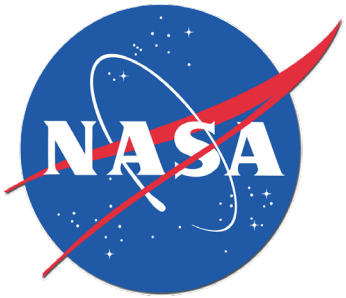
Analysis of Interactions Between Urban Air Mobility (UAM) Operations and Conventional Traffic in Urban Areas: Traffic Alert and Collision Avoidance System (TCAS) Study for UAM Operations

Vishwanath Bulusu
Banavar Sridhar
Andrew C. Cone
David Thipphavong

AIAA Aviation (June 20, 2019)



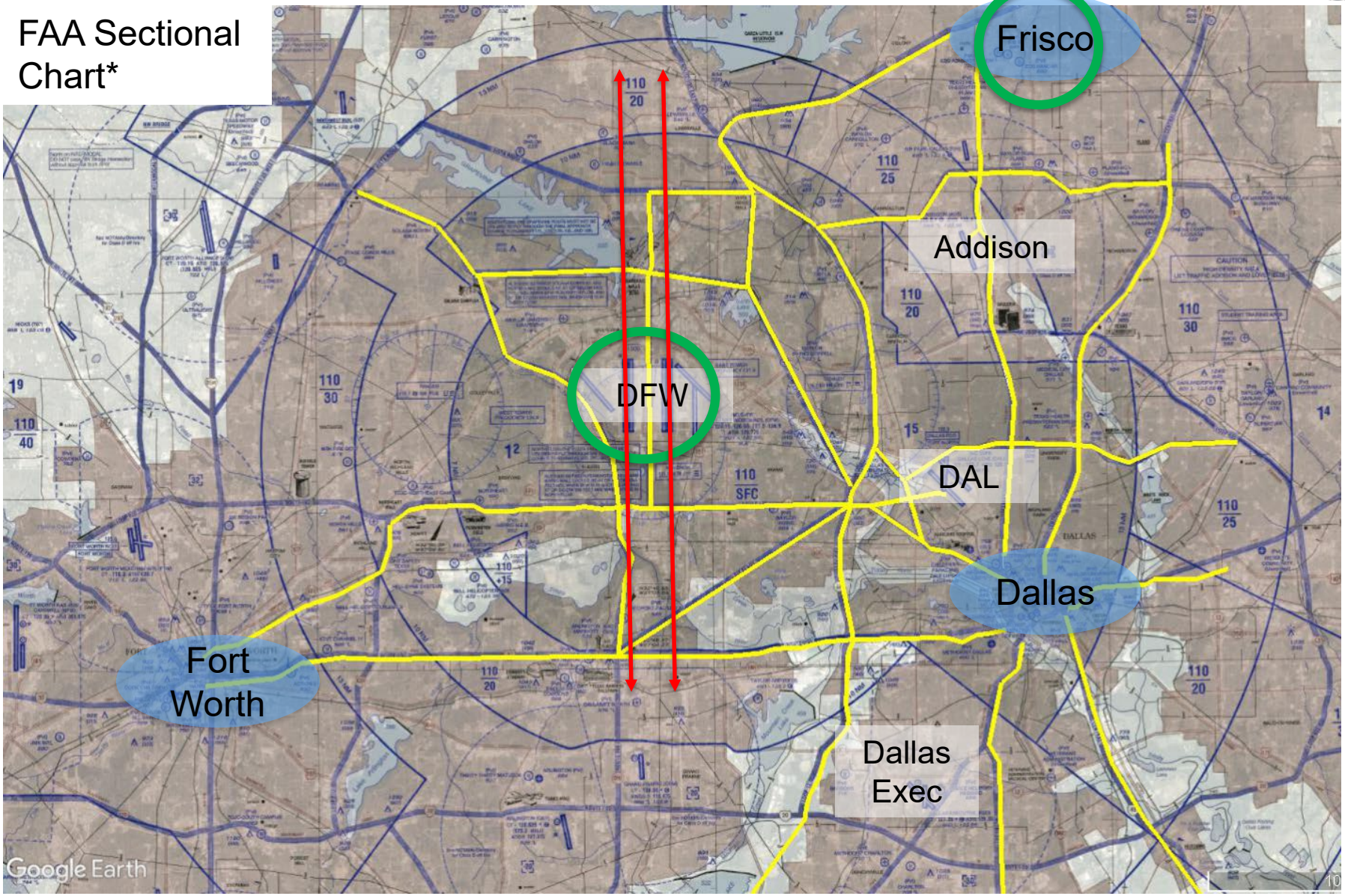
The skies today!

The skies of future?

Explore already-existing approved routes

Helicopter Routes in Dallas-Fort Worth

FAA Sectional Chart*



*"FAA Helicopter Routes Map for Dallas-Fort Worth Area," http://aeronav.faa.gov/content/aeronav/heli_files/PDFs/Dallas-Ft_Worth_Heli_7_P.pdf, 2019. Images produced by the U.S. Government and in the public domain.

Can UAM vehicles fly *existing routes* with minimal *impact* on conventional air traffic?

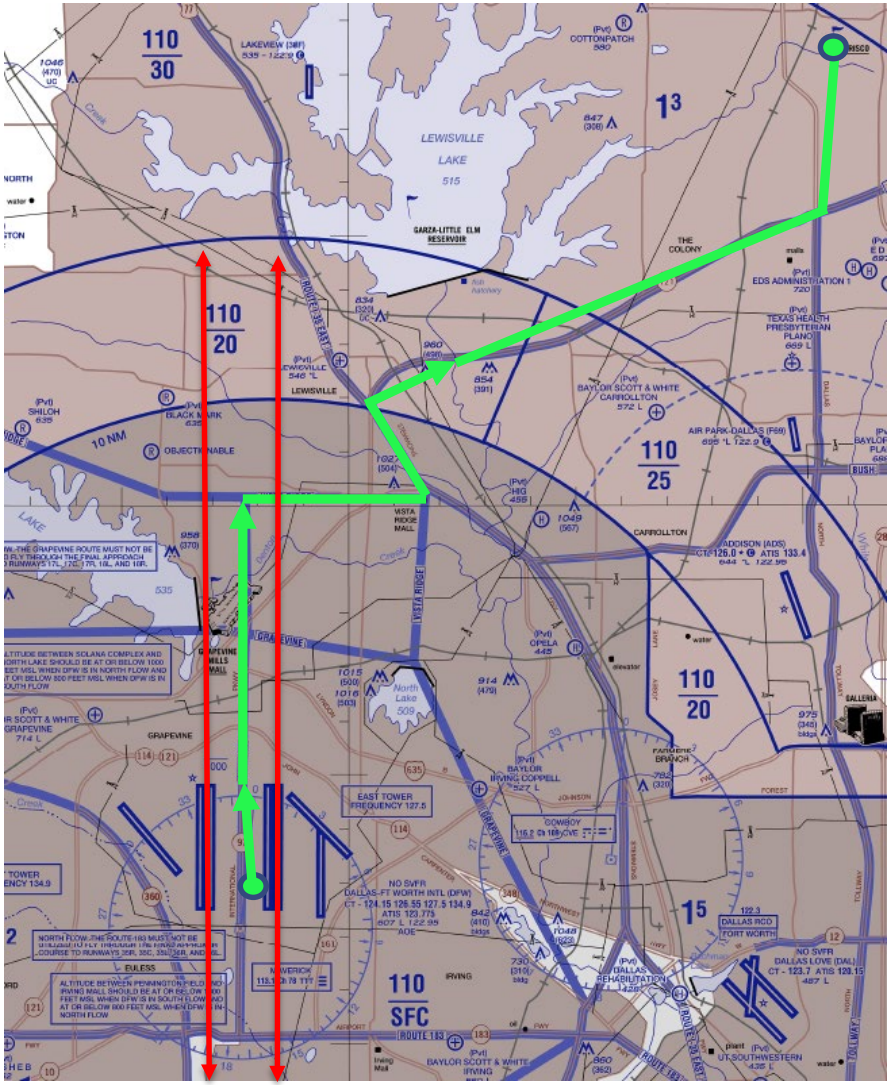
Routes Explored

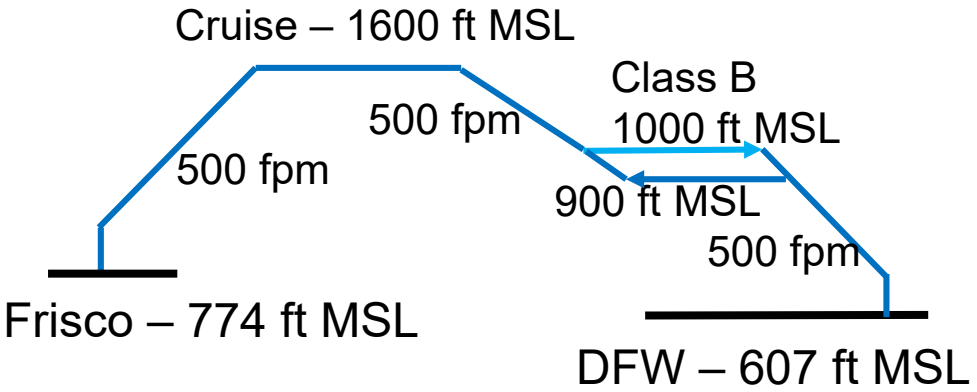
Helicopter Routes in Dallas-Fort Worth Metropolitan Region

Impact Evaluated

*TCAS **Resolution Advisories (RA)** on Conventional Aircraft.*

UAM Routes

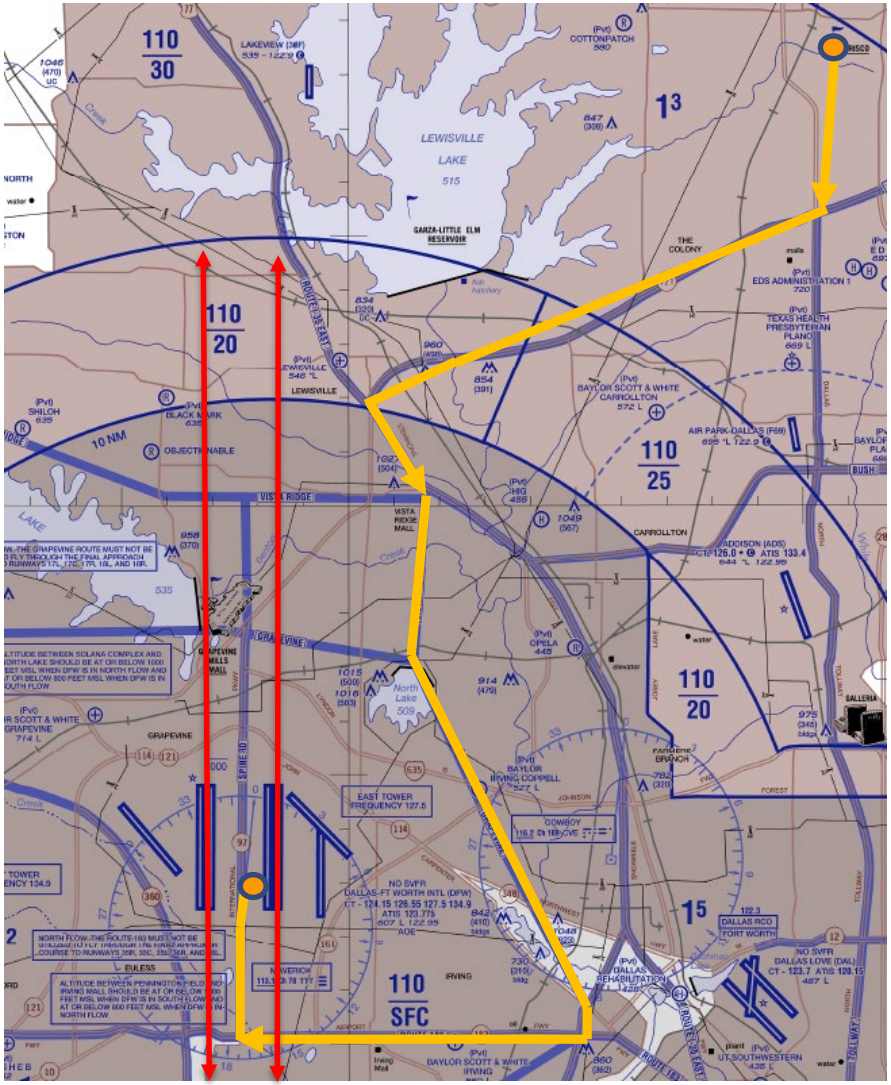


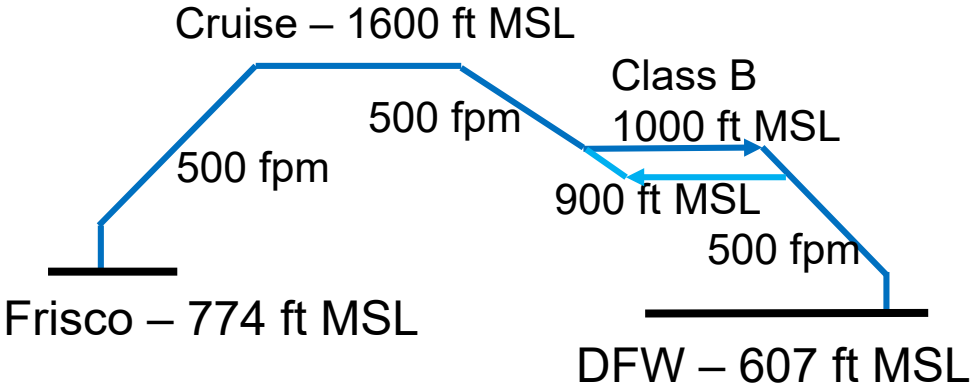


Flight time 13.0 minutes

*"FAA Helicopter Routes Map for Dallas-Fort Worth Area," http://aeronav.faa.gov/content/aeronav/heli_files/PDFs/Dallas-Ft_Worth_Heli_7_P.pdf, 2019. Images produced by the U.S. Government and in the public domain.

UAM Routes

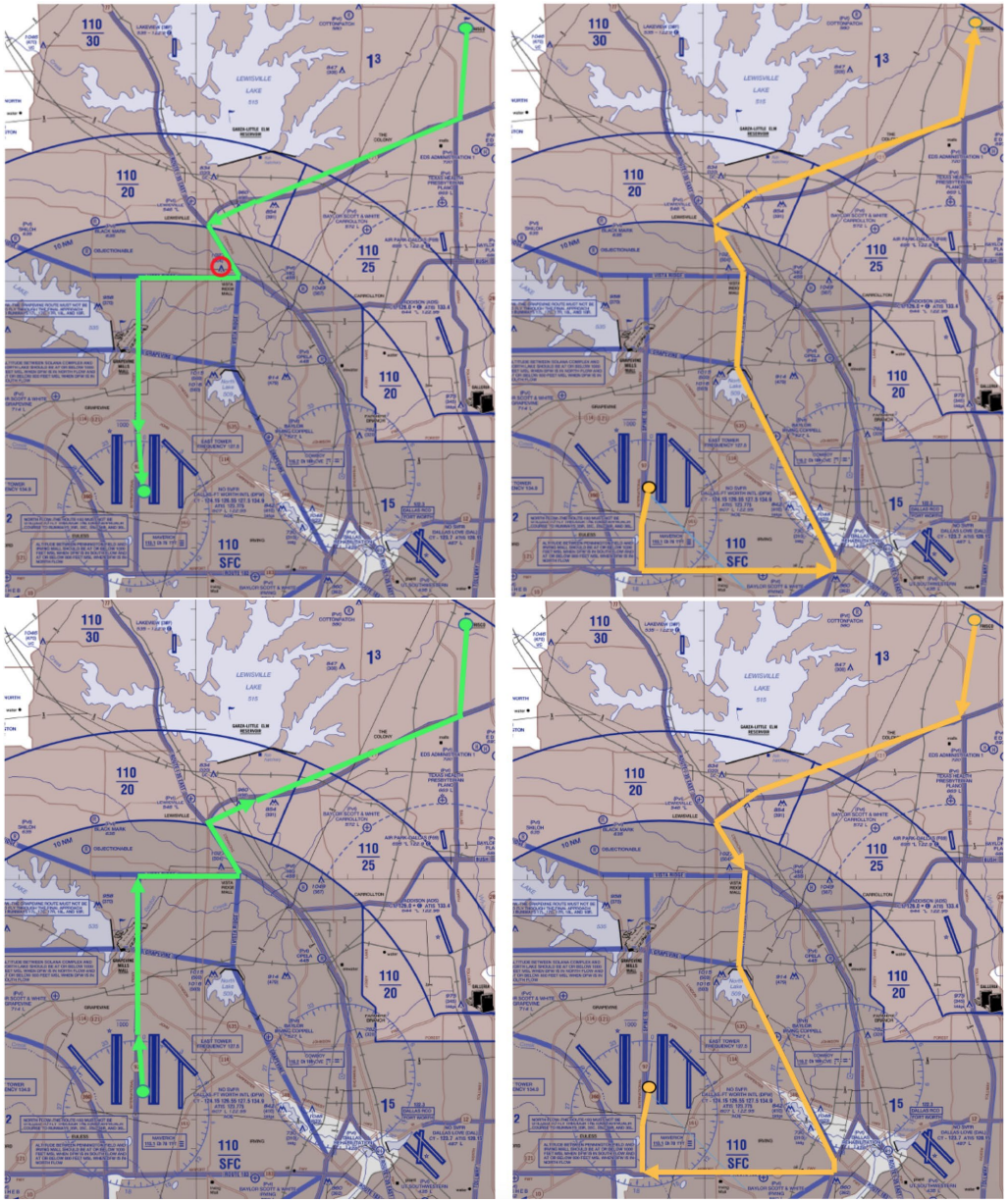




Flight time 18.4 minutes

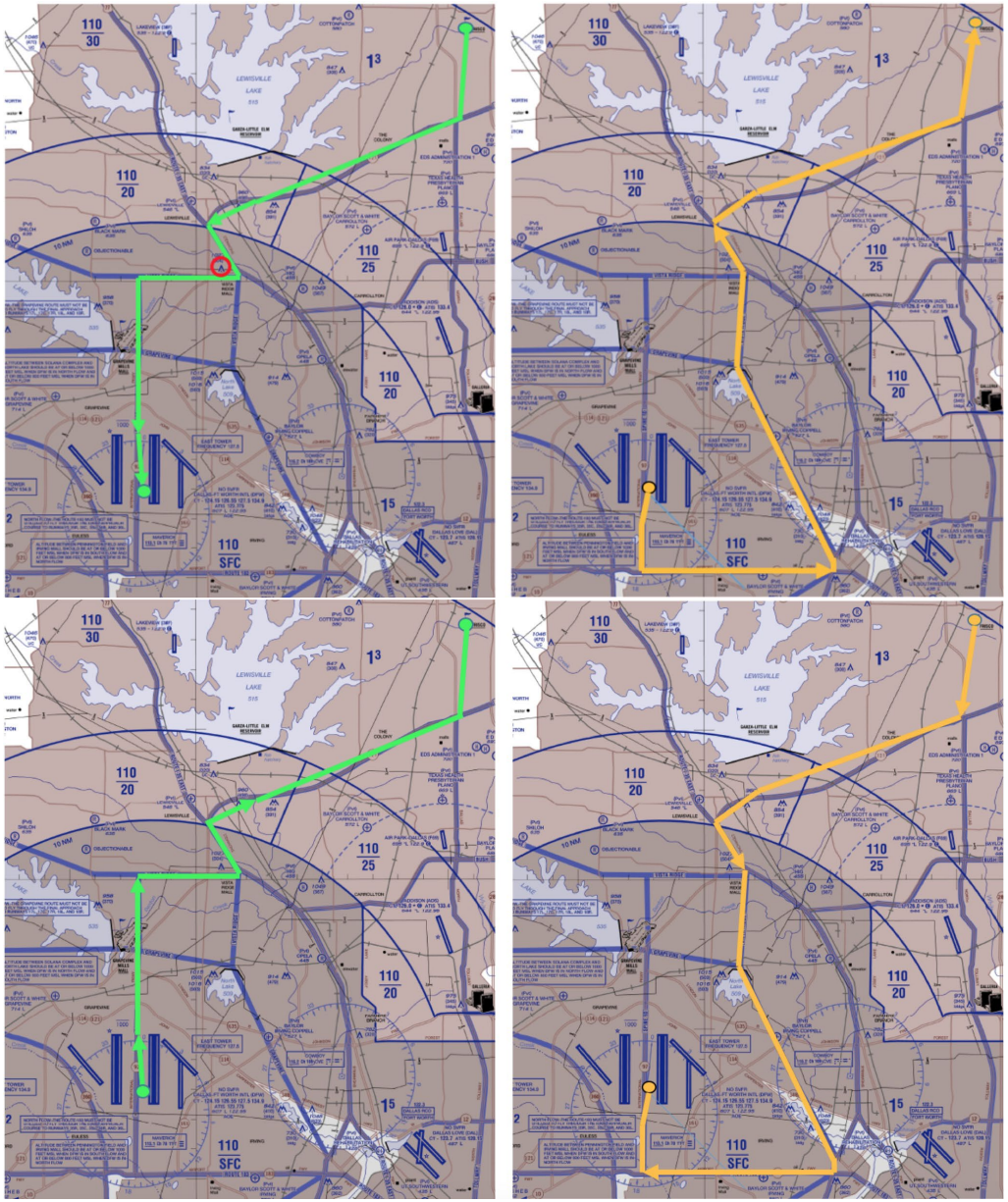
*"FAA Helicopter Routes Map for Dallas-Fort Worth Area," http://aeronav.faa.gov/content/aeronav/heli_files/PDFs/Dallas-Ft_Worth_Heli_7_P.pdf, 2019. Images produced by the U.S. Government and in the public domain.

UAM Routes

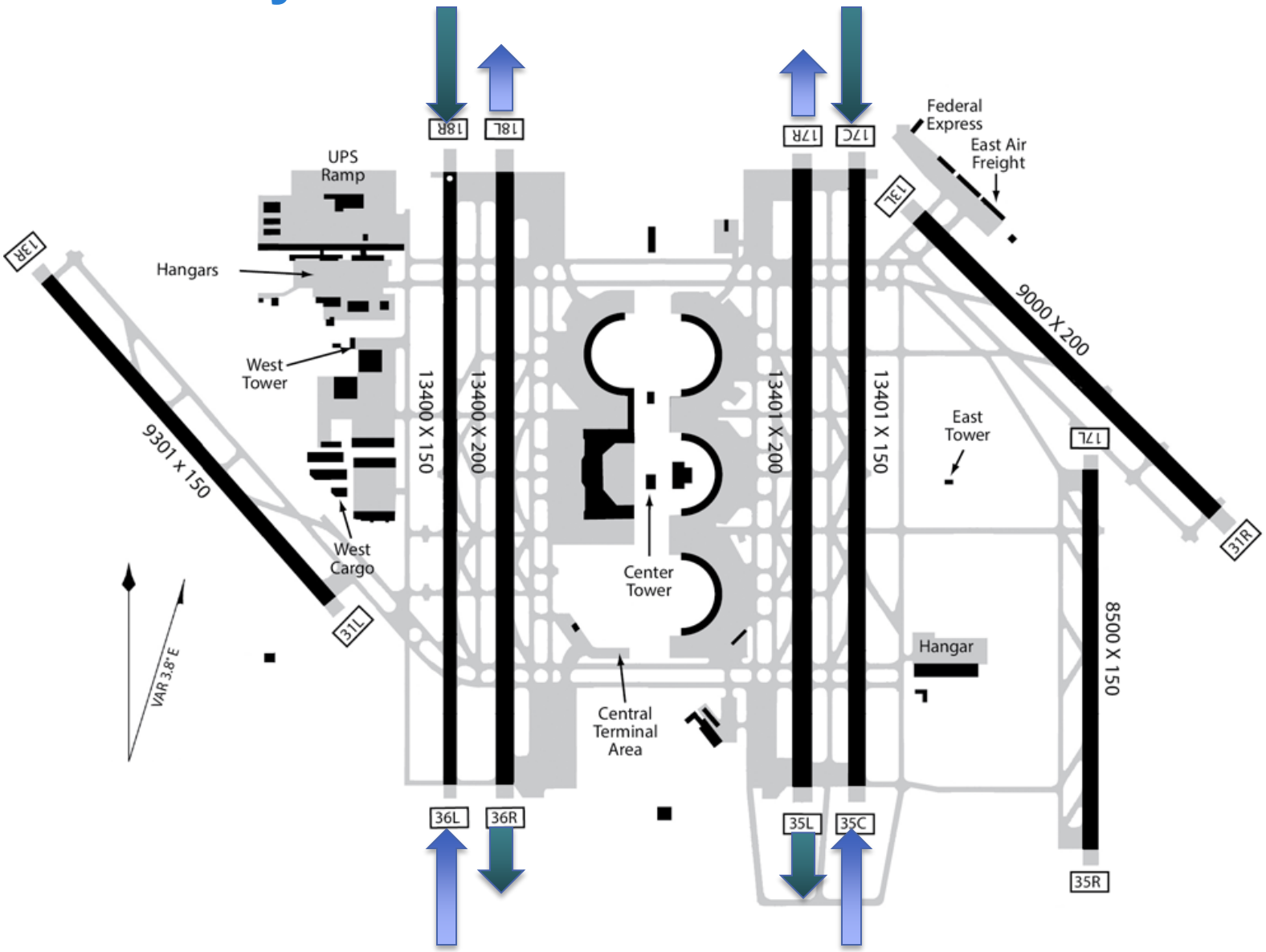


*"FAA Helicopter Routes Map for Dallas-Fort Worth Area," http://aeronav.faa.gov/content/aeronav/heli_files/PDFs/Dallas-Ft_Worth_Heli_7_P.pdf, 2019. Images produced by the U.S. Government and in the public domain.

UAM Routes



DFW Runways


18R
18L
17R
17C
Federal Express
East Air Freight
UPS Ramp
13R
Hangars
13L
9000 X 200
West Tower
13400 X 150
13400 X 200
13401 X 200
13401 X 150
East Tower
17L
9301 X 150
West Cargo
31L
31R
VAR 3.8°E
Center Tower
Hangar
8500 X 150
Central Terminal Area
36L
36R
35L
35C
35R

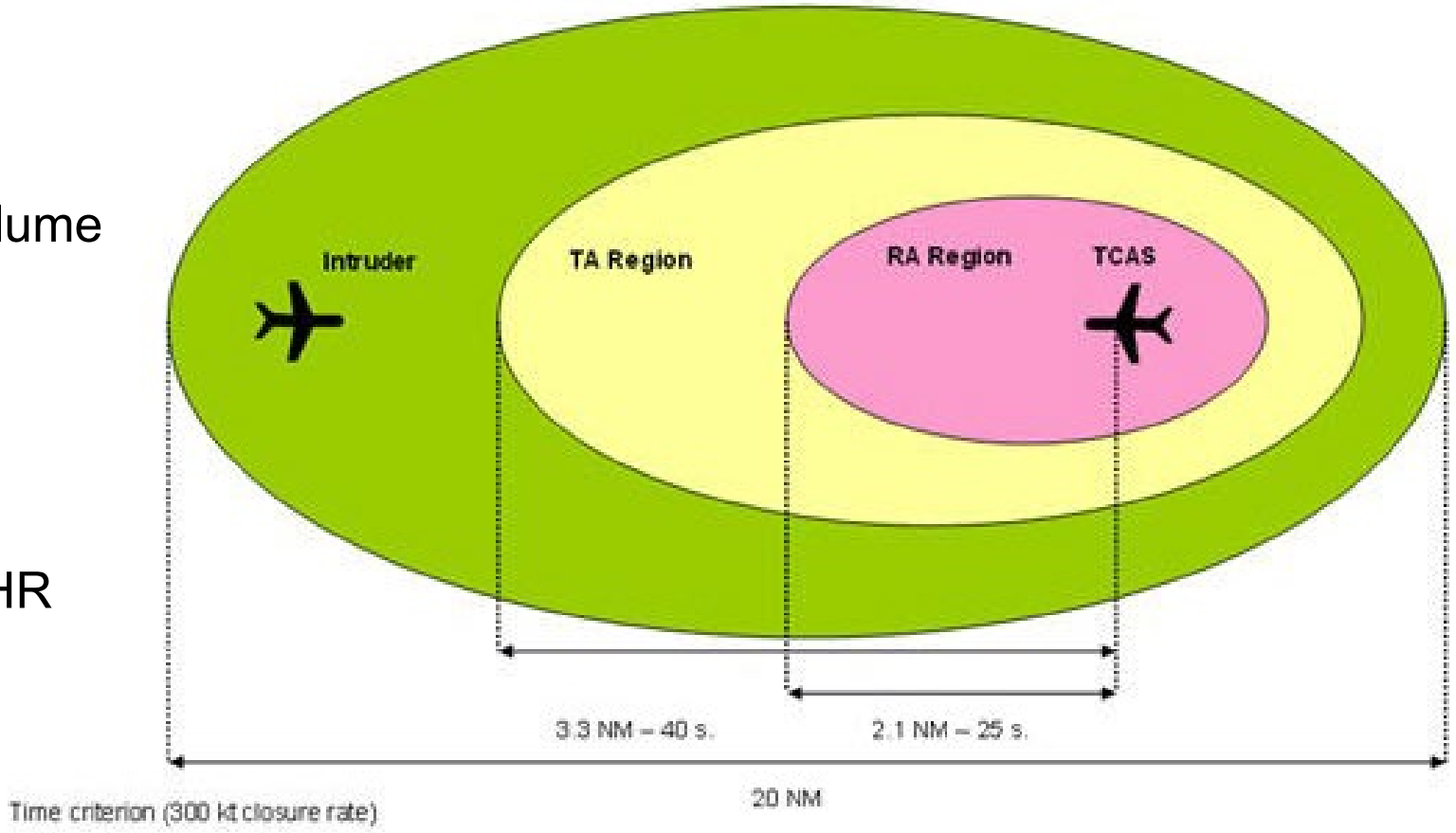
Traffic Alert & Collision Avoidance System (TCAS)

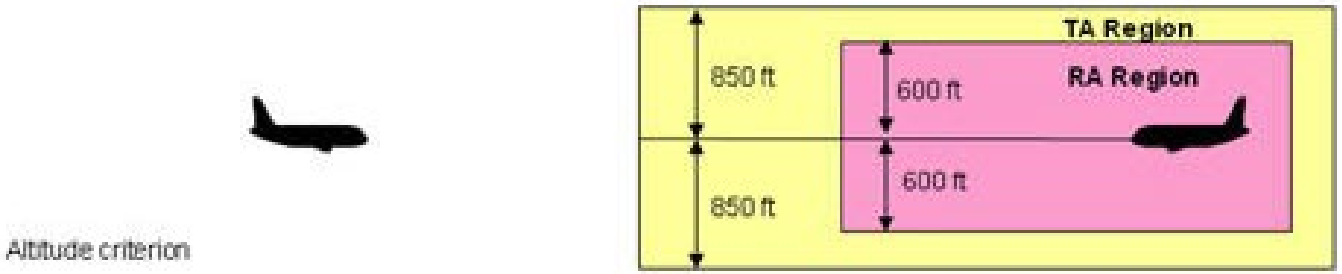
Criteria:

DMOD –
Protected Volume

Time –
τ_{mod} and τ_{vert}

Altitude - ZTHR





Source: http://www.eurocontrol.int/msa/public/standard_page/ACAS_Overview_Principles.html

Traffic Alert & Collision Avoidance System (TCAS)

Aircraft State information

Ownship Altitude (ft)	SL	Tau(sec)	DMOD(nmi)	ZTHR(ft)
<1000 (AGL)	2	N/A	N/A	N/A
1000-2350 (AGL)	3	15	0.20	600
2350-5000	4	20	0.35	600
5000-10000	5	25	0.55	600
10000-20000	6	30	0.80	600
20000-42000	7	35	1.10	700
>42000	7	35	1.10	800

Advisories (based on Sensitivity Level (SL))

Traffic Adv.(TA) – *Traffic*

Resolution Adv. (RA) – *Climb, Descend, etc*

TCAS RA Criteria used

A Resolution Advisory (RA) is issued if

Advisories –

1. τ_{mod} < threshold

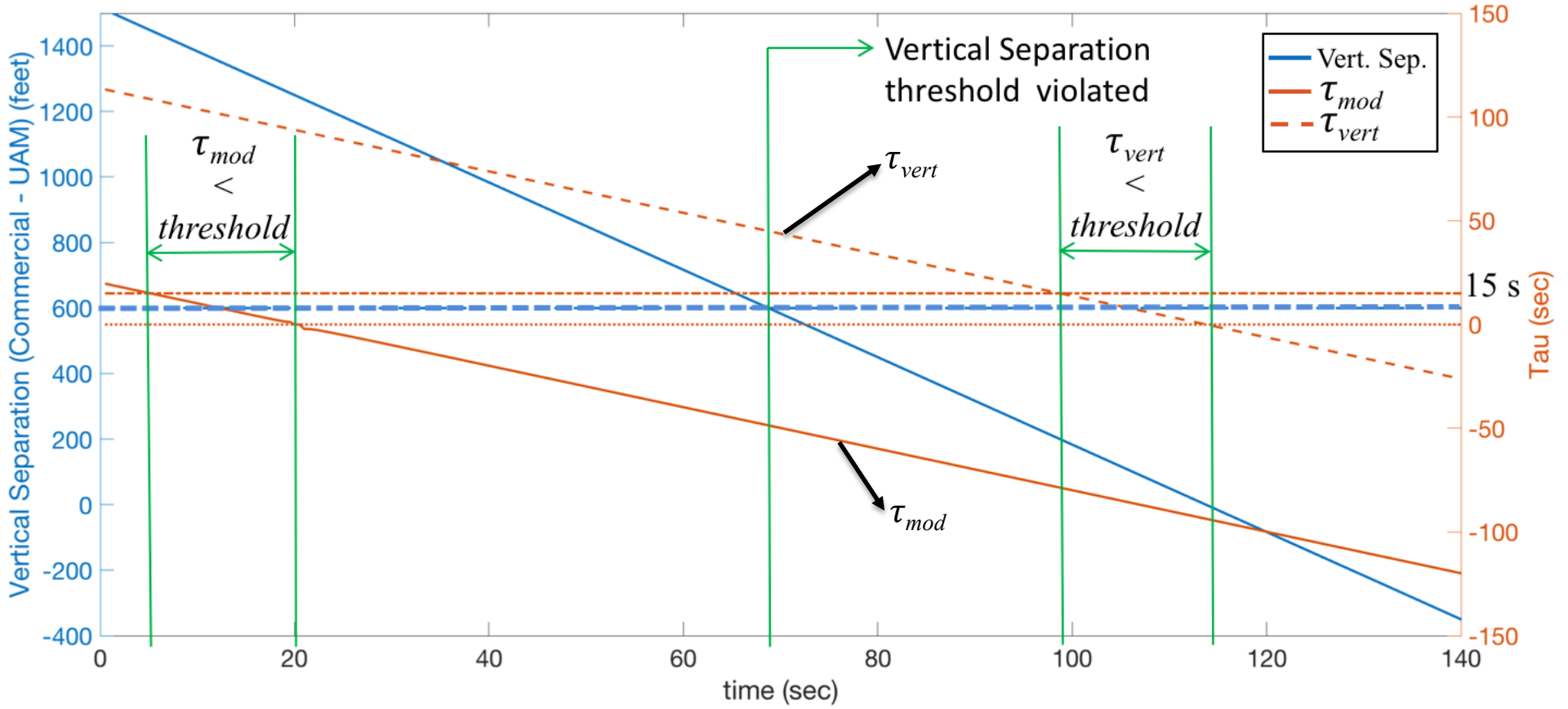
and

2. τ_{vert} < threshold OR Vert. Sep. < ZTHR

and

3. Conventional Aircraft Altitude > 1000 ft AGL

TCAS RA Criteria Used



A graphical representation

STUDY APPROACH

Assumptions

- All UAM vehicles same aircraft type. (Speed, turn rate, etc)
- UAM trajectories completely deterministic in first run.
- Altitude uncertainty studied in second run.
- Conventional aircraft modelled with TCAS II version 7.1.
- UAM not modelled with TCAS but provide required state information.
- Conventional aircraft adhere to published navigational routes.

Simulation

DFW runway operational configurations –

- Nominal Day in South Flow (June 03, 2017).
- Nominal Day in North Flow (November 11, 2017)
- Peak Demand Day in South Flow (July 20, 2017)
- Peak Demand Day in North Flow (August 7, 2017)

Total Test Cases = 16 (4 routes X 4 runway operational configurations)

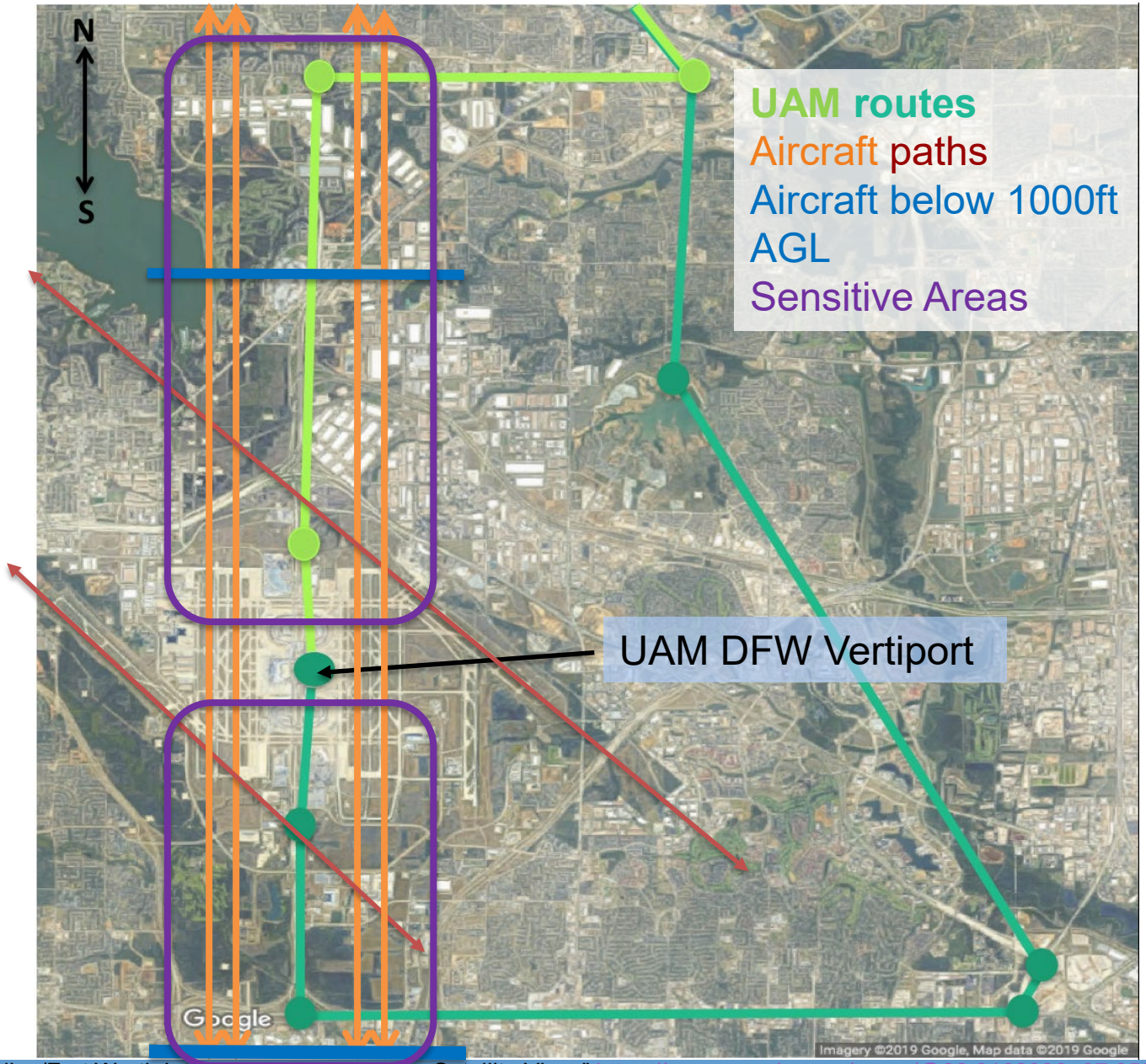
Uncertainty Study – only for peak traffic – August 7, 2017

Software:

- SaaControl - Fast-time simulation developed by NASA for the UAS integration into NAS project (NASA/TM-2017-219507)
- Matlab for detailed analysis and altitude uncertainty study

RESULTS

Area of Interest



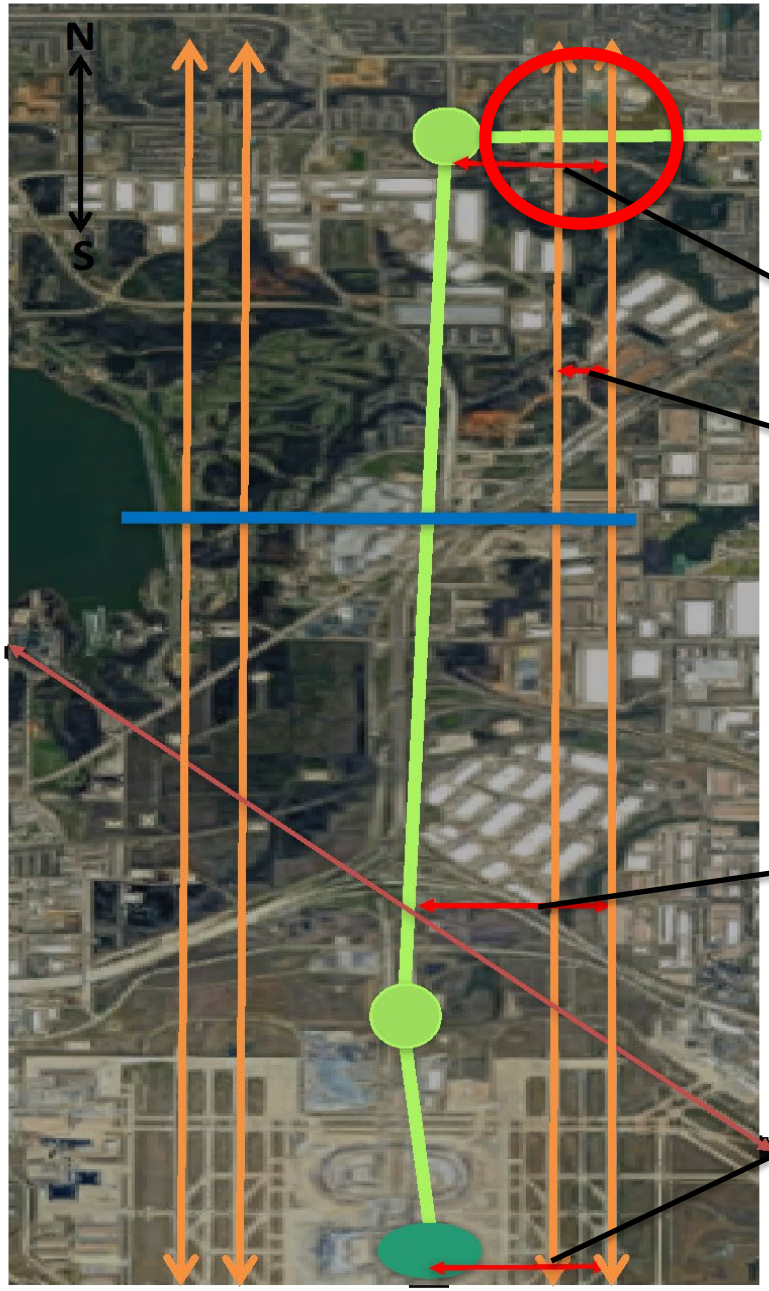
Google Maps, "Dallas/Fort Worth International Airport Area Satellite View," https://www.google.com/maps/@32.9162036,-97.0537879,20210m/data=!3m1!1e3, 2019. Accessed: 2019-05-16.

North of DFW

SL > 2
Vert. Sep. > 600 ft
τ_{vert} > threshold

No RAs!

SL 2
TCAS issues no RAs



Horz. Dist. – 0.62nm
Vert. Sep. – 1000 ft

Horz. Dist. – 0.2nm

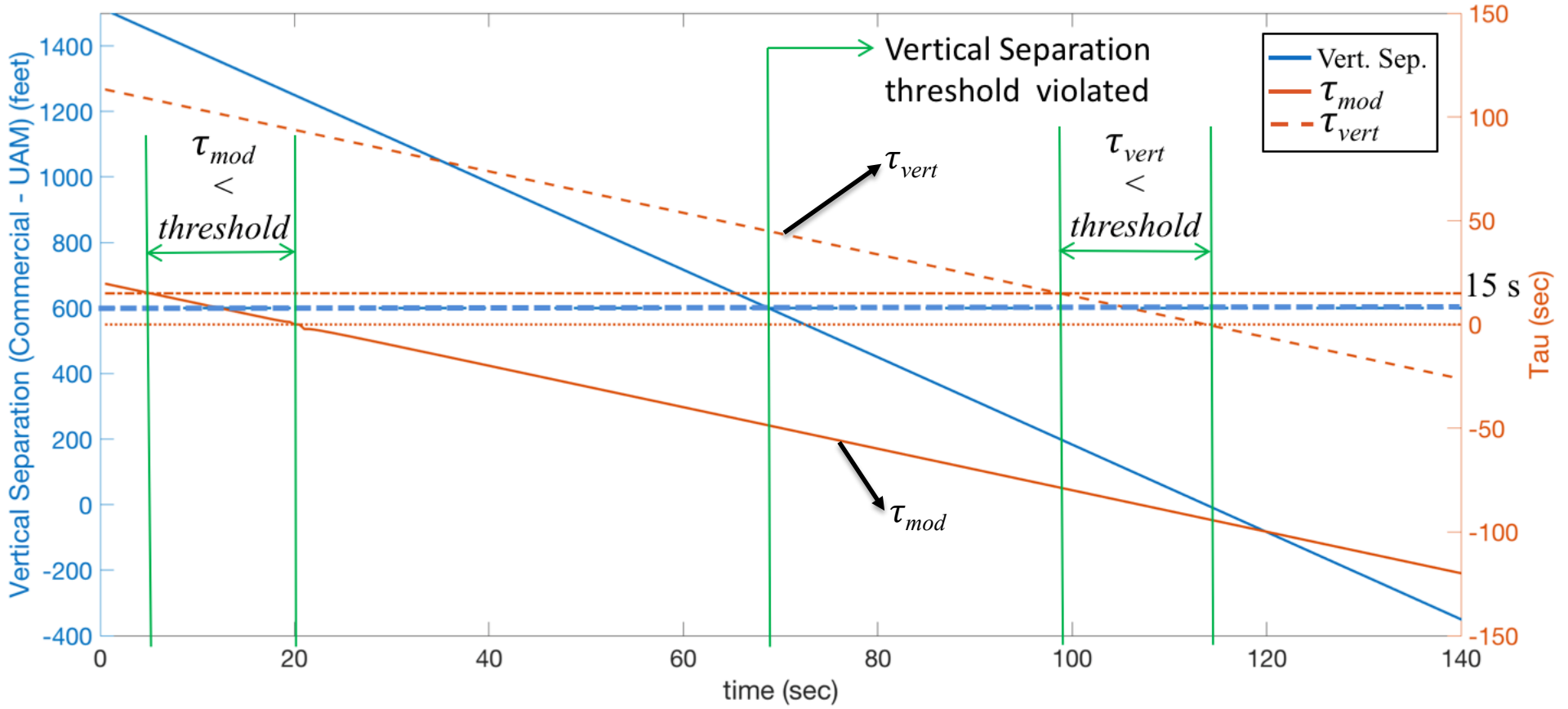
CPA
Horz. Dist. – 0.62nm
Vert. Sep. – 1000ft
*Slant Range – **0.64nm***

Horz. Dist – 0.65nm
Vert. Sep. – 0 ft

Horz. Dist. – 0.64nm
Vert. Sep. – 0ft
Both on ground

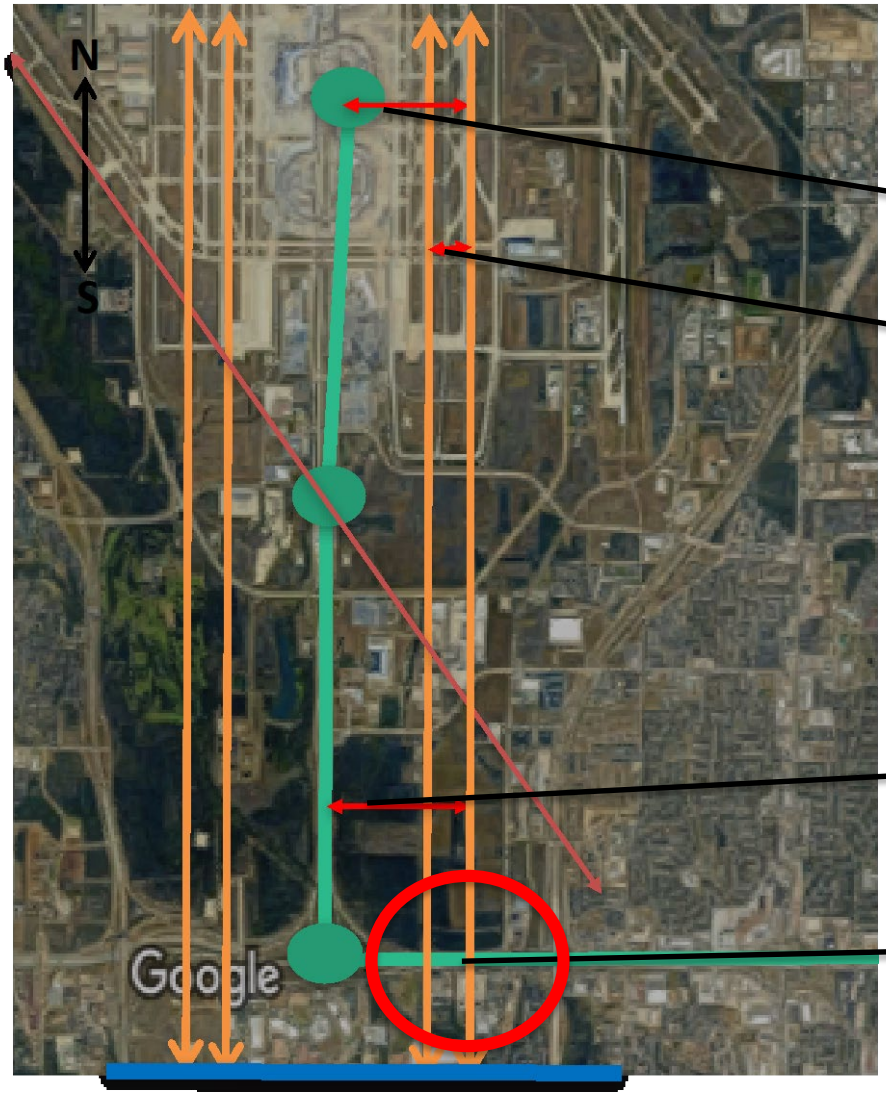
Google Maps, "Dallas/Fort Worth International Airport Area Satellite View," https://www.google.com/maps/@32.9162036,-97.0537879,20210m/data=!3m1!1e3, 2019. Accessed: 2019-05-16.

North of DFW



A sample encounter at crossing

South of DFW



Horz. Dist. – 0.64nm
Vert. Sep. – 0ft
Both on ground

Horz. Dist. – 0.2nm

CPA (Conventional < 1000ft AGL)
Horz. Dist. – 0ft
Vert. Sep. – 500ft
Slant Range – 500ft

Horz. Dist. – 0.70nm
Vert. Sep. – 400ft

Horz. Dist. – 0nm
Vert. Sep. – 500ft

SL 2
TCAS issues no RAs

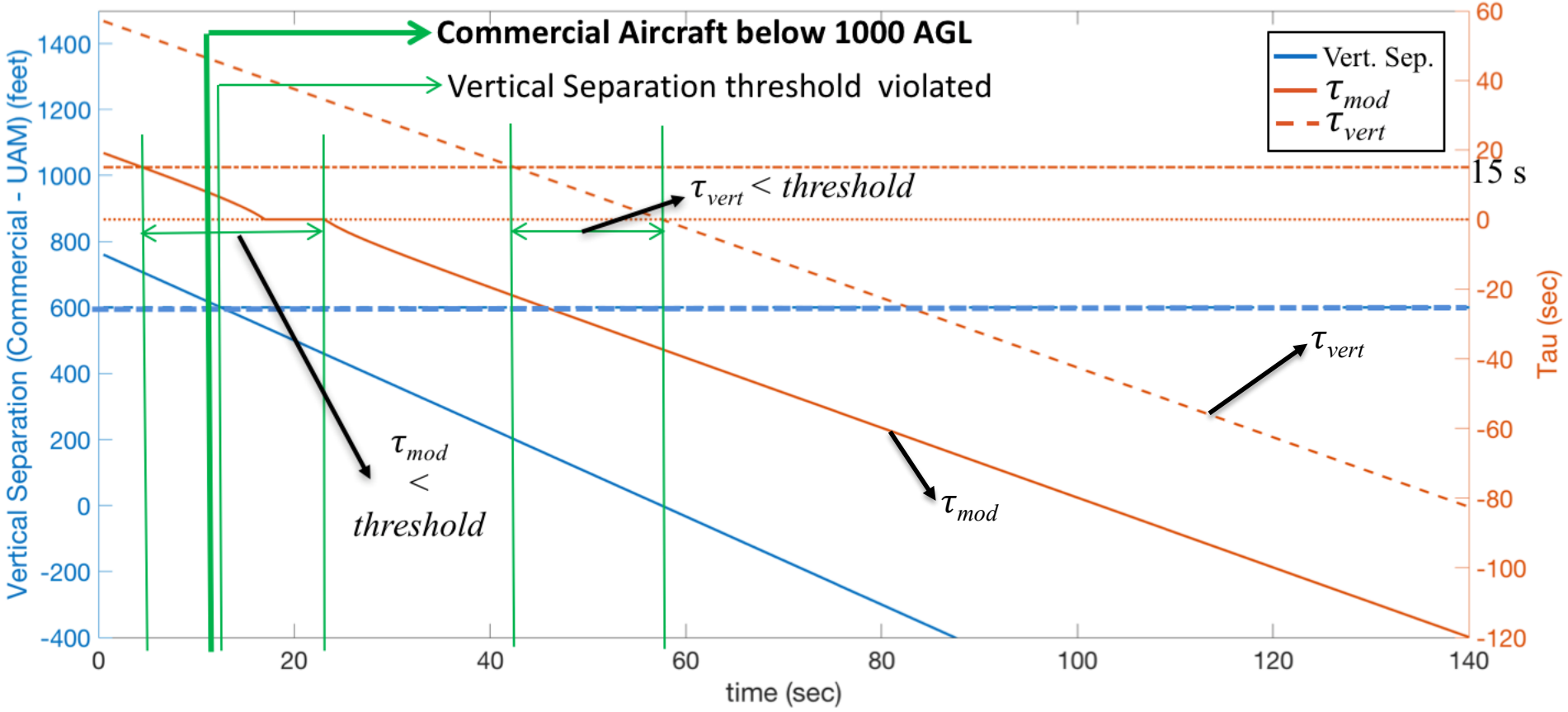
No RAs!

SL > 2
Vert. Sep. > 600 ft

τ_{vert} > threshold

Google Maps, "Dallas/Fort Worth International Airport Area Satellite View," https://www.google.com/maps/@32.9162036,-97.0537879,20210m/data=!3m1!1e3, 2019. Accessed: 2019-05-16.

South of DFW

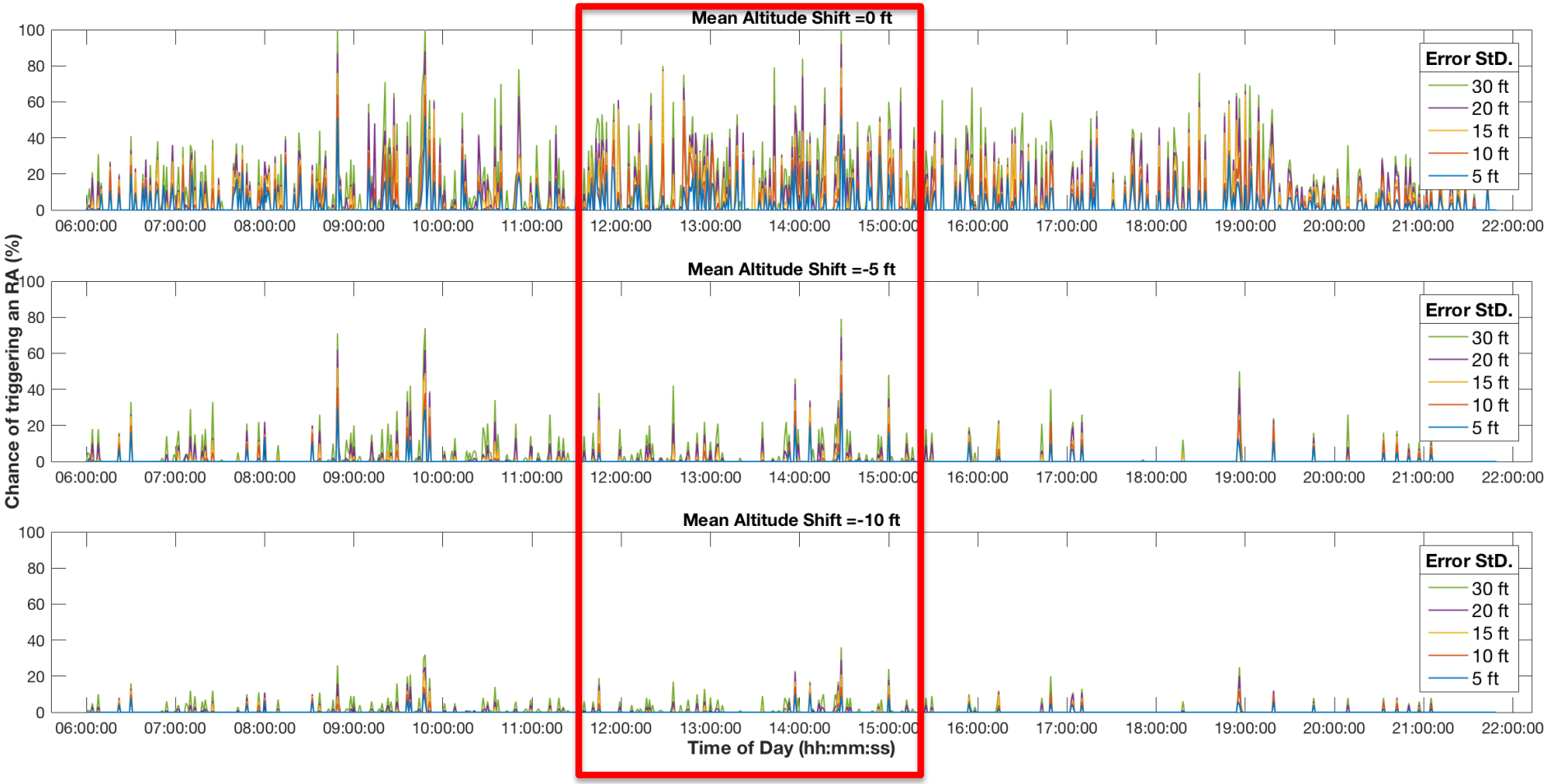


But NOT SAFE!

Altitude Uncertainty

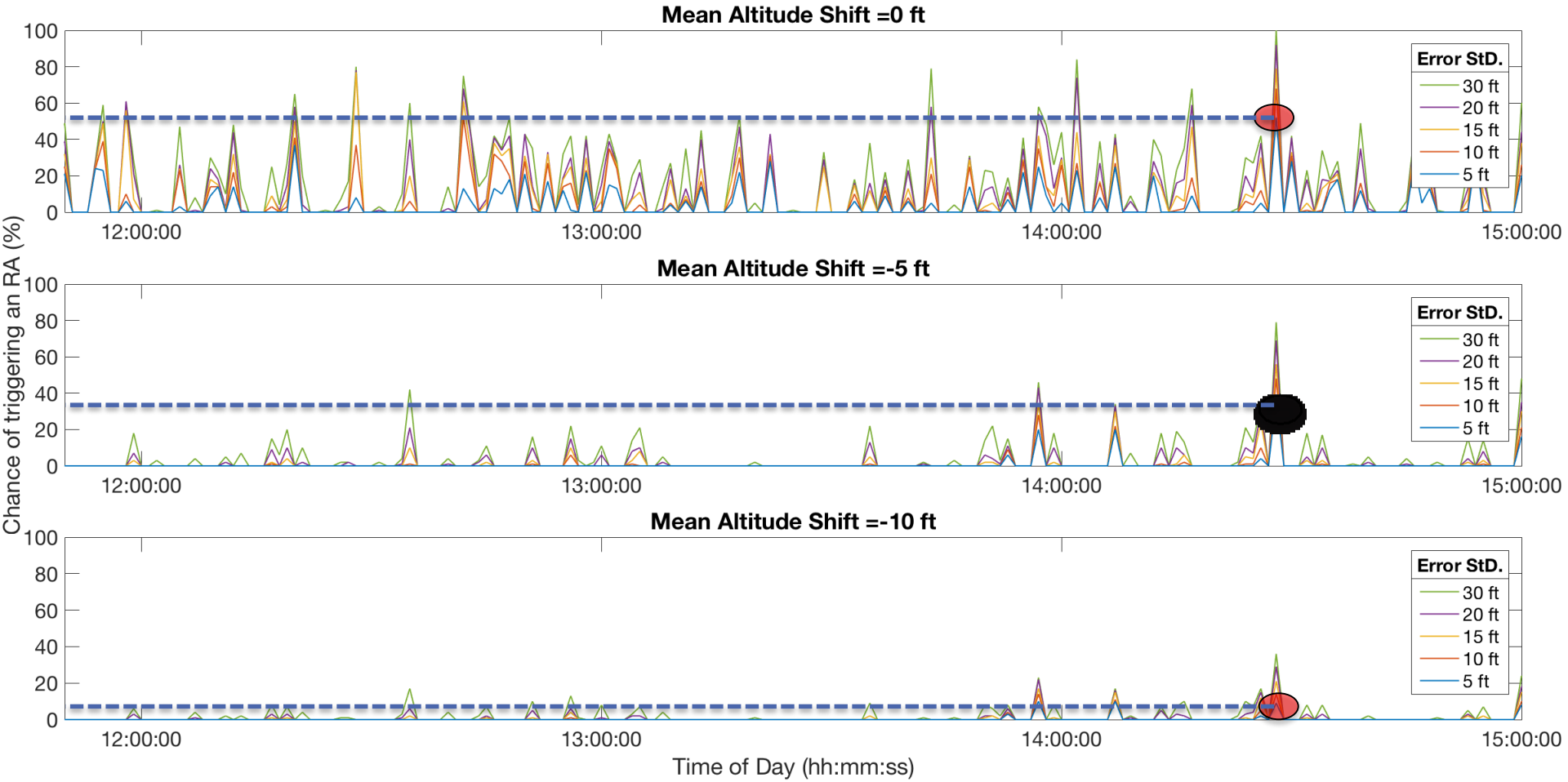
- Analyzed sensitive area south of DFW.
- Errors assumed only in UAM trajectory altitude (not in Conventional aircraft)
- Added normally distributed error with 0 mean and StD = {5, 10, 15, 20, 30} in feet.
- Lowered mean altitudes by 0, 5 and 10 feet.
- Conventional trajectories unchanged.
- Analyzed highest traffic day – August 7, 2017.

Altitude Uncertainty Results



RA chance (variation through the day)

Altitude Uncertainty Results



Potential Solution – *Lowering mean altitude by 10 ft reduces the chance of triggering RAs to under 10% even with a 5 ft error StD*

Conclusions

- UAM ***adhering precisely*** to designed routes triggered **no RAs** on conventional aircraft.

- Altitude uncertainty analysis
  UAM vehicles operating **at or below 990 ft MSL** triggered **no RAs** with **maximum error of 15 ft**.

- Limitations –
  Not a referendum on Safety
  Not a Route Analysis – Attend talk in afternoon: Savvy Verma

Future Work

- To enable operations with high trajectory determinism,
  Very high navigational performance requirement on UAM

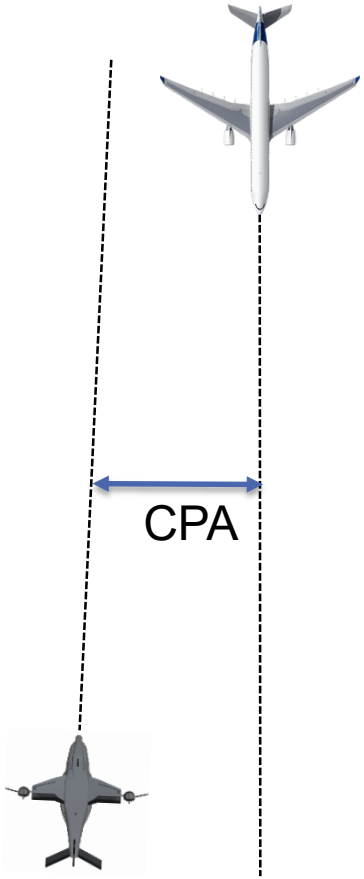
- Analysis approach and software tools can be extended to other airports.

- UAM below 967ft MSL (360ft AGL) near DFW will be automatically ignored by the current system.
  - **Early UAM operations anywhere below 360 ft AGL**.
  - **Long term – TCAS logic update?**

Questions/Comments/Suggestions?

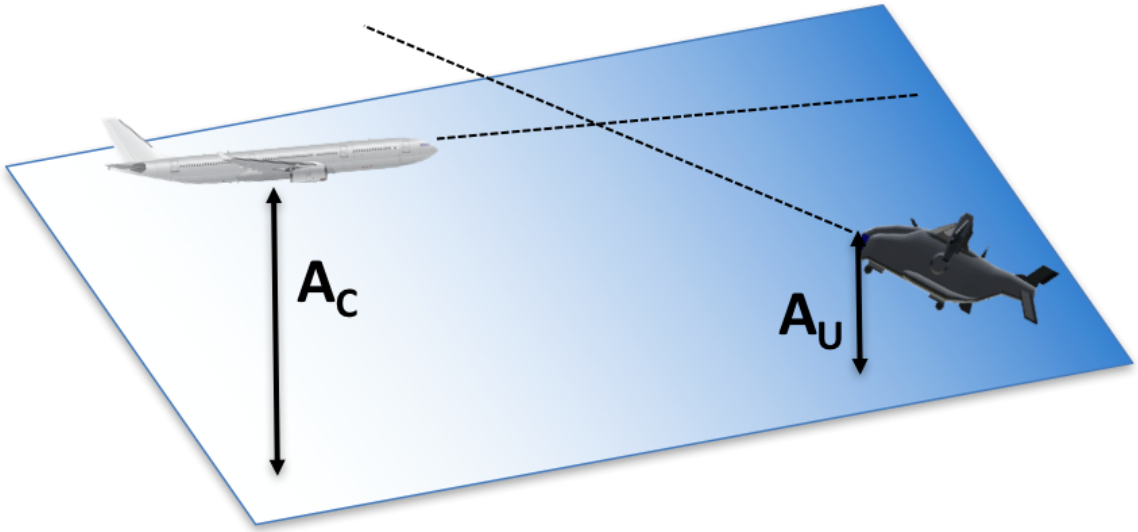
Appendix

Analysis



Aircraft Altitude = 500 AGL
UAM Altitude = 300 AGL
Horizontal Separation: 0.6883 nm
Vertical Separation: 200 ft
Vertical Closure Rate: 871 ft/min
Slant Separation: 0.6891 nm
Slant Closure Rate: 219.96 knots
τ_{vert} = *13.77 sec*
τ_{mod} (Sim) = *1 sec* => **RA**
τ_{mod} (SL3) = *10.33 sec* => **RA**
τ_{mod} (SL2) = N/A (below 1000ft AGL) => **no RA**

North of DFW



Aircraft Altitude = A_C (>1000 ft)
UAM Altitude = A_U
Vertical Separation = $A_C - A_U$ (>600 ft)
Vertical Closure Rate: $|A_C|$ ft/min
$\tau_{vert} = (1 - A_U/A_C)*60$ sec > 36 sec
$\tau_{vert} > 15$ *sec* => **no RA**
(Even if $\tau_{mod} = 0$)

A sample encounter (worst case)

Credit: Federal Aviation Administration (FAA), Google, Landsat/Copernicus