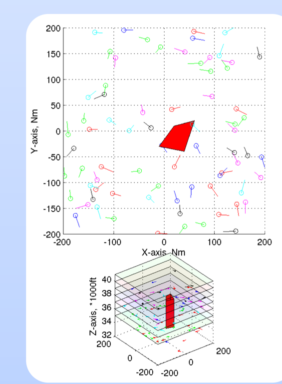
M. Gariel and E. Feron , **3D Conflict Avoidance under Uncertainties,** *Digital Avionics Systems* Conference, October 2009.
Session best paper award
Graduate student best paper award, 3rd place

GraDeMap : Graceful Degradation Maps

Modeling the CNS degradation and displaying its impact on traffic

•Degradation is modeled as an increase in separation distance between aircraft.
•The degradation introduces new potential conflicts represented in blue. The opacity of the blue area increases as time to potential conflict decreases.
•The shape of the blue area indicates the conflict's type: high or small relative velocity.





Existence of solution to ensure the safety of the airspace in case of degradation measures airspace health
•Single heading change for some aircraft.
•Solution computed using an algorithm of avoidance in the presence of uncertainty
•Aircraft color indicates the severity of the heading change/health.
•The new heading is proposed using a colored velocity vector.

MODEST: Minimum Origin DEstination Schedule Time

Impact of traffic density + safety requirements on system delay

Transfer Problem: How does the minimum time, T, required to safely move agents between source and destination points, scale as n becomes large?
Let q_i denote the position of agent. The system is conflict-free if

$$|q_i - q_j|^2 \geq k(q_j - q_i)^T (v_i - v_j) \quad k \geq 0, \text{ for all active agents } i,j \text{ and, for all } t \geq 0.$$

The following algorithm leverages inter-agent communication to ensure safety and realize the asymptotic bound $T = O\,log(n)$.

Algorithm
1. Let c be the center of the largest disk not containing any source/destination points.
2 Two phases: All active mobile units move at an angular offset α w.r.t. to the radial direction, with speed proportional to their distance from c. The first phase ends when all agents are inside the largest initially empty disk.
3 Activation/deactivation (takeoff/landing) times computed in such a way that the boundary conditions are matched.

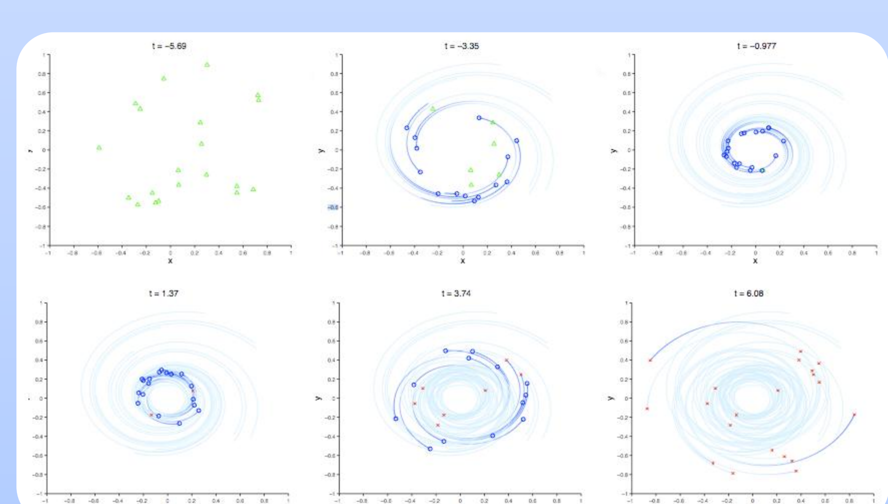
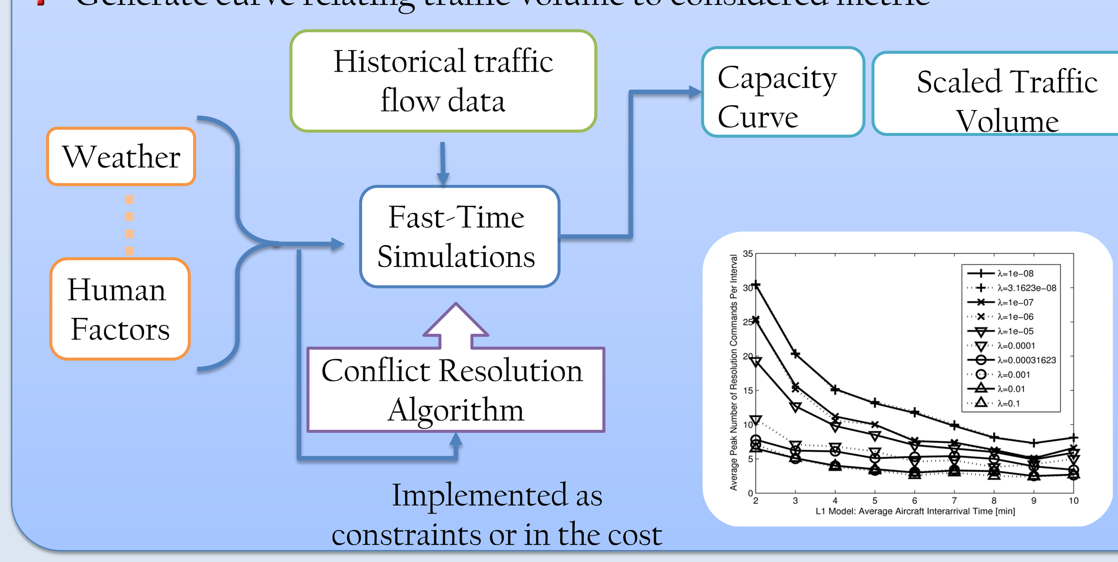


Figure: Initial work showing progression of agent trajectories during transfer. Green triangles denote agents that have not left their destination point. Red crosses denote agents that have reached their destination. Blue circles represents agents in the process of being transferred. The last 0.3s of each agent's trajectory is shown in varying shades of blue; the darker the shade, the more recently the point was visited.

CapEst: Calculation of Safe Capacity Curve

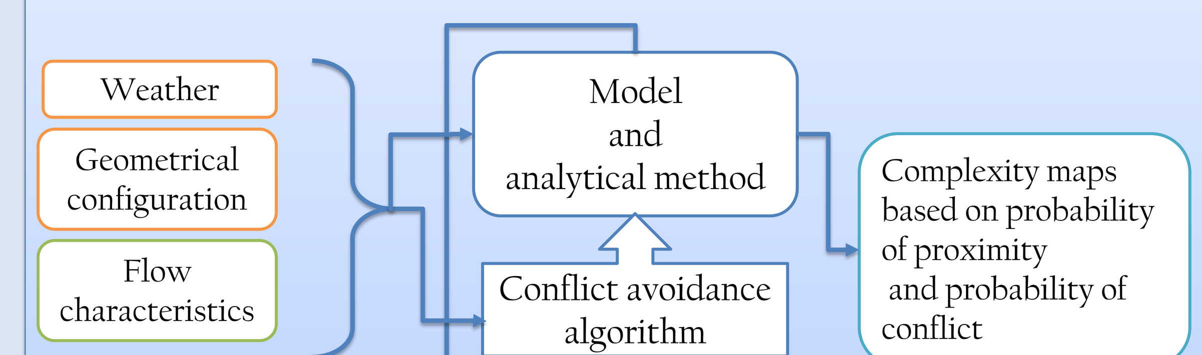
Health monitoring to support TFM

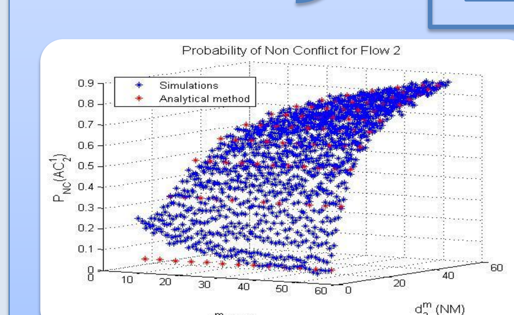
Goal: Estimate various airspace health/safety metrics through Monte-Carlo simulations over range of traffic volumes.
Result: Curves describing safe maximum traffic volume as a function of considered metric.
Strategy: Evaluate ability of algorithm to satisfy metric based on traffic volume using curves. Maximum traffic volume within constraints yields capacity of airspace.
Methodology
- Generate traffic based on historical data
- Provide metric, constraints, and perturbations
- Run Monte-Carlo simulations with traffic through airspace based on conflict resolution algorithm
- Generate curve relating traffic volume to considered metric



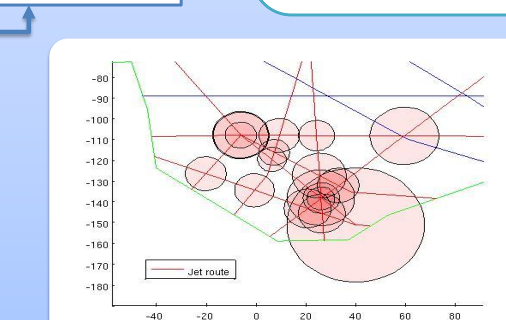
RaGeCoM: Rapidely Generated Complexity Maps

Generating health and complexity maps from statistical data





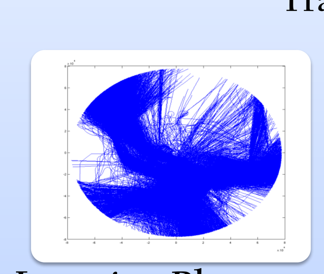
Validation of assumptions and model

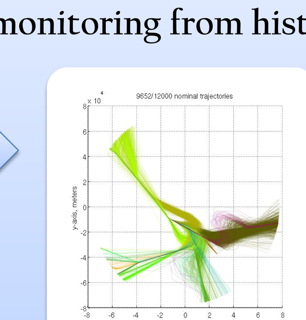


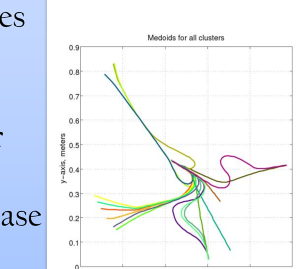
Ex: A sector in Cleveland center

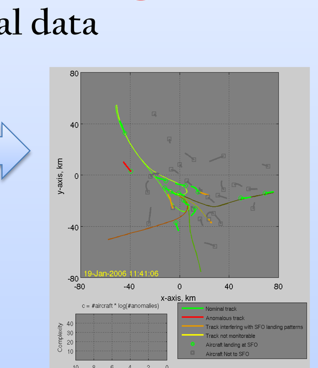
TracMon:TRACON Monitoring

Track monitoring from historical data





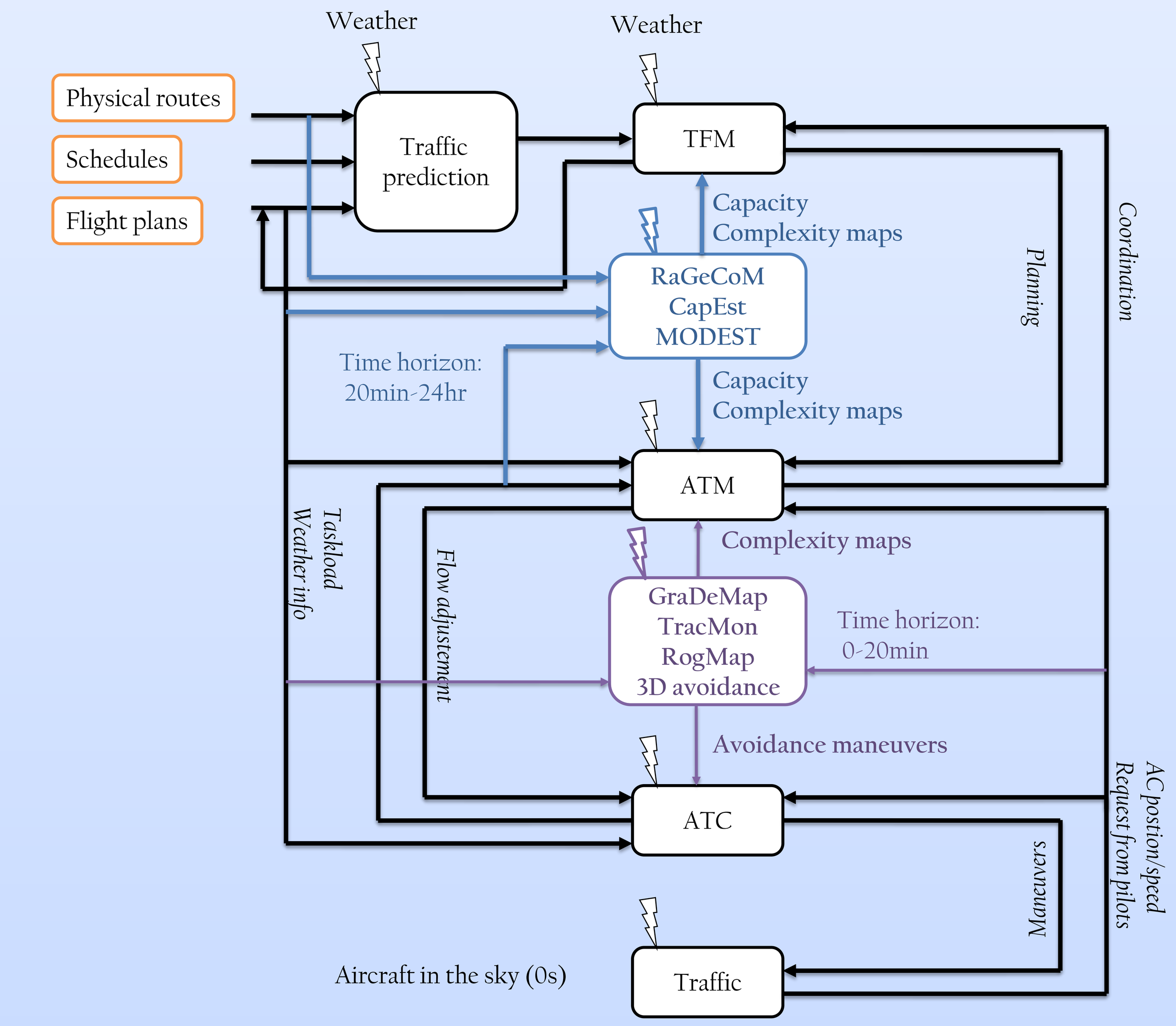




Learning Phase:
- Identify nominal trajectories and procedure using data mining techniques to clean, format, integrate and cluster data.
- Creation of a knowledge base of nominal trajectories

Monitoring:
Real time detection of off-nominal, safety-critical behaviors and possible interaction between aircraft flows

Tools integration in the ATM/ATC environment



	RaGeCoM	CapEst	GraDe Map	TracMon	Rog Map	3D avoidance
General information						
Description	Complexity maps with statistical approach	Estimation of capacity through Monte-Carlo simulations	Complexity maps based on potential CNS degradation	TRACON monitoring using Trajectory clustering and health monitoring algorithm	Complexity maps based on airspace response to disturbances	Algorithm of avoidance under uncertainties. Increases spacing distances between aircraft
Users	TFM / ATM	TFM / ATM	ATC/ATM	ATC/ATM	ATC/ATM	ATC
Strategic	x	x				
Tactical			x	x	x	x
Time horizon	1hr-24hr	1hr-24hr	0-20min	instantaneous	0-20min	0-20 min
Inputs						
AC flows	x	x				
AC position			x	x	x	x
Routes	x	x				
Flight plans	x	x				
Sector boundaries	x	x	x		x	x
Weather	x	x	x		x	
Human factor	x	x				
Degradation			x	x		x
Outputs						
Complexity map	x		x	x	x	
Capacity		x				
Avoidance maneuver			x			x

References:

Z.-H. Mao, E. Feron, and K. Bilimoria, **Stability and performance of intersecting aircraft flows under decentralized conflict avoidance rules,** *IEEE Transactions on Intelligent Transportation* Systems, 2001.

K. Lee, E. Feron, and A. Pritchett, **Air traffic complexity: An input-output approach**. *American Control Conference, 2007.*

J.P. Clark, S. Solak, Y.H. Chang, L. Ren, A. Vela, "**Air Traffic Flow Management in the Presence of Uncertainty**," *Eighth USA/Europe Air Traffic Management Research and Development Seminar (ATM2009)*, 2009.

Maxime Gariel, Eric Feron and John-Paul Clarke, **Air Traffic Management complexity maps induced by degradation of Communication, Navigation and Surveillance**, *AIAA Guidance Navigation and Control Conference, 2008.*