# iFly Progress Report
# WP5


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# WP5: Pushing the limits of conflict resolution algorithms

- Service CR needs of $A^3$ concept
- Organised in 4 tasks
  - **WP5.1**: Comparative study of conflict resolution methods
    - Corresponding Deliverable:
      - ✔ D5.1: Due T0+6; Public
  - **WP5.2**: Analysis of conflict resolution needs for $A^3$ operation developed by WP1 and WP2
    - Corresponding Deliverable:
      - ✔ D5.2: Due T0+12; Public
  - **WP5.3**: Further development of conflict resolution methods
    - Corresponding Deliverables:
      - ✔ D5.3i: Due T0+21; Internal
      - D5.3ii: Due T0+30; Internal
      - D5.3(final): Due T0+36; Public
  - **WP5.4**: Validation of the resulting conflict resolution method against the requirements
    - Corresponding Deliverable:
      - D5.4: Due T0+44; Public

# D5.1 Report

- **Report on conflict resolution methods**
- **Literature review with an emphasis on**
  - Methods applicable to autonomous aircraft
  - Resolution guarantees
- **Autonomous aircraft: Decentralization**
- **Centralized**
  - All aircraft jointly reach resolution,
  - Using global information
- **Decentralized**
  - Each aircraft makes its own decision
  - Using local information and possibly communication

# D5.1 Report

- **Long Term CR (Flow management problem)**
  - Only centralized methods available in literature
  - Mainly ground holding techniques
    - On-line, distributed TFM impractical, TFM in support of autonomous operations
- **Mid Term CR (horizons of tens of mins)**
  - Available methods in literature were investigated
  - Emphasis was given on their decentralizability
  - Methods were classified according to dimensions, CR maneuvers, multiple aircraft CR and trajectory propagation.
- **Short Term CR (within minutes)**
  - One level above TCAS, ACAS
  - Several algorithms were reviewed
  - Emphasis on methods providing conflict avoidance guarantees

# D5.2 Report

- **Report on the requirements of the autonomous aircraft concept**

- **Long Term CR**
  - Following D1.3, redefinition to horizons of 10s of mins to hours
  - Divided in:
    - Ground based "strategic flow management"
    - Airborne "trajectory management"
  - Common Themes:
    - Efficiency oriented, e.g. stick to the RBT, avoid congestion
    - Safety through constraints on airspace capacity/complexity
    - "Global" information required: Weather, intents, etc.
    - Optimization based formulation (computing load, certification)

# D5.2 – Ground based strategic flow management

- **Several methods have been proposed in non-A3 context**
- **Reviewed in D5.1**
- **Based on large scale optimization**
  - Optimize schedule, e.g. minimize arrival times
  - Subject to constraints, e.g. sector capacities
  - MILP formulations, heuristics, etc.
- **Could be adapted to ground support for A3 concept**
- **Bottleneck not CDR methods but input to them**
  - Replace "sector capacities" by "airspace density", "complexity"
  - WP3: Inherent complexity metrics
  - WP5: Abstract capabilities of mid- and short- term CDR
- **No algorithmic development for the time being**

# D5.2 – Airborne trajectory management

- **Propose to use mid-term CDR methods**
  - Current thinking for mid-term CDR optimization based
  - Decentralized update of reference trajectories or intents
  - Communication of intent information
  - "Optimal" reference trajectories subject to safety constraints
- **Use the same methods for trajectory management**
  - Blend TM into mid-term CDR optimization problem, e.g.
    - Minimize airspace complexity s.t. safety constraints, or
    - Minimize travel time s.t. safety and congestion constraints
  - Formulate separate TM problem, seed mid-term CDR with TM solutions
- **Again, added difficulty not algorithms, but input**
  - How are "congestion" or "complexity" quantified?

# D5.2 – Mid-term CDR algorithms

- **Initial effort on centralized mid-term CDR**
  - Stochastic model predictive control
  - Randomized optimization
  - Particle filter implementation

**Efforts to decentralize**

- **Short-term + mid-term coupling**
  - Navigation functions + model predictive control
  - Collision avoidance guarantee of NF
  - Preview afforded by MPC
  - Get the best of both worlds

**Efforts to decentralize**

# Midterm CDR: MPC

- **MPC = Model Predictive Control**

- **Automatic control method, allows one to deal with dynamic optimization in the presence of constraints**

- **Use model to predict the future**
  - Predict future trajectories of aircraft
    - E.g. over the next 20min
  - For different resolution manoeuvres
  - Select the "optimal" manoeuvre
    - E.g. Minimum conflict free deviation from RBT
  - Execute the first part of the selected manoeuvre
    - E.g. The first 3 minutes
  - Measure where the aircraft ended up and repeat

- **Feedback introduced through periodic measurement → Receding horizon implementation**

- **Optimization based, choice of optimization criteria and constraints makes a big difference in performance and computation time**

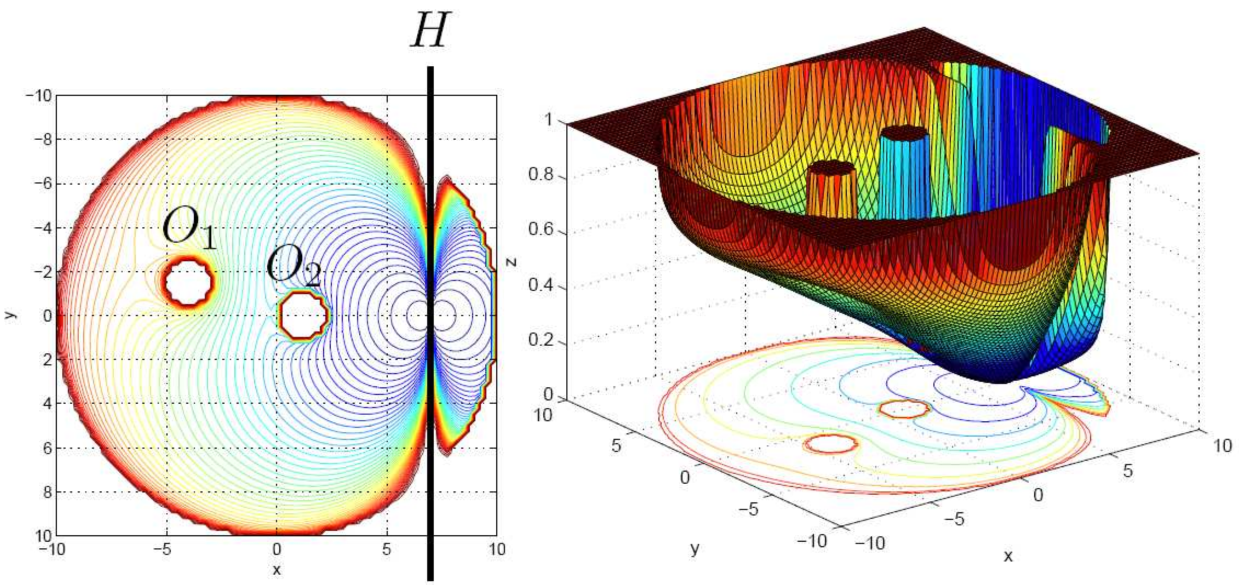
# D5.2 – Short term CDR algorithms

- **Extended navigation functions**
- **Good A$^3$ short term CDR candidate**
  - Short term horizon
  - Based on state + 1st level of intent information
  - Implicit coordination
  - No priority rules
  - No secondary conflicts
  - 1-to-N resolution
  - Resolution guarantees
- **Extensions needed**
  - 3D case
  - Input (speed, turning radius, acceleration …) constraint
- **Natural extension of NTUA research**

# Short term CDR: Navigation functions

- **Robotic path planning method**

- **Set up artificial potential**
  - Loosely speaking, think of aircraft as charges in electric field
  - Each aircraft attracted by its destination
  - Each aircraft repelled by other aircraft
  - Each aircraft repelled by restricted areas, ...



# Short term CDR: Navigation functions

- **Release aircraft in this artificial potential**
- **Can be shown that**
  - Aircraft converge to their destination
  - With the desired orientation
  - While avoiding conflicts with other aircraft, and
  - While remaining in the desired airspace region
- **But classical navigation function methods**
  - Only work in 2D
  - Do not account for input and state constraints
  - E.g. Aircraft can stop or turn on the spot
- **Further developments needed for A3**
  - Develop 3D variant (NTUA)
  - Enforce constraints → MPC provides preview (ETH, UCAM)

# D5.3i – Mid Term CDR algorithms

- **Decentralized model predictive control**
  - Robust formulation for Multiplexed MPC
  - Each aircraft optimizes future trajectory separately using
    - Local information
    - Any available global information: weather, etc.
    - Intent information of other aircraft
  - Plans communicated between aircraft
  - Process repeated in receding horizon manner
  - Formulate tractable optimization problems
  - Symmetry breaking

  - Theoretical guarantees
    - If a feasible plan exists initially, one will exist for ever

# D5.3i – Mid Term CDR algorithms

- **Combined MPC & NF approach**
  - Each aircraft optimizes the navigation function goals using
    - Local information
    - Any available global information: weather, etc.
    - Intent information of other aircraft
    - Operational constraints of the system
  - Plans communicated between aircraft
  - Process repeated in receding horizon manner
  - Minimization of a cost that can take into account operational goals for the aircraft

  - Theoretical guarantees
    - If the corresponding centralized problem is feasible, so is the decentralized
    - The conflict avoidance guarantees of NF are maintained

# D5.3i – Short term CDR algorithms

- **Further extensions of navigation functions**
  - 3D extensions
    - Implicit coordination
    - No secondary conflicts
    - 1-to-N resolution
    - Resolution guarantees still applicable

- **Initial thoughts on alternatives:**
  - Trajectory synthesis by logic
  - Concatenate
    - Straight, level flight segments
    - Turns
    - Climbs, descents
  - Synthesis using logic formulas and “model checking” tools
    - More difficult to include optimality considerations
    - Resolution guarantees by construction

# Current research

- **WP5.3: Further development of conflict resolution methods**
  - D5.3ii: Intermediate report on advanced conflict resolution algorithms for $A^3$ ConOps (T0+30)
  - D5.3: Report on advanced conflict resolution mechanisms for $A^3$ ConOps (T0+36)

- **WP5.4: Validation of the resulting conflict resolution method against the requirements**
  - D5.4: Final report including validation (T0+44)