
Traffic and Collision Avoidance System (TCAS) Tutorial



Briefer:

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Date:

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U.S. AIR FORCE



Topics



- **TCAS II Details Overview**
- **Ueberlingen Collision**
- **Sense Reversal logic**
- **Adjust Vertical Speed Adjust**
- **TCAS II Version 7.1 – US and Europe**
- **Hybrid Surveillance**



Objective

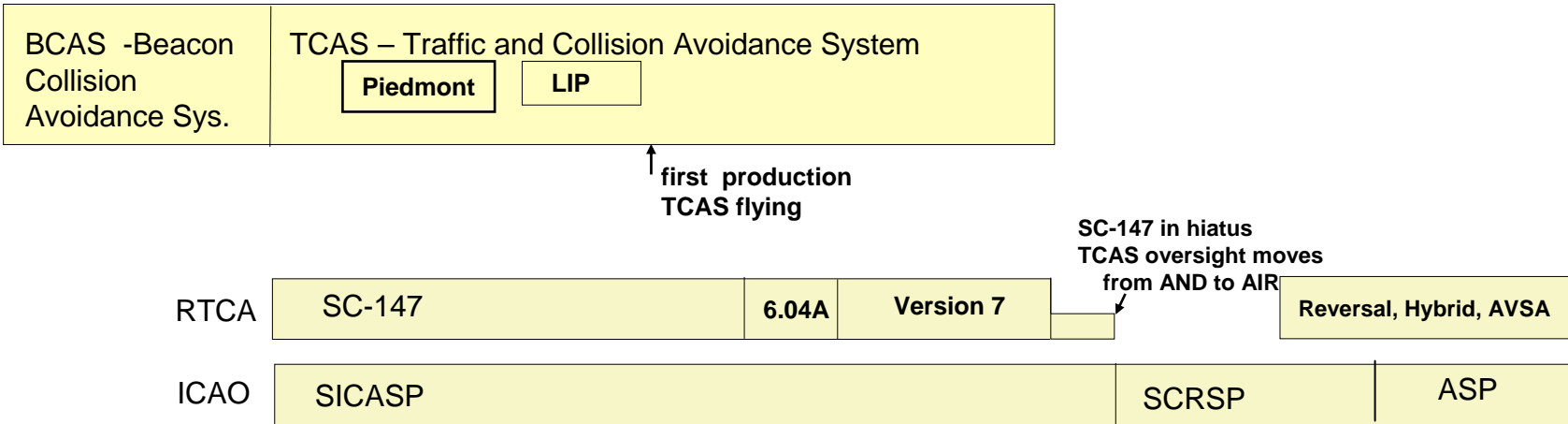
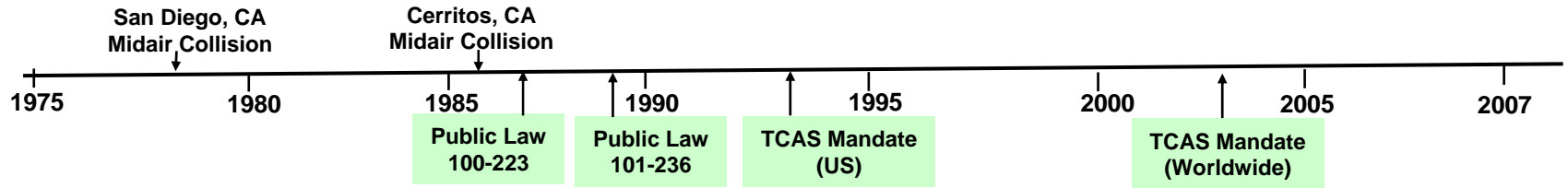


At the end of this presentation you will have a deeper understanding of

- **How TCAS II works,**
- **What problems have been identified how they are being fixed**
- **What future changes that are coming**
- **Some knowledge of the Military specific variants of TCAS II**



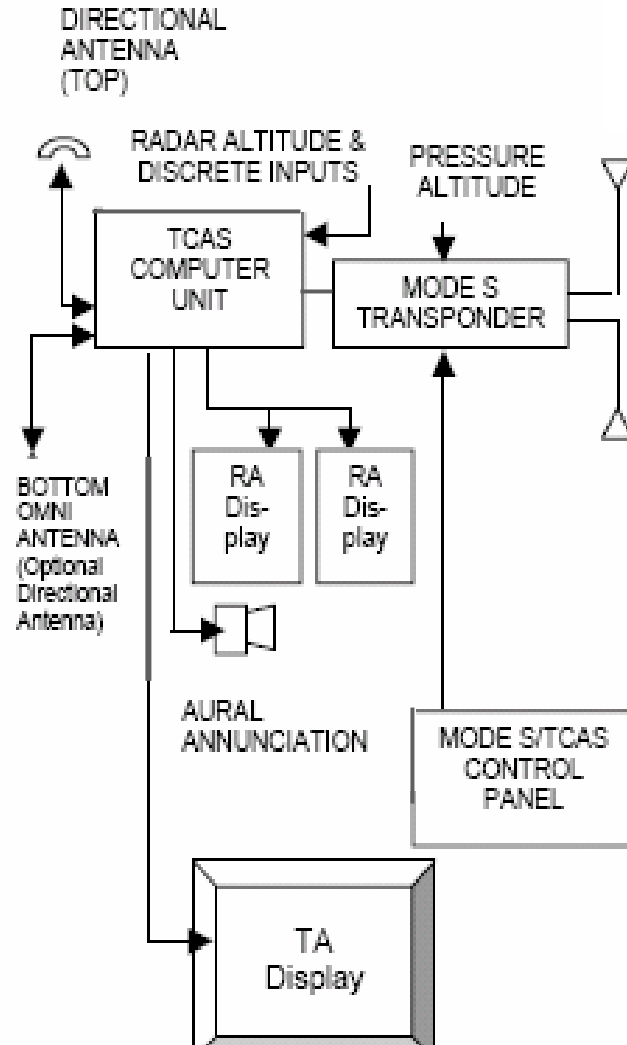
TCAS II Overview - Timeline



- LIP** Limited Installation Program
 - Allied Signal / UAL
 - Honeywell / NWA
- SICASP** ICAO Panel - SSR Improvements and Collision Avoidance Systems Panel
- SCRSP** ICAO Panel - Surveillance and Conflict Resolution Systems Panel
- ASP** ICAO Panel - Aeronautical Surveillance Panel
- Reversal** Sense Reversal Logic for TCAS
- Hybrid** Hybrid Surveillance for TCAS
- AVSA** Adjust Vertical Speed Adjust for TCAS



TCAS II – General Architecture



Directional Antenna – Top and optional omnidirectional or directional on bottom

Radar Altimeter – Used to reduce Operation as the ground is approached

Pressure Altitude – To transponder with highest precision available.

Note that TCAS own altitude comes through the transponder.

Control Panel

Aural Annunciation

Resolution Advisory (RA) and Traffic Advisories (TA) displays



What TCAS II Uses



- **Identification of the aircraft in the area.**
 - **Mode S Address if available**
- **Altitude and Address of own aircraft**
 - **From own transponder**
- **Range to the intruder and Altitude**
 - **From interrogation of the intruder (Mode C or UF=0/16 interrogation replies)**
- **Equipage of the intruder (TCAS or not)**
 - **Coordination with the intruder if TCAS equipped**



TCAS II –ATCRBS Intruders



- **TCAS interrogates (1030 MHz) around 360° with Mode C (altitude) ATCRBS-only All-Call (only ATCRBS aircraft reply – not Mode S equipped aircraft)**
- **A track is developed on the aircraft in the TCAS processor (based on interrogation replies)**
- **RAs and TAs are developed per the logic**
- **RAs are downlinked to the ground Mode S sensor**



TCAS II – Mode S Intruders



- **TCAS acquires the 24-bit aircraft address (Address Announced – AA) from the Acquisition Squitter or from replies to ground interrogations.**
- **A track is developed on the aircraft in the TCAS processor (based on interrogation replies to UF=0 or DF=16)**
- **RAs and TAs are developed per the logic**
- **RAs are coordinated with the intruder if it is also TCAS II equipped.**
- **RAs are downlinked to the ground Mode S sensor**



Resolution Advisories (RAs) and Traffic Advisories (TAs)



- **Use Range to the intruder and the rate of change of that range to determine the time to Closest Point of Approach (CPA).**
- **Use intruder track to estimate vertical separation at CPA**
- **A TA is generally developed before an RA**



RA and TA criteria



Own Altitude (feet)	SL	Tau (Seconds)		DMOD (nmi)		Altitude Threshold (feet)	
		TA	RA	TA	RA	TA	RA (ALIM)
< 1000	2	20	N/A	0.30	N/A	850	N/A
1000 - 2350	3	25	15	0.33	0.20	850	300
2350 - 5000	4	30	20	0.48	0.35	850	300
5000 - 10000	5	40	25	0.75	0.55	850	350
10000 - 20000	6	45	30	1.00	0.80	850	400
20000 - 42000	7	48	35	1.30	1.10	850	600
> 42000	7	48	35	1.30	1.10	1200	700

SL – Sensitivity level

Tau – Time to Closest Point of Approach (CPA) in seconds

DMOD – Distance MODification – range to intruder modified to improve RA and TA performance



TCAS –TCAS Coordination



- **In a TCAS/TCAS encounter, each aircraft transmits interrogations to the other via the Mode S link to ensure the selection of complementary RAs by the two aircraft.**
- **The coordination interrogations use the same 1030/1090 MHz channels used for surveillance interrogations and replies and are transmitted once per second by each aircraft for the duration of the RA**
- **Coordination interrogations contain information about an aircraft's intended RA sense to resolve the encounter with the other TCAS-equipped intruder.**



Sense Reversal in Coordinated Encounters



- Version 7 has the ability to issue RA reversals in coordinated encounters
- The aircraft with the low Mode S address can reverse the sense of its initial RA and communicate this to the intruder. The intruder will then reverse its displayed RA.
- **Only one RA reversal can be issued**
- The initial RA sense will not be reversed until it has been displayed for at least nine seconds (unless the low Mode S address aircraft has a vertical rate higher than 2500 feet per minute and acts contrary to the RA).



Ueberlingen Collision





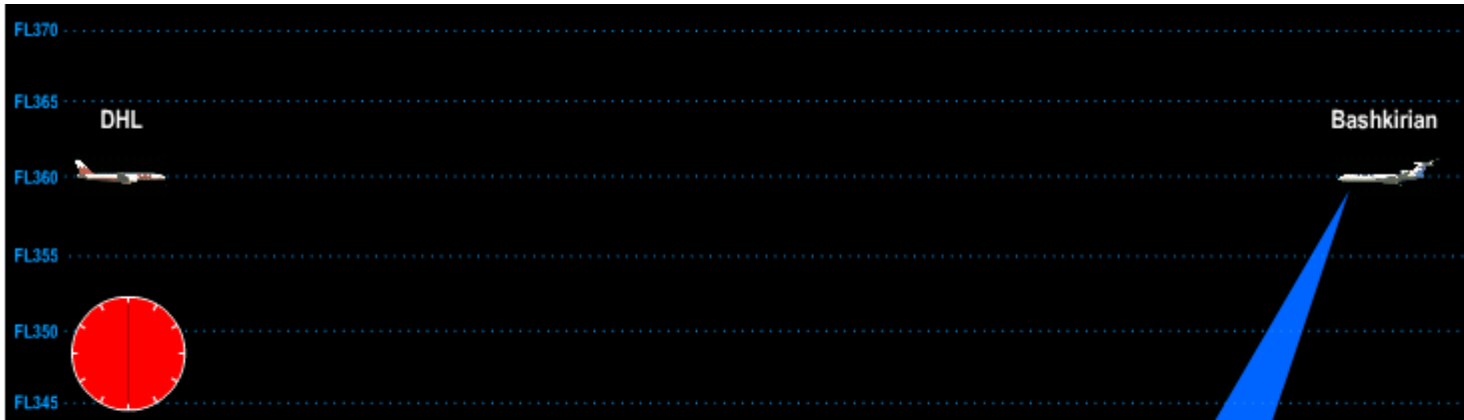
Ueberlingen 1 July 2002



Source: Aviation Week,
July 8, 2002, page 42
July 15, 2002, page 33



Fly through



CONTINUE



Revised Sense Reversal Logic

Either Aircraft can initiate a sense reversal



Safety Problem Background



- **Concerns with TCAS RA reversal logic were raised in mid-1990s during Version 7 safety assessments**
 - Exposure to problems in actual operations was not known
 - TCAS development ended before concerns were resolved
- **Japanese near miss (2001) and Überlingen mid-air collision (2002) brought focus to the vulnerability**
 - Common thread: “vertical chase” where RA reversals were not triggered when they should have been
- **Europeans proposed a logic change (CP112E) to improve reliability of RA reversals**
- **2004: RTCA SC-147 tasked to assess exposure to risk in US airspace and evaluate CP112E**



SA01 Characteristics

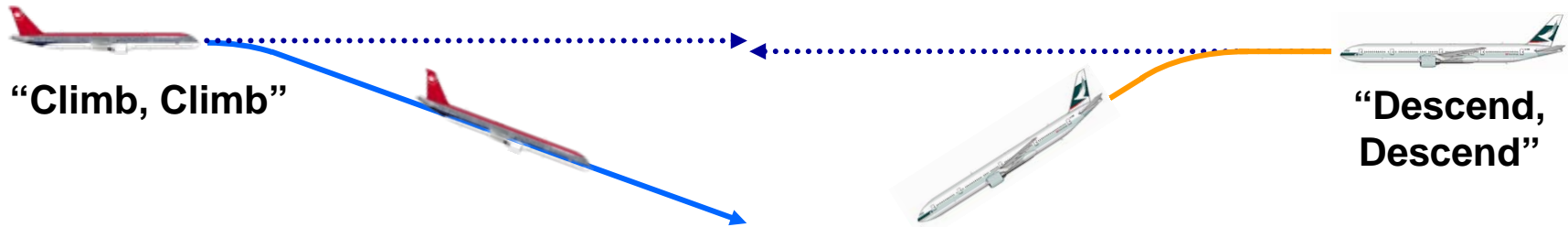


SA01a: TCAS – TCAS

One aircraft does not follow its RA

Vertical chase ensues

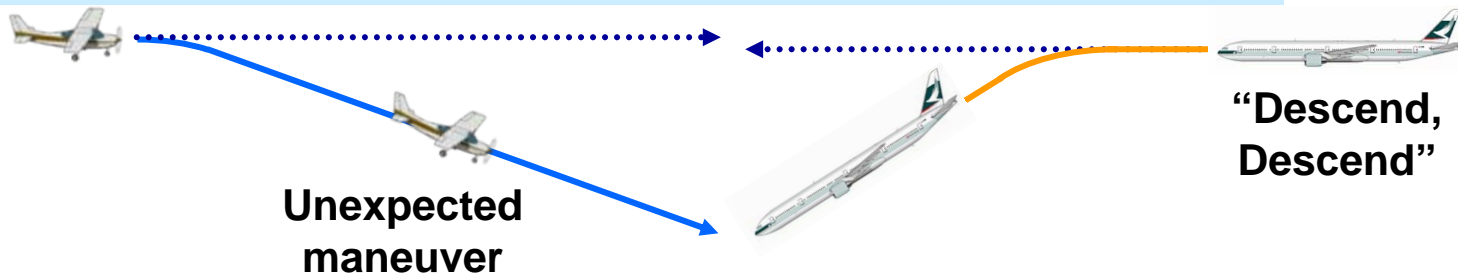
No RA reversal occurs to save aircraft that is following its RA



SA01b: TCAS – unequipped aircraft

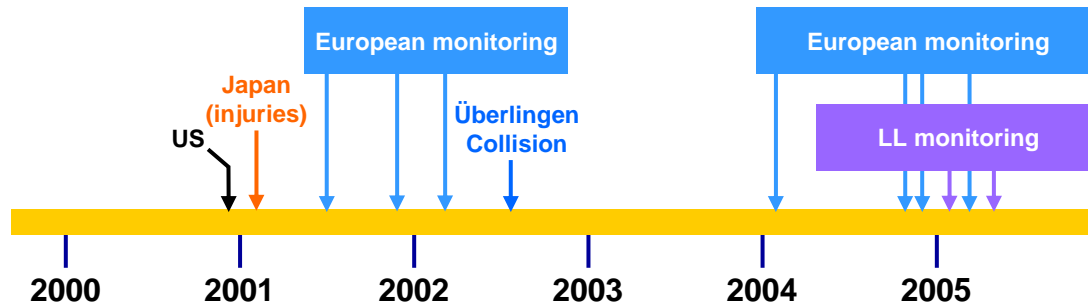
Vertical chase ensues

No RA reversal occurs to save aircraft that is following its RA





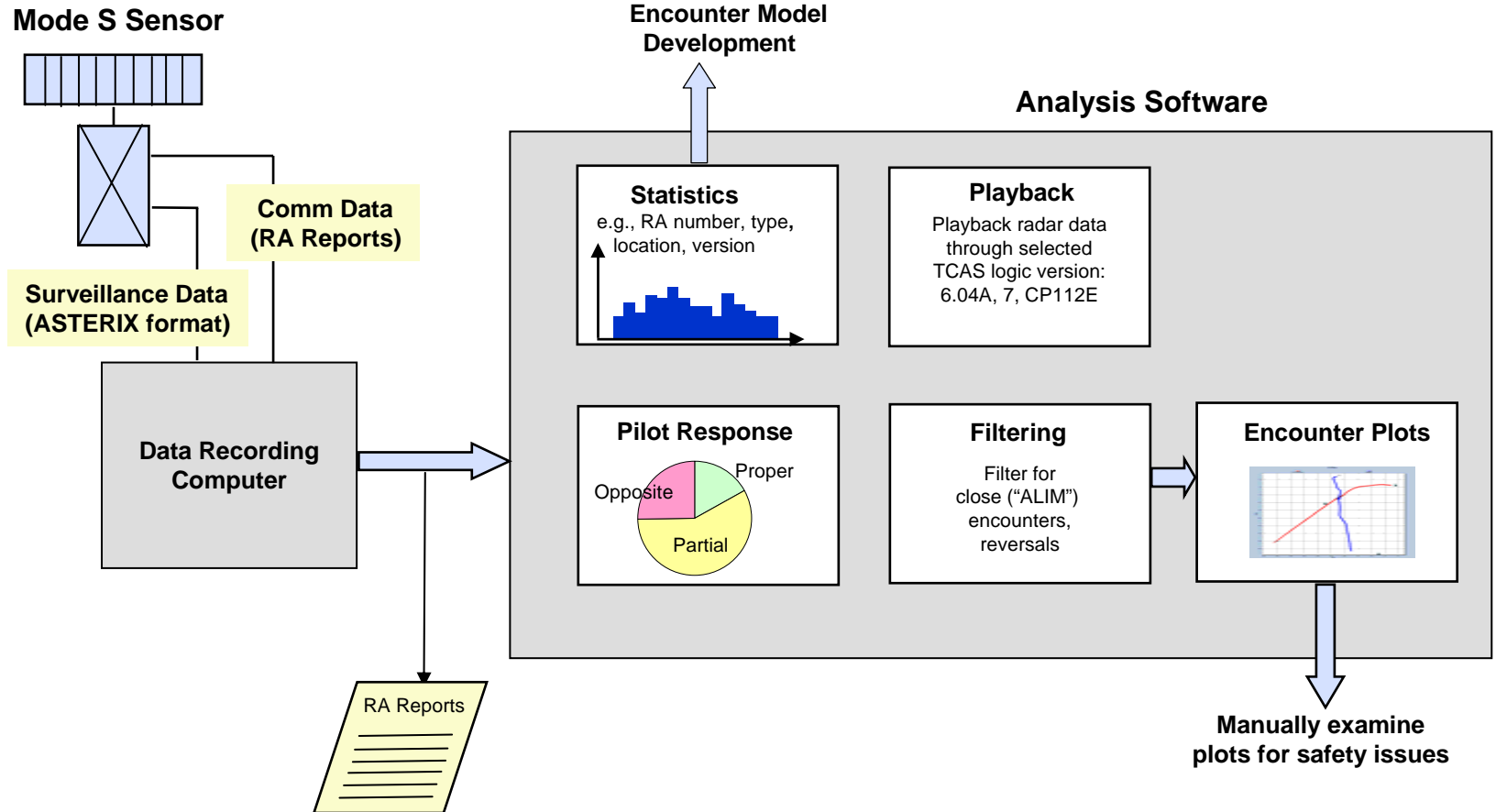
Known SA01 Events



- **SA01 difficult to detect unless critical incident / accident occurs or focused monitoring is conducted**
- **European airspace estimates**
 - SA01a events occur at $\sim 4.7 \times 10^{-6}$ per flight-hour = 58 events per year in Europe
 - Expect 1 mid-air collision due to SA01a every 4 years in Europe
- **Initial US estimate based on Lincoln Lab monitoring of Boston airspace**
 - Reversal problems occur at a rate comparable to Europe



TCAS Monitoring Facility

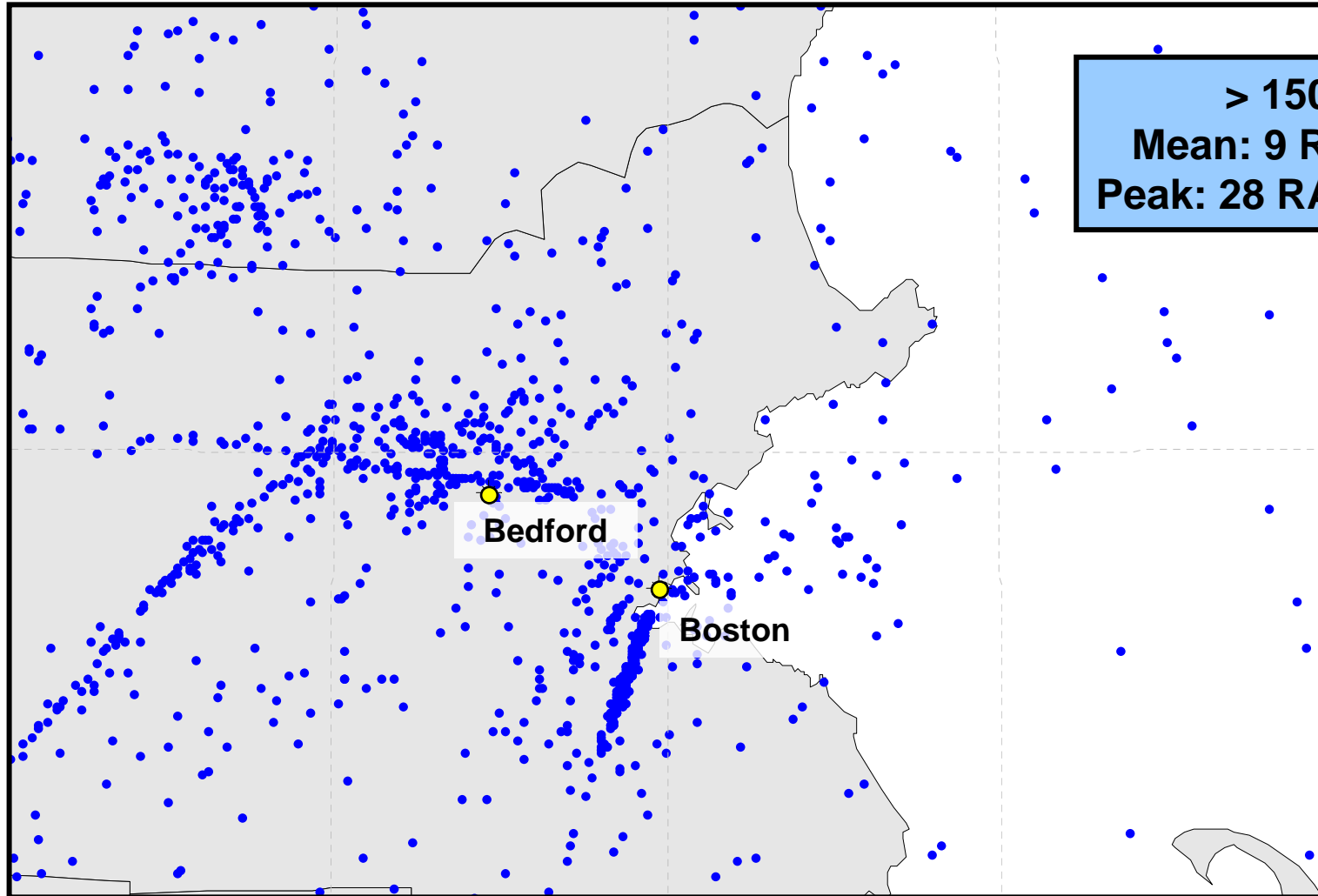




RA Events Monitoring



1 Nov 2004 – 31 May 2005



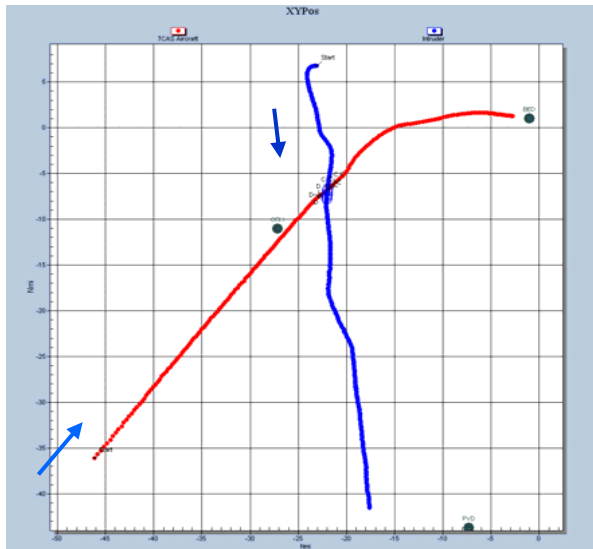
> 1500 RAs
Mean: 9 RAs per day
Peak: 28 RAs in one day



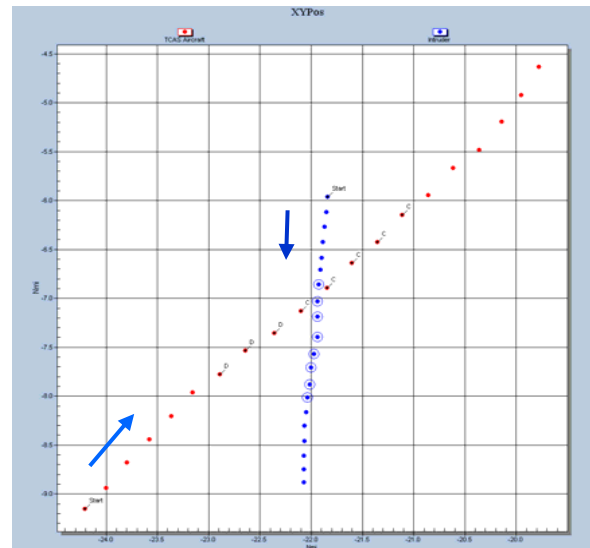
April 2005 Encounter in Boston Airspace



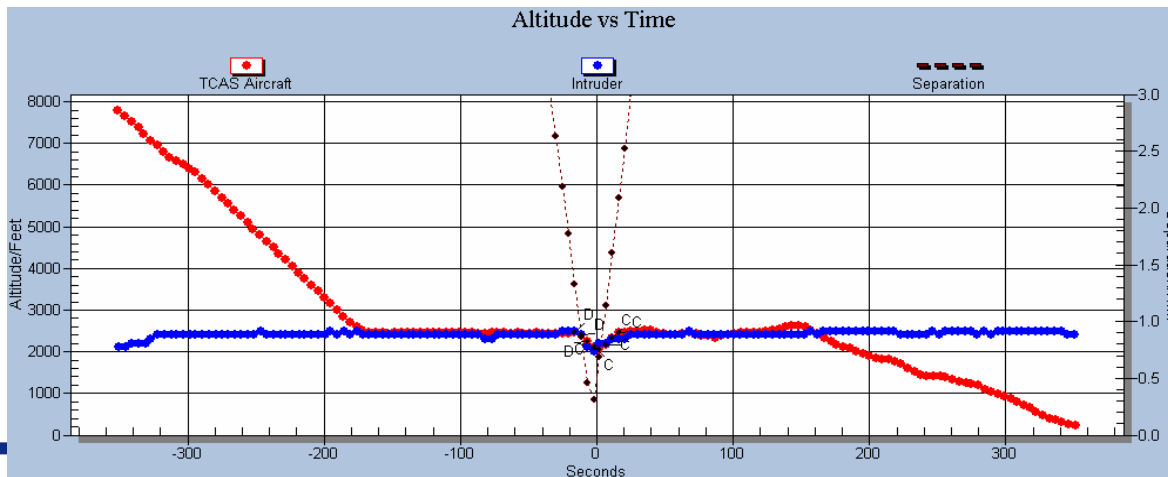
XY Position



XY Position
Enlarged

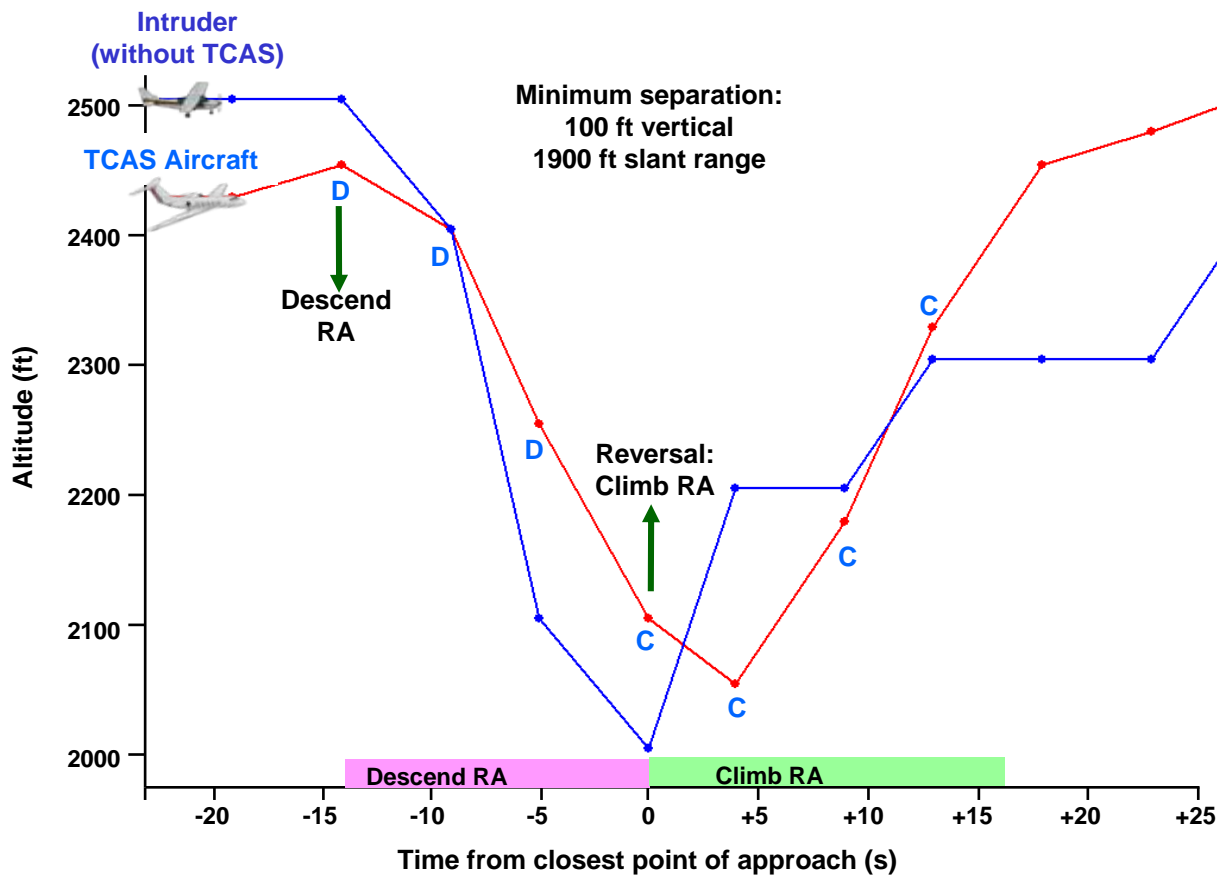


Red: TCAS aircraft
Blue: Intruder
(without TCAS)





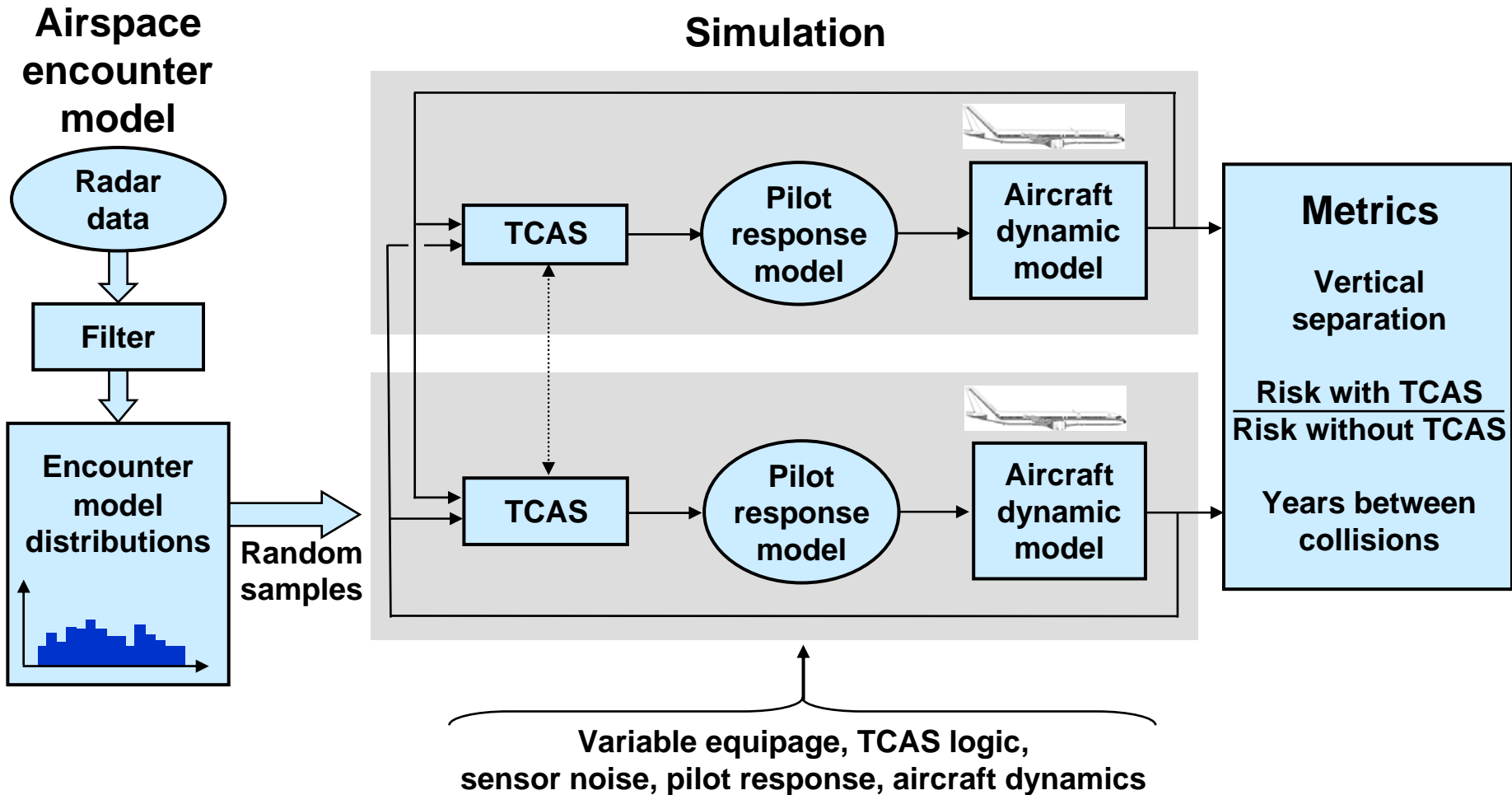
April 2005 SA01b Encounter Vertical Profile Detail



Earlier reversal would have improved separation

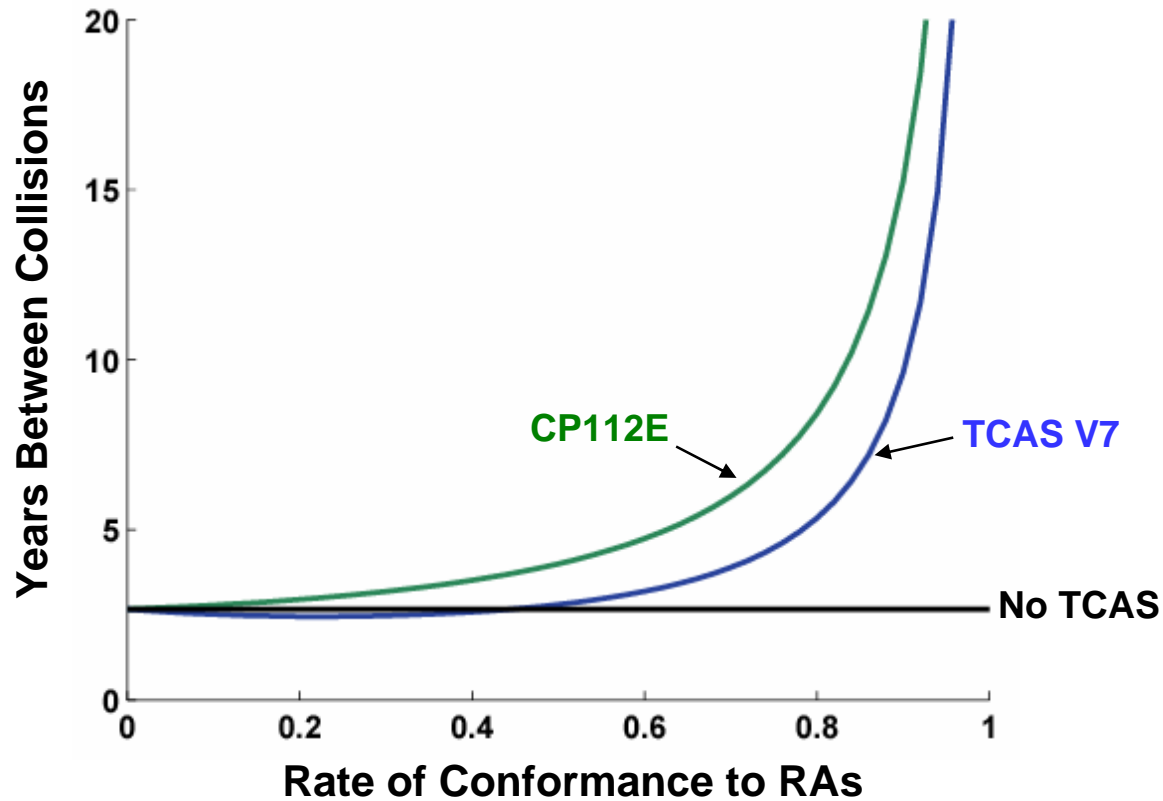


Lincoln Laboratory TCAS Simulation





Example Result –Prediction



Estimated Years Between Mid-Air Collisions in European Airspace



SA01 / CP112E Summary



- **SC-147 - SA01 to be a significant safety issue**
 - Potential for 1 collision every 4 years in Europe
 - Not unique to Europe
- **SC-147 Safety Report recommends that:**
 - (1) **FAA and international authorities commence work towards regulatory action that would expedite implementation of the revised logic...**

Regulatory measures could include Airworthiness Directives, requirements to enhance pilot and controller training, and mandatory equipage of the change by specific dates...
 - (2) **RTCA proceed with a revision to TCAS MOPS based on CP112E**
 - (3) **Airspace monitoring be expanded**
 - (4) **Expertise and tools for TCAS technical analysis be sustained**



Risk Ratios for TCAS-TCAS Encounters, U.S. Encounter Model



Configuration	Altitude Quantization	Version 7 – Version 7	Version 7 – CP112 E	CP112E – CP112 E
Both aircraft follow RAs	25	.02319*	.02320	.02334
One aircraft does not follow its RAs	25	.0903	.0884	.0766
Both aircraft follow RAs	100	.02293	.02288	.02322
One aircraft does not follow its RAs	100	.09666	.09436	.08132
Both aircraft follow RAs, one with slow response	25	.0412	.0411	.0389
One aircraft does not follow RAs, the second does with slow response	25	.3191	.3118	.3014
Both aircraft follow RAs, one with slow response	100	.0420	.0418	.0415
One aircraft does not follow RAs, the second does with slow response	100	.3249	.3279	.3076

* Risk Ratio – lower is safer

Current Systems

With Vertical Logic Change



What does the Mean?



Take the case with 25 foot vertical resolution and one aircraft does not follow the resolution – Near Miss Probability reduced to

- **V7 to V7: 9.03%**
- **V7 to new: 8.84%**
 - **improvement proportion 2.1%**
- **New to new: 7.66% of**
 - **Improvement proportion 15.1%**



Adjust Vertical Speed Adjust



TCAS – AVSA



- **Monitoring of TCAS performance has identified instances where flight crews respond in the opposite direction to that specified by TCAS when a negative resolution advisory (RA) is displayed and announced to the flight crews**
 - Negative RAs are those that require a reduction in an existing vertical speed
 - These RAs are accompanied by an aural annunciation of ‘Adjust Vertical Speed, Adjust’ (AVSA)
- **Probability of AVSA occurrence (European Estimate) = 3.82×10^{-6} per flight hour (15 opposite reactions in France in 2004 & 2005 leading to altitude busts)**
 - **Probability of collision given that an AVSA event has occurred = 1.41×10^{-3} (5.4 collisions per 109 flight hours – equivalent to a collision every 15 years in Europe)**



TCAS – AVSA Continued



- **AVSA issue & proposed European fix requires additional U.S. operational analysis – currently not funded**
- **European Aviation Safety Agency (EASA) letter to RTCA (09/22/06)**
 - **Formally requests that RTCA “actively investigate a possible modification of the ‘Adjust Vertical Speed, Adjust’ aural annunciation”**
 - **Formal change proposal (CP115) submitted to SC-147 at Oct 2006 Plenary – specifically addresses a fix for the aural annunciation “Adjust Vertical Speed, Adjust”**
 - **Follow-up analysis presented at Feb 2007 Plenary indicates not just European problem**



Scope of AVSA Change

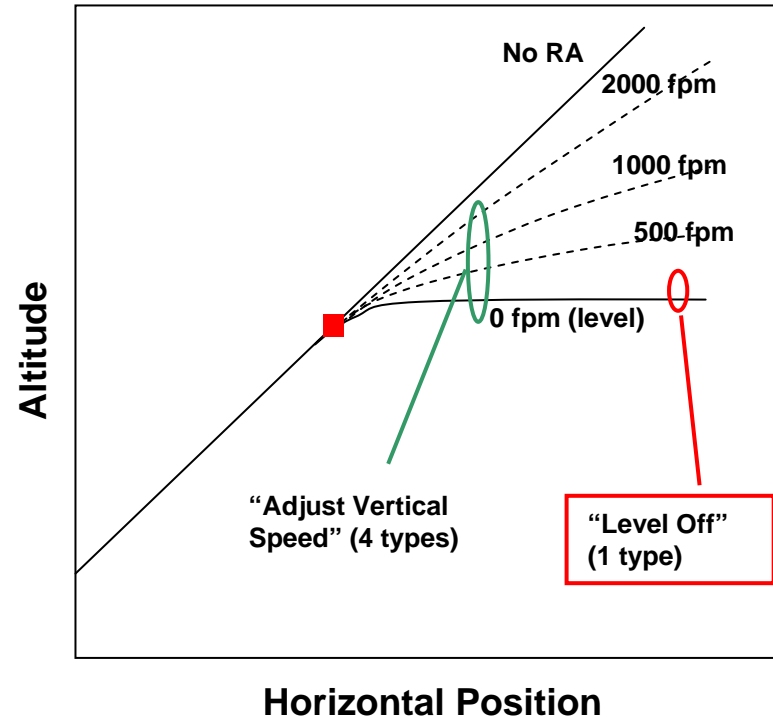


- **Aural**

- “Level Off, Level Off” vs. “Adjust Vertical Speed, Adjust”

- **Logic**

- Collapse 4 possible vertical speed reductions to 1: a true level-off of 0 feet-per-minute





TCAS II V 7.1 - FAA & Eurocontrol



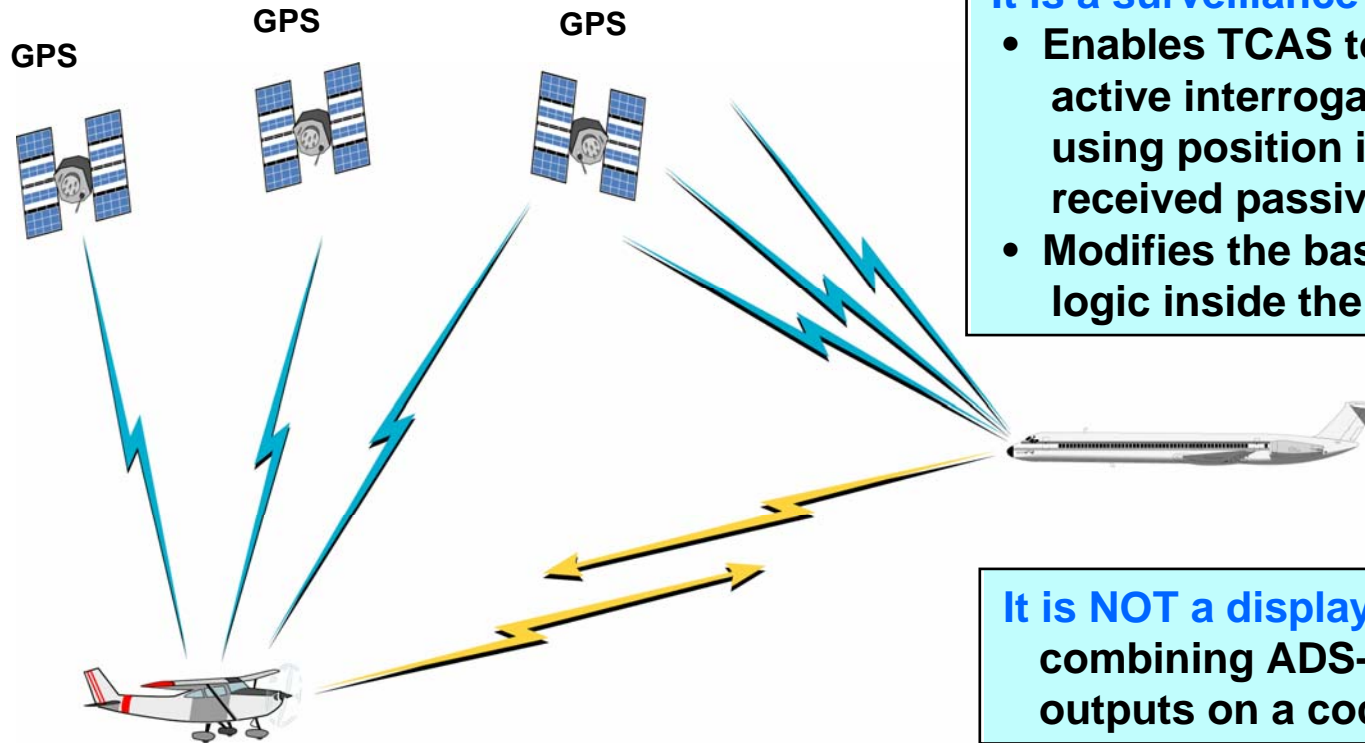
- **Agreement on Sense Reversal logic need**
 - Disagree on Urgency – Eurocontrol wants it done by 2010, FAA date is much later.
- **Eurocontrol is clear that AVSA needs correction.**
 - FAA is not certain that it is necessary – operational testing will be needed
- **Uncertainties**
 - What will Version 7.1 include?
 - When will Version 7.1 be required?



Hybrid Surveillance



What is Hybrid Surveillance?



It is a surveillance technique that

- Enables TCAS to reduce its active interrogation rate by using position information received passively via ADS-B
- Modifies the basic surveillance logic inside the TCAS unit

It is NOT a display technique for combining ADS-B and TCAS outputs on a cockpit display

ADS-B data received via hybrid surveillance is not passed to the CAS logic

Control (8 bits)	Mode S Address (24 bits)	GPS Position (56 bits)	Parity (24 bits)
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Mode S Extended Squitter



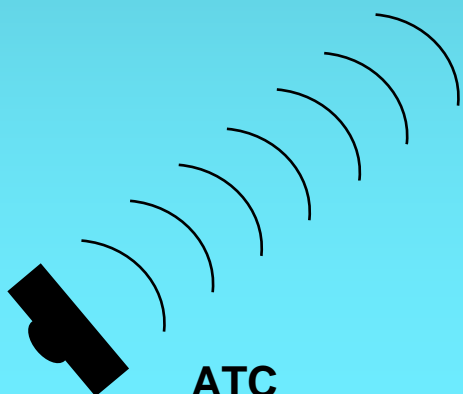
TCAS Hybrid Surveillance

Why is it needed?

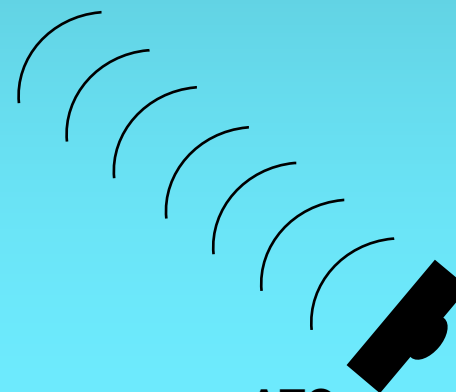


**Victim
Transponder**

**Interference Limiting algorithms
were developed to keep TCAS
utilization of transponders < 2%**



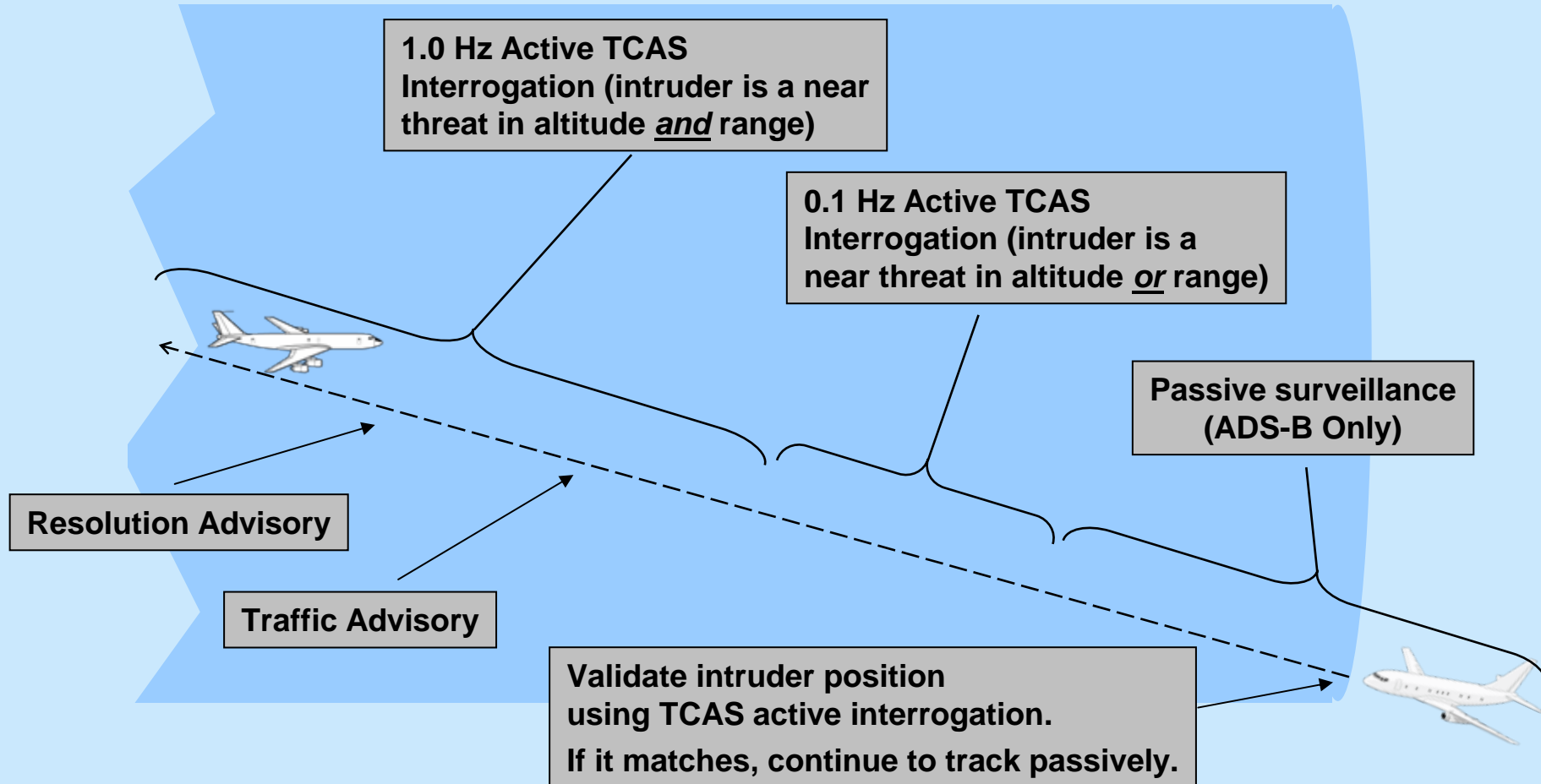
**ATC
Ground Radar**



**ATC
Ground Radar**



How does it work?





How do we proceed?



- **Minimum Operational Performance Standards (MOPS) have been developed ensure consistent requirements and implementation**
 - Hybrid surveillance will migrate to civil TCAS systems
 - Military TCAS systems need to demonstrate proper operation for access to civil airspace, nationally and internationally
 - FAA needs MOPS in order to certify Hybrid Surveillance systems
- **The three TCAS manufactures are pursuing Hybrid surveillance and ADS-B applications**



Military Variants



- **Honeywell**
 - **E-TCAS (Enhanced TCAS) on C/KC-135, KC-10, C-130, HC-130 P/N**
 - Used for Refueling and Formation flight
 - Some restrictions on use over US, UK, and Germany
 - **MILACAS FR on C-17**
 - Used for Formation flight
 - On path for full International approval for use
 - First formal use of Mode S UL=19 and DL=19 (formats set aside by ICAO for Military use)
- **ACSS has some products in development**
 - **Military Airborne Surveillance System (MASS)**
 - Used by Formation Flying – used on the Italian military B767