

Traffic Alert and Collision Avoidance System II (TCAS II) Tutorial

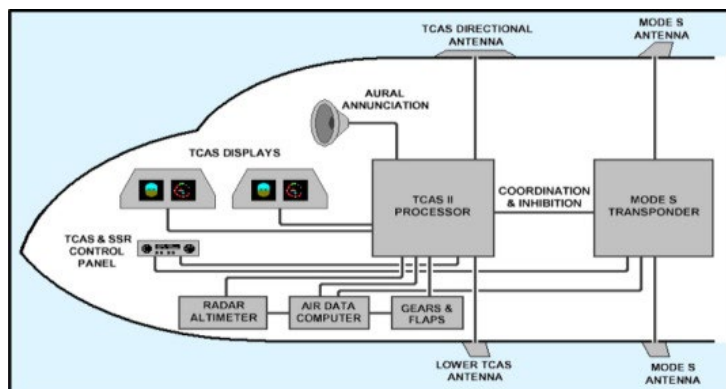
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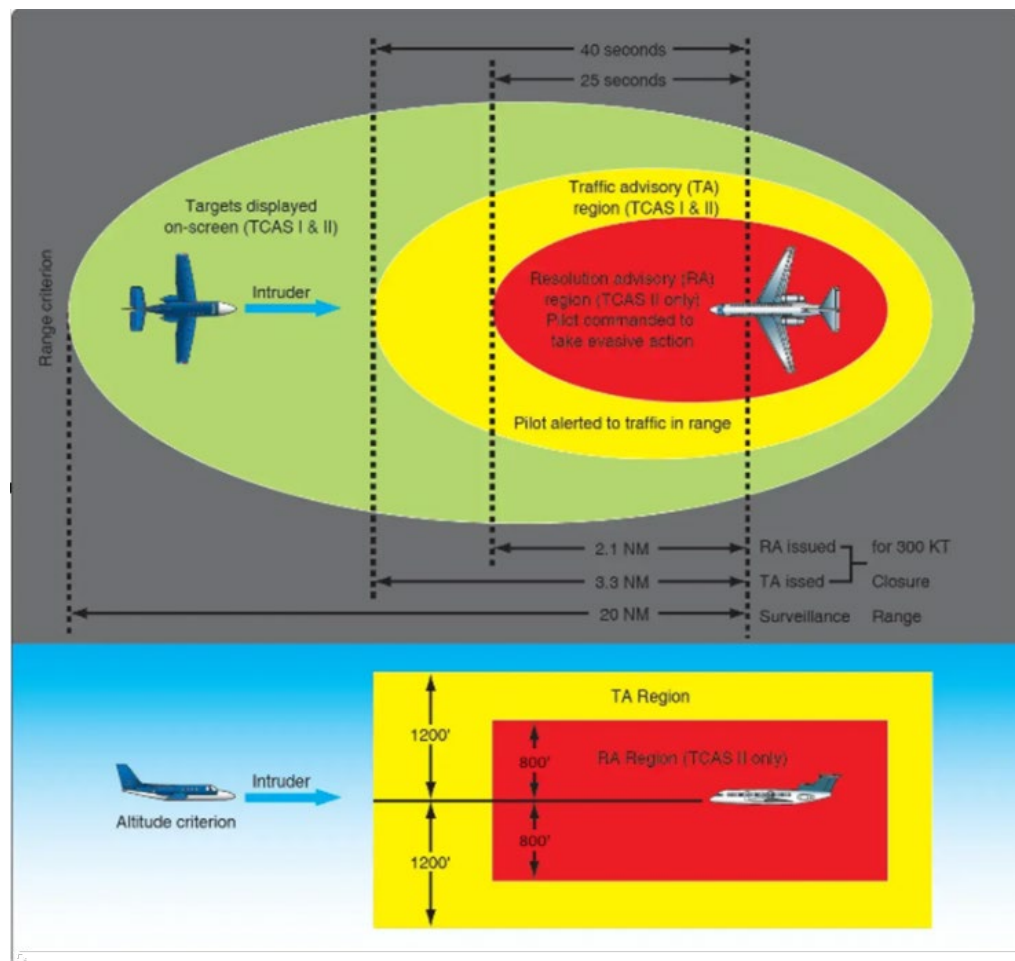
Traffic Alert and Collision Avoidance System II (TCAS II)

Airborne Avionic System: intended as a last resort protection against risk of airborne collision



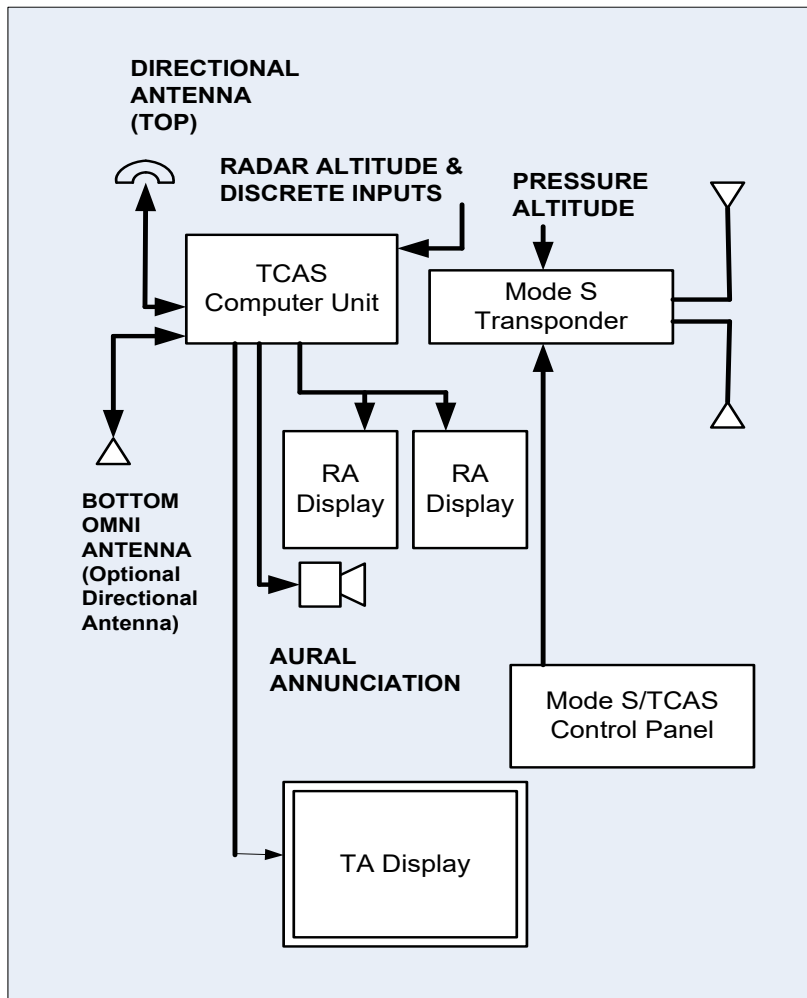
Known internationally as **ACAS II** – Airborne Collision Avoidance System II

~20,000 ACAS II equipped aircraft US (~6,000 commercial aircraft, ~14,000 business jets)
~30,000 ACAS II equipped aircraft World-wide



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TCAS II Characteristics



Avionics function autonomous of the aircraft navigation equipment and independent of the ground-based Air Traffic Control system

Ownship equipage: comprised of a radio transmitter & receiver, Mode S transponder, directional antennas, baro and radio altimeter, computer & cockpit displays

Algorithms and parameters (as far as possible) chosen to be compatible with separation standards - but:

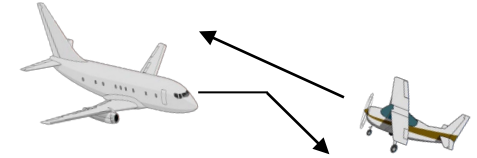
- Does not warn of loss of separation
- Sometimes generates unnecessary (nuisance) alerts

RAs coordinated between TCAS II equipped aircraft

Complying with RAs can result in deviation from clearance



TCAS II Standardization



- Set of standards defined by aviation standard development organizations
 - US: RTCA in the form of TCAS Minimum Operational Performance Standards (MOPS)
 - Europe: European Organization for Civil Aviation Equipment (EUROCAE)
 - Internationally: ICAO in the form of ACAS Standards and Recommended Practices (SARPS)
- Includes resolution advisories (RA) if a collision is imminent instructing flight crews to descend or ascend to escape maneuvers in the vertical dimension
 - Version 6.04a specified in RTCA DO-185 (Mandated in the US: 12-1-1994)
 - Version 7 specified in RTCA DO-185a (allowed in the US (required RVSM airspace), ICAO Mandate: 1-1-2003)
 - Version 7.1 specified in RTCA DO-185b (ICAO Mandate: 1-1-2014 new, 1-1-2017 retrofit)
- Europe:
 - The carriage of ACAS II has been mandatory from 1-1-2005 (updated v7.1 from 12-1-2015 all required aircraft) for all civilian turbine-engined aircraft carrying more than 19 passengers or with the maximum take-off mass more than 5700 kg, with the exception of unmanned aircraft systems
- US:
 - TCAS II has been mandatory in US airspace since 1994, for all civilian turbine-engined aircraft carrying more than 30 passengers



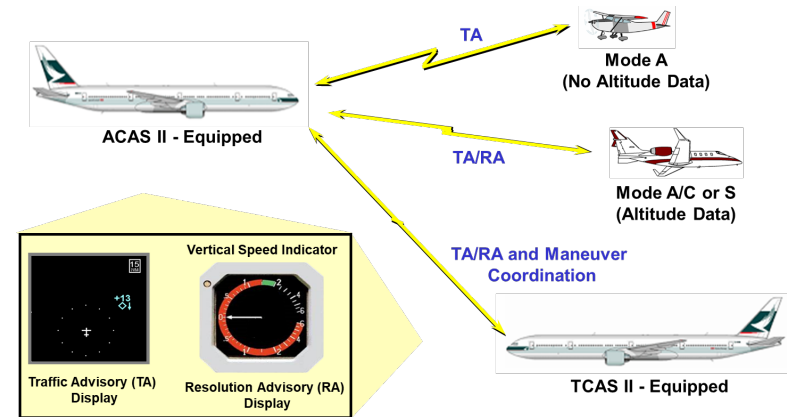
Normal System Operation

- Surveillance of adjacent transponders (range = 14 NM)
- Maximum number of aircraft processed = 30
- Determination of the alerts: TA and RA
- Coordination between two TCAS units (through the mode S data-link)
- Aural annunciations
- Display of information on Vertical Speed Indicators (VSI) or on EFIS (ND + PFD)
- Processing cycle = 1 second

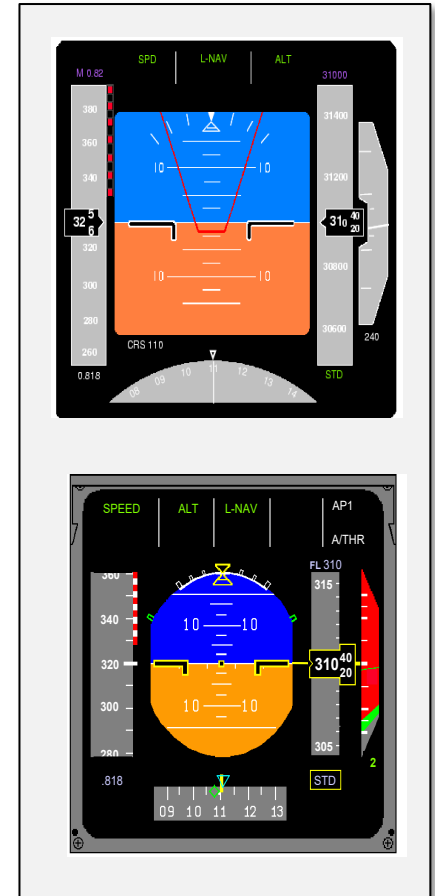
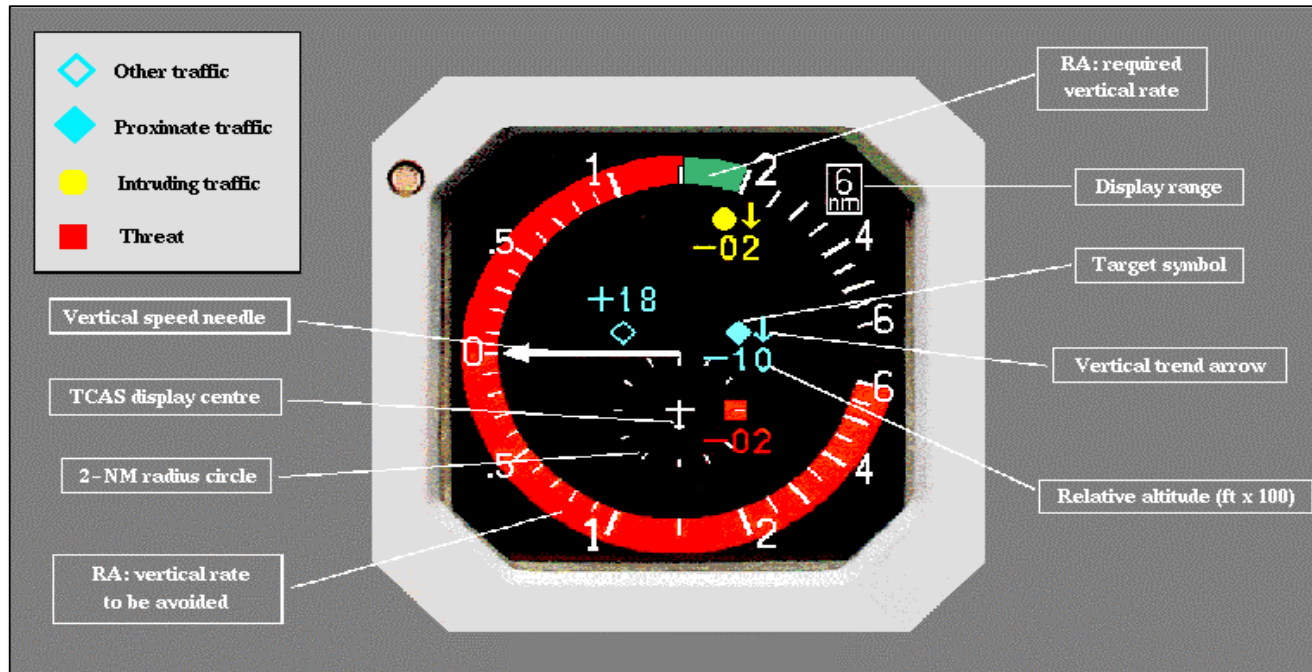


TCAS II in Operation

- 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: What it Provides to Pilots



1. Traffic Display – assists with visual acquisition of traffic

- Traffic targets displayed relative to own ship
- Relative altitude is displayed numerically with +/- symbols

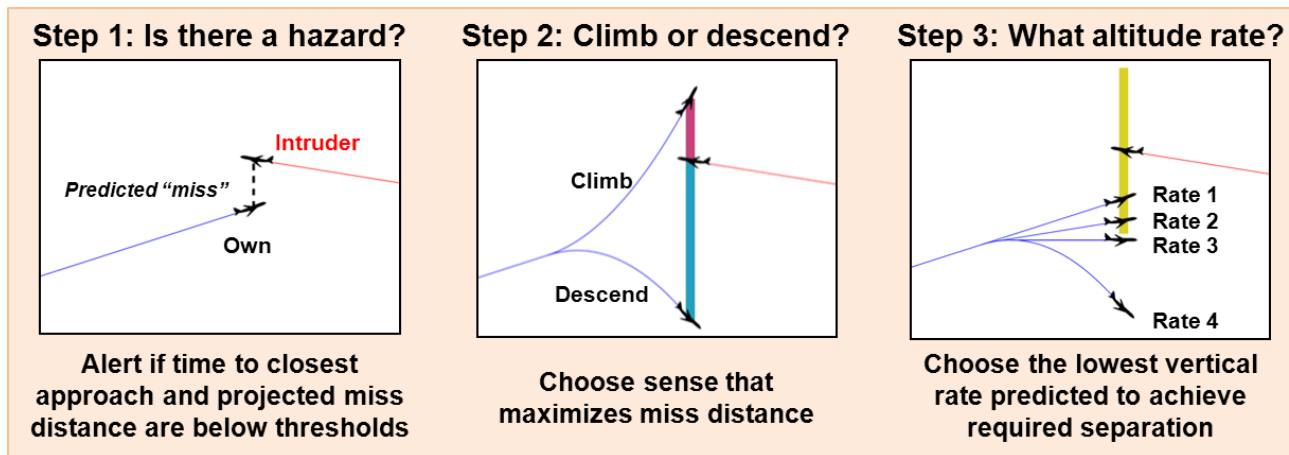
2. Alerts – Situation awareness (TA) and vertical guidance (RA)

- Auditory (ex. “Traffic, Traffic” for TA, “Climb, Climb NOW” for RA)
- Traffic display - traffic symbols colors/shape coded to indicate threat level
- Vertical maneuver guidance – on VSI or PFD



TCAS II Alerting Construct

- RA alerting based on the time-to-go to the Closest Point of Approach (CPA) and not on range alone
- Both horizontal and vertical tests need to be passed before an RA is issued
 - Horizontal test: time to reach the CPA (or "DMOD" distance if the closing speed is low)
 - Vertical test: time to reach co-altitude (or "ZTHR" if the aircraft are steady)
- RA sense selection: objective of safe vertical distance "ALIM"
 - RAs intended to provide at least 300'-700' separation
- The TA/RA threshold values increase with the altitude (i.e., Sensitivity Level)

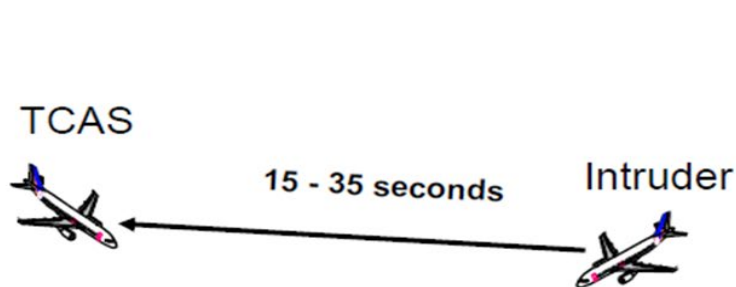


An RA is not necessarily indicative of a near mid-air collision, nor does it indicate that separation standards have been violated

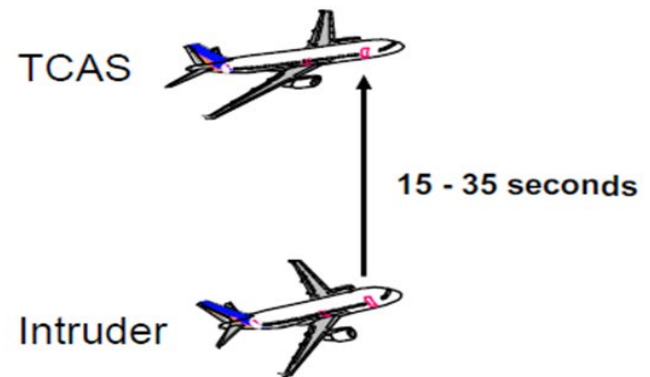


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Horizontal & Vertical Tests



Horizontal Test

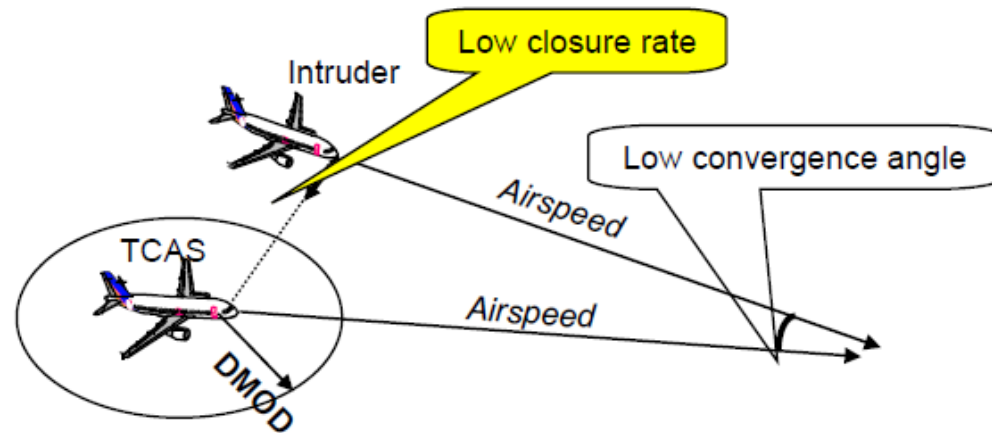


Vertical Test

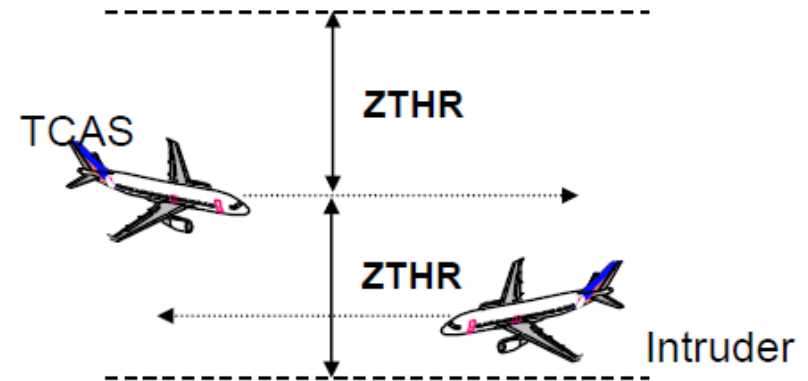
- Collision avoidance criterion is generally a time calculated parameter based on two projected (straight line) tests:
 - Range Tau (range/closure rate) or "DMOD" distance if the closing speed is low
 - Horizontal miss distance less than 0.2 to 1.1 NM depending on altitude
 - Vertical Tau (time to reach co-altitude) or "ZTHR" altitude threshold if closing speed is low
 - Vertical miss distance of 600 to 800' depending on altitude



Low Closure Rate



Horizontal Test

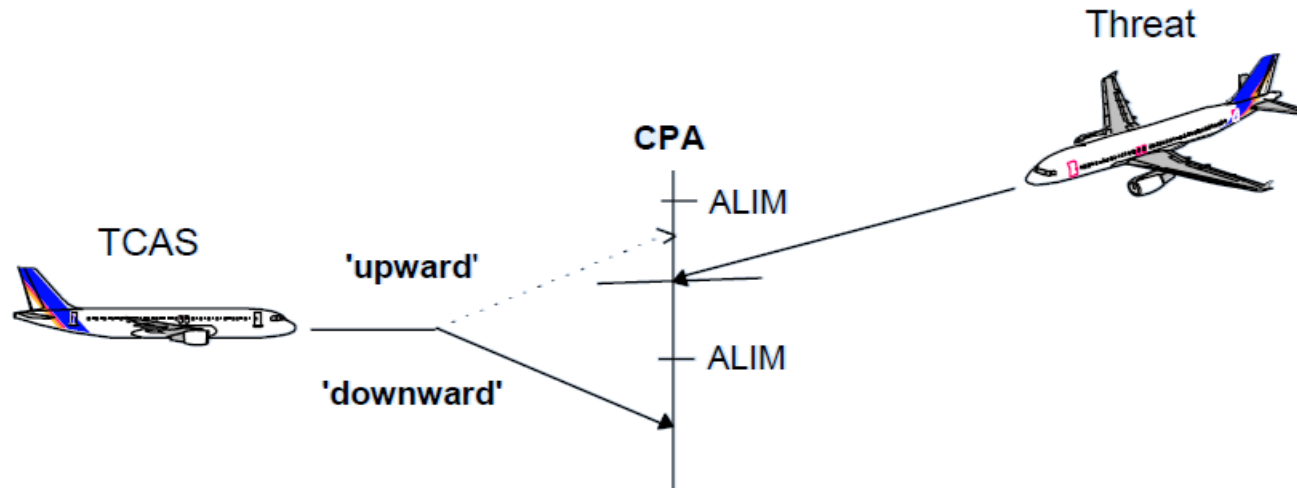


Vertical Test

The closure rate may be low, in this case, the minimum distance (DMOD) or Altitude (ZTHR) is taken into account



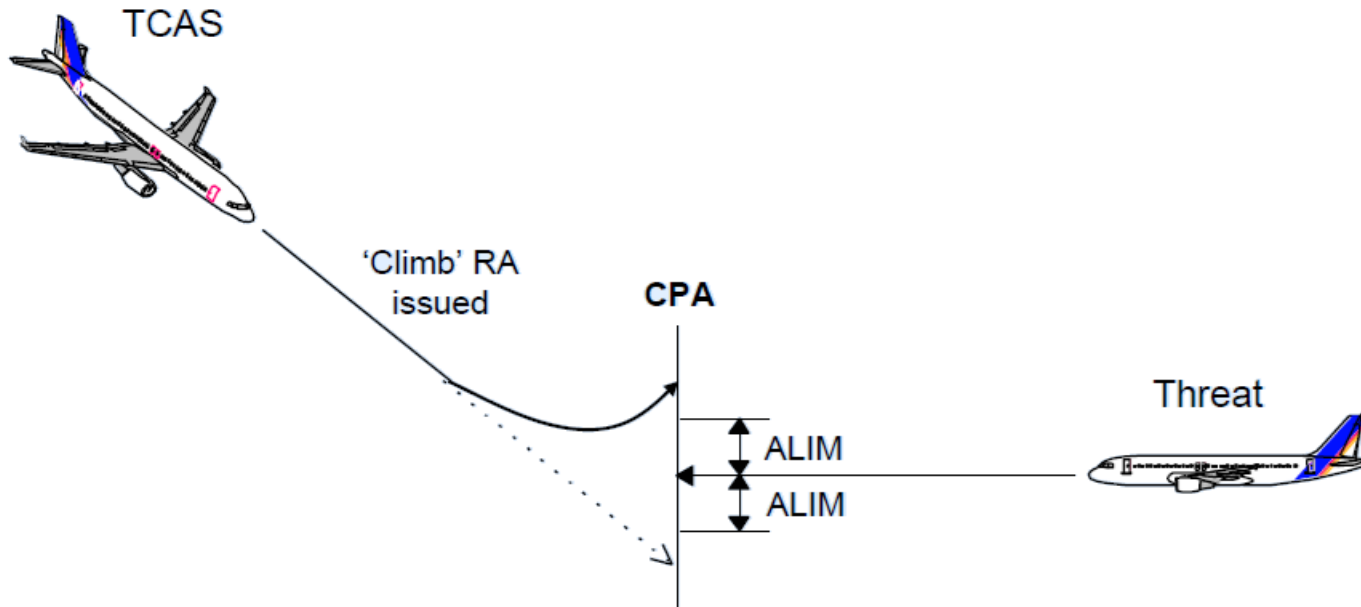
RA Sense Selection Process



- 'Downward' RA sense will achieve ALIM and the 'upward' sense will not. The 'downward' option is therefore selected.
 - RAs are selected to achieve or maintain adequate vertical distance (300 – 700') and minimize pilot response/vertical deviations

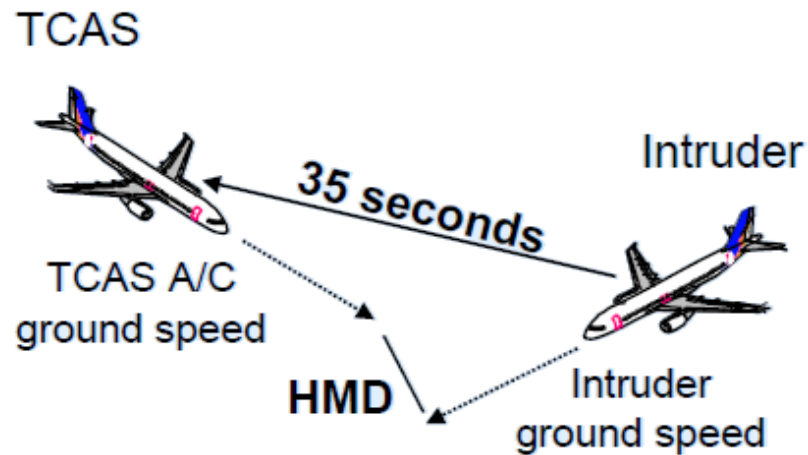


Altitude Crossing Consideration



- If both 'downward' and 'upward' senses will achieve ALIM. The 'upward' sense is selected because it prevents the TCAS aircraft from crossing through the intruder's altitude

Addition of Miss Distance Filtering



- TCAS computes the Horizontal Miss Distance (HMD). If the HMD is "sufficient", no RA



Summary of RA and TA Criteria

Own Altitude (feet)	SL	Tau (Seconds)		DMOD (nmi)		ZTHR (feet) Altitude Threshold		ALIM (feet)
		TA	RA	TA	RA	TA	RA	RA
< 1000 (AGL)	2	20	N/A	0.30	N/A	850	N/A	N/A
1000 - 2350 (AGL)	3	25	15	0.33	0.20	850	600	300
2350 – 5000	4	30	20	0.48	0.35	850	600	300
5000 – 10000	5	40	25	0.75	0.55	850	600	350
10000 – 20000	6	45	30	1.00	0.80	850	600	400
20000 – 42000	7	48	35	1.30	1.10	850	700	600
> 42000	7	48	35	1.30	1.10	1200	800	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

Some airspace procedures have horizontal and vertical separation levels that fall within TCAS alerting thresholds



Traffic Advisories

- Thresholds:
 - horizontal: 20 to 48s (or DMOD = 0.3 to 1.3 NM)
 - vertical: 20 to 48s (or ZTHR = 850 or 1,200 ft)
- Aural annunciation: "Traffic, traffic"
- Intruder: solid amber circle
- Aids in the visual acquisition of the intruder
 - A TA is generally developed before an RA
- Prepares the crew for a possible RA
- No maneuvers shall be made in response to TA
- TA shall not be reported to ATC



*Traffic Advisory (TA),
900 feet below and level.
Filled yellow/amber circle.*



Resolution Advisories

- Thresholds:
 - horizontal: 15 to 35s (or DMOD = 0.2 to 1.1 NM)
 - vertical: 15 to 35s (or ZTHR = 600 to 800 ft)
- Aural annunciations: "climb", "descend", "increase climb", "increase descent", "monitor vertical speed", etc.
- Display of a range of vertical speeds or attitudes to avoid
- Objective: a safe vertical distance ALIM varying from 300 to 700ft
- An RA takes into account all existing threats
- The RA intensity is checked and revised, if necessary, every second



*Resolution Advisory (RA),
500 feet below and climbing.
Filled red square.*



Primary RA Types (US Monitoring)

- Climb/Descend RAs (~25% of all RAs)
 - 1500 fpm climb or descend rate
 - Can be increased to 2,500 fpm
- Adjust Vertical Speed Adjust (AVSA) (~20% of all RAs)
 - Always requires a reduction in vertical rate to between 2,000 and 0 fpm
- Monitor Vertical Speed (~55% of all RAs)
 - Requires pilot to keep existing vertical rate
- Direction of RA can reverse one time if required (very rare)



System Expectations

- The pilot must react within 5 seconds
 - Required altitude excursion rarely exceed 300-500 ft
- A vertical speed of +/-1,500 fpm (acceleration = 0.25 g) is generally required, but may vary according to the event
- Pilots shall never maneuver in the opposite sense to the TCAS RA (RAs are coordinated with other suitably equipped aircraft)
- The pilot must inform ATC as soon as possible
- The "Clear of Conflict" message is issued when the aircraft diverge vertically / horizontally
- The pilot must then resume the ATC clearance

Situation	Phraseology
Responding to an RA	"TCAS Climb" or "TCAS Descend"
Initial RA report issued after RA is completed	"TCAS Climb (or descent), returning to [assigned clearance]"
Initial RA report issued after returning to assigned clearance	"TCAS Climb (or descent) completed, [assigned clearance] resumed"
Unable to follow a newly issued clearance because of an RA	"Unable to comply, TCAS resolution advisory"
Controller acknowledgement of any TCAS report	No specific phraseology is defined

Recommended Phraseology for Reporting RAs Within U.S. Airspace



Pilot Experience

- An RA is usually stressful experience: surprise, very rapid development (around 30s)
- Consequences:
 - Potential for excessive deviations (650ft or greater)
 - Slow returns to the ATC clearance (brief loss of confidence)
 - Discussions on the frequency and correct phraseology not always used
- Crews often use the TCAS display as a surveillance tool: high risk of misinterpretation
- Air crew training is essential



Controller Perspective

- Consequences of an RA:
 - Disturbance to the tactical control plan
 - Possibility of an induced conflict, although TCAS has a multiple threat processing
 - Frequency overload, initial lack of understanding
- In practice:
 - Controller will not know about the RA until notified by the pilot
 - If the RA event is known, the controller must cease issuing any instructions, but should provide traffic information
 - The controller must not consider the TCAS equipment of the aircraft to establish and maintain spacing (ICAO)



Summary

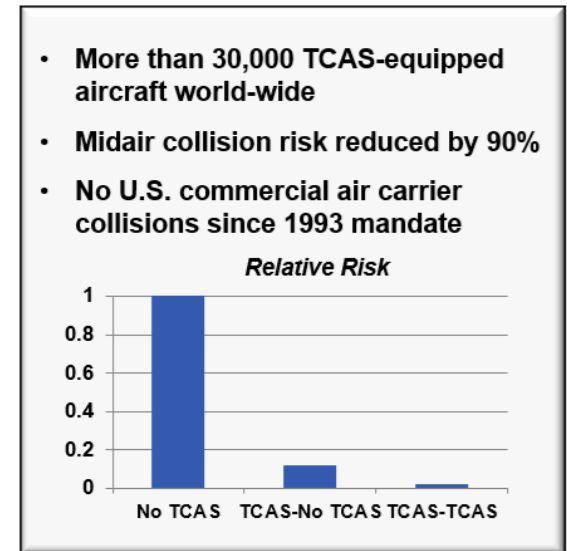
Safety Post-TCAS

- **Advantages:**

- Independent system, which acts as a last resort safety barrier
- Highly accurate distance measurements, with a one-second refresh rate
- All threats taken into account
- TCAS-TCAS coordination
- Detection of all transponding aircraft, including those which are not displayed on the controller's screen
- TCAS II has reduced the risk of mid-air collision

- **Distinctions:**

- No detection of aircraft without or not operating transponders (e.g. VFRs, military flights)
- Does not consider a pilot/controller's intent, IFR/VFR status, or established ATC separation minima
- Unnecessary Alerts
 - Some alerts seen by the pilots and controllers as unnecessary (nuisance) alerts, especially 1000-ft level offs
 - The alerts are unnecessary only in hindsight
 - Limited horizontal tracking – unless ground tracks of both aircraft remain very straight, an RA can be generated even if the aircraft are 3 NM apart

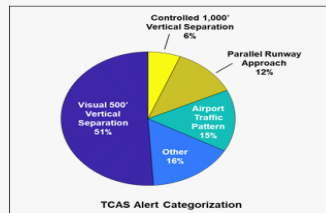


NextGen Airborne Collision Avoidance System

Objective: Mitigate TCAS Shortcomings

Operational Suitability

- >80% of alerts in intentional, safe operations
- E.g., landings on parallel runways



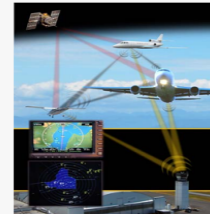
Environment

- ICAO predicts 4.6% annual growth in air traffic
- New entrants: uncrewed aircraft, eVTOL



Surveillance

- Other surveillance sources available or required
- Spectrum limits on active surveillance



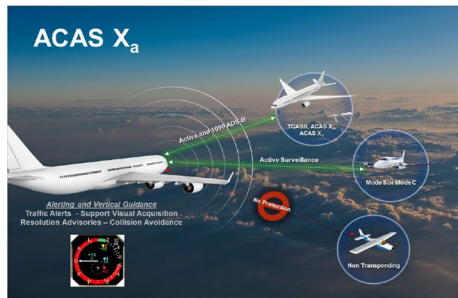
Adaptability

- Heuristic threat logic too difficult to update
- Cannot accommodate new surveillance or different vehicle dynamics

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if (...)
...
elseif (...)
...
else
...

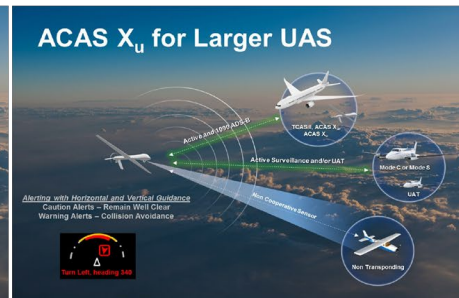
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Coming Soon: ACAS X variants optimized for current and new user classes



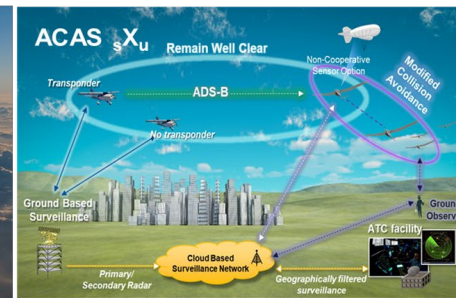
New ACAS II 2008-2018

- TCAS replacement for large piloted aircraft
- Vertical avoidance maneuvers
- TCAS active surveillance
- ADS-B surveillance



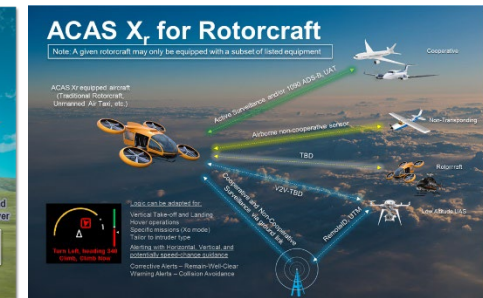
New ACAS III 2014-2020

- Larger uncrewed aircraft
- Vertical and horizontal avoidance maneuvers
- TCAS active surveillance
- ADS-B surveillance
- Air-to-air radar surveillance



2017-2022

- Smaller uncrewed aircraft
- Vertical and horizontal avoidance maneuvers
- ADS-B surveillance / no active surveillance
- V2V and generic surveillance
- Terrain and obstacle awareness
- Onboard and offboard architectures



New ACAS III ~2026

- Crewed & Uncrewed
- Vertical and horizontal avoidance maneuvers
- ADS-B surveillance / Omni active surveillance
- Air-to-air radar surveillance
- A2X and generic surveillance
- Low Altitude Functionality / Terrain and obstacle awareness



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Questions / Discussion



ICAO ACAS Manual Definitions

- **False RA.** The ACAS II system generated an advisory which was based on a false track created by erroneous surveillance data or an onboard system malfunction.
- **Phantom RA.** A form of a false RA in which the TCAS II system generated an advisory against a non existing threat aircraft.
- **Unclassifiable RA.** The ACAS II system generated an advisory that cannot be classified because of insufficient data.
- **Unnecessary (Nuisance) RA.** The ACAS II system generated an advisory in accordance with its technical specifications in a situation where there was not or would not have been a risk of collision between the aircraft.
- **Useful RA.** The ACAS II system generated an advisory in accordance with its technical specifications in a situation where there was or would have been a risk of collision between the aircraft.

