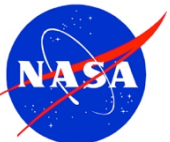


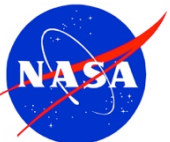
Investigating the Airspace Safety Threshold of the NAS

Kyle Flenar



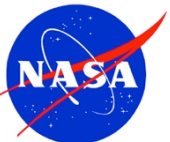
Outline

- Motivation
- Simulation Data
- Background
- Results
- Future Work



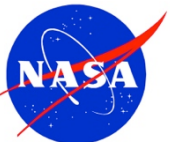
Outline

- Motivation
- Simulation Data
- Background
- Results
- Future Work



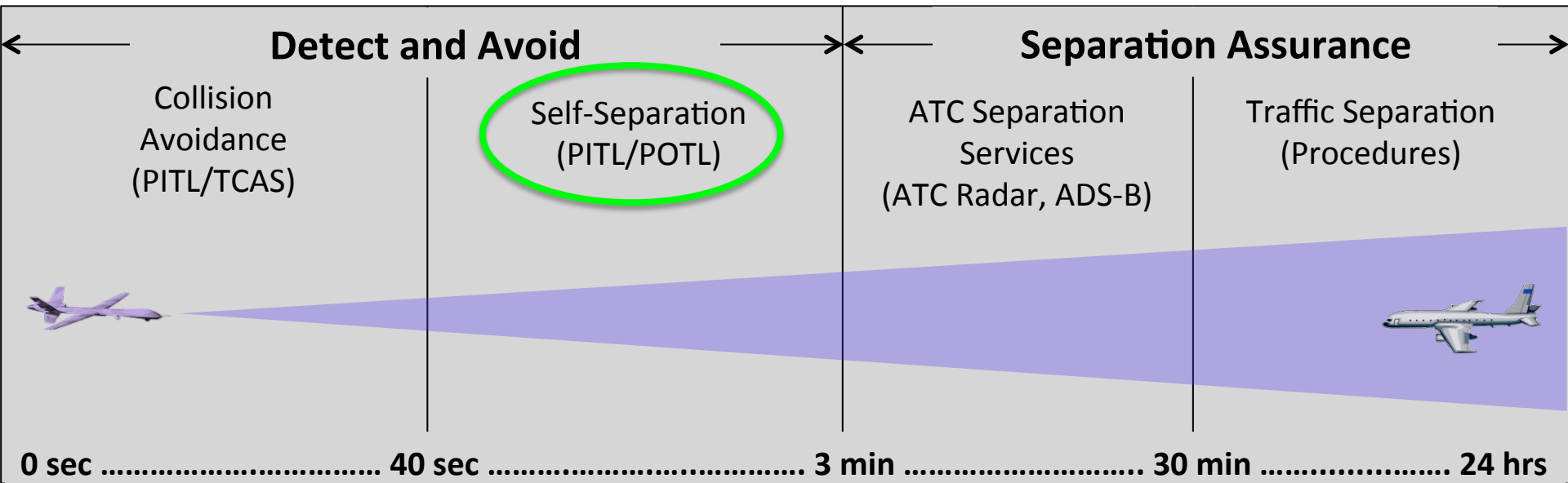
Motivation

- Investigate the airspace safety threshold of the NAS by analyzing encounter statistics of mitigated air traffic.
- No measure of current mitigation impact.
- Require a metric for future Detect and Avoid (DAA) systems on UAS so that the system is at least as good as current mitigations.



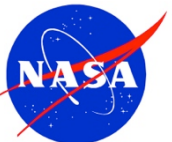
Assumptions

- Current safety level of the NAS can be measured through historical data that represents the result of air traffic mitigations
 - ATC separation services
 - See and avoid of pilots
- Future UAS will be IFR and self-separation will only be required against VFR traffic



Outline

- Motivation
- **Simulation Data**
- Background
- Results
- Future Work



Simulation Information

- Flight Data Set
 - 31,061 VFR
 - 50,360 IFR
 - Same day (7/25/2012)
 - NAS-wide
- ACES Set-up
 - AAC disabled (non-centralized Autoresolver)
 - SAA enabled
 - Attached to all VFR flights
 - Surveillance only, no resolving

2 Miles



1 Mile



1/2 Mile

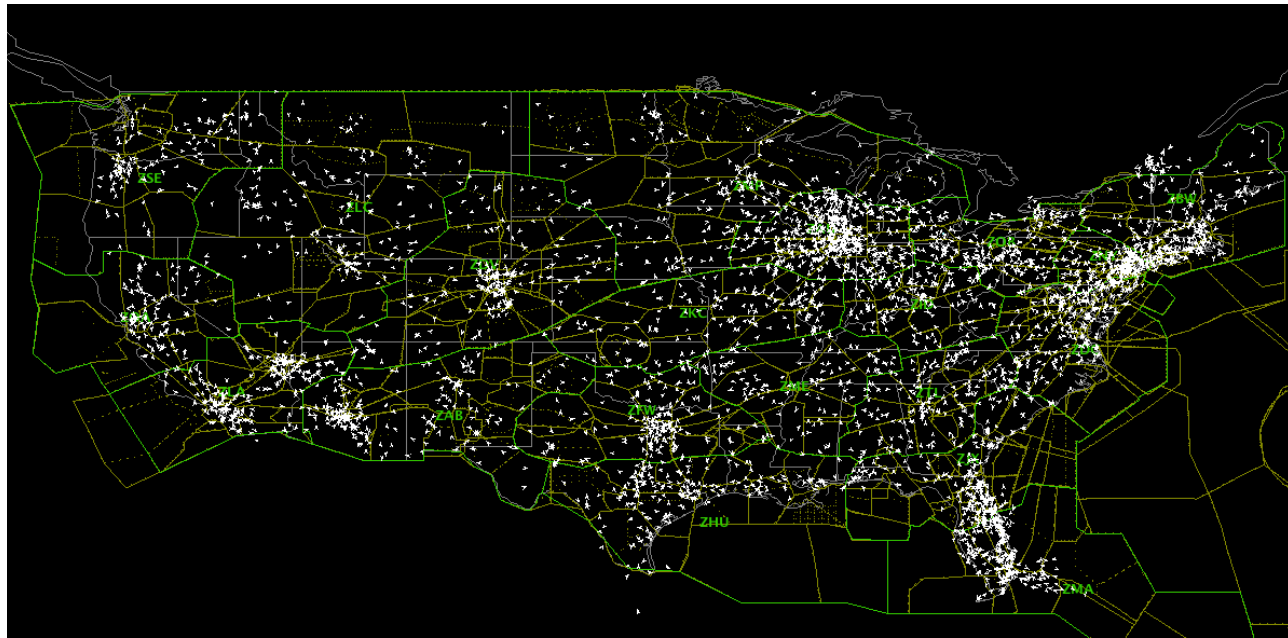


NEVERMIND



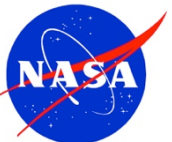
Simulation Results

- Database size: 728 GB
 - SaaEncounterStats size: 424 GB
- Total Flights: 73,395
 - 8,026 rejected (9.9%)



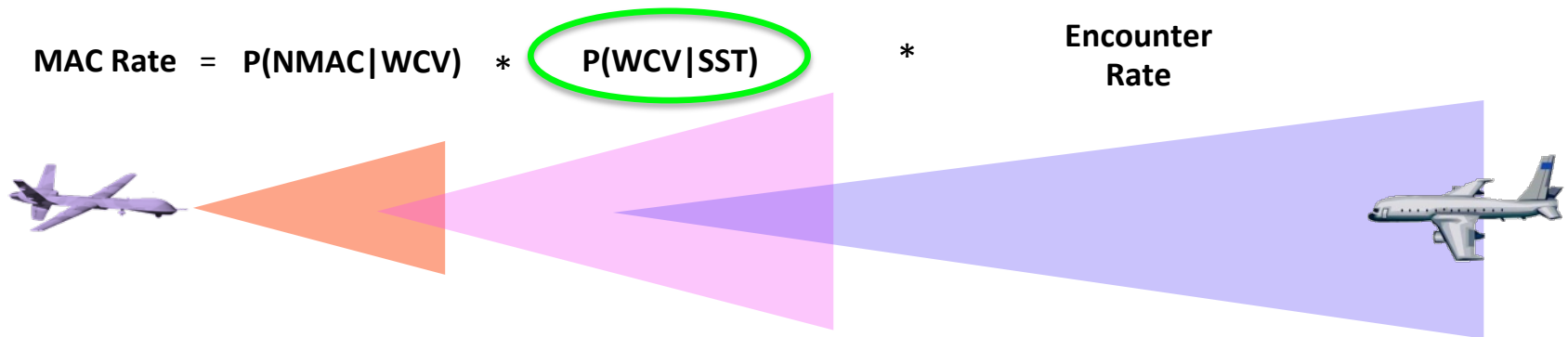
Outline

- Motivation
- Simulation Data
- **Background**
- Results
- Future Work



Determining a Safety Threshold

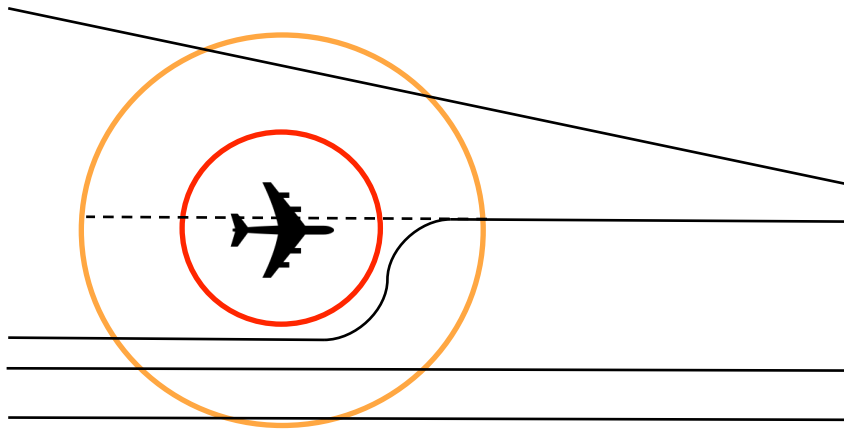
- A safety threshold for the NAS can be determined based on encounter probabilities for separation regions:



Determining a Safety Threshold – Risk Ratio

- Probability of an encounter based on current airspace mitigations is determined by a risk ratio and an unmitigated encounter rate:

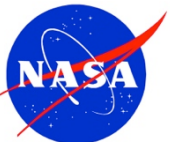
$$P(WCV|SST) = RR_{SS} \cdot \lambda_{unmit} \quad \text{where} \quad \lambda_{unmit} = \begin{array}{l} \text{encounter rate} \\ \text{if no mitigations} \end{array}$$



$$\lambda_{unmit} = 0.25$$

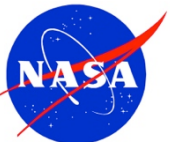
- The risk ratio (RR) is used to express the relative impact of a mitigation on airspace safety, independent of encounter geometry:

$$RR = \frac{\text{Mitigated WCV Rate}}{\text{Unmitigated WCV Rate}} \quad \text{where} \quad \text{WCV Rate} = \frac{\# \text{ Encounters}}{\text{Flight Hour}}$$



Definition of an Encounter

- Aircraft pair analyzed if within 30 nmi
- Considered an “encounter” if:
 - $\Delta h < 4000 \text{ ft}$
 - $\dot{r} \leq 0$
 - $\dot{h} \leq 0$



Definition of a Well Clear Violation

WCV definition has spatial and temporal criteria.

- Horizontal

1. $0 \text{ s} \leq \tau_m \leq 30 \text{ s}$

2. $r_{h,CPA} \leq DMOD$

} Both must be true

AND

- Vertical

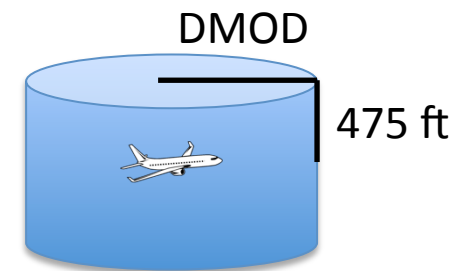
1. $0 \text{ s} \leq \tau_v \leq 30 \text{ s}$

2. $\Delta h \leq 475 \text{ ft}$

} One must be true

$$\tau_m = -\frac{r^2 - DMOD^2}{r \dot{r}}$$

$$\tau_v = -\frac{\Delta h}{\Delta \dot{h}}$$

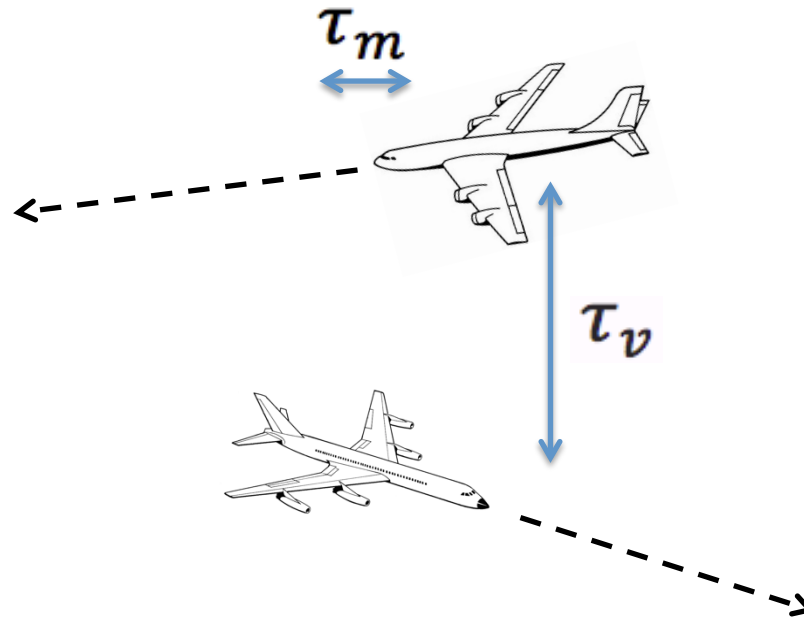


Thresholds			
τ_m (s)	τ_v (s)	Δh (ft)	DMOD (ft)
30	30	475	6000



Determining a Safety Threshold - Tau

- Calculate τ_m and τ_v at each point in time.
 - Higher of the two values characterizes the encounter at that time.

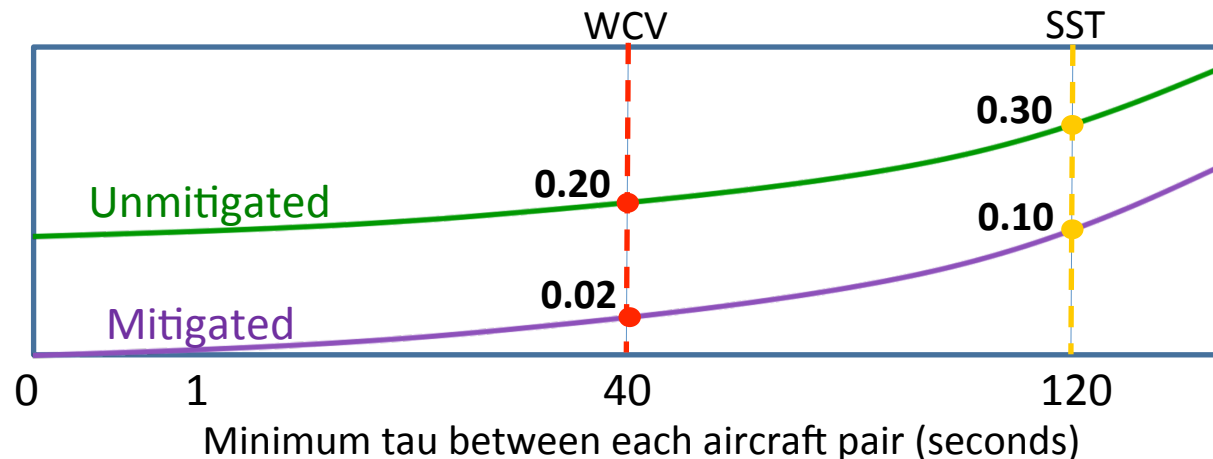


- The minimum of these values defines the encounter

Determining a Safety Threshold - Tau

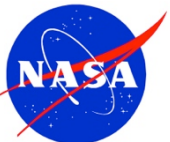
- Aggregate of Tau for each encounter creates a cumulative Tau distribution that determines the RR

$$RR = \frac{\text{Mitigated WCV Rate}}{\text{Unmitigated WCV Rate}} \quad \text{where} \quad \text{WCV Rate} = \frac{\# \text{ Encounters}}{\text{Flight Hour}}$$



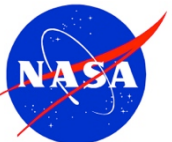
Number of encounters per VFR flight hour with tau below the minimum

Risk Ratios: $\frac{0.02}{0.20} = 0.10$ $\frac{0.10}{0.30} = 0.33$



Outline

- Motivation
- Simulation Data
- Background
- **Results**
- Future Work

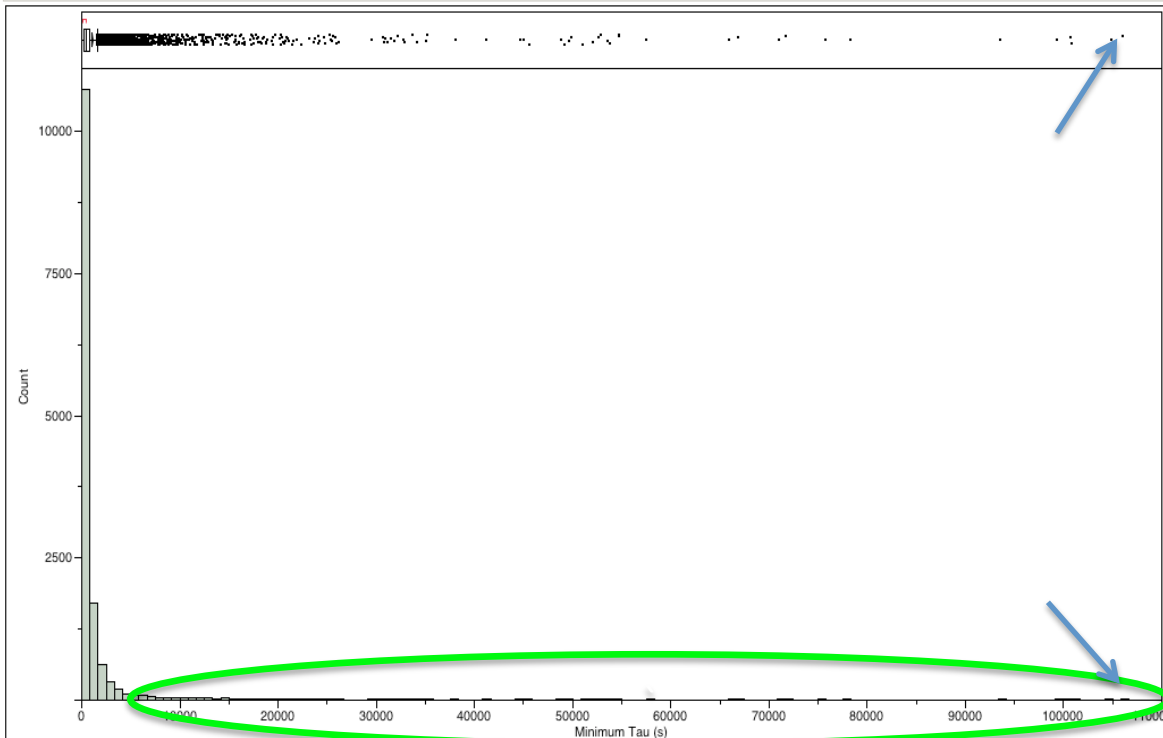


Results

- Sample of 1604/29770 VFR flights
 - 59,421 pairs within 30 nmi
 - 13,983 encounters meeting $r_{h,CPA} < DMOD$, $\tau \geq 0$
 - 75 WCV

Distributions

tauMin



Quantiles

100.0%	maximum	106045
99.5%		20505.2
97.5%		5894.07
90.0%		1851.25
75.0%	quartile	785.12
50.0%	median	406.062
25.0%	quartile	240.657
10.0%		136.022
2.5%		57.2879
0.5%		0
0.0%	minimum	0

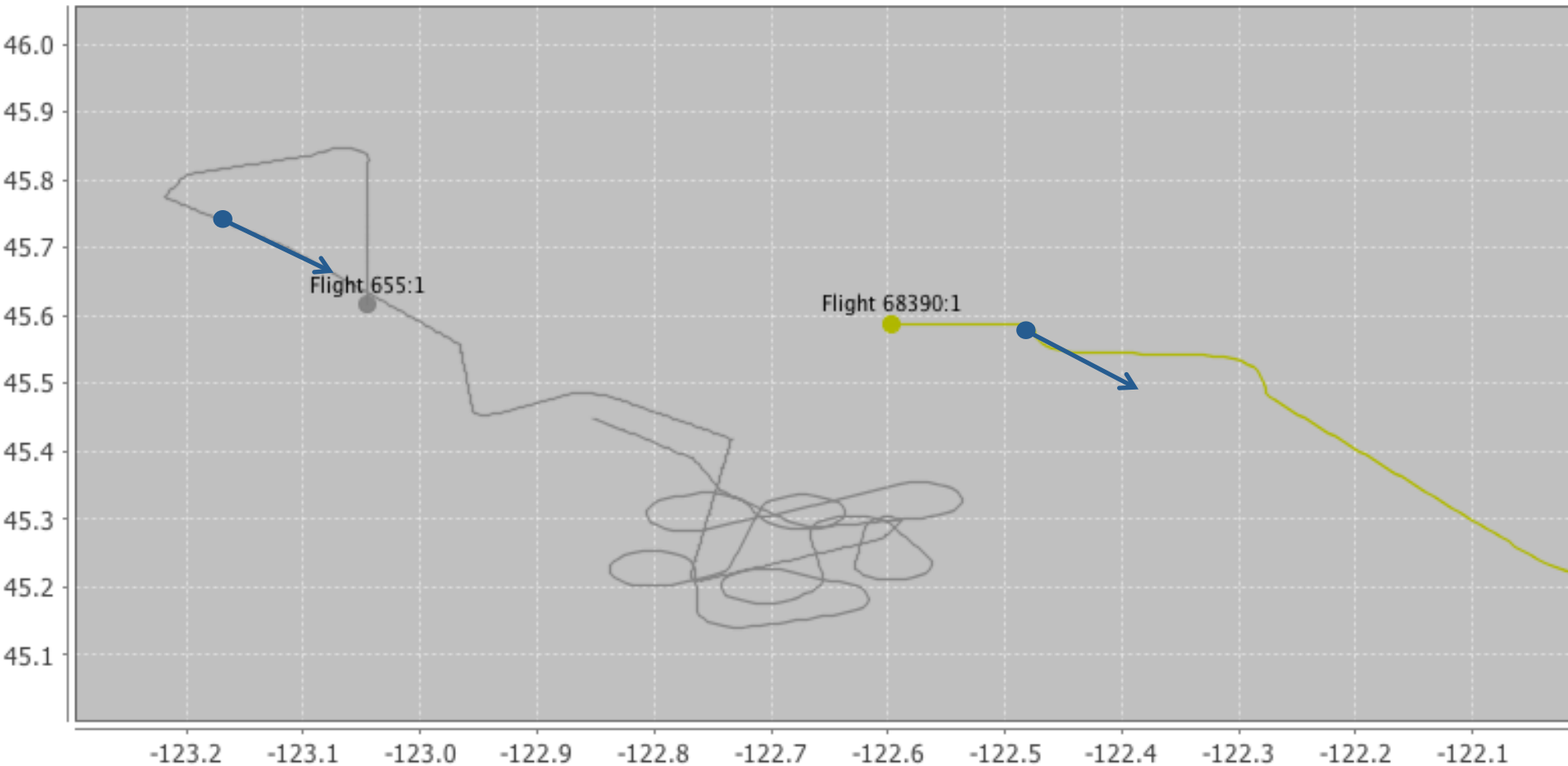
Summary Statistics

Mean	1077.629
Std Dev	3772.1378
Std Err Mean	31.899757
Upper 95% Mean	1140.1568
Lower 95% Mean	1015.1012
N	13983

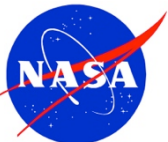
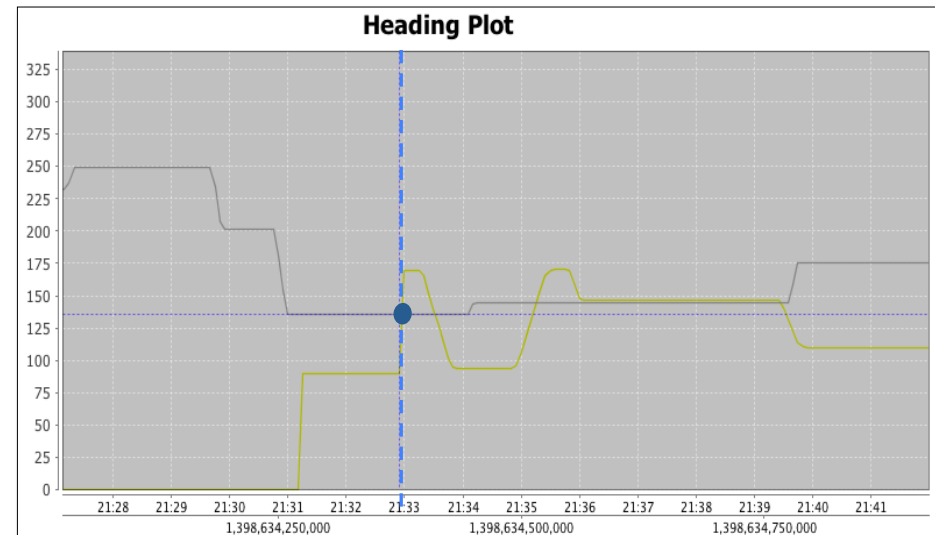
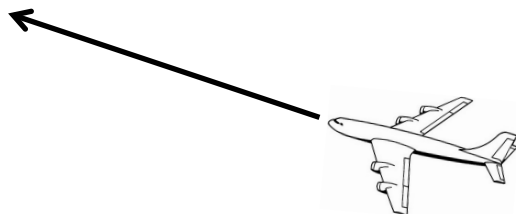
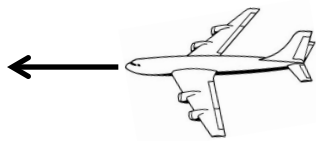
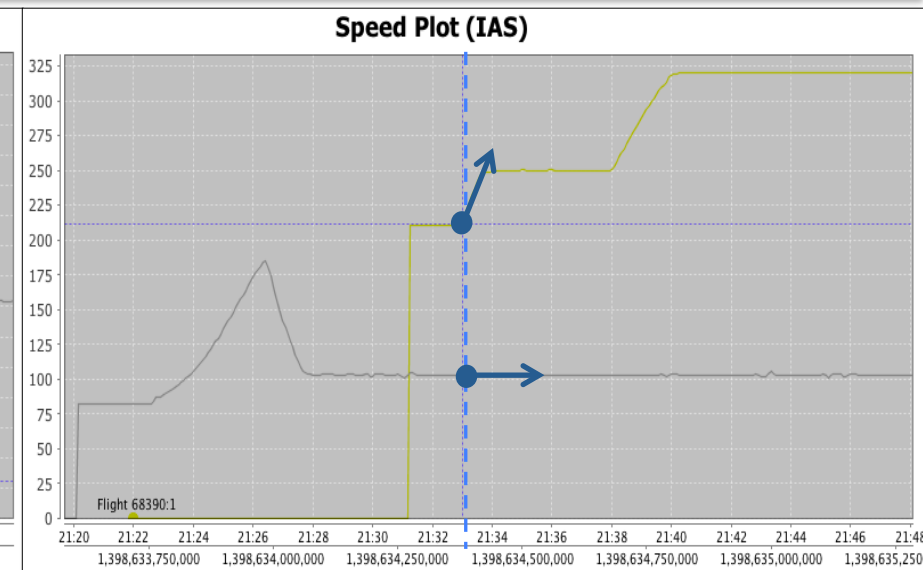
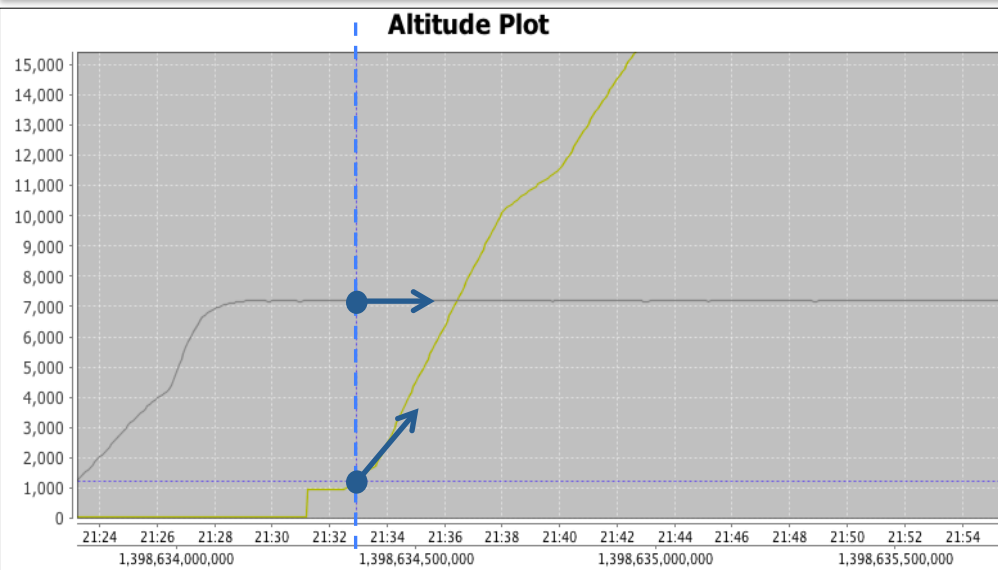


Results – Outlier Case

Lateral Path



Results – Outlier Case

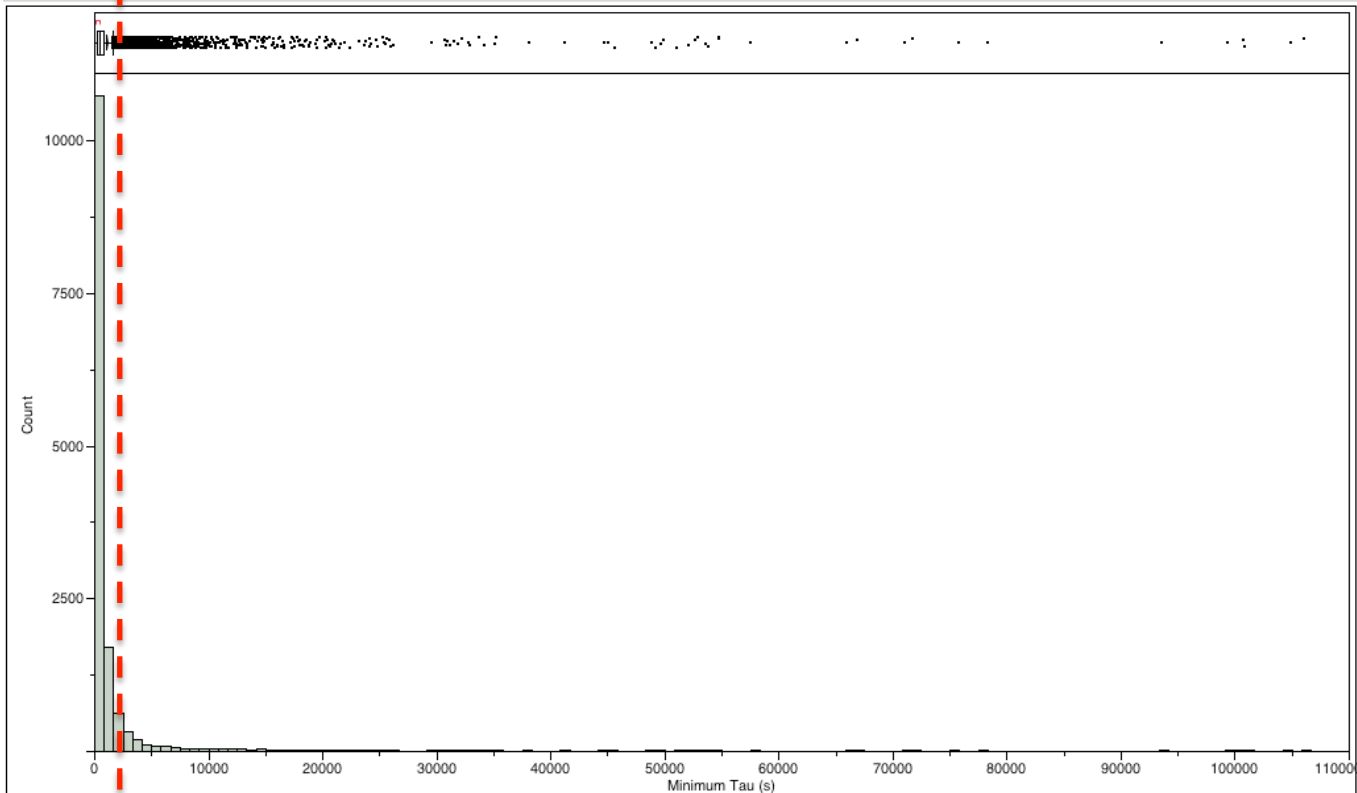


Results

- Sample of 1604 flights, 13983 encounters.

Distributions

tauMin



Quantiles

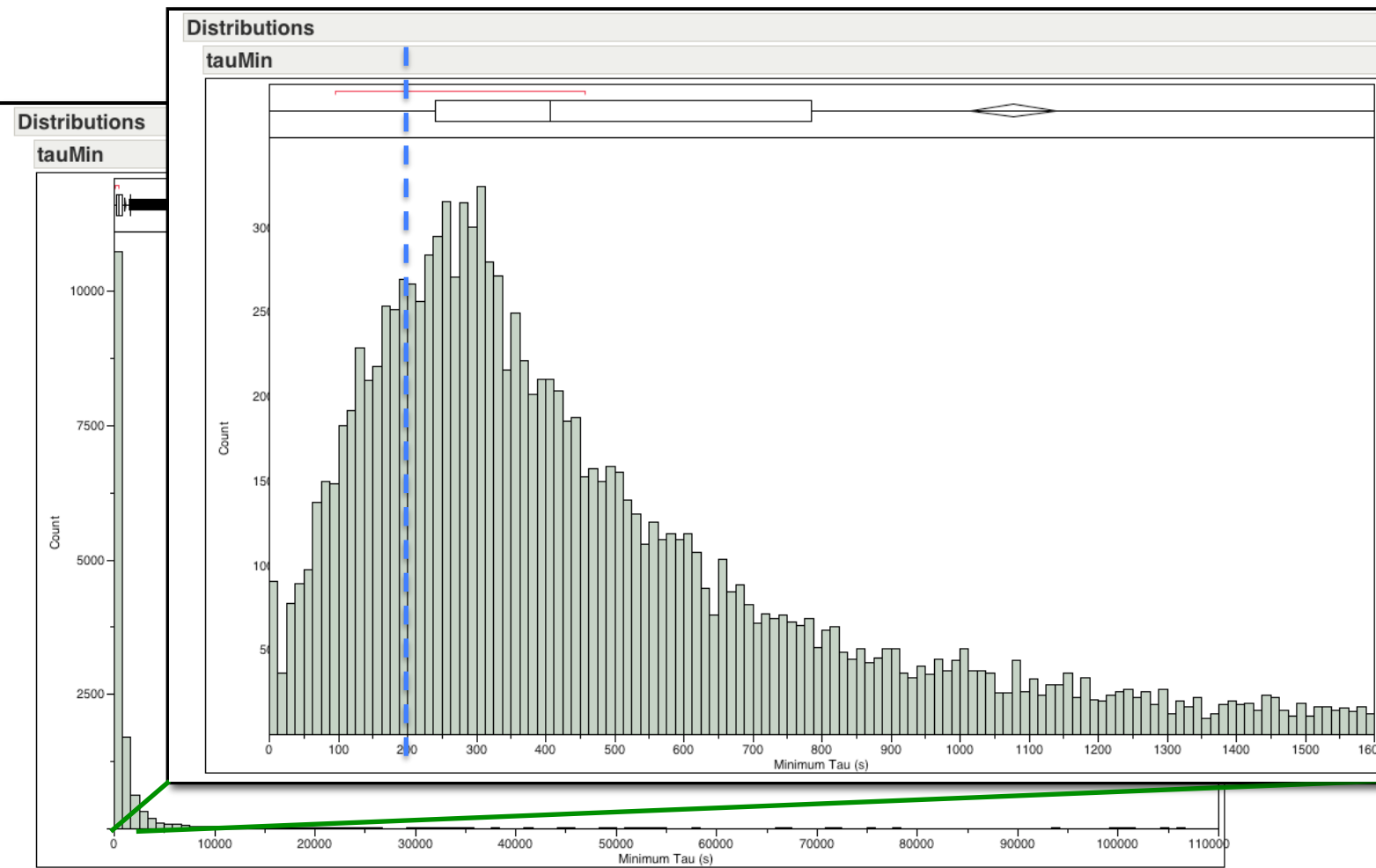
100.0%	maximum	106045
99.5%		20505.2
97.5%		5894.07
90.0%		1851.25
75.0%	quartile	785.12
50.0%	median	406.062
25.0%	quartile	240.657
10.0%		136.022
2.5%		57.2879
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	1077.629
Std Dev	3772.1378
Std Err Mean	31.899757
Upper 95% Mean	1140.1568
Lower 95% Mean	1015.1012
N	13983



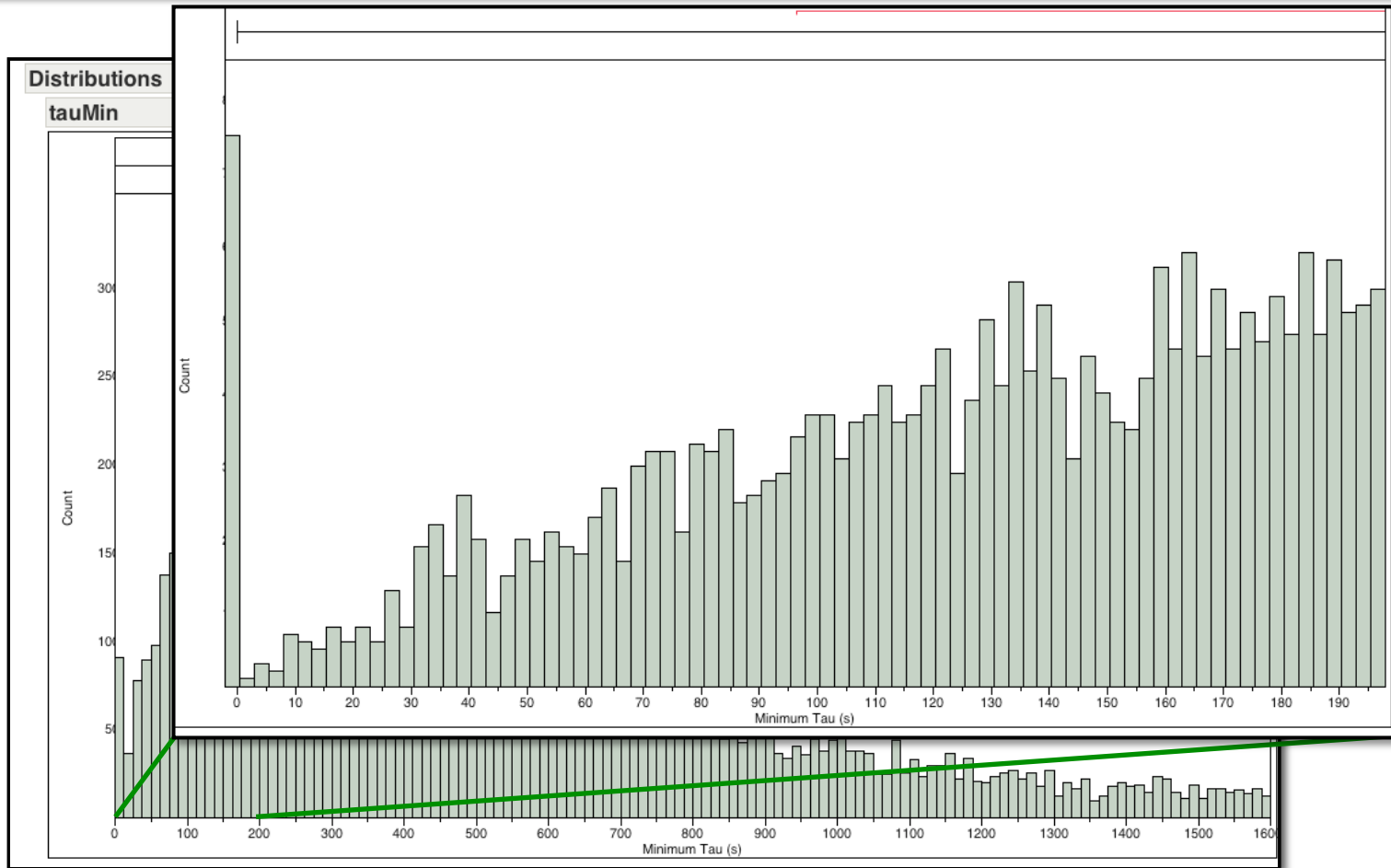
Results



$N = 12,329$

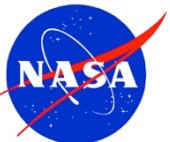
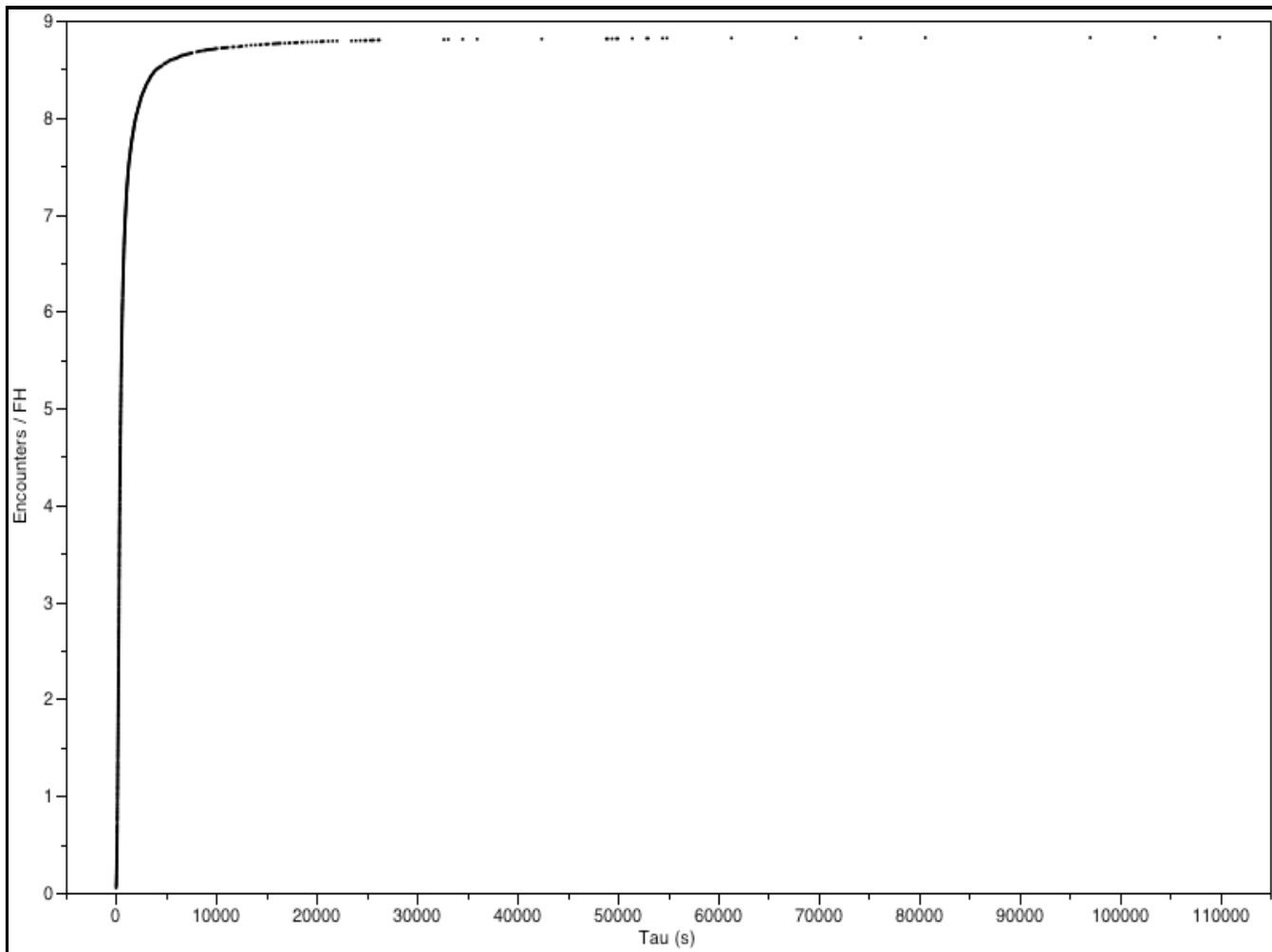


Results

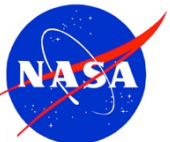
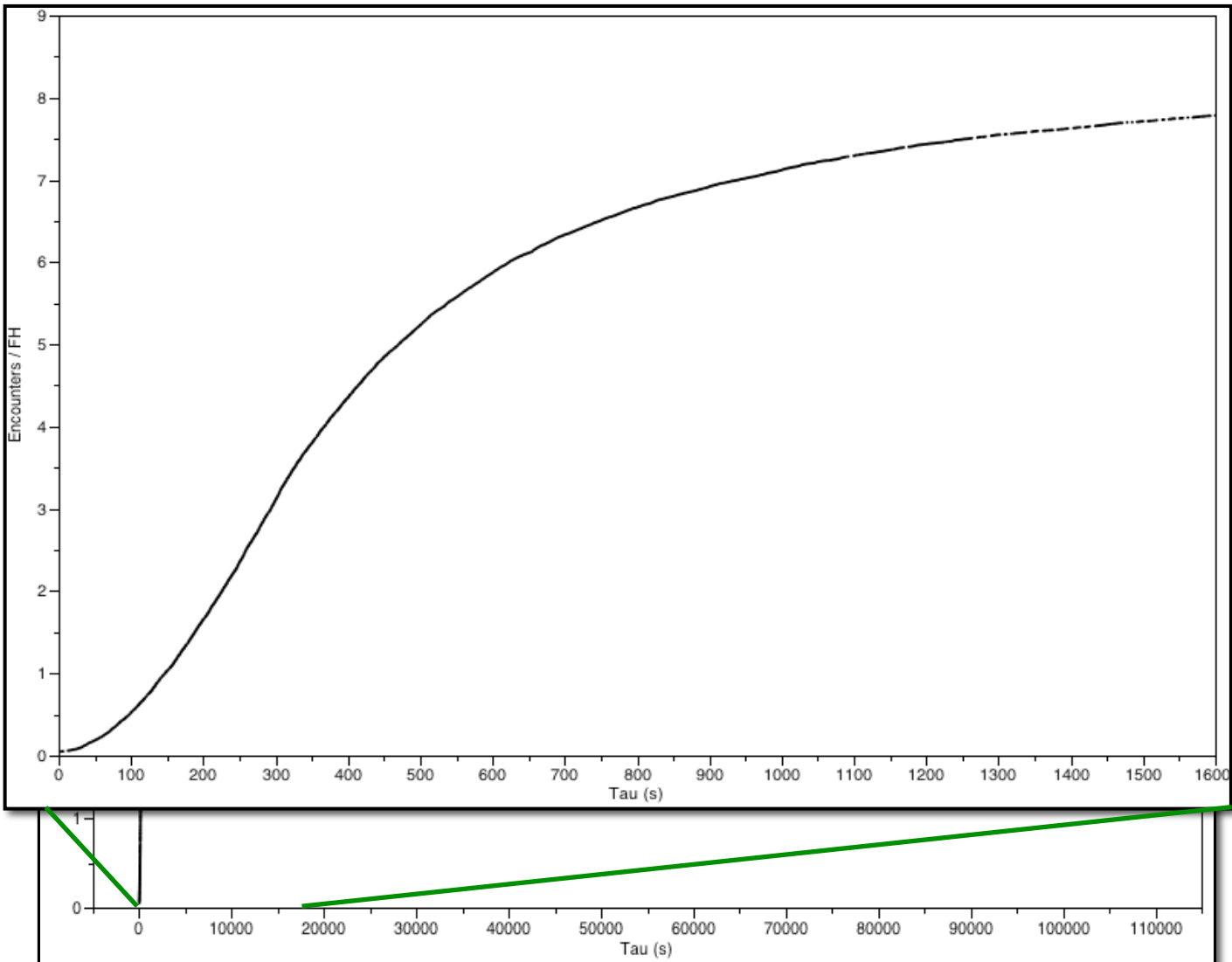


N = 2,623

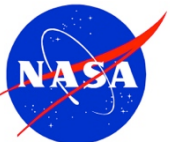
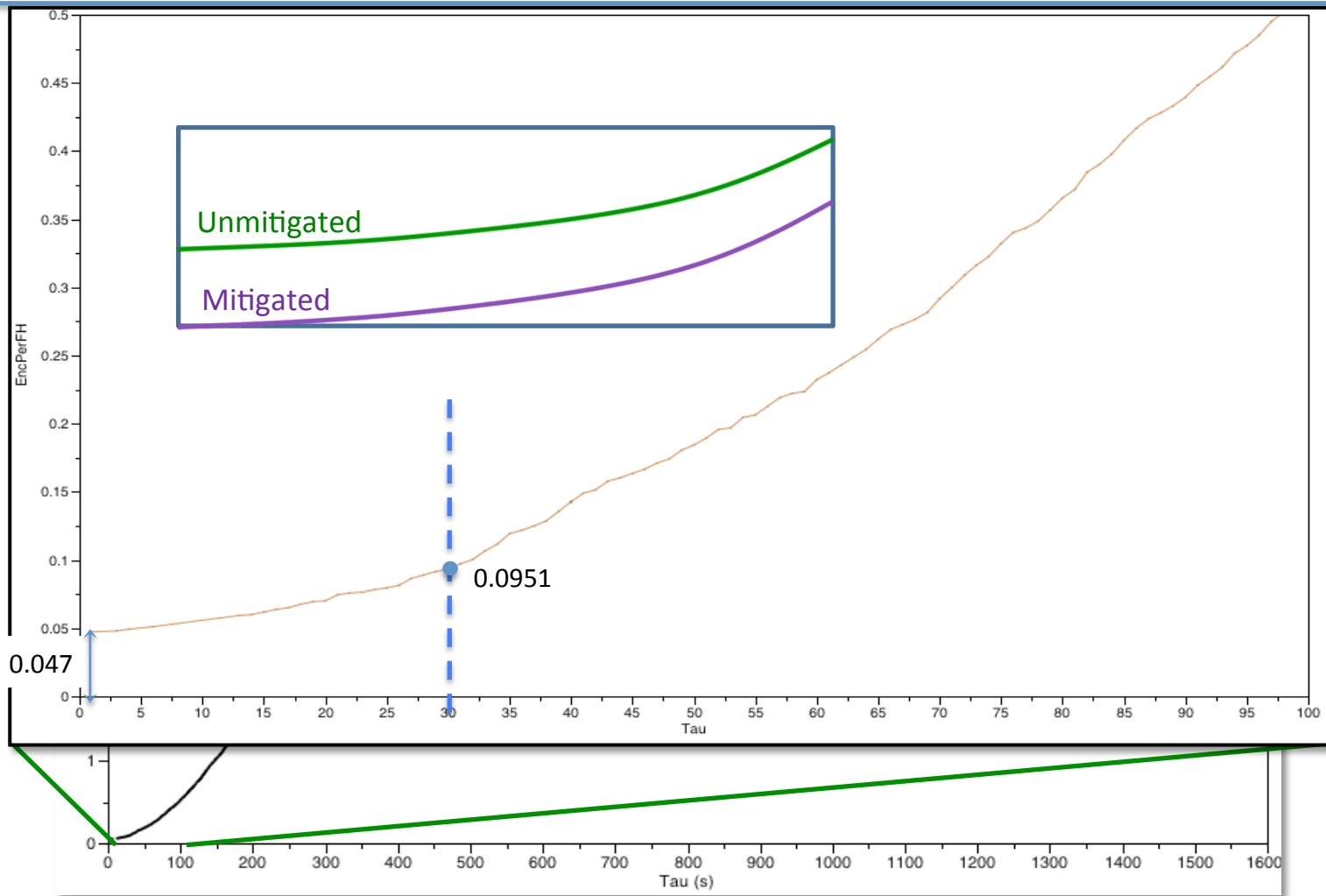
Results



Results

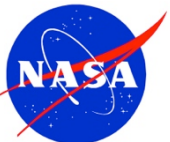


Results



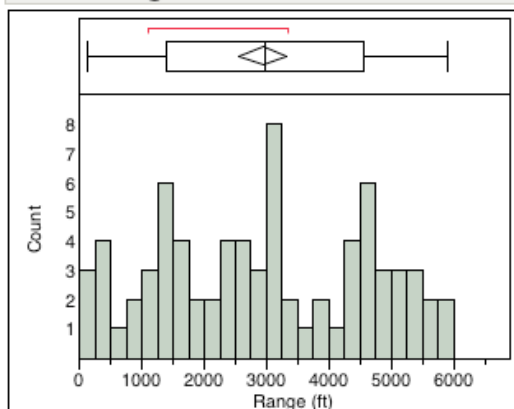
Results – WCV Encounter Statistics

- 75 WCV out of:
 - 59,421 aircraft pairs = 0.126%
 - 13,983 encounters = 0.536%



Results – WCV Encounter Statistics

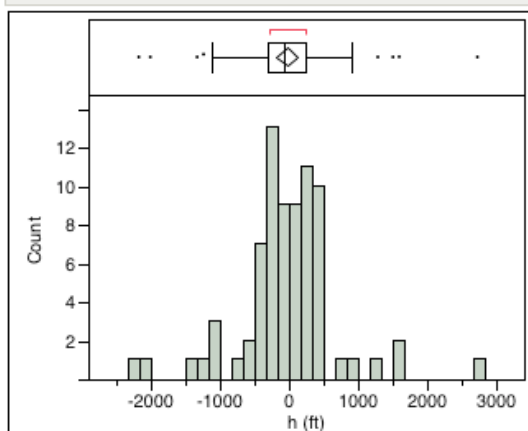
Slant Range



N	75
Maximum	5893.82
Mean	2943.26
Median	2977.29
Minimum	121.52
Std Dev	1649.26

- Evenly distributed

h

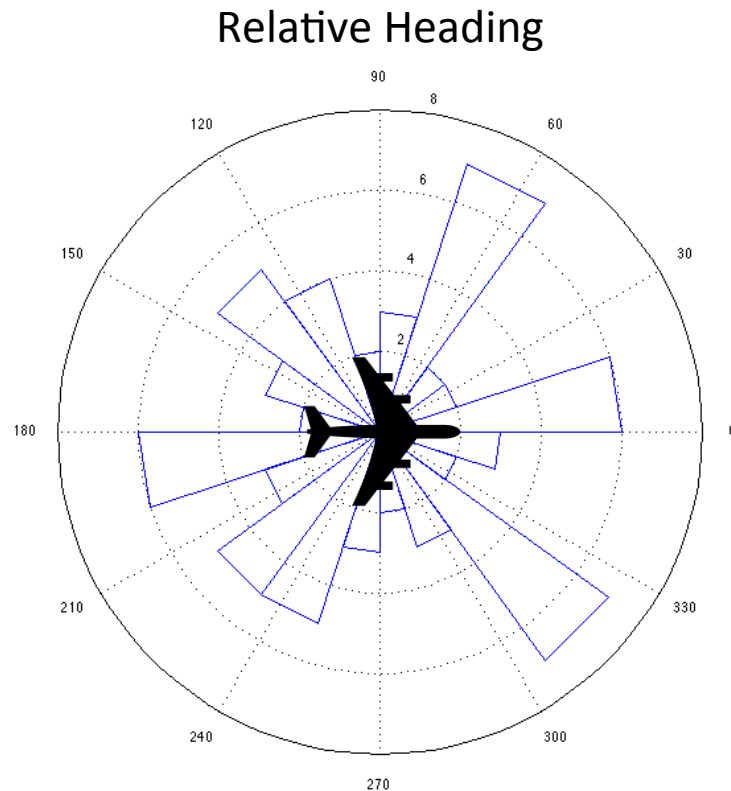


N	75
Maximum	2738
Mean	-33.24
Median	-68
Minimum	-2184
Std Dev	704.43

- Majority met 475 ft spatial threshold



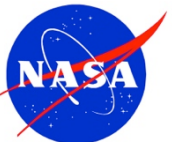
Results – WCV Encounter Statistics



N	75
Maximum	180
Mean	98.94
Median	109
Minimum	0
Std Dev	59.81

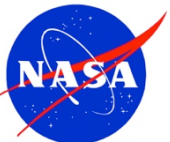
Outline

- Motivation
- Simulation Data
- Background
- Results
- **Future Work**



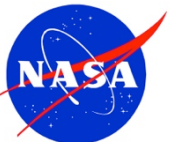
Future Work

- Unmitigated study analysis
- Further analyze encounter statistics
 - Possible relationships (i.e. relative heading vs relative velocity)
- Further investigate anomalous data points
- Optimize code for efficiency



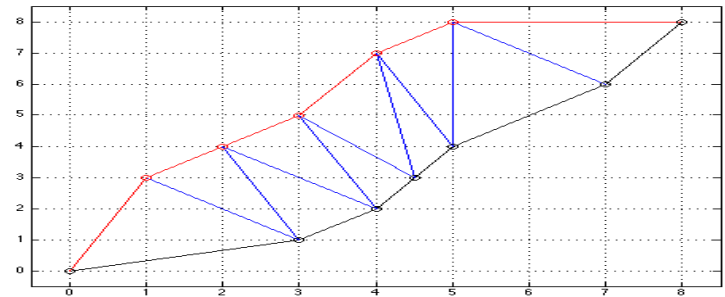
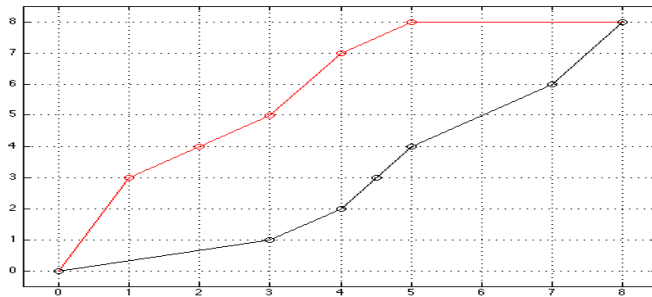
Challenges Faced

- Large databases
 - Memory issues
 - Code efficiency
 - Time required for analysis
- Balancing priorities between different studies
- Shift of studies over time

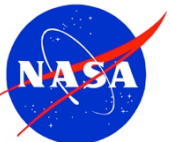


Other Projects

- Direction of studies shifted over time
 - Familiarization with:
 - ATM concepts, Java, MySQL, ACES, JMP, GIT
 - Calculating path lateral deviation as another metric for Autoresolver

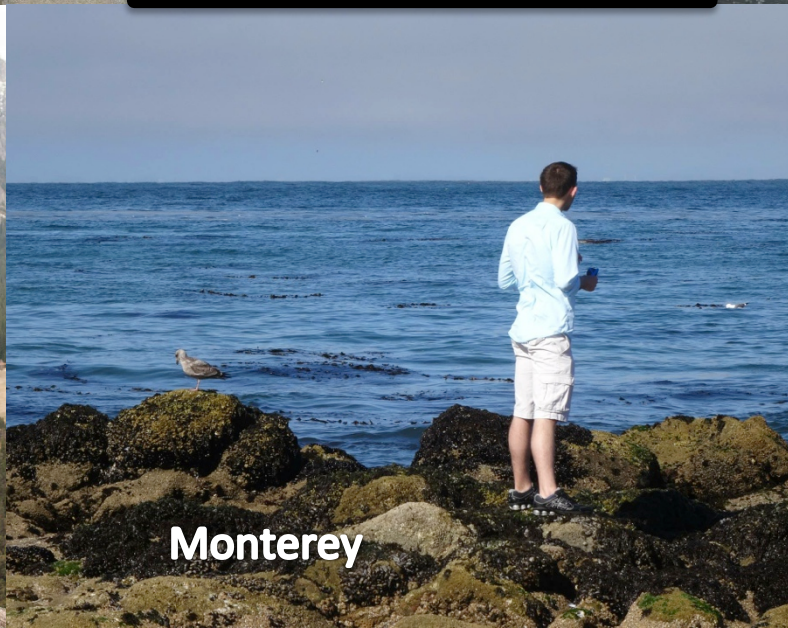


- Calculating range between all aircraft pairs NAS-wide
- Determining the effectiveness of Autoresolver
 - Cost function results
 - Number of reversals, succeeded maneuvers, reduced trialplan time

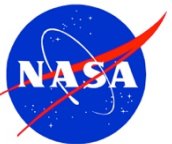




Questions?

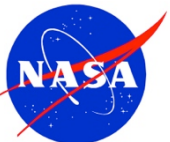


Backup Slides



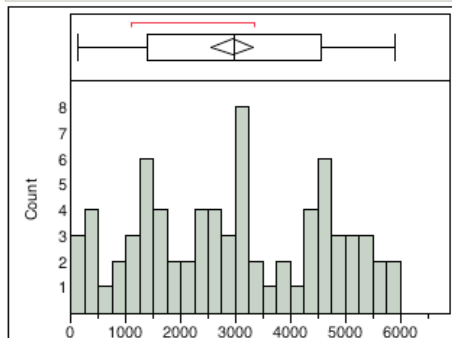
Definition of an Encounter

- Aircraft pairs are analyzed if within 30 nmi horizontal range
- Considered an “encounter” if:
 - $\Delta h < 4000 \text{ ft}$
 - $r_{h,CPA} < DMOD$
 - *If $\dot{h} = 0$, then $\Delta h < 475$*
 - $\tau_m \geq 0$
 - $\tau_v \geq 0$



Results – WCV Encounter Statistics

Slant Range



Quantiles

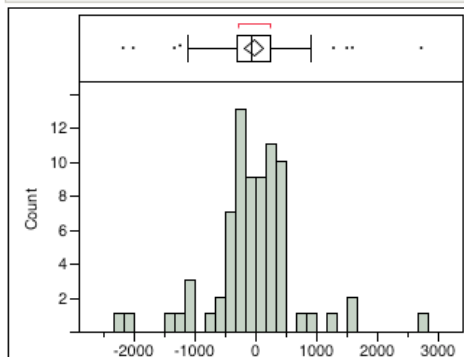
100.0%	maximum	5893.82
99.5%		5893.82
97.5%		5839.13
90.0%		5249.75
75.0%	quartile	4557.08
50.0%	median	2977.29
25.0%	quartile	1397.5
10.0%		631.914
2.5%		230.892
0.5%		121.522
0.0%	minimum	121.522

Summary Statistics

Mean	2943.2628
Std Dev	1649.2591
Std Err Mean	190.44004
Upper 95% Mean	3322.7229
Lower 95% Mean	2563.8028
N	75

- Within DMOD = 6000 ft
- Relatively evenly distributed

h



Quantiles

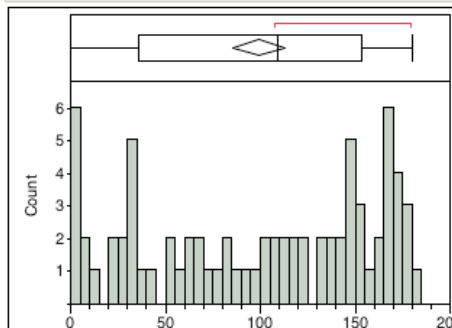
100.0%	maximum	2738
99.5%		2738
97.5%		1715.6
90.0%		463.4
75.0%	quartile	250
50.0%	median	-68
25.0%	quartile	-311
10.0%		-910.6
2.5%		-2033.7
0.5%		-2184
0.0%	minimum	-2184

Summary Statistics

Mean	-33.24
Std Dev	704.42658
Std Err Mean	81.340175
Upper 95% Mean	128.83384
Lower 95% Mean	-195.3138
N	75

- Majority met 475 ft spatial threshold

Rel Heading



Quantiles

100.0%	maximum	180
99.5%		180
97.5%		179.73
90.0%		170.88
75.0%	quartile	153.7
50.0%	median	109
25.0%	quartile	36.1
10.0%		5.9
2.5%		0.18
0.5%		0
0.0%	minimum	0

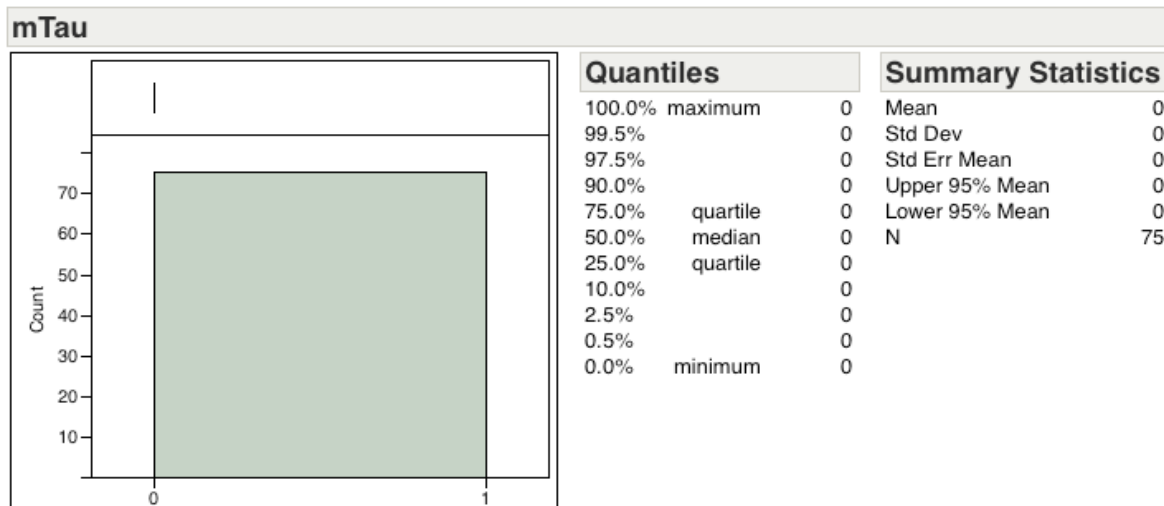
Summary Statistics

Mean	98.937333
Std Dev	59.812755
Std Err Mean	6.906582
Upper 95% Mean	112.699
Lower 95% Mean	85.175668
N	75

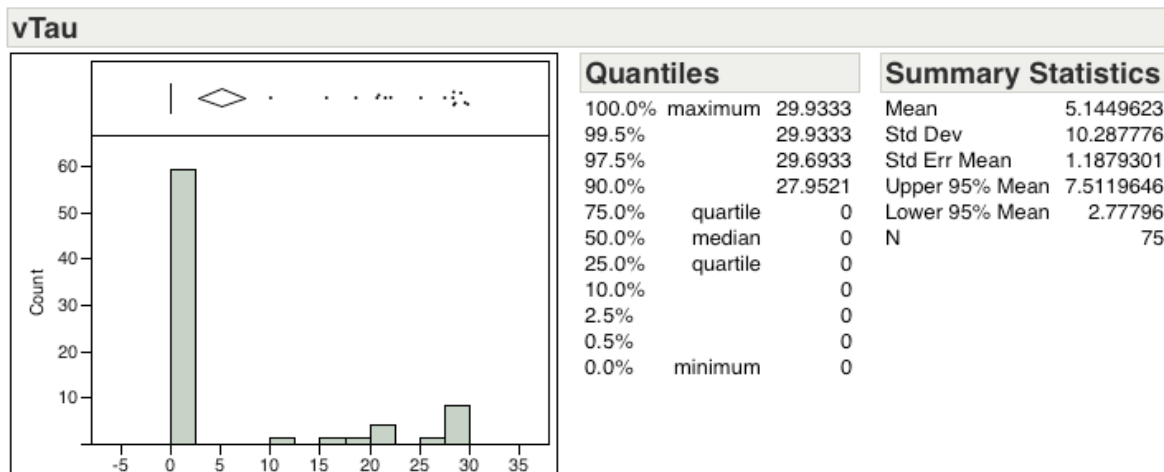
- Most are in near-parallel flight paths (0°, 180°)
 - Skewed left
 - More head-on



Results – WCV Encounter Statistics



- Redefined to 0 once WCV occurred

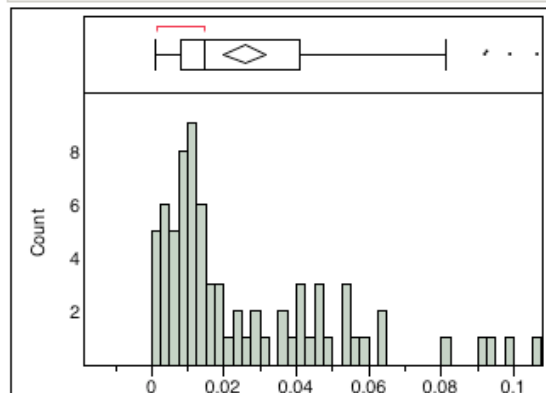


- Redefined to 0 if within 475ft threshold
- Non-zero values met temporal threshold (30 s)



Results – WCV Encounter Statistics

rDot



Quantiles

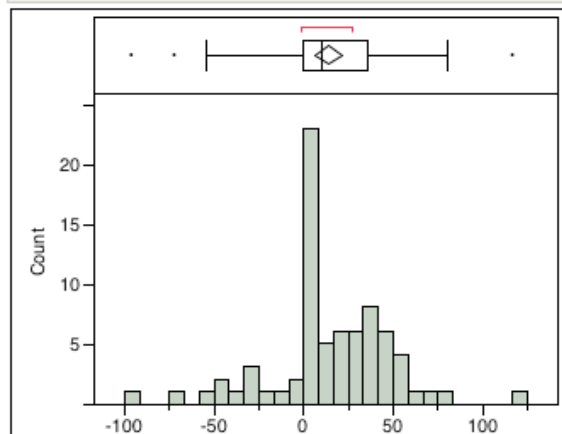
100.0%	maximum	0.10667
99.5%		0.10667
97.5%		0.09992
90.0%		0.06056
75.0%	quartile	0.04083
50.0%	median	0.01444
25.0%	quartile	0.00806
10.0%		0.00267
2.5%		0.00133
0.5%		0.00083
0.0%	minimum	0.00083

Summary Statistics

Mean	0.0257889
Std Dev	0.0255606
Std Err Mean	0.0029515
Upper 95% Mean	0.0316698
Lower 95% Mean	0.0199079
N	75

- Requires further investigation

hDot



Quantiles

100.0%	maximum	117
99.5%		117
97.5%		83.7
90.0%		50.8
75.0%	quartile	36
50.0%	median	10
25.0%	quartile	0
10.0%		-30
2.5%		-74.4
0.5%		-96
0.0%	minimum	-96

Summary Statistics

Mean	13.88
Std Dev	33.876549
Std Err Mean	3.9117269
Upper 95% Mean	21.674286
Lower 95% Mean	6.085714
N	75

- Requires further investigation