TCAS Safety Study
Collision risk due to TCAS safety issues

(20 July 2010, EASA, Koeln)

Prepared by Stéphan Chabert & Thierry Arino

Presentation content

- **Background**
- **Data set and methodology**
- **TCAS operational performance**
- **Collision risk due to SA01 & SA-AVSA**
- **Conclusion**

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Introduction

- **TCAS II version 7.0 safety issues SA01 & SA-AVSA identified in 2000 & 2003**
  - ✓ **Associated collision risks implied rectifications**
  - ✓ **Solutions now implemented in version 7.1 (ED143/DO-185B MOPS issued in 2008)**
- **SA01 & SA-AVSA rates of occurrence used in the collision risk computation now dating from 2002 & 2005**
  - ✓ **Need to update the collision risk**
  - ✓ **Verify if safety issues SA01 & SA-AVSA still occur in the European airspace**
  - ✓ **Additionally, opportunity to analyse the current operational performance of TCAS in the European airspace**

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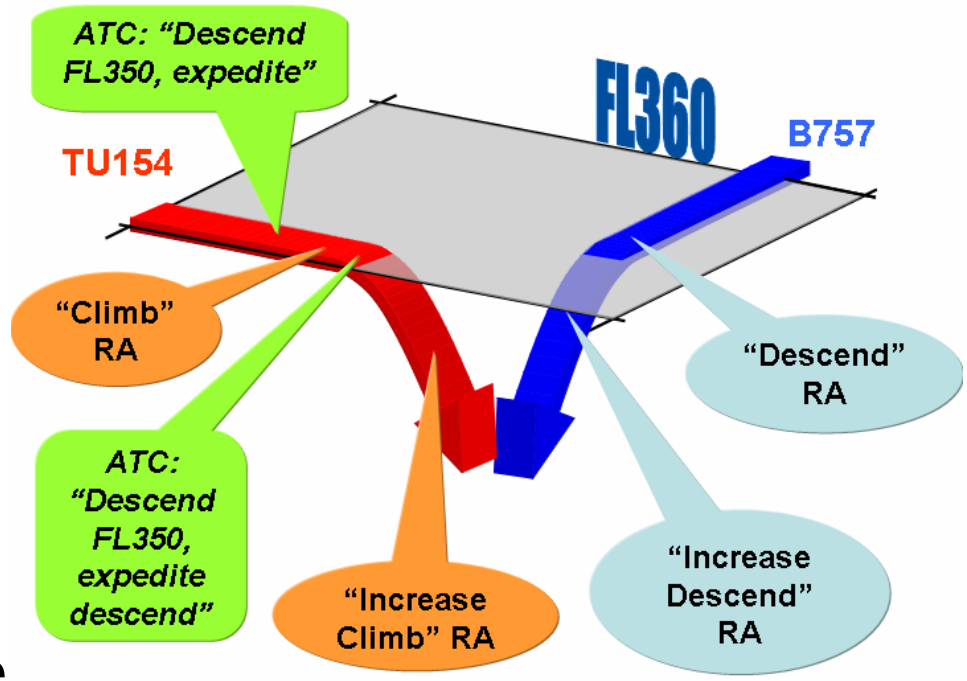
Safety issue SA01

- **Failure of TCAS to reverse on time some RAs when a reversal is required**
- **Two aircraft flying at the same FL and converging in range**
  - ✓ **Very late ATC instruction inducing an intruder manoeuvre that thwarts the initial RAs**
  - ✓ **TCAS II version 7.0 fails to reverse**
  - ✓ **Issue SA01a**



- **Yaizu accident, Überlingen collision, recurring severe incidents worldwide**
- **Überlingen accident probably avoided with version 7.1**
- **Issue SA01b similar with an unequipped intruder or an intruder with a TCAS unit set on TA-only mode**

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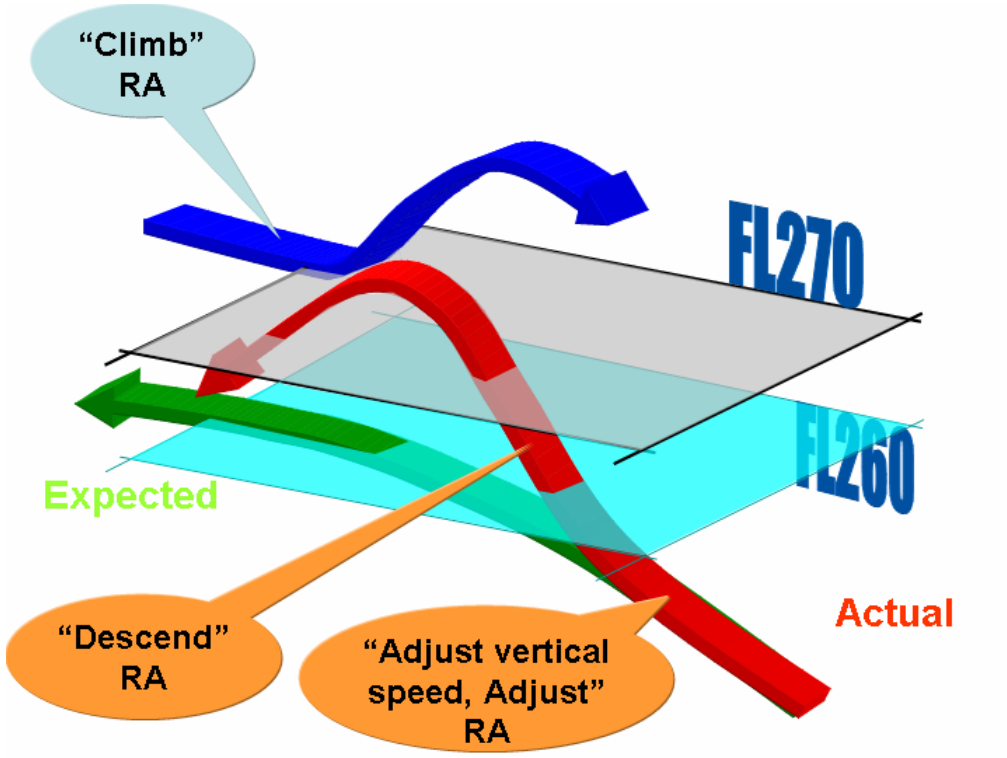
Safety issue SA-AVSA

- **Unintentional manoeuvre in the wrong direction to "Adjust Vertical Speed, Adjust"**
- **Level-off at 1000 ft separation**
  - ✓ **Level bust induced by opposite reaction to AVSA RA requesting vertical speed reduction**
- **Recurring severe incidents**
- **Issue addressed by the "Level-Off, Level-Off" solution introduced by version 7.1**



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Probability of occurrence & Severity

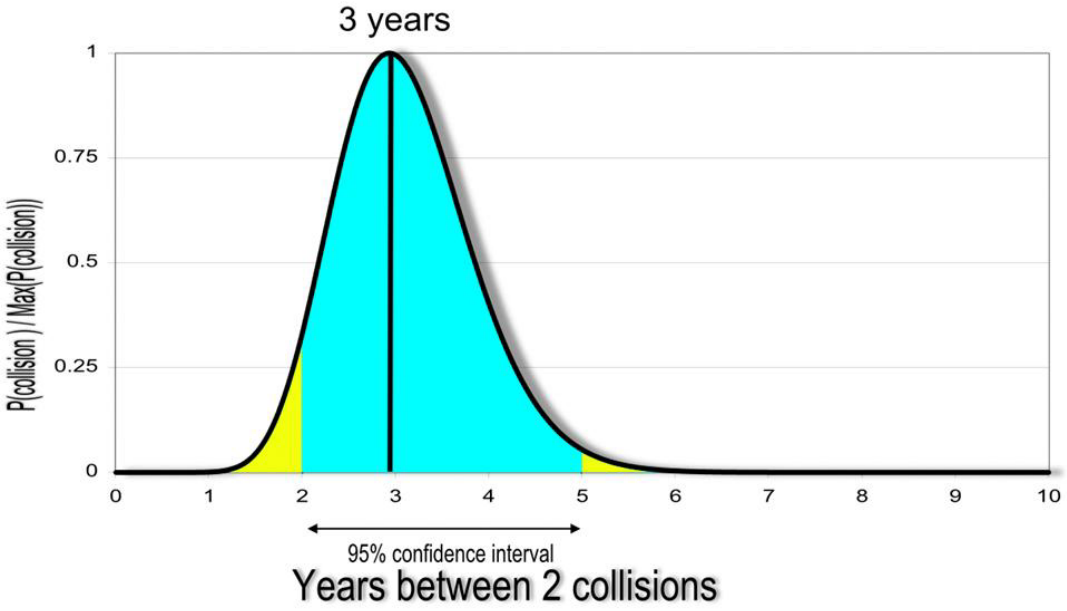
- **Probability of occurrence = Rate of observed incidents**
  - ✓ **SA01: 4.7×10^{-6} per flight hour**
    - **Based on data gathered with British Airways between 2001 & 2002**
  - ✓ **SA-AVSA: 3.8×10^{-6} per flight hour**
    - **Based on data gathered in the French airspace between 2004 & 2005**
- **Severity = Probability that, knowing that an event (SA01 or SA-AVSA) occurs, it will lead to a collision**
  - ✓ **Severity SA01 = P (Collision | SA01)**
  - ✓ **Severity SA-AVSA = P (Collision | SA-AVSA)**

Risk of collision

- **Risk of collision = Probability of occurrence x Severity**

- **Risk of collision**
  - ✓ **SA01: 2.2×10^{-8} per flight hour**
  - ✓ **SA-AVSA: 5.4×10^{-9} per flight hour**

- **Corresponding risk in the European airspace**
  - ✓ **One collision every 3 years**
  - ✓ **Between 2 and 5 years with a confidence of 95%**



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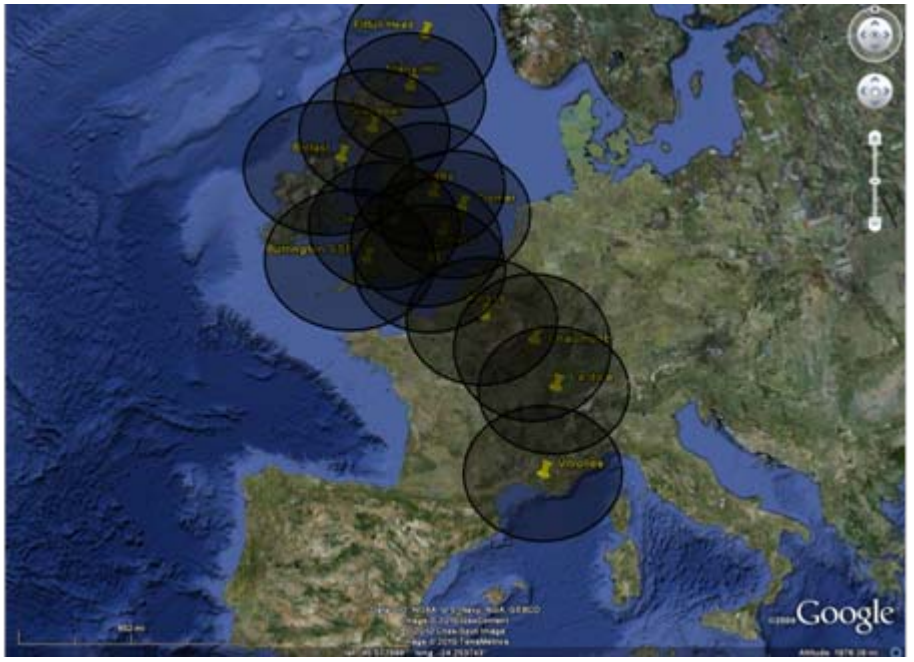
Data set

Data gathered in the European Core Area

- **6 months of RA downlink data (DSNA)**
  - ✓ From April to September 2009
  - ✓ 4 radars
- **8 months of ASMT data (NATS)**
  - ✓ From March to November 2009
  - ✓ 12 radars



Methodology

- **Step1: Decode RA downlink / ASMT data and extract encounters with RAs**
- **Step 2: Apply automatic / manual filtering to remove**
  - ✓ **Duplicated encounters (due to radar overlap)**
  - ✓ **Encounters with RAs caused by military interceptions**
  - ✓ **Encounters with missing plots, too short encounters, etc.**
- **Step 3: Analyse safety and operational performance of TCAS RAs**
  - ✓ **1268 RAs included in 1104 encounters**
- **Step 4: Compute collision risk**
  - ✓ **Using methodology applied in DO-298 & ER-1**

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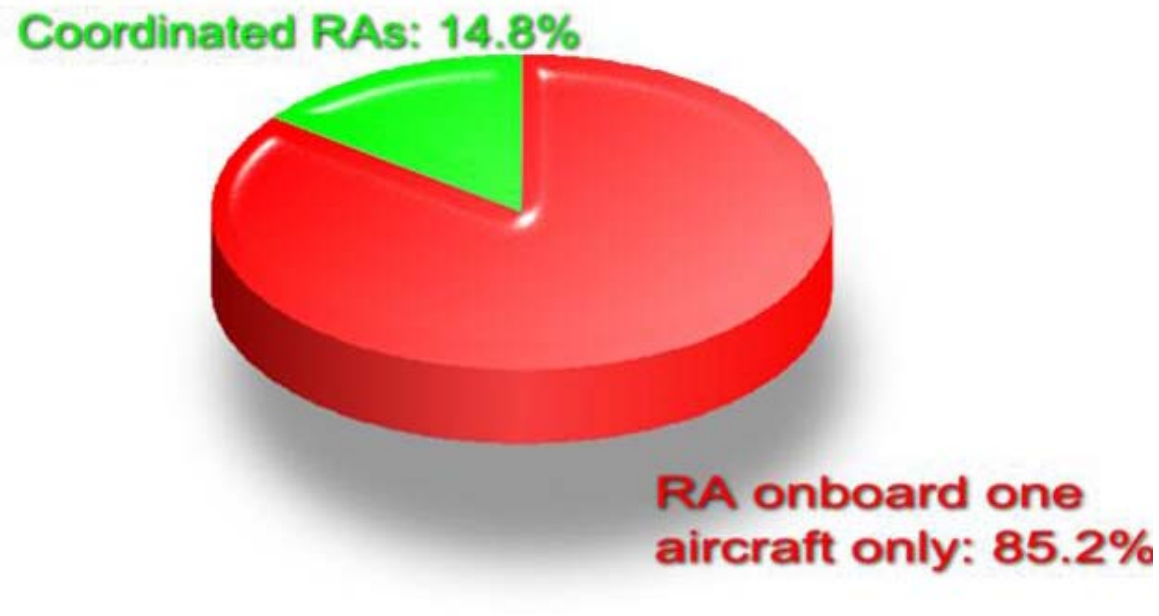
Coordinated RAs

- **Confirms observations made in previous studies (with 2007 & 2008 data)**
- **Rate of encounters with coordinated RAs is low**
  - ✓ **IFR / VFR encounters**
  - ✓ **VTT logic in level-off geometries**



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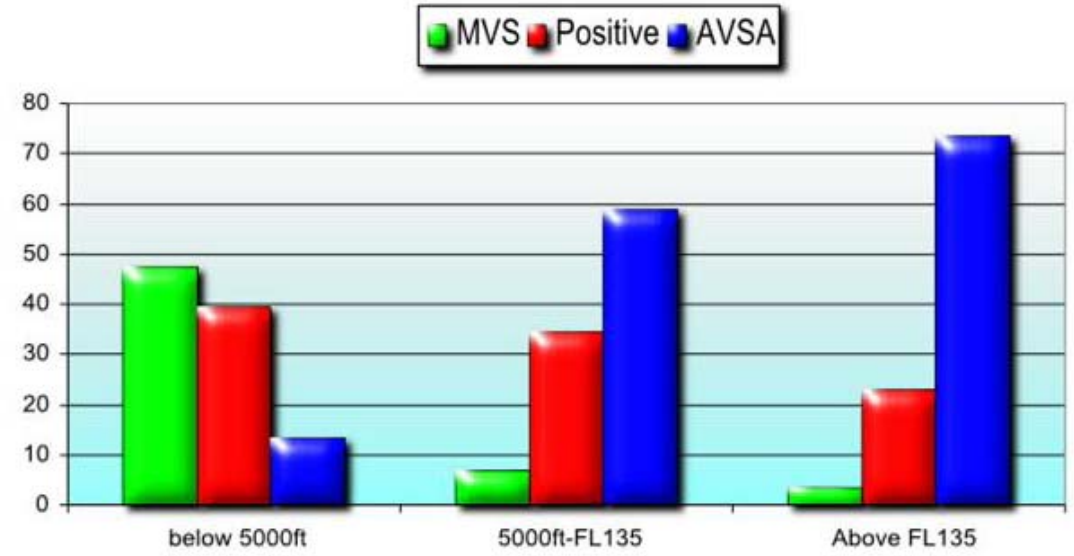
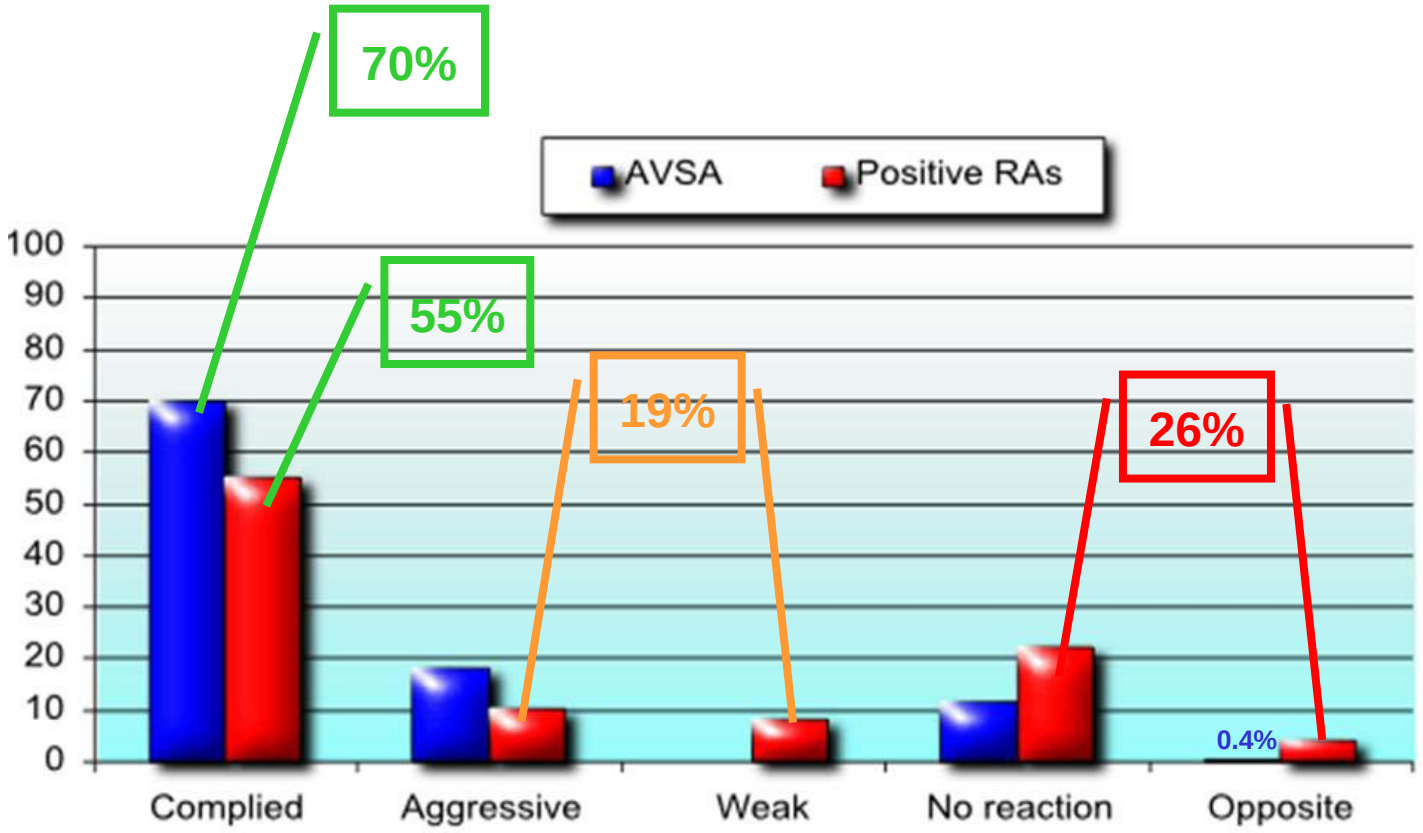
RA type

- **Two main features observed in the Europe airspace**
- **Below 5000 ft**
  - ✓ **50% of Monitor Vertical Speed RAs due to IFR / VFR encounters**
- **Above FL135**
  - ✓ **75% of Adjust Vertical Speed RAs due to day-to-day 1000 ft level-off geometry**



Reaction to RAs in TMA (< FL135)



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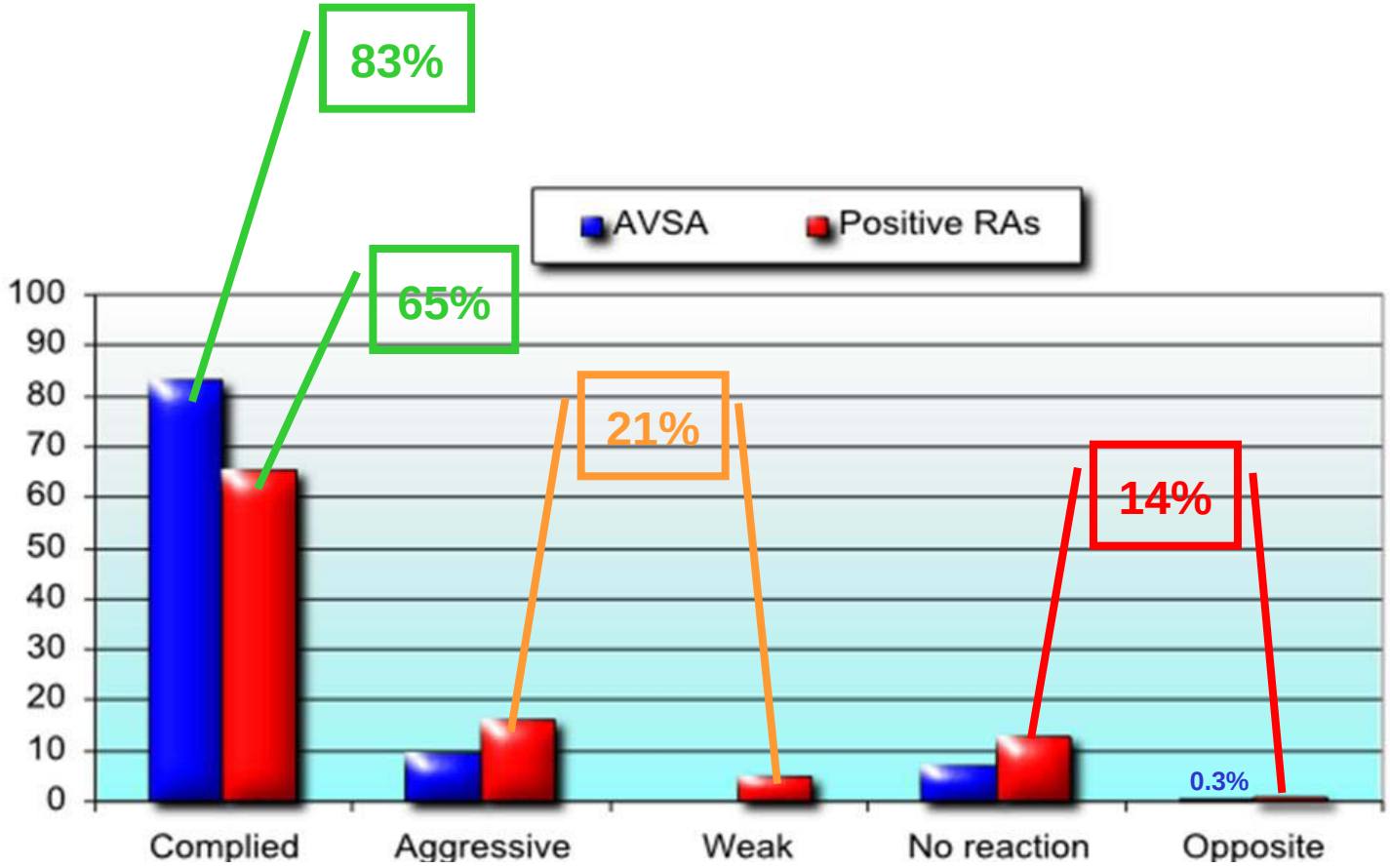
Reaction to RAs in EnRoute (> FL135)



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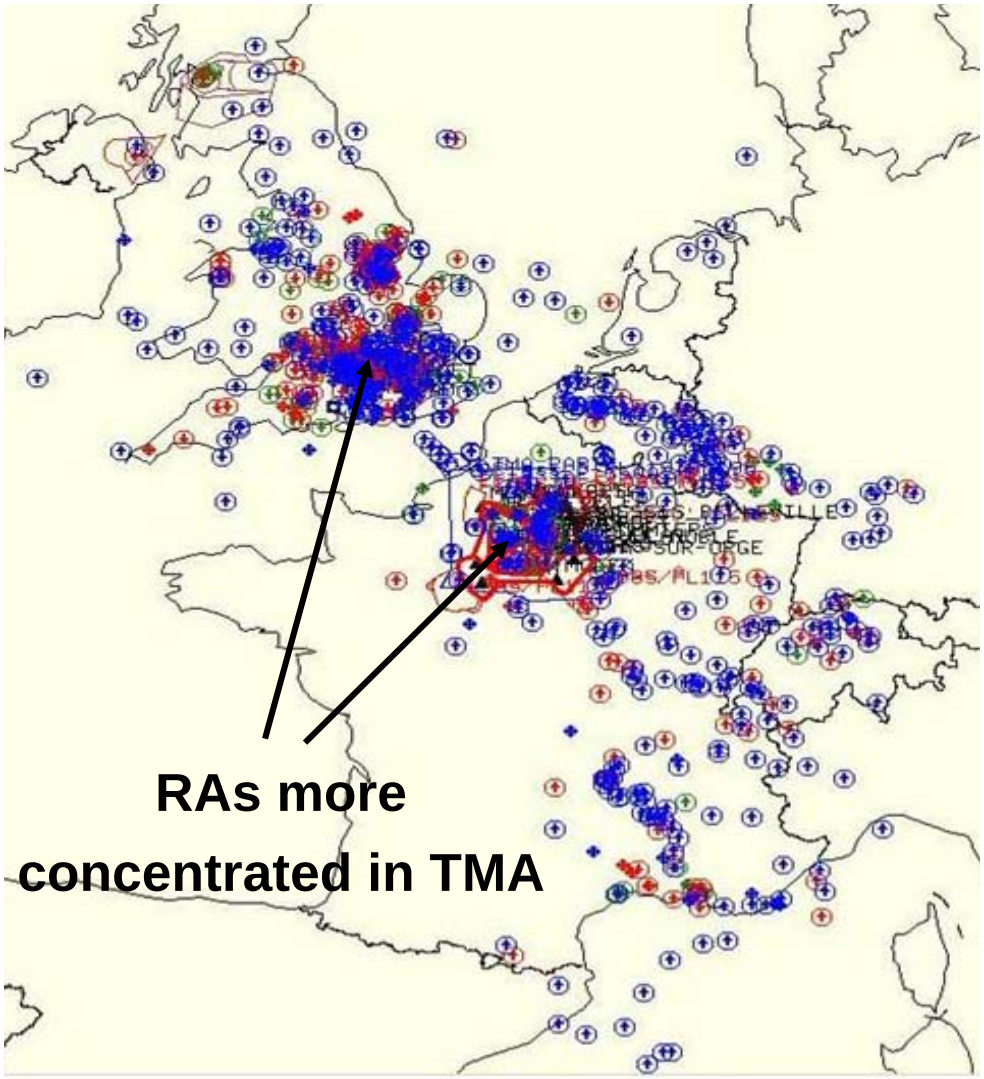
RA localisation



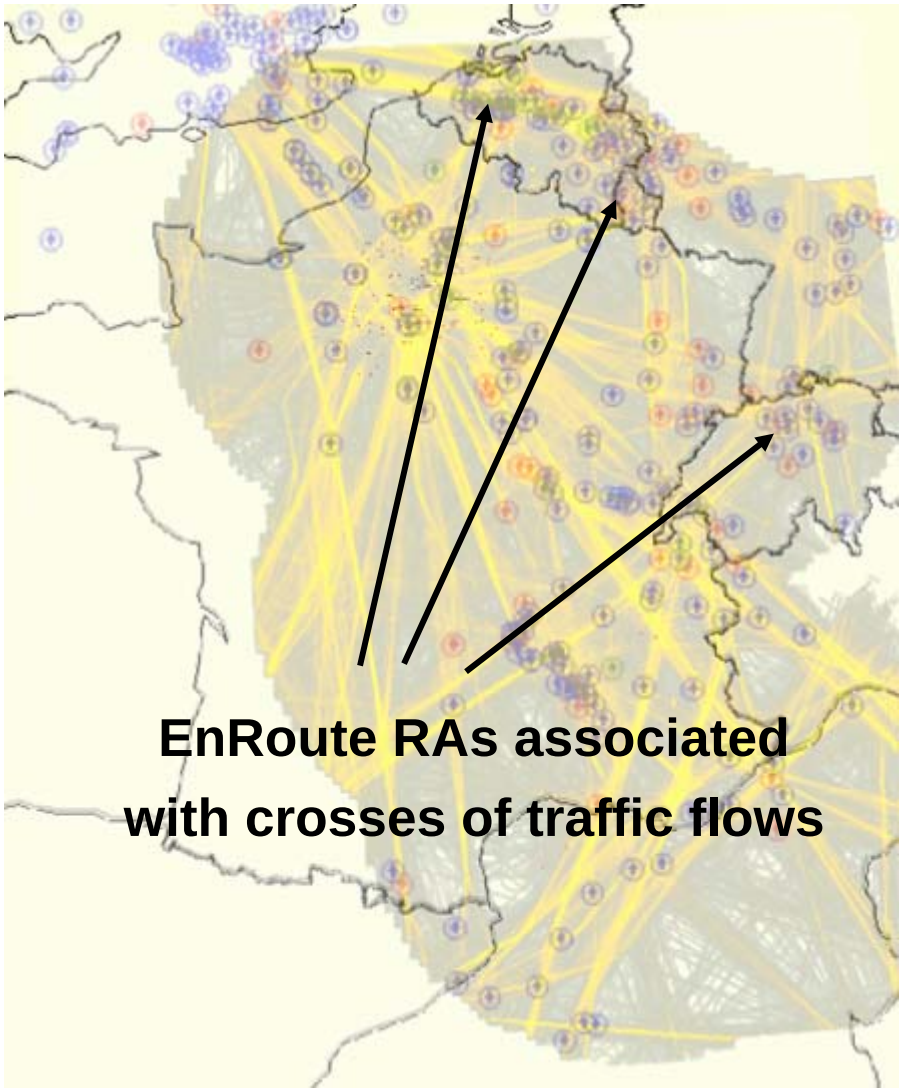


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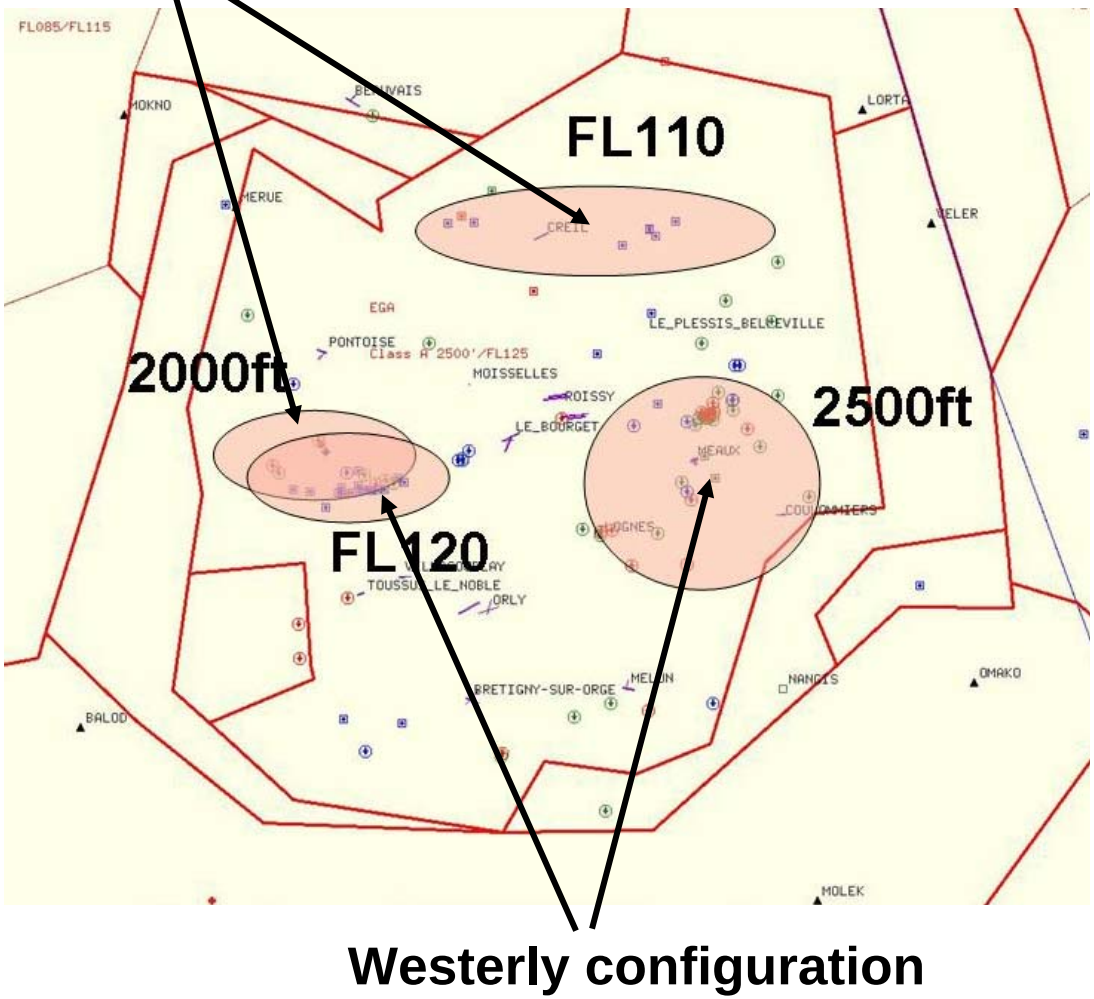
Illustration of the Paris TMA hotspots

Two type of hotspots

- ✓ **Below 5000ft**
  - IFR/VFR traffic
  - VMD=500 ft
- ✓ **Around FL100**
  - Crossing between arrivals & departures
  - VMD=1000 ft

Hotspot are configuration dependent



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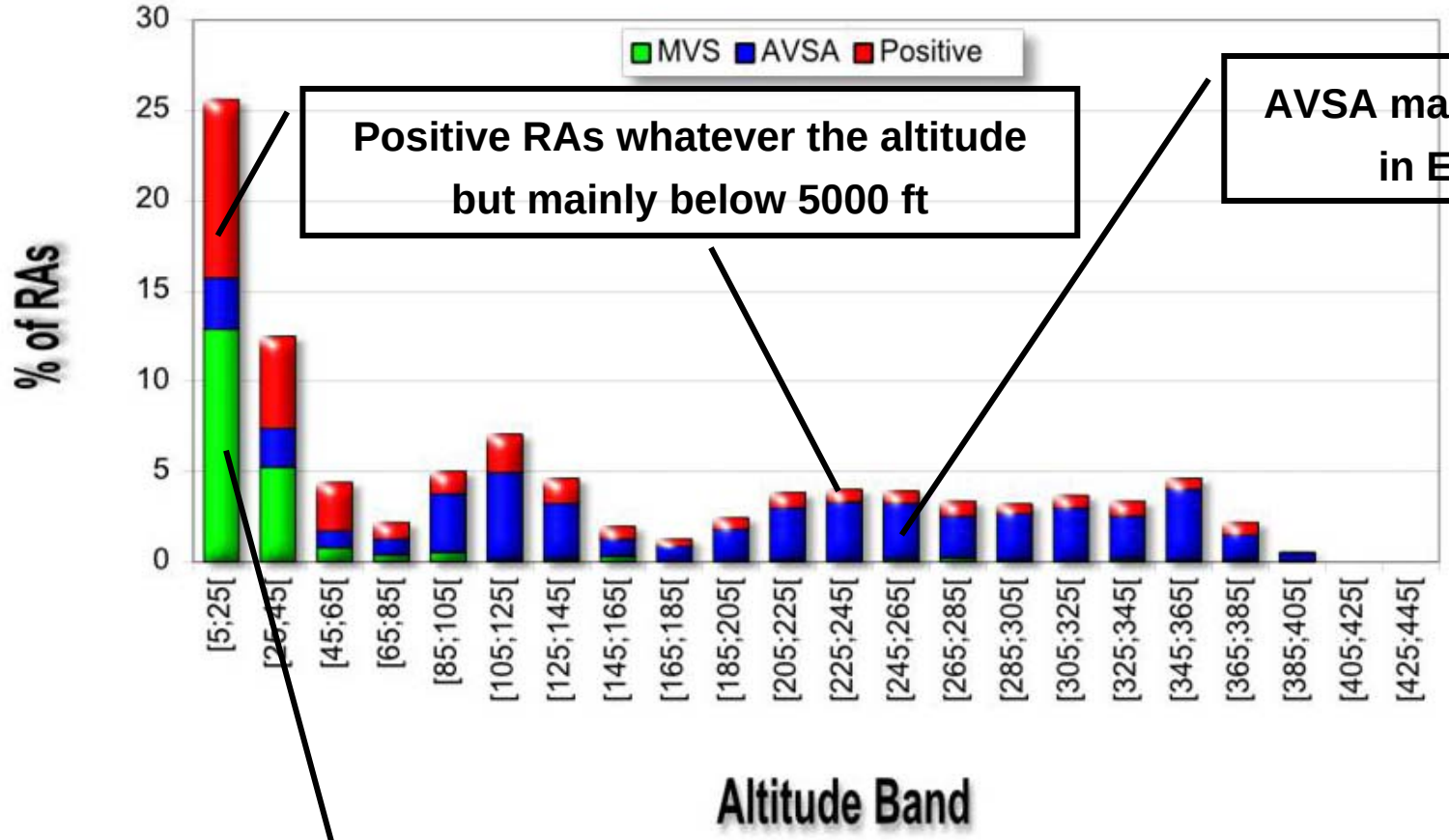
Altitude distribution



Positive RAs whatever the altitude but mainly below 5000 ft

AVSA mainly triggered in EnRoute

MVS close to the ground (VFR / IFR crossings)

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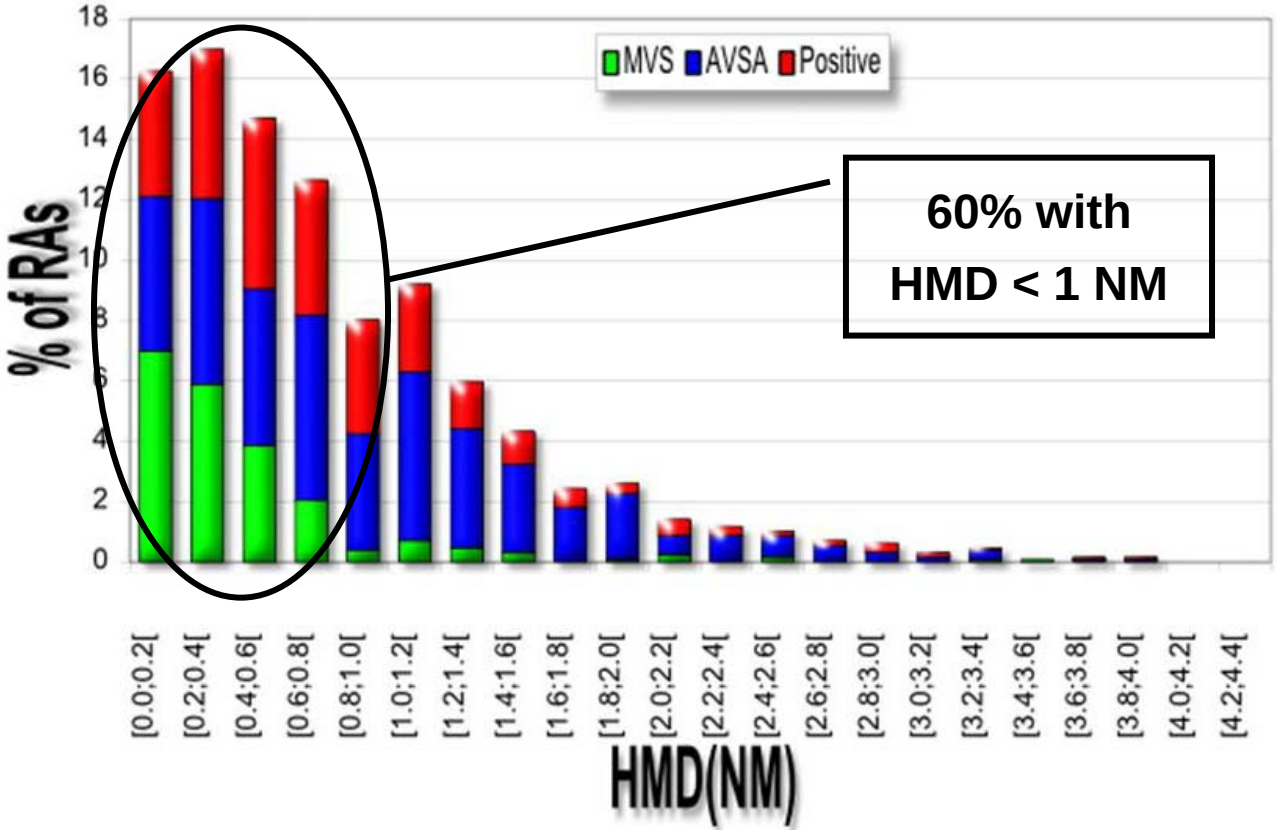
HMD distribution



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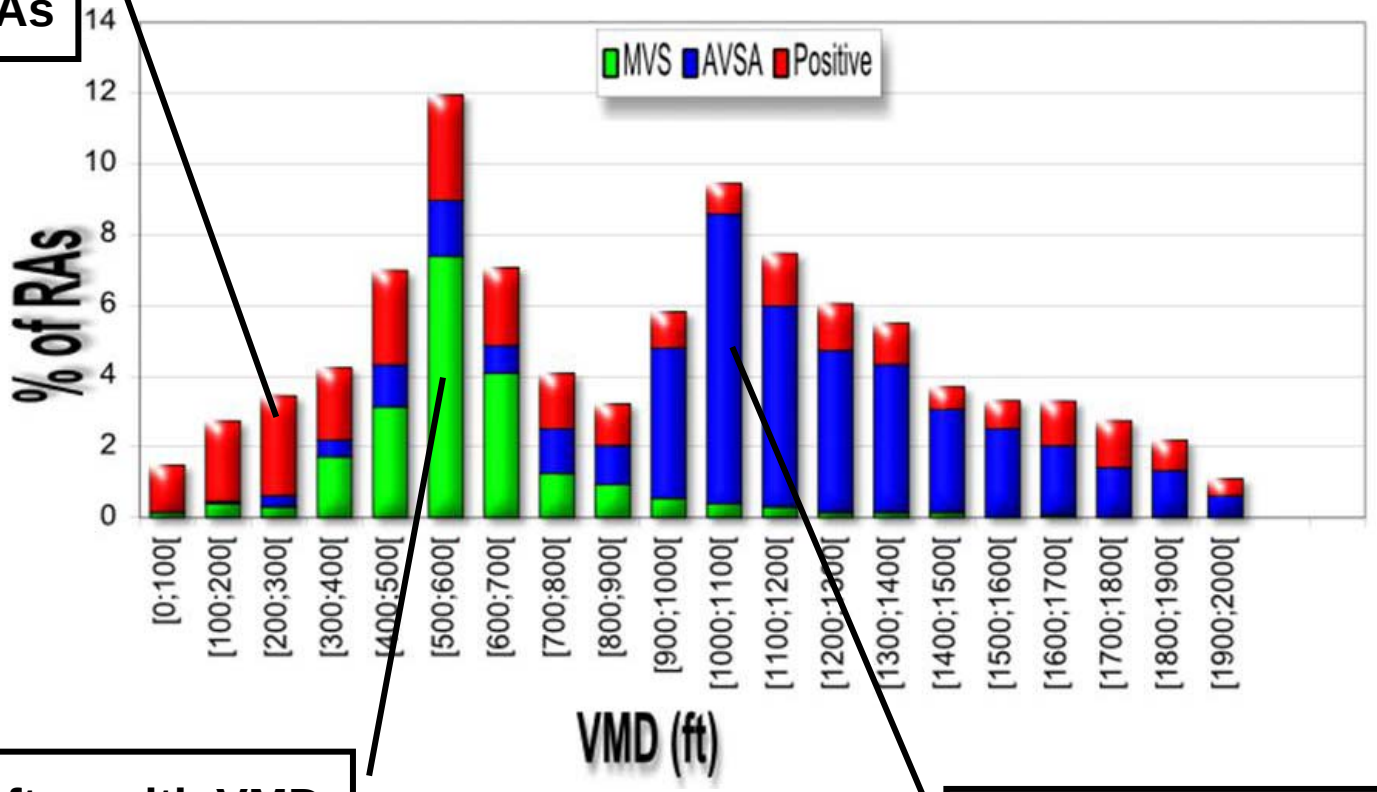
VMD distribution

Small VMDs are mostly positive RAs



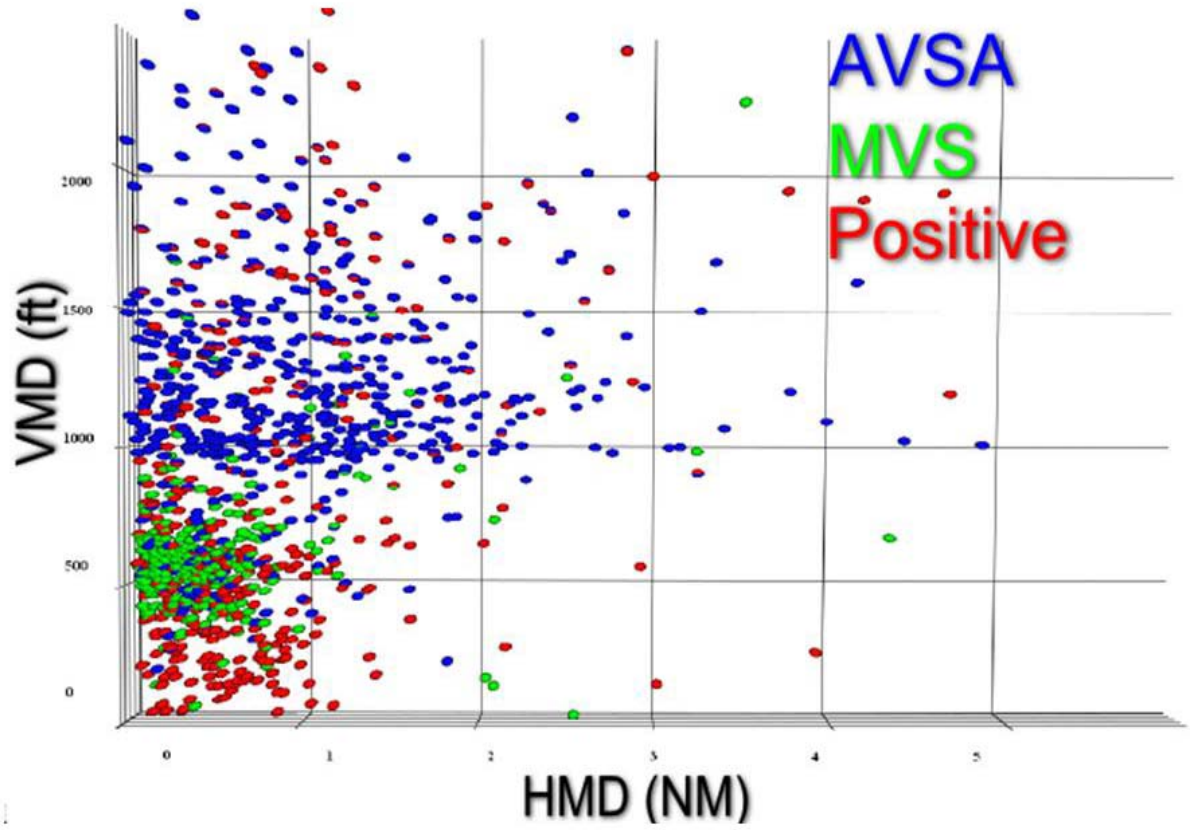
MVS often with VMD around 500 ft

AVSA often with VMD around or above 1000 ft

VMD vs HMD (vs Altitude)

Two main clusters

- ✓ MVS RAs with 500ft VMD and <1NM HMD (close to the ground)
- ✓ AVSA RAs with 1000ft VMD and <2NM HMD (at higher altitudes)



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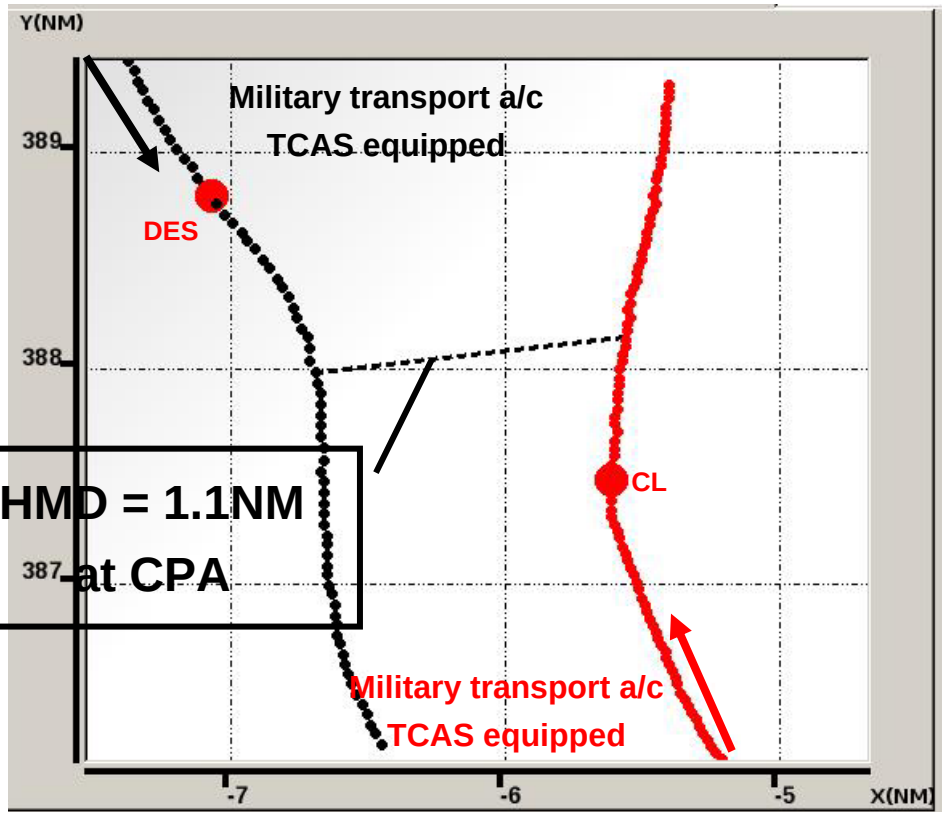
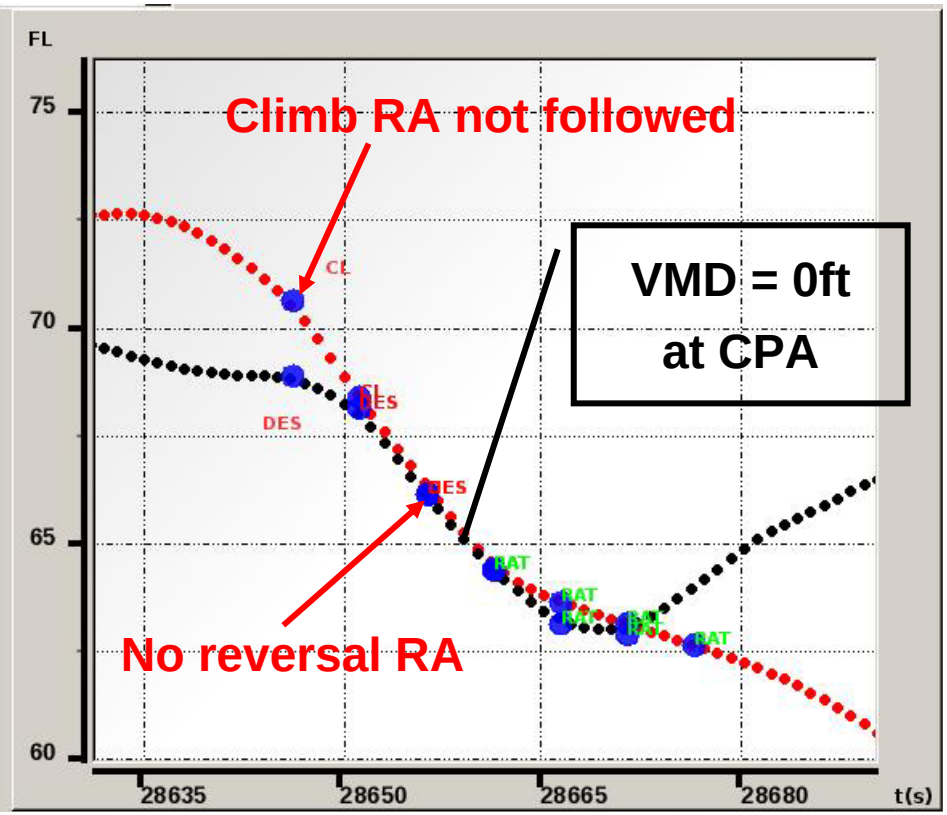
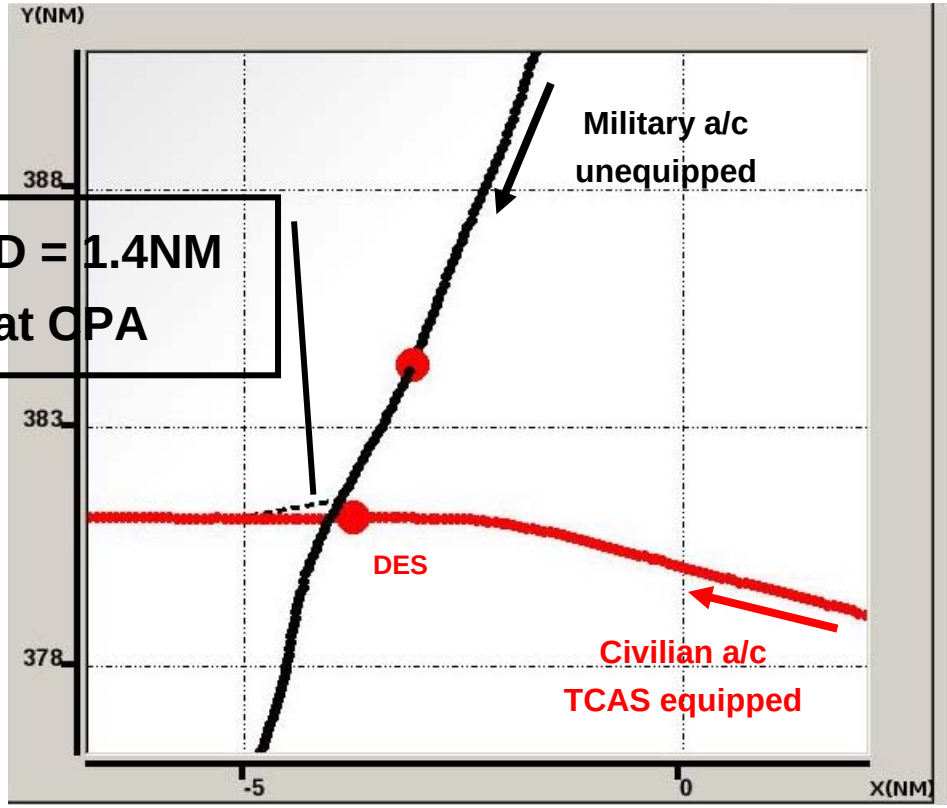
SA01a incident n°1

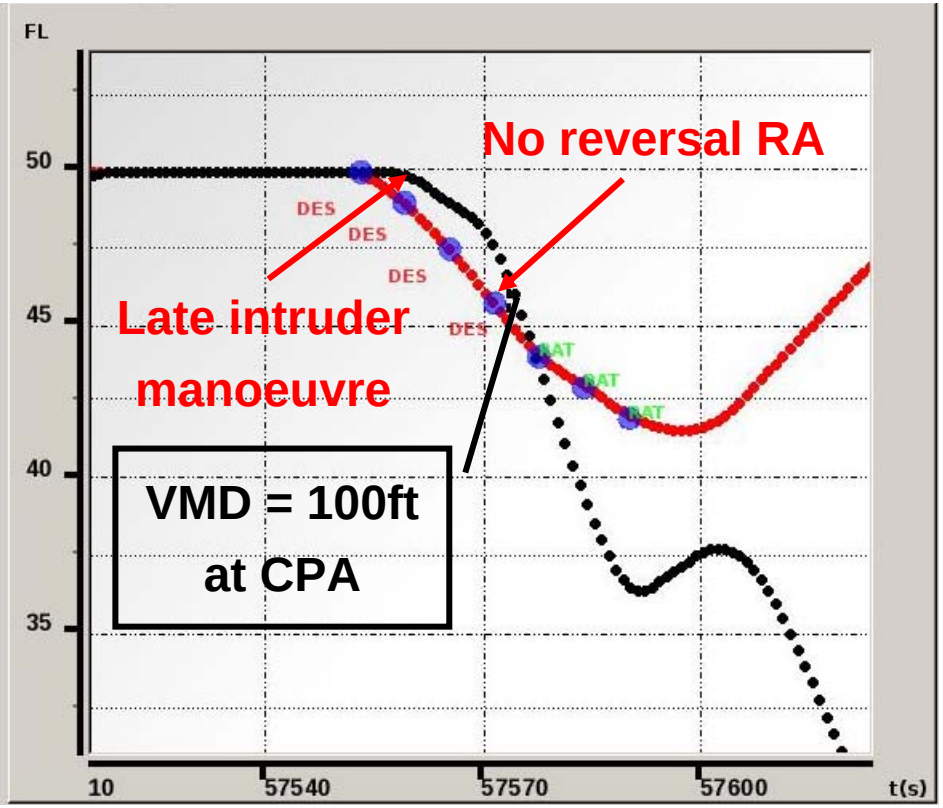




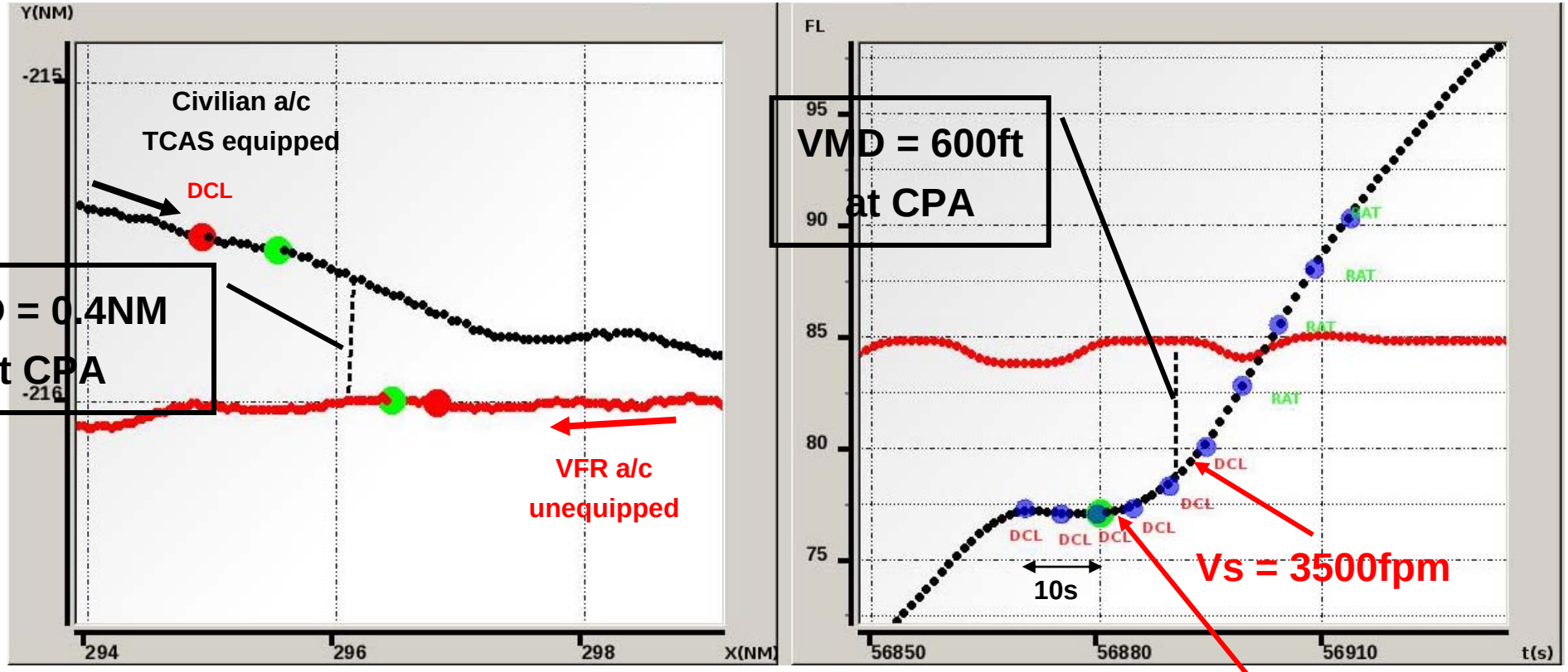
SA01b incident n°2



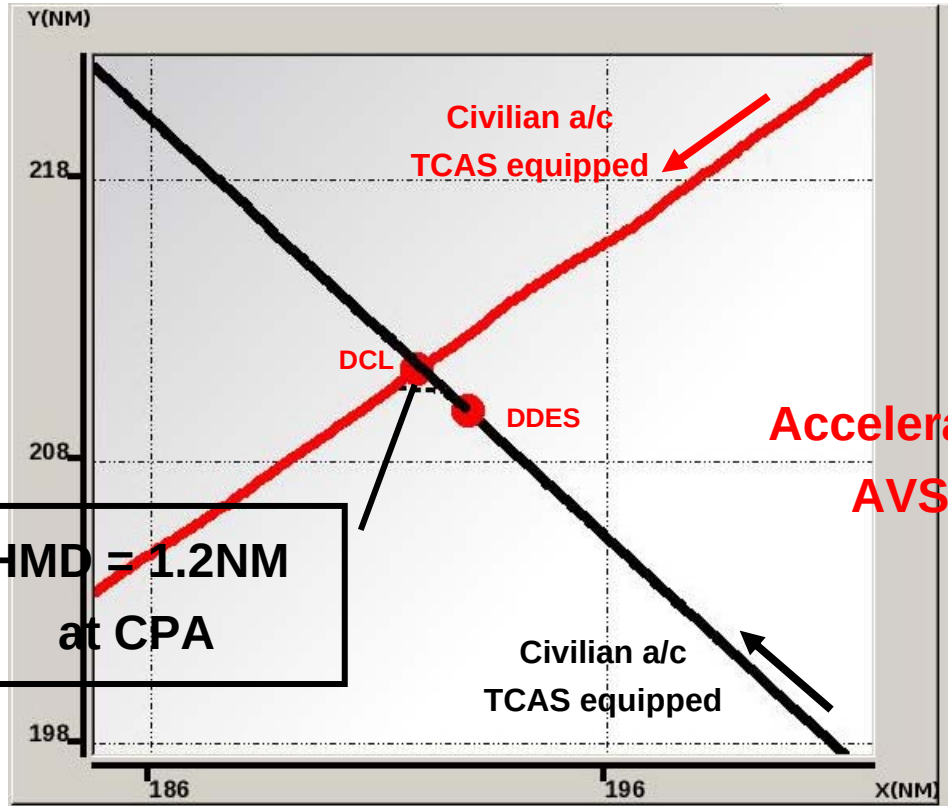
HMD = 1.4NM
at CPA



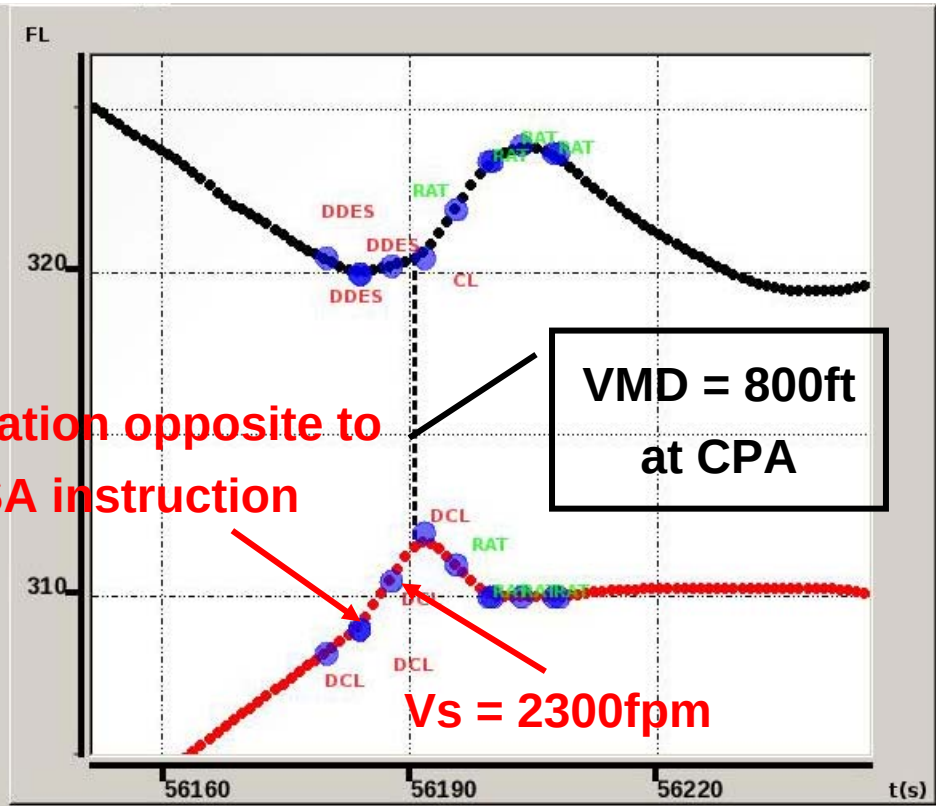
SA-AVSA incident n°3



SA-AVSA incident n°4



HMD = 1.2NM
at CPA



Acceleration opposite to
AVSA instruction

VMD = 800ft
at CPA

Vs = 2300fpm

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Collision risk computation

Methodology applied in DO-298 & ER-1

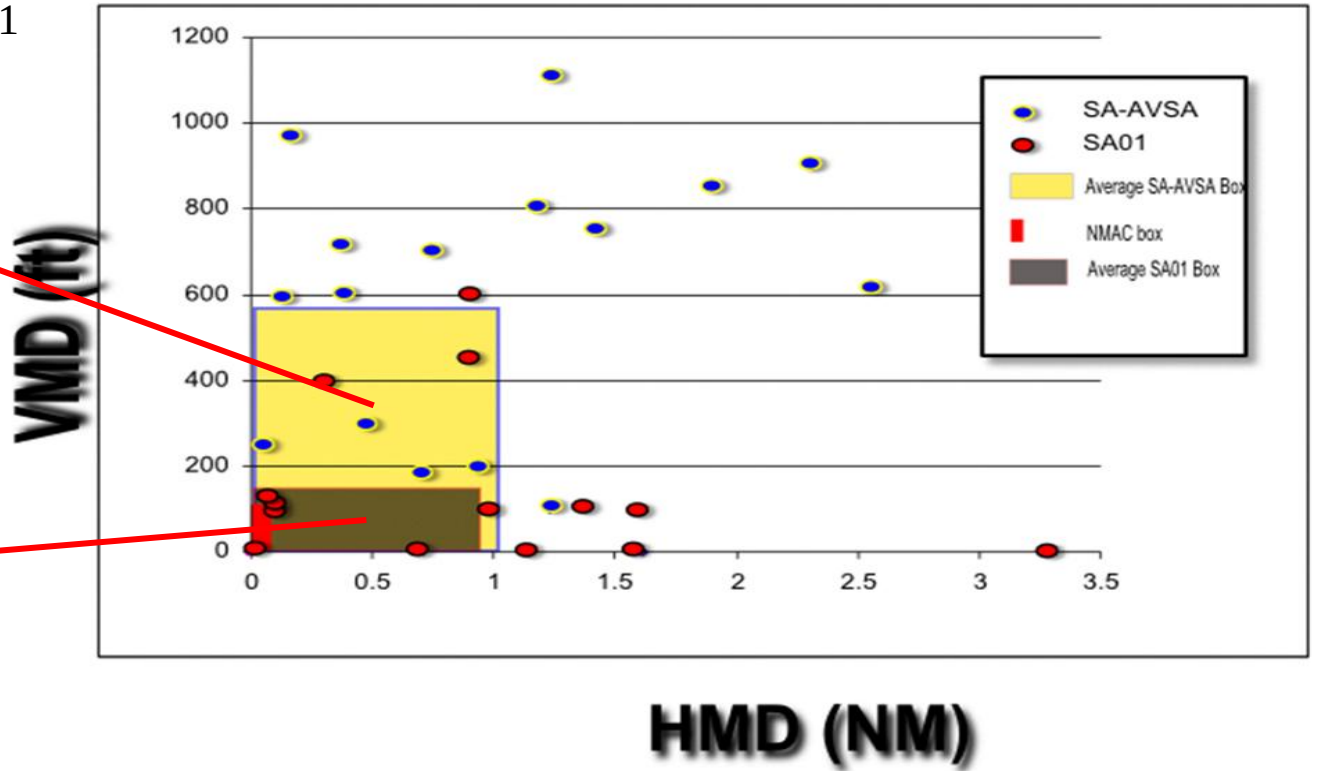
$$P(\text{SA01/AVSA and collision}) = P(\text{SA01/AVSA}) \times P(\text{collision} \mid \text{SA01/AVSA})$$

$$P(\text{Collision} \mid \text{SA01/AVSA}) = \frac{\text{Vertical NMAC box}}{\text{Vert. SA01/AVSA Miss Dist.}} \times \frac{\text{Horiz. NMAC box}}{\text{Horiz. SA01/AVSA Miss Dist.}} \times P(\text{Collision} \mid \text{NMAC})$$

$$P(Collision \mid NMAC) = 0.1$$

SA-AVSA
1.0 NM / 570 ft

SA01
0.9NM / 150 ft



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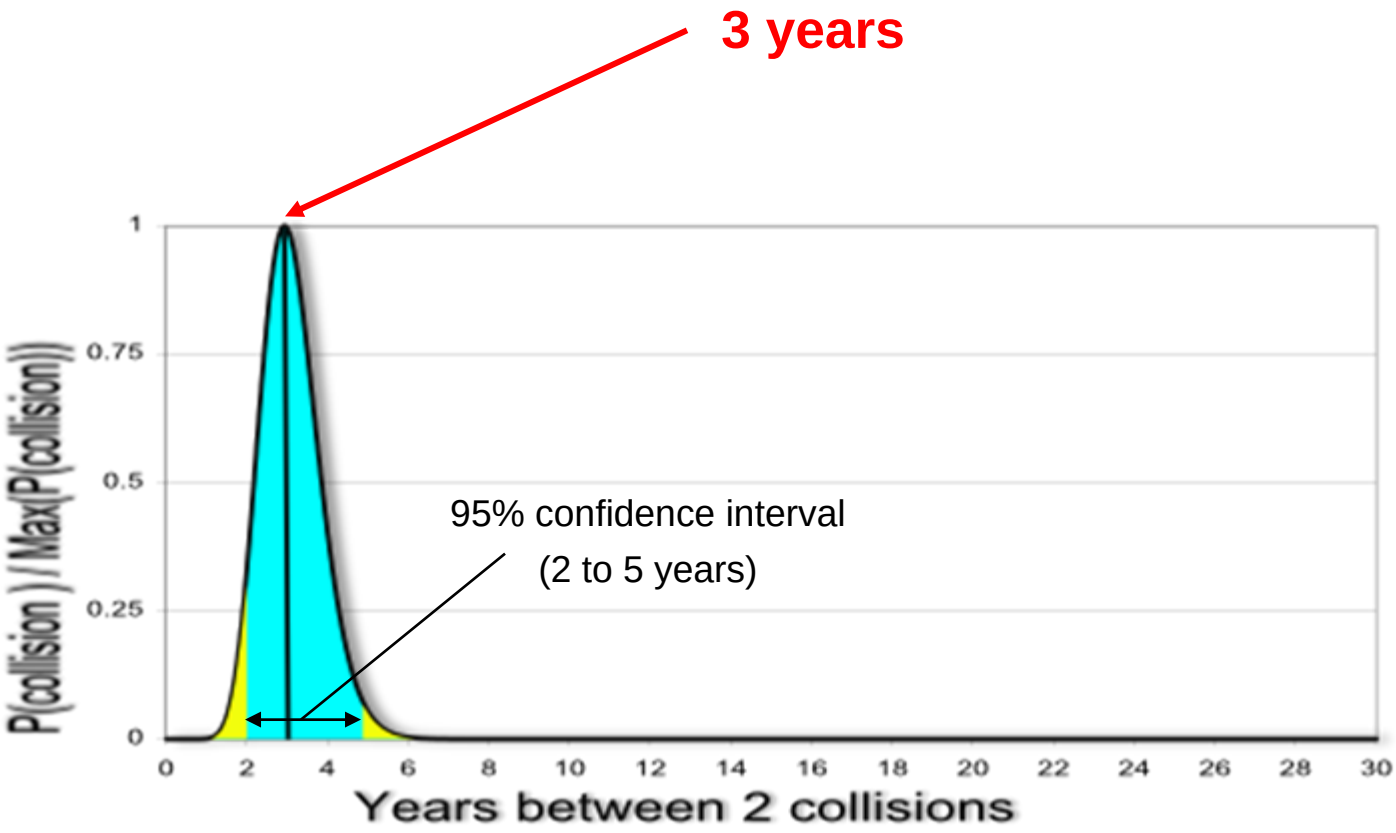
Initial computation



- **Exceeds the tolerable rate for catastrophic events caused by equipment related hazards by a factor of more than 25**
  - ✓ **Collision Risk = 27.4×10^{-9} pfh**

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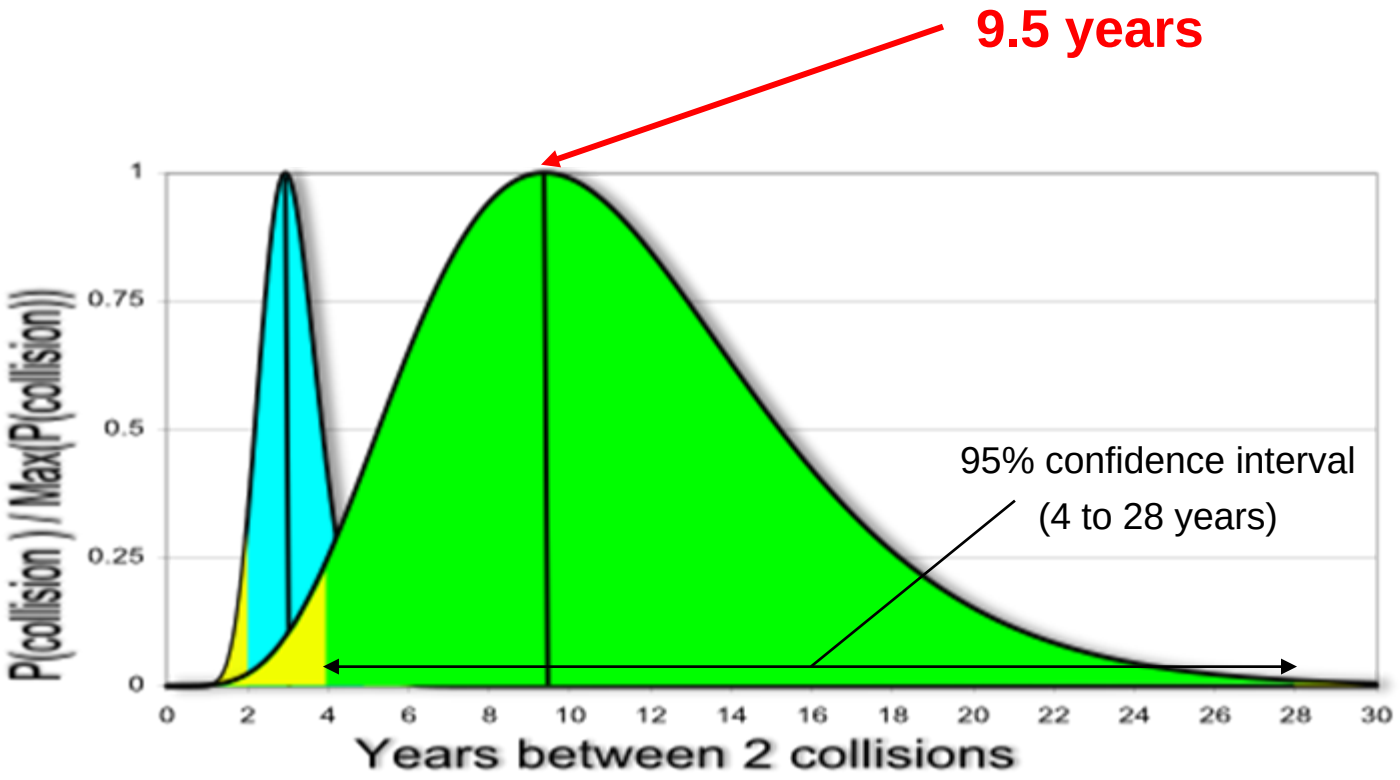
Computation based on latest incidents



- **Exceeds the tolerable rate for catastrophic events caused by equipment related hazards by a factor of more than 7**
  - ✓ **Collision Risk = 7.6×10^{-9} pfh**

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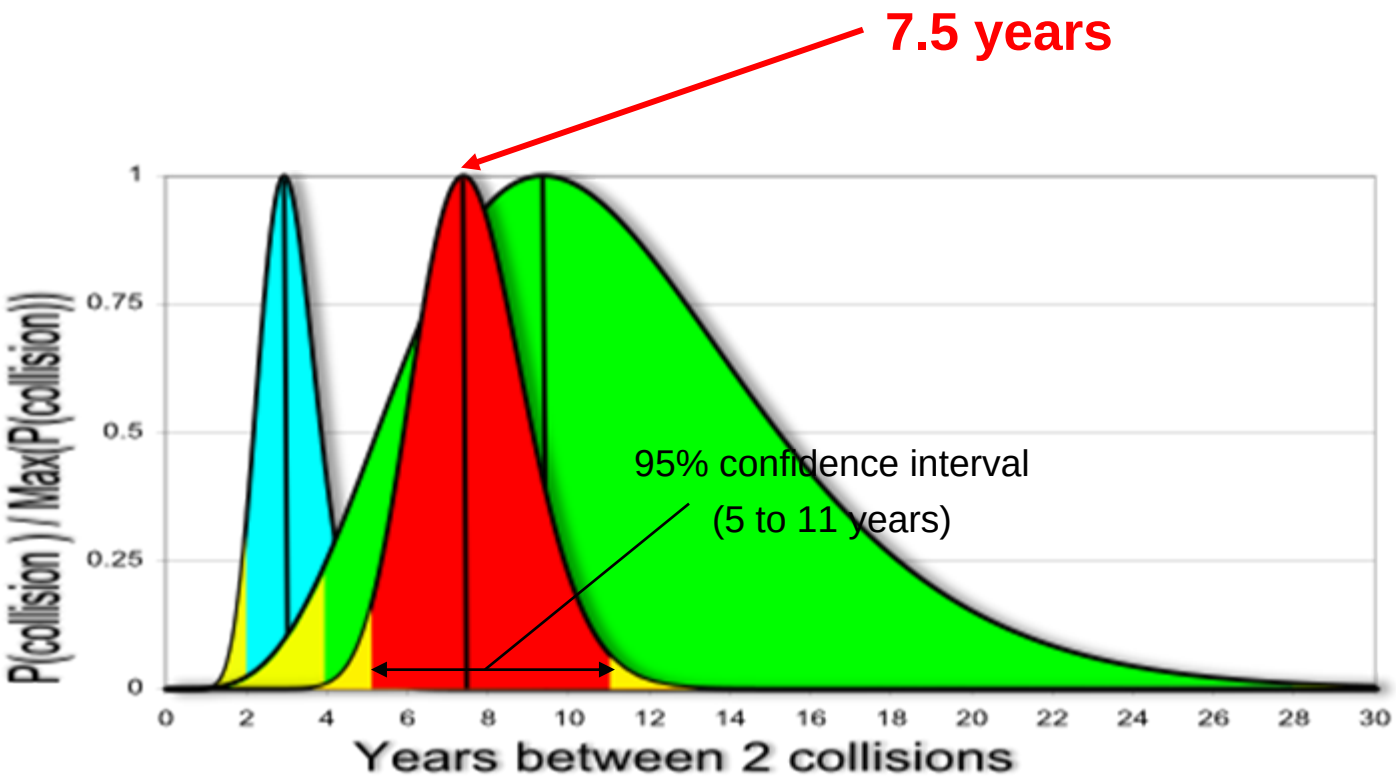
Updated computation



- **Exceeds the tolerable rate for catastrophic events caused by equipment related hazards by a factor of about 10**
  - ✓ **Collision Risk = 9.8×10^{-9} pfh**

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Conclusion

- **Safety issues SA01 & SA-AVSA still occur in the European airspace**
  - ✓ **Two SA01 incidents & two SA-AVSA incidents found in 2009 over a short period of time (half a year)**
- **Severity of these two issues continues to call for a rapid implementation of the TCAS II version 7.1 solution**
  - ✓ **VMDs < 100ft for the SA01 incidents**
- **Updated risk of collision for the European airspace is of concern**
  - ✓ **One collision every 7.5 years**
  - ✓ **Exceeds the tolerable rate by a factor of about 10**

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