Aircraft Emergency Trajectory Design

A. Guitart and Pr D. Delahaye

Optim and ML team - French Civil Aviation University - Toulouse France
ANITI Research Chair (AI for ATM and UTM)
AMLD

March, 28, 2022
Agenda

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

Auto-Pilot

Figure – Auto Pilot: manoeuvres

FMS

Figure – FMS: navigation
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 Flight 1549

January 15, 2009

US Airways Flight 1549

Start turn 15:27:41
Path of the birds

Bird Strike 15:27:11 2,818'

3:28 pm takeoff from LaGuardia Airport
150 passengers
5 crew members

3:28

3:27

3:26

3:29

3:29

48th street

3:31 pm water landing into Hudson River

3:31

3:30

3:29

New York

Queens

Brooklyn

New Jersey

Manhattan

Hudson River

Bronx

New York

Teterboro Airport

US Airways Flight 1549
January 15, 2009

3:26
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.
Fallast, A.; Messnarz, B.
Automated trajectory generation and airport selection for an emergency landing procedure of CS23 aircraft.
*DEAS Aeronautical J.* 2017, 8, 481–492.

Computation time limitation
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
Agenda

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

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.
Algorithm

Single Turn Curve
Algorithm

Node connection
Algorithm

Node connection
Algorithm

Graph of curves
Algorithm

Graph of curves
Algorithm

Computed path
Algorithm

Objective function: Minimization of the curvature

- Trajectory composed of $n$ curves $c_1, c_2, ..., c_n$
- $\phi_i$: the turn angle of the curve $c_i$

$$\min f(c_1, c_2, ..., c_n) = \sum_{i=1}^{n} e^{\phi_i}$$
Minimization of the curvature

- Penalize trajectories with big turns

Figure – Red trajectory cost $>\,\text{Green Trajectory cost}$
Agenda

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

- A320
- Emergency near to Grenoble in France
- ASAP
- ANSA
Figure – Emergency declared near to Grenoble at an altitude of 32000ft
As Soon As Possible (ASAP)
Results

Vertical Profile (ASAP)

Grenoble airport
Results

At Nearest Suitable Airport (ANSA)
Results

Vertical Profile (ANSA)
Results

<table>
<thead>
<tr>
<th>Emergency type</th>
<th>ASAP</th>
<th>ANSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computing time (s)</td>
<td>10</td>
<td>15</td>
</tr>
</tbody>
</table>

**Table** – Computing time in seconds to generate 10 trajectories
What is the objective of this work?

Resolution Algorithm

Results

Conclusions and Perspectives
## 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 ?