Identification of Spatiotemporal Interdependencies and Complexity Evolution in a Multiple Aircraft Environment

Marko Radanovic, Miquel Angel Piera, Thimjo Koca - UAB
Christian Verdonk, Francisco Javier Saez – Cranfield University

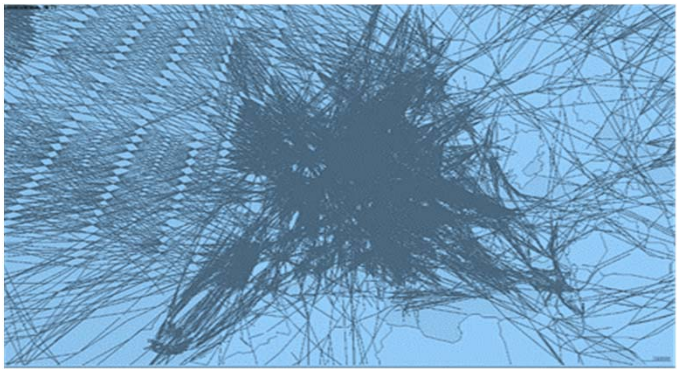
7th SESAR Innovation Days
28 - 30 November 2017
Belgrade, Serbia

SESAR JOINT UNDERTAKING

Founding Members
EUROPEAN UNION EUROCONTROL

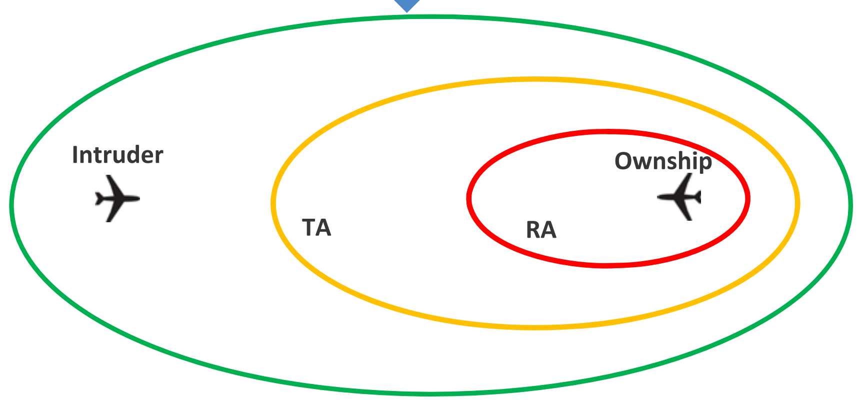
Outline

Introduction (I)

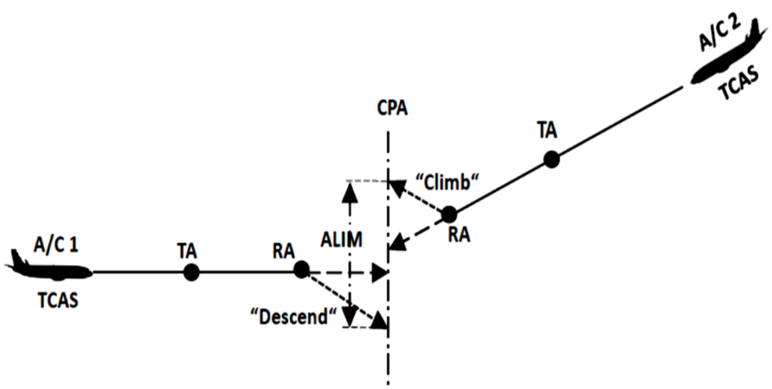


Increased traffic demand: 50% increase in flights by 2035 comparing to 2012

Continuous pressure on ACC for SM provision



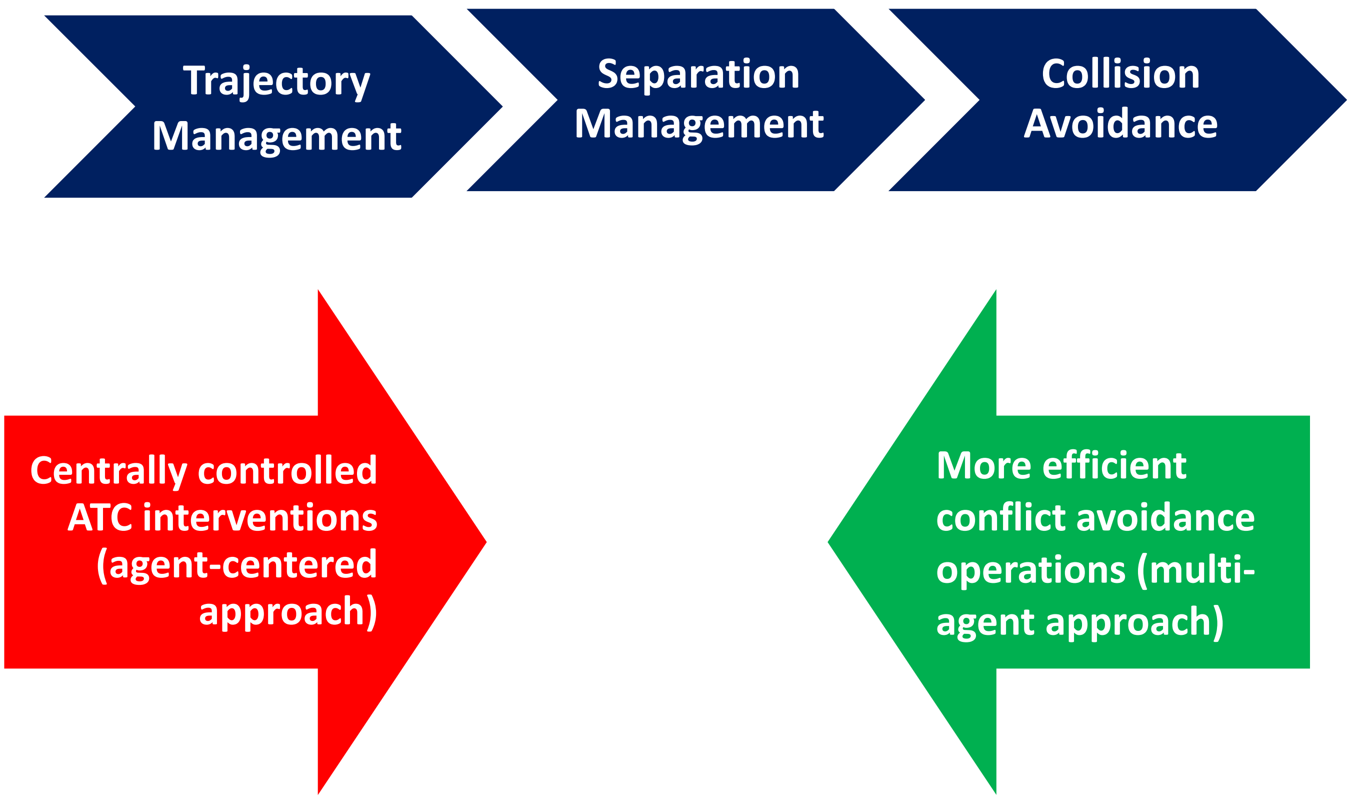
Missed provision due to increased ATC workload & insufficient time for reaction: CA activation



CA usually produces inefficient trajectory resolutions: higher vertical rate)

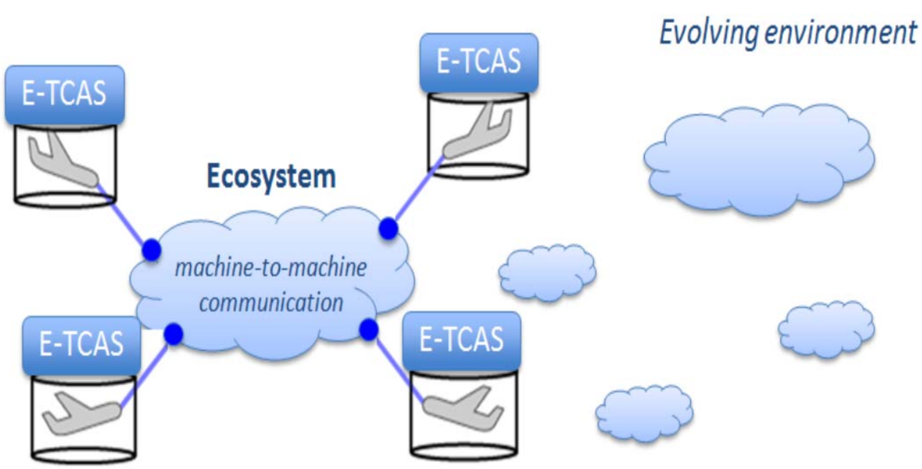
Introduction (II)

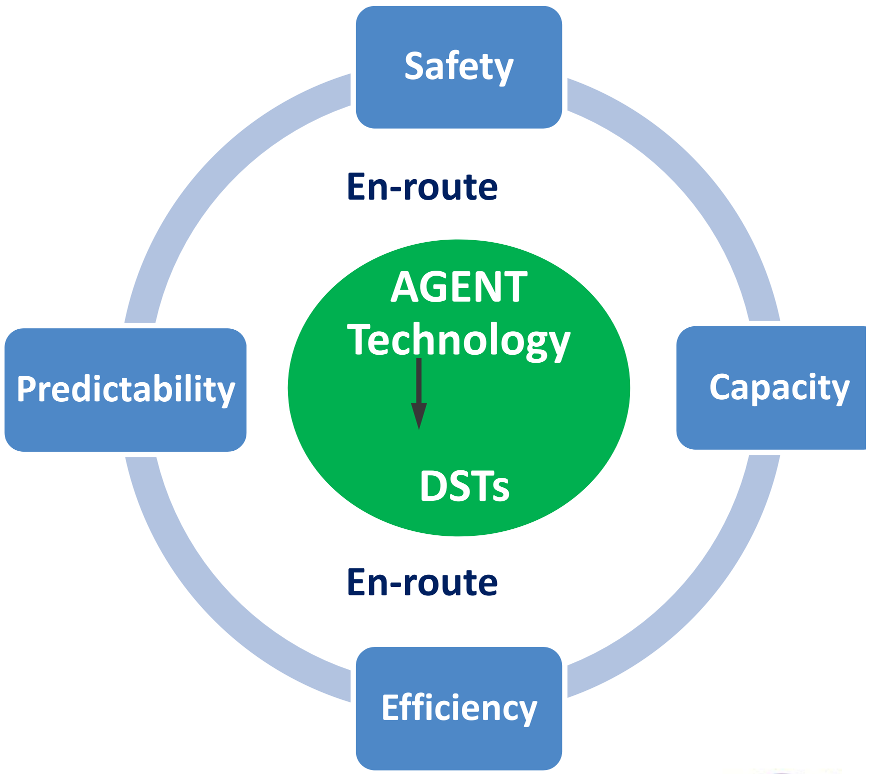
- Goal: SESAR and NextGen toward future harmonization of air traffic operations through development of airborne and ground-based DMTs
- Response: project AGENT seeks for smooth and coherent transition between safety nets



Introduction (III)

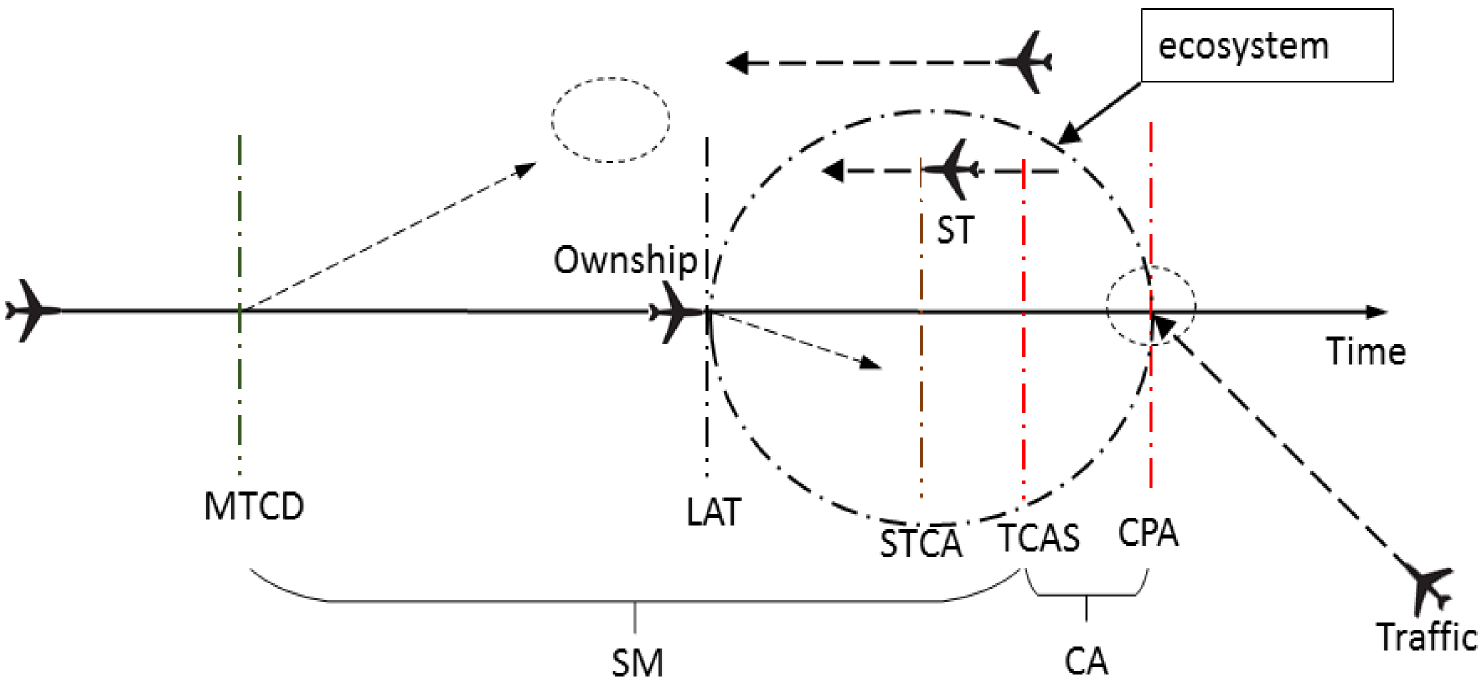
- AGENT claims for the collaborative and proactive SM system considering a socio-technological approach: multi-agent system (MAS)
- Driven by the certain SESAR KPIs
- ER-TRL 1: no ATC position fully considered





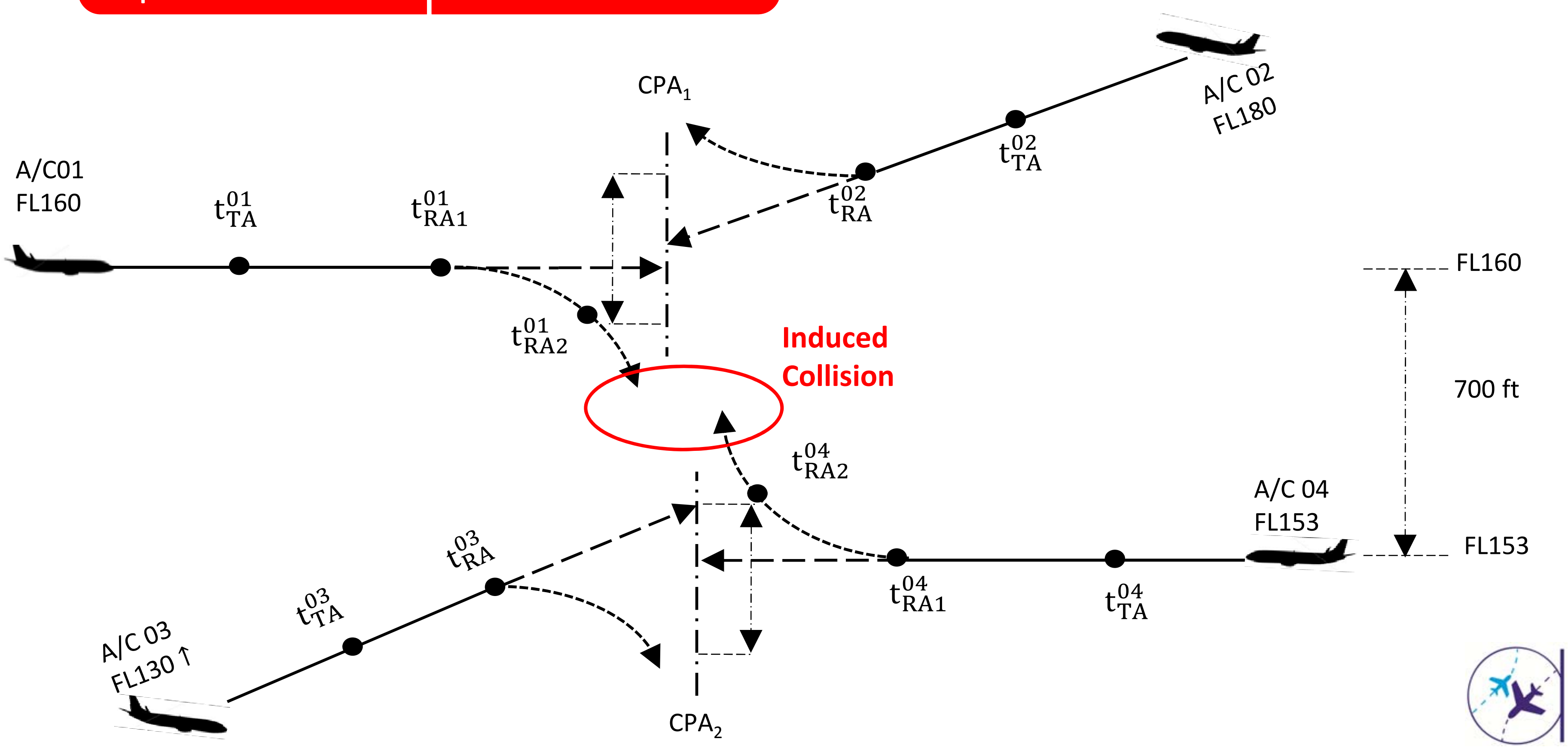
Introduction (IV)

- State-based CD function at strategic level and MAS-based CR algorithm at tactical level
- Assumptions:
    1. Lookahead time (LAT): 5’-to-CPA
    2. No uncertainty at TM level: a linearity of the trajectory segments within LAT



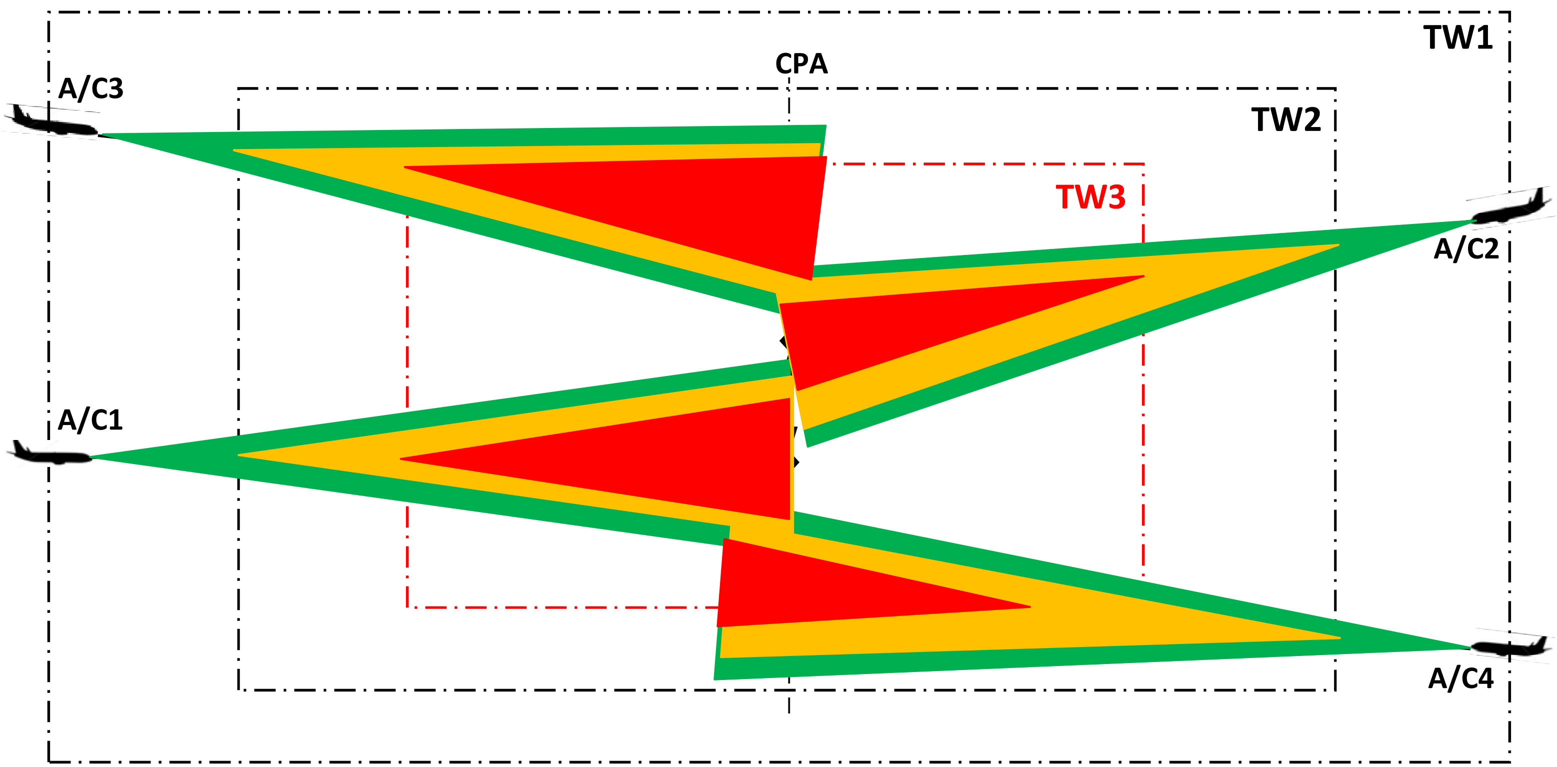
Problem definition (I)

Designed for operations in traffic densities of 0.3 ac/NM²	Excellent performances for pair-wise encounters
TCAS II v 7.1	
Logic drawbacks due to induced collisions in complex traffic scenarios	System-variant for closure rate changes towards CPA

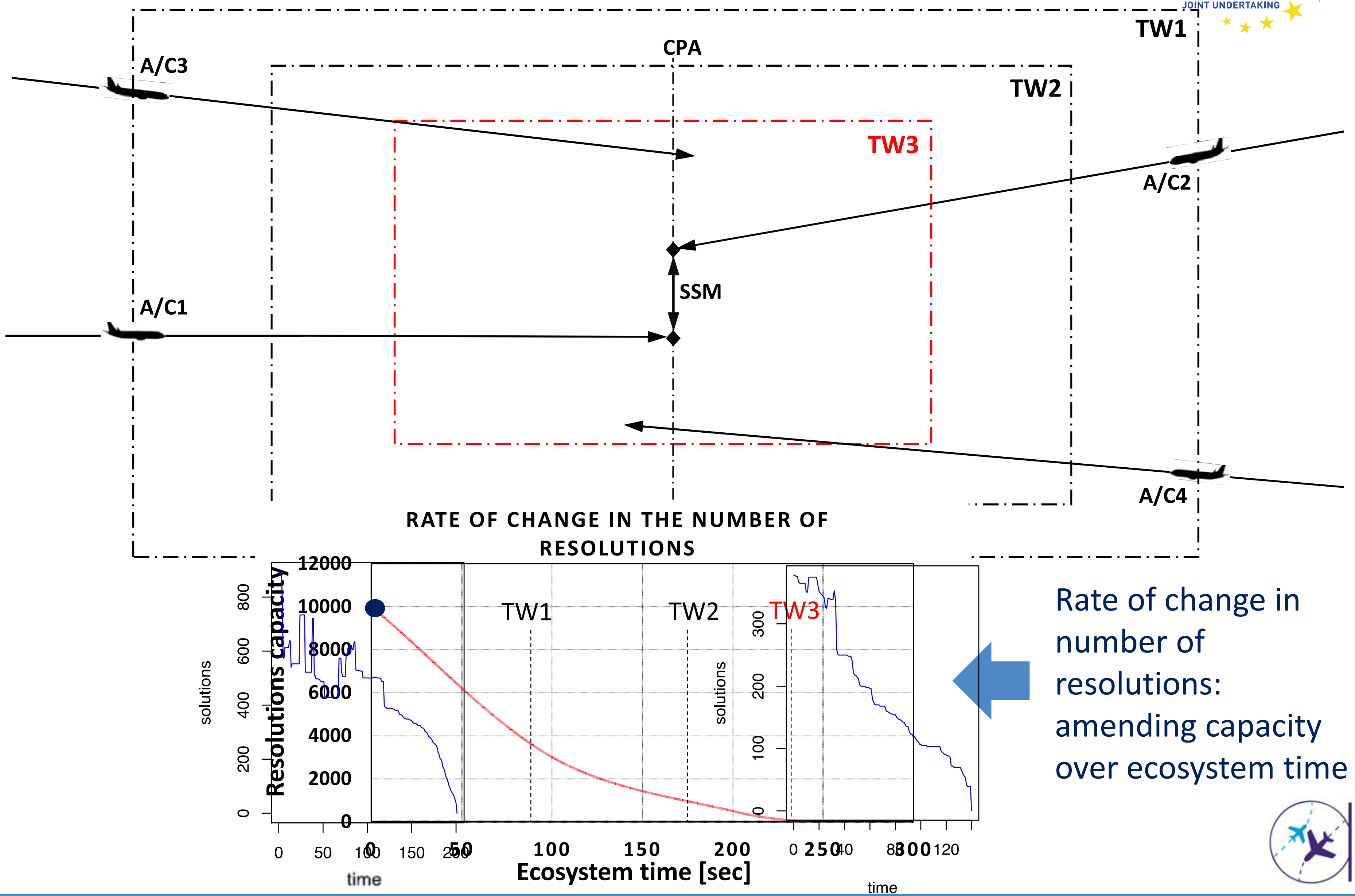


Problem definition (II)

Scenario evolution towards Ecosystem Deadlock Event (TW1 --- TW2 --- TW3)



Problem definition (III)

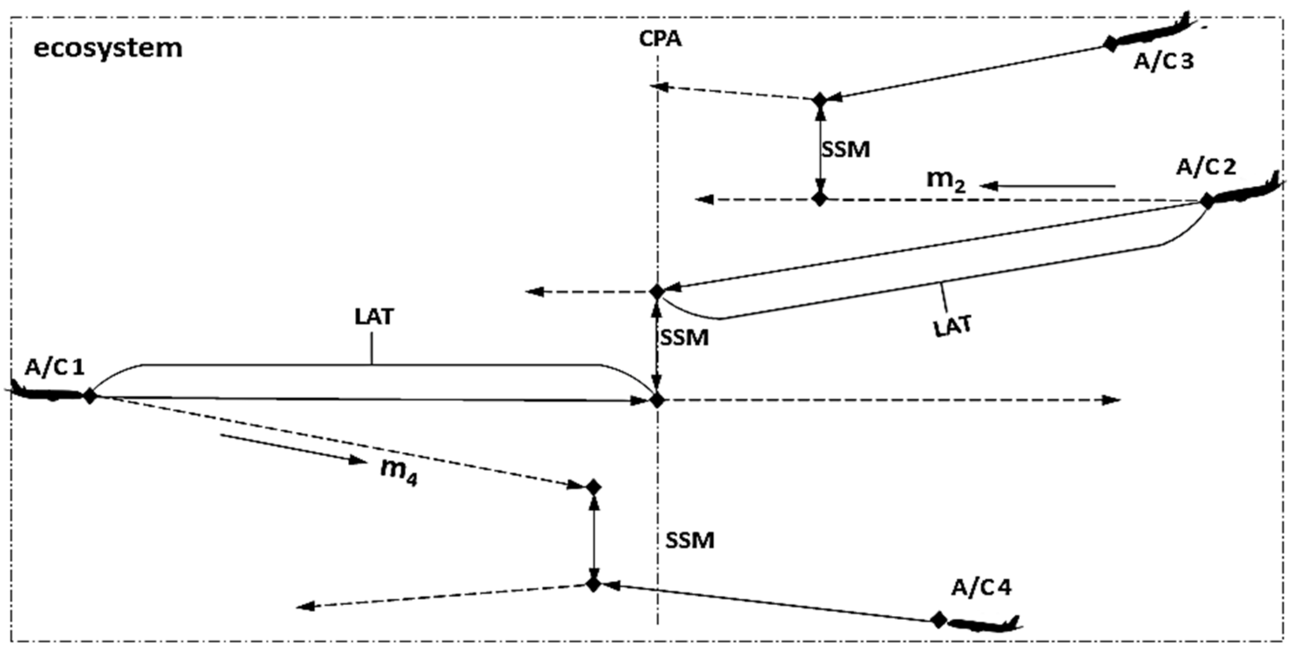


Rate of change in number of resolutions: amending capacity over ecosystem time

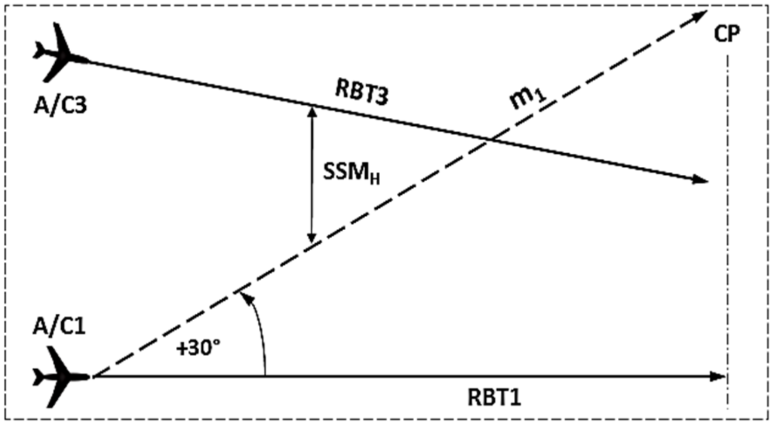
STI identification (I)

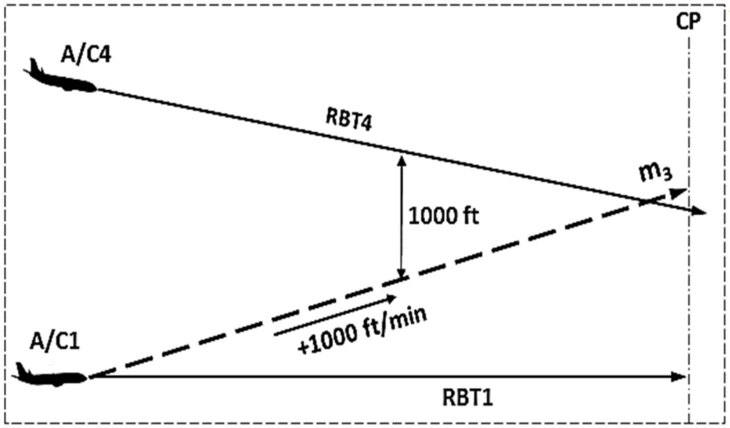
- DEF: set of aircraft inside computed airspace volume, with the trajectory-amendment, decision-making capability, causally involved in safety event
- STI parameters:

1. m_0: RBT follow-up
2. m_1: left HDG-C with DA of +30°
3. m_2: right HDG-C with DA of −30°
4. m_3: climb at VR of +1000 ft/min and FPA of +2°
5. m_4: descent at VR of −1000 ft/min and FPA of −2°

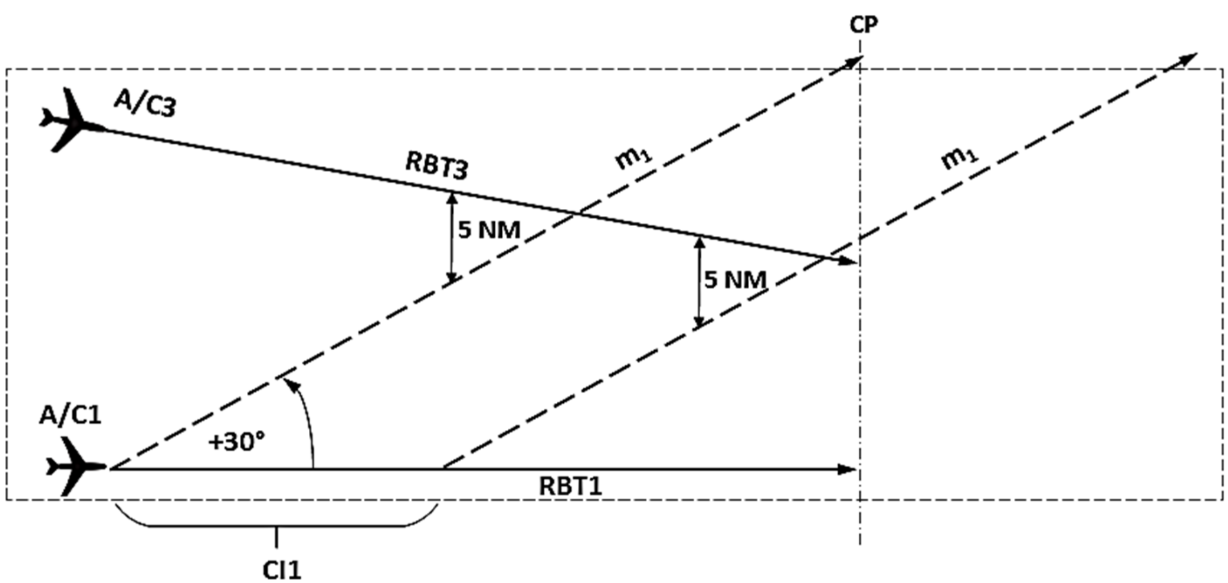


STI identification (II)





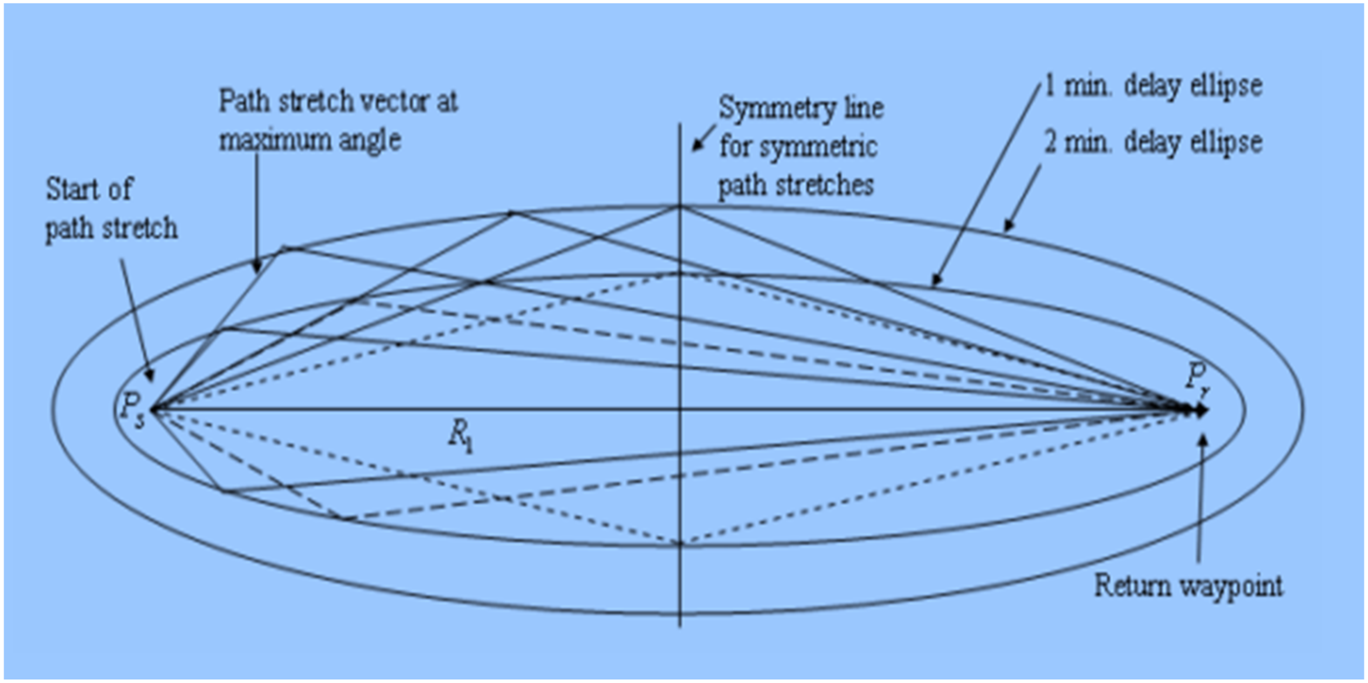
→ Identification of two ST aircraft: A/C3 through HDG-C and A/C4 through VR



→ CI for a single RBT applying a DA of +30°

CRT generation

- Complexity of ecosystem evolution based on decreasing/perishable rate in number of CRTs over time
- CRT generation: set of TWPs + RWP to RBT
- CRTs evaluated one against another by computation of intrinsic complexity (complexity value larger than the values analogous to the TCAS TAs: proposal rejected



→ Locus of tactical waypoints for introducing delay to resolution

Simulation results (I)

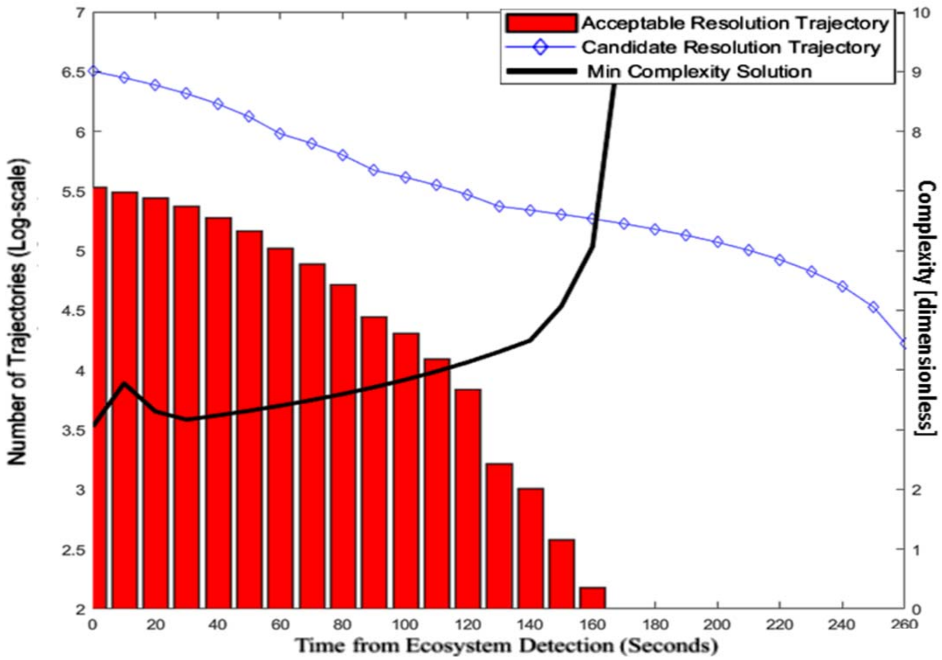
- Historical traffic dated on 24/08/2017: DDR2_M1.so6 data format (flight plans)
- Traffic extraction in the selected period: 08:00 – 09:00
- Operational environment: ECAC en-route airspace above FL300
- Ecosystem test case: nominal structure (4 members)

Flight ID	**4D structure of ecosystem trajectories**							
	φ_1 [°]	*λ_1 [°]*	*h_1 [ft]*	*t_1 [sec]*	*φ_2 [°]*	*λ_2 [°]*	*h_2 [ft]*	*t_2 [sec]*
A/C1	39.0000	-3.542	36000	0.00	39.5278	-3.489	36000	262.29
A/C2	39.0462	-3.874	36000	0.00	39.5506	-3.593	36000	262.29
A/C3	39.1109	-4.334	36000	0.00	39.5142	-3.814	36000	262.29
A/C4	39.7103	-4.075	39000	0.00	39.2788	-4.448	39000	262.29
A/C5	38.9277	-4.570	36000	0.00	39.3302	-4.052	36000	262.29

Ecosystem STI output			
STI_ID	***Interdependent aircraft***	***Maneuvering combination***	***Conflict interval [sec]***
STI_1	A/C1 – A/C2	m0 – m0	0.00 – 188.26
	A/C1 – A/C2	m0 – m3	0.00 – 188.26
	A/C1 – A/C2	m0 – m4	0.00 – 188.26
	A/C1 – A/C2	m2 – m1	0.00 – 188.26
	A/C1 – A/C2	m3 – m0	0.00 – 188.26
	A/C1 – A/C2	m3 – m3	0.00 – 188.26

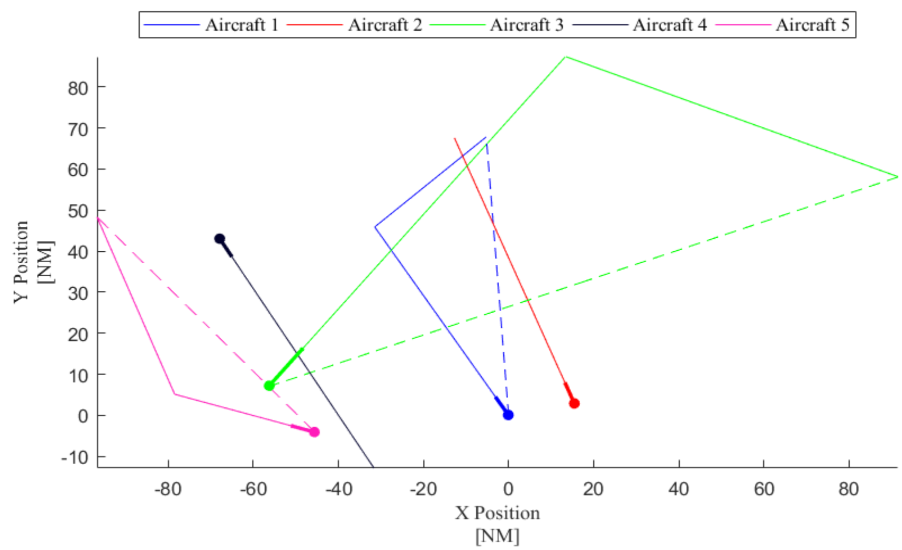
Ecosystem STI output			
STI_ID	***Interdependent aircraft***	***Maneuvering combination***	***Conflict interval [sec]***
	A/C1 – A/C2	m3 – m4	0.00 – 188.26
	A/C1 – A/C2	m4 – m0	0.00 – 188.26
	A/C1 – A/C2	m4 – m3	0.00 – 188.26
	A/C1 – A/C2	m4 – m4	0.00 – 188.26
STI_2	A/C2 – A/C3	m0 – m1	0.00 – 51.48
	A/C2 – A/C3	m0 – m3	0.00 – 51.48
	A/C2 – A/C3	m0 – m4	0.00 – 51.48
	A/C2 – A/C3	m3 – m0	0.00 – 51.48
	A/C2 – A/C3	m3 – m3	0.00 – 51.48
	A/C2 – A/C3	m3 – m4	0.00 – 51.48
	A/C2 – A/C3	m4 – m0	0.00 – 51.48
	A/C2 – A/C3	m4 – m3	0.00 – 51.48
	A/C2 – A/C3	m4 – m4	0.00 – 51.48
STI_3	A/C2 – A/C5	m2 – m0	120.00 – 130.28
	A/C2 – A/C5	m2 – m3	120.00 – 130.28
	A/C2 – A/C5	m2 – m4	120.00 – 130.28
STI_4	A/C3 – A/C4	m2 – m4	90.00 – 91.01

Simulation results (II)

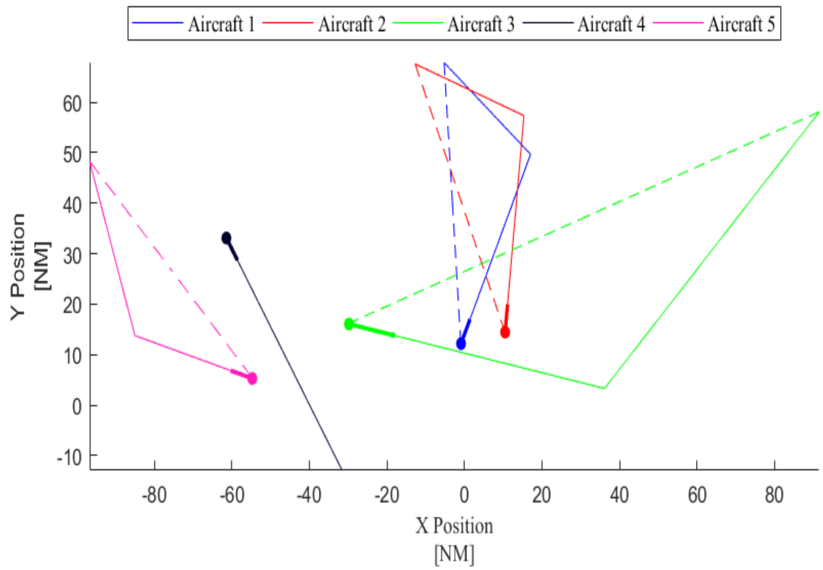


Evolution of acceptable and candidate RTs and complexity of the minimal complexity solution

Resolutions scenario I: Timestamp 0, lower complexity level

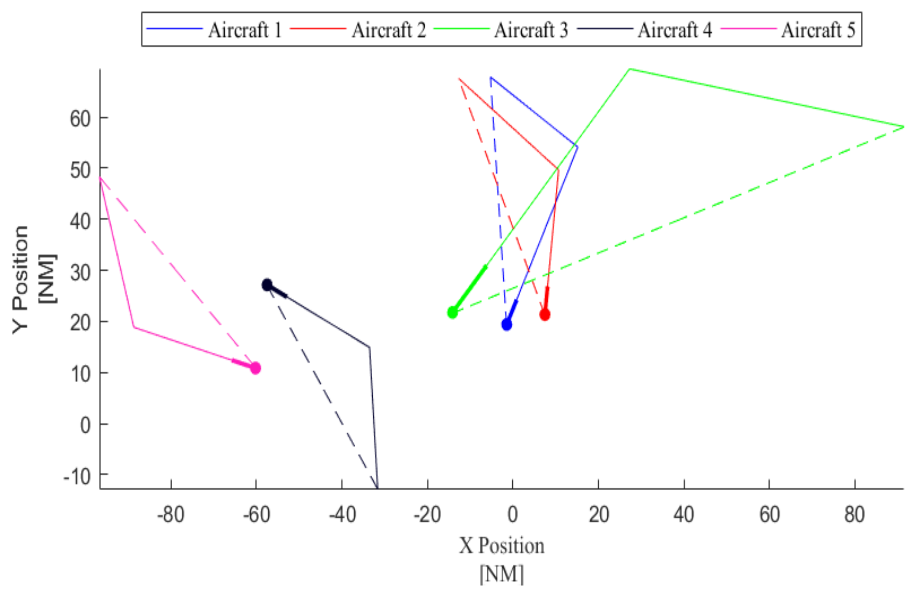


Simulation results (III)



Resolutions scenario II: Timestamp 100-seconds, medium complexity level (A/C1 and A/C2)

Resolutions scenario III: Timestamp 160-seconds, maximum complexity level (A/C1, A/C2 and A/C3)



Conclusions & follow-up research (I)

- ✓ Ecosystems creation to support automation at tactical level in the monitored airspace volume
- ✓ Analysis of the complexity levels coming from different traffic scenarios to increase the system robustness
- ✓ Smooth transition from the ecosystem membership identification to the acceptable candidate resolutions generation provides very valuable insight of the STI structure and a complexity level at a certain moment in a time evolution
- ✓ Number of the available RTs drops over time, for a fixed returning point of the intended trajectory; an exponential complexity trend due to chosen metric in evaluation
- ✓ Solutions can be compared on basis of the heading changes and delay propagation, followed by the minimal complexity value; prevention of the separation infringements in the horizontal plane, and provision of the compatible aircraft states with TCAS function in which the TAs would not be triggered

Conclusions & follow-up research (II)

- Analysis of the multi-thread conflicts with respect to time to the CPA
- Reduction of the computational time and an incorporation of the fine trajectory predictions for the ecosystem detection and resolution algorithms
- Extension of the parametric values for more robust STI testing
- Development of the agents' negotiation process and a deterministic prediction of the EDE

7th SESAR Innovation Days

Thank you for your attention!

Questions?

This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 699313

SESAR JOINT UNDERTAKING

Founding Members

EUROPEAN UNION EUROCONTROL