European Commission

8th August 2017
Prague, Czechia

RULES FOR AVOIDANCE SYSTEM

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Honeywell

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This project has received funding from European Union`s Horizon 2020 research and innovation programme, under the Marie Sklodowska-Curie grant agreement No 642153

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Introduction

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Airspace classification

Space is separated into levels defined by boundaries:

Level C-F	– altitude in	Flight Levels	(FL)
Level G	– altitude in feet	Above Ground Level	(AGL)

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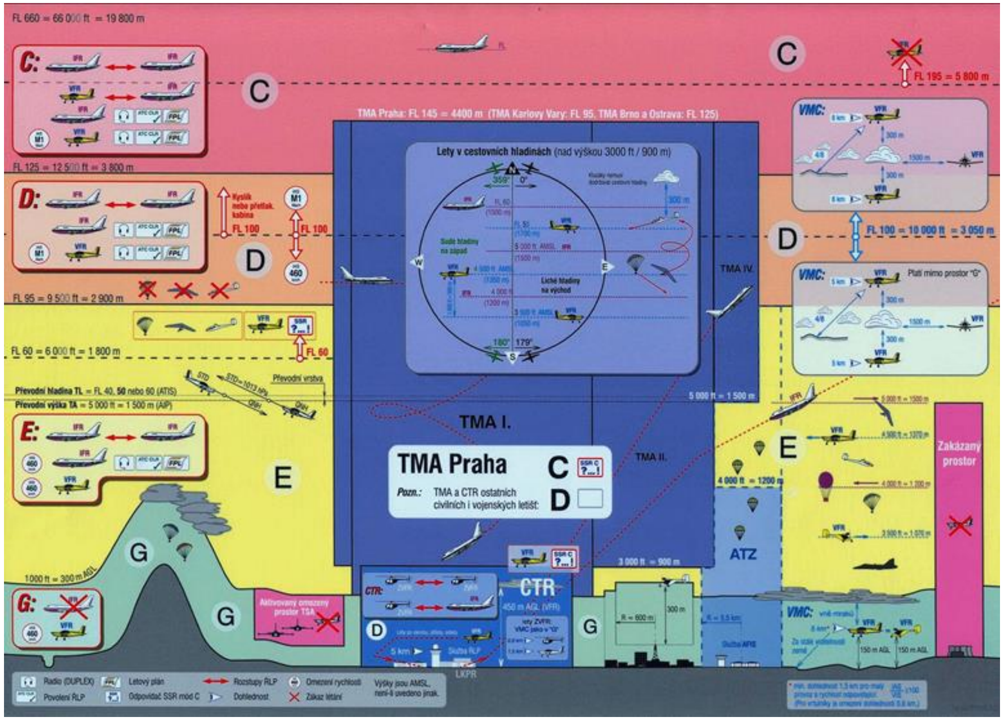
<u>Level G</u> – altitude in feet Above Ground Level (AGL)



Example of European Airspace classification (Czech republic)

Next slide

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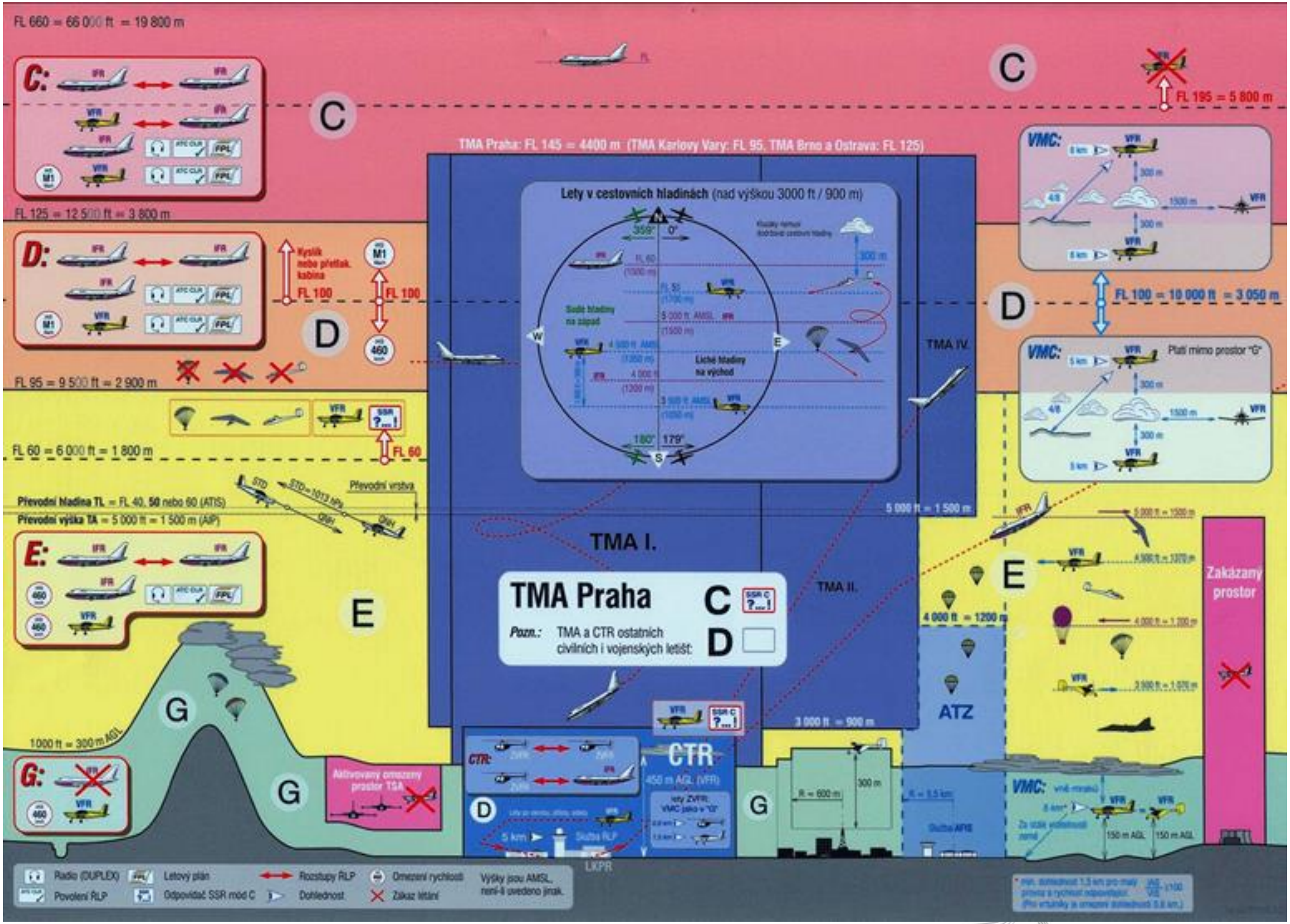
Airspace classification (Detail)



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Airspace levels for UAV operations

ICAO airspace classification:

- **Class F(E)**: Operations may be conducted under IFR or VFR. ATC separation will be provided, so far as practical, to aircraft operating under IFR. Traffic Information may be given as far as is practical in respect of other flights.
- **Class G**: Operations may be conducted only under VFR. ATC has no authority but VFR minimums are to be known by pilots. Traffic Information may be given as far as is practical in respect of other flights.

Class	Controlled	IFR	SVFR	VFR	ATC Clearance	Separation	Traffic Information
F	Uncontrolled	Yes	No	Yes	advisory only	Provided for IFR/SVFR to other IFR/SVFR where possible	Provided where possible if requested
G	Uncontrolled	No	No	Yes	Not provided	Not provided	Provided where possible if requested

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Expected mission types and constraints

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Surveillance and reconnaissance tasks

Goals:

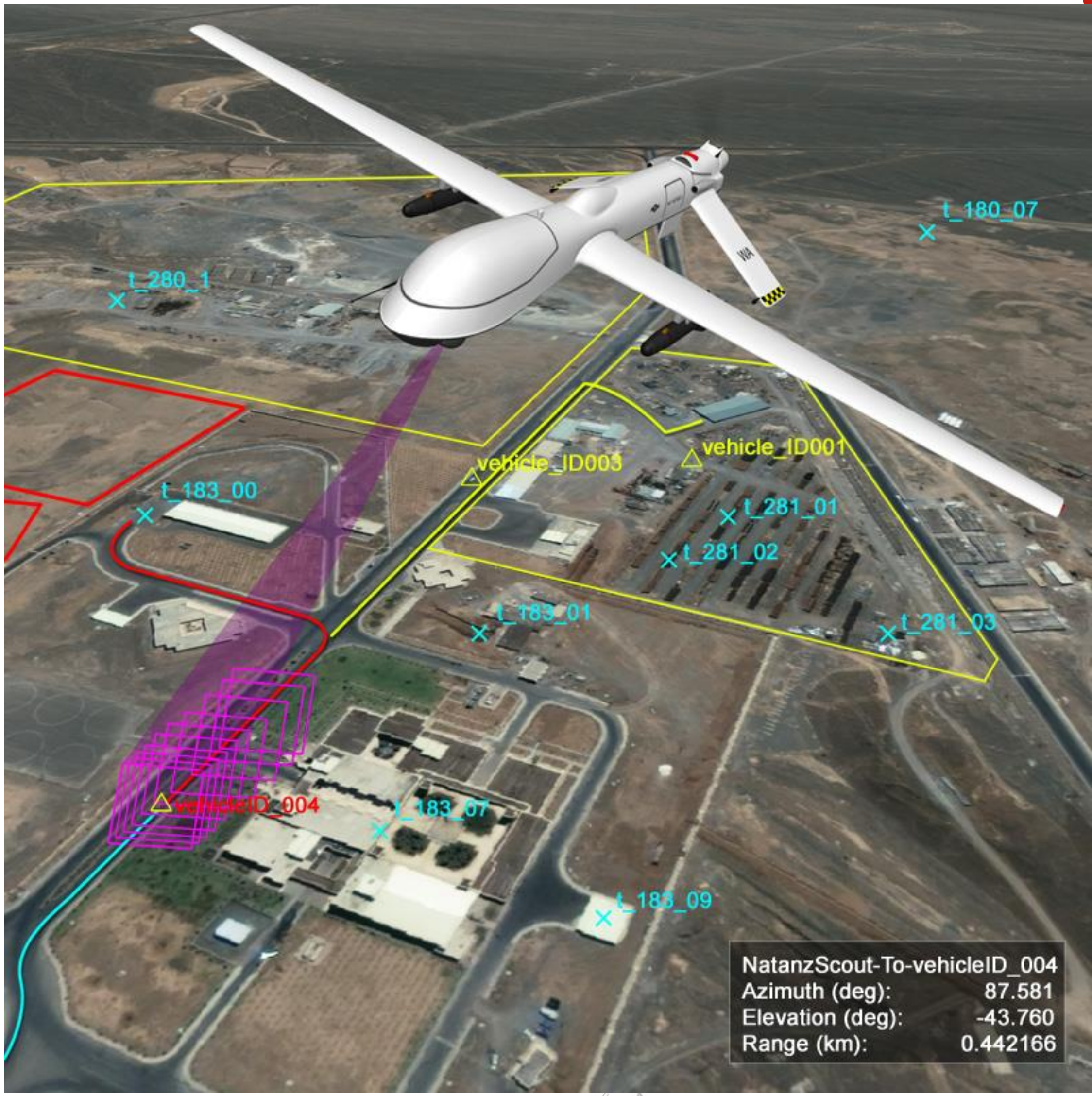
- Cover most of the area
- Stay safe

Long term plan:

- Generate surveillance plan (Fotios Balampanis USE)

Short term avoidance:

- Avoid intermediate obstacles
- Maintain maximal scanning height



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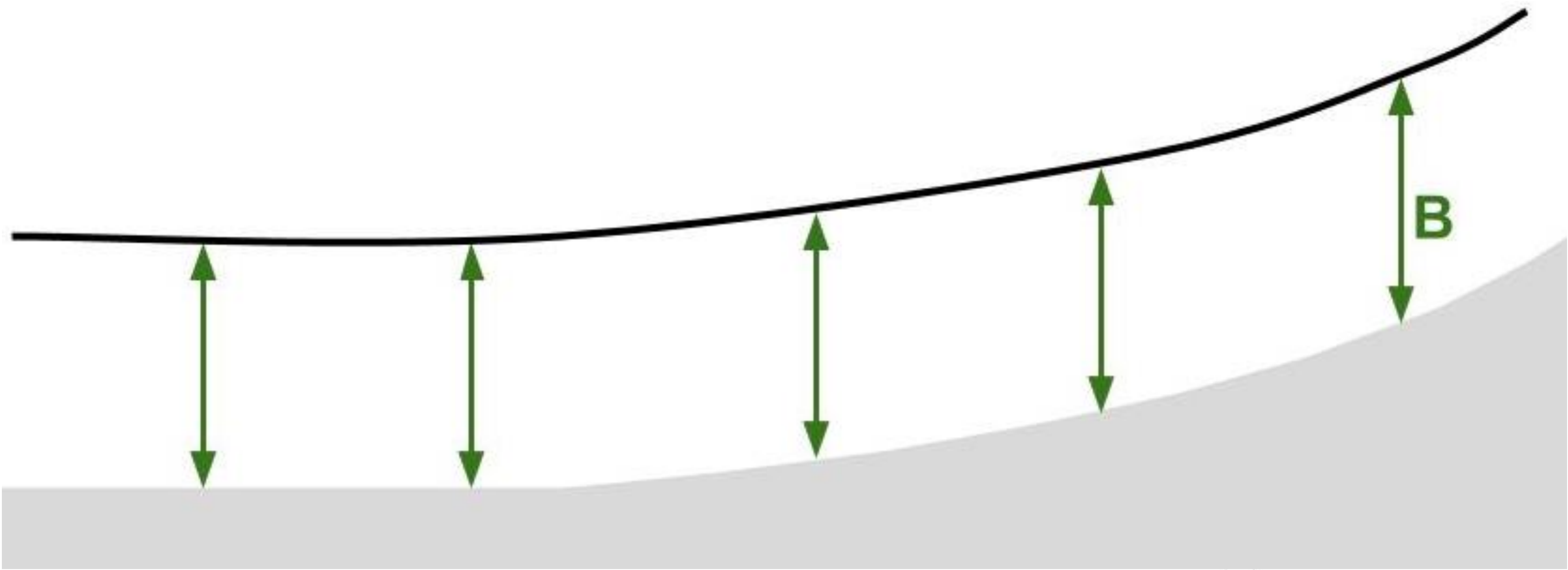
Low altitude flight

Long term goals:

- Follow terrain within given altitude B
- Avoid detection from adversary

Rules:

- Prioritize trajectory leading closest to the ground



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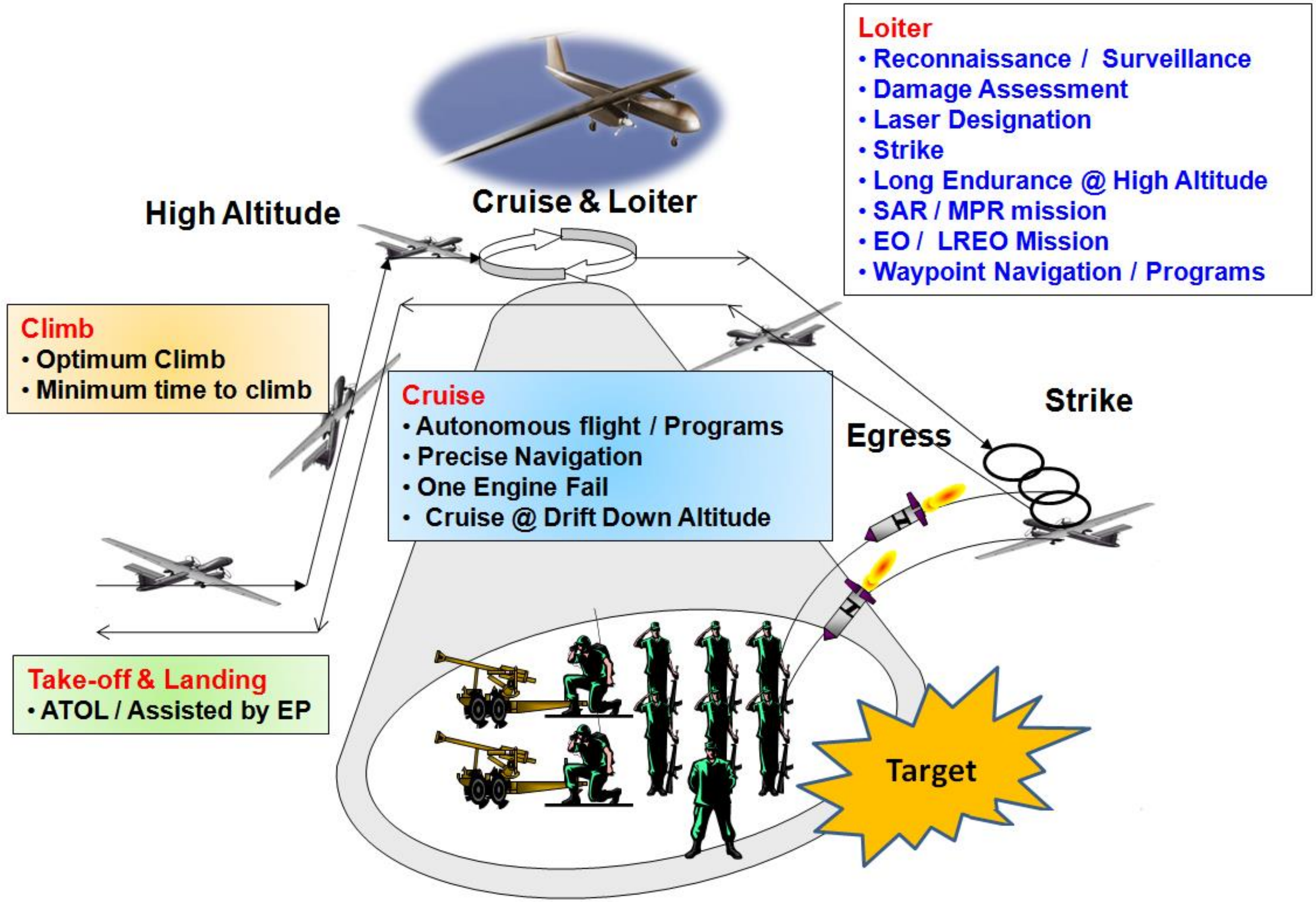
Package delivery



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Constraints and rules in non-segregated air space

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Airspace level constraints

Traffic in G level of airspace

- There is possible traffic occurrence under 500 feet AGL
- Manned aviation is often executing rescue service or emergency maneuvers
- Portions of G level of airspace can be occupied by restricted fly zones, especially in case of airport surroundings or military exercises.
- The exceptions for manned operations are given by local flight authority and they are bounded to some altitude levels defined from AMSL

Traffic in F(E) level of airspace

- There is expected traffic occurrence over 500 feet AGL to 10k feet AMSL, there is also possibility to encounter larger manned aircrafts due the flight pathways intersections
- All previous constraints applies

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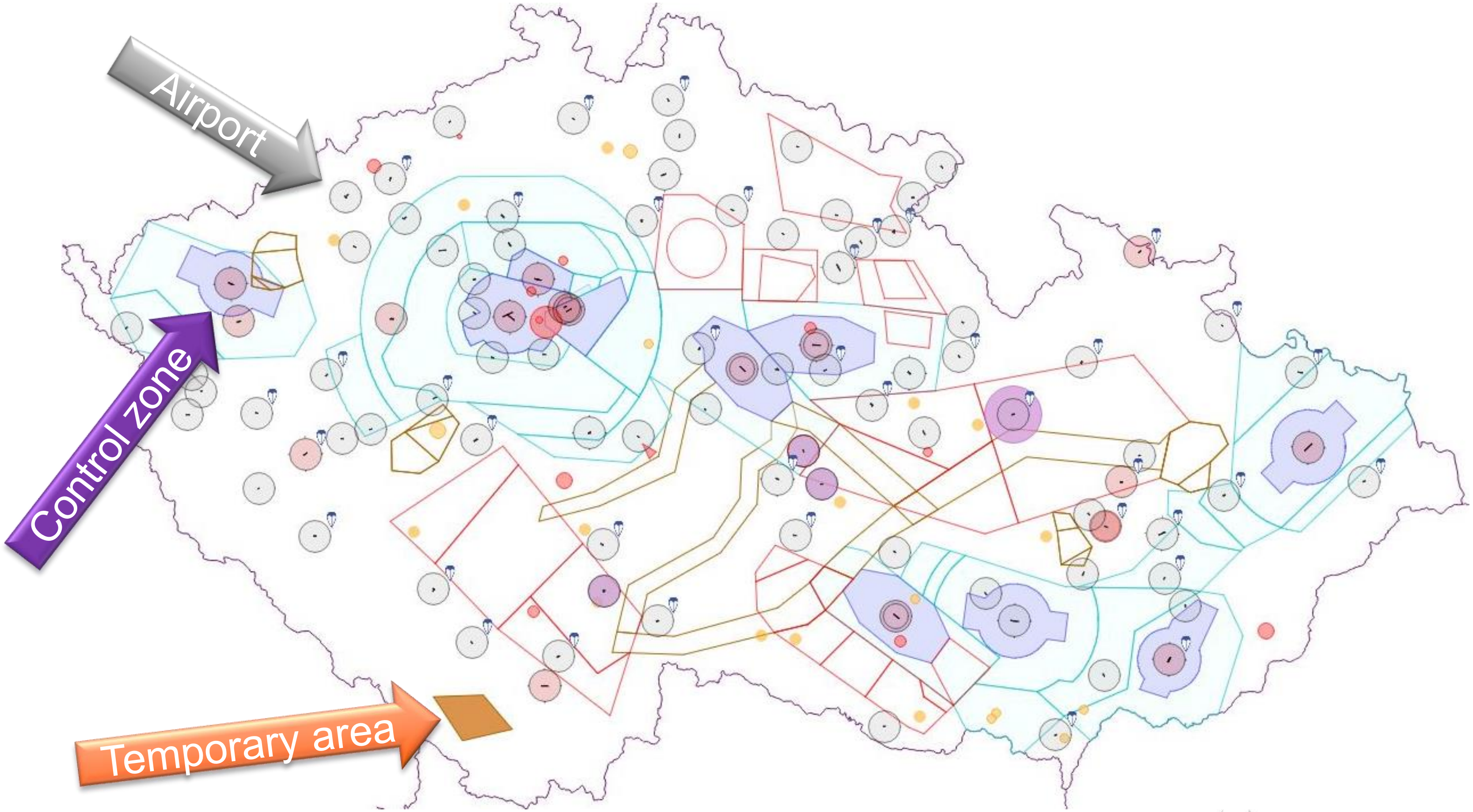
Example of air traffic constraints

- Example of air traffic constraints is taken from Czech national air traffic control portal (http://aisview.rlp.cz/)



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Traffic constraints

Airport control zone

- Restrictions defined with reference pressure at airport (AMSL)
- To execute maneuvers in airport area the rules for B/C level zones applies
- Defined as static zones
- Starts at 0 feet AGL

Open air control zone

- Restrictions defined with reference pressure (AMSL)
- Reference pressure is given by local meteorological authority

Temporary restricted areas

- Same reference conditions as Open Air Control zone
- Temporary restricted areas starts usually in E class airspaces
- Reference altitude is usually set above small UAV operational level
- Temporary restricted areas must be avoided by any air traffic manned or unmanned
- High violation fees are enrolled in case of any restriction breech

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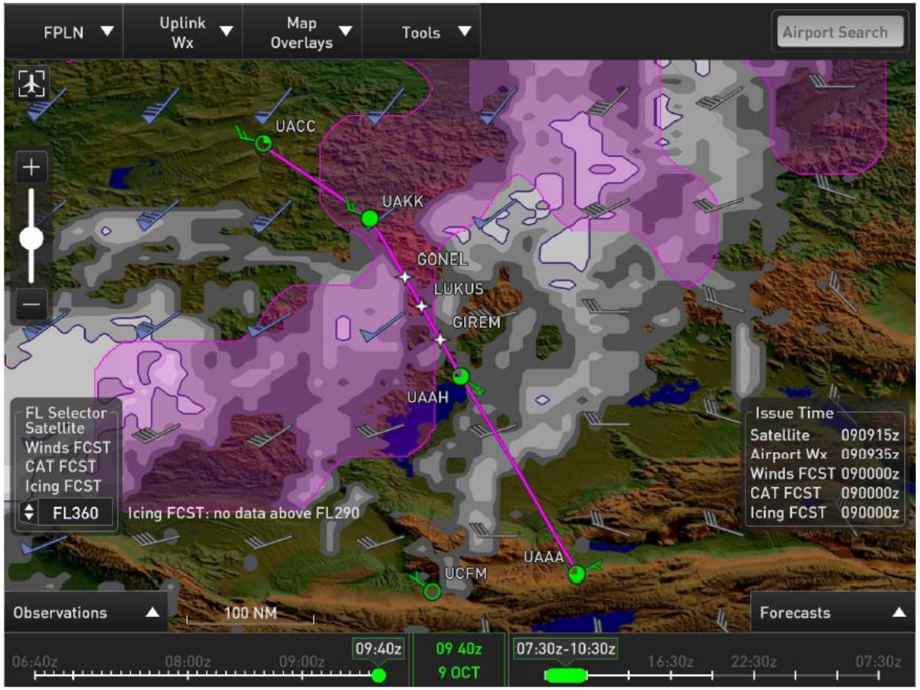
Weather constraints

- UAV system in general is more sensitive to weather conditions than standard manned aviation (icing, storms, turbulences)
- Clouds can generally render UAV sensing system
- Especially thick fog renders LiDAR sensor range tremendously
- Modern manned aviation system can provide data necessary for weather situation avoidance



Example of advanced weather warning system developed by Honeywell.

Extracted data can be used as a source of restrictions for UAV

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Manned aviation constraints summary

UAV must avoid all manned aviation at all costs, pilot usually does not have a chance to detect the unmanned vehicle of very small scale. There is no will to change the manned aviation regulations, therefore autonomous vehicles must adapt to this situation.

There was an effort to enforce ADS-B transmitter on every manned aviation vehicle, but it was refused by ICAO and other organizations.

UAV must implement following, to be successfully integrated into non-segregated airspace:

- Consider every manned aviation vehicle as blind adversary
- Respect ICAO zonation of airspace and stay in F(E),G levels open for free flight
- Respect altitude constraints based on atmospheric pressure valid for region of operation (AMSL from airport/local authority)
- Respect weather conditions

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Manned aviation constraints impact on UAV

Constraints map, reference atmospheric pressure and weather map is updated on hourly basis, therefore actual data from authorities must be considered by UAV (short term operations can be executed without established communication link)

Outline of rules identified from short analysis are like follow:

- UAV must consider airspace and weather space constraints as virtual obstacles with very high avoidance priority
- UAV must consider atmospheric pressure or have very precise altitude (AMSL and AGL) approximation
- UAV must consider every manned aviation vehicle as adversary vehicle

These rules can be reflected in long term planning and waypoint selection to dynamically append mission plan according to situation.

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Intruder avoidance priority

Our vision is based on various projects:

- Amazon Drone platform – fully autonomous UAV
- NASA – UTM (UAV Traffic Management) – rules in development
- JARUS – SAA regulation framework (in development)

The rules of the air are formulated (ICAO annex II.) around avoidance priority, depending on technical capabilities of manned aircraft type (Jumbo jet should avoid glider due higher maneuverability).

The expected behavior of UAV platform is given by following table:

Intruder	Our vehicle	Priority
Manned aircraft	Any UAV	Manned aircraft
VLOS piloted UAV	VLOS piloted UAV	Coordinated avoidance
VLOS piloted UAV	Autonomous UAV	Autonomous UAV
Autonomous UAV	Autonomous UAV	Coordinated avoidance

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Rules of the air – "Right of the way"

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Aviation classes for immediate avoidance

FIRST: Manned aviation in distress

Mayday, mayday, mayday!

SECOND Balloons

THIRD Gliders

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Aviation classes for immediate avoidance

FOURTH: Aerial fueling and towing

Fueling of aircraft

Towing a sign, aircraft or other dependable load

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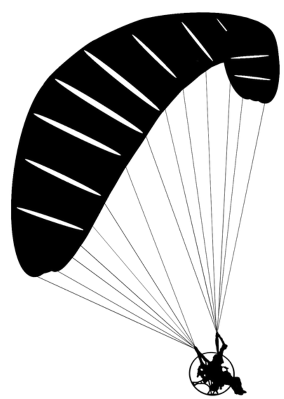
Aviation classes for immediate avoidance

FIFTH: Airships

Sixth: Manned aviation with propeller



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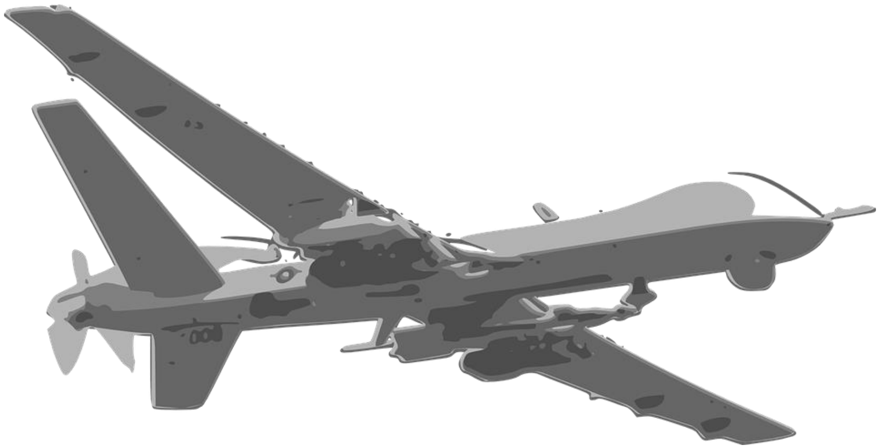
Proposed unmanned aviation classes

Seventh: Unmanned aviation with standardized avoidance system



Eighth: Unmanned aviation for VLOS operations piloted from ground

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Right of the way rules

- Right of the way rules aid pilots in avoiding each other visually
- The rules are found:
  - Part 91 Federal Aviation Regulation (USA)
  - ICAO Annex 2 -> Chapter 3 - General Rules -> 3.2 Avoidance of collisions -> 3.2.2 Right of way (International)
- When aircrafts are converging, the right of way is generally given to the least maneuverable aircraft (higher class)
- The aircraft now having the right of the way is to pass well clear of the aircraft having the right of the way
- Application for rules of the air in case of UAV seems to be reduced to immediate avoidance in case of manned aviation
- The avoidance rules can be applied between the same class of UAV

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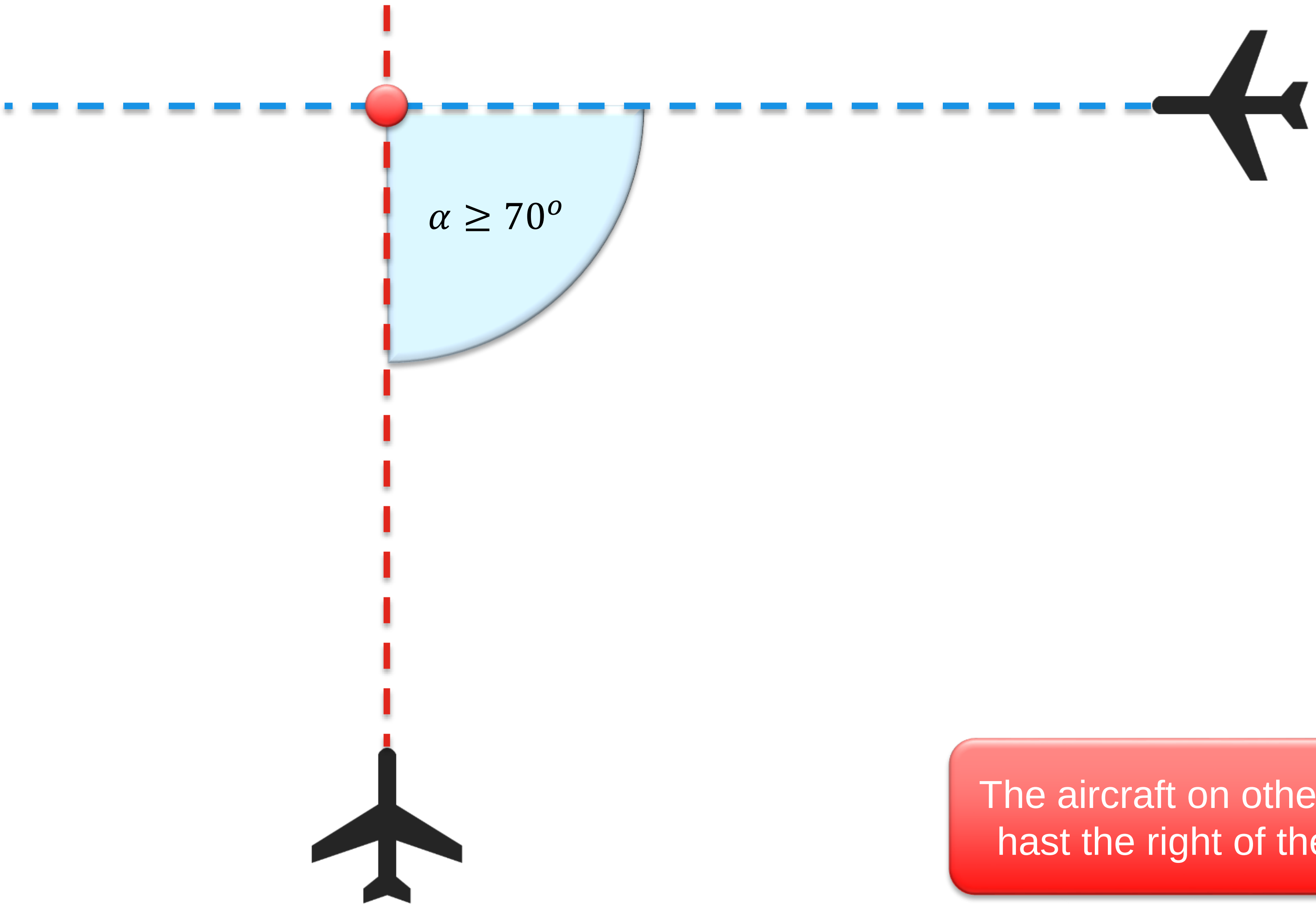
Converging aircrafts of the same category



The aircraft on other right, hast the right of the way

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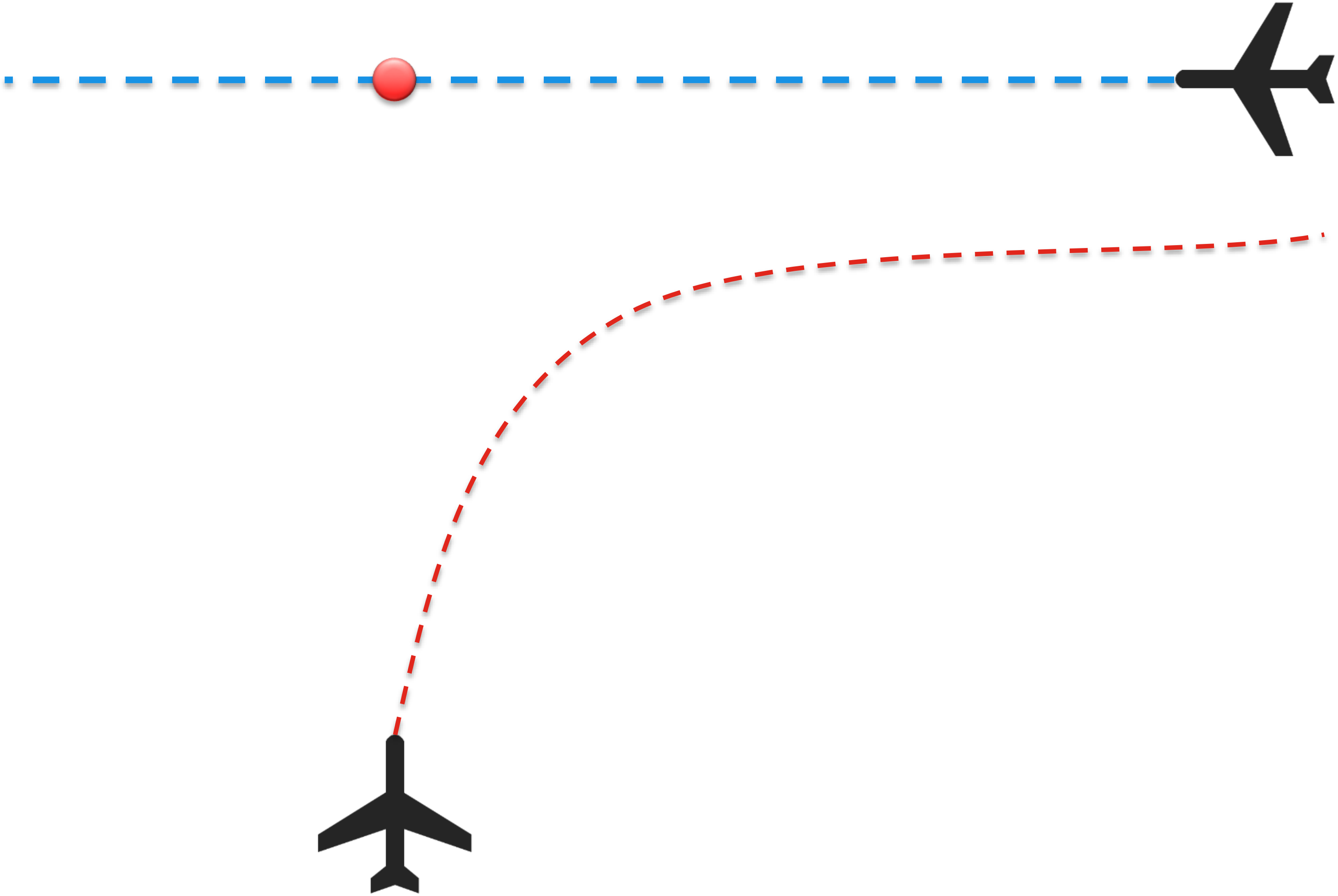

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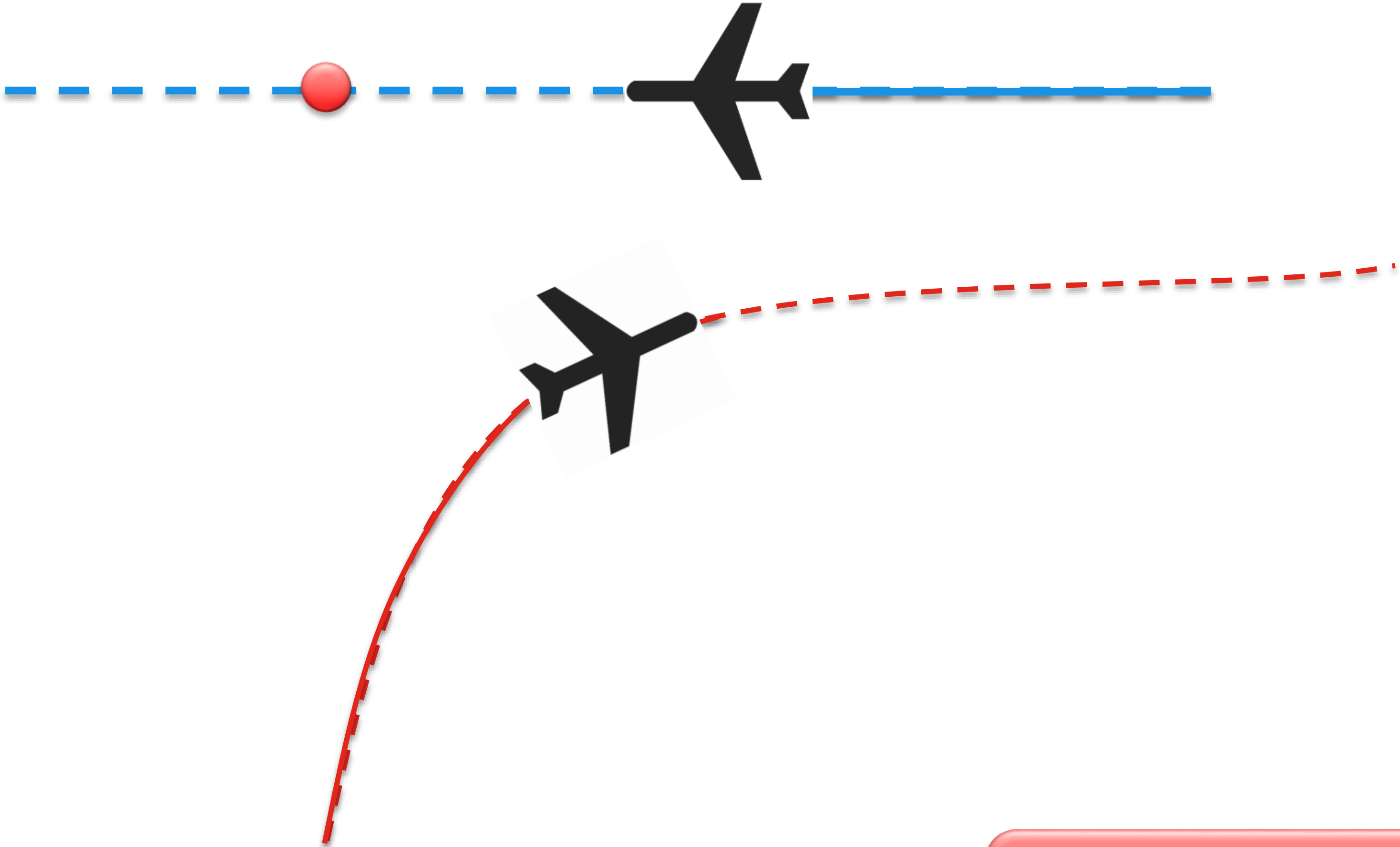

Turn right and stay away from approaching aircraft

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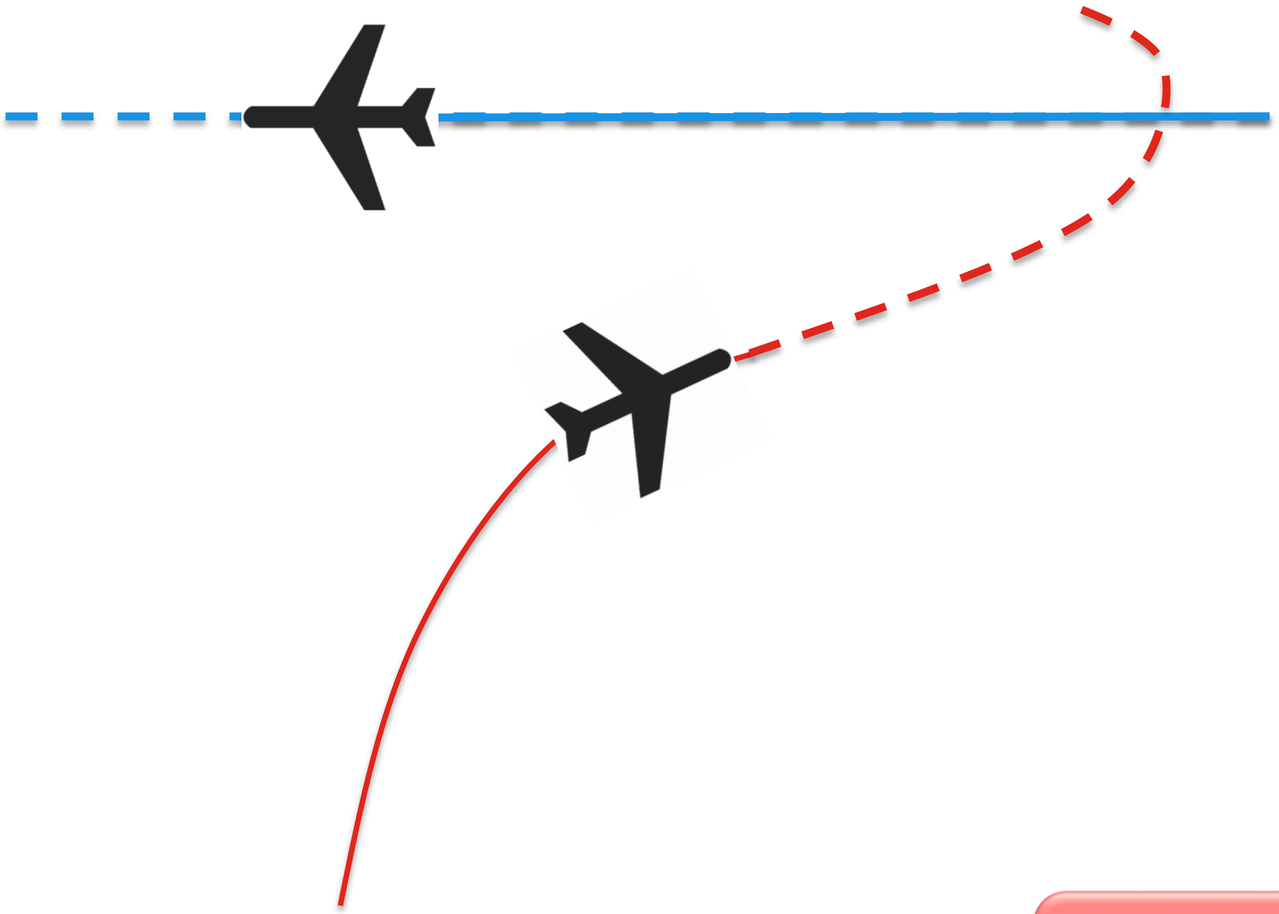
Converging aircrafts of the same category



Return to original path behind other aircraft

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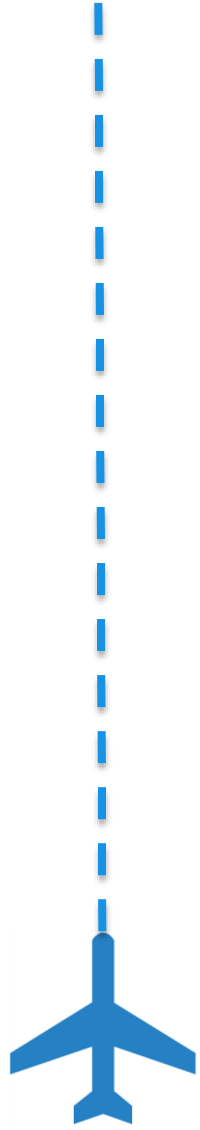
Overtaking aircraft of the same category



Lower speed aircraft is being overtaken

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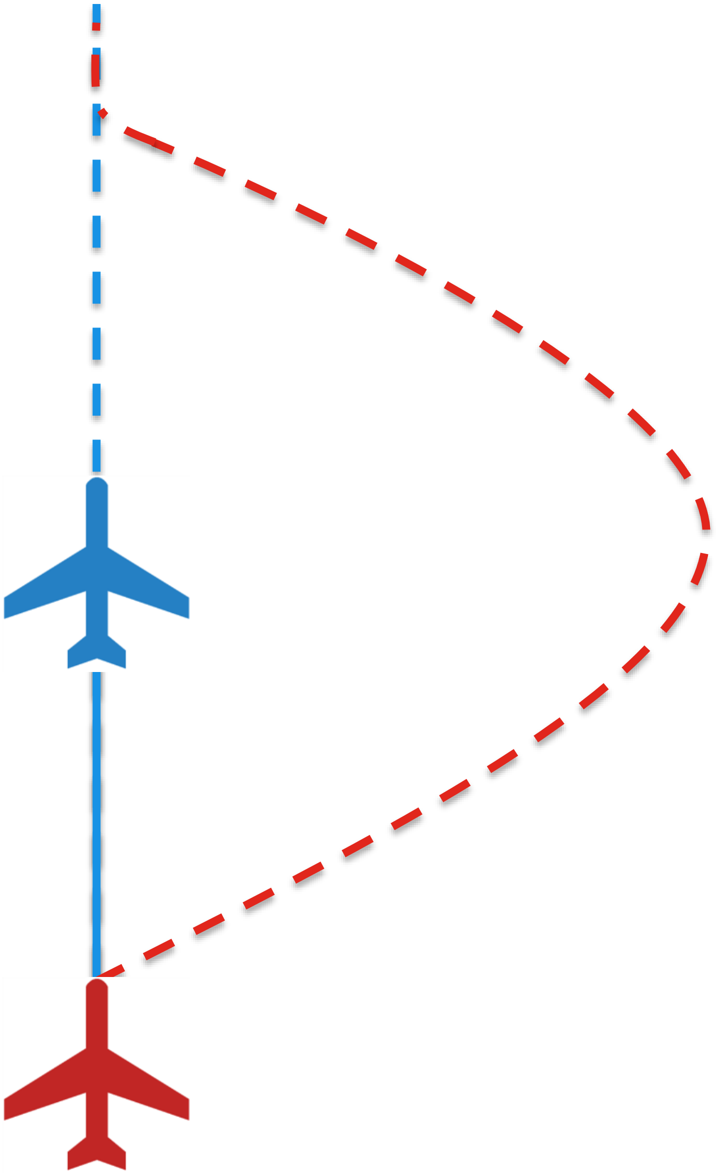
Overtaking aircraft of the same category



The aircraft being overtaken has the right of the way

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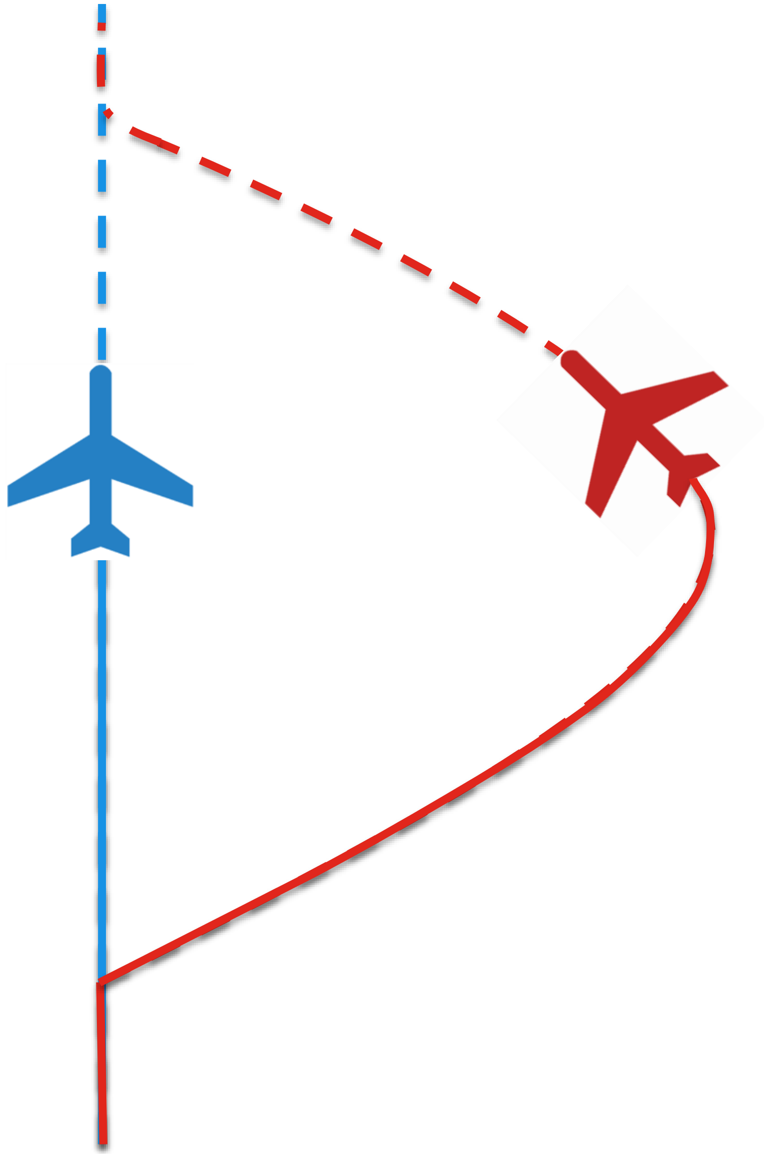
Overtaking aircraft of the same category



Overtake is executed from right

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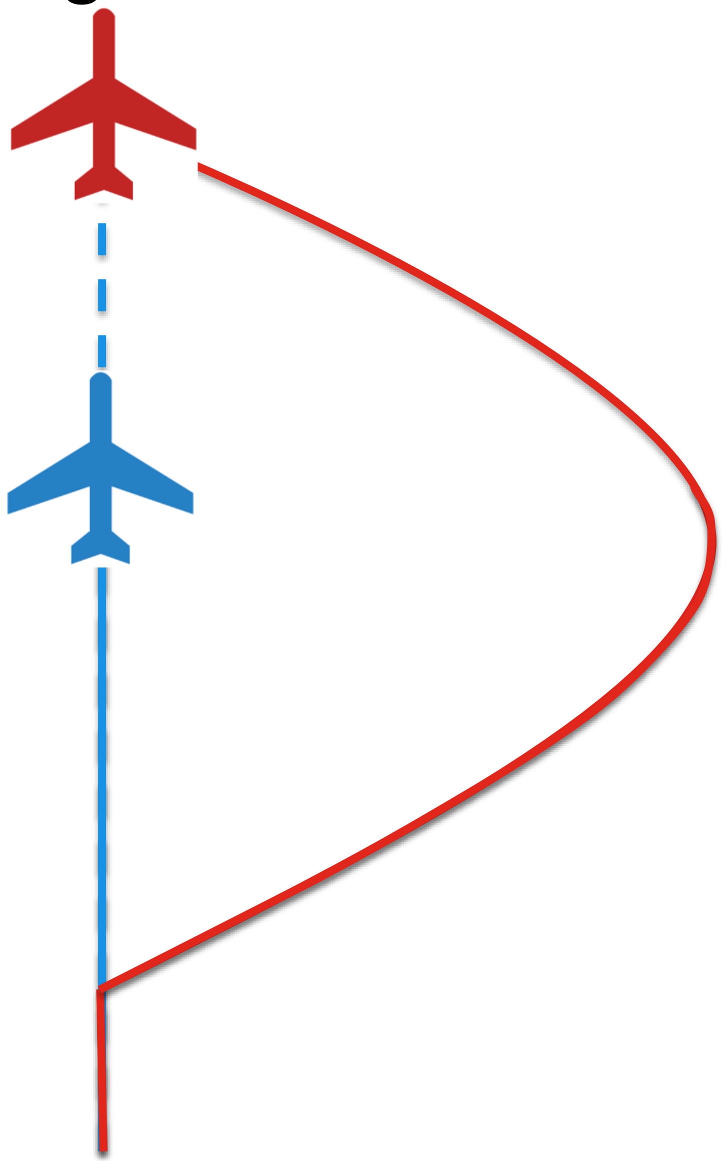
Overtaking aircraft of the same category



Overtake rule apply also for convergence under $\alpha < 70^o$

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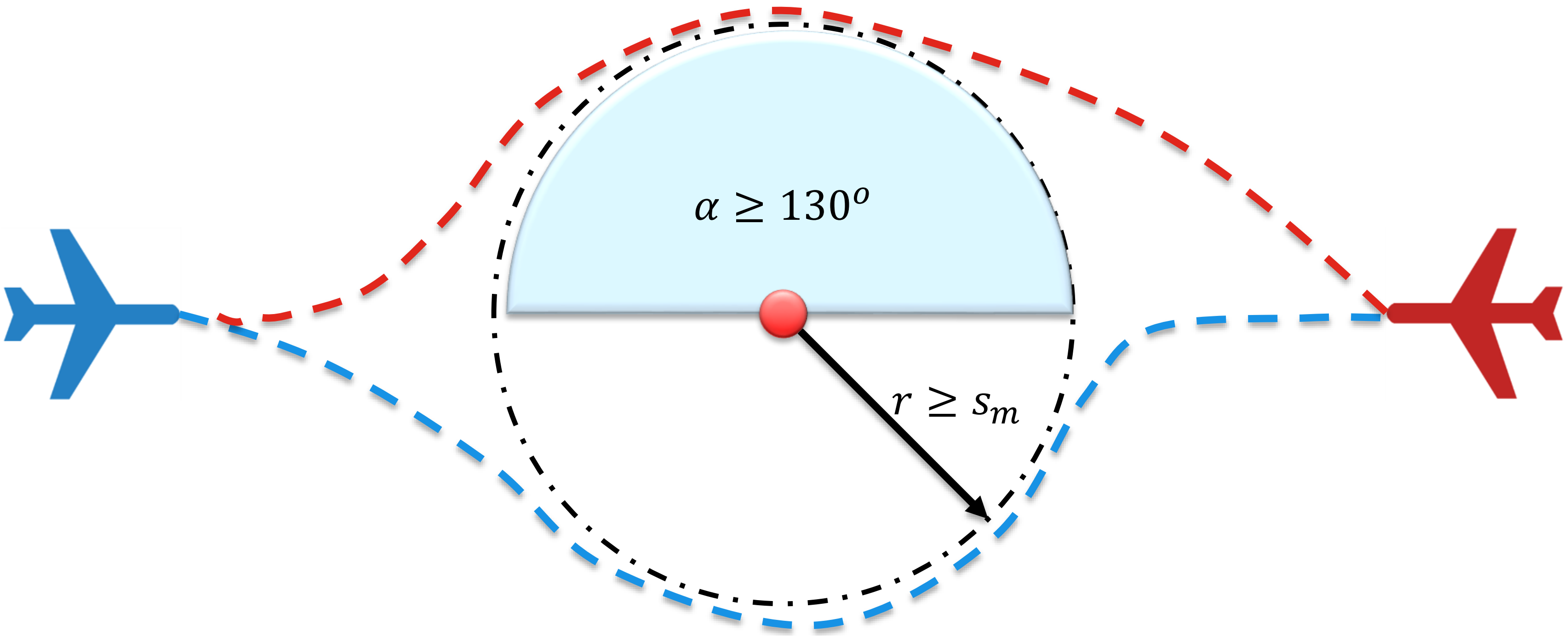
Head on approach of same category



Applies when angle of approach $\alpha \geq 130^o$, Safety margin s_m must be defined

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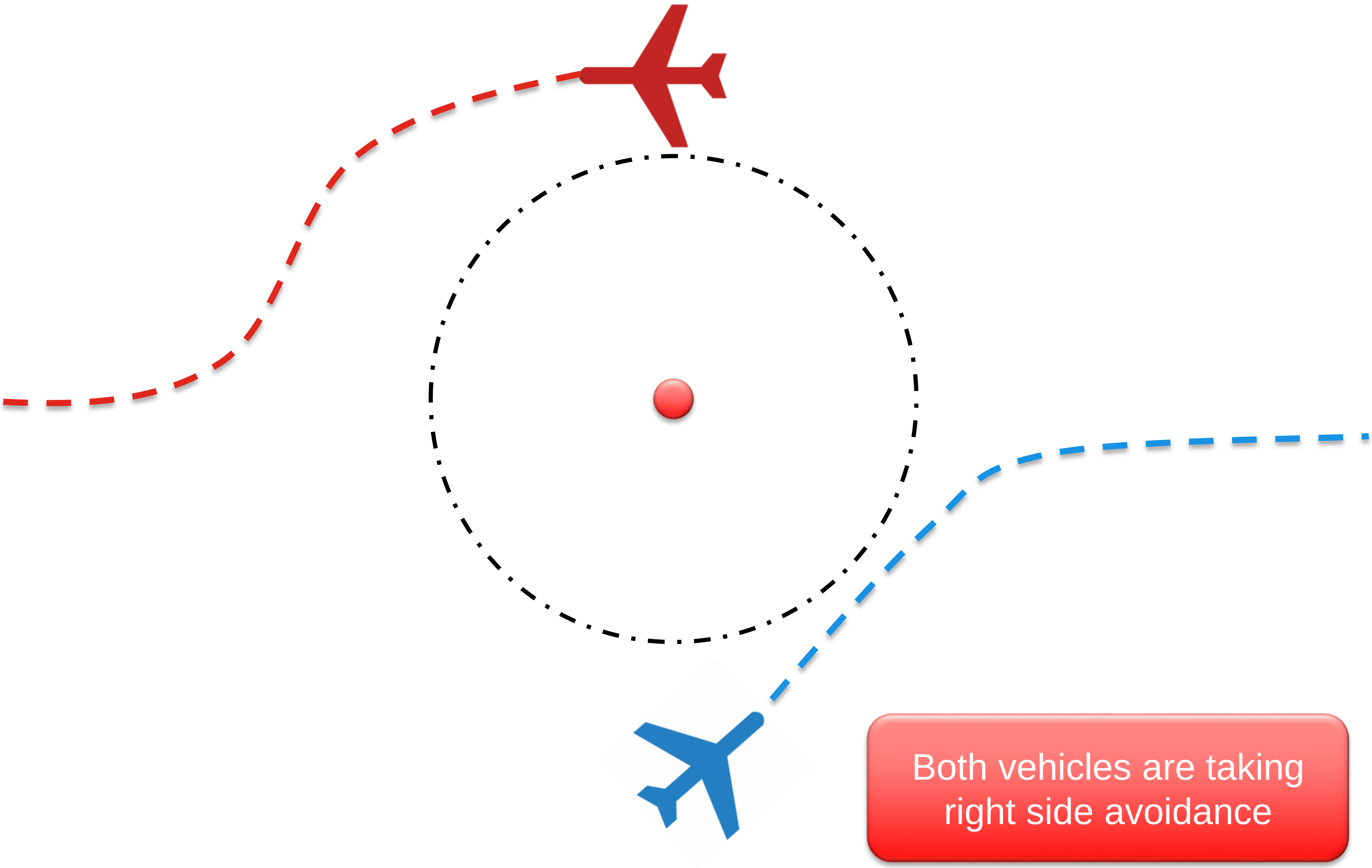
Head on approach of same category



Both vehicles are taking right side avoidance

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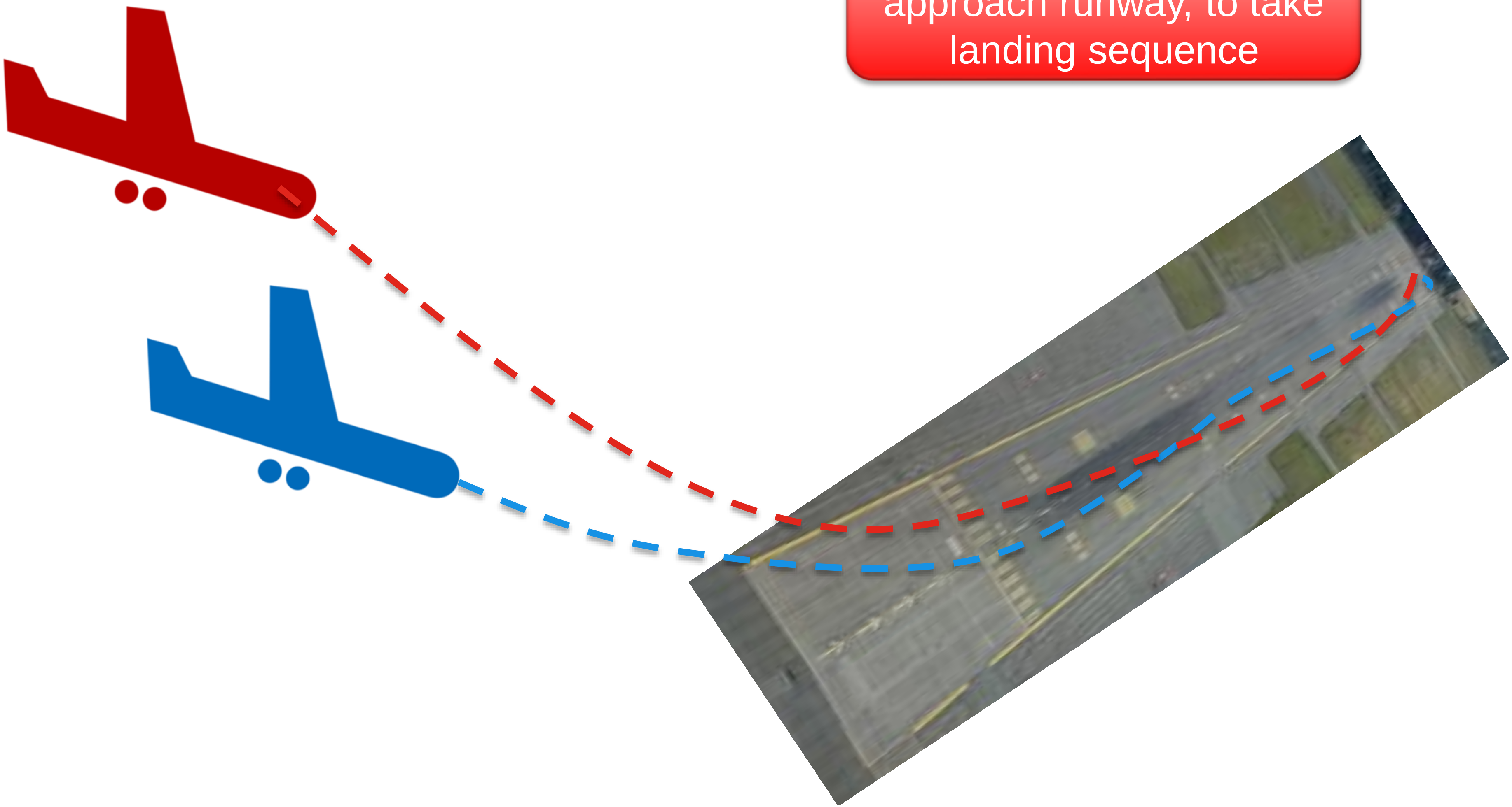
Approaching a runway of same category

Both aircrafts are trying to approach runway, to take landing sequence



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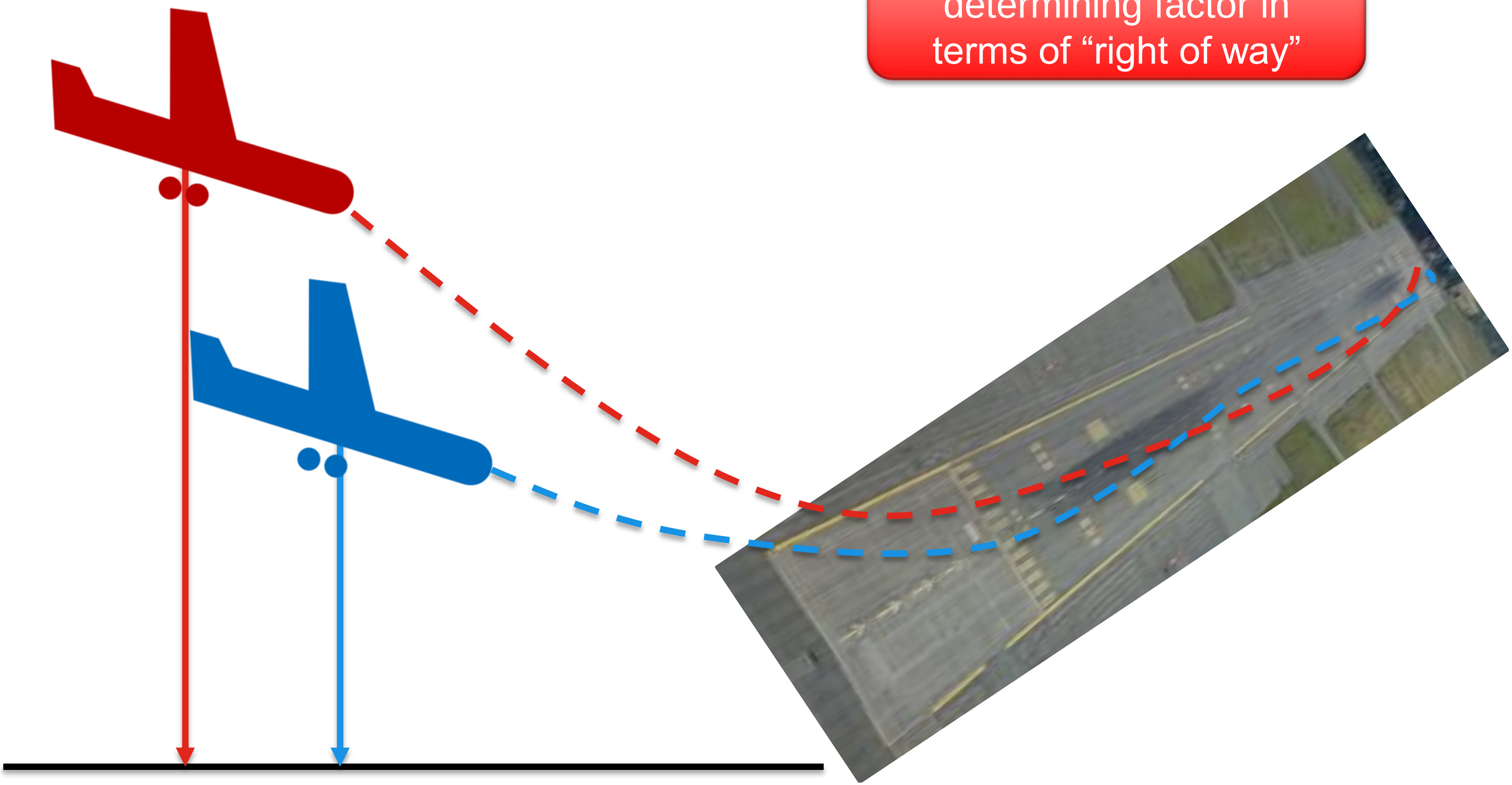
Approaching a runway of same category

Aircraft altitude is determining factor in terms of "right of way"



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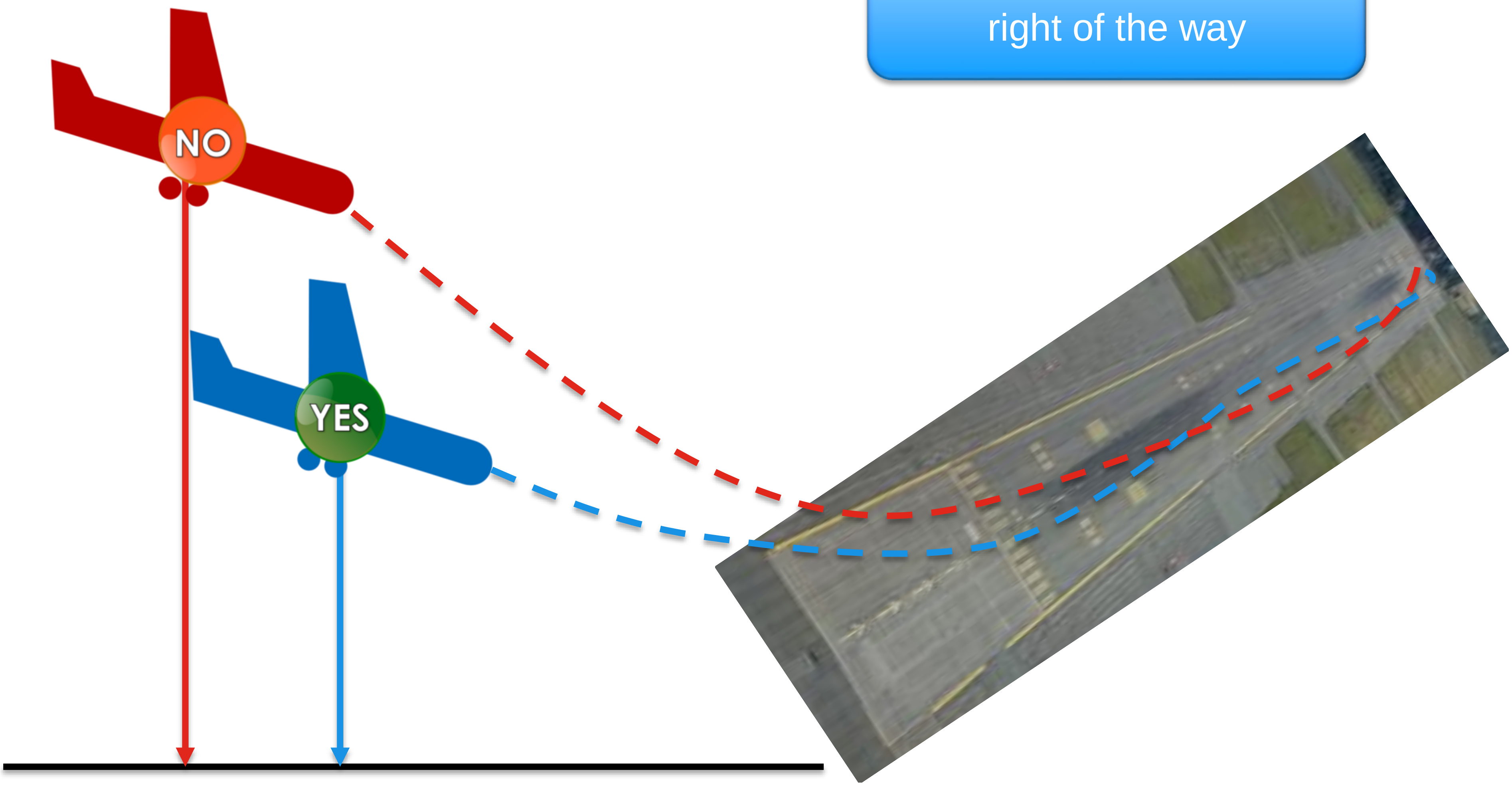
Approaching a runway of same category

Lower aircraft has the right of the way



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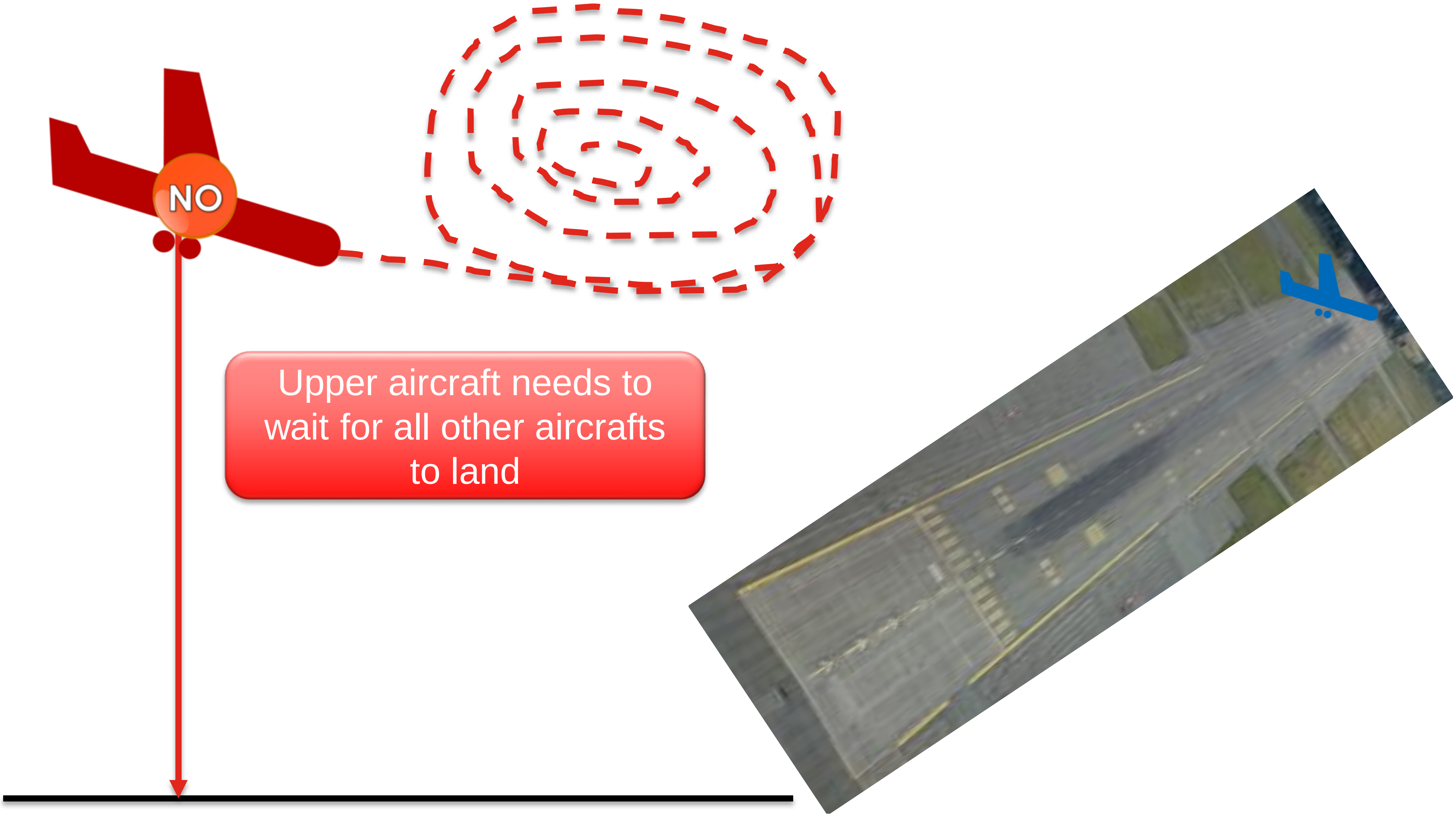
Approaching a runway of same category



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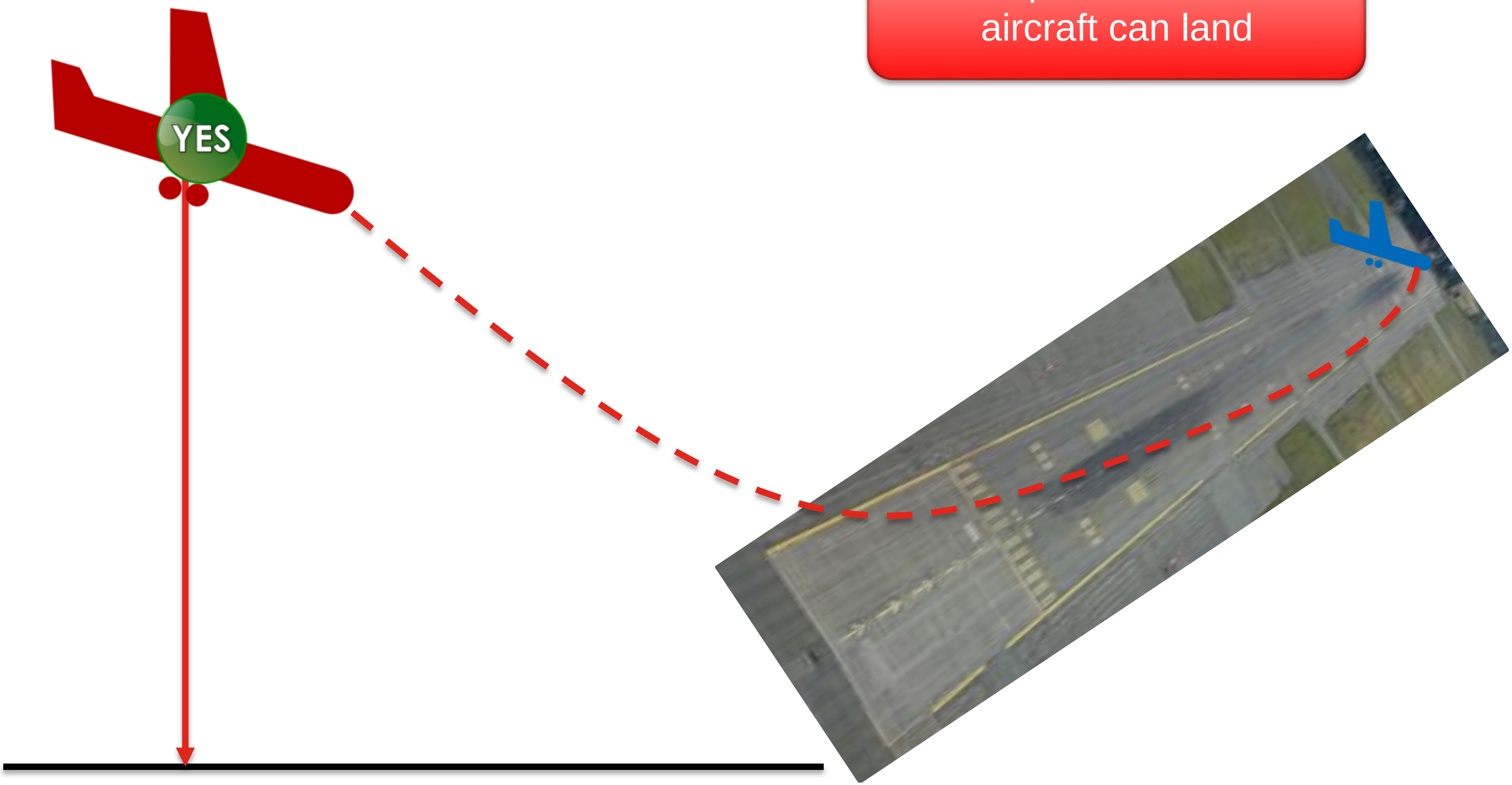
Approaching a runway of same category

When path is free other aircraft can land



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Approaching a runway of same category

Both aircrafts have landed sucessfully

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Summary - Right of the way

- Manned aviation defines only horizontal avoidance, vertical avoidance is considered in TCAS, horizontal avoidance will be added in ACAS-Xu
- Manned aviation does not define angle of approach strictly, it is usually used following margins:
  - $180^o \geq \alpha \geq 130^o$ Head on avoidance (both avoiding)
  - $130^o > \alpha \geq 70^o$ Covering avoidance (the left avoiding)
  - $\alpha < 70^o$ Overtake (faster avoiding)

- Safety margin s_m for Head on avoidance is defined as sufficient distance to avoid vehicle induced turbulence or obstruction of airflow, in case of UAV it must be defined based on UAV class size (bigger UAV), this can induce additional problems

- Overall “rules of air” and “right of the way” should be amendment to be compatible with UAV integration into non-segregated airspace

- Pilot judgement is always the main consideration, therefore manned aviation behavior is unpredictable to some extent

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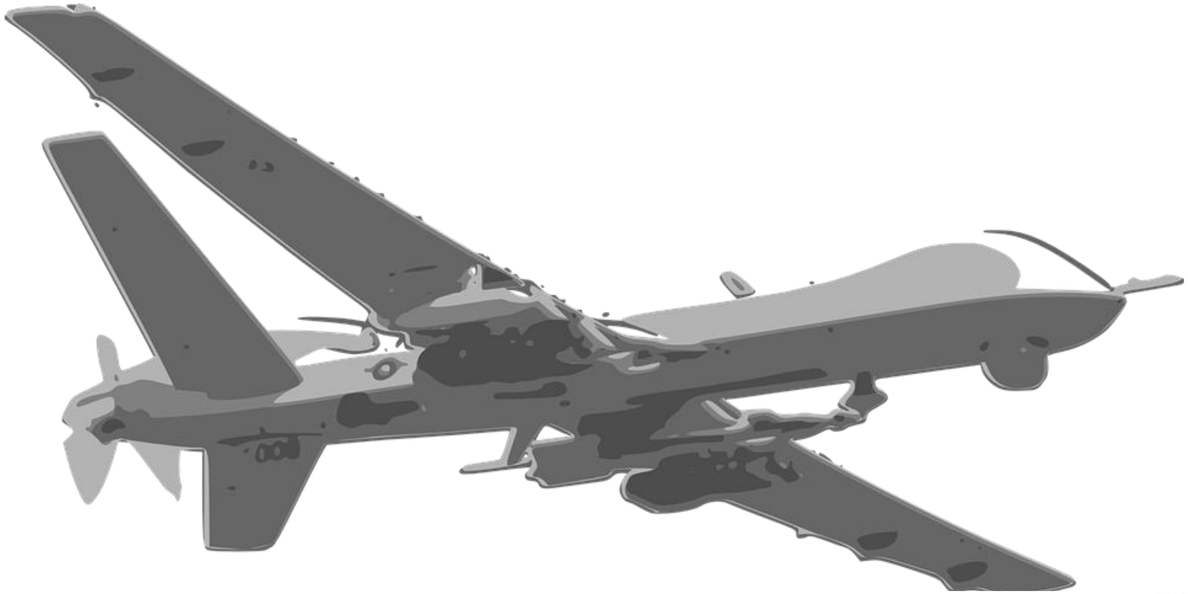
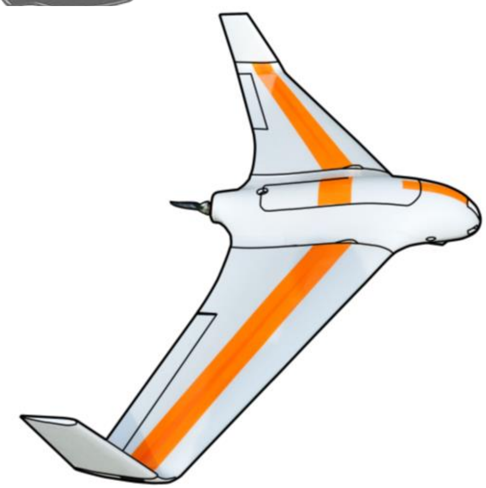
ACAS-Xu (Next generation safety framework)





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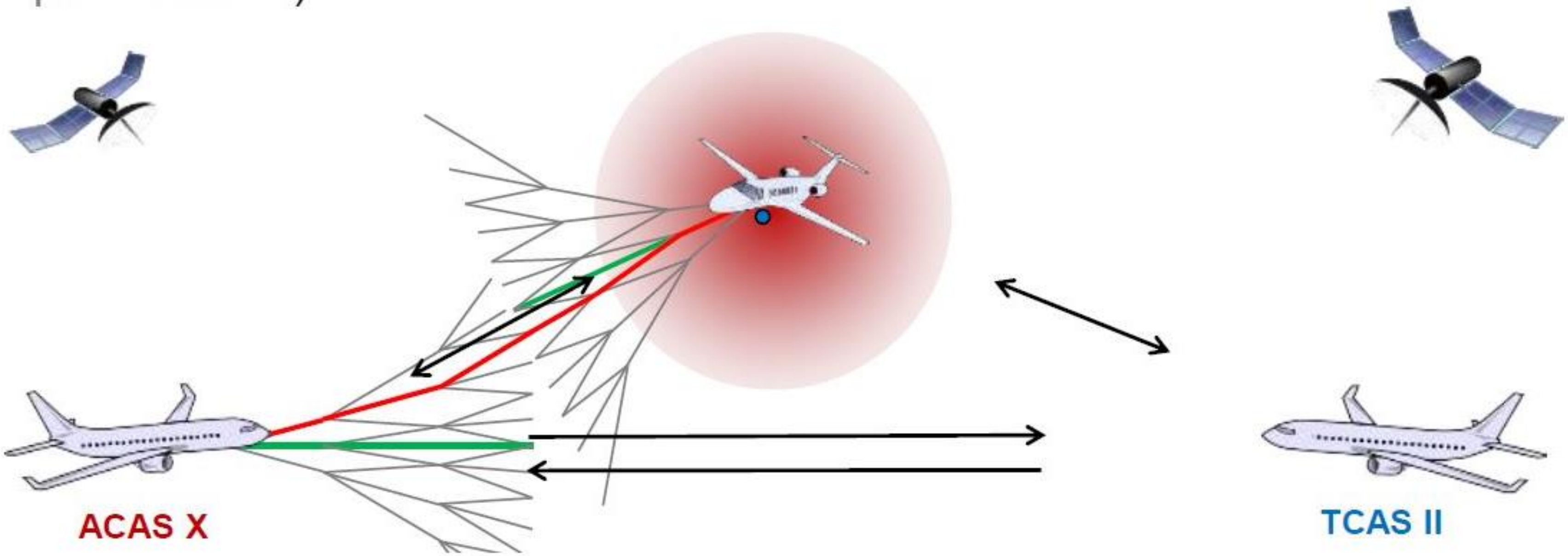
What is ACAS-X

- New logic (interoperable with TCAS II) and system architecture
- ADS-B (automatic dependent surveillance – broadcast) track can be used also for threat resolution (active validation)
- New trackers allow to estimate not only the position of the intruder, but also **the error of this estimate**
- Improved robustness due to accounting for relative likelihood of all possible future trajectories (nominal used by TCAS, worst case, probabilistic)



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ACAS X_A vs. ACAS X_U

	 ACAS X_A	 ACAS X_U
Cooperative Surveillance	• ADS-B validated by active surveillance	• ADS-B validated by active surveillance
Non-cooperative Surveillance	• Does not provide protection for non-transponder equipped intruders	• Tracked output from primary radar, EO, IR or other sensor
Threat logic	• Tuned for aircraft meeting TCAS performance assumptions (2,500 fpm climb/descent)	• Accommodates range of vehicle vertical performance • “Nucleus” function switches between vertical and horizontal tables based on surveillance quality and vehicle performance
Advisories	• Traffic Alerts • Standard TCAS Vertical RAs • Either manual or automated RA response	• TA or Self Separation Alert • Vertical Resolution Advisories • Horizontal Resolution Advisories • Automatic RA response
Coordination	• Standard TCAS coordination over 1030 MHz	• Supports • TCAS coordination over 1030 MHz • Responsive coordination over 1030 MHz • Active Coordination over 1090 MHz ADS-B

RTCA, SC−147, ACAS Xu WG Kick−off, January 12, 2016

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ACAS X_A vs. ACAS X_U

	 ACAS X_A	 ACAS X_U
Cooperative Surveillance	• ADS-B validated by active surveillance	• ADS-B validated by active surveillance
Non-cooperative Surveillance	• Does not provide protection for non-transponder equipped intruders	• Tracked output from primary radar, EO, IR or other sensor
Threat logic	• Tuned for aircraft meeting TCAS performance assumptions (2,500 fpm climb/descent)	• Accommodates range of vehicle vertical performance • "Nucleus" function switches between vertical and horizontal tables based on surveillance quality and vehicle performance
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Automatic response downfall

Depending on the communication link, it is expected that *there may be significant latency associated with RA data transmission* to a ground-based flight crew and subsequent pilot aircraft control commands back to the aircraft in response to the RA

Loss of uplink or downlink communications with the UAS would entirely prevent ground-controlled collision avoidance, and may also degrade collision avoidance effectiveness on other aircraft in coordinated encounters

UAS may also *lack additional outside information*, such as visual identification of intruders, which allows pilots in manned aircraft to make real-time decisions regarding RA response.

The pilot has *the ability to override auto-response* at any time before or after the aircraft has started maneuvering

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TCAS/ACAS RA advisories (!Horizontal only!)

Table 3. Possible Initial RAs for Single Threat

RA Type	Upward Sense		Downward Sense	
	RA	Required Vertical Rate (fpm)	RA	Required Vertical Rate (fpm)
Positive (Corrective)	Climb	1500 to 2000	Descend	-1500 to -2000
Positive (Corrective)	Crossing Climb	1500 to 2000	Crossing Descend	-1500 to -2000
Positive (Corrective)	Crossing Maintain Climb	1500 to 4400	Crossing Maintain Descend	-1500 to -4400
Positive (Corrective)	Maintain Climb	1500 to 4400	Maintain Descend	-1500 to -4400
Negative (Corrective)	Reduce Descent	0	Reduce Climb	0
*Negative (Corrective)	Reduce Descent	> -500	Reduce Climb	< 500
*Negative (Corrective)	Reduce Descent	> -1000	Reduce Climb	< 1000
*Negative (Corrective)	Reduce Descent	> -2000	Reduce Climb	< 2000
Negative (Preventive)	Do Not Descend	> 0	Do Not Climb	< 0
Negative (Preventive)	Do Not Descend > 500 fpm	> -500	Do Not Climb > 500 fpm	< 500
Negative (Preventive)	Do Not Descend > 1000 fpm	> -1000	Do Not Climb > 1000 fpm	< 1000
Negative (Preventive)	Do Not Descend > 2000 fpm	> -2000	Do Not Climb > 2000 fpm	< 2000

* These Initial RAs cannot occur in Version 7.1

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ACAS Xu Summary

- Safety – weather avoidance, mid air collisions
  - Strategic layer – flight planning (Hours/10^{ths} of minutes) [Mission plan]
  - Tactical layer – separation (10^{ths} of minutes/minutes) [Other systems]
  - Emergency layer – Collision avoidance (10^{ths} of seconds/seconds) (ACAS)
- ACAS X merits to TCAS II limitations
  - Reducing nuisance alert rate while improving safety
  - New classes of users/Adaptation to new operations
  - Adaptable system allowing different sensors configuration
  - Backward compatibility with TCAS II
- ACAS Xu should guarantee that UAV system does not enter RA zone of manned aviation
- ACAS Xu provides look-up table for avoidance maneuvers on horizontal/vertical separation level, which determines vehicle behavior during avoidance
- ACAS Xu is designed for big UAVs which are equipped with Transponder

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Conclusion

Room for improvement:

- Emergency autonomous avoidance maneuvers in short term collision situations
  - When future implementation of ACAS-XU fails,
  - When maneuver set for ACAS-XU is incompatible with vehicle dynamics

- Long term trajectory planning including “virtual obstacles”
  - Avoid restricted flight areas
  - Avoid weather obstacles

- Rules of air and ”Right of the way” amendment
  - The rules of the air needs to be amended to define UAV classes
  - The behavior patterns for UAV classes needs additional parameters
  - The vertical separation (right-up/down) must be added for UAVs

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Q&A Session

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