

On the design of UAS horizontal separation maneuvers

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Some concepts...

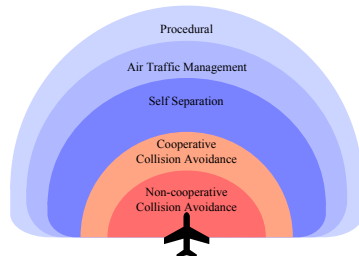
Separation Assurance & Collision Avoidance

Separation Assurance

- Aims at keeping minimum separation distance between aircraft and potential intruders.
- Typically responsibility of the ATC.

Collision Avoidance

- Aims at preventing imminent collision in case of loss of separation.



Some concepts...

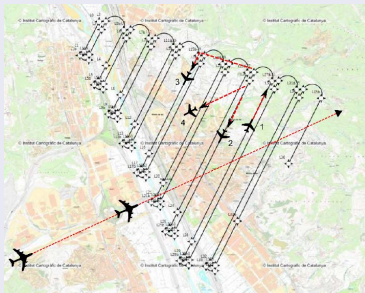
Unmanned Aircraft Systems & Applications

UAS

- UAS applications are increasing worldwide.
- Lack of regulation basis.

Unconventional Flight Plans

- Flight plans more complex than point-to-point.
- UAS will loiter over certain areas of interest beyond the rigid nature of the airspace where they operate.



Some concepts...

UA vs. Airliner

Performance comparison

- UAS may have **poorer flight performance** than commercial airliners

Performance Parameter	Unmanned Aircraft	Manned Aircraft
Cruise airspeed	↓↓↓	↑↑↑
Rate of climb	↓↓↓	↑↑↑
Cruise altitude	≈	≈



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Research Goals

Motivation

- Conventional separation maneuvers may have a **negative impact** on the UAS mission.
- Significant **performance differences** between UA and airliners may lead separation maneuvers more complex.

Objectives

- **Model scenarios** where a UA enters in conflict with a much faster airplane.
- Establish a taxonomy of UA **separation maneuvers** as a function of the conflict geometry that takes into account these dissimilarities.
- Apply **latency and turn limitation** aspects to the proposed separation maneuvers in order to validate them.

1 Introduction

- Some concepts...
- Main goals

2 Geometry

- Assumptions and Geometry definition
- Taxonomy definition

3 Maneuvers

- Catalog

4 Turn limitation and latency

- Latency
- Turn limitations

5 Conclusions & Further Work

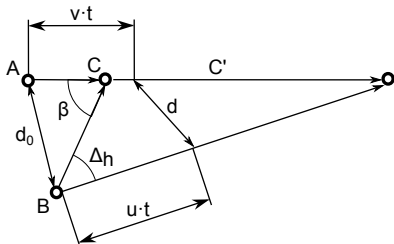
- Conclusions & Further work
- Questions

Assumptions and initial geometry definition

Initial assumptions

- Only UAS is deviated and its heading change Δ_h is performed instantaneously.
- Aircraft are moving at constant speed.
- No latency in UAS communications are considered.
- Intruder position and velocity are known by the UAS via ADS-B.

Symbol	Definition
A	Airliner initial position
B	UA initial position
C	Conflict Position (4-D)
v	Airliner velocity ($\in [300, 600]$ kt)
u	UA velocity ($\in [150, 300]$ kt)
β	Conflict angle
Δ_h	Heading change ($\in [-90, 90]^\circ$)
d_0	Initial separation distance
d	Current separation distance



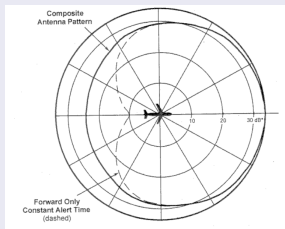
ADS-B

Requirements

- For ADS-B systems, **the required acquisition range** for a minimum alert time is **5 min.**
- Therefore, acquisition range must remain constant regardless the conflict geometry.

Coverage

- ADS-B antenna radiation pattern is **not omnidirectional.**



Time to conflict and heading change analysis.

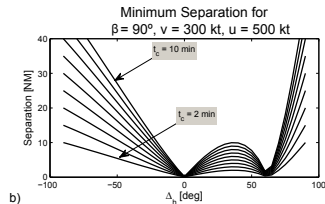
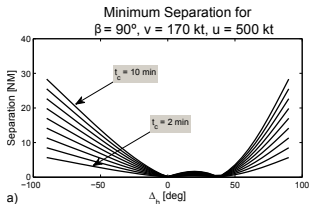
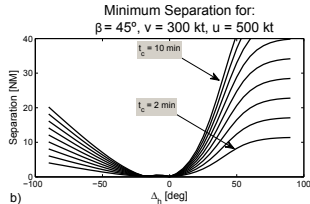
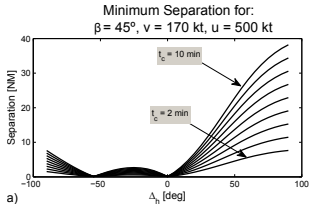
- Forward conflict ($\beta = 180^\circ$)

Separation Minima	Δh for 170 kt t_c [minutes]			Δh for 300 kt t_c [minutes]		
	2	5	10	2	5	10
3 NM	35°	15°	10°	20°	10°	5°
5 NM	55°	25°	15°	30°	15°	10°
10 NM	N/A	45°	25°	65°	25°	15°

- Backward conflict ($\beta = 0^\circ$)

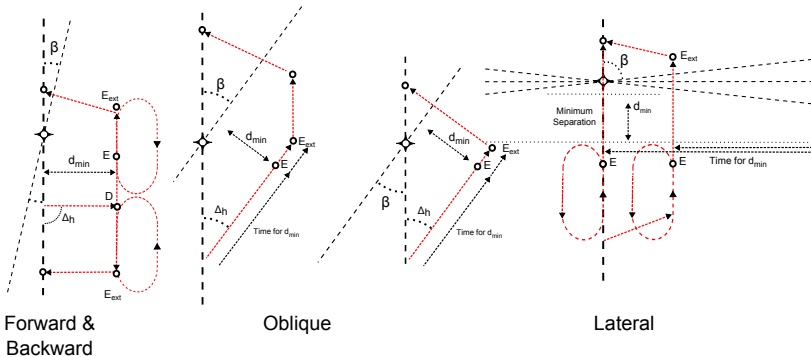
Separation Minima	Δh for 170 kt t_c [minutes]			Δh for 300 kt t_c [minutes]		
	2	5	10	2	5	10
3 NM	40°	15°	10°	25°	10°	5°
5 NM	N/A	25°	15°	N/A	15°	10°
10 NM	N/A	N/A	25°	N/A	50°	15°

Time to conflict and heading change analysis. Other β .



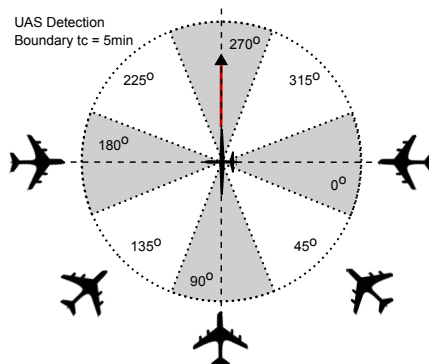
- M. Perez-Batlle, et al. "Evaluation of separation strategies for unmanned aerial systems" 5th ICRAT. Berkeley, CA (USA): EUROCONTROL / FAA, May 2012.

Catalog of separation maneuvers



Maneuver selection criterion

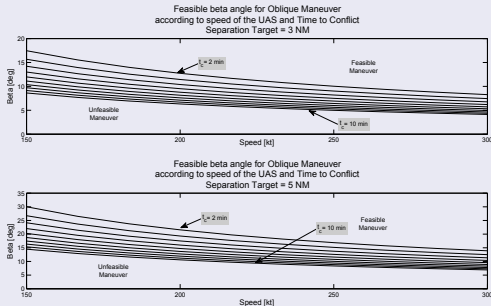
- The selection of the most effective maneuver depends on both UA speed and time to conflict t_c . But...**in which manner?** and...**When the UA could resume normal navigation?**



Maneuver selection results

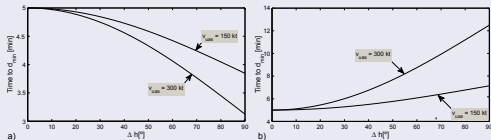
β threshold

- When oblique separation maneuver **has to be replaced** with back/forward ones?



Time to d_{min}

- When the UA could **resume navigation** on oblique separation maneuvers?



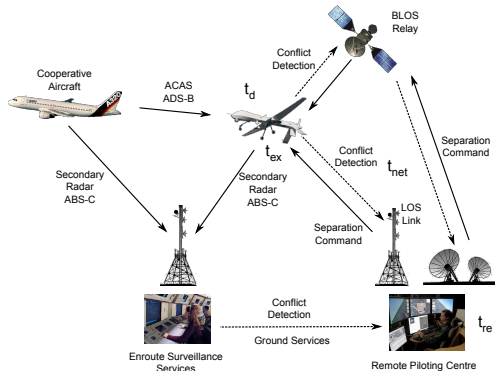
Latency issues

Assumptions

- Conflict detection will be done **on-board the UAS** (t_d, t_{ex}).
- **LOS/BLOS** communications (different t_{net} for each case).
- UA pilot on the **decision loop** (t_{re}).
- **Non-negligible latency**.

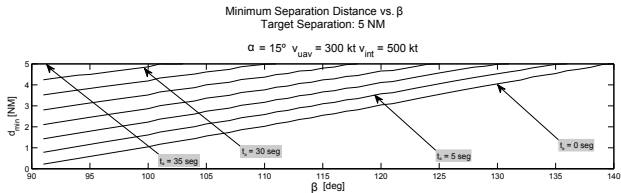
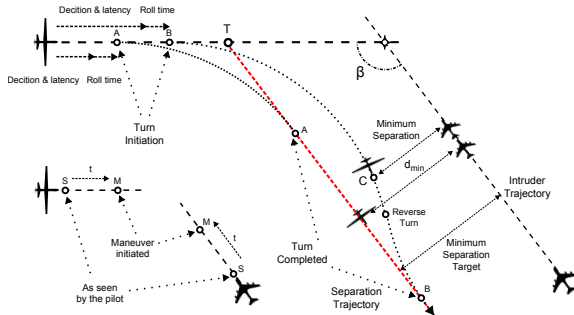
Proposed solution

- t_d, t_{ex}, t_{net} are effectively **bounded**.
- Use of **predicted positions** of both the UA and the intruder.



Turn limitations

Scheme & Results



Conclusions & Further work

Conclusions

- A taxonomy of UAS separation maneuvers has been addressed.
- Turn limitation and latency issues have been applied.
- Latency impact on separation conflicts may be minimized by means of coarse trajectory prediction.
- The impact caused by turn limitation is bounded to certain geometries.

Further work

- Full automation of the decision process for a realistic range of aircraft performances.

Questions?