

National Aeronautics and Space Administration



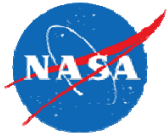
Sense and Avoid Concept of Integration for UAS Operations in the NAS

Separation Assurance/Sense and Avoid Interoperability Subproject

Presented by: Jim Chamberlain
NASA Langley Research Center

NASA UAS Integration in the NAS
Annual Meeting
July 31-August 1, 2012
Mountain View, CA



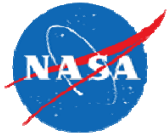


Presentation Outline



- Sense and Avoid Background and Design Questions
- “Well Clear” Encounters
- Threat Declaration Times
- Trajectory Change Guidance
- Summary

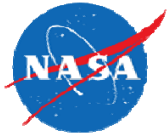
Reference: Consiglio M., Chamberlain J., Munoz C., and Hoffler K. Concept of Integration for UAS Operations in the NAS. 28th International Congress of the Aeronautical Sciences, Brisbane, Australia, 23-28 September 2012.



The Sense and Avoid (SAA) Challenge for UAS



- Pilots are required to see and avoid other aircraft
 - 14CFR 91.111 (a) No person may operate an aircraft **so close to another aircraft as to create a collision hazard.**
 - 14CFR 91.113 (b) *General.* When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, **vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.** When a rule of this section gives another aircraft the right-of-way, the pilot shall give way to that aircraft and **may not pass over, under, or ahead of it unless well clear.**
- Sense and Avoid (SAA) was defined by the FAA sponsored SAA for UAS Workshop Final Report published in October 9, 2009 as “the combination of UAS Self-Separation (SS) plus Collision Avoidance (CA) as a means of compliance with 14CFR Part 91, § 91.111 and § 91.113”
- SAA-equipped UAS should seamlessly interoperate with other aircraft, air traffic services and existing collision avoidance technologies



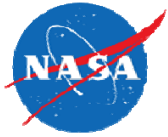
Self Separation and Collision Avoidance



From the SAA Workshop Final Report:*

- Self Separation (SS) Function
 - SS is “essential” and “could be the only function”
 - Intended as a means to remain “well clear”
 - “Normal/operational, non obtrusive maneuvers”
 - Maneuvers made early enough to avoid CA activation
- Collision Avoidance (CA) Function
 - CA engages “when all other modes of separation fail”
 - Intended as a means to avoid Near Mid-Air Collisions (NMACs)
 - CA maneuvers made “within a relatively short time horizon before closest point of approach [CPA]”

* Sense and Avoid (SAA) for Unmanned Aircraft Systems (UAS). Prepared by: FAA Sponsored Sense and Avoid Workshop, October 9, 2009.

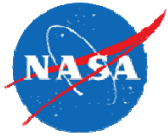


Design Questions for SAA Implementations

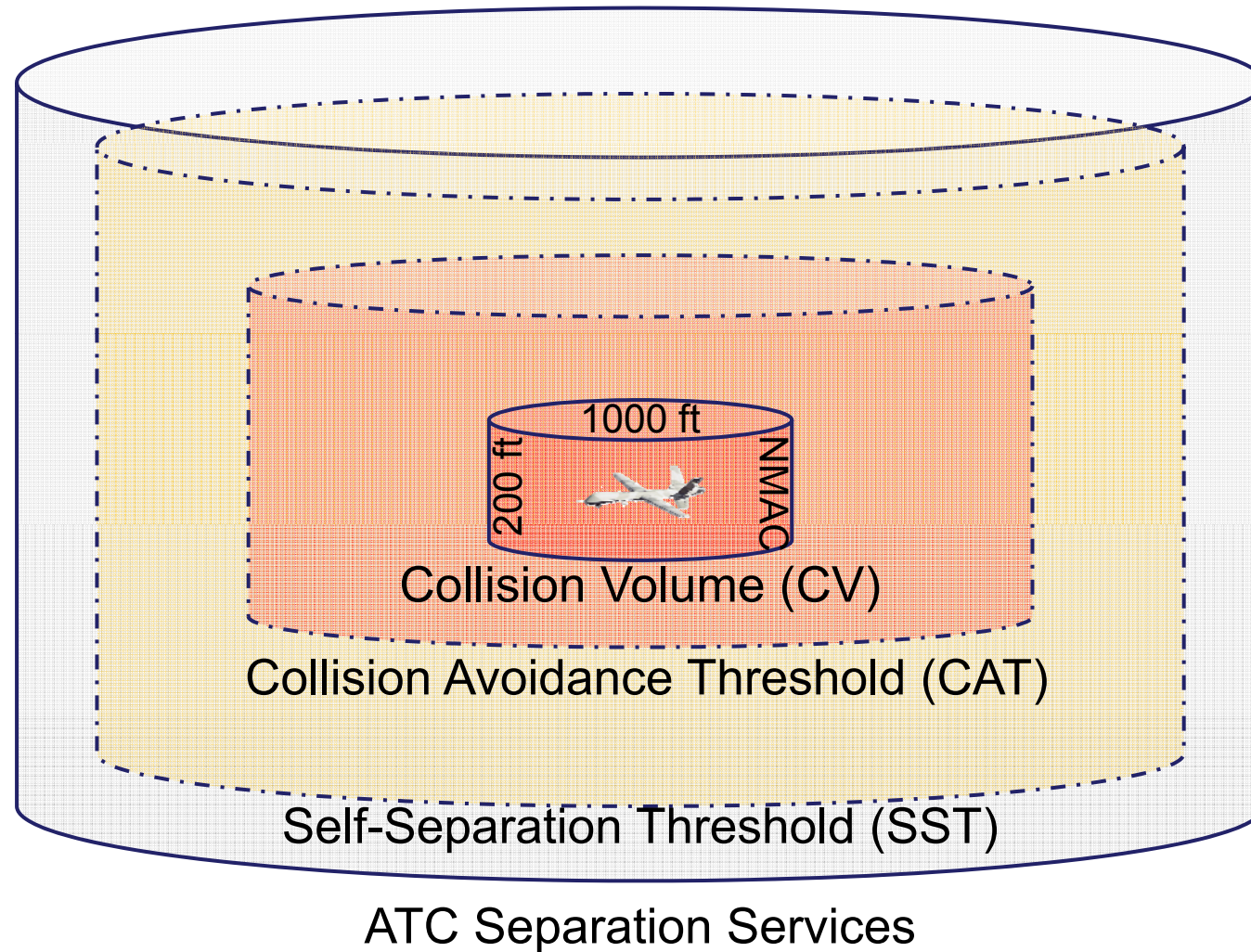


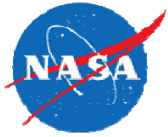
- SAA concepts and implementations must address at least three questions:
 1. What Ownship trajectories, either current or planned, may need to be changed to avoid a future loss of well clear separation (and what is appropriately “well clear”)?
 2. When should such a possible change be declared to the pilot?
 3. What trajectory change guidance is appropriate?

Answers to these three questions will inform the design space for SAA implementations



CV, CAT, SST and “Well Clear”

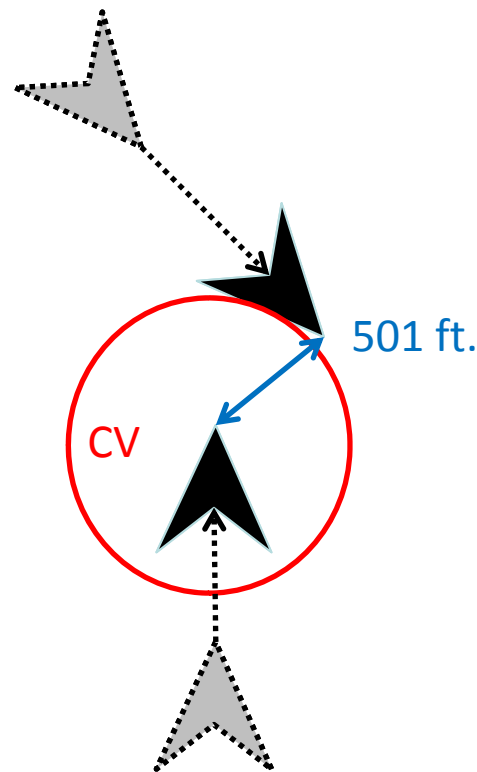




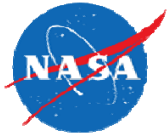
No NMAC But Not Well Clear!



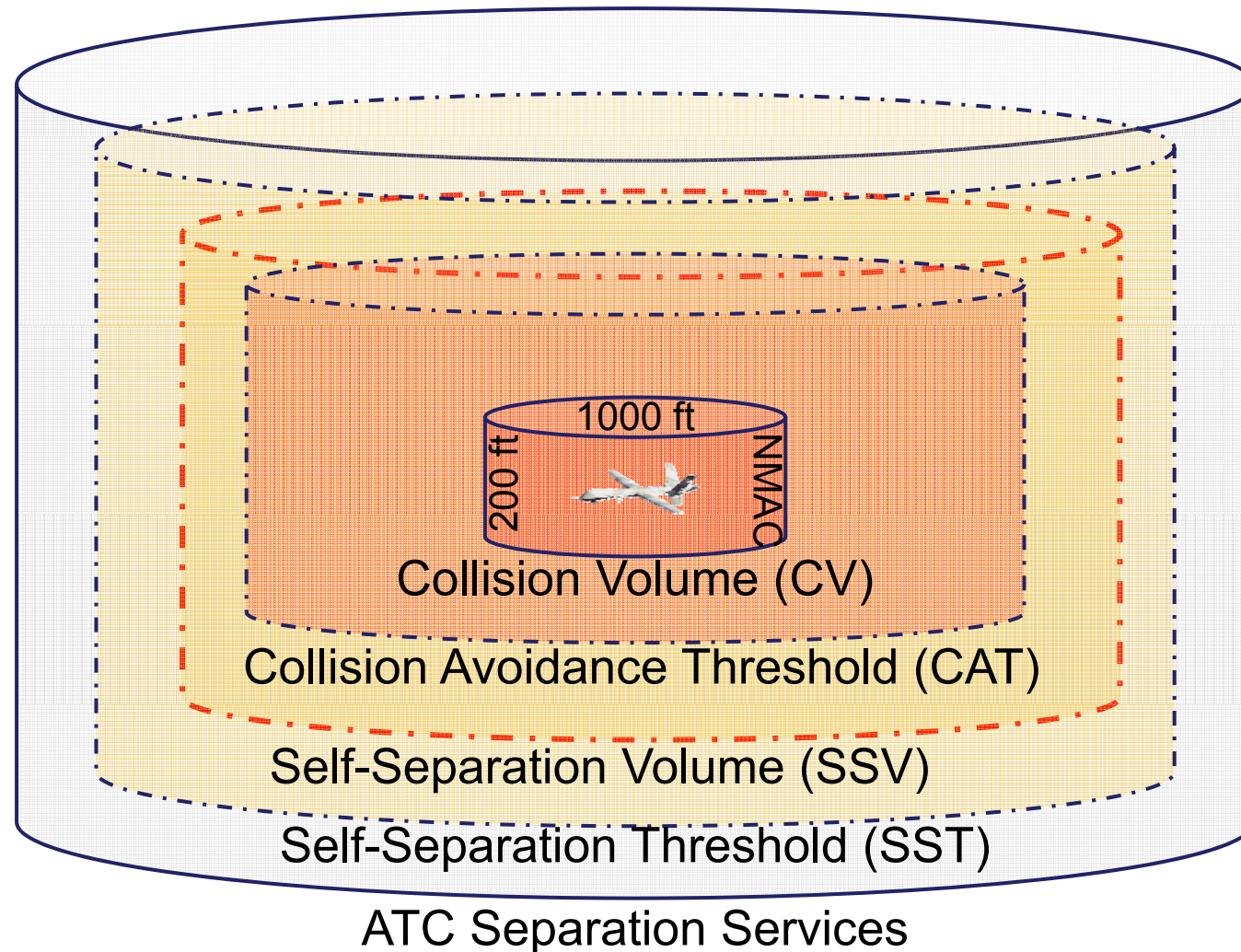
- Assume a hypothetical CA function with perfect surveillance data (i.e., $CAT = CV$ for this encounter):

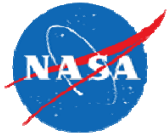


- Actual CA implementations (TCAS II) have protection volumes that are larger than the CV and independent of CAT times



CV, CAT, SSV, SST and “Well Clear”



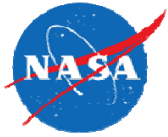


Clear of SSV = Well Clear



- SSV size should be large enough to avoid:
 - Corrective RAs for TCAS-equipped intruders
 - Traffic alert issuances by controllers
 - Undue concern for proximate see-and-avoid pilots
- SSV size should be small enough to avoid disruptions to traffic flow
- SSV size should vary appropriately with operational area (airport vicinity, en route, etc.)

Determination of minimum and maximum operationally acceptable SSV sizes will inform the design space for required SAA surveillance accuracy



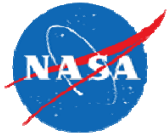
TCAS II Interoperability



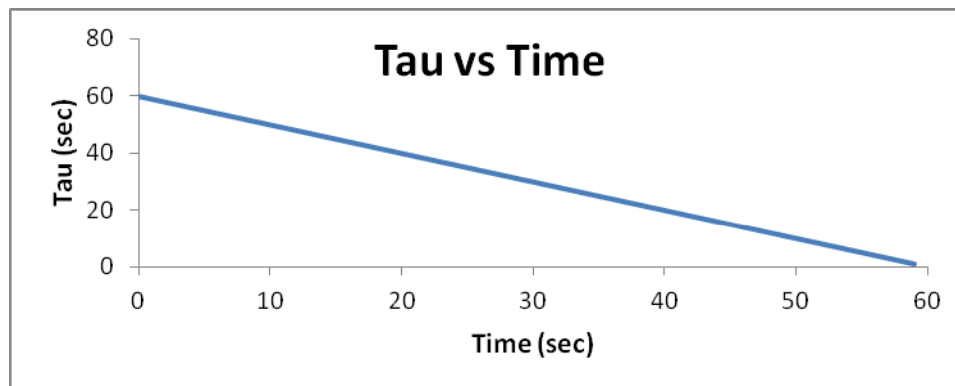
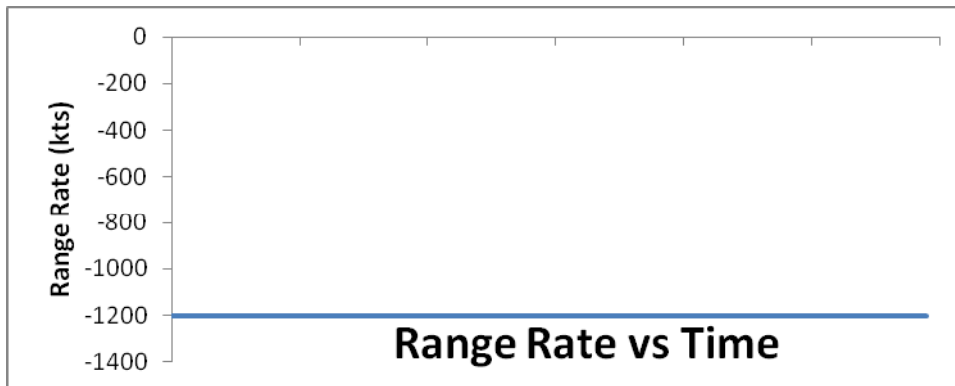
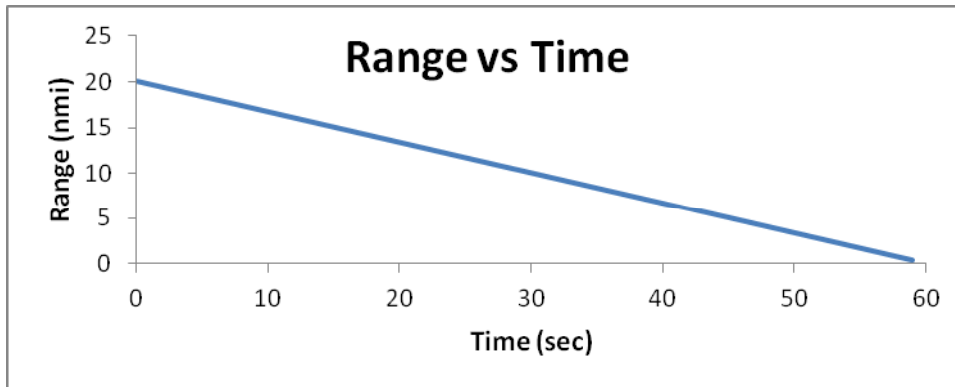
- TCAS = Traffic Alert and Collision Avoidance System
 - Designed for collision avoidance between cooperative (i.e., transponder-equipped) aircraft
 - TCAS II is mandated in the U.S. for aircraft with >30 seats or >33,000 lbs.
 - TCAS II provides Resolution Advisories (RAs) – escape maneuver guidance in the vertical plane – for intruders that are collision threats
 - Corrective RAs require active evasive maneuvers and are disruptive to pilots and ATC. SAA-equipped UAS should avoid causing them.
- Understanding TCAS mechanisms will inform minimum SSV sizes
- The foundation (but not the whole story) of TCAS protected airspace sizes (and also alert times) is the concept of tau (τ):

$$\tau = -r/\dot{r}$$

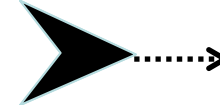
- where r is intruder range and $\dot{r}$ is intruder range rate



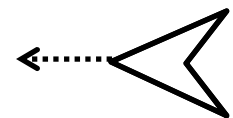
Tau = Time to CPA for Collision Courses



Ownship
600 kts



Intruder
600 kts



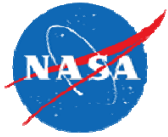
Collision course, 1200 kts
closure rate, head-on
from 20 nmi

Range decreases linearly,
20 nmi $\rightarrow$ 0

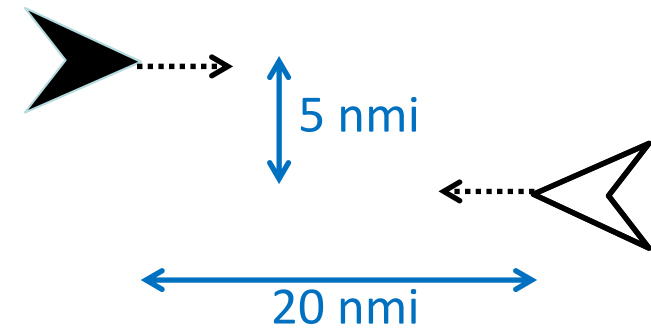
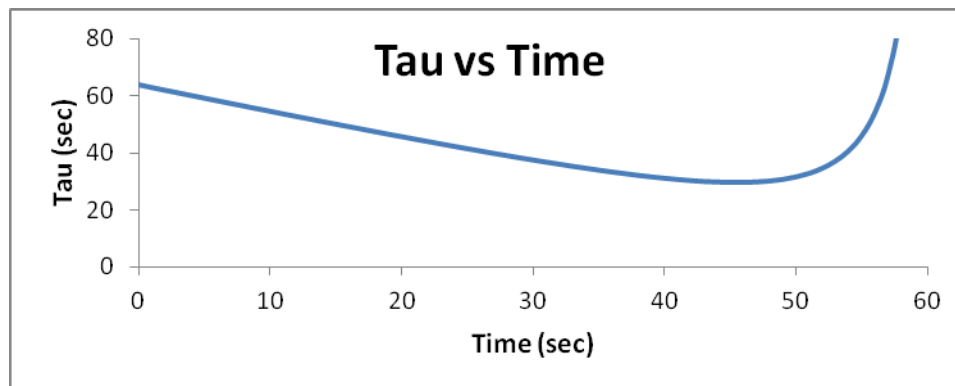
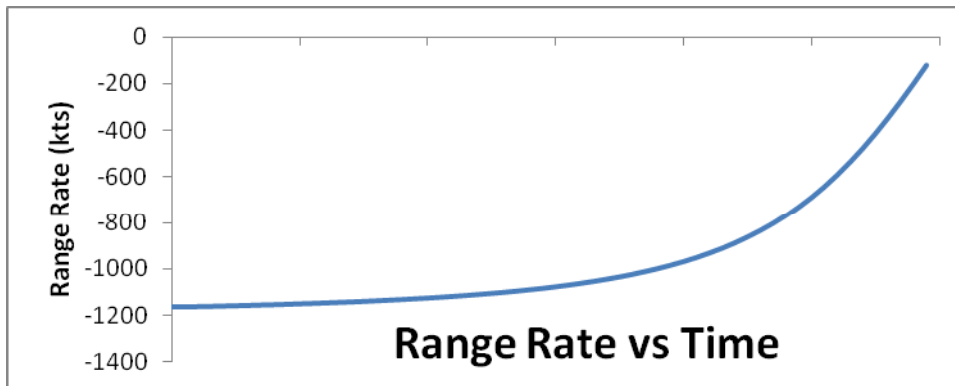
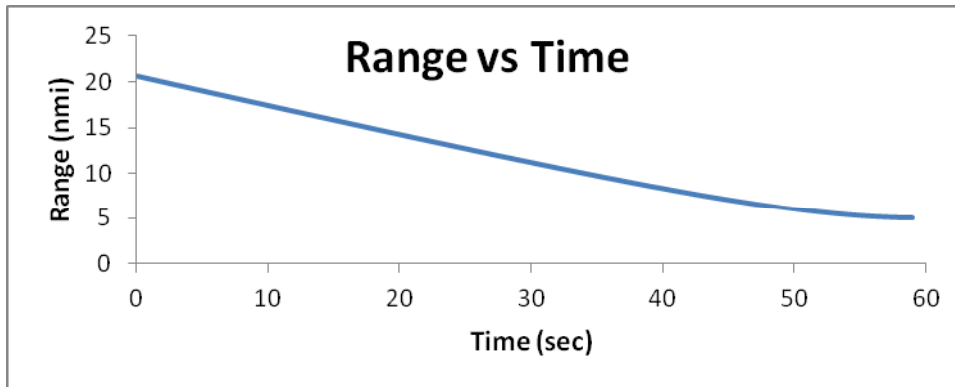
Range rate is constant at
-1200 kts (-0.33 nmi/sec)

Tau decreases linearly,
60 sec $\rightarrow$ (0)

Tau = Time to Collision



Tau approximates time to CPA for “Fly-by”

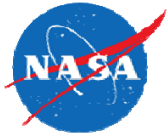


Same encounter but with 5 nmi offset

Range, range rate, tau are no longer linear

$\tau \neq$ Time to CPA, but...

Choice of tau threshold value affects size of protected airspace

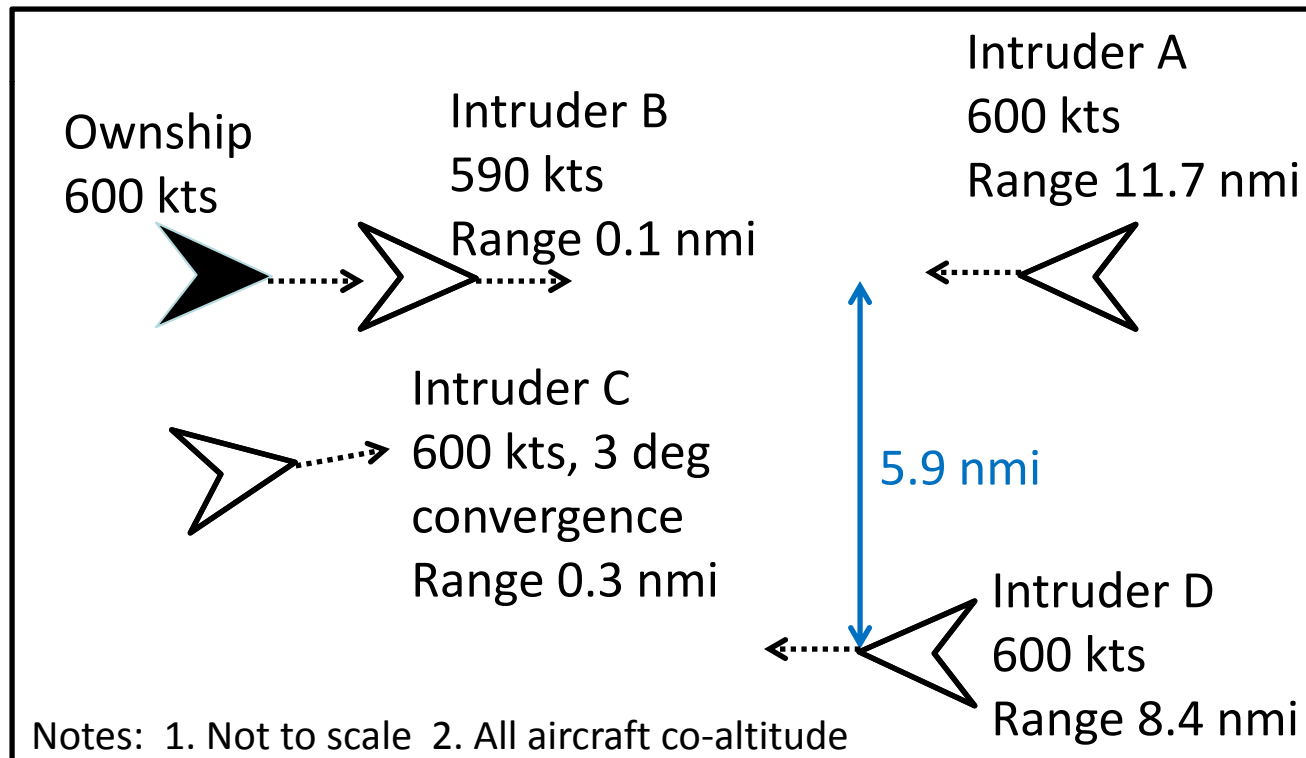


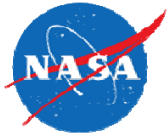
Shortcomings of “True Tau”



- Low closure rates and small distances (Intruders B and C)
- High closure rates with sufficient miss distances (Intruder D)

All Intruders at Tau = 35 seconds:





Fixes for “True Tau”

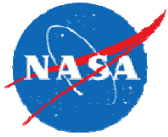


- Low closure rate problem is addressed by using a “modified tau” (τ_{mod}):

$$\tau_{mod} = -(r - (DMOD^2/r))/\dot{r} \quad (r \geq DMOD)$$

$$\tau_{mod} = 0 \quad (r < DMOD)$$

- $DMOD$ is a distance modification value that varies with altitude. It provides minimum-distance and intruder-acceleration protection.
- High closure rate problem is addressed with a “horizontal miss distance” (HMD) filter
 - Uses higher derivatives of range to detect safe HMD
 - HMD values are approximately the same as $DMOD$ values



DMOD/HMD Implications for SSV Size

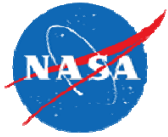


- Minimum SSV size should be the larger of **DMOD** or HMD for interoperability with TCAS

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

- Comparisons of these minimum SSV sizes with controller/pilot assessments will/can be further informed with HITL studies

Source of table: Introduction to TCAS Version 7.1. Prepared by U.S. Department of Transportation Federal Aviation Administration. February 28, 2011.

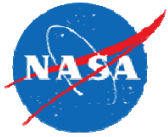


SAA Threat Declaration Times

- SAA's threat declaration times should be small enough to avoid nuisance queries and large enough to allow
 - Query/negotiation with controller (if receiving services)
 - Normal/operational maneuvers as required
 - Avoidance of TCAS corrective RAs

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
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10000 – 20000	6	45	30	1.00	0.80	850	600	400
20000 – 42000	7	48	35	1.30	1.10	850	700	600
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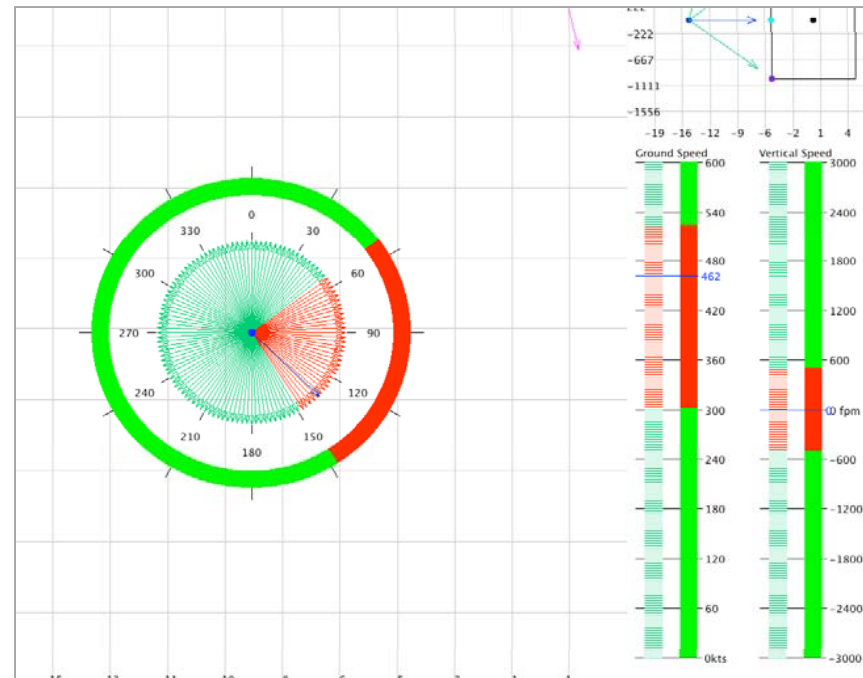
Determination of minimum and maximum operationally acceptable declaration times will inform the design space for required SAA surveillance range

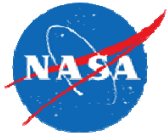


SAA Trajectory Change Guidance



- Concept is that the UAS pilot is Pilot in Command and uses SAA to restore “intelligent sight,” through display of information elements and decision aids, to enable selection of appropriate operational maneuvers
- One approach is the use of “maneuver bands” to provide
 - Declaration,
 - Rate-of-change, and
 - Planning information
- Late detection considerations
 - Maneuver first, then talk to ATC
 - Maneuver more aggressively
 - Maneuver compatibly with a TCAS-equipped intruder
- Lost Link: Lots of open research issues

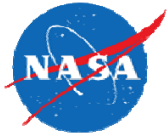




Summary



- Three questions identified for SAA implementations:
 - What trajectories may need changes to avoid loss of well clear?
 - When should such possible changes be declared?
 - What trajectory change guidance is appropriate?
- Well Clear concept expanded to include a Self Separation Volume (SSV)
 - Minimum operational SSV size for TCAS interoperability determined
- Approach identified to inform SAA design space for SSV sizes and declaration time ranges
 - Knowledge of design space will inform surveillance requirements
- Approach identified to provide trajectory change guidance to UAS pilots



SAA Concept of Integration

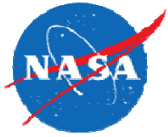


Thank You for Your Attention

Questions?

Jim Chamberlain

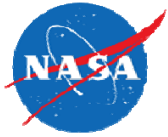
James.P.Chamberlain@nasa.gov



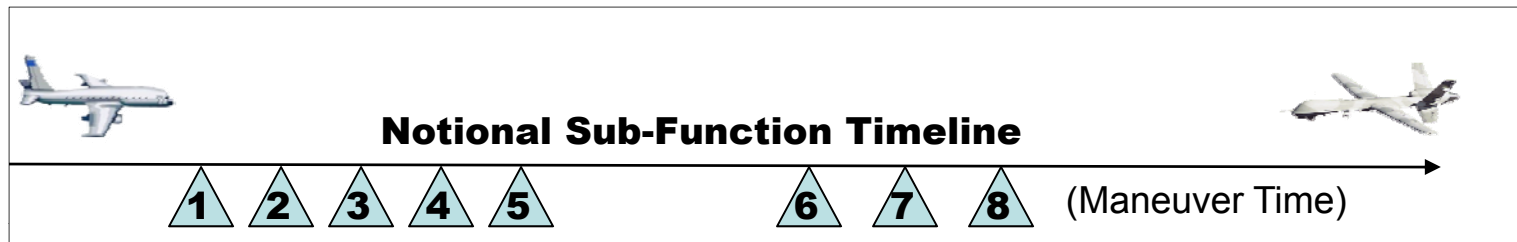
SAA Concept of Integration



Back up slides



SAA Sub-Functions and Allocation



1. **Detect** intruder
2. **Track** intruder (position & velocity)
3. **Evaluate** (assess collision or self-separation risk)
4. **Prioritize** intruder risks
5. **Declare** that some action may be required
6. **Determine** what action(s), if any, to take
7. **Command** determined action, if any
8. **Execute** commanded action

These Sub-Functions performed by sensors and algorithms, with traffic information elements/decision aids displayed to the GCS pilot

GCS pilot evaluates info elements, queries or responds to ATC as necessary, commands action if needed

Action executed by UA systems

If late detection leaves insufficient time for ATC coordination and a maneuver is necessary for safe separation, the pilot may maneuver first and then inform ATC (same as a see-and-avoid pilot)

If lost link is detected by the UA, Sub-Functions 6 & 7 **may** be autonomously performed, at the CA threshold or possibly earlier (TBD)