The Viability of See-and-Avoid for Midair Collision Avoidance for UAM

Richard Mogford, Walter Johnson

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Introduction

Outline

- Motivation
- Definition of see-and-avoid (SAA)
- Review of SAA research
- Review of multi-object tracking (MOT) and other relevant research
- Traffic density considerations
- How to improve SAA
- Conclusions

Motivation

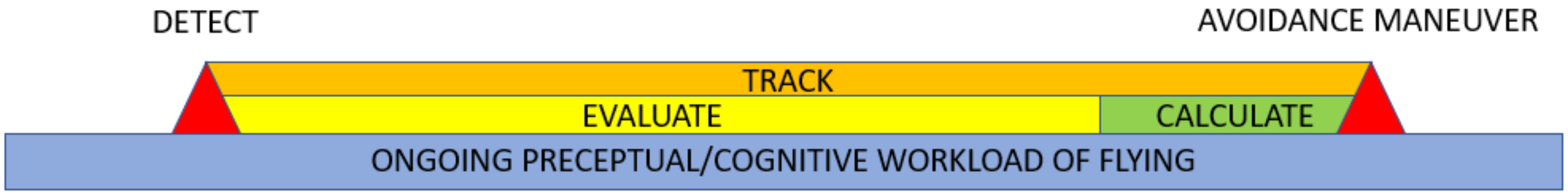
- Initial UAM flights will use Visual Flight Rules (VFR) in Visual Meteorological Conditions
- The pilot may be expected to perform the separation function by visually detecting and avoiding other aircraft using SAA
- Will be high public expectations for the safety of commercial UAM flights versus general aviation (GA) operation
- Previous research shows that GA flights using SAA have an average accident rate of 7.2 mid-air collisions per year
- This presentation reviews SAA-related research and how it applies to UAM

Definition of SAA

Definition: The in-flight detection and avoidance of other aircraft using the unaided perceptual and cognitive abilities of the pilot.

Stages of SAA

- Detect (see)
- Track
- Evaluate collision potential
- Calculate avoidance maneuver
- Execute avoidance maneuver



Review of SAA Research

Closure Rate

- Graham & Orr (1970) reported that SAA was effective at low closing speeds, but not at higher closing speeds
- Between 101 and 199 knots closing speed, SAA prevents 97% of collisions (modeling data)
- At closing speeds greater than 400 knots, SAA prevents only 47% of collisions
- A pilot warning indicator could reduce collisions by a factor of 120 to 600 (depending upon closing speed)

> “Because of its many limitations/the see-and-avoid concept should not be expected to fulfil a significant role in future air traffic systems." (Hobbs, 1991)

Effects of Closure Speed on SAA

TABLE II. PROBABILITY OPTIMAL OBSERVER OR REAL PILOT CAN SEE AND AVOID A RANDOM CONVERGING AIRCRAFT.

			Probability Can See and Avoid Aircraft		
Closure Speed (kn)	Seconds to Impact when Visual Angle = 0.2 °	See-and-Avoid Window of Opportunity Duration (s)	Optimal Observer Scanning All of Flight Time	Theoretical Pilot Scanning 2/3 of Flight Time	Theoretical Pilot Scanning 1/3 of Flight Time
100	68.1	55.6	1.000	1.000	0.723
200	34.1	21.6	0.907	0.605	0.302
300	22.7	10.2	0.487	0.324	0.162
400	17.0	4.5	0.276	0.184	0.092
500	13.6	1.1	0.150	0.100	0.050

“Although these are profoundly low probabilities, real-world probabilities are probably lower due to obstruction of aircraft from view, poor conspicuity, imperfect scanning, and inadequate avoidance maneuvering following detection.” (Morris, 2005)

Flight Evaluation

- Andrews (1991) did a study where 24 GA pilots flew cross-country in VFR conditions thinking they were participating in a workload study
- Another aircraft was planned to intercept them on a near-collision course during low workload conditions
- Three encounters per pilot
- Pilots were asked to call out any traffic sighted
- Noted that visual detection can be more difficult on extremely clear days due to reduced contrast

Pilots sighted the other aircraft 36 out of 64 encounters (56%). (Andrews, 1991)

Conspicuity

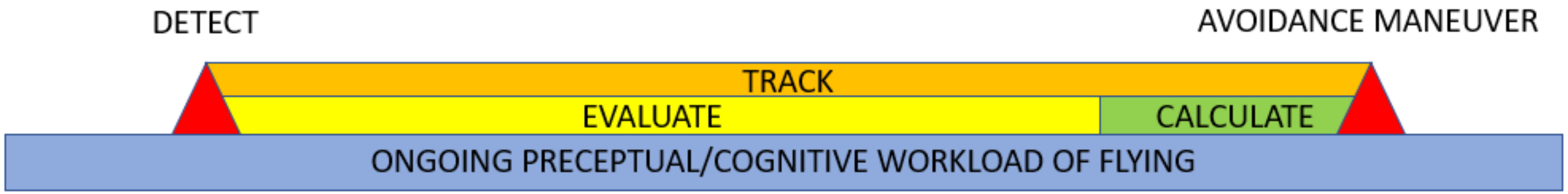
- The failure of SAA is mostly due to the failure to see as opposed to avoid
- Conspicuity of aircraft (paint color, etc.) does not have much effect on visual detection success
- Aircraft identification lights have little effect on target detection in the daytime (including strobe lights)

"Research on the ability of a pilot to see and avoid other aircraft has been conducted for over 50 years. The majority of this research has found a consistent inability on the part of a pilot to see other aircraft with a high degree of probability." (Williams & Gildea, 2014)

Other Relevant Research

Tracking

- There are perceptual/cognitive stages between “see” and “avoid”
- Once visually acquired, the pilot must track one or more possible threats
- Evaluate each threat for collision potential
- Calculate avoidance maneuver
- Change aircraft trajectory to avoid collision
- In parallel with flying tasks (aviate, navigate, communicate)



MOT Research

- Some laboratory studies found that up to four objects can be tracked simultaneously
  - No distractors or secondary tasks
- Performance is different across individuals (Tripathy, Narasimhan, & Barrett, 2007)
- Holcombe (2022) said, “The number that can be tracked is quite specific to the display arrangement, object spacing, and object speeds.”
- Can conclude that there are a limited number of objects that an observer can track
- Affected negatively by other tasks that require cognitive and perceptual resources

MOT Research

- In an experiment by Horowitz et al. (2007), subjects tracked objects with unique appearances (cartoon characters)
- At the end of each trial, the objects moved behind occluding objects
- About four objects could be tracked but for final location of a specific object, the results were more like two
- This could have implications for tracking possible aircraft threats

> “These results of multiple identity tracking experiments suggest that our ability to update the location of one of multiple objects of interest is much better than our ability to maintain knowledge of what that object is.”

Driving Research

- Not much aviation literature on the effect of distractors or secondary tasks on SAA
- Cell phone use results in a higher incidence of missed traffic signals, slower reactions to signals, and problems detecting changes in traffic
- SAA is part of aircraft operation and may be limited by other tasks (e.g., communicating, passenger requests, etc.)

> "These experimental studies converge with the 70-year literature on attention and establish that when attention is diverted to an activity unrelated to the safe operation of a motor vehicle, driving performance is impaired." (Strayer, 2015)

Improving SAA

Guided Visual Search

- Traffic Collision Avoidance System (TCAS) was used to guide pilot visual search (Andrews, 1989)
- One second of visual search using a TCAS advisory was as effective as eight seconds of search with no alert

TCAS advisories increased the effectiveness of visual search by a factor of eight.

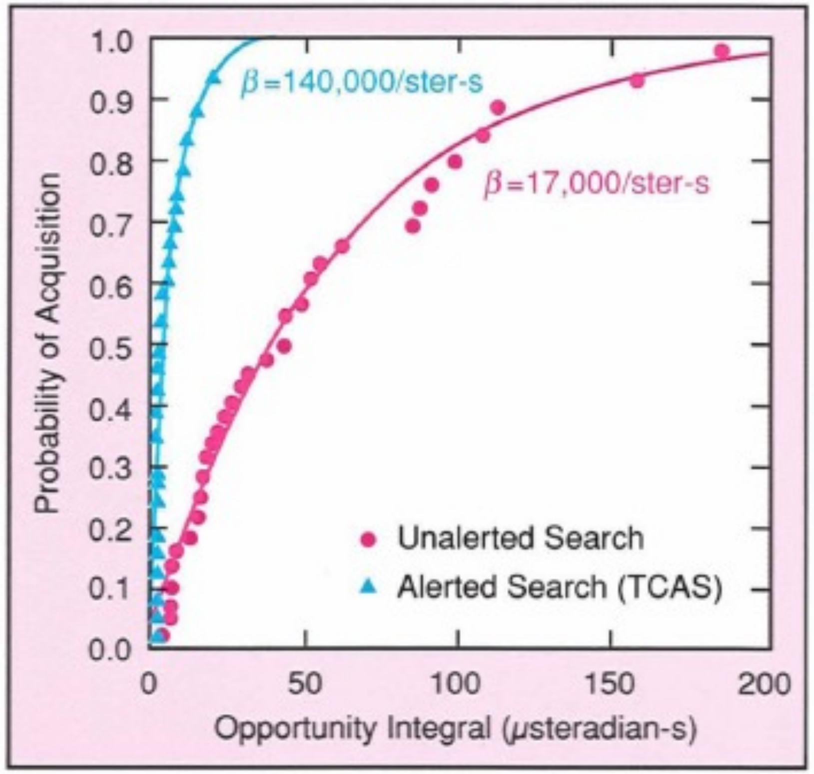


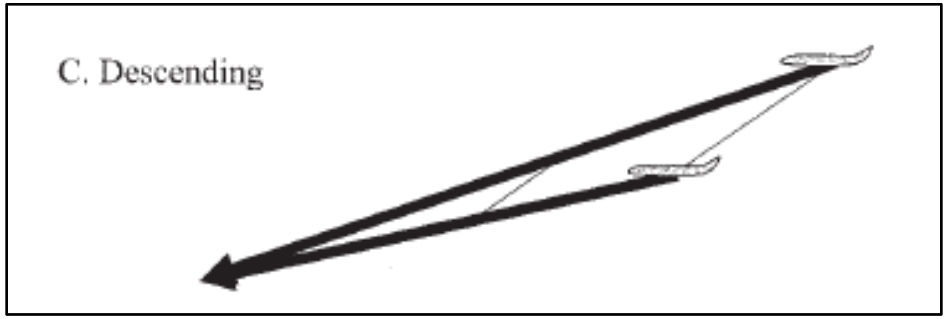
Fig. 3—Measured and modeled visual acquisition probabilities. The probability is defined in terms of the opportunity integral—a measure of the angular size of the visual target and the duration of the search.

Andrews (1989)

Traffic Organization

- Structured airspace such as tracks and corridors could reduce risk by increasing predictability
  - However, a large proportion of collisions involve head-to-tail configurations
- In uncontrolled airspace away from airports, there may be fewer aircraft to pose a risk to UAM flights

Morris, 2005



Morris, 2005

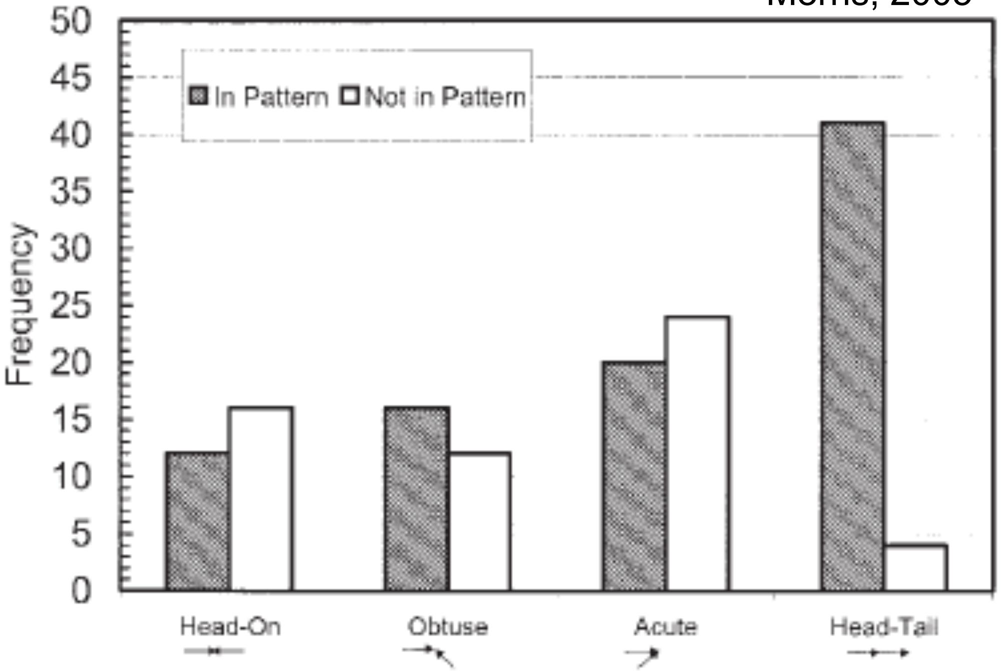
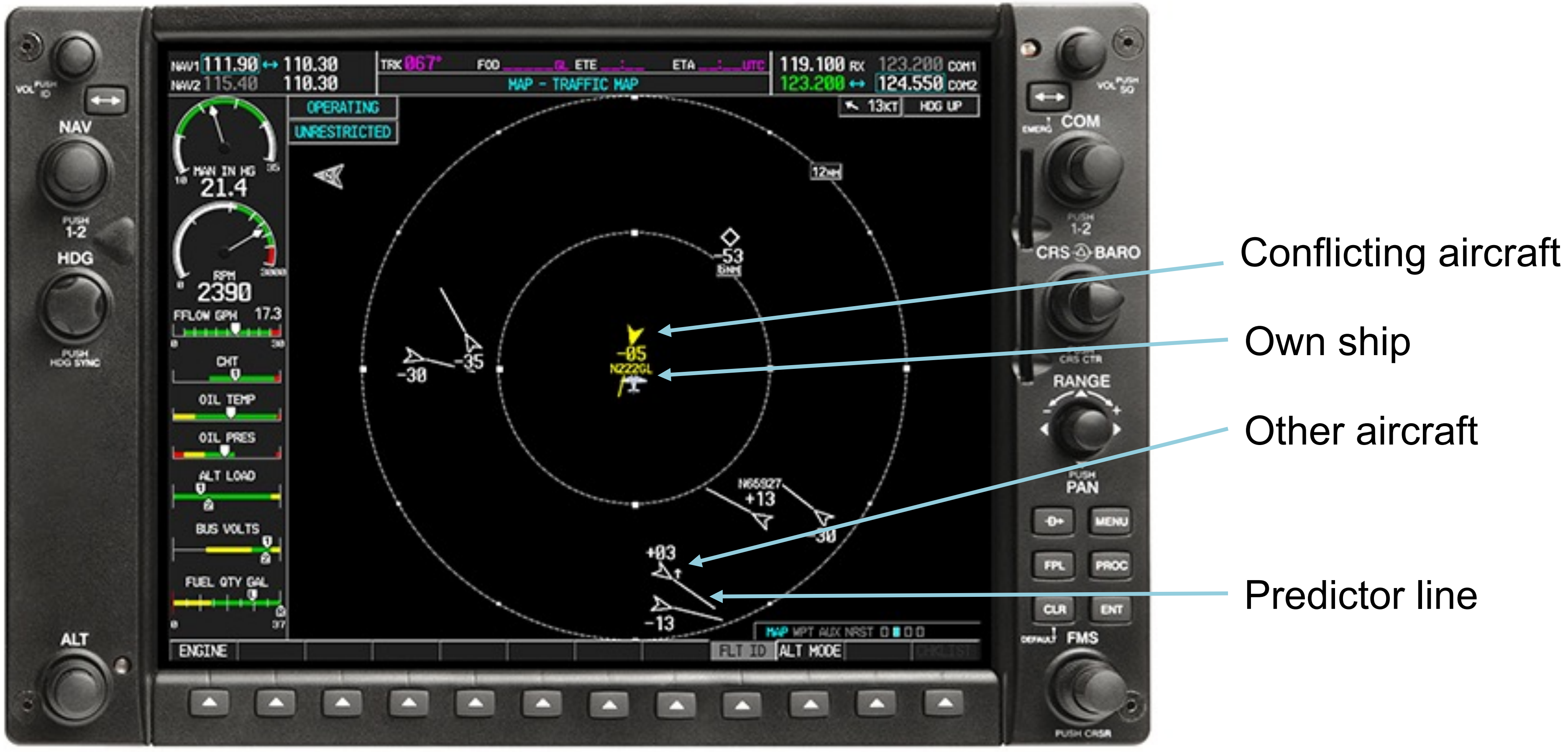


Fig. 2. U.S. civil aviation midair collisions by convergence angle, 1991–2000.

ADS-B

- ADS-B (in and out) could improve detection and tracking of other aircraft
- Could include intent sharing and conflict alert/resolution
- ADS-B is only required within Mode C veil (30 mile radius from airport)
- Outside of Class B airspace, ADS-B usage may be inconsistent
- SAA could be required

ADS-B Display



ADS-B Display

Conclusions

- From 2016 to 2021, 43 reports of GA midair collisions in the United States with 79 fatalities or 7.2 per collisions per year
- Unaided SAA is an insufficiently safe collision avoidance strategy for UAM
- Will become a limiting factor for scalability of UAM
- SAA can be enhanced using flight deck displays and airspace structure (e.g., corridors)
- Recommend that ADS-B based detect-and-avoid systems be made available on initial UAM aircraft