Traffic Alert and Collision Avoidance System (TCAS)

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Introduction

TCAS is a family of airborne devices that function independently of the ground-based Air Traffic Control (ATC) system, and provide collision avoidance protection for a broad spectrum of aircraft types.

All TCAS systems provide some degree of collision threat alerting, and a traffic display. TCAS I and II differ primarily by their alerting capability:

- TCAS I provides Traffic Advisorys (TAs) to assist the pilot in the visual acquisition of intruder aircraft.
- TCAS II provides TAs and Resolution Advisorys (RAs), i.e., recommended escape manoeuvrers, in the vertical dimension to either increase or maintain the existing vertical separation between aircraft.

Introduction

The TCAS concept makes use of the same radar beacon transponders installed on aircraft to operate with ATC's ground-based radars.

The level of protection provided by TCAS equipment depends on the type of transponder the target aircraft is carrying.

	INTRUDER			
OWN A/C	TCAS II	TCAS I	MODE S or C TRANSPONDER	MODE A TRANSPONDER
TCAS I	TA	TA	TA	TA
TCAS II	TA and coordinated vertical RA	TA and vertical RA	TA and vertical RA	TA

Notice

TCAS provides **no protection** against collision with aircraft that do not have an operating transponder.

Development

In 1981, FAA made a decision to develop and implement TCAS.

TCAS is designed to work independently of the aircraft navigation equipment and the ground systems used to provide ATC services.

TCAS interrogates transponders of all aircraft in the vicinity and based on the replies received, tracks the slant range, altitude (when it is included in the reply message), and relative bearing of surrounding traffic.

From several successive replies, TCAS calculates a time to reach the Closest Point of Approach (CPA) with the intruder, by dividing the range by the closure rate.

Notice

Time to CPA is the main parameter for issuing alerts.

If transponder replies include altitude, TCAS also computes the time to reach co-altitude.

Issued Alerts

TCAS can issue two types of alerts:

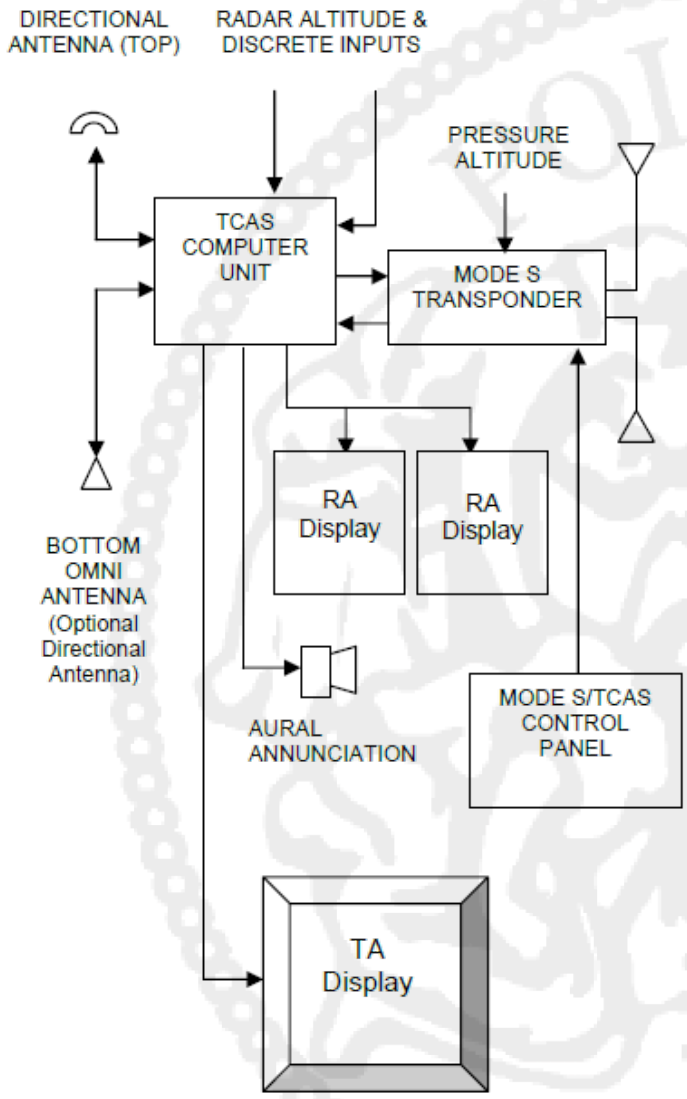
- **Traffic Advisory (TA)** to assist the pilot in the visual search for the intruder aircraft and to prepare the pilot for a potential RA.
- **Resolution Advisory (RA)** to recommend manoeuvrers that will either increase or maintain the existing vertical separation from an intruder aircraft.

RAs coordination

When the intruder aircraft is also fitted with TCAS II, both TCAS' **co-ordinate** their RAs through the Mode S data link to ensure that complementary RAs are selected.

TCAS II was designed to operate in traffic densities of up to 0.3 aircraft per square nautical mile (nmi), i.e., 24 aircraft within a 5 nmi radius.

Components


DIRECTIONAL ANTENNA (TOP)
RADAR ALTITUDE & DISCRETE INPUTS
PRESSURE ALTITUDE
TCAS COMPUTER UNIT
MODE S TRANSPONDER
RA Display
RA Display
BOTTOM OMNI ANTENNA (Optional Directional Antenna)
AURAL ANNUNCIATION
MODE S/TCAS CONTROL PANEL
TA Display

TCAS Computer Unit

TCAS Computer Unit performs airspace surveillance, intruder tracking, own aircraft altitude tracking, threat detection, RA maneuver determination and selection, and generation of advisories.

The TCAS Processor uses pressure altitude, radar altitude, and discrete aircraft status inputs from own aircraft to control the collision avoidance logic parameters that determine the protection volume around the TCAS.

If a tracked aircraft is judged to be a threat, TCAS computer Unit selects an avoidance maneuver that will provide adequate vertical miss distance from the intruder while generally minimizing the perturbations to the existing flight path.

If the threat aircraft is also equipped with TCAS II, the avoidance maneuver will be coordinated with the threat aircraft

Mode S Transponder

A Mode S transponder is required to be installed and operational for TCAS II to be operational.

If the Mode S transponder fails, the TCAS Performance Monitor will detect this failure and automatically place TCAS into Standby.

The Mode S transponder performs the normal functions to support the ground-based ATC system and can work with either an Air Traffic Control Radar Beacon System (ATCRBS) or a Mode S ground sensor.

The Mode S transponder is also used to provide air-to-air data exchange between TCAS-equipped aircraft so that coordinated, complementary RAs can be issued when required.

Mode S/TCAS Control Panel

A single control panel is provided to select and control all TCAS equipment including the TCAS Processor, the Mode S transponder and the TCAS displays. Typically it provides four (4) basic control positions:

- Stand-by: Power is applied to the TCAS Processor and the Mode S transponder, but TCAS does not issue any interrogations and the transponder will reply to only discrete interrogations.
- Transponder: The Mode S transponder is fully operational and will reply to all appropriate ground and TCAS interrogations. TCAS remains in Stand-by.
- TA Only: The Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions However, TCAS will only issue TAs.
- Automatic or TA/RA: The Mode S transponder is fully operational. TCAS will operate normally and issue the appropriate interrogations and perform all tracking functions. TCAS will issue TAs and RAs when appropriate.

Antennas

The antennas used by TCAS II include a directional antenna that is mounted on the top of the aircraft and either an omni-directional or a directional antenna mounted on the bottom of the aircraft. Most installations use the optional directional antenna on the bottom of the aircraft.

These antennas transmit interrogations on 1030 MHz at varying power levels in each of four 90 azimuth segments. The bottom mounted antenna transmits fewer interrogations and at a lower power than the top-mounted antenna.

These antennas also receive transponder replies, at 1090 MHz, and send these replies to the TCAS Processor. The directional antennas permit the partitioning of replies to reduce synchronous garbling.

New transponder-TCAS integrated systems only require two antennas that are shared by the transponder and TCAS.

Cockpit Presentation

The TCAS interface with the pilots is provided by two displays:

- Traffic display
- RA display

These two displays can be implemented in a number of ways, including incorporating both displays into a single, physical unit. Regardless of the implementation, the information provided is identical.

The standards for both the traffic display and the RA display are defined in DO-185B and ED-143.

Traffic Display

The traffic display depicts the position of nearby traffic, relative to own aircraft.

Displayed traffic information also includes traffic vertical speed indications, and Proximate, TA, and RA status.

The primary purpose of the traffic display is to aid the flightcrew in the visual acquisition of transponder equipped aircraft.

The secondary purpose of the traffic display is to provide the flightcrew with confidence in proper system operation, and to give them time to prepare to maneuver the aircraft in the event an RA is issued.

Traffic Display Symbology

Both color and shape are used to assist the pilot in interpreting the displayed information.

Each symbol is displayed on the screen, according to its relative position to own aircraft.

Relative altitude is displayed in hundreds of feet above the symbol if the intruder is above own aircraft and below the symbol if the intruder is below own aircraft. When the intruder is above own aircraft, the relative altitude information is preceded by a $+$ sign. When the intruder is below own aircraft, a $-$ sign precedes the relative altitude information.

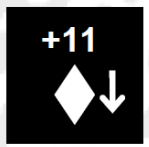
An arrow is displayed immediately to the right of a traffic symbol when the target aircraft is reporting its altitude and is climbing or descending at more than 500 fpm. An up arrow is used for a climbing aircraft; a down arrow is used for a descending aircraft. The arrow is displayed in the same color as the aircraft symbol.

Traffic Display Symbology

- Own-aircraft is depicted as a white or cyan airplane-like symbol.
- Unfilled diamond is used to depict "Other" non-threat traffic.
- Filled diamond is used to depict Proximate Traffic (Non-threat traffic that is within 6 nmi and $\pm$1200 ft from own aircraft).
- Filled amber or yellow circle is used to display intruders that have caused a TA to be issued.
- Filled red square is used to display intruders that have caused an RA to be issued.

Own-aircraft. Airplane-like symbol, in white or cyan.

Other Traffic, altitude unknown. Unfilled diamond in white or cyan



Proximate Traffic, 1100 feet above and descending. Filled diamond in white or cyan

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

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

Resolution Advisory Display

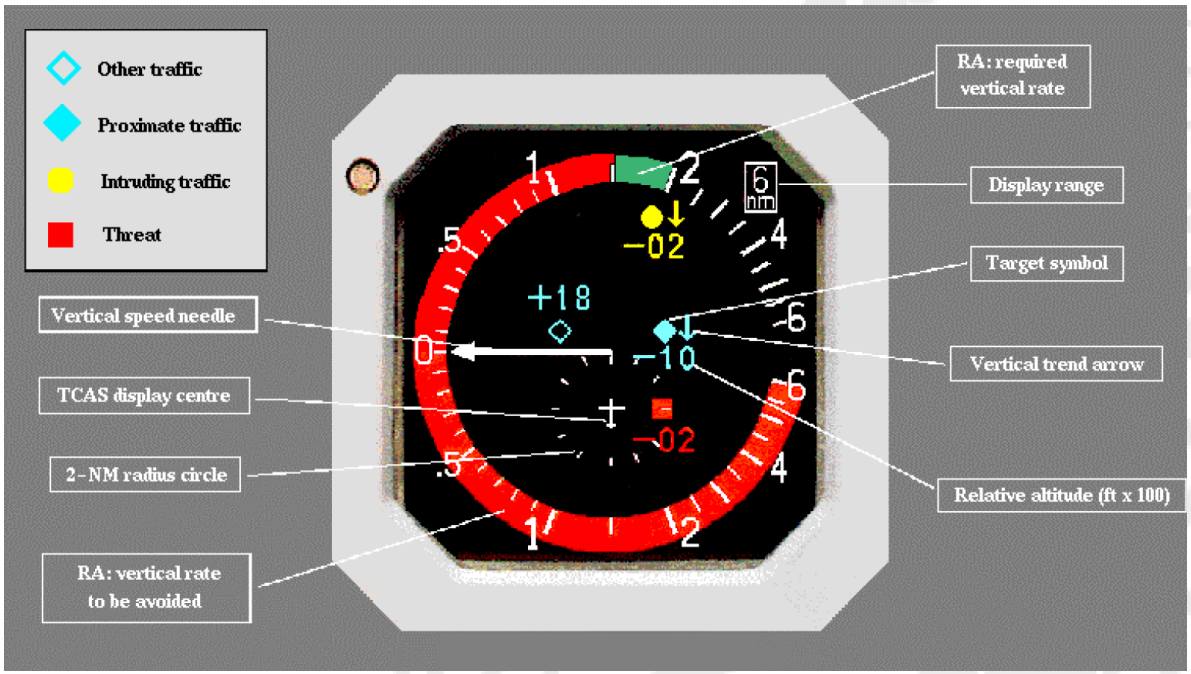
The RA display provides the pilot with information on the vertical speed or pitch angle to fly or avoid to resolve an encounter.

The RA display is typically implemented on an Instantaneous Vertical Speed Indicator (IVSI), a vertical speed tape that is part of a Primary Flight Display (PFD), or using pitch cues displayed on the PFD.

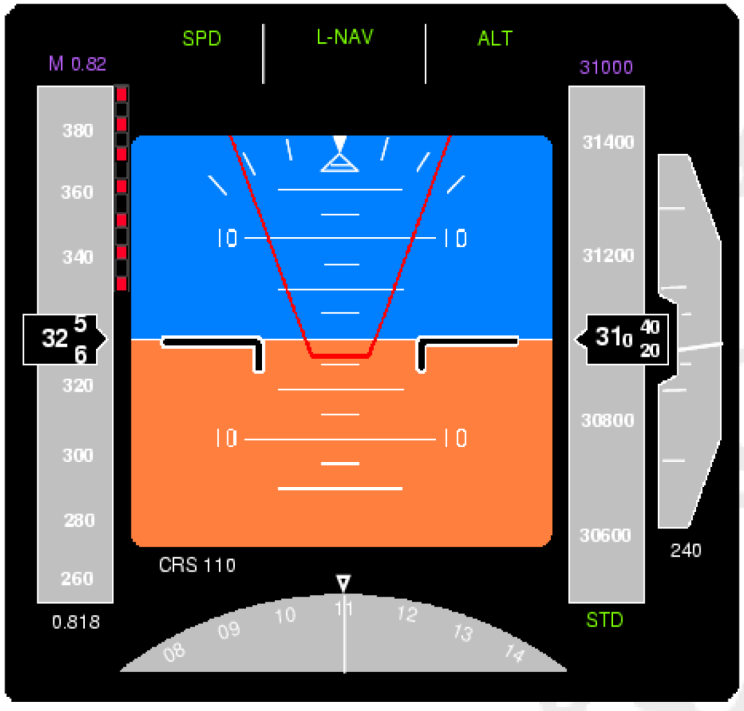
The implementation on the IVSI or a vertical speed tape utilize red and green lights or markings to indicate the vertical speeds to be avoided (red) and the desired vertical speed to be flown (green).

An implementation using pitch cues uses a unique shape on the PFD to show the pitch angle to be flown or avoided to resolve an encounter.

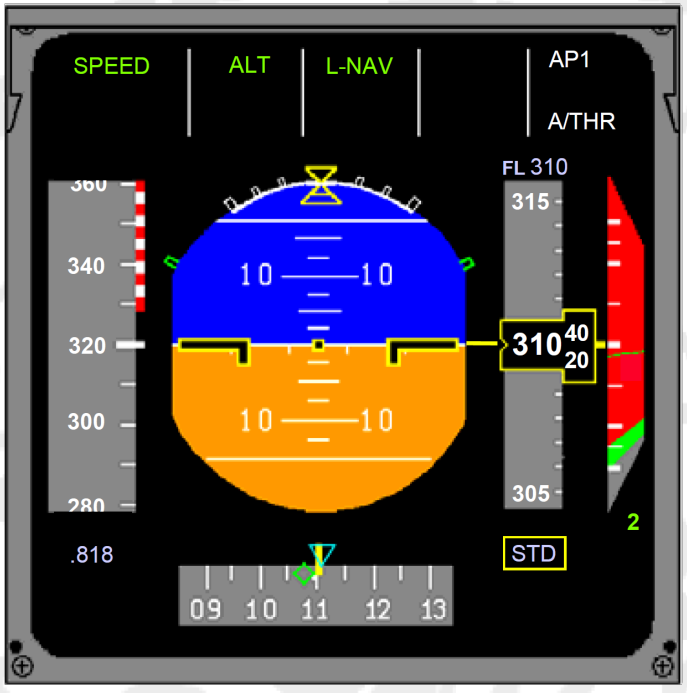
Resolution Advisory Display



Resolution Advisory Display



Pitch Cue Implementation



Vertical Speed Tape Implementation

Aural annunciations

Whenever the collision avoidance algorithms issue a TA or an RA, a voice alert is issued to ensure that the pilots are aware of the information being displayed on the traffic and RA displays

Aural annunciations are inhibited below 500 ± 10 feet AGL.

The TCAS aural annunciations are integrated with other environmental aural alerts available on the aircraft.

The priority scheme established for these aural alerts gives windshear detection systems and ground proximity warning systems (GPWS) a higher annunciation priority than a TCAS

Aural messages

TCAS Advisory	Version 7.1 Annunciation	Version 7.0 Annunciation	6.04a Annunciation
Traffic Advisory	Traffic, Traffic		
Climb RA	Climb, Climb		Climb, Climb, Climb
Descend RA	Descend, Descend		Descend, Descend, Descend
Altitude Crossing Climb RA	Climb, Crossing Climb; Climb, Crossing Climb		
Altitude Crossing Descend RA	Descend, Crossing Descend; Descend, Crossing Descend		
Reduce Climb RA	Level Off, Level Off	Adjust Vertical Speed, Adjust	Reduce Climb, Reduce Climb
Reduce Descent RA	Level Off, Level Off	Adjust Vertical Speed, Adjust	Reduce Descent, Reduce Descent
RA Reversal to Climb RA	Climb, Climb NOW; Climb, Climb NOW		
RA Reversal to Descend RA	Descend, Descend NOW; Descend, Descend NOW		
Increase Climb RA	Increase Climb, Increase Climb		
Increase Descent RA	Increase Descent, Increase Descent		
Maintain Rate RA	Maintain Vertical Speed, Maintain		Monitor Vertical Speed
Altitude Crossing, Maintain Rate RA (Climb and Descend)	Maintain Vertical Speed, Crossing Maintain		Monitor Vertical Speed
Weakening of RA	Level Off, Level Off	Adjust Vertical Speed, Adjust	Monitor Vertical Speed
Preventive RA (no change in vertical speed required)	Monitor Vertical Speed		Monitor Vertical Speed, Monitor Vertical Speed
RA Removed	Clear of Conflict		

Surveillance

TCAS performs surveillance of nearby (up to a range of 14 nmi) aircraft to provide information on the position and altitude of these aircraft so that the collision avoidance algorithms can perform their function.

The TCAS surveillance function operates by issuing interrogations at 1030 MHz that transponders on nearby aircraft respond to at 1090 MHz.

These replies are received and decoded by the surveillance portion of the TCAS software and the information is then provided to the collision avoidance algorithms.

Following the receipt and decoding of a squitter message, TCAS sends Mode S interrogations to the Mode S address contained in the squitter. These interrogations generally occur once per second.

The Mode S transponder replies to these interrogations and the reply information is used by TCAS to determine range, bearing, and altitude of the Mode S aircraft.

Collision Avoidance

Airborne collision avoidance is a complex problem.

It has taken many years to develop an operationally acceptable solution and refinement of the system continues to maximize the compatibility between TCAS, ATC systems throughout the world, and existing cockpit procedures.

The heart of collision avoidance is the collision avoidance system logic.

To explain the operation of the collision avoidance system logic, the basic concepts

- Sensitivity level
- Tau
- Protected volume

need to be understood.

Sensitivity Level

Effective Collision Avoidance System logic operation requires a trade-off between necessary protection and unnecessary advisories.

This trade-off is accomplished by controlling the sensitivity level (SL), which controls the time or tau thresholds for TA and RA issuance, and therefore the dimensions of the protected airspace around each TCAS-equipped aircraft.

The higher the SL, the larger the amount of protected airspace and the longer the alerting thresholds. However, as the amount of protected airspace increases, the incidence of unnecessary alerts has the potential to increase.

When the pilot has selected the TA-RA mode on the Control Panel, the operating SL is automatically selected via inputs from the aircraft's radar or pressure altimeter.

Sensitivity Level

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

Tau

TCAS primarily uses time-to-go to CPA rather than distance to determine when a TA or an RA should be issued.

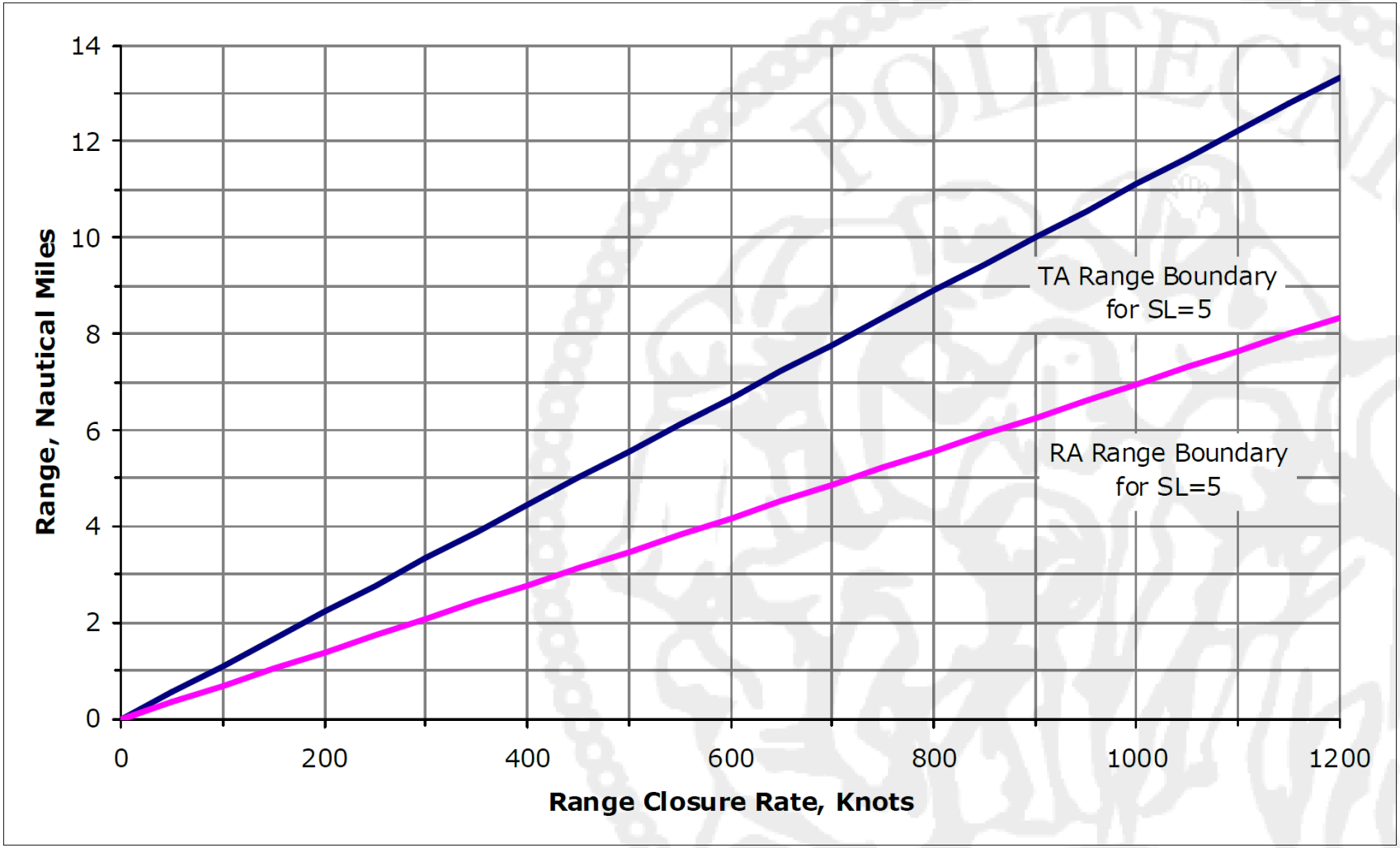
The time to CPA is called the *range tau* and the time to co-altitude is called the *vertical tau*. Tau is an approximation of the time, in seconds, to CPA or to the aircraft being at the same altitude.

- The range tau is equal to the slant range (nmi) divided by the closing speed (knots) multiplied by 3600.
- The vertical tau is equal to the altitude separation (feet) divided by the vertical closing speed of the two aircraft (feet/minute) times 60.

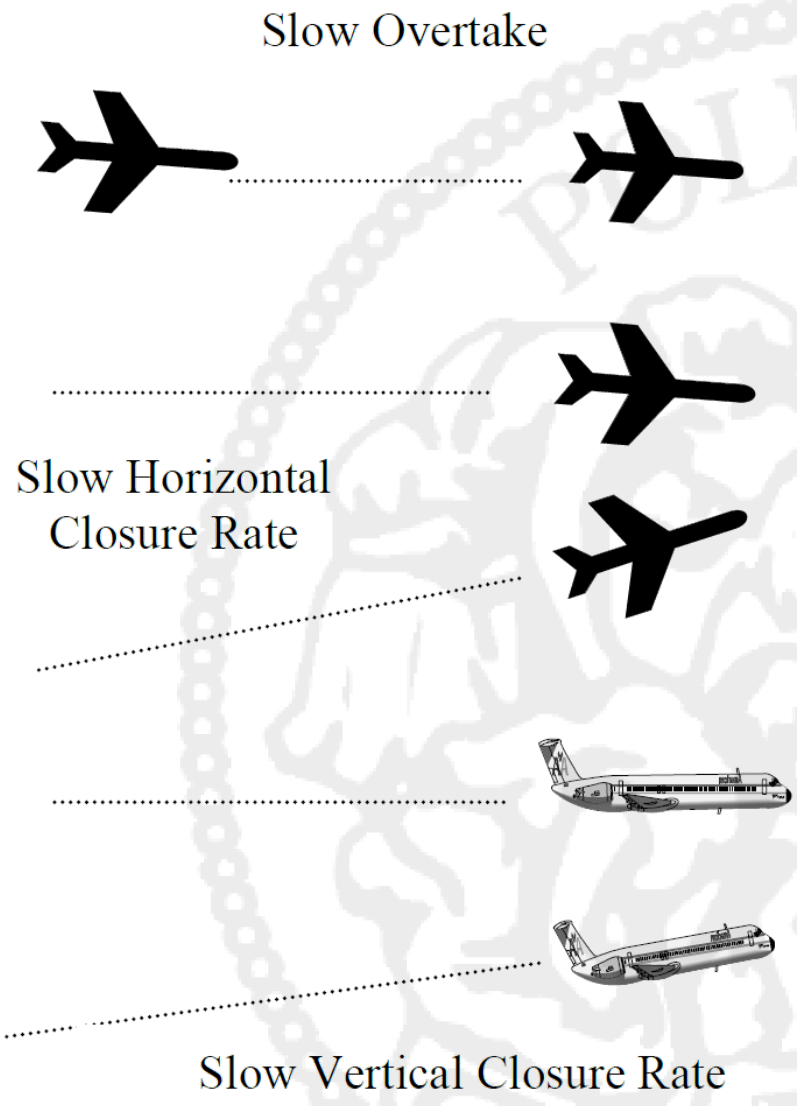
Tau concept for all alerting functions

A TA or an RA is displayed only when **both** the range tau and vertical tau are less than certain threshold values that depend on sensitivity level.

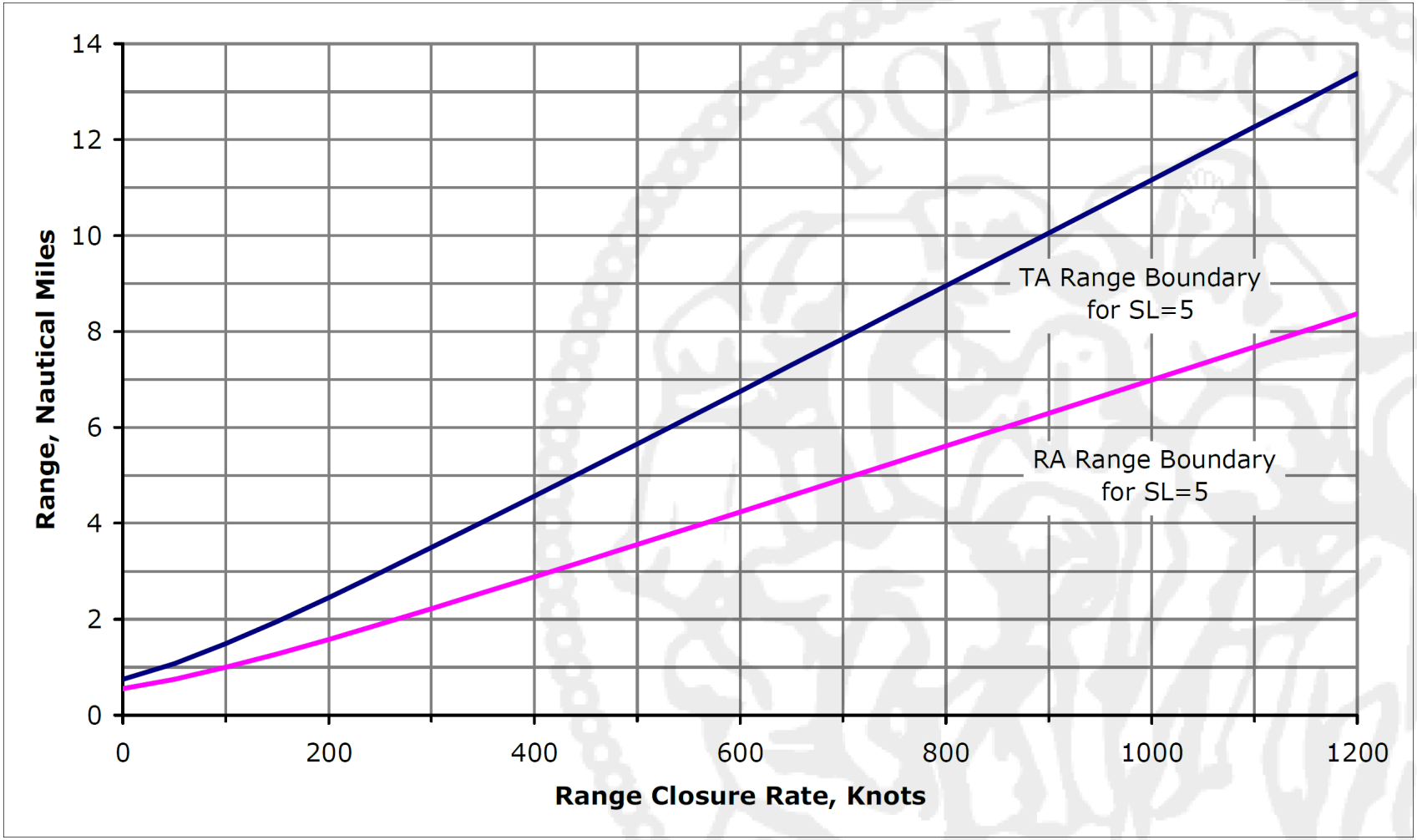
Tau


14
12
10
8
6
4
2
0
Range, Nautical Miles
0
200
400
600
800
1000
1200
Range Closure Rate, Knots
TA Range Boundary
for SL=5
RA Range Boundary
for SL=5

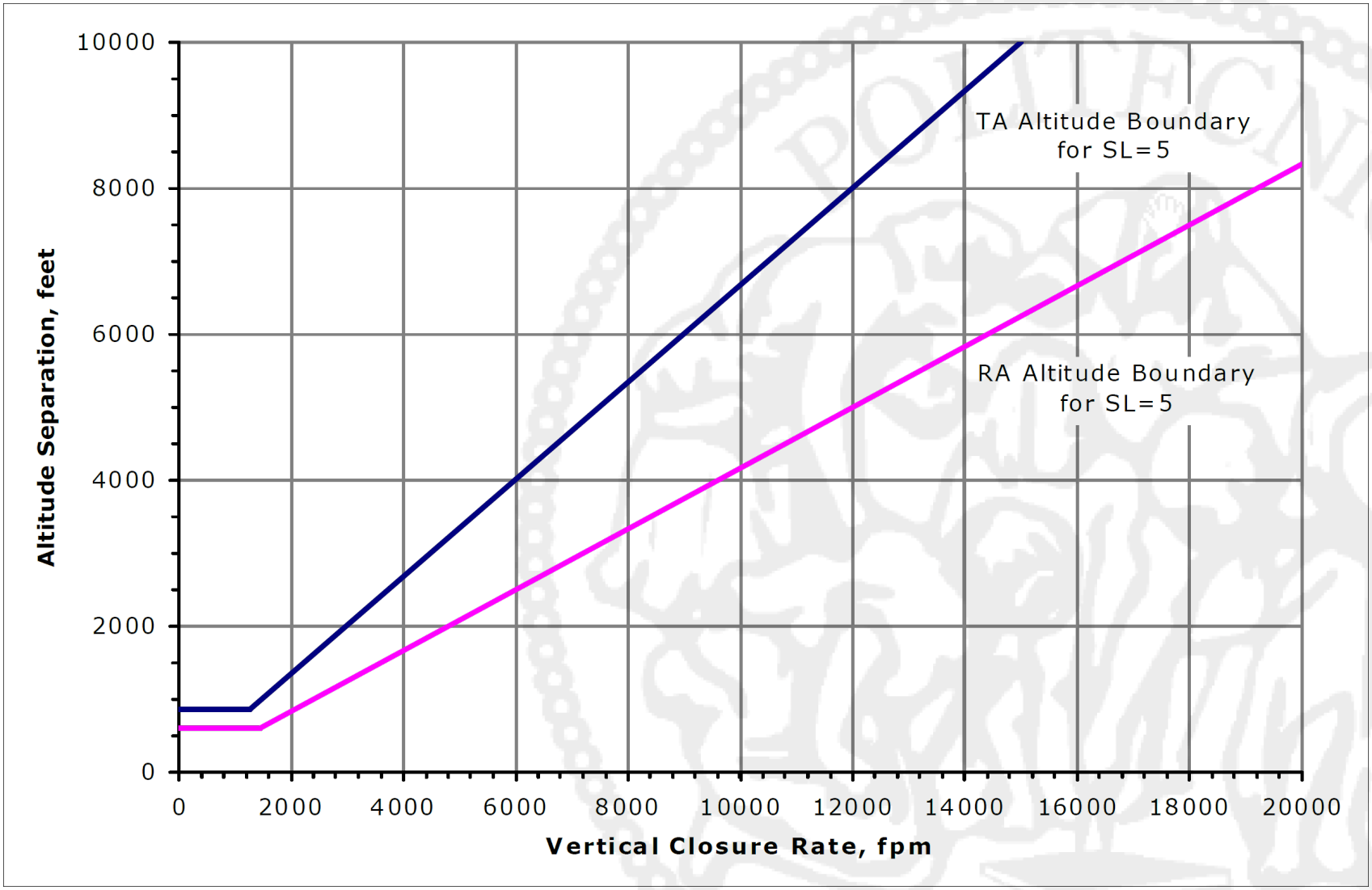
Need for modified Tau



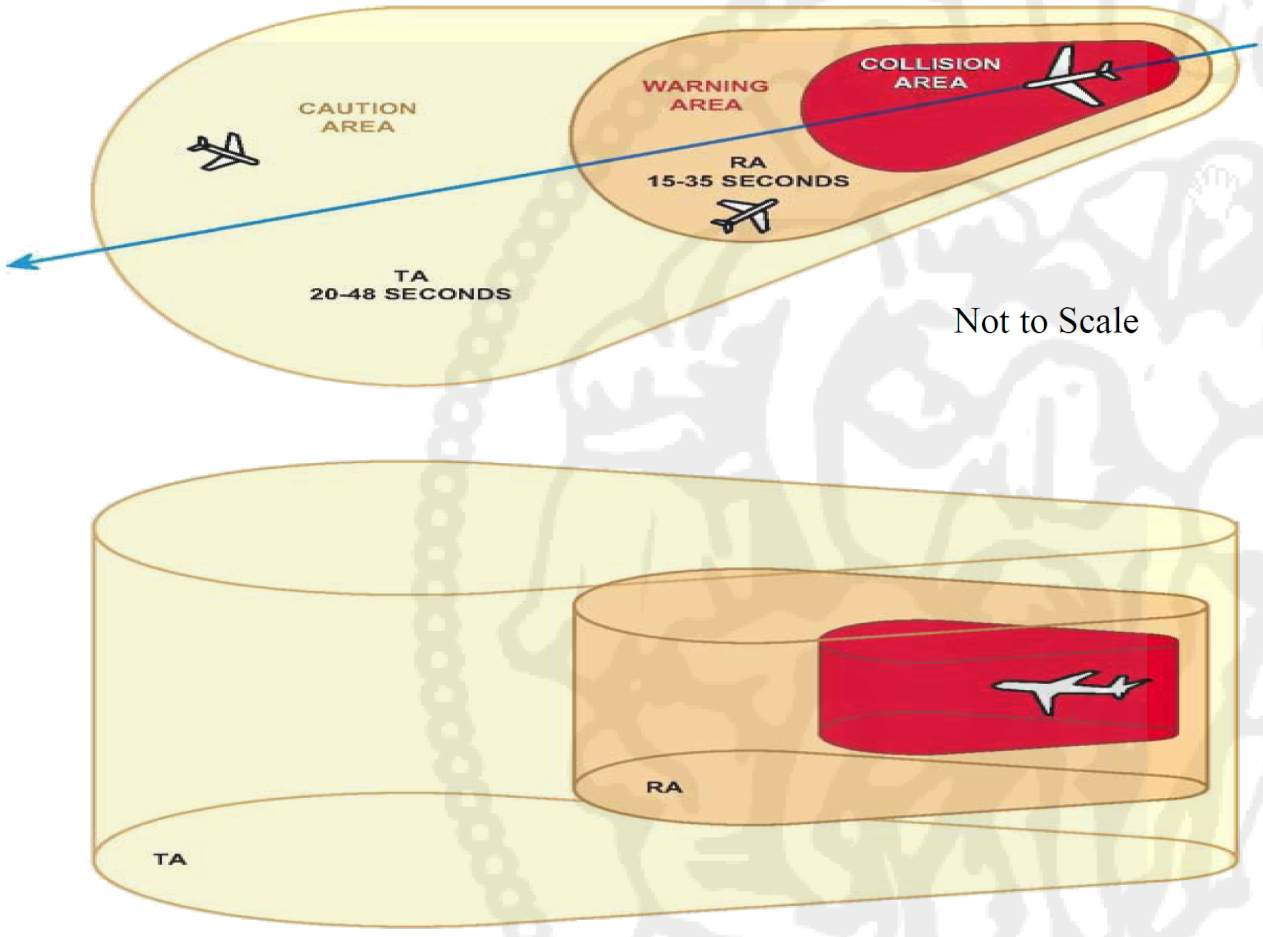
Tau modified



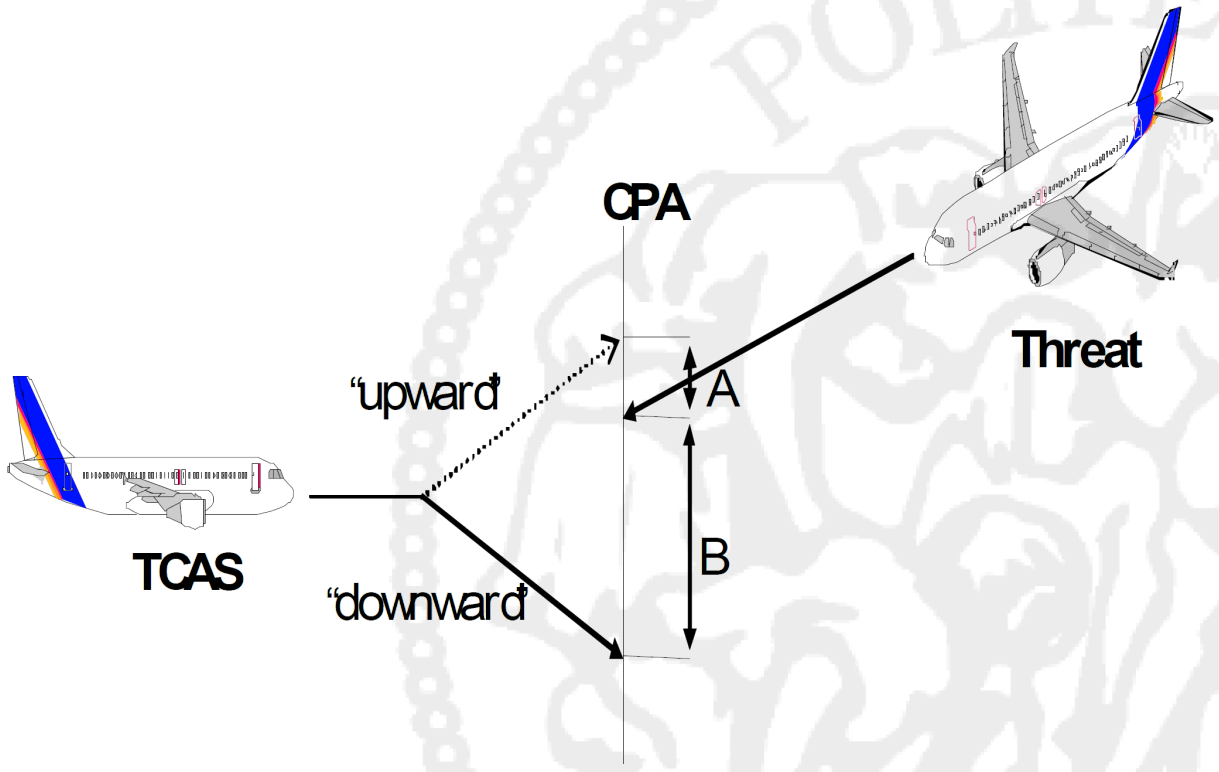
Tau modified



Protected Volume

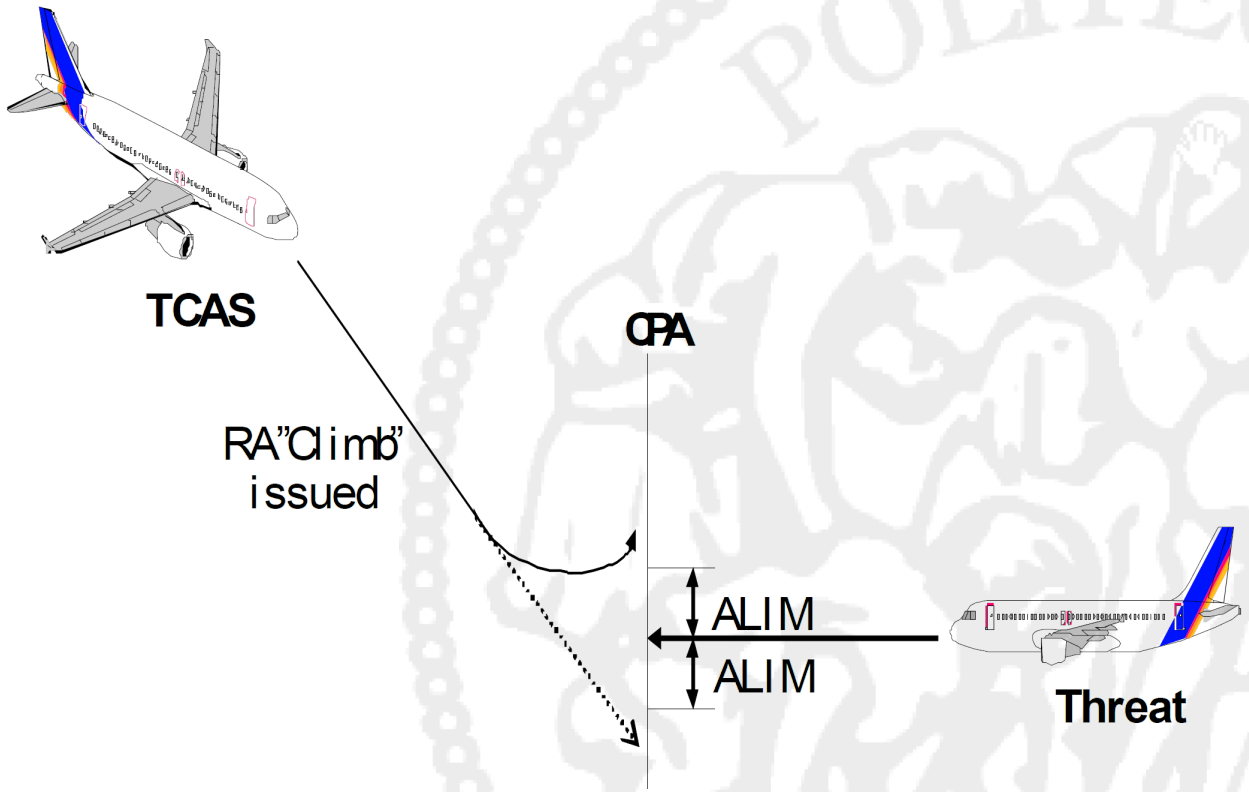


RA Selection



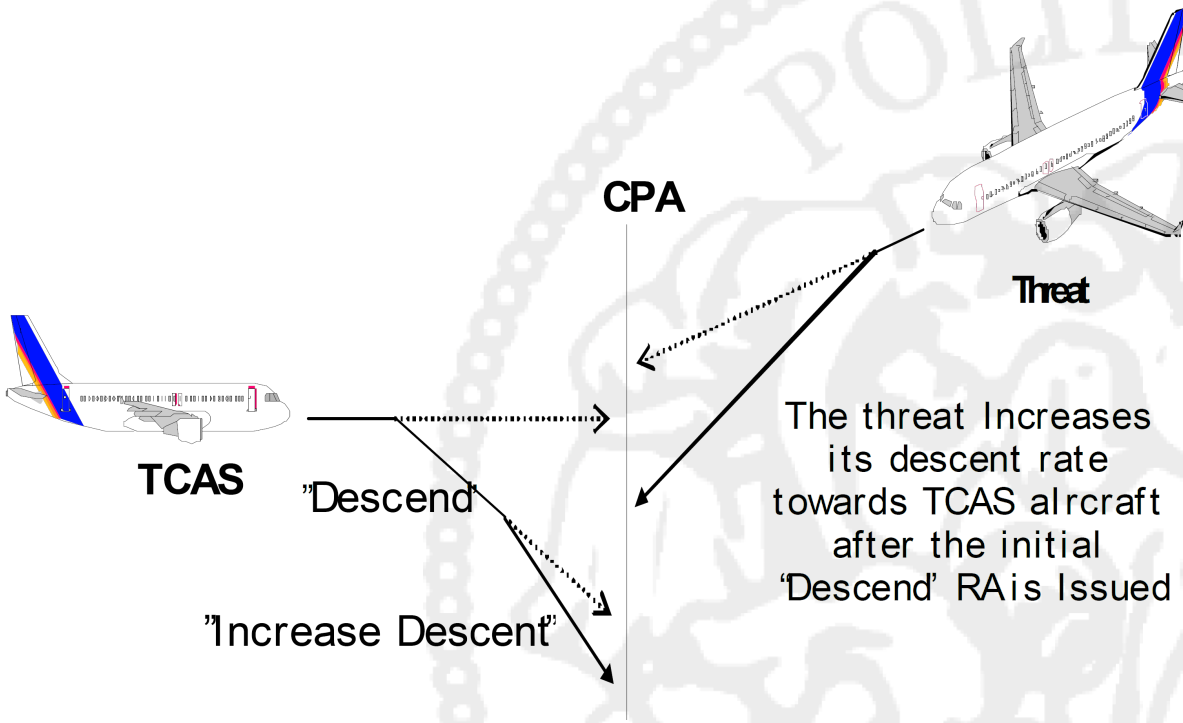
Downward will be selected since it will provide the greatest separation.

RA Selection



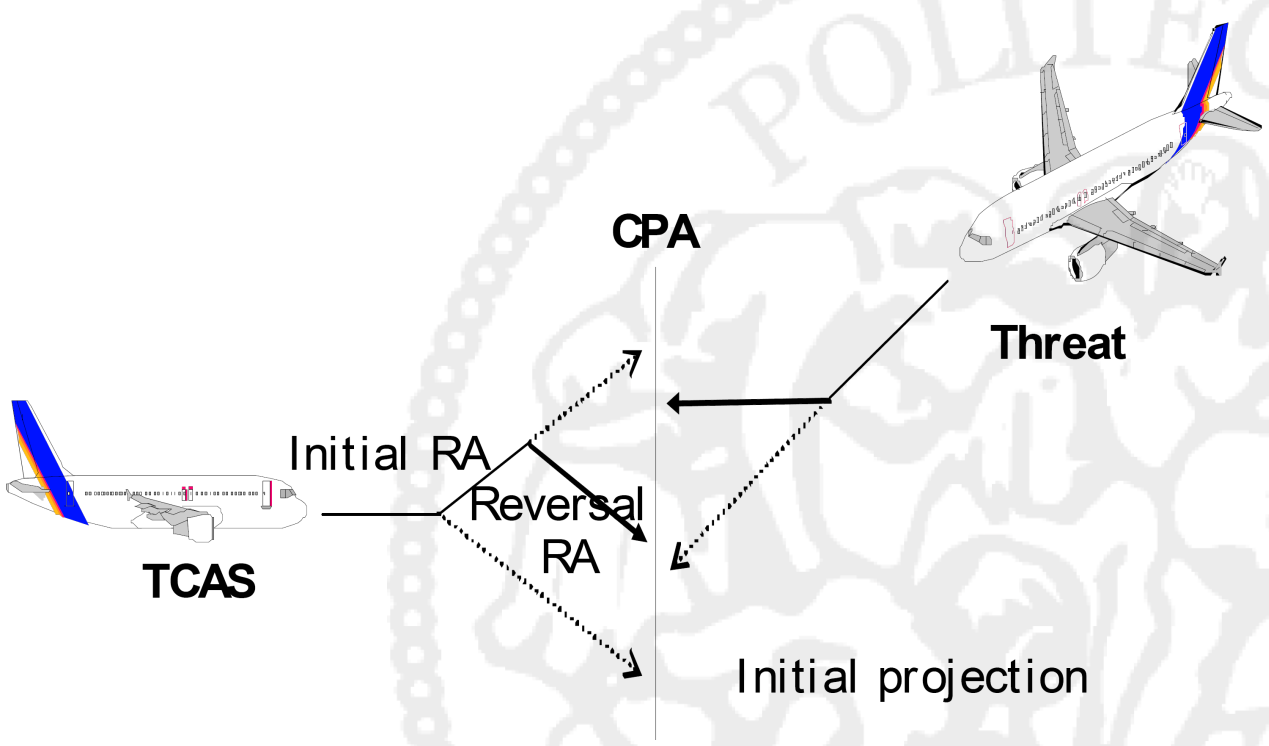
Upward will be selected since it will provide a non-crossing manoeuvre.

RA continuous monitoring



It is necessary to increase the descent rate from the 1500 fpm required by the initial RA to 2500 fpm.

RA reversal



An initial Climb RA requires reversal to a Descend RA after the intruder manoeuvrers.

List of Acronyms

ATCRBS	Air Traffic Control Radar Beacon System
ATC	Air Traffic Control
CPA	Closest Point of Approach
IVSI	Instantaneous Vertical Speed Indicator
PFD	Primary Flight Display
RA	Resolution Advisory
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System