MID-AIR COLLISION AVOIDANCE FOR RPAS – FINDINGS FROM MIDCAS*

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Session A1

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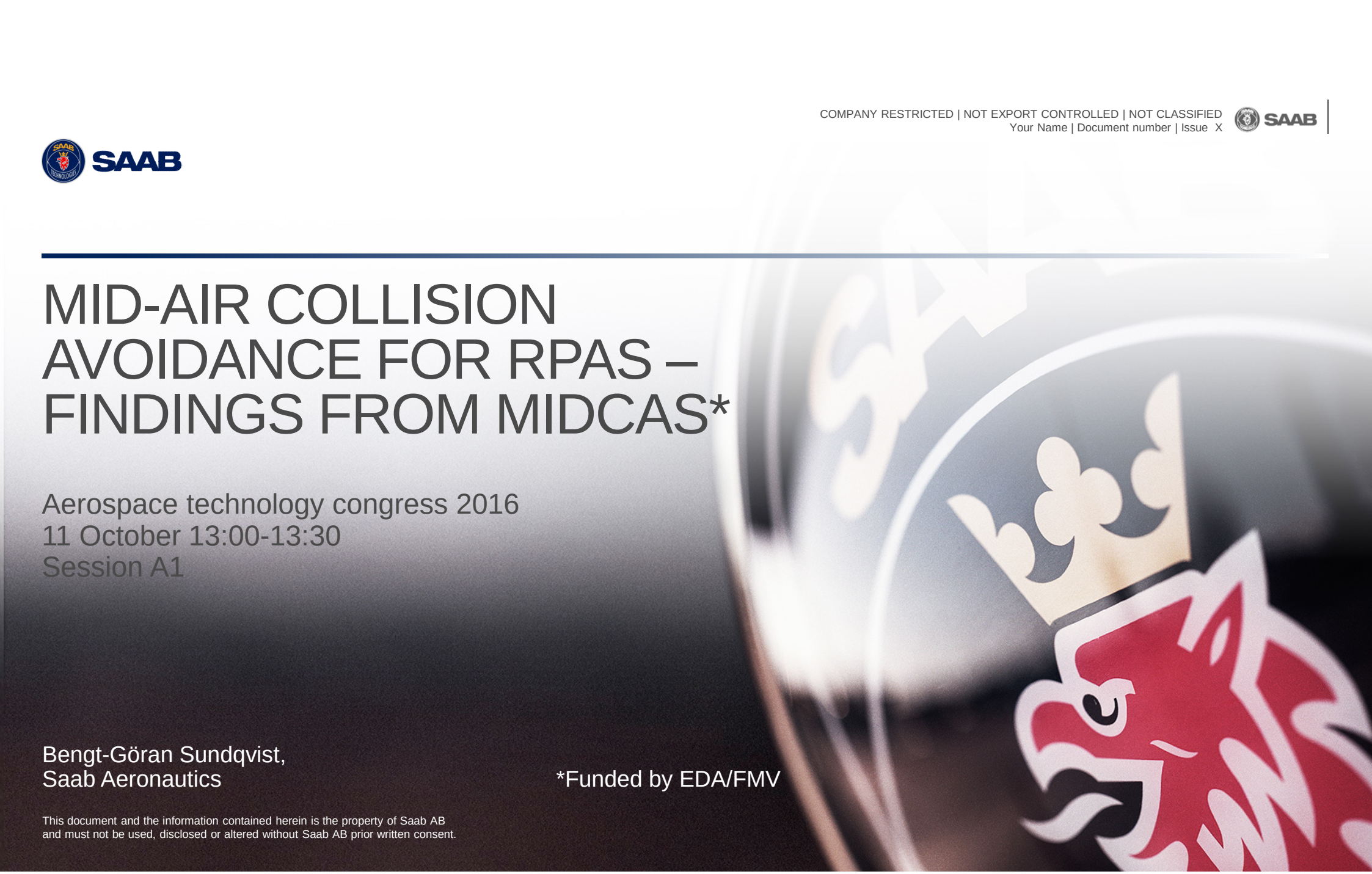


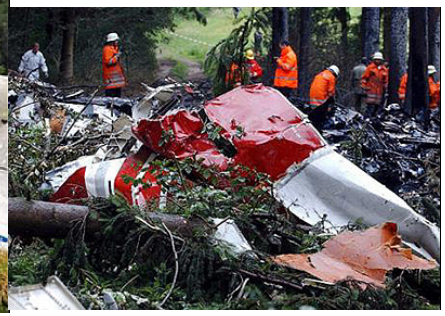
DISPOSITION

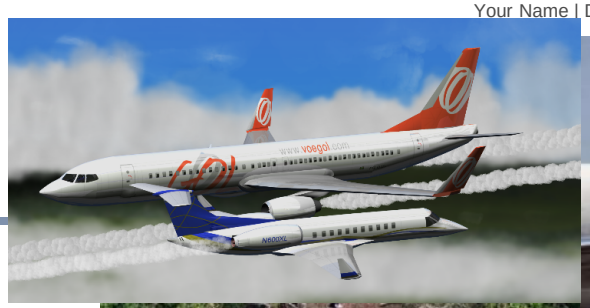
- Background
  - Mid-Air Collision
  - Airspace classes
- MIDCAS
- Standardization material (OSED, SPR, INTEROP, MASPS, MOPS)
  - Operational scenario
  - Interoperability
  - Safety and Performance requirements
- System requirements and design
  - Traffic Avoidance (Remaining Well-Clear)
  - Collision Avoidance
- Summary

MID-AIR COLLISIONS

1996 Combat training

2002 Überlingen





2006
South America

2004 LUNA (UAV)
over Afghanistan

AIRSPACE CLASSES (ICAO ANNEX 11)

	Class	Type of flight	Separation Provided	Service Provided	Radio comm. requirement	Subject to ATC clearence
Controlled Airspace	**A**	**IFR only**	**All aircraft**	**Air traffic control service**	**Continous two-way**	**Yes**
	B	**IFR**	**All aircraft**	**Air traffic control service**	**Continous two-way**	**Yes**
		VFR	All aircraft	Air traffic control service	Continous two-way	Yes
	C	**IFR**	**IFR from IFR IFR from VFR**	**Air traffic control service**	**Continous two-way**	**Yes**
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		VFR	Nil	Traffic information as far as practical	No	No
Uncontrolled Airspace	**F**	**IFR**	**IFR from IFR as far as practical**	**Air traffic Advisory service; flight information service**	**Continous two-way**	**No**
		VFR	Nil	Flight information service	No	No
	G	**IFR**	**Nil**	**Flight information service**	**Continous two-way**	**No**
		VFR	Nil	Flight information service	No	No

AIRSPACES IN EUROPE

FL or Alt Band	Albania	Armenia	Austria	Azerbaijan	Belgium/ Lux	Bosnia H'zeg	Bulgaria	Croatia	Cyprus	Czech Rep	Denmark	Estonia	Finland
Up Limit CAS	660	460	660		660	410	660	1 Jul 07	460	660	460	660	660
245-460	C	C	C		C	C	C	C	G	C	C	C	C
205-245													
195-205													
150-195	G	G	D		B		E	D		D	E		D
130*-150			E				G			E	G		
95*-130*					G	G		G		G		G	G
3K*-95*							G						
SFC-3K*													
Major TMA	C	C	C D E		B	E	C	C	No TMAs	C	C	C	C D
Minor TMA								D		D	D	D	
CTA/Awy					B D	C above 100		C D	200 up to 195	C D	E	C D	D
CTR*	G		D E		C	G		G	F ATZ C	D	D G*	C D *	C G *

FL or Alt Band	France/ Monaco	FYROM	Germany	Georgia	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Malta	Moldova	Netherlands
Up Limit CAS	660	660	660	460		660	660	460	460	660	460	660	660
245-460	C	C	C	A		C	C	C	C	C	C	C	C
205-245													
195-205													
150-195	D	D		C				G			G C		A B
130*-150			C E										
95*-130*	G	E	E			E	G		G	G		G	G
3K*-95*		G	G	G		G							
SFC-3K*													
Major TMA	A	D	C	C		C	C	A E	C	C D	C	C	A
Minor TMA	C D E	E	C D E					D E		D			B E
CTA/Awy	D E	D E											A
CTR*	A D G	G	D F					A C D		C D			C

FL or Alt Band	Norway	Poland	Portugal	Romania	Slovak Rep	Slovenia	Spain	Sweden	Switzerland	Turkey	Ukraine	UK	Serbia & Montenegro
Up Limit CAS	660	460	1 Jul 07	660	660	660	460	460	660		660	660	660
245-460	C	C	C		C	C	C		C		C	C	C
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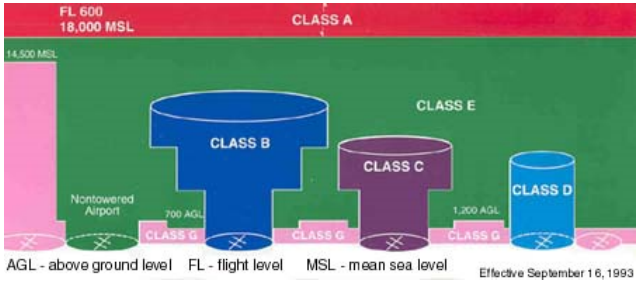
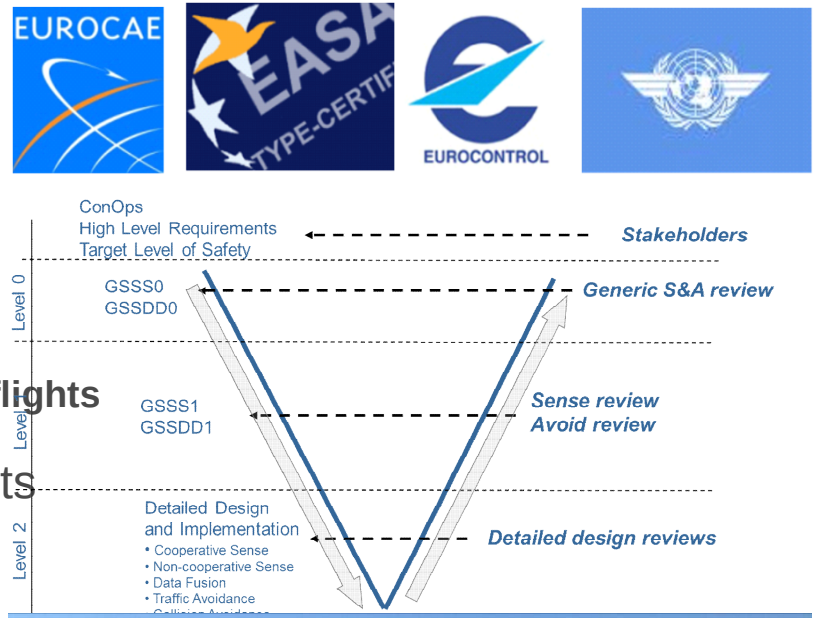
150-195	D G		G	G		D	G	C	C D			G	
130*-150					C				C D E		C		
95*-130*		C				C		C G	C E				
3K*-95*	G	G				E			E		D		
SFC-3K*					G	G		G	G		G		
Major TMA	C	C	C	A	C D E	C D	A	C	C		C D	A C	
Minor TMA	D						D E		D				
CTA/Awy	D E				C		A E		C		C	A C D F	
CTR*	0*			C D	C D	D	G		D		C D	A D	



AIRSPACE IN US

MIDCAS

- 5 nations (Sweden, France, Germany, Italy, Spain)
- 11 industries, consensus decision model
- 5 year program designed with focus on 3 main tracks :
  - Progress on **Standards** for D&A
  - Design of a **Generic D&A function** to be tested **in simulations**
  - Design of **a D&A Demonstrator** to be tested in **Manned and RPAS flights**
- **Incremental System engineering approach;** with 4 increments
- SCOPE
  - **Remotely Piloted Aircraft** (Not autonomous)
  - Operated according to **Instrument Flight Rules**
  - during **enroute flight** (include climb, descent and turning).
  - **above 3000ft** with respect to ground
  - with **maximum take off weight > 150 kg**



MIDCAS MAIN requirements

- The resulting Mid-Air collisions shall be ≤ 1e-9 /fh vs. large aeroplanes and ≤ 1e-7 /fh vs. other.
- Shall NOT impair safety of other airspace users.
- Shall be nuisance free:
  - Unjustified manoeuvre suggestions to remote pilot ≤ 0.5/fh.
  - Unjustified manoeuvres leading to ATC workload ≤ 1e-3/fh.
  - Unjustified manoeuvres potentially resulting in MAC is included in TLS
- Should minimise the impact on existing ATM. Impacts on controller workload and required updates of clearances shall be minimised.
- Compatible with ACAS.
- Auto-compatible (D&A equipped RPAS vs D&A equipped RPAS).
- Compatible with existing airspace rules
- Reduce the risk of collision with non-cooperative intruders.

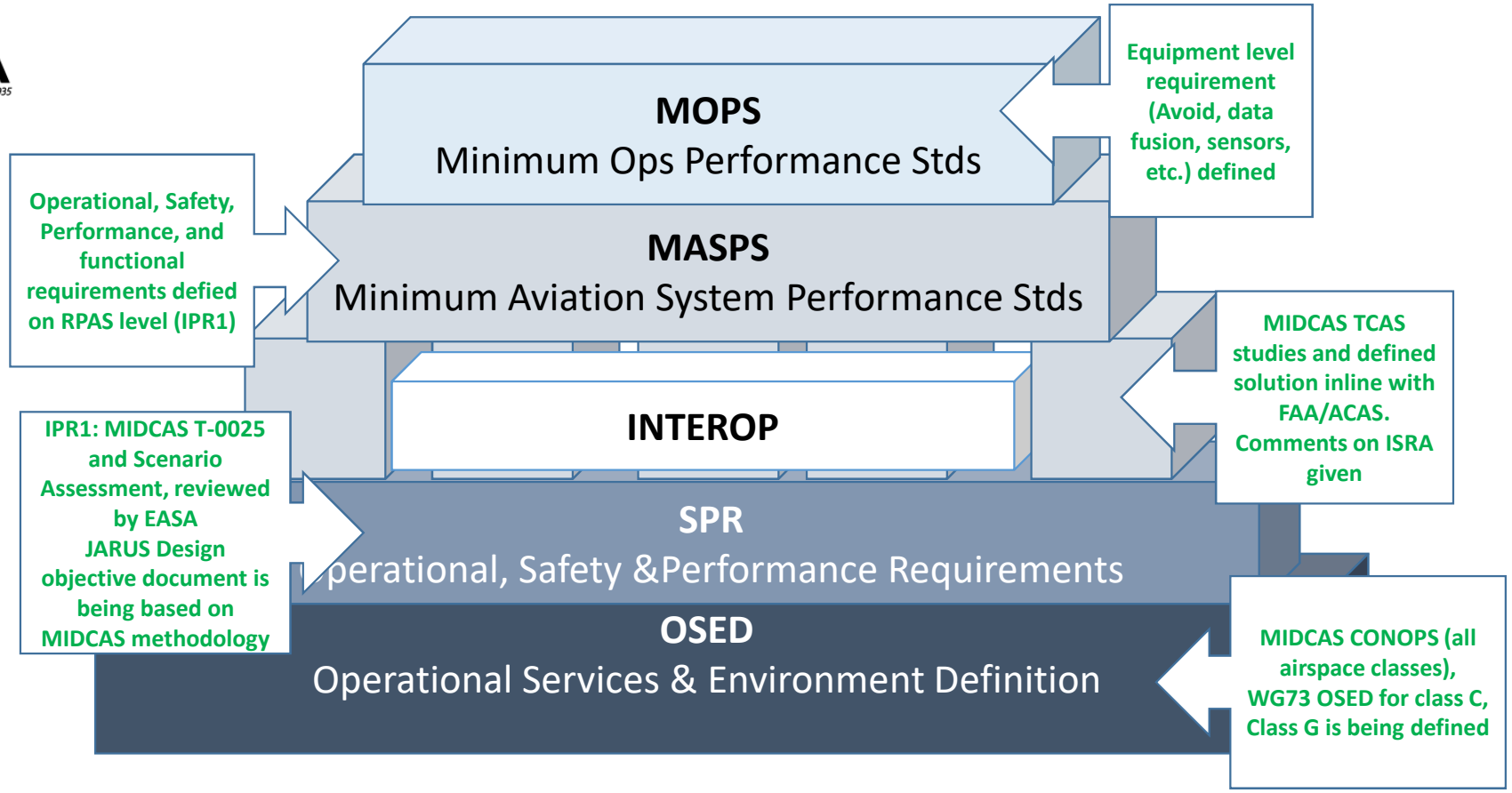
Do good

Don't do BAD or unnecessary

Be compatible

Exact semantics see the High Level Requirements of MIDCAS

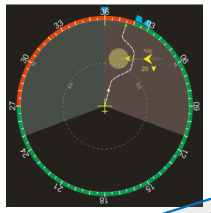
STANDARDS WITH OPERATIONAL CONTEXT
MIDCAS APPLICABLE



Inter Special Committee Requirements Agreement: “MASPS for Interoperability of ACAS”, Oct 2015 issue

OPERATIONAL CONCEPT (DEPENDENCE ON AIRSPACE CLASS)

Situation Awareness



Since Intruder flight rules are unknown to the system the manoeuvre will be suggested against all intruders.
It should however only be suggested after plausible ATC separation has failed (not interfere with ATC responsibility in Airspace D-E)

intruder

Traffic Avoidance
(Self Separation in D-G only)

Pilot

Manoeuvre according to clearance (airspace D&E)
Both avoidance and return manoevre

ATC

UAV

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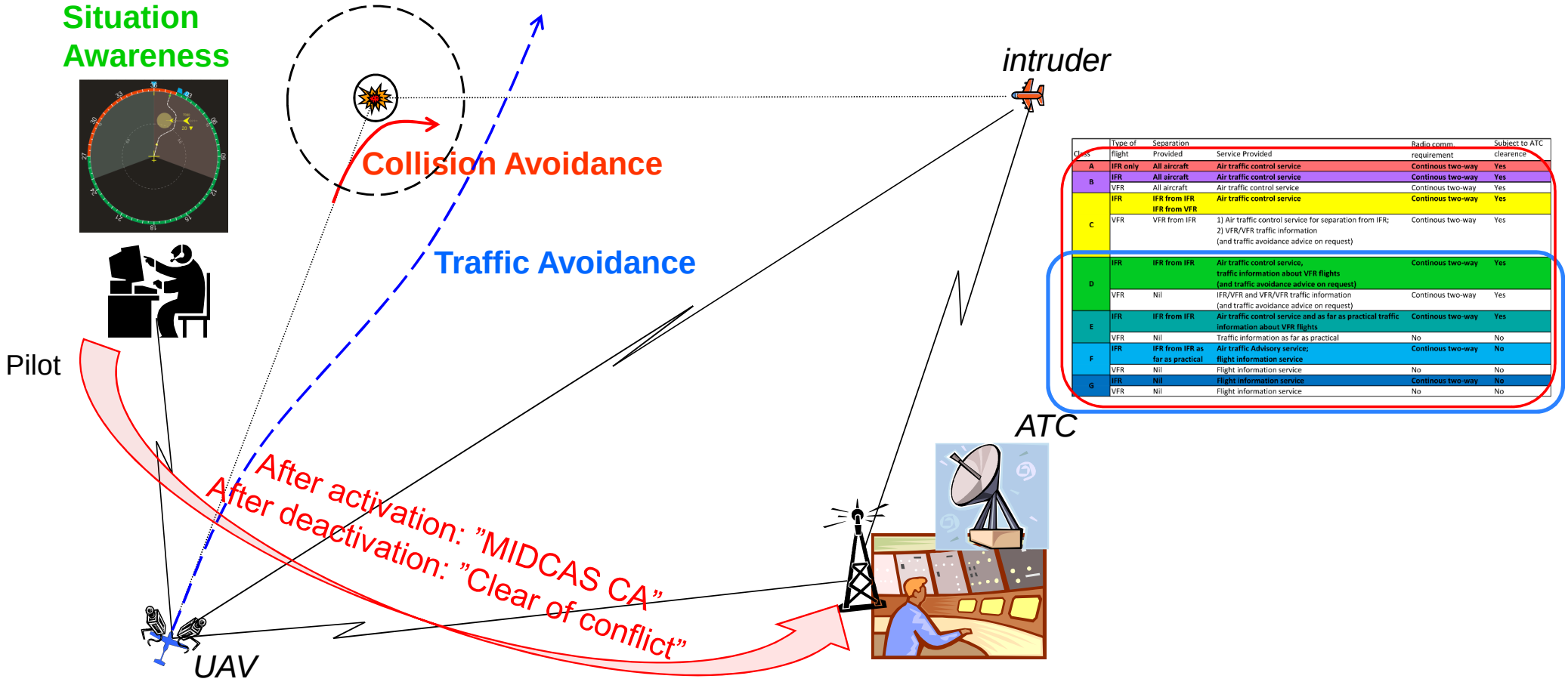
OPERATIONAL CONCEPT (SUMMARIZED)



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Interoperability against TCAS equipped intruders

Intruder

Transmits TCAS capability via transponder

Host

Tracks intruder

Interrogates and
Executes ACAS logics

"TCAS capable" as interrogation reply

Answers "TCAS capable"

Computes and executes **TrA** manoeuvre which will not trigger RA onboard Intruder => resolved conflict

Generates TA and RA if needed

Communicates VRC* at triggered RA
Manoeuvres based on RA

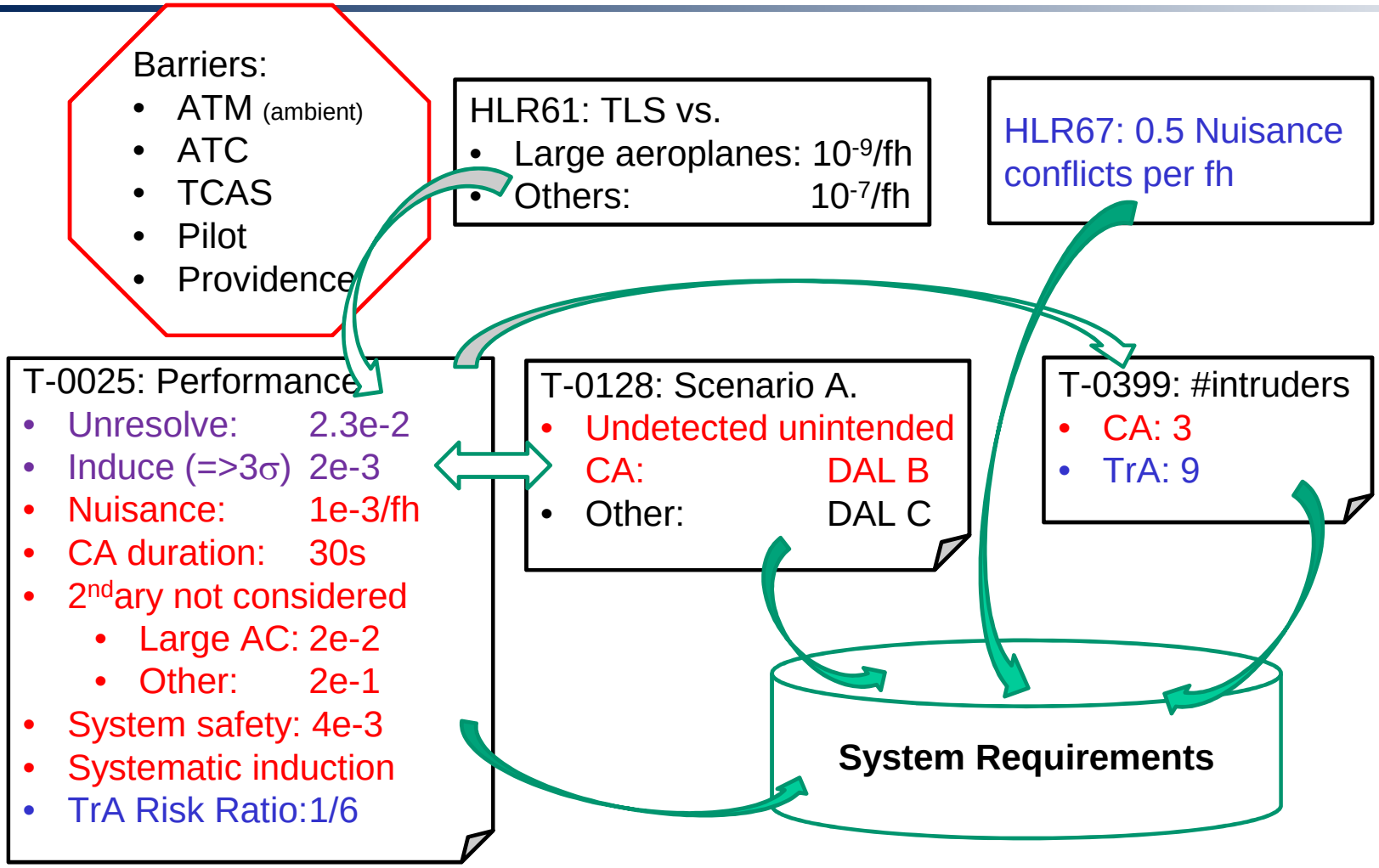
VRC against aircraft with <ICAO code>

Computes a compatible **CA** manoeuvre at received VRC and triggers it after 1.2s

Last instance CA logic is running in parallel and is triggered independently of if the VRC is received or not

*Vertical Resolution Compliment (Inverse of own manoeuvre direction)

Safety and performance; Target level of safety / Nuisance



TRAFFIC AVOIDANCE (SELF SEPARATION)

- Objective: “not scaring other”:
  - Clearing SEP minima (0.5NM horizontally/500ft vertically distance from AC) or
  - not triggering RA (for TCAS equipped intruder).

  - Provide warning to the pilot of predicted breach
  - Providing trajectory/manoeuvre to pilot with ability to activate semi automatic manoeuvre.
  - “Clear of Traffic” is issued when return to original track would not violate the objective.
  - Pilot assess violation of flight clearance

- Uses path planning technique with constraints to find best solution, Constraints:
  - **Normal performance**: 3deg/s turns, low climb/descend
  - Complies with the **Rules of the Air** (using geometry, ADS-B information or pilot input)
  - Considers up to **15 simultaneous** intruders
  - Avoidance trajectory in **one dimension**, {Heading or Flight Level or speed}

COLLISION AVOIDANCE

Objective “not scraping paint”:

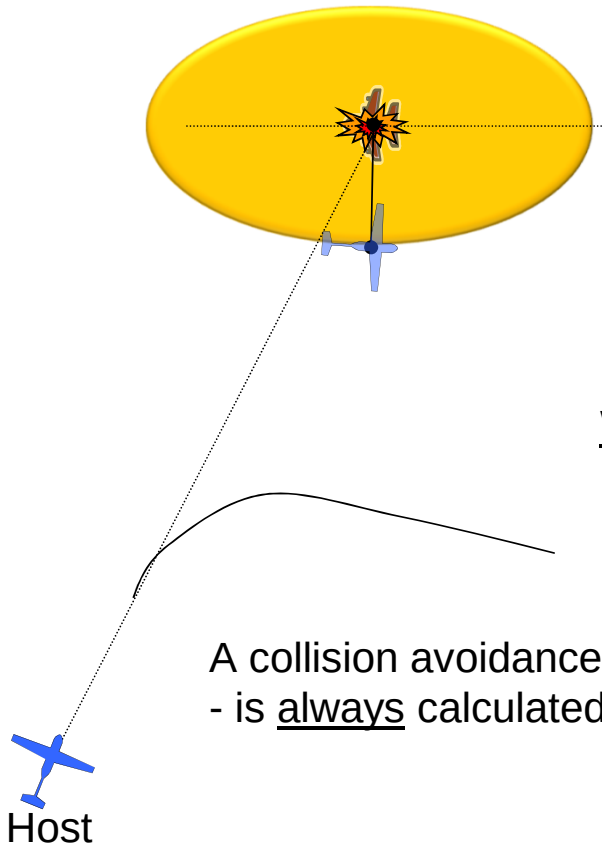
- **Clearing the Collision Volume (500ft horizontal/130ft vertical radii from AC)**

- Automatic last instance manoeuvre
- Knowledge of RA on TCAS intruder results in compatible manoeuvre and automatic triggering.
- CA Alert to pilot ~10seconds before automatic manoeuvre is performed
  - Disables any TrA trajectory indication.
  - Enables Pilot to activate manoeuvre early
- Post activation: straight and level flight; then hand over to flight management system

Features:

- Pilot ability to **inhibit/abort** manoeuvre at available link
- **Automatic** (not constrained by link delay or failure) activation at **last instance** when a safe manoeuvre can be performed - given current performance.
- Uses aircraft specific **performance model** to ensure that the UAS can follow the trajectory.
- Prefer right bound manoeuvre if intruder to the right or in front sector to consider **rules of the air**
- **Direction allowed to change** during ongoing manoeuvre (taking into account change in scenario)
- Considers **3 simultaneous** threatening aircraft
- **Minimizing nuisance** activations (Late activations, High performance) - compliant with manned.
- Meeting the objective including considering **3sigma uncertainties** {sensing, manoeuvring, computational}

CA Concept - illustrated



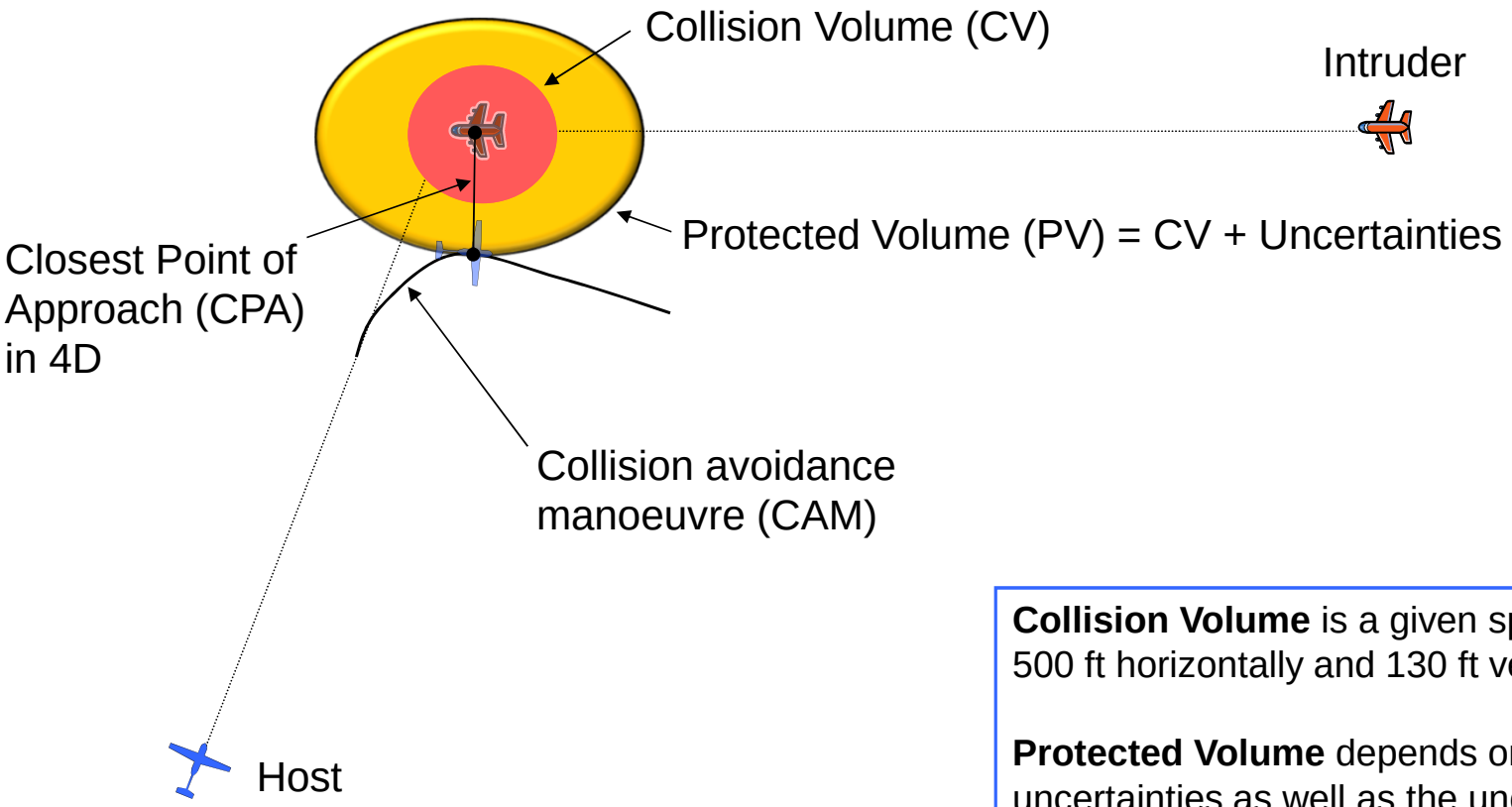
Last instant automatic activation of avoidance manoeuvre – keeps pilot in command, reduces uncertainties and sensor range req.

Warn when CA manoeuvre is imminent – Possibility to activate early by pilot

The manoeuvre is continuously optimized w.r.t. the three most threatening intruders

A collision avoidance manoeuvre - including recovery back to straight & level flight - is always calculated

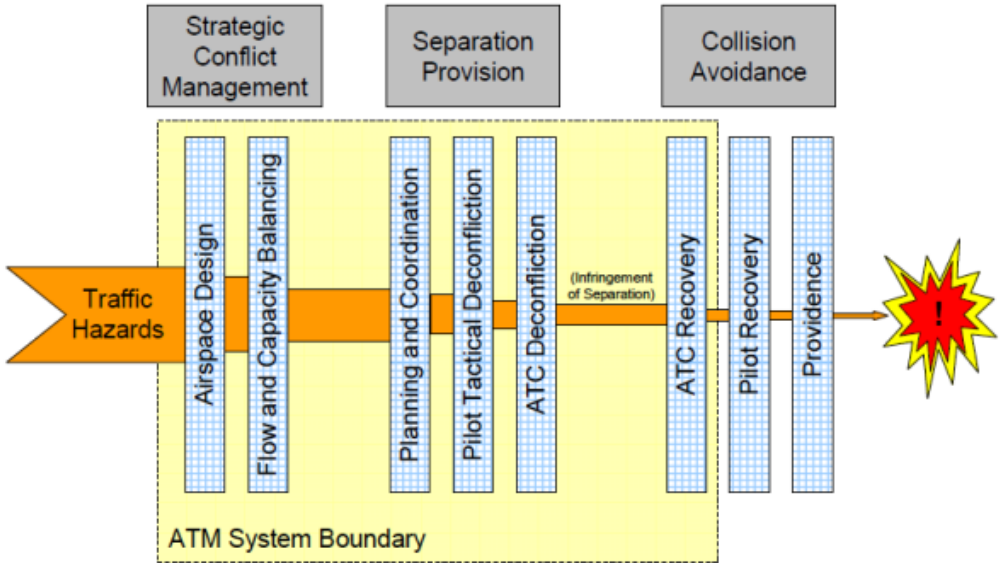
CA CONCEPT - TERMS & DEFINITIONS



Collision Volume is a given spheroid volume extending 500 ft horizontally and 130 ft vertically.

Protected Volume depends on current sensor/track uncertainties as well as the uncertainties in the CAM trajectory prediction.

MONTE-CARLO SIMULATION RESULT (POST ANALYSIS)



*) by fulfilling RR 5% in-FOV
and assigning all responsibility
to intruder outside FOV

OR

increasing FOV to
±180° az, ±25° el

OR

any combination in-between

Function	RR vs Coop	RR vs Non-Coop	Nuisance
Collision Avoidance	< 1% Feasible	< 10% Feasible *	< 0.001 / fh Feasible
Traffic Avoidance	< 16% Feasible	< 16% Feasible, within FOV	< 0.5 / fh Not assessed

DONE, DEFINED & DEMONSTRATED

System Engineering

- **Identification of main D&A functions**
  - **Support Situation Awareness**
  - **Provide Traffic Avoidance**
  - **Provide Collision Avoidance**
  - **Inform RP about S&A**
- **Allocation of requirements incl. performance to subsystems**
- **Definition of feasible non-cooperative / cooperative sensors requirements and design**
- **Investigation of needs for Situation Awareness wrt D&A**
- **Definition and validation of ACAS compatibility principles**
- **Definition of acceptable and feasible safety requirements**
- **Developed SW for Avoid, Fusion, IM, HMI and sensor models**

Simulation

- **Validation of CA and TRA design and performances**
- **Validation and acceptability of CONOPS**
- **Validation of ACAS compatibility**

Flight Demonstrations

- **Support Sensors, data fusion and Avoid development**
- **Demonstrate CA and TRA feasibility in real conditions**