Potential of Detect and Avoid in the Flight Deck to Mitigate Collision Risk

NASA Langley RC

Victor Carreño

August 2021

Outline

- Regulations
- Collision Risk
- Detect and Avoid
- ADS-B
- DANTi prototype
- DAIDALUS
- Case study
- Summary and conclusion

Regulations

- **Title 14, Code of Federal Regulations, Part 91, Section 91.113 paragraph b (14 CFR 91.113 (b)) requires that pilots perform "see and avoid"**

(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.

- **In some types of operations, see and avoid is the only method to remain clear of other aircraft**

Collision Risk

- The 30th Joseph T. Nall Report has been released by the Aircraft Owners and Pilots Association (AOPA) Air Safety Institute (November 2020)
- This report contains GA (General Aviation) accident data for the years 2009 to 2018
- For the year 2018, there where 21 collisions of which 5 resulted in fatalities
- See and avoid alone is not always sufficient to remain well clear of other aircraft and avoid collisions

Detect and Avoid (DAA)

- **Detect and Avoid is the process of:**
  - **Determining the location and trajectory of a traffic aircraft**
  - **Determining whether the ownship trajectory and the traffic trajectory are in conflict**
  - **Calculating actions by the ownship to remain well clear of the traffic**
- **Well clear is not quantified in the regulations**
- **A definition of well clear has been formalized in RTCA Special Committee SC-228 for the purpose of developing and evaluating DAA strategies and methods**

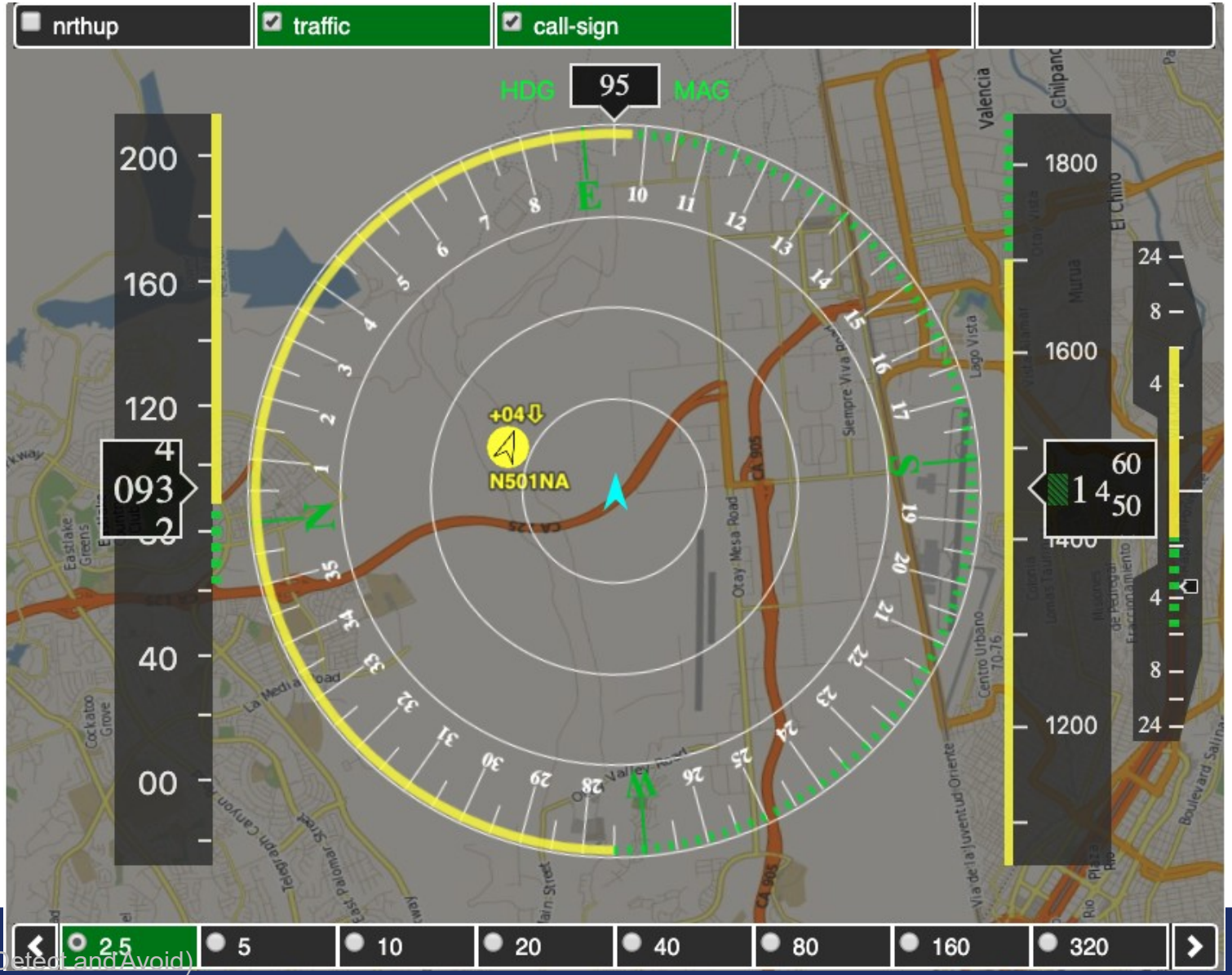
ADS-B (Automatic Dependent Surveillance-Broadcast)

- **ADS-B equipment on-board aircraft has been mandated in the US and many other countries. In the US, ADS-B is required in Class A, B, C airspace and Class E above 10,000 feet, and within 30 NM of a Class B airport.**
- **ADS-B equipment transmits an aircraft's position, velocity vector, identification, and other information every second.**
- **The FAA has also implemented the TIS-B (Traffic Information Service-Broadcast) service which broadcasts a combined representation of aircraft position derived from GPS and radar data**
- **An aircraft equipped with an ADS-B *receiver*, allows a pilot (with additional equipment, e.g. a tablet coupled to the ADS-B receiver and suitable application) to view traffic information of surrounding aircraft from the traffic aircraft's ADS-B or from the TIS-B service**

DANTi Concept

- **DANTi is a concept to enhance see and avoid with detect and avoid in the flight deck**
- **Using the ADS-B and TIS-B enabling capabilities, DANTi provides situational awareness, conflict detection, and resolution advisories and guidance**
- **DANTi uses the DAIDALUS algorithm, developed at NASA Langley, to detect conflicts and provide resolution guidance**

DANTi Prototype, EFB display



DAIDALUS

- **DAIDALUS is a Detect and Avoid (DAA) algorithm which conforms to *RTCA DO-365 Minimum Operational Performance Standards for Detect and Avoid***
- **It was developed at NASA Langley as part of RTCA Special Committee SC-228 for Unmanned Aircraft Systems**
- **DAIDALUS is configurable in terms of the Well Clear volume, look ahead time, tau, and other parameters**

DAIDALUS' Configuration

The configuration parameters for the protective volume and time parameters used in the case study and simulations are:

Horizontal threshold: 0.66 NM (1062 m)

Vertical threshold: 450 ft (137 m)

tau*: 35 seconds

Time to co-altitude: 0 seconds

Alerting time: 25 seconds

* tau is approximately the time to Closest Point of Approach

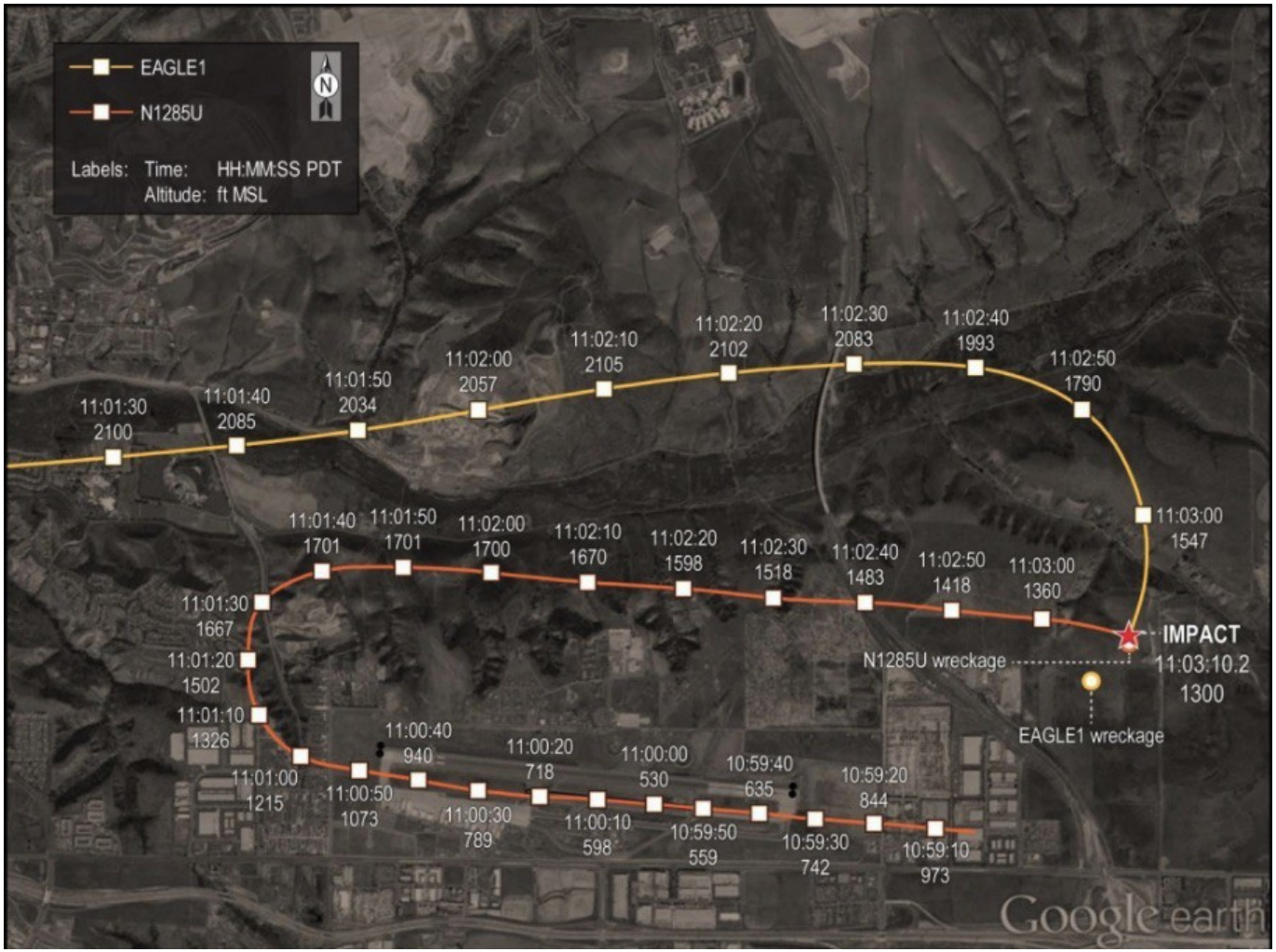
Case Study

- **The possible mitigation effects of Detect and Avoid in the flight deck is explored through the analysis of a mid-air collision accident**
- **The accident occurred on 16th of August 2015 over Brown field (KSDM), San Diego, Cal. (towered airport)**
- **Collision between a North American Rockwell Sabreliner (EAGLE 1) and a Cessna 172M (N1285U)**

Sabreliner

Cessna 172M

Radar Track of Aircraft



Case 1, C172 is Ownship

- The encounter is analyzed from the C172 perspective
- It is assumed that the C172 is equipped with the DANTi prototype
- The scenario is advanced without any evasive maneuver taken by either aircraft
- The objective is to observe how the alerting and guidance evolves as the encounter develops

- **At 11:02:40, 30 seconds before collision, the DANTi prototype shows the traffic aircraft 500 feet above the ownship and descending. Horizontal distance is 5,109 feet. No conflict or conflict alerts are issued.**
- **The speed tape shows a yellow and red bar indicating that increasing the ownship speed to 122-173 kts will induce a conflict**

- **At 11:02:44, 26 seconds before collision, as the traffic aircraft turns towards the ownship, a red band appear to the left of the ownship. The traffic is shown 400 feet above the ownship and descending. Horizontal distance is 4,994 feet.**
- **The bands indicate that increasing speed above 111 kts, or turning left to less than 083 heading will induce a conflict**

- **At 11:02:46, 24 seconds before collision, the traffic display shows a loss of well clear and escape maneuvers in green. The traffic is shown 400 feet above and descending. Horizontal is 4,869 feet.**
- **The guidance is to reduce speed to 78 knots, turn right to a 105 heading, or descend at 2,000 feet per minute**

- **At 11:02:59, 11 seconds before collision, the guidance shows a new escape maneuver to the left. The traffic is shown 200 feet above the ownship and descending. Horizontal distance is 3,029 feet.**
- **The guidance is to turn left to a 067 heading, right to a 186 heading, or reduce speed to 52 knots.**

- **Collision occurs at 11:03:10**

Case 2, Sabreliner is Ownship

- The encounter is analyzed from the Sabreliner perspective
- It is assumed that the Sabreliner is equipped with the DANTi prototype
- The scenario is advanced without any evasive maneuver taken by either aircraft
- The objective is to observe how the alerting and guidance evolves as the encounter develops

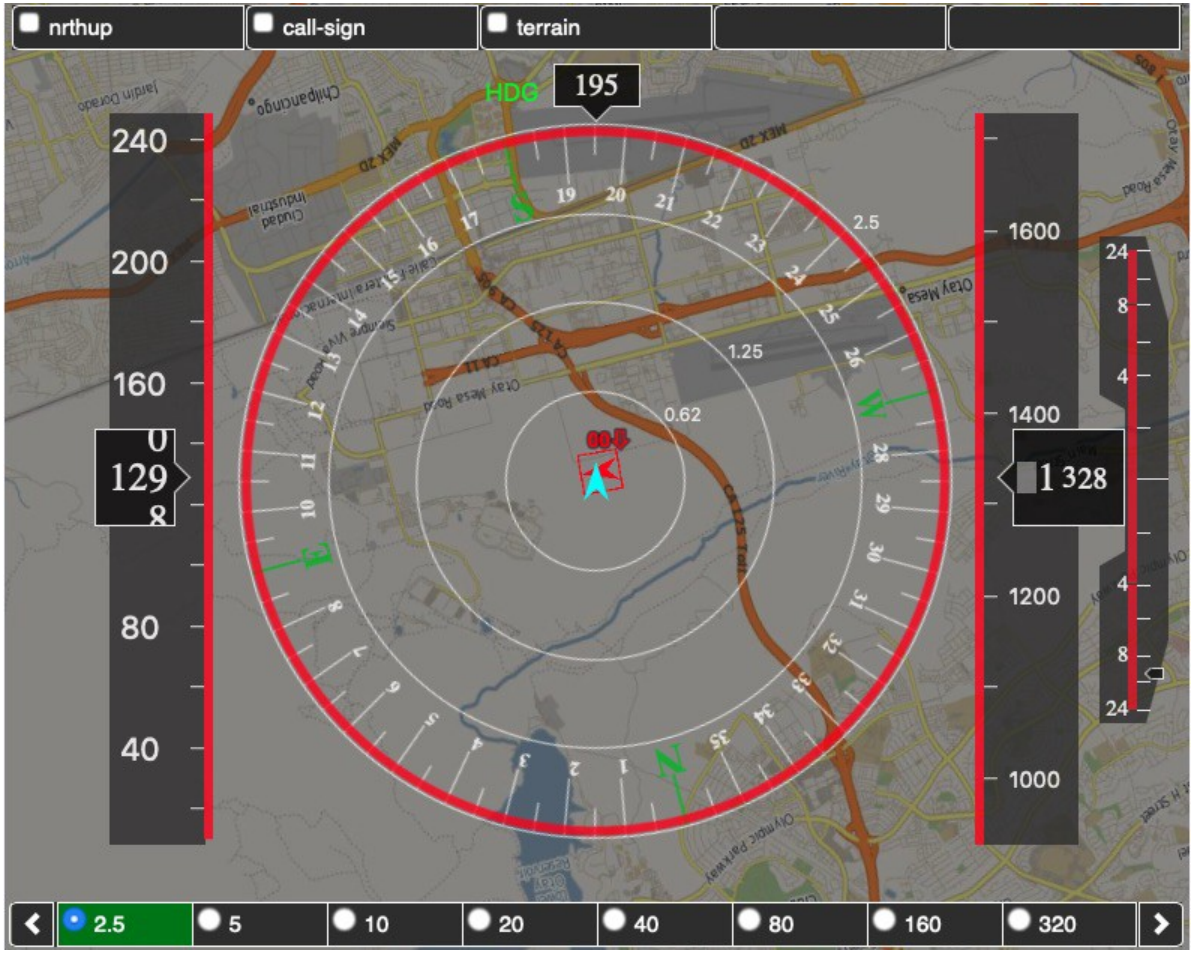
- **At 11:02:40, 30 seconds before collision, the DANTi prototype shows the traffic aircraft 500 feet below the ownship and descending. Horizontal distance is 5,109 feet. No conflict or conflict alert are issued.**
- **The bands show that turning to a heading greater than 113 will result in a conflict**

- **At 11:02:44, 26 seconds before collision, as the ownship turns towards the traffic, the heading of the ownship approaches the red band. The traffic is shown 400 feet below and descending. Horizontal distance is 4,994 feet.**
- **The bands indicate that any further turn to the right will result in conflicting trajectories. The speed tape also show that slowing down will result in conflicting trajectories.**

- **At 11:02:46, 24 seconds before collision, the traffic display shows a loss of well clear and escape maneuvers in green. The traffic is shown 400 feet below and descending. Horizontal distance is 4,869 feet.**
- **To reestablish well clear, the ownship can turn left to a 113 heading, increase speed from 129 to 150 kts, or stop descending and climb at 250 feet/min. All maneuvers are feasible.**

- **At 11:02:59, 11 seconds before collision, as the ownship continues to turn right and the encounter is more severe, the turn and climb escape maneuvers are still feasible to avoid the collision. Even stopping the descent will avoid the collision. The traffic is shown 200 feet below the ownship and descending. Horizontal distance is 3,029 feet.**
- **The guidance is to turn left to a 121 heading or climb at 1,000 ft/min**

- **Collision occurs at 11:03:10**



Simulations

- An encounter simulation was developed to evaluate the effectiveness of the DAIDALUS Detect and Avoid algorithm in preventing loss of well clear and collisions
- A dynamics module moves aircraft on their trajectories
- When a conflict is detected and guidance is produced by DAIDALUS, the information is provided to a virtual pilot which maneuvers the ownship according to the guidance
- The virtual pilot can be configured to implement the heading, vertical speed, or horizontal speed guidance

Simulation Run

- Using the simulation capability, the Case Study encounter was performed with the C172 as the ownship and then the Sabreliner as the ownship
- The virtual pilot was configured to implement the guidance with a delay, randomly distributed over a Rayleigh distribution and 5 seconds mean
- The virtual pilot was also configured to either select the horizontal direction resolution or the vertical speed resolution
- Each case was run 10,000 times with small random variations in speed, altitude, and location

Simulation Results

	Severity					
Scenario	No loss of well clear	Minimal	Minor	Major	Near Mid-air collision	Collision
C172 ownship horizontal	0	0.01%	0.98%	8.39%	90.62%	0
C172 ownship vertical	2.44%	23.10%	33.90%	24.64%	15.92%	0
Sabreliner ownship horizontal	0	79.9%	16.6%	2.72%	0.79%	0
Sabreliner ownship vertical	13.20%	66.50%	16.50%	2.73%	0.97%	0

Summary

- A concept for a detect and avoid EFB (Electronic Flight Bag) has been developed
- The concept uses the NASA Langley developed DAIDALUS DAA algorithm
- The DANTi concept has been implemented in a tablet and flown on-board NASA Langley's research aircraft
- A simulator has been developed to evaluate the effectiveness of the concept and the DAIDALUS algorithm
- More than 500,000 simulation runs have been performed with multiple scenarios, random conditions, and different magnitude and direction of wind

Conclusion

- **The case study presented is one of the most challenging encounters for see and avoid. This is because one of the aircraft is turning into the other, both aircraft are descending, and because of the difference in performance of the aircraft.**
- **Other cases studied such as crossing, overtaking, head-on, climbing or descending on top of each other resulted in significantly less severe encounters**
- **Detect and avoid in the flight deck has the potential for virtually eliminating mid-air collisions as a yearly occurrence making collisions extremely improbable events for general aviation**

Additional Material

Centennial Mid-air Collision

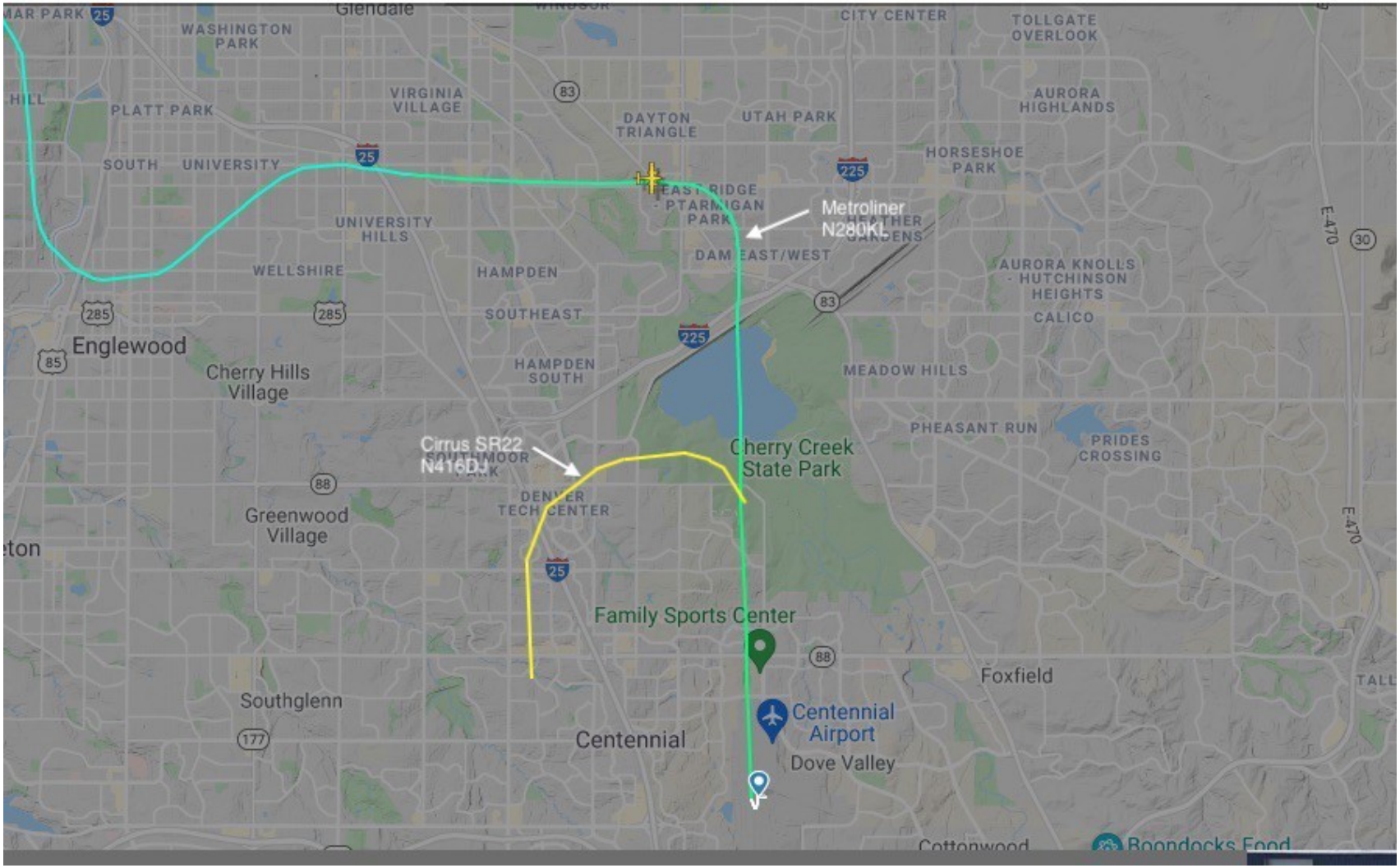
Synopsis

- On the 12th of May, 2021, at about 16:23:13z, (10:23:13 local time) a Cirrus SR22 single engine piston aircraft, registration N416DJ, collided with a Metroliner twin turboprop aircraft, registration N280KL, near Centennial airport, Colorado, KAPA.
- Centennial is a towered airport and there were two tower air traffic controllers on duty at the time of the accident.
- There were 2 persons on-board the Cirrus SR22 and a single pilot on the Metroliner.
- Both aircraft were in communications with tower controllers.

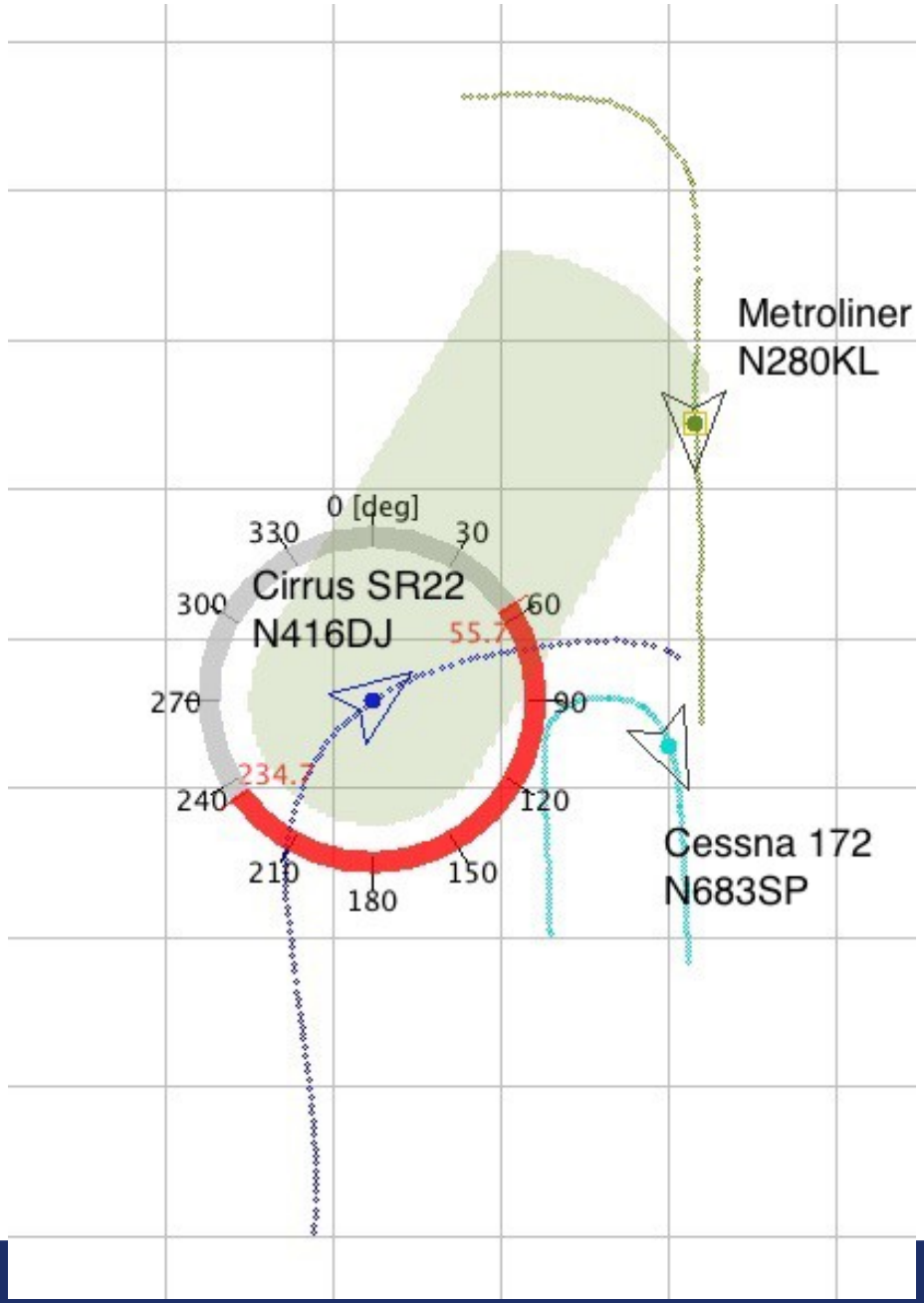
Synopsis, continued

- **Both aircraft had been cleared to land. The Metroliner to runway 17L and the Cirrus to runway 17R following a Cessna 172 on final also cleared to 17R.**
- **Tower controllers gave traffic advisory to the Cirrus of the Metroliner traffic. Cirrus responded “traffic in sight.”**
- **Cirrus, at high speed for maneuvering in the traffic pattern, overshot the turn from base to final and collided with the Metroliner.**
- **The Cirrus aircraft deployed the Cirrus Airframe Parachute System (CAPS) and both occupants survived without injuries. The aircraft was destroyed.**
- **The Metroliner sustained extensive damage to the fuselage but was able to land on runway 17L.**

Trajectories



Location of the aircraft 38 seconds before collision

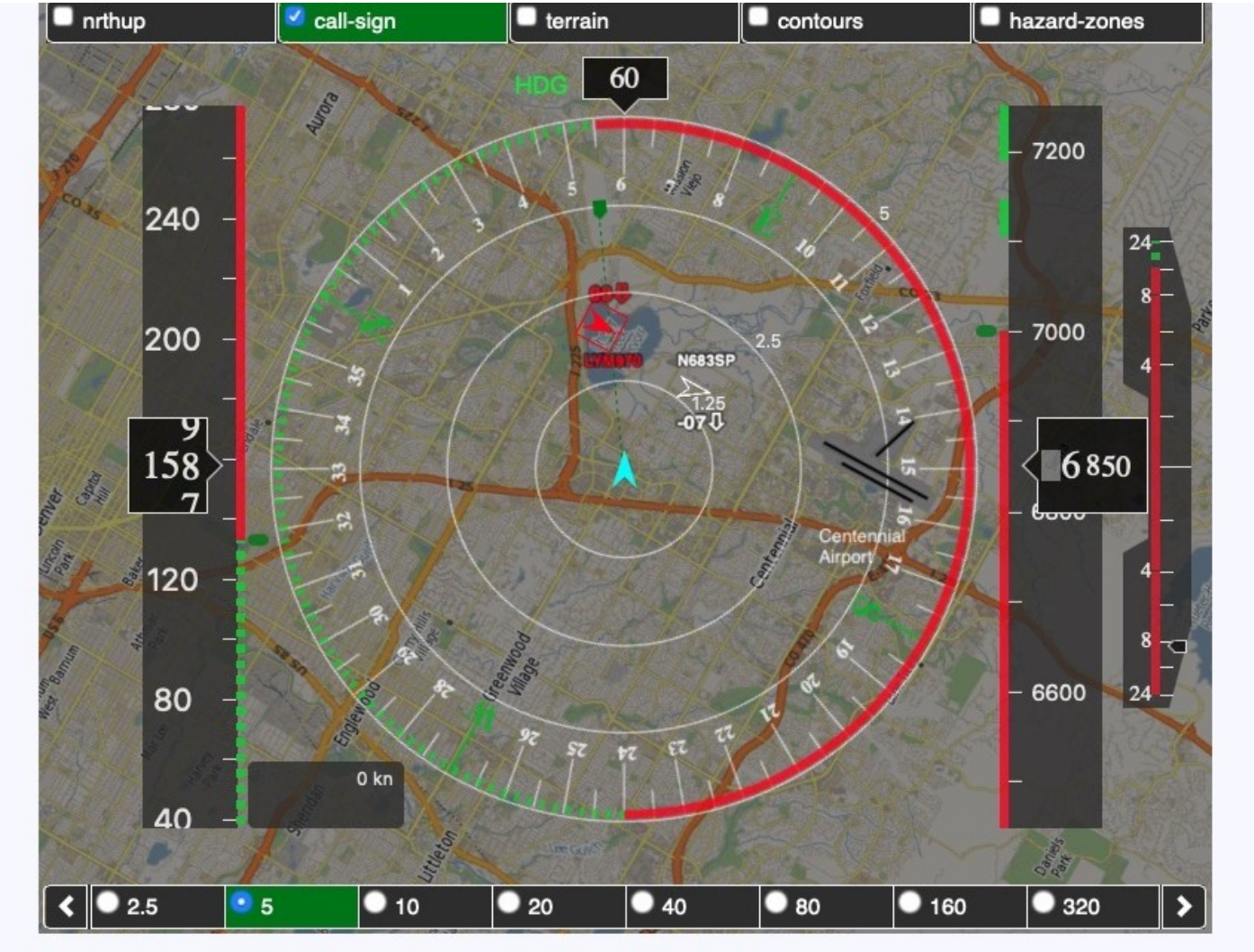


Results

- The simulation was performed with the Centennial trajectories input file.
- The simulation was configured for both aircraft equipped with DAIDALUS DAA.
- A conflict was detected and level 3 alerts and resolutions issued 37 seconds before the collision.
- The virtual pilots implemented the resolutions with a 5 seconds delay.
- The calculated severity of the encounter when the virtual pilots intervene is 12.2% (0% represents no loss of well clear and 100% represents potential collision).

Traffic display from the Cirrus perspective

Metroliner ahead, Cessna at 1 O'clock, airport and runways at 3 o'clock
37 sec. before collision



Summary and Conclusion

- **As previous analysis have shown, the use of Detect and Avoid supplemental equipment on the flight deck has the potential of eliminating the majority of the approximately 20 mid-air collisions that occur every year in the United States.**