ACES Preliminary Results Supporting Selection of SARP Well-Clear Definition

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TCAS Model Summary

- As a proxy for whether a TCAS Corrective RA would be presented we use model published by NASA Langley in GNC 2013 paper

- Given UAV encounter, TCAS RA model is computed from standpoint of the intruder (assumed TCAS equipped)

- At every cycle as intruder encounters UAV, we compute if Equation (12) and Equation (14) are true, then its marked as a TCAS RA

- Mathematical model is the same as the one used by NASA and MIT-LL for well-clear definition (modTau and time to co-alt)

- However, altitude dependent thresholds are used based on intruder's own altitude

- Also, there is a single tau threshold (for SARP we decoupled modTau and vertTau)

TCAS RA Model Altitude Dependent Thresholds

Own Altitude (ft)	SL	Tau (sec)	DMOD (nmi)	ZTHR (ft)	ALIM (ft)	HMD (ft)
1000 - 2350	3	15	0.20	600	300	1215
2350 - 5000	4	20	0.35	600	300	2126
5000 - 10000	5	25	0.55	600	350	3342
10000 - 20000	6	30	0.80	600	400	4861
20000 - 42000	7	35	1.10	700	600	6683
> 42000	7	35	1.10	800	700	6683

Intruder Altitude: 2,000 ft – 17,999ft

* Source: "A TCAS-II RESOLUTION ADVISORY DETECTION ALGORITHM,"
Cesar Muñoz, Anthony Narkawicz, and James Chamberlain,
AIAA Guidance, Navigation, and Control Conference, 2013.
Table 1: TCAS Sensitivity Level Definition and Alarm Thresholds for RAs

TCAS RA Model

```
[( r <= DMOD) or
        ((0 <= tau_mod <= tau_thresh) and
        (HMD <= HMD_thresh))]


    and


[(h <= ZTHR) or
        (0 <= vert_tau <= tau_thresh)]
```

TCAS RA Metrics

- Unmitigated
  - Probability of WCV with TCAS RA prior to WCV
- Mitigated
 - TCAS RA rate (per flight hour)
  - No presenting today (August)

TCAS-RA Unmitigated ACES Result

<u>Probability of Well-Clear Violation (WCV) with TCAS RA prior to WCV</u>

- Assumption: Intruders (manned) experiencing TCAS-RA's while UAS DAA system detects it as well-clear is undesirable.

- The smaller the better

- $$\frac{\text{Number of WCVs with TCAS-RA prior to WCV}}{\text{Total Number of WCVs}}$$

- To measure TCAS RA used data from 2 seconds prior to WCV

TCAS-RA Unmitigated ACES Result
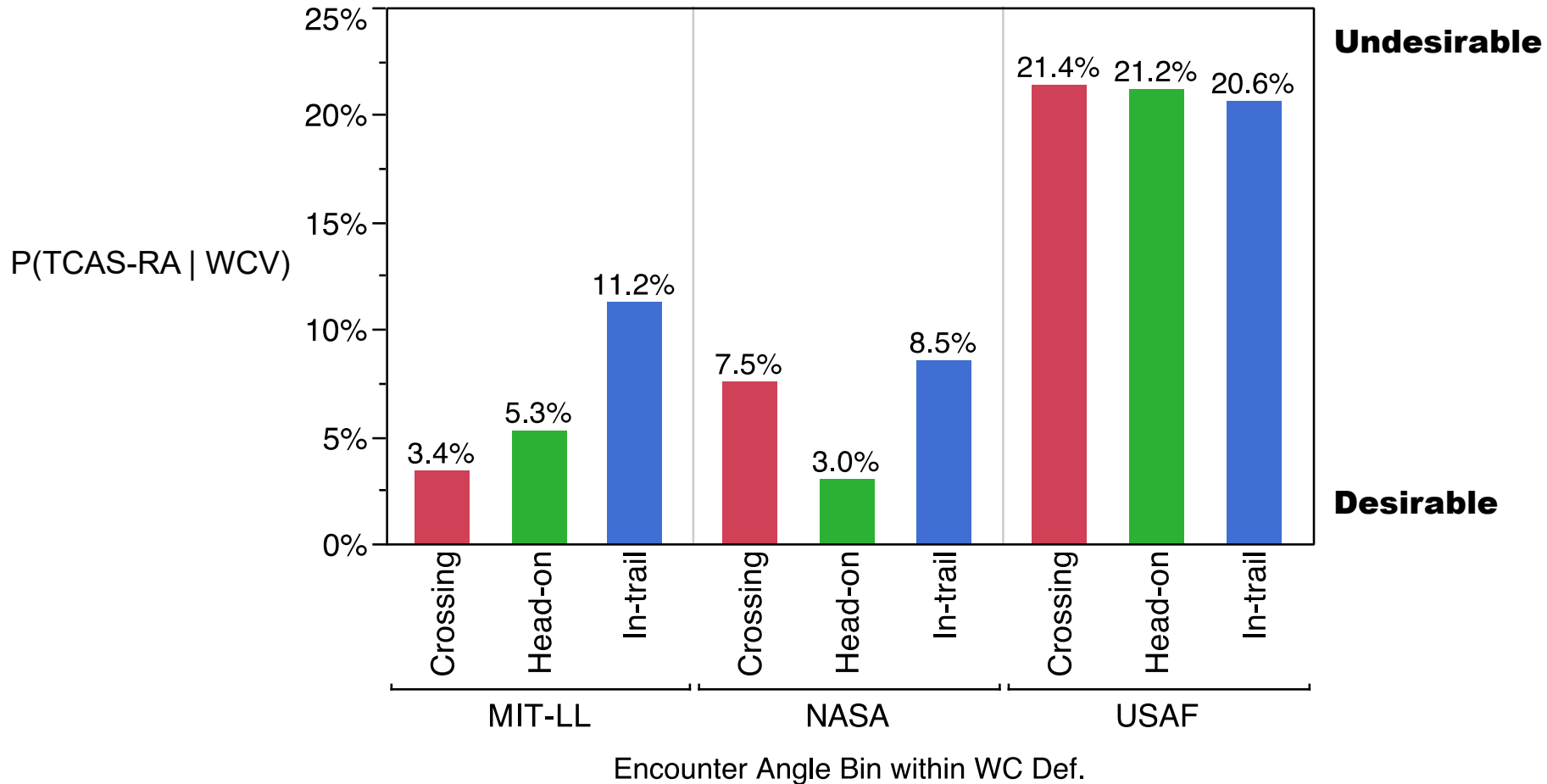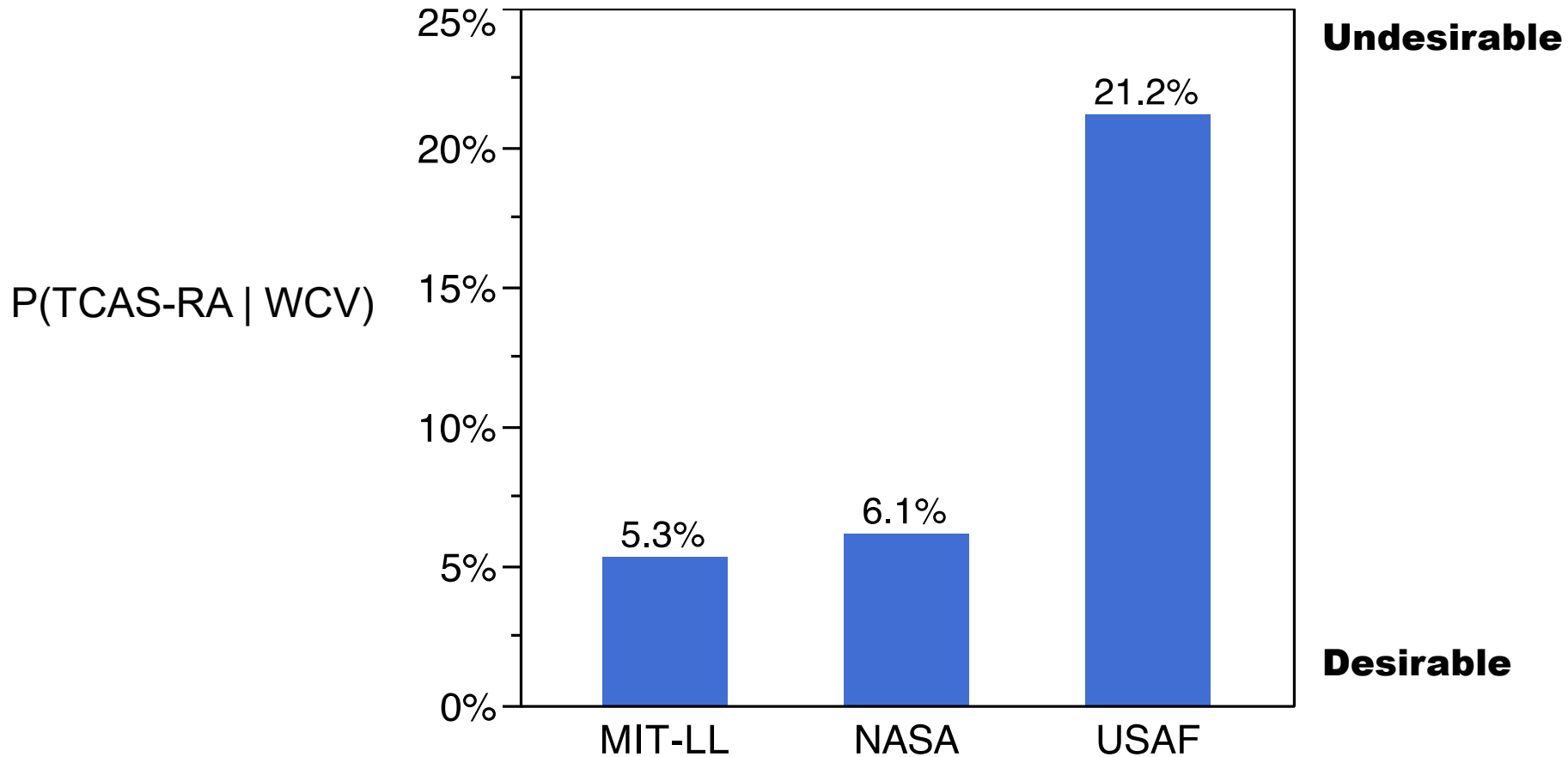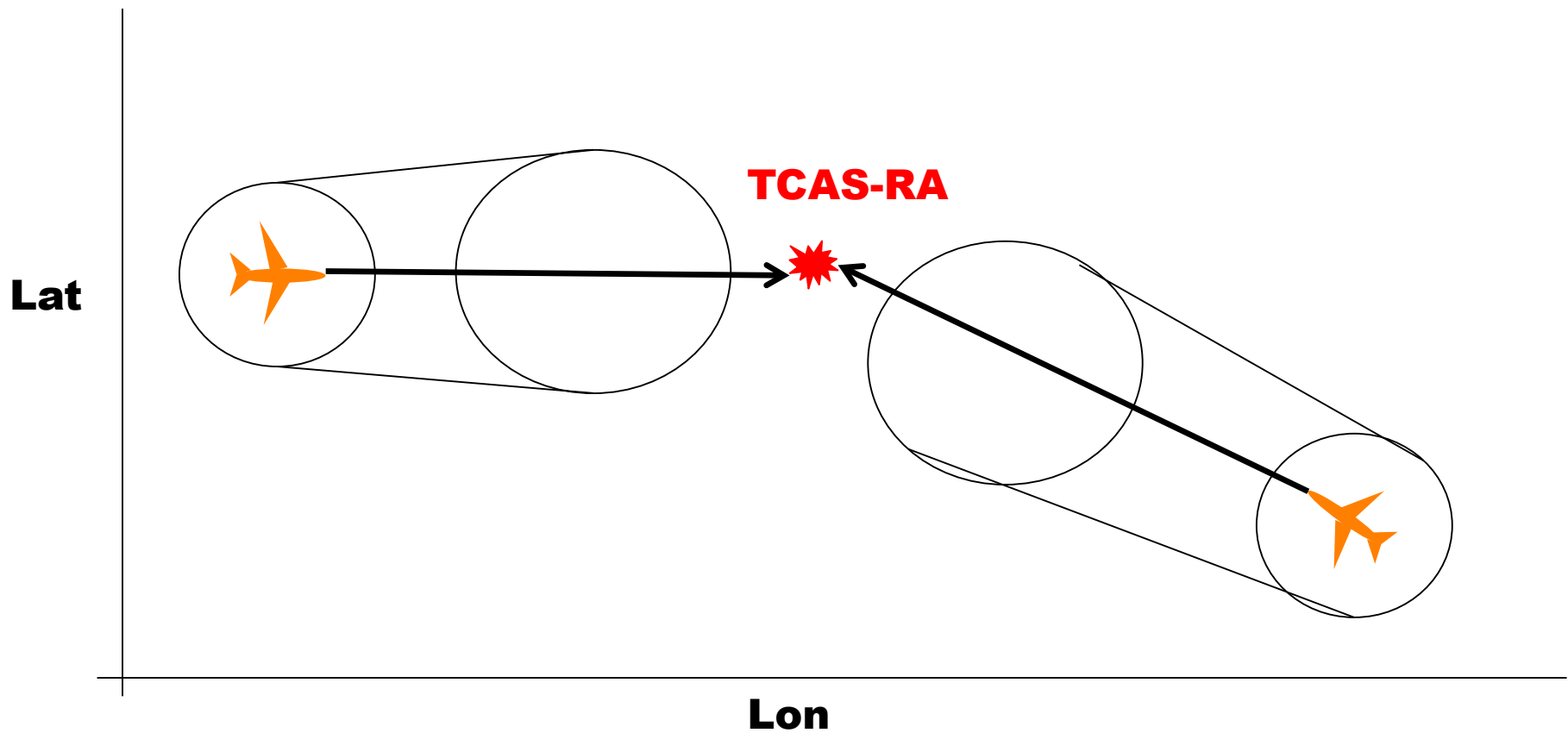
TCAS-RA Unmitigated ACES Result

Illustration of Typical USAF Case with TCAS-RA

- A lot of the time, TCAS-RA model which is based on modTau triggers further out than the length of the horizontal cone for head-on and crossing encounters
- More of an issue in the modTau, rather than the Z_THR

WCV Rate Unmitigated ACES Result

Well-Clear Volume Penetration Rate per Flight Hour

- Intuition tells me the lower the rate the better.
- The complement is interesting, because the higher the rate points to presumably that the well-clear definition is larger, which may make the system safe, however may not be acceptability to the ATC.
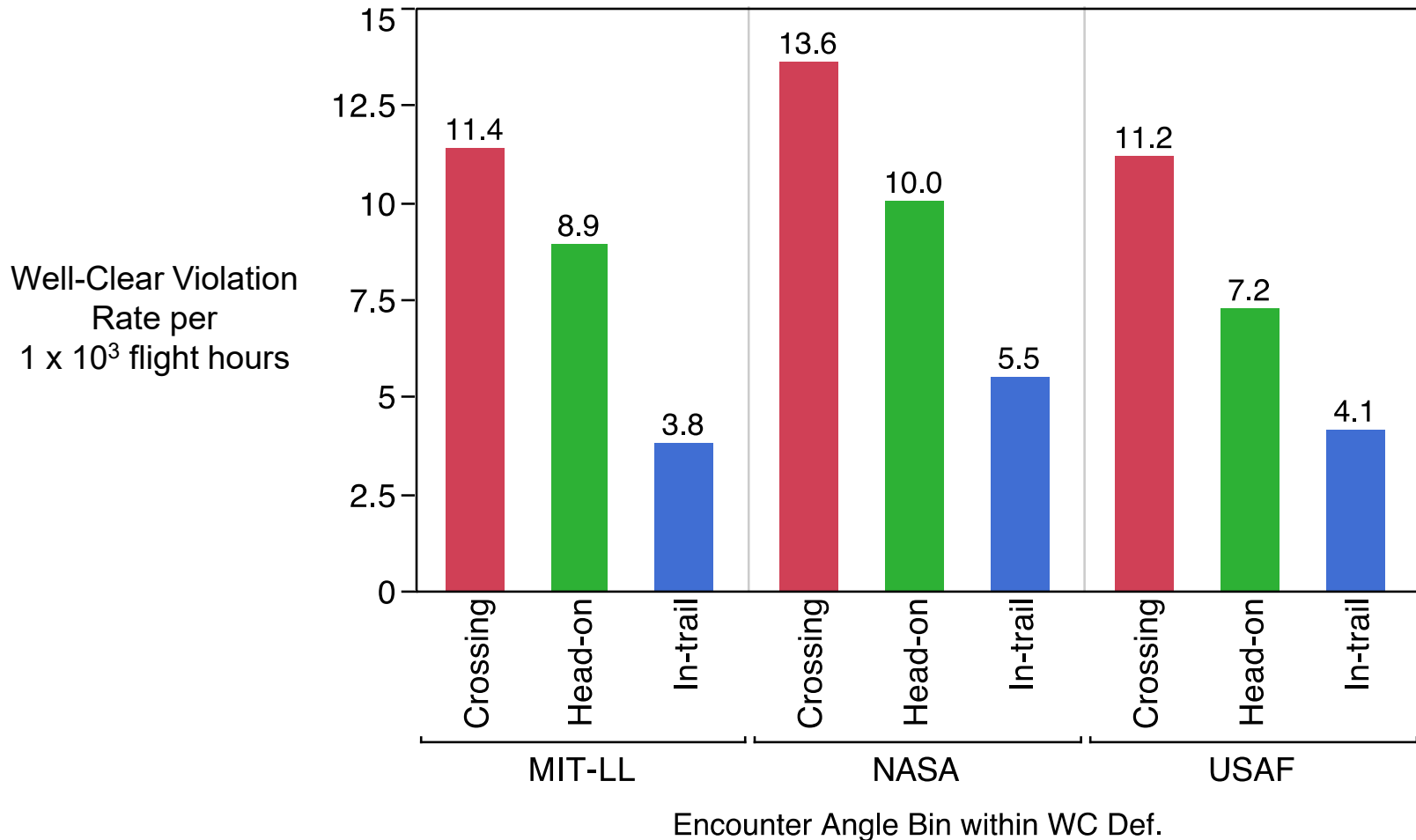- There is a tradeoff here…

$$\frac{\text{Number of WCVs}}{\text{Number of flight hours}}$$

WCV Rate Unmitigated ACES Result

WCV Rate Unmitigated ACES Result

Well-Clear Violation Rate per 1×10^3 flight hours

Encounter Angle Bin within WC Def.

Encounter Angle Bin — Crossing — Head-on — In-trail

WCV Rate Unmitigated ACES Result

Well-Clear Violation Rate per 1×10^2 flight hours