

Aircraft Emergency Trajectory Design

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AMLD

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- What is the objective of this work ?
- Resolution Algorithm
- Results
- Conclusions and Perspectives

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Auto-Pilot



Figure – Auto Pilot : manouvers

FMS

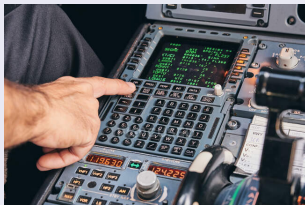


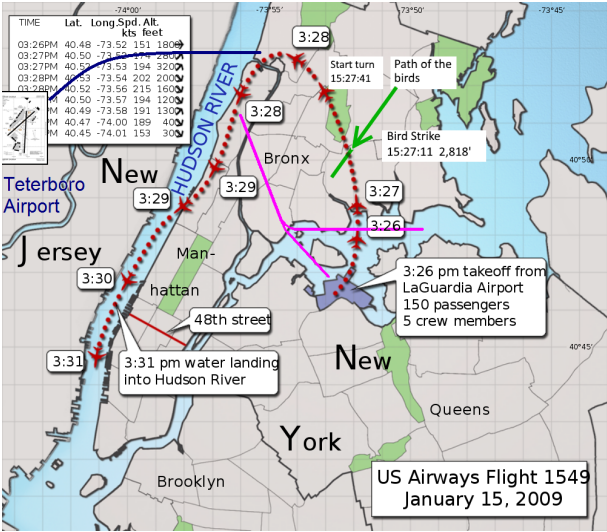
Figure – FMS : navigation

An example of critical situation : US-Airways 1549



Figure – On January 15, 2009, US Airways Flight 1549, an Airbus A320 struck a flock of birds shortly after take-off, losing all engine power.

US-Airways 1549



On-Board A/C Optimal Trajectory Generation

- Over 70% of fatal aviation accidents are in **take-off/landing phases**.
- Critical in mountainous terrain (e.g., LinZhi airport in China)
- Must take into account weather (wind, thunderstorms)

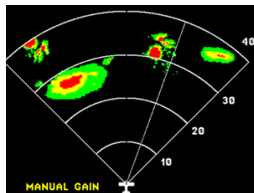


Figure – Thunderstorms avoidance

Types of Emergencies

As Soon as Possible (ASAP)

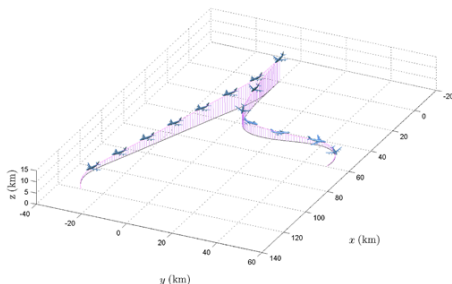
- Most critical emergencies, the pilot has to find the fastest way to land
- Examples : cabin fire, depressurization

At Nearest Suitable Airport (ANSA)

- Safest landing
- Example : dual engine failure

Aircraft Emergency Landing

- **Time** is the most critical factor
 - US Airways flight 1549 : **3min**
- **Fuel** may be a limiting factor too
- **Challenges**
 - **Real-Time** requirement
 - **Convergence** guarantees



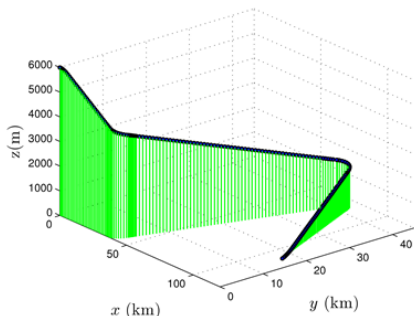
Principle : hierarchical approach

① Geometric planner

- State constraints, obstacles
- Path generator

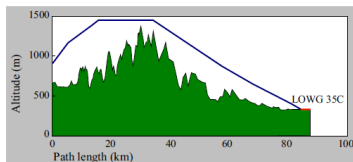
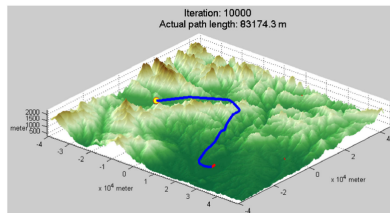
② Motion planner

- Time parameterization
- Trajectory generator



⇒ **Key Idea** : First find flyable **path** to avoid obstacles ; then find a feasible **trajectory** to follow along this path.

Previous Related Works



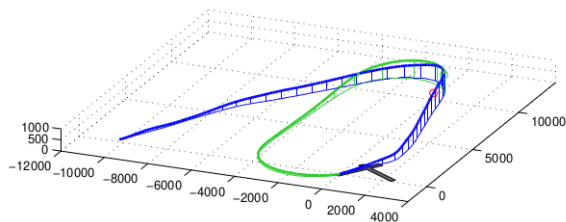
Fallast, A. ; Messnarz, B.

Automated trajectory generation and airport selection for an emergency landing procedure of CS23 aircraft.

DEAS Aeornautical J. **2017**, *8*, 481–492.

Computation time limitation

Previous Related Works



Zhao, Y. Efficient and Robust Aircraft Landing Trajectory Optimization. Ph.D. Thesis, Georgia Institute of Technology, Atlanta, Georgia 2012.

Do not take into account obstacles

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Objectives

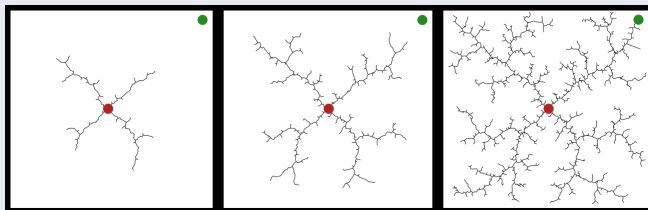
- Find a **safe** flyable trajectory
- ASAP or ANSA
- **Fast computation**

Constraints

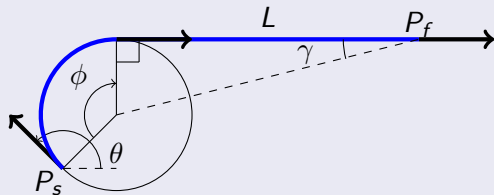
- Current heading and landing site direction
- Terrain and weather avoidance
- Curvature (radius turn and number of turns)
- Descent profile
- Wind
- Failure feature

Rapidly-Exploring Random Tree

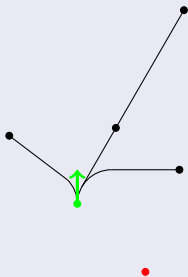
- Generation of a random point at each iteration
- Search for the path in parallel with the creation of the graph. For each new node, the father of the node is retained to determine the path.



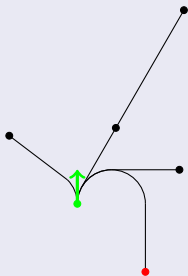
Single Turn Curve



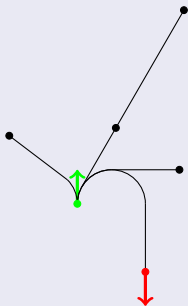
Node connection



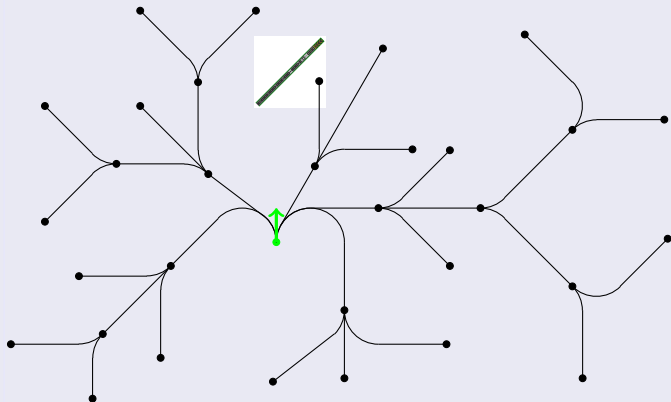
Node connection



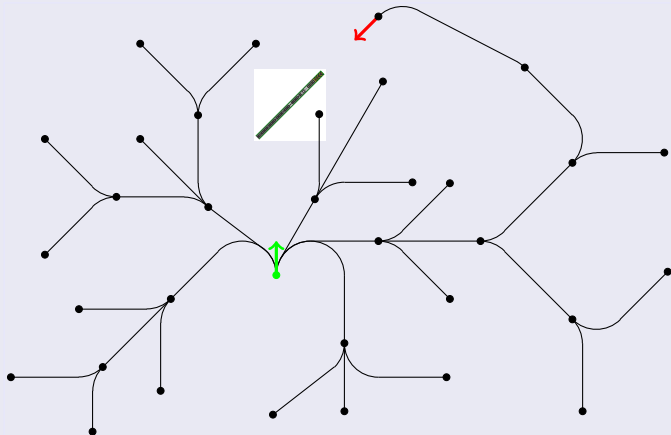
Node connection



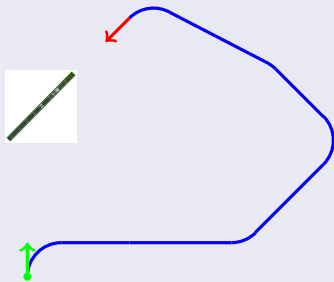
Graph of curves



Graph of curves



Computed path



Objective function : Minimization of the curvature

- Trajectory composed of n curves c_1, c_2, \dots, c_n
- ϕ_i the turn angle of the curve c_i

$$\min f(c_1, c_2, \dots, c_n) = \sum_{i=1}^n e^{\phi_i}$$

Minimization of the curvature

- Penalize trajectories with big turns

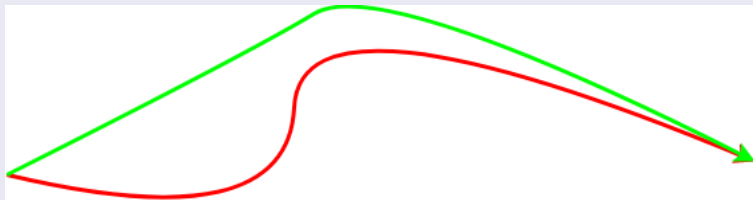


Figure – Red trajectory cost $>$ Green Trajectory cost

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- **Results**
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Emergency Example

- A320
- Emergency near to Grenoble in France
- ASAP
- ANSA

Emergency Example

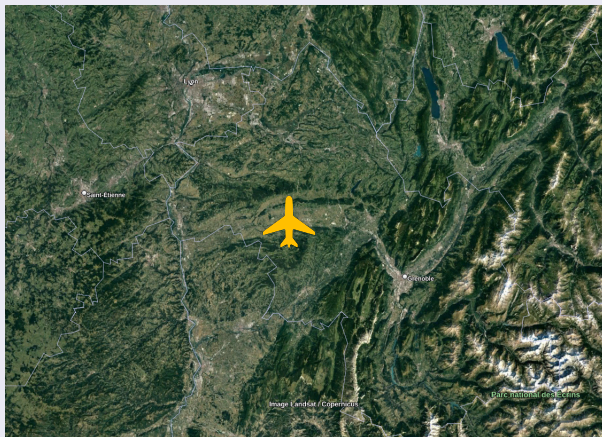
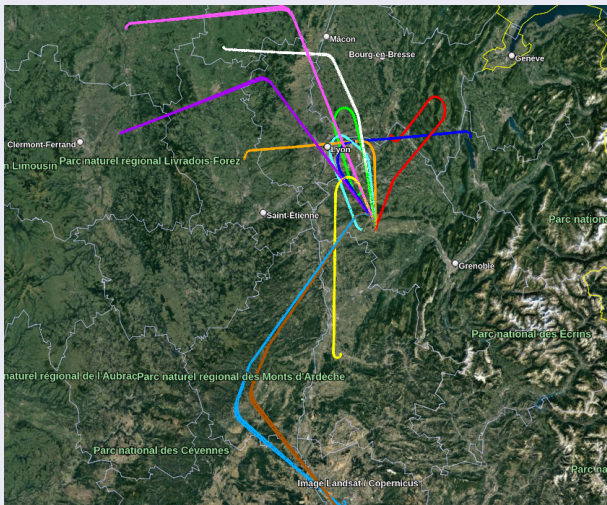


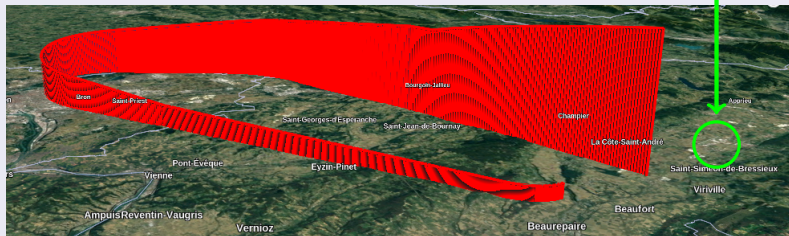
Figure – Emergency declared near to Grenoble at an altitude of 32000ft

As Soon As Possible (ASAP)

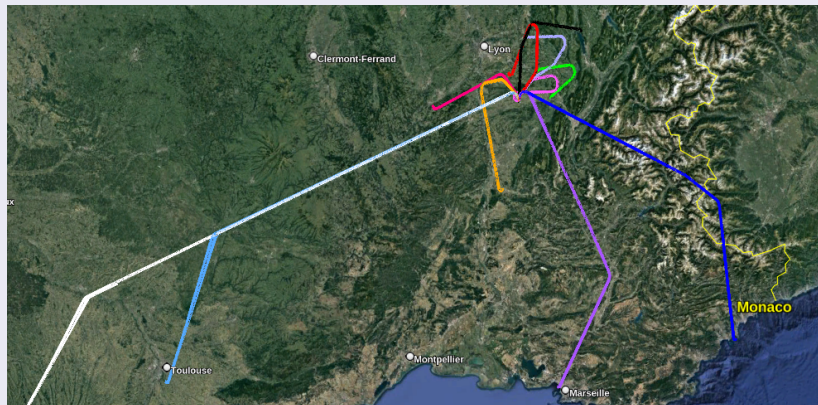


Vertical Profile (ASAP)

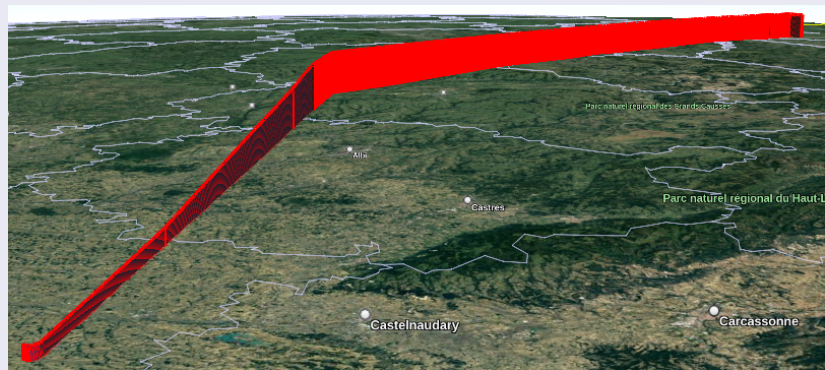
Grenoble airport



At Nearest Suitable Airport (ANSA))



Vertical Profile (ANSA)



Computing time

Emergency type	ASAP	ANSA
Computing time (s)	10	15

Table – Computing time in seconds to generate 10 trajectories

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Conclusions

- Emergency \Rightarrow huge workload for pilots
- \Rightarrow new DST
- Efficient algorithm has been proposed
- Extended with a landing sites selector (Clean Sky project : Safency)

Perspectives

- Real case tests
- UAV
- SID-STAR design

Questions ?