Traffic Alert and Collision Avoidance System (TCAS)

FAA Flight Standards Pilot Outreach Program

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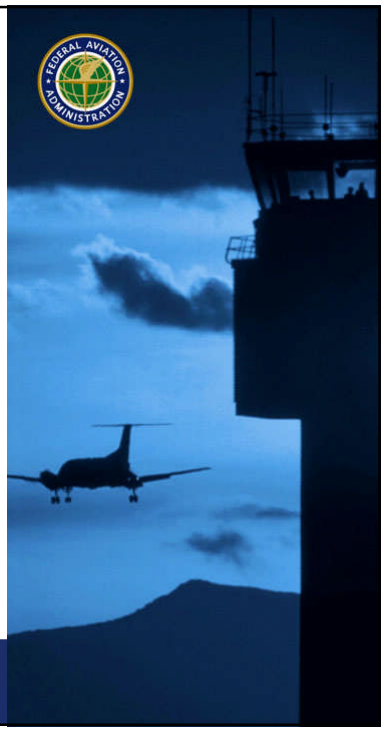
June 7, 2012 / TEB (Teterboro, NJ)



Overview

- **Collision Avoidance System (CAS) History**
- **TCAS* System Operation**
- **Pilot Responses**
- **TCAS Operational Performance and Assessment Program (TOPA)**
- **Wrap-Up**

*Unless specifically noted:
- TCAS II will be referred as TCAS for remainder of briefing
- Data/trends derived from U.S. airspace operations

Collision Avoidance Systems History

CAS History (Slide 1 of 5)

- CAS in the U.S. is known as TCAS and internationally as ACAS (Airborne Collision Avoidance System)
- Series of midair collisions led to airline and governmental action to develop airborne devices that function ***independent*** of air traffic control (ATC) for alerting and collision avoidance
- Early attempts (late 50s-60s) for reliable systems proved to be impractical
- Mid 70s Beacon Collision Avoidance System (BCAS) became the basis of FAA decision for TCAS interrogation and tracking capabilities
- Aircraft ***must*** have ***operating transponder*** for TCAS to provide collision avoidance protection

CAS History (Slide 2 of 5)

- **Major Midair Accidents**

1956 Grand Canyon, AZ — United DC-7 / TWA L-1049 (**128** fatalities)
1960 New York, NY — United DC-8 / TWA L-1049 (**134** fatalities)
1978 San Diego, CA — PSA B-727 / Cessna 172 (**144** fatalities)
1986 Cerritos, CA — Aeromexico DC-9 / Piper PA-28 (**82** fatalities)
1996 Charkhi Dadri, India — Saudi B-747 / Kazakhstan IL-76 (**349** fatalities)
1997 Namibia (off-coast) — USAF C-141 / German AF Tu-154 (**33** fatalities)
2002 Überlingen, Germany — Bashkirian Tu-154 / DHL B-757 (**71** fatalities)

CAS History (Slide 3 of 5)

- **Rulemaking Process**
  - Congressionally-mandated structured process with aviation stakeholders and public comment that normally takes 38-42 months
  - Becomes official when Federal Register publishes Final Rule
  - One segment's pro can be another segment's con
- **RTCA**
  - Formerly known as the Radio Technical Commission for Aeronautics, (private, not for profit corporation) with Federal Advisory Committee status
  - Develops government/industry consensus on communications, navigation, surveillance and air traffic management issues
  - Special Committees consist of volunteers to develop Minimum Operating Performance Standards (MOPS) with approved recommendations made available to the public
  - Works in conjunction with European Organization for Civil Aviation Equipment (EUROCAE) to develop technical standards

CAS History (Slide 4 of 5)

- **TCAS I**
  - Mandated in U.S. (31 Dec 1995*) for turbine-powered, passenger aircraft having more than 10 and less than 31 seats
  - Also installed on numerous GA aircraft and helicopters
  - Provides only traffic alerts (TAs) — no resolution advisories (RAs)
  - TCAS I and TCAS II development had some shared elements but was concurrent — not consecutive
  - TCAS I envisioned to be cheaper alternative to assist pilot in visual acquisition of intruder aircraft

*TCAS I Final Rule, 14 CFR 121,129,135 amendment, Docket #27663 [29DEC1994]

CAS History (Slide 5 of 5)

- **TCAS II**
  - Mandated in U.S. (Dec 31,1993*) for commercial aircraft with more than 30 seats
    - Mandate later revised to include max takeoff weight greater than 33,000 lbs
  - Also installed on numerous GA aircraft and helicopters
  - Provides both TAs and RAs
  - Extra benefit of coordinated RAs between TCAS II aircraft
  - **Version 6.0/6.04a** (RTCA - May 1993) reduced nuisance alerts and corrected problem in altitude crossing logic
  - **Version 7.0** (RTCA - Dec 1997) changed algorithms to reduce RAs and minimize altitude displacement during RA response, 25 foot tracking
  - **Version 7.1** (RTCA - Jun 2008) changed RA logic to permit additional sense-reversal RAs for certain vertical chase geometries and revised certain verbal guidance phraseology

*Public Law 100-223 modified by P.L.101-236

TCAS Version Status

- **Three versions of TCAS II are approved and currently in use in the U.S.**
  - **Version 6.04a**
    - **Mandated** – Dec 31,1994 in U.S.
  - **Version 7.0**
    - **Mandated** – Jan 1, 2003 worldwide . . . but . . .
    - ***Not*** **mandated** in U.S. ***except*** for TCAS-equipped aircraft in Reduced Vertical Separation Minima airspace (RVSM: FL290-FL410 effective Jan 1, 2005)
  - **Version 7.1**
    - **Mandated** – Mar 1, 2012 by European Union (EU) for new aircraft (forward-fit) and Dec 1, 2015 for existing aircraft (retrofit)
    - **Mandated** – Jan 1, 2014 by ICAO Annex 10 on new aircraft and existing aircraft by Jan 1, 2017
    - ***Not*** **mandated** in U.S.

National Airspace System (NAS)

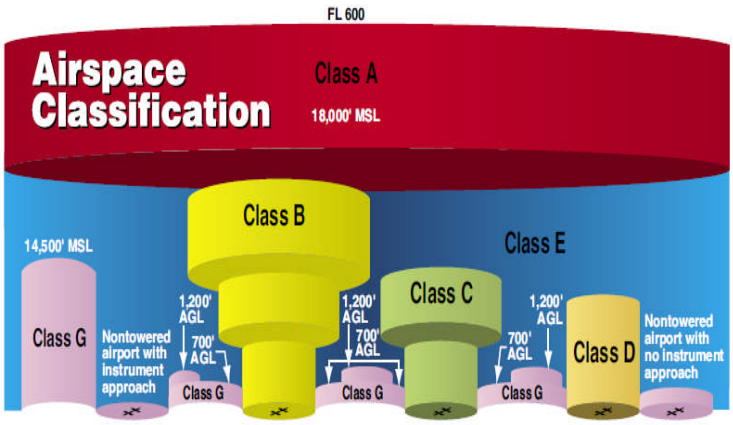
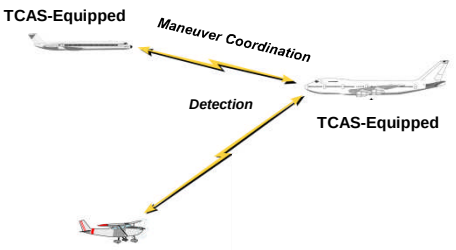
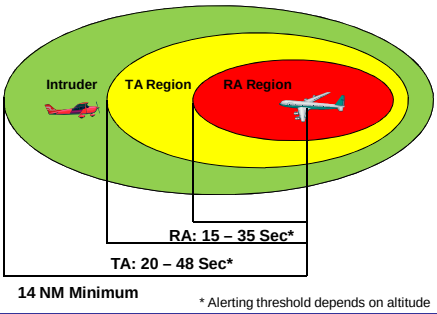


Figure 14-1. *Airspace profile.*

TCAS System Operation

TCAS – System Description

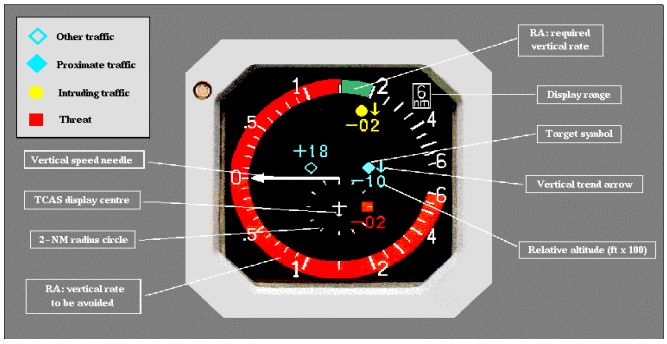


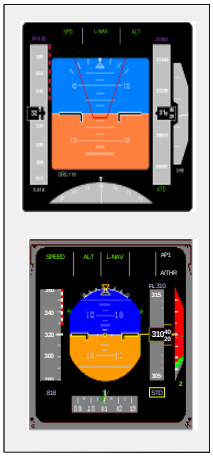


* Alerting threshold depends on altitude

- **TCAS uses on-board surveillance to detect transponder-equipped traffic and provides:**
  - Traffic Display and Traffic Alerts (TA) for situational awareness of close aircraft
  - Resolution Advisories (RA) with vertical guidance
- **Alerts are based on both *projected:***
  - Time to Closest Point of Approach (CPA) and
  - Miss distance less than:
    - 600 to 800' depending on altitude (vertical miss distance)
    - 0.2 to 1.1 NM depending on altitude (horizontal miss distance)
- **Resolution Advisories are selected to *achieve or maintain* adequate vertical distance (300 – 700') and minimize pilot response/vertical deviations**

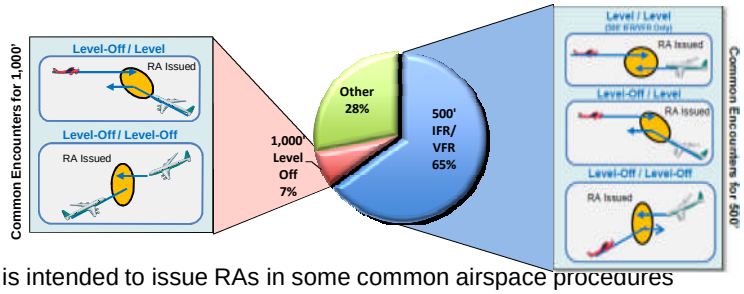
TCAS – Flight Deck View





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 Design and RA Experiences

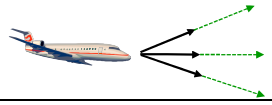
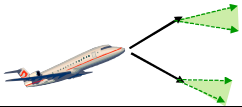
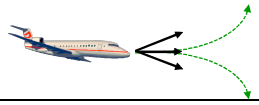


- TCAS is intended to issue RAs in some common airspace procedures
  - Preventive RAs issued for 500’ vertical spacing
    These RAs are intended to alert pilots to traffic that may quickly become a significant threat if the intruder maneuvers vertically
  - RAs (annunciated as “Adjust Vertical Speed, Adjust”) for high vertical rates prior to level-offs 1,000’ above/below other IFR traffic
    These RAs are intended to mitigate risk of aircraft failing to level off as intended
- These RAs should match pilot intentions and require minimal change to aircraft flight path

Most RAs result from intended TCAS design and have minimal airspace impact

Primary RA Types

Current path: →
TCAS guidance:

		
Monitor Vertical Speed (MVS)	**Adjust Vertical Speed, Adjust (AVSA)**	**Climb/Descend**
no change	**reduction**	**increase**
• Remain level (if level) • Avoid a vertical rate in the red area	• 4 Possible Targets: Level, 500 fpm, 1,000 fpm, 2,000 fpm • Level-off only (v7.1)	• Initial target: 1,500 fpm • "Increase Climb/Increase Descend" RA requires 2,500 fpm

- **TCAS logic selects RA sense (direction) and type to provide vertical distance (300 – 700') while minimizing maneuvering**
- **RAs are based on *projected* time to closest approach and may:**
  - Strengthen (increase vertical rate guidance) or weaken (decrease vertical rate guidance)
  - Reverse sense (one time)
  - Cross flight path of threat aircraft
  - Issue optimized guidance during encounters with multiple threat aircraft

Alerting Threshold Values

- **TCAS alerts based on time to closest approach and time to being co-altitude (tau)**
  - All RAs are inhibited below 1,000' AGL
- **Fixed distance alerting thresholds are also used in some situations**
  - Many parallel runway operations
  - 500' IFR/VFR separation when both aircraft are level
- **TCAS does not consider IFR/VFR status or pilot intentions**

Altitude	TAU (s)	DMOD (NM)	ZTHR (ft)	ALIM (ft)
FL > 420	35	1.1	800	700
FL200~420	35	1.1	700	600
10K ~ FL200	30	0.8	600	400
5K ~ 10K ft	25	0.55	600	350
2350ft ~ 5K ft	20	0.35	600	300
1000 ~ 2350ft AGL	15	0.2	600	300
0 ~ 1000 ft AGL	No RA	No RA	No RA	No RA

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

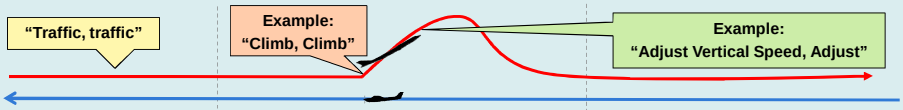
Operational Concept

	Prior to Advisories	Traffic Alert (TA)	Resolution Advisory (RA)
TCAS System	Uses bearing and range from TCAS surveillance to track aircraft	Issues TA 20 – 48 Sec prior to projected Closest Point of Approach	Issues RA 15 – 35 Sec prior to projected Closest Point of Approach
Flight Crew	**Do:** - Use Traffic Display to maintain situation awareness	**Do:** - Use traffic display to visually acquire traffic and prepare to maneuver	**Do:** – Promptly follow RA guidance – Inform ATC if deviating from ATC clearance and when RA is terminated
	Do not: - Maneuver based solely on traffic display	**Do not:** - Deviate from ATC clearance solely on basis of TA information	**Do Not:** - Maneuver opposite RA guidance - Maneuver horizontally based solely on TCAS traffic display
ATC*			- Avoid issuing conflicting ATC clearance if informed of TCAS RA - Not responsible for separation until informed RA is terminated or aircraft has returned to ATC clearance

*ATC has no direct indication of TCAS TA/RA alerts in the U.S.

Pilot Response to RAs

Expected Pilot Response



Upon TA

- Utilize traffic display to help visually acquire threat
- Do NOT deviate from ATC clearance based solely on TA or traffic display

Upon RA

- Respond to initial RA within 5 sec
- Respond to increase rate and reversal RAs within 2.5 sec
- Pitch change ~2º enroute, ~5 - 7º on approach for Climb/Descend RAs
- Required response is moderate (1/4 g or less for an initial RA)
- Most autopilots do not meet TCAS design criteria - the autopilot should be disengaged prior to RA response

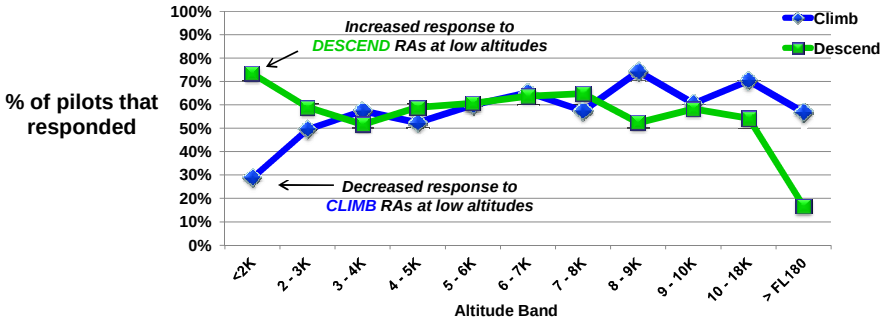
Upon Weakening

- Prompt response to "Weakening RAs" which command a reduction in vertical rate once sufficient vertical miss distance is attained

If RA contradicts ATC clearance, comply with TCAS RA

- **FAA guidance (AC 120-55C) allows non-response to TCAS RAs under certain conditions:**
  - Responding would compromise safety (some air carriers require response except in this case)
  - Pilots have visually acquired the correct threat aircraft and can maintain safe separation
  - Misidentifying the wrong threat aircraft or misjudging separation can occur and increase collision risk

Observed Pilot Response
Climb and Descend RAs



- **In many cases flight crews do not respond to Climb/Descend RAs**
  - Often likely due to visual acquisition with TCAS threat
  - Pilots may also respond less to Climb RAs when close to arrival airport at low altitudes
- **Following TCAS RA guidance increases miss distance from threat**
  - Non-response is often a factor in low separation encounters
  - Following "weakening" guidance if provided also minimizes altitude deviation and airspace impact
  - Over-response is less common, but can result in secondary conflicts and increased workload

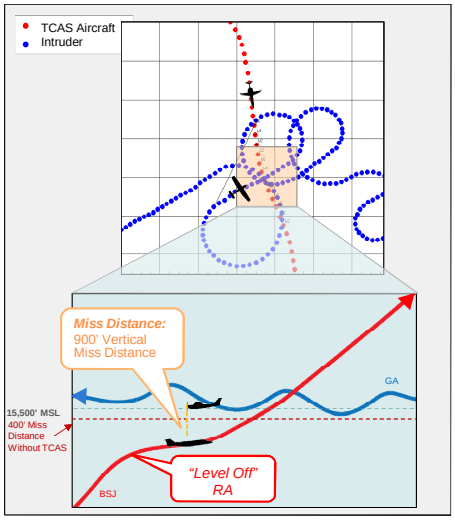
Correct Response

Correct Response Prevented Low Vertical Miss Distance

Normal operations can lead to undesirably low miss distances due to mistakes, lack of ATC services, or failure to “see and avoid”

Scenario: TCAS aircraft was climbing at ~2,500 fpm when a level-off RA (AVSA) was issued due to aircraft above. Proper pilot response greatly increased vertical miss distance.

Proper pilot response to TCAS RAs can significantly increase vertical miss distance (safety)



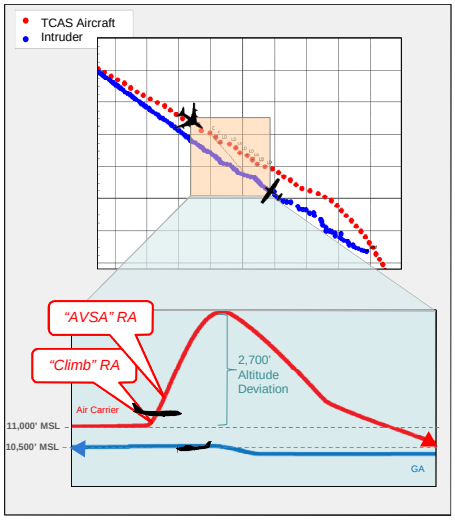
Over-Response

Over-Response Led to Large Altitude Deviation

Over-response to RAs can lead to large altitude deviations which may impact airspace efficiency

Scenario: TCAS issued RA during head-on encounter with 500' IFR/VFR vertical separation. Flight crew over-responded to RA and deviated 2,700' from original altitude.

Correct, timely pilot response to TCAS guidance is essential to minimize altitude excursion



Failure to Weaken

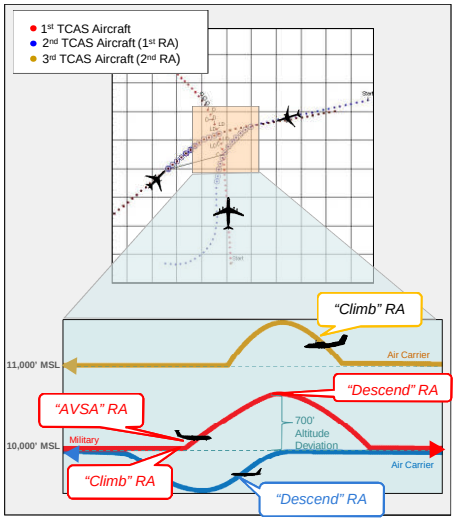
Failure to Follow Weakening RA Caused 2nd RA

Delayed response to the weakening RA can lead to large altitude deviations and other conflicts

Scenario: Initial encounter between military cargo plane and co-altitude traffic was due to ATC error.

Response to initial Climb RA resolved first conflict, but failure to follow weakening RA (level-off) resulted in second conflict.

Following strengthening/weakening guidance during RAs is necessary to increase safety benefit and ensure minimal airspace disruption



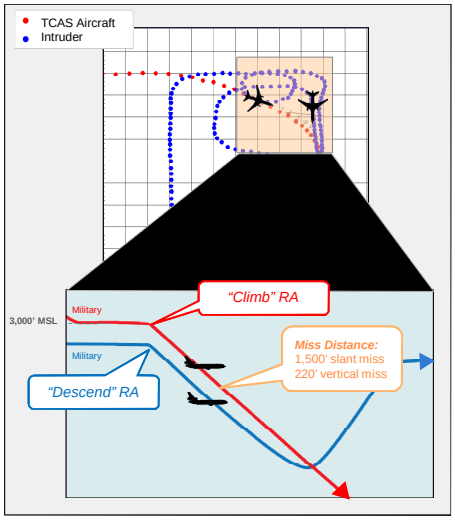
Opposite-Response

Opposite-Response Led to Low Miss Distance

Opposite-response to RAs can lead to very low vertical miss distance encounters

Scenario: During this TCAS-TCAS encounter, both aircraft received coordinated RAs (Descend vs. Climb). Only 1 flight crew complied, the other flight crew maneuvered opposite the TCAS guidance and a "vertical chase" ensued; the resulting miss distance was very low.

Correct, timely pilot response to TCAS guidance is essential to ensure adequate vertical miss distance



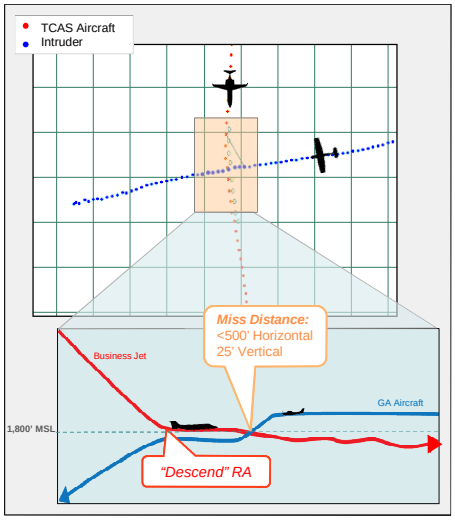
Low Miss Distance Encounter

Flight Crew Did Not Respond to RA

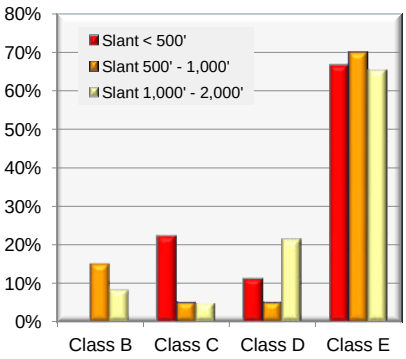
A well-constructed, legal plan by ATC involving participating aircraft may result in a low miss distance encounter in the event of sudden maneuvering by either aircraft

Scenario: Business Jet on final approach to AFW encountered a GA aircraft on a 1200 Mode A code in Class E airspace. The business jet received a Descend RA and did not descend, but instead leveled off; likely due to a failure to identify or a mis-identification of the intruder.

Correct, timely pilot response to TCAS guidance is essential to ensure adequate vertical miss distance



Low Miss Distance Encounters

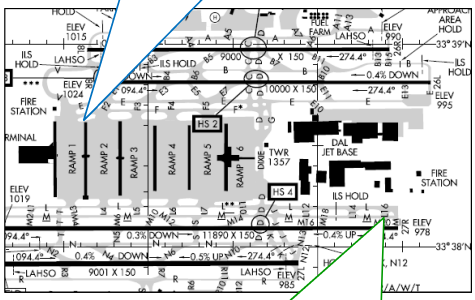


- **TCAS is designed to provide at least 300' vertical miss distance**
  - Miss distance < 2,000' slant range & < 300' vertical is observed in 0.5% of TCAS encounters
- **Most low miss distance encounters:**
  - Are in Class E airspace below 5,000' with a piston-driven GA intruder
  - Involve pilot response to Climb/Descend RAs that does not meet TCAS design intentions

TCAS provides independent alerts even in case of visual "see and avoid" separation
Correct, timely pilot response is essential for maximizing TCAS benefit/safety

TCAS Use During Ground Operations (FAA AC 120-55C)

Taxi-out: Do not operate in TA-only or TA/RA until taking active runway for departure



After Landing: Select "XPNDR" or "ON" while taxiing to the ramp area. Upon shutdown, select "STBY" on the transponder.

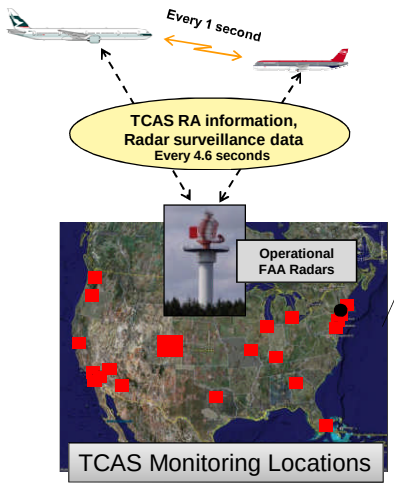
- In order to minimize transponder interrogations and avoid interference with ATC radar and surface surveillance systems, pilots should minimize TCAS use during ground operations
- When TCAS is operational (TA Only or TA/RA) on the ground it interrogates other aircraft at high power levels, at busy airports the combined effects can create frequency congestion issues
  - Operating with the transponder on is sufficient to ensure aircraft are visible to surface surveillance systems

Pilot Reporting

Forum	Reporting Requirement	Notes	Web Address
NTSB	**Mandatory** – used for safety monitoring	**Reporting Criteria:** • Operating under IFR and the RA was necessary to avert "substantial risk of collision" • RA occurred in Class A airspace	www.ntsb.gov
FAA TCAS Program Office	Voluntary – used for system development and performance monitoring	Pilot and Controller reports	www.tcasreport.com
Aviation Safety Reporting System (ASRS)	Voluntary – summaries available on web	Compilation of safety-related issues in aviation	asrs.arc.nasa.gov
Aviation Safety Action Program (ASAP)	Voluntary - protected	Shared safety reporting system	Report via company-specific process

TCAS Monitoring and Performance Assessment

TCAS Operational Performance Assessment (TOPA)



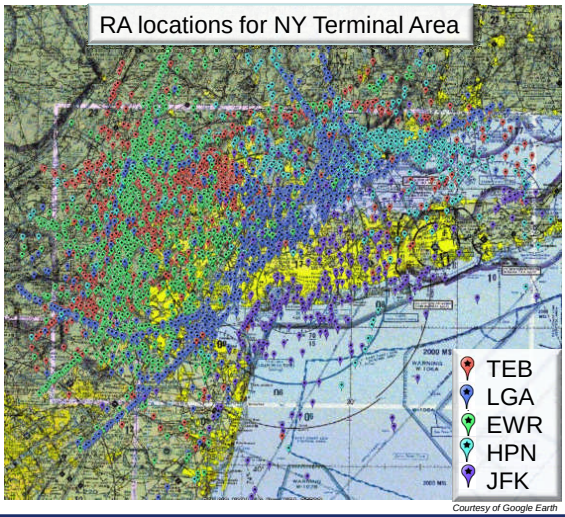
TOPA: Implemented by FAA to Characterize and Assess TCAS operational performance in U.S. National Airspace System

GOAL: Provide empirical data to support recommendations for current and future collision avoidance systems

- MIT Lincoln Laboratory processes and maintains de-identified data
  - -21 TOPA monitoring locations (map)
  - -135,000+ RAs in database
  - - ***Privacy is protected !!!!***
- Analyses reported to ATC and operational communities
  - - *Ongoing international harmonization*

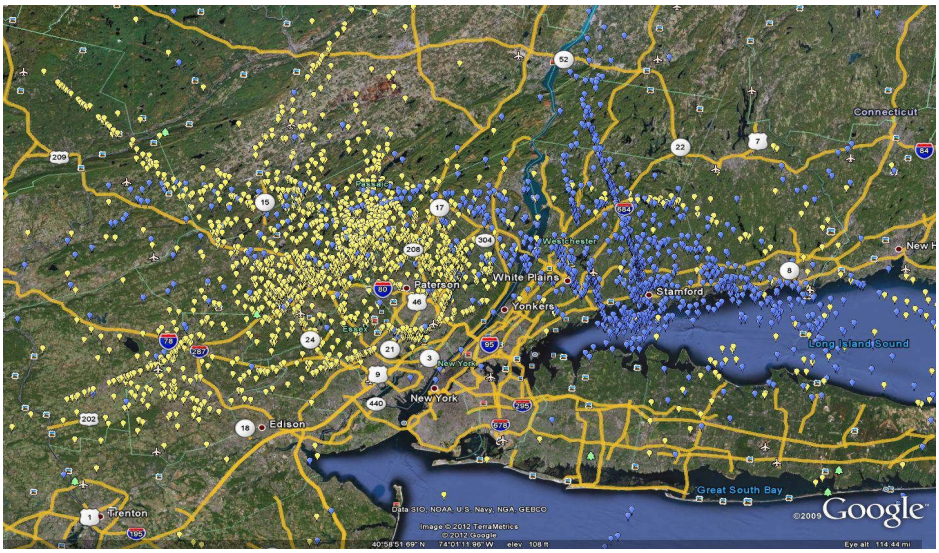
TCAS RAs — New York Metroplex

- RA locations correlate with arrival/departure routings
- TCAS RA frequency generally varies in relationship to airport-specific routings and proximity to VFR traffic and Class E airspace

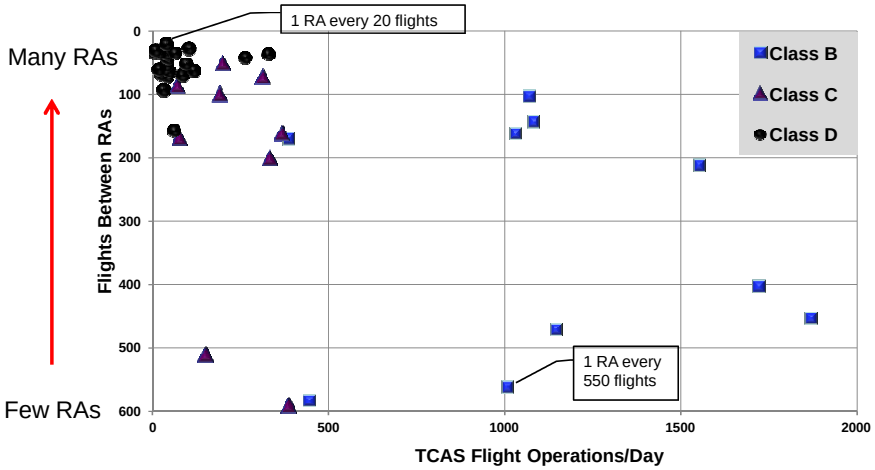


Courtesy of Google Earth

TCAS RAs — TEB & HPN

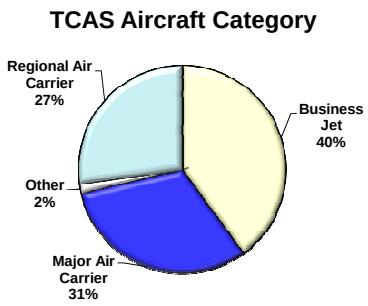


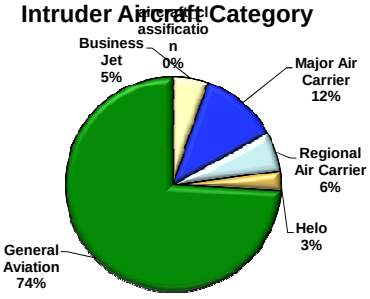
RA Rates by Airport



RAs are most common operating at Class D airports
~ 4 times more frequent than at Class B airports

Aircraft in RA Encounters

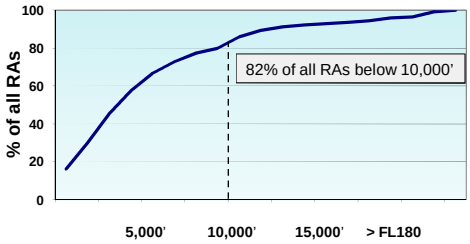




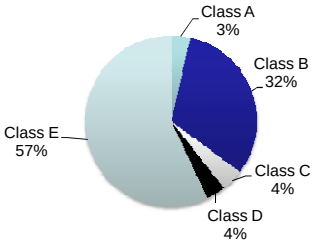
Business Jet category aircraft receive disproportionate share of RAs due to more frequent operations near GA aircraft outside Class B airspace

Why RA Frequencies Vary ?

Altitude



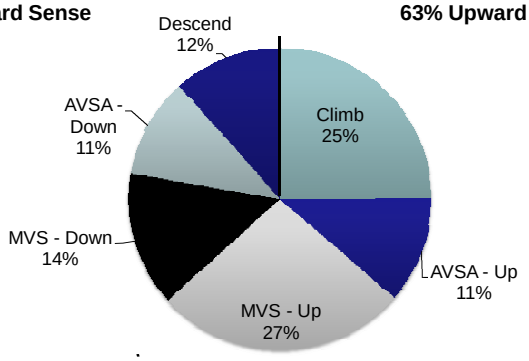
Airspace



- RAs often occur when TCAS-equipped IFR traffic interact with VFR traffic
  - Lower RA rates under IFR-only operations demonstrate benefit of ATC separation
- Most RAs occur at low altitude in Class E airspace due to the increased interaction with traffic operating under VFR
- RA rates show seasonal and weather-related variations in certain locations due to fluctuations in VFR traffic

RA Types (v7.0)

37% Downward Sense **63% Upward Sense**



- Most RAs are MVS (Monitor Vertical Speed) or AVSA (Adjust Vertical Speed Adjust) and require minimal pilot response
- Only 37% of RAs are Climb/Descend which require 1,500 fpm vertical rate

Wrap-Up

On-going CAS Efforts

- **FAA**
  - TOPA program identifies potential issues for current TCAS system (TCAS Program Office)
  - Regulatory and information guidance is being updated to reflect changes associated with TCAS v7.1 (Flight Standards and Aircraft Certification)
  - Sponsoring human factors research on use of existing TCAS system
  - Automated RAs (A380, A350, retrofit for Airbus family)
- **Standards Development (RTCA / EUROCAE)**
  - Updating standards for Hybrid Surveillance (limited use of ADS-B data)
  - Examining issues with existing TCAS that may improve performance in the short term
  - Standards development for ACAS X
- **Safety Activities (NTSB, Civil Aviation Safety Team [CAST])**
  - Identifying operational impact of TCAS alerting and performance

ACAS X

- **Objective** – Address current TCAS II limitations by leveraging the technologies of ADS-B for the next generation of collision-avoidance systems (addressing only vertical solutions)
- **ACAS X Versions**
  - **X** Term for overall program
  - **Xa** Active surveillance system + new threat logic
  - **Xo** Optimized program (for specific applications)
  - **Xp** Passive ADS-B reception + threat logic >>> surveillance
  - **Xu** UAS (Unmanned Aerial System)
- **Status** – Ongoing development with MIT Lincoln Labs, MITRE, Johns Hopkins Applied Physics Lab, FAA Atlantic City Technical Center with flight demonstration proposed for FY2013

Review

- **TCAS** is a mature system proven to be effective in mitigating the risk of mid-air collision with **transponder-equipped aircraft**
- Most **RAs** occur at **lower altitudes** in Class E airspace and involve VFR or GA intruders
  - Most RAs arise from interaction between ATC separation standards and TCAS alerting criteria (i.e., 500' IFR/VFR separation, 1,000' Level-Off geometries)
- **Pilot response** is a key component of the TCAS system
  - Data indicate pilots often do not achieve vertical rate targets for Climb/Descend RAs
  - While non-response is within FAA guidance when the intruder has been visually acquired, non-response is a common factor in low vertical miss distance encounters
  - *Never maneuver opposite to a TCAS RA*
- **Pilot reporting** of RAs to NTSB is ***mandatory**** in the U.S.
  - To an aircraft operating in Class A airspace . . . *or*
  - On an IFR flight plan to avert a *substantial risk of collision* between two or more aircraft

* Effective March 8, 2010

TCAS Resources

Operator	Content	Web Address
TCAS Program	• Pilot and controller reports • Link to Introduction to TCAS booklet • Links to other TCAS websites	www.tcasreport.com
EUROCONTROL	• Training material • General information • Research library • ACAS bulletins	http://www.eurocontrol.int/msa/public/standard_page/ACAS_Startpage.html
FAA Regulatory Guidance	FAA Advisory Circular 120-55C and AC 120-151A	http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/
NBAA	Many links to TCAS-related material	www.nbaa.org

Questions ?

Back Up Slides

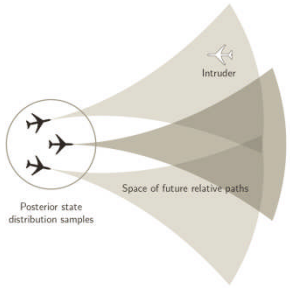
Traffic Alert and Collision Avoidance System (TCAS)

- **TCAS II* is intended to reduce mid-air collision risk**
  - Provides traffic information and alerting to the flight deck
  - Independent of Air Traffic Control (ATC)
- **TCAS II is mandated in the U.S. for commercial, turbine-powered, transport aircraft (30+ passenger seats or > 33,000 lbs MTOW)**
  - Other aircraft such as business jets may voluntarily equip
  - Smaller aircraft may use TCAS I which provides traffic information but does not issue vertical maneuver guidance
- **This briefing provides information to pilots about:**
  - TCAS operational concept, how it works, and the information and guidance it provides to the flight deck
  - Summary of TCAS experiences in the U.S. National Airspace System (NAS)
  - Recommended pilot actions and "Hot Topics"

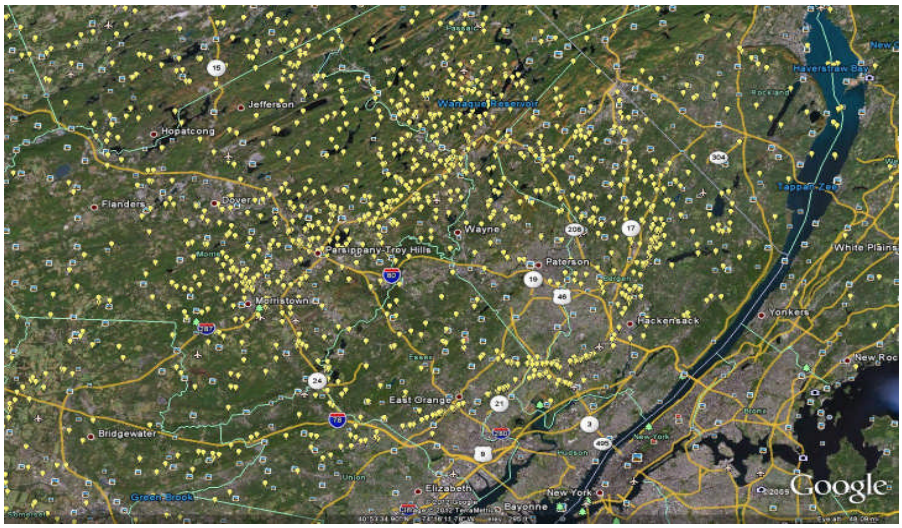
*TCAS II will be referred to as "TCAS" for the remainder of this briefing

Future Collision Avoidance

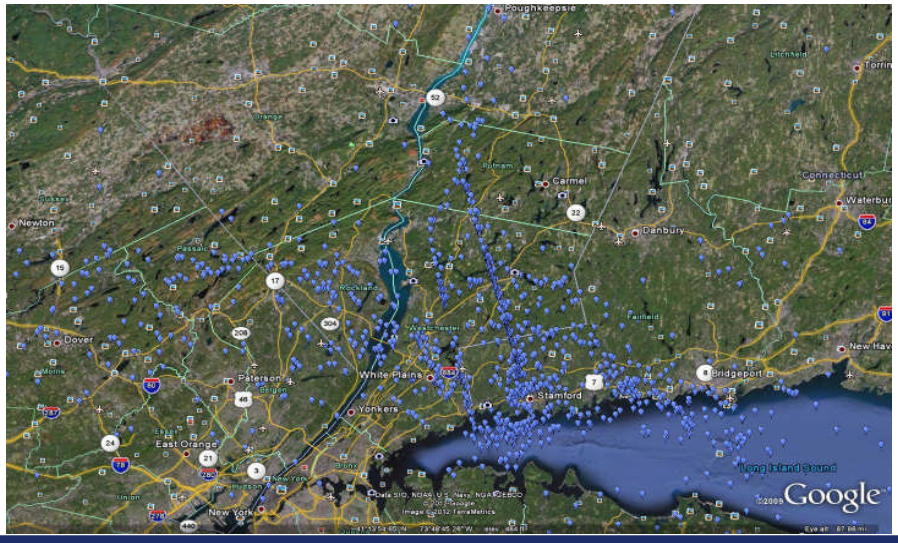
- Improved future collision avoidance system may be required to facilitate NextGen procedures and applications
- Standards development is underway to improve future collision systems
  - New collision avoidance logic – ACAS X
  - Use of ADS-B information
  - Updating system requirements for future airspace
  - Improved surveillance and tracking algorithms
  - Active and passive surveillance versions



TCAS RAs — TEB



TCAS RAs — HPN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