Analysis of See-and-Avoid in Surface Operations: EFVS vs. Non-EFVS Ops

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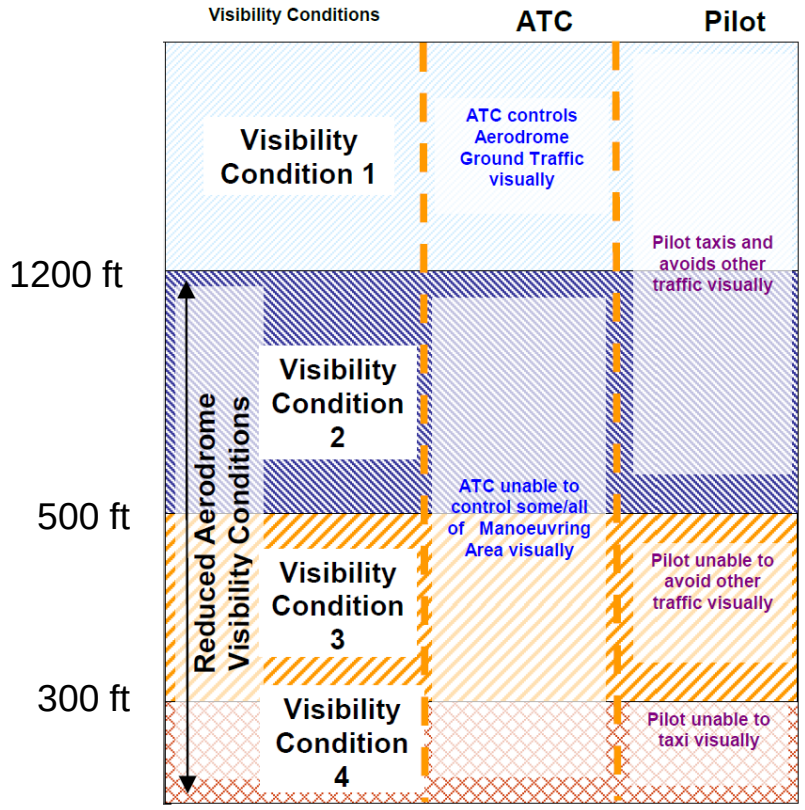
Outline

- Evaluating Possible Operational Credit for Enhanced Flight Vision System (EFVS) and Low Visibility Operations / Surface Movement Guidance and Control Systems (LVO/SMGCS)
  - RTCA SC-213, Working Group 2
- Monte Carlo Simulation Results
  - Different scenarios evaluated to assess potential impact of EFVS on LVO/SMGCS in see-and-avoid surface operations
- Variations in
  - Scenario (Intercept Angle)
  - Visibility
  - Taxi speed

Low Visibility Operations / SMGCS

- ***Current Regulations:***
  - ***Visibility condition 1.*** Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference, and for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
  - ***Visibility condition 2.*** **Visibility sufficient for the pilot to taxi and to avoid collision with other traffic on taxiways and at intersections by visual reference**, but insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
  - ***Visibility condition 3.*** **Visibility sufficient for the pilot to taxi but insufficient for the pilot to avoid collision with other traffic on taxiways and at intersections by visual reference**, and insufficient for personnel of control units to exercise control over all traffic on the basis of visual surveillance.
  - ***Visibility condition 4.*** Visibility insufficient for the pilot to taxi by visual guidance only. This is normally taken as a RVR of 75 m or less.

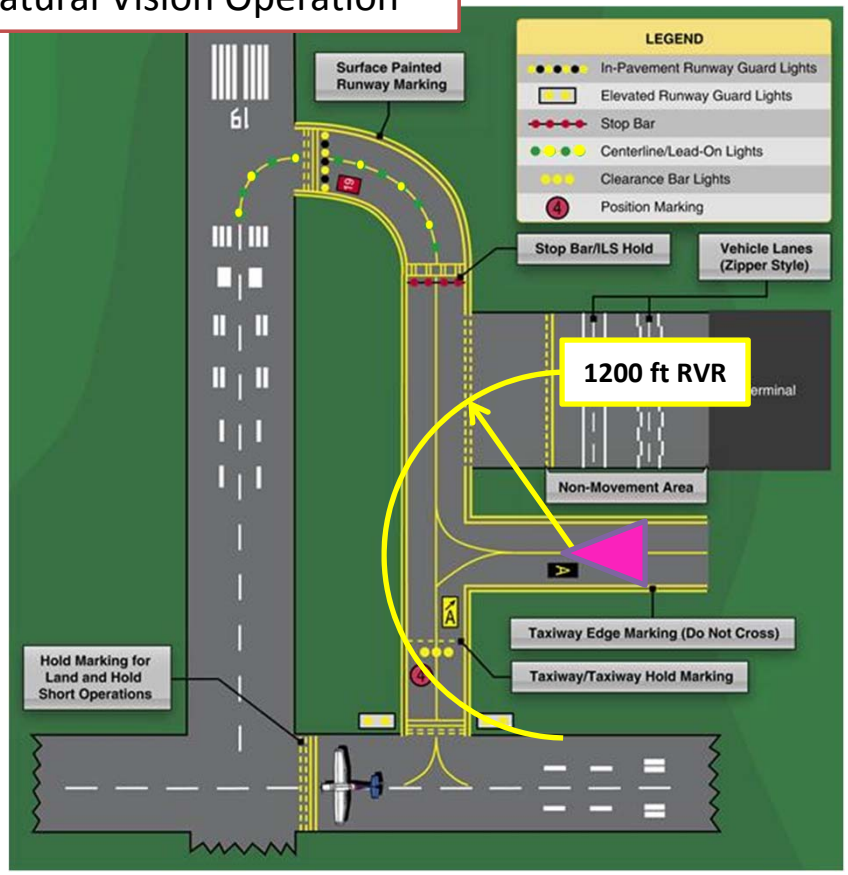


From European All Weather Operations Guidance Manual, Edition 4

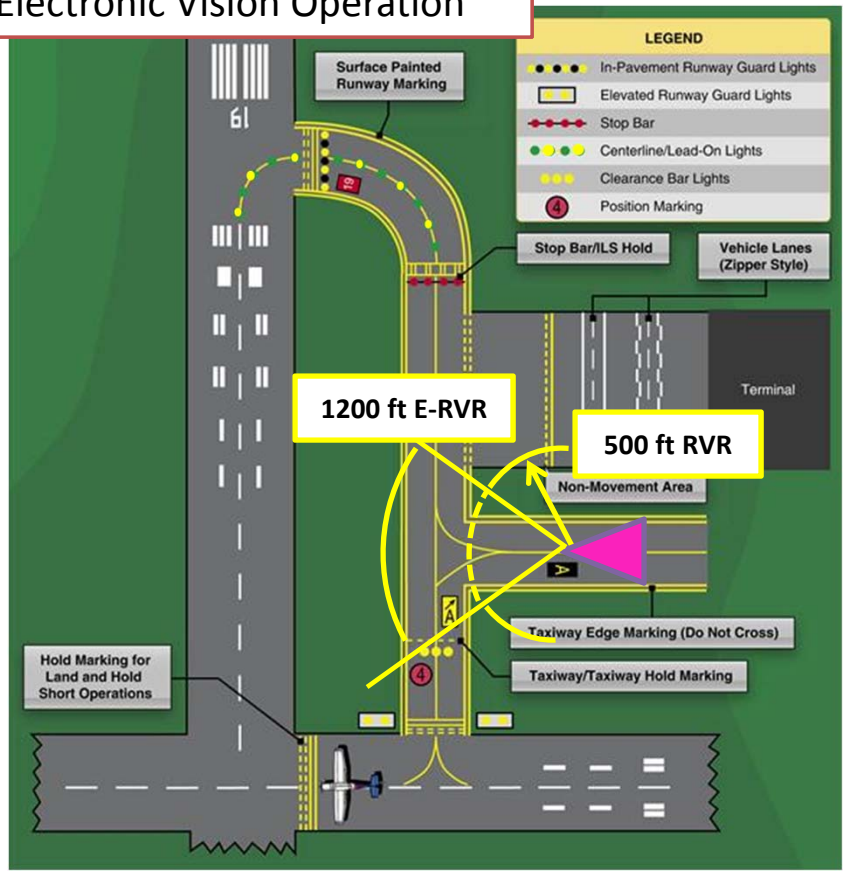
RVR: Runway Visual Range

Two Visibilities to Consider in EFVS Ops

Natural Vision Operation



Electronic Vision Operation



AC 90-48C "Pilot's Role in Collision Avoidance" …
(1) The flight rules prescribed in Part 91 of the Federal Aviation Regulations (FAR) set forth the concept of "See and Avoid."
This concept requires that vigilance shall be maintained at all times, by *each person* operating an aircraft, regardless of whether the operation is conducted under Instrument Flight Rules (IFR) or Visual Flight Rules (VFR).

AC 25.773 Pilot Compartment View

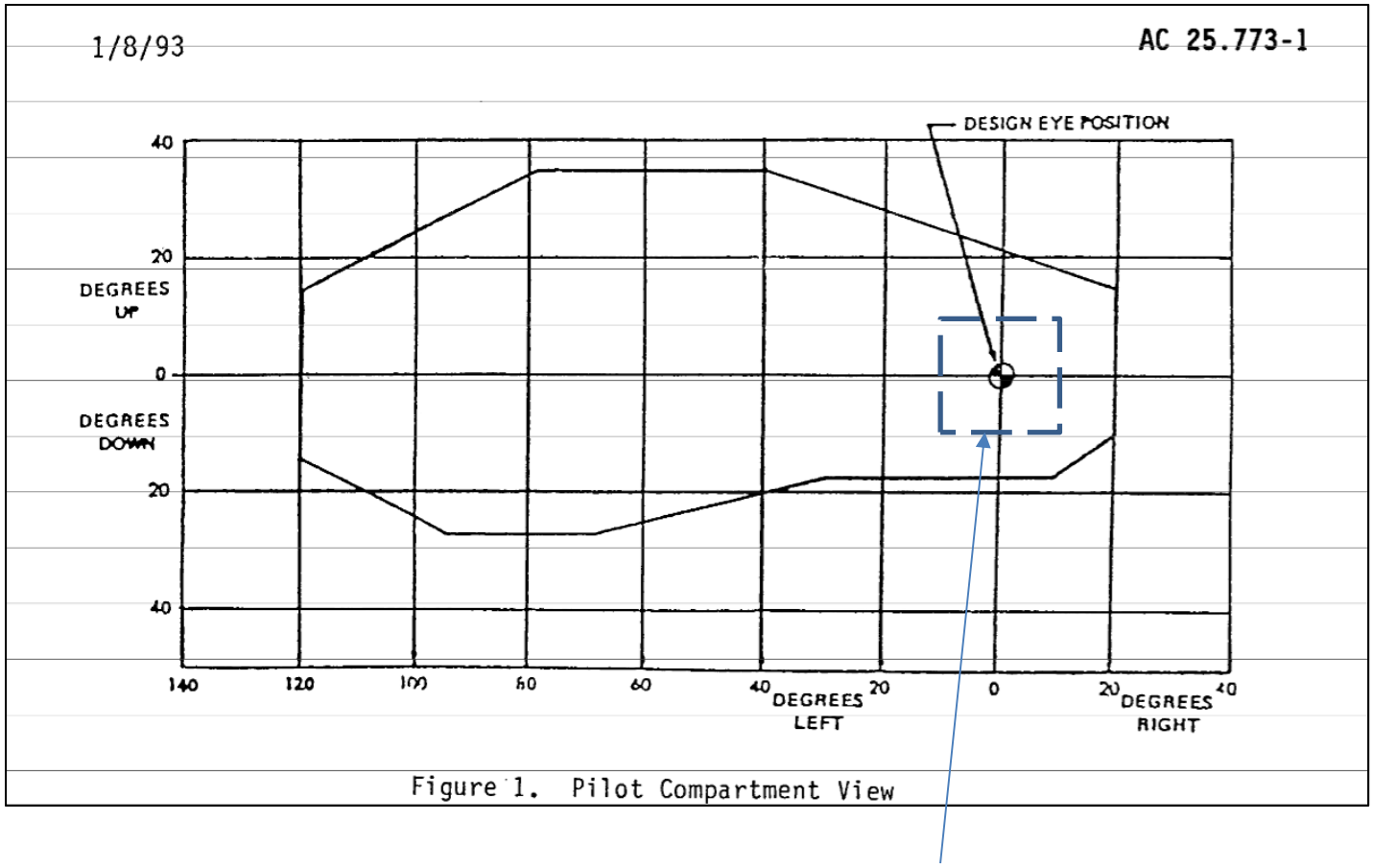


Figure 1. Pilot Compartment View

EFVS Min. Field-of-View (FOV)

Objective

- Various surface operations scenarios simulated using a Monte Carlo analysis to evaluate effect of EFVS usage during LVO/SMGCS surface operations
  - See-and-avoid operation
  - Quantify current operational procedures
  - Evaluate impact of EFVS during LVO/SMGCS on collision avoidance

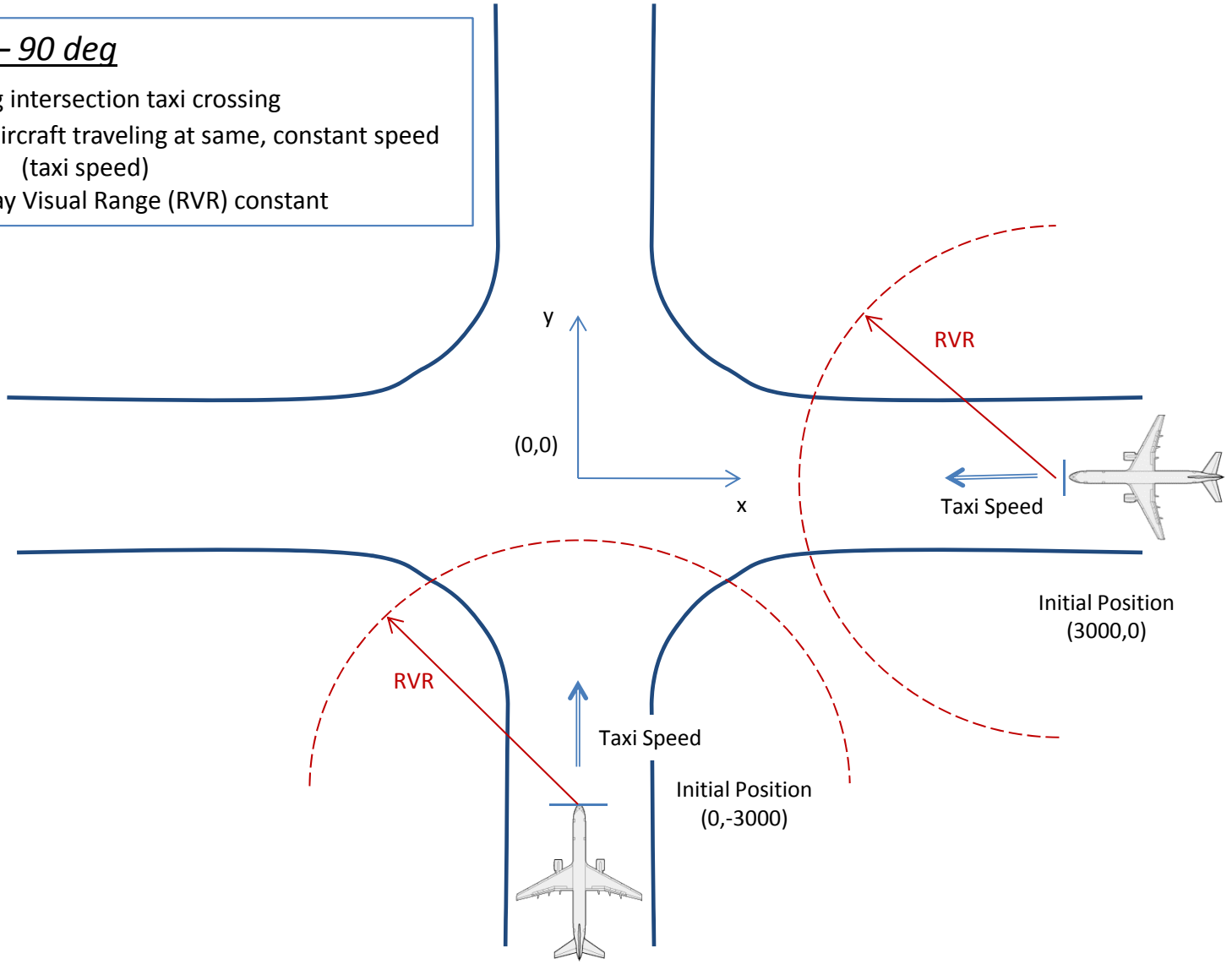
Scenario Concept – 90 Degree Intercept Example

Scenario – 90 deg

> 90 deg intersection taxi crossing

> Both aircraft traveling at same, constant speed (taxi speed)

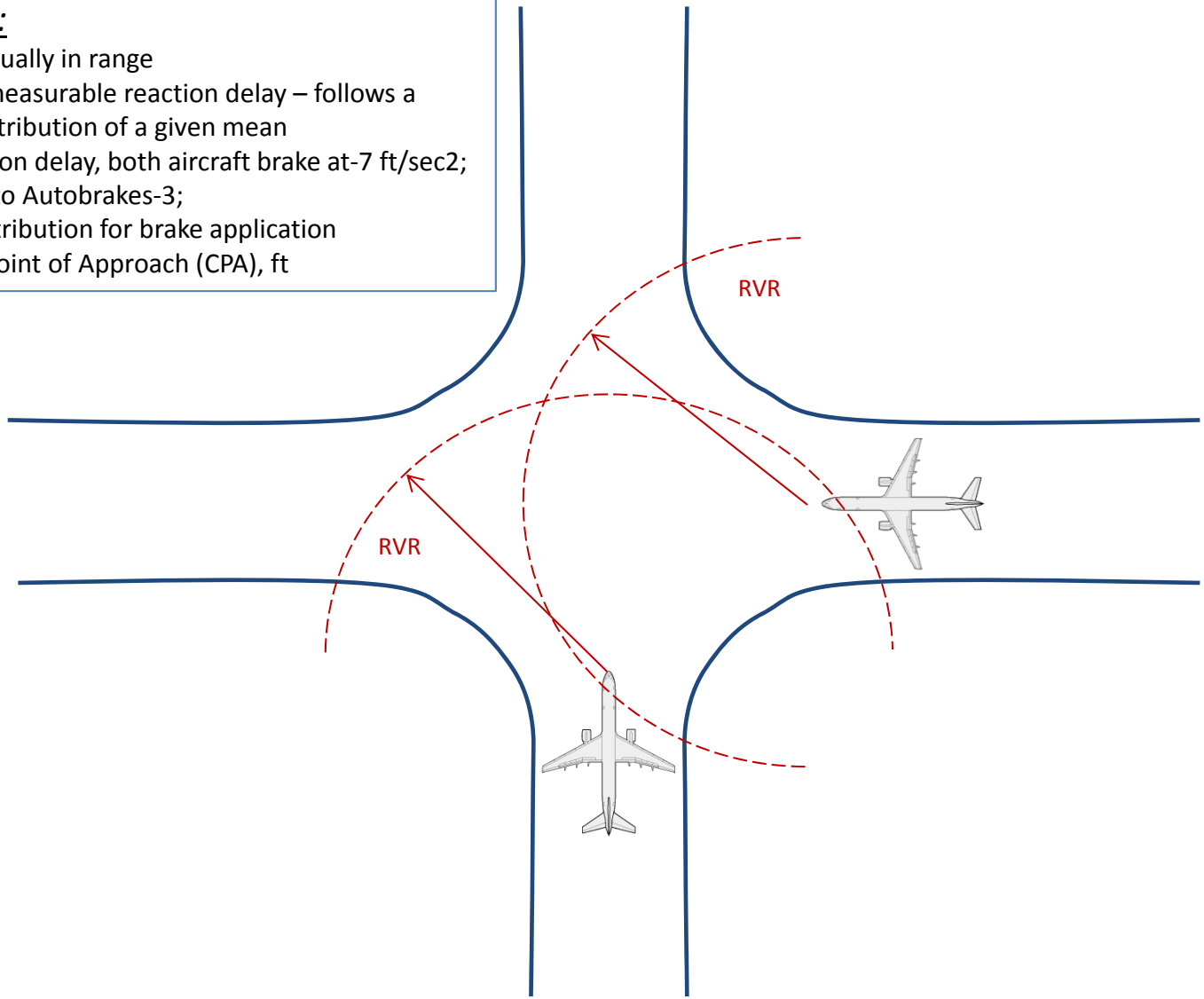
> Runway Visual Range (RVR) constant



Scenario Concept – 90 Degree Intercept Example

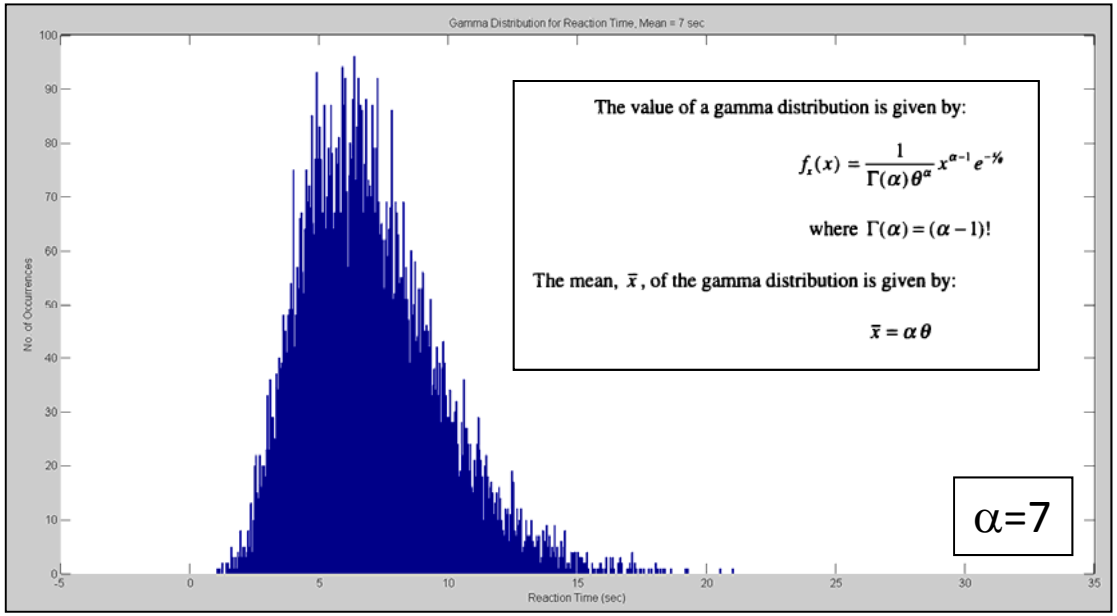
Scenario – Reaction:

> Once aircraft are visually in range
> *Both* pilots have a measurable reaction delay – follows a Gamma distribution of a given mean
> Following the reaction delay, both aircraft brake at-7 ft/sec2; analogous to Autobrakes-3;
> Apply a Gamma distribution for brake application
> Computing Closet Point of Approach (CPA), ft

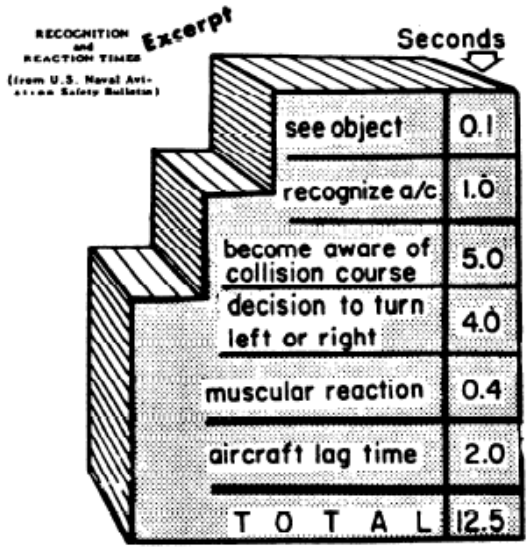


Pilot Reaction Time -> Gamma Distribution Function

Gamma Distribution with 7 second mean value



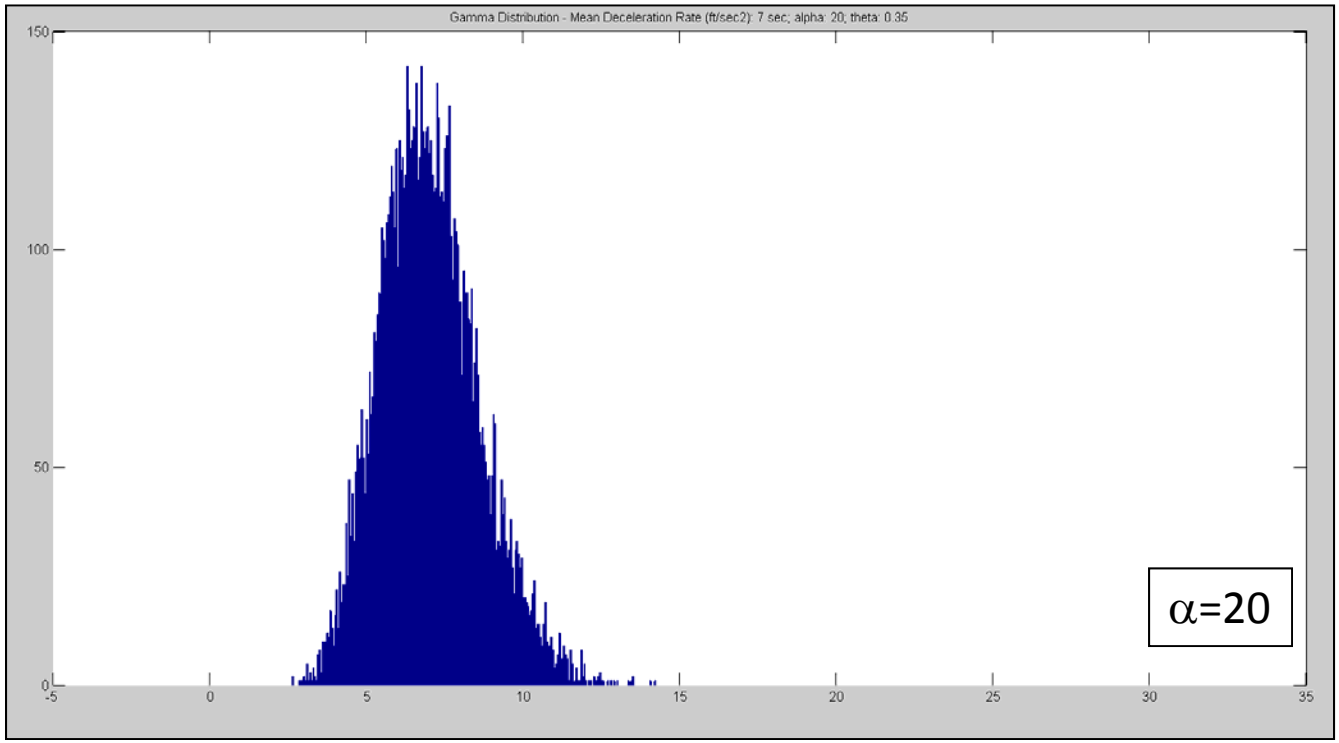
AC90-48C: Pilot's Role In Collision Avoidance



- According to Kuchar et al*, 5 second mean reaction time is typical for hazard alerting scenarios, ***Used 7 second mean time instead. Rationale:***
  - This is not a hazard alerting situation.
  - This is see-and-avoid and 7 seconds is comparable to AC90-48C
    - Capture "see", "recognize", "react" latencies;
    - "Decision" and "Aircraft lag time" next
  - Conservative

*Kuchar, J.K., "A Unified Methodology for the Evaluation of Hazard Alerting Systems, MIT, Jan. 1995
S.D. Thompson and J.R. Eggert, Surveillance Performance Requirements for Runway Incursion Prevention Systems, MIT ATC Report 301, September 2001

Upon Seeing Traffic, Braking/Deceleration Reaction



- Mean is chosen to be 7 ft/sec^2; analogous to Autobrakes-3;
  - Captures "Decision" and "Aircraft lag time"
  - Note that DO-289 specified 8 ft/sec^2 as the maximum assumed surface movement deceleration during taxi; 19.5 ft/sec^2 max during landing
    - Conservative
  - A much higher value for alpha (α=20) was used (compared to reaction time) to minimize the tails (maximum braking)

Monte Carlo Simulation

- Scenarios:
  - 90 degree Intercept
  - Head-On
  - EFVS worse-case
- Variation:
  - RVR (1200, 500, 300 ft)
  - Taxi speed (15 kts, 5 kts)
- 10,000 runs for Monte Carlo simulation

Results

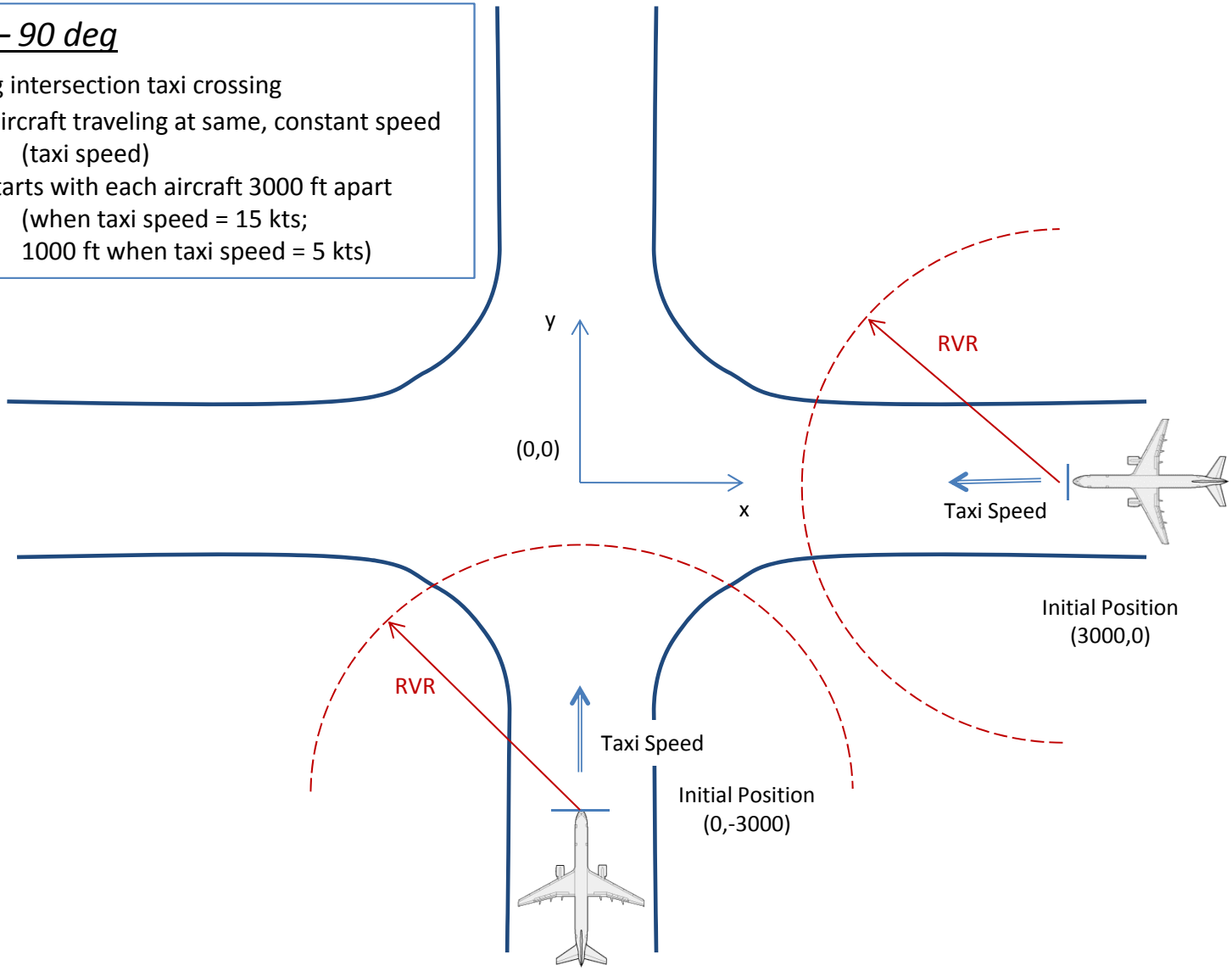
Scenario – 90 Degree Intercept

Scenario – 90 deg

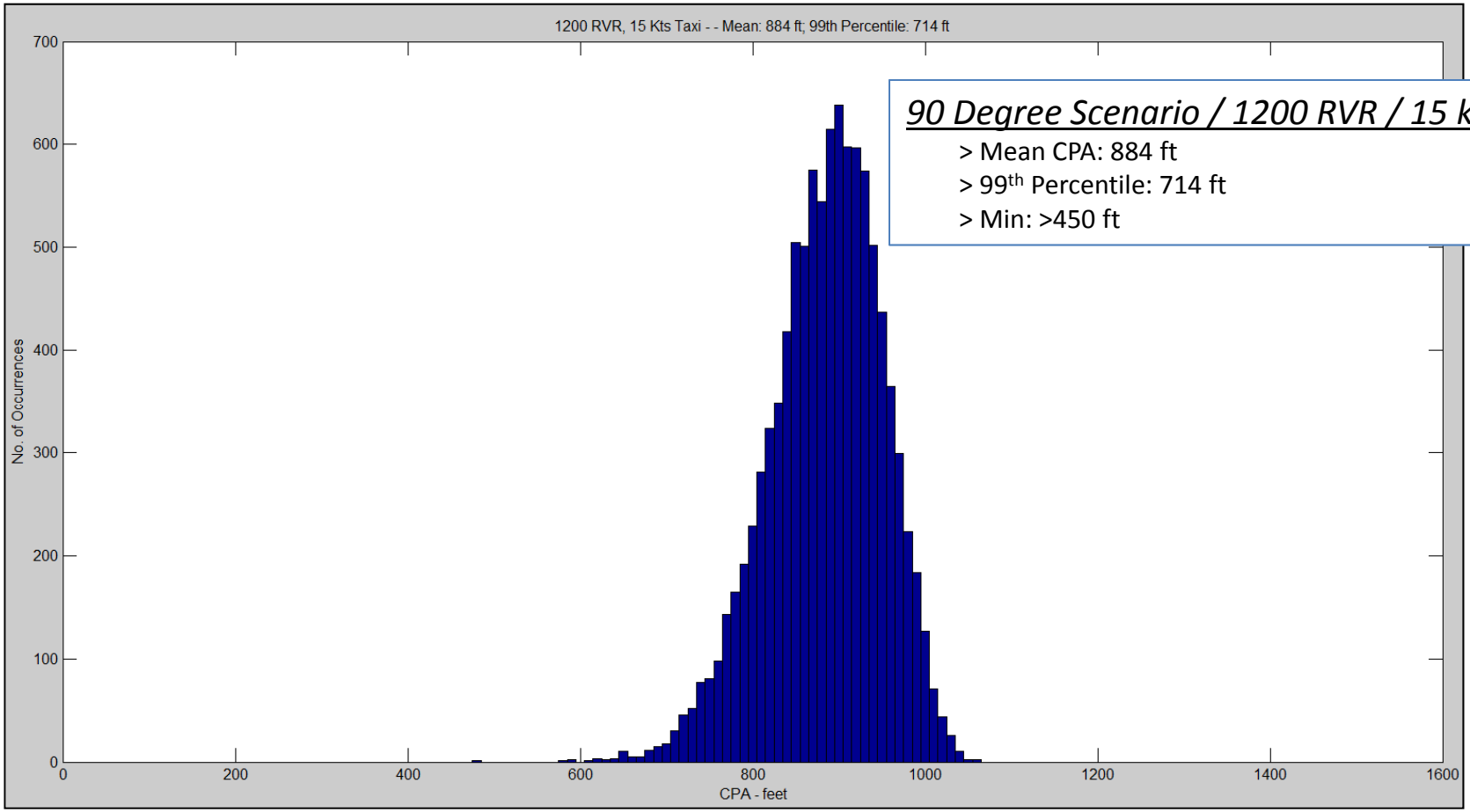
> 90 deg intersection taxi crossing

> Both aircraft traveling at same, constant speed (taxi speed)

> Sim. starts with each aircraft 3000 ft apart (when taxi speed = 15 kts; 1000 ft when taxi speed = 5 kts)



CPA Results: 90 Degree Intercept, 1200 RVR, 15 kts

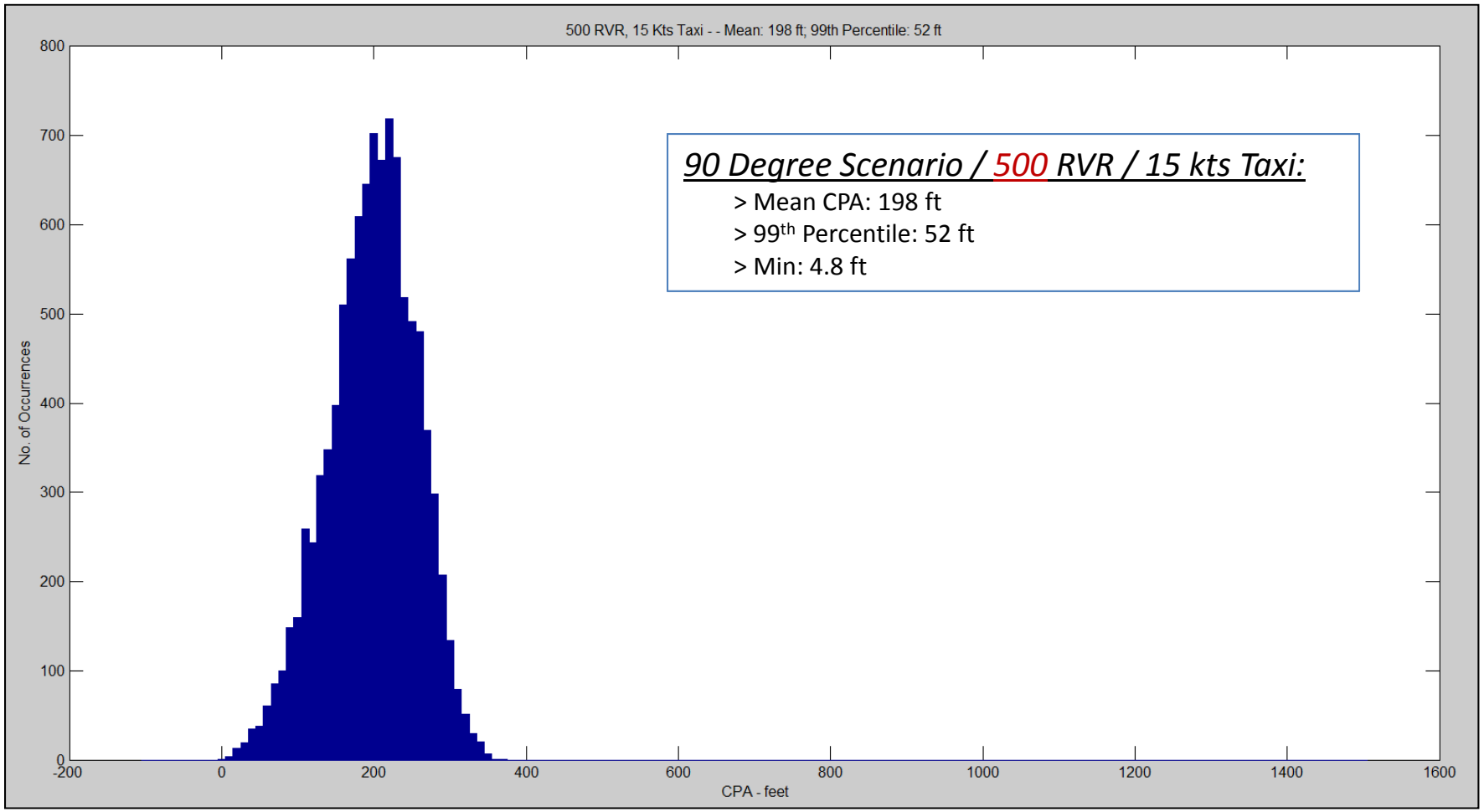


90 Degree Scenario / 1200 RVR / 15 kts Taxi:

> Mean CPA: 884 ft
> 99th Percentile: 714 ft
> Min: >450 ft

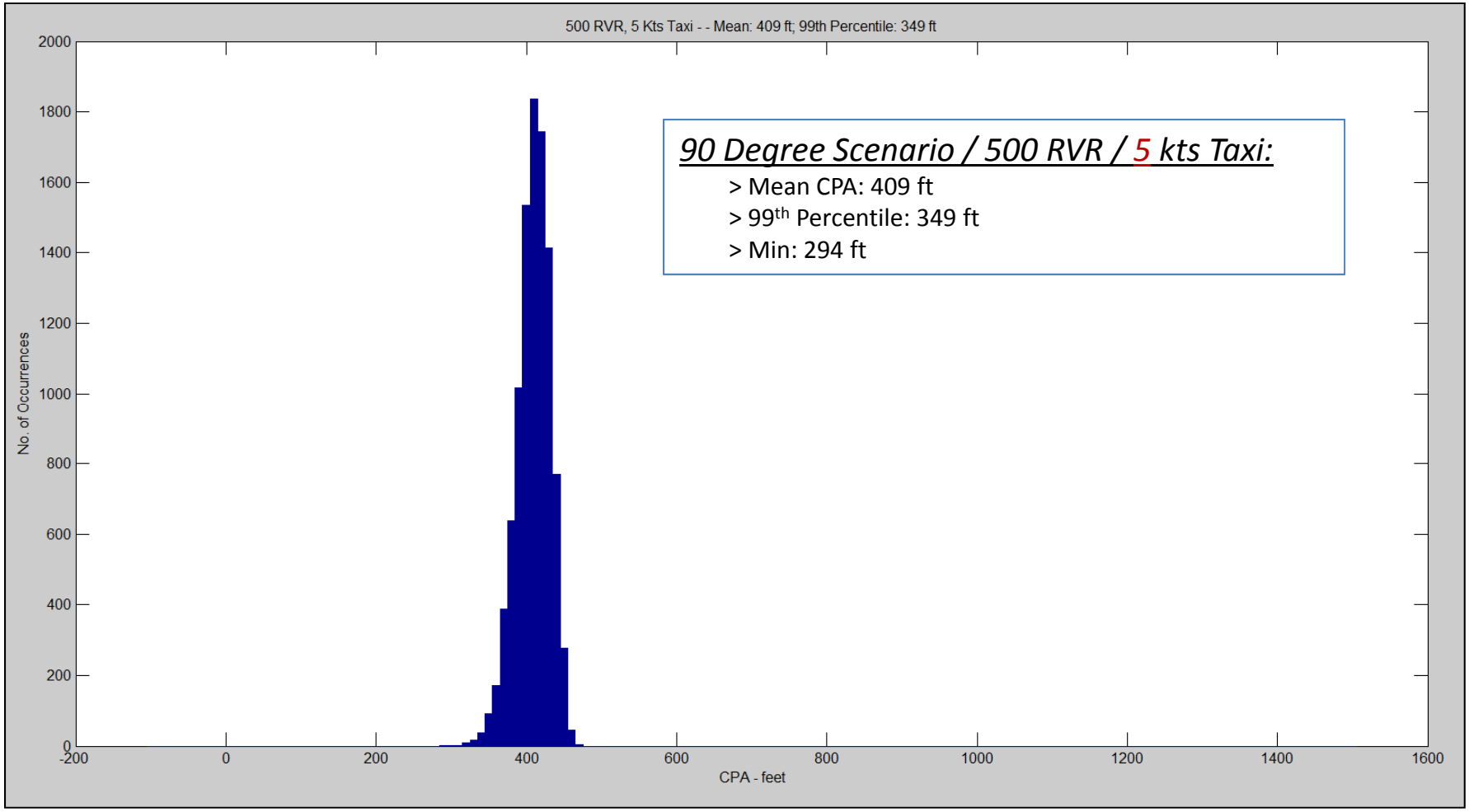
- In 1200 RVR, plenty of margin to see-and-avoid

CPA Results: 90 Degree Intercept, 500 RVR, 15 kts



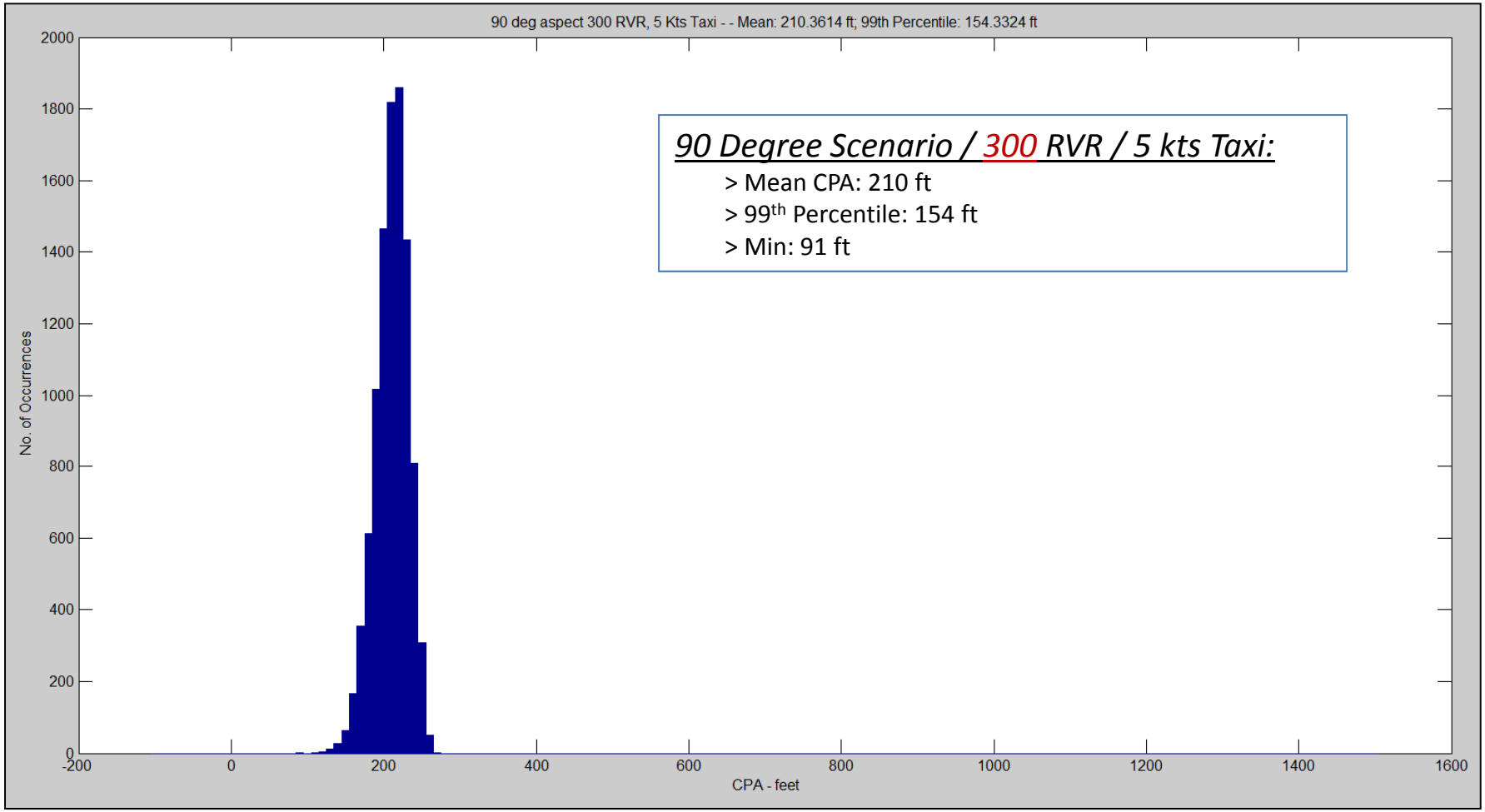
- In 500 RVR, 15 kts taxi speed:
  - See-and-avoid is problematic at 15 kts taxi speed;
  - 12 events less than 20 ft CPA

CPA Results: 90 Degree Intercept, 500 RVR, 5 kts



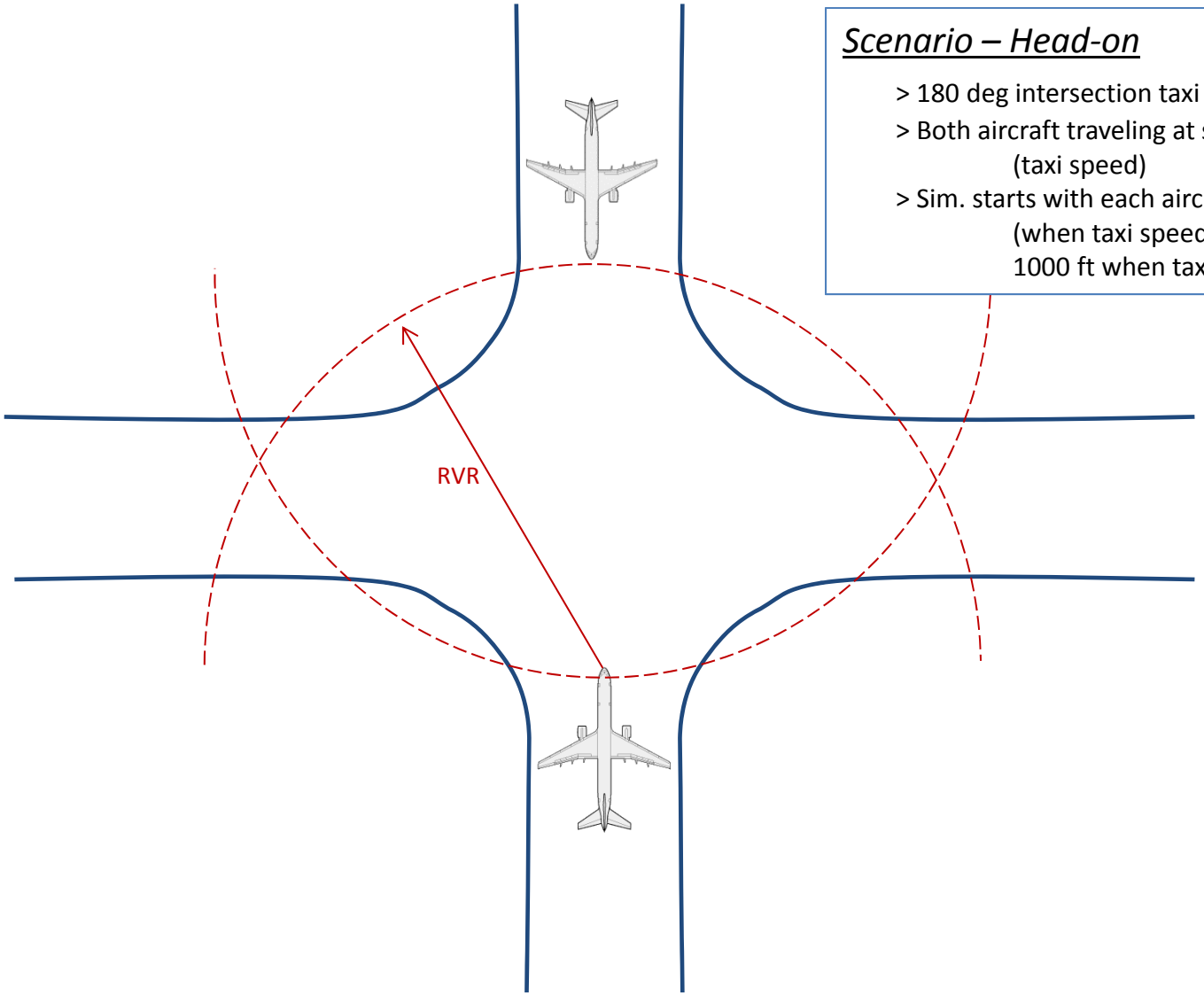
- In 500 RVR, Down to 5 kts taxi speed:
  - See-and-avoid is quite possible at 5 kts taxi speed;

CPA Results: 90 Degree Intercept, 300 RVR, 5 kts



- In 300 RVR, 5 kts taxi speed:
  - See-and-avoid is possible;

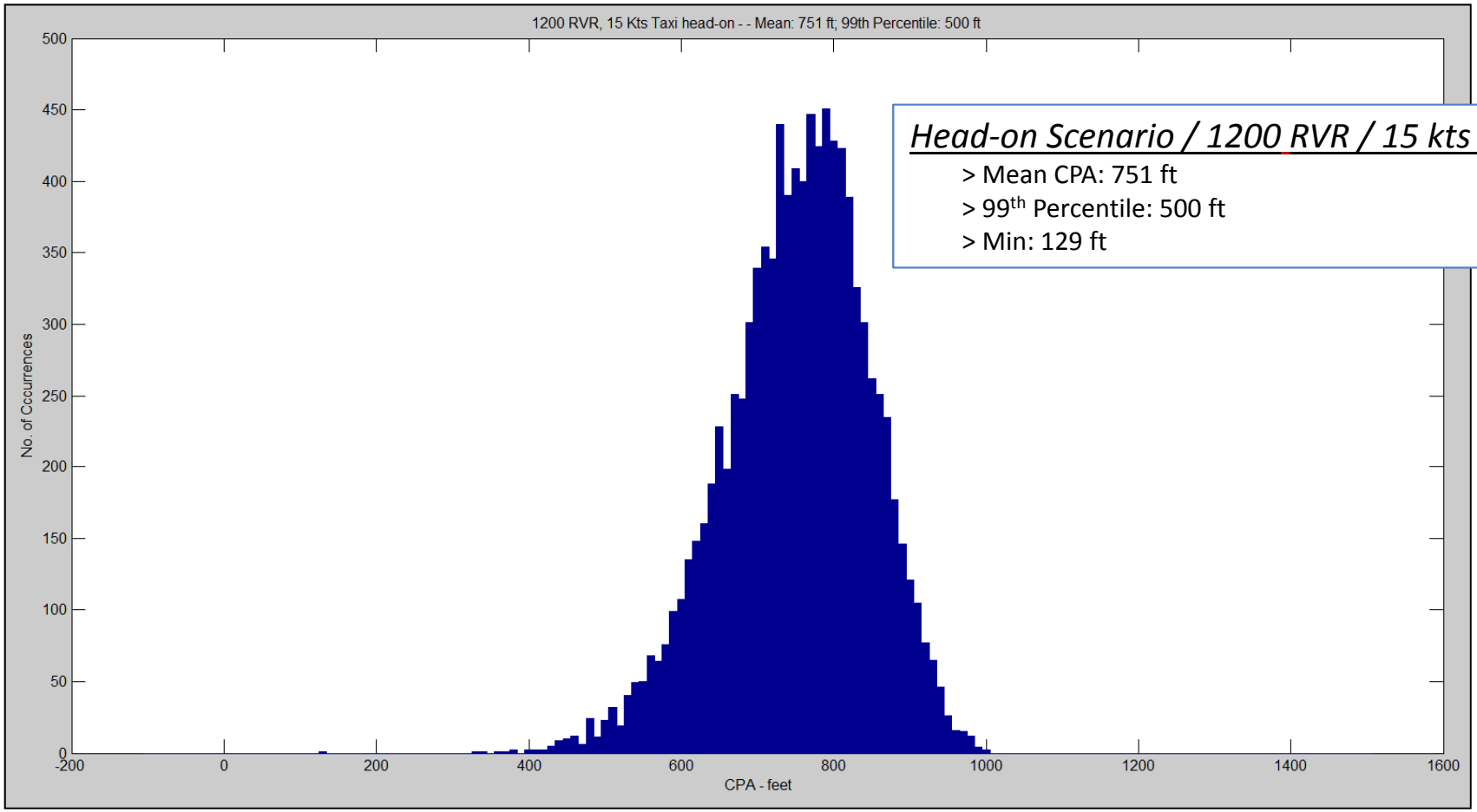
Scenario – Head-on Intercept



Scenario – Head-on

> 180 deg intersection taxi crossing
> Both aircraft traveling at same, constant speed (taxi speed)
> Sim. starts with each aircraft 3000 ft apart (when taxi speed = 15 kts; 1000 ft when taxi speed = 5 kts)

CPA Results: Head-on Intercept, 1200 RVR, 15 kts

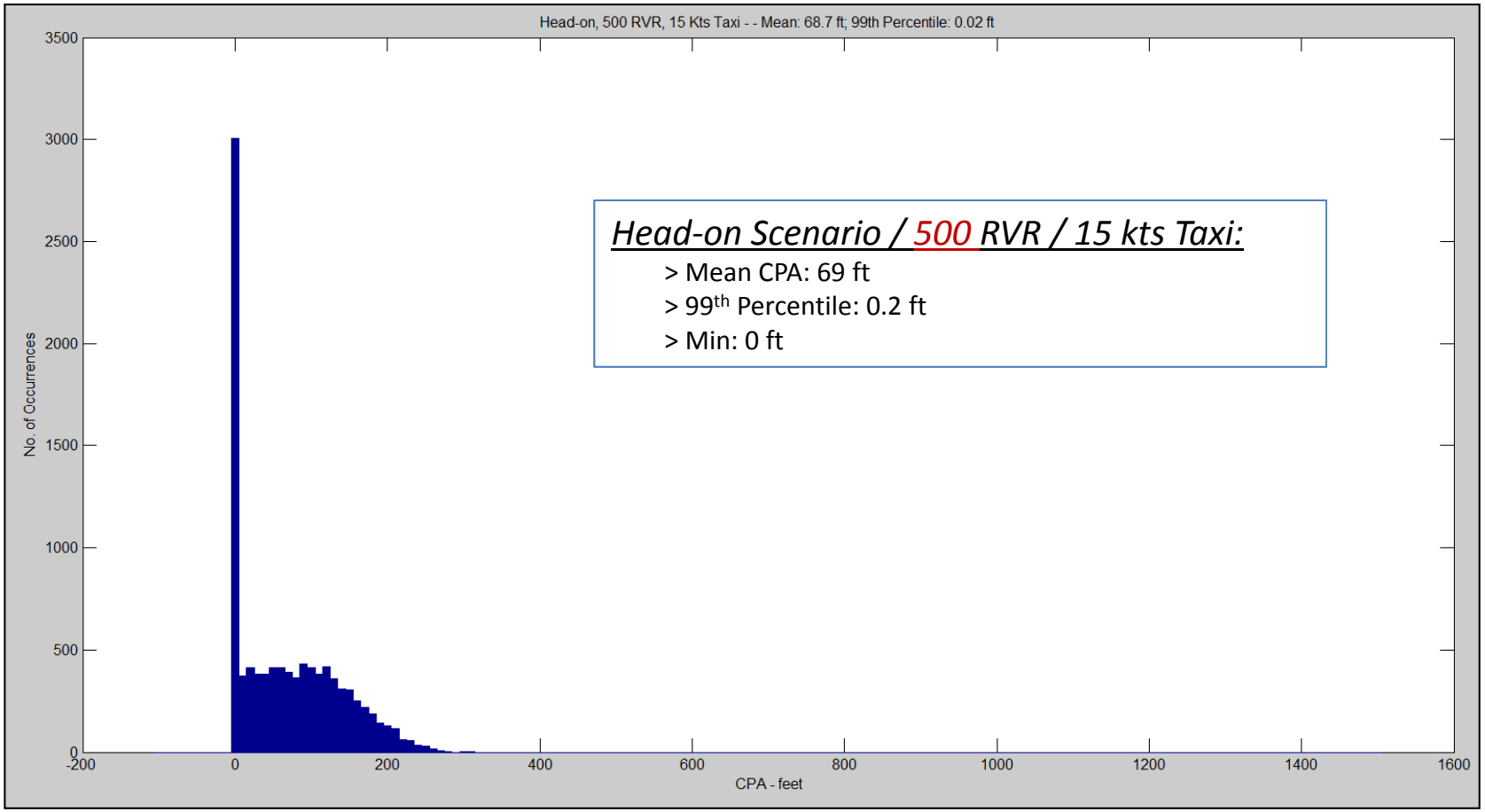


Head-on Scenario / 1200 RVR / 15 kts Taxi:

> Mean CPA: 751 ft
> 99th Percentile: 500 ft
> Min: 129 ft

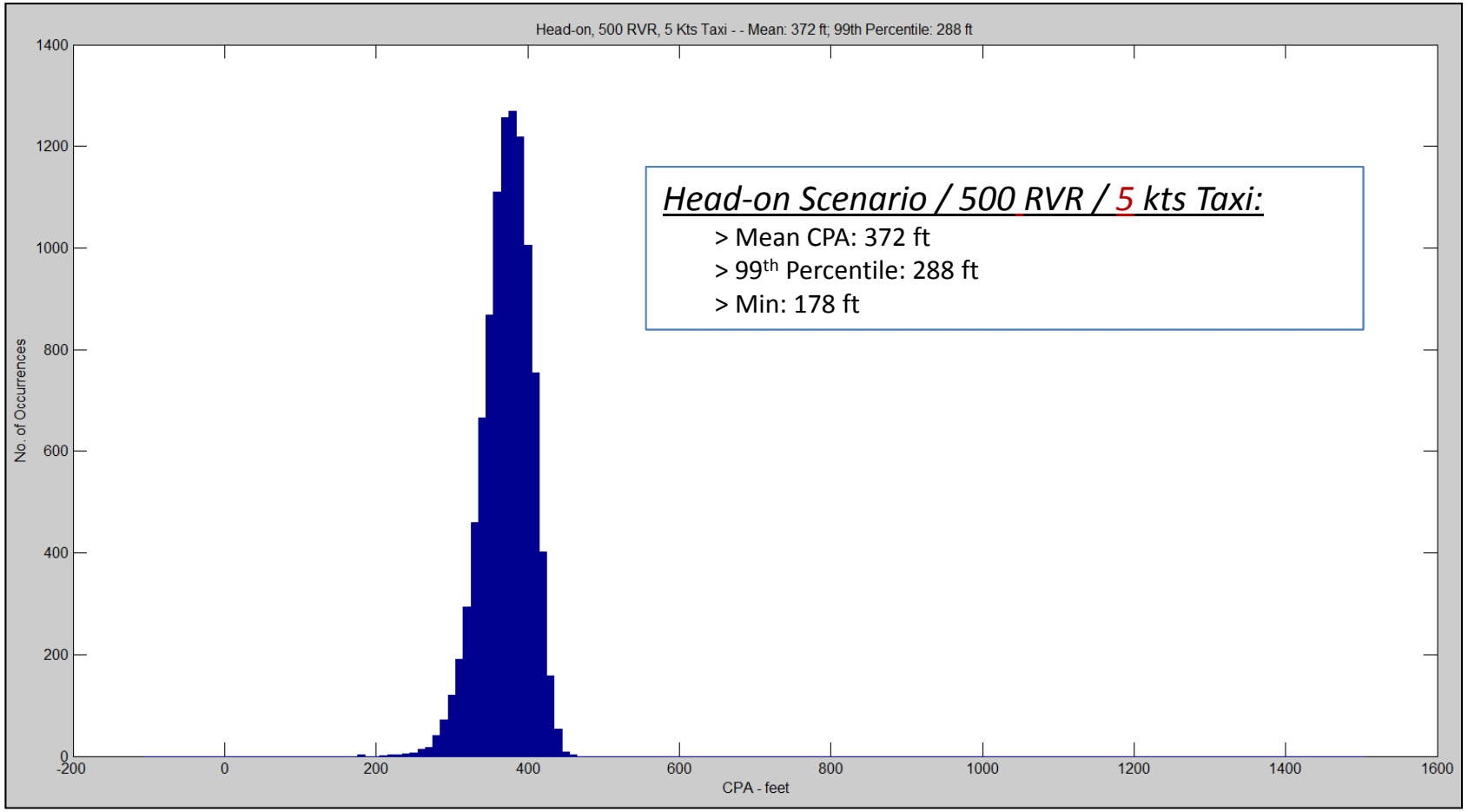
- In 1200 RVR, See-and-avoid is very possible at 15 kts taxi speed
  - No Collisions; very few occurrences of CPA < 300 ft

CPA Results: Head-on Intercept, 500 RVR, 15 kts



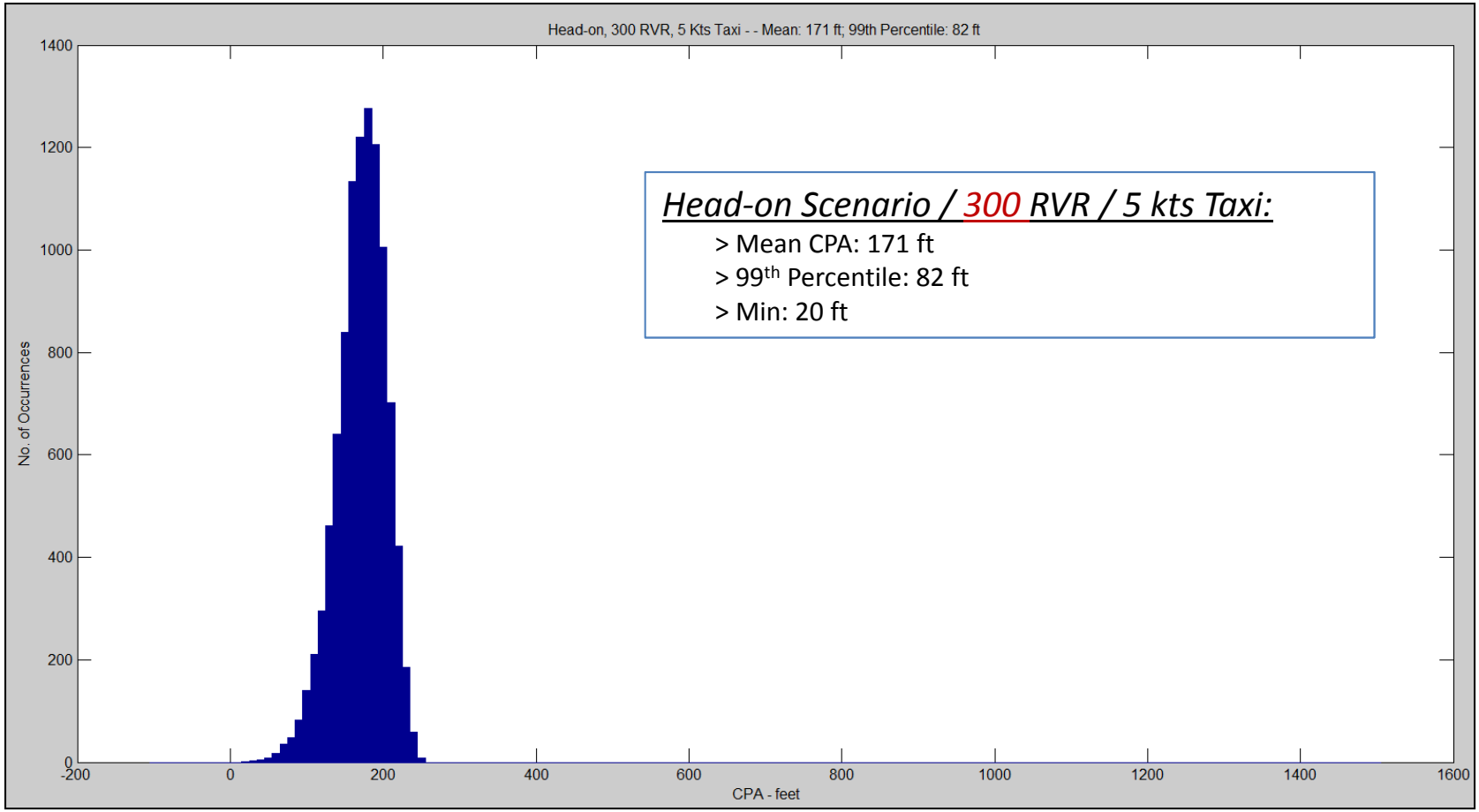
- In 500 RVR, see-and-avoid is *not* possible at 15 kts taxi speed
  - Numerous collisions; very few occurrences of CPA < 300 ft

CPA Results: Head-on Intercept, 500 RVR, 5 kts



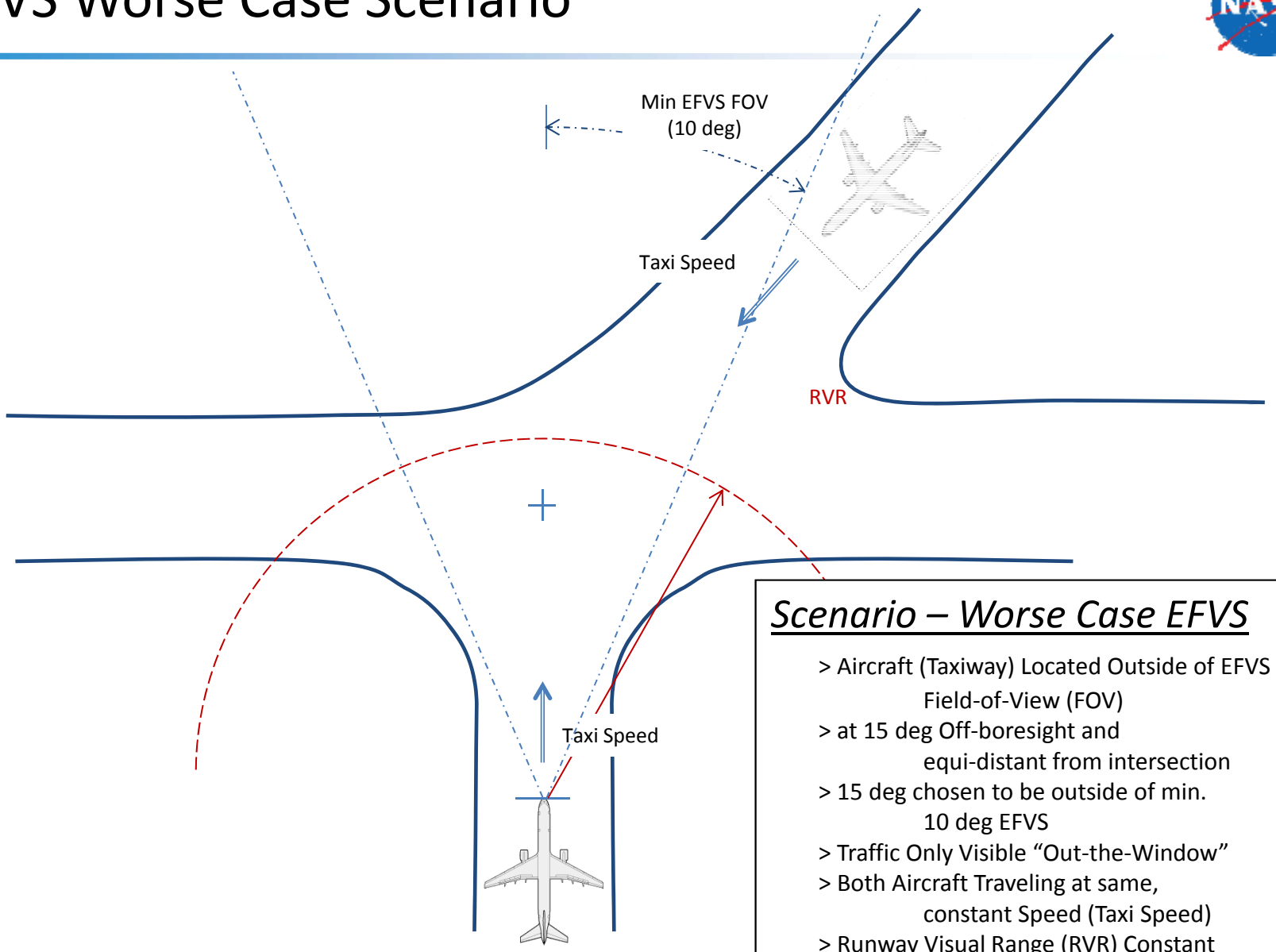
- In 500 RVR, see-and-avoid is possible at 5 kts taxi speed
  - No collisions; margin available

CPA Results: Head-on Intercept, 300 RVR, 5 kts



- In 300 RVR, see-and-avoid is *not* possible at 5 kts taxi speed
  - No 'collisions' per se but 99th percentile of CPA < 100 ft

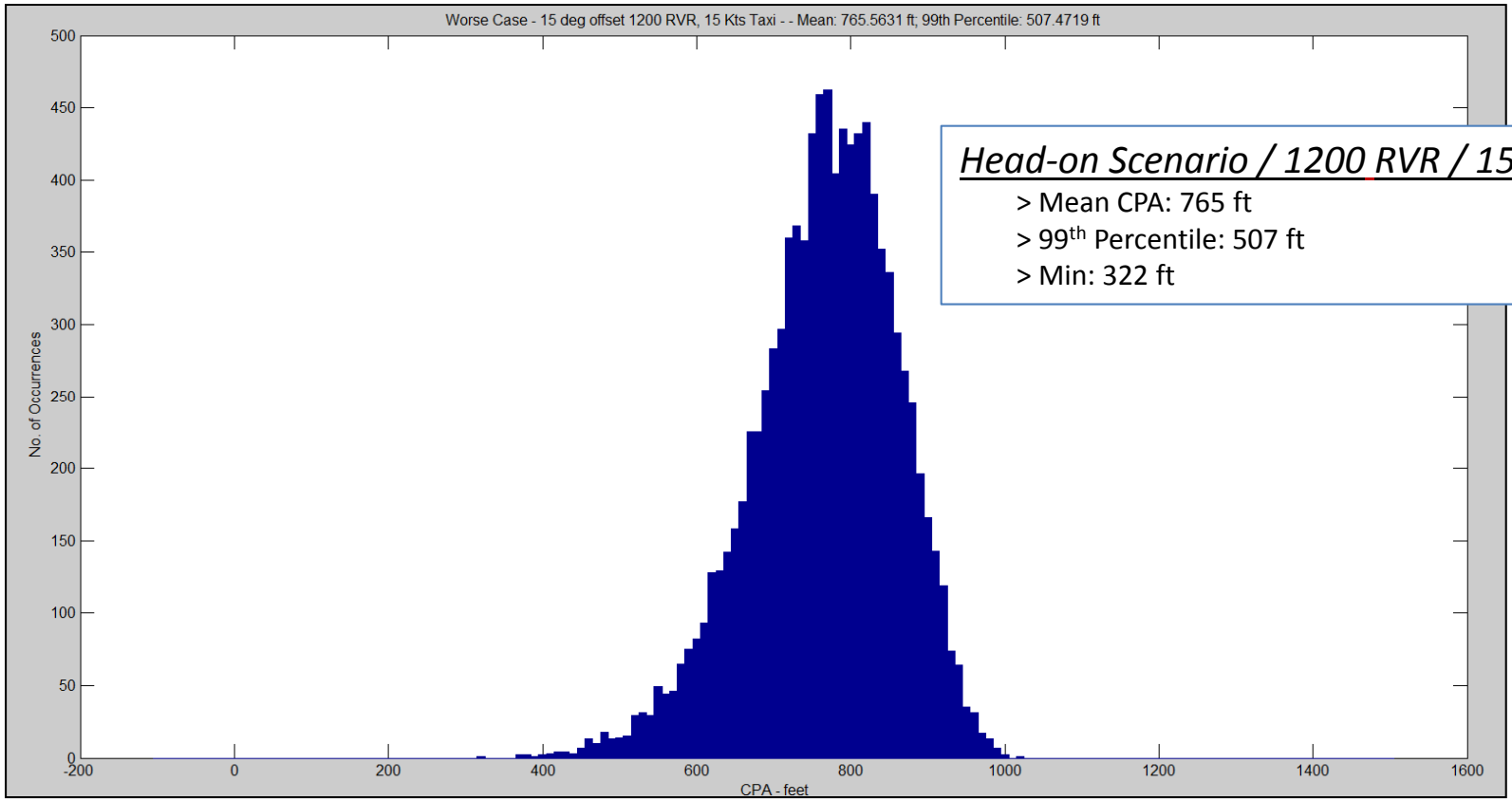
EFVS Worse Case Scenario



Scenario – Worse Case EFVS

> Aircraft (Taxiway) Located Outside of EFVS Field-of-View (FOV)
> at 15 deg Off-boresight and equi-distant from intersection
> 15 deg chosen to be outside of min. 10 deg EFVS
> Traffic Only Visible "Out-the-Window"
> Both Aircraft Traveling at same, constant Speed (Taxi Speed)
> Runway Visual Range (RVR) Constant

CPA Results: EFVS Worse-case, 1200 RVR, 15 kts



Head-on Scenario / 1200 RVR / 15 kts Taxi:

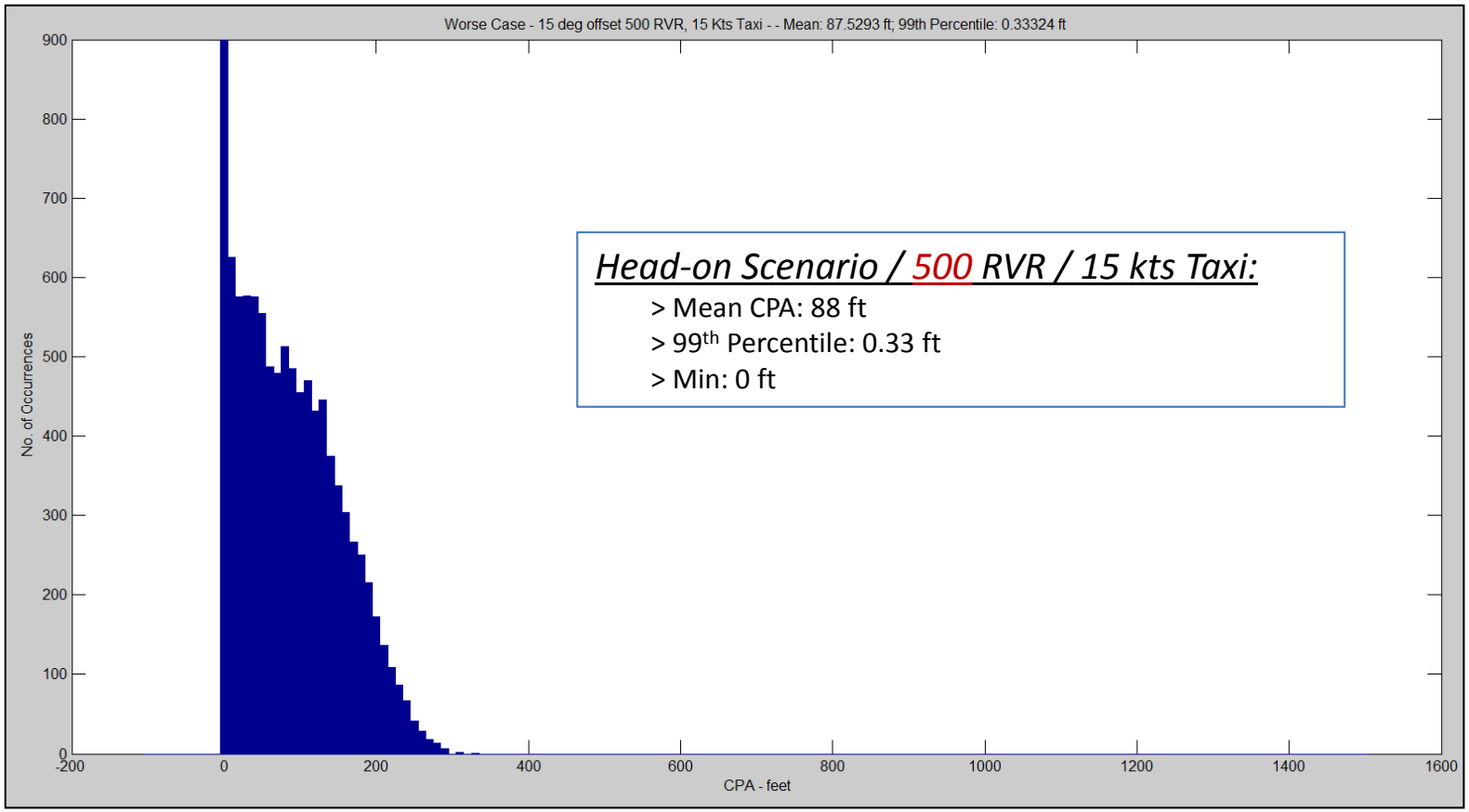
> Mean CPA: 765 ft

> 99th Percentile: 507 ft

> Min: 322 ft

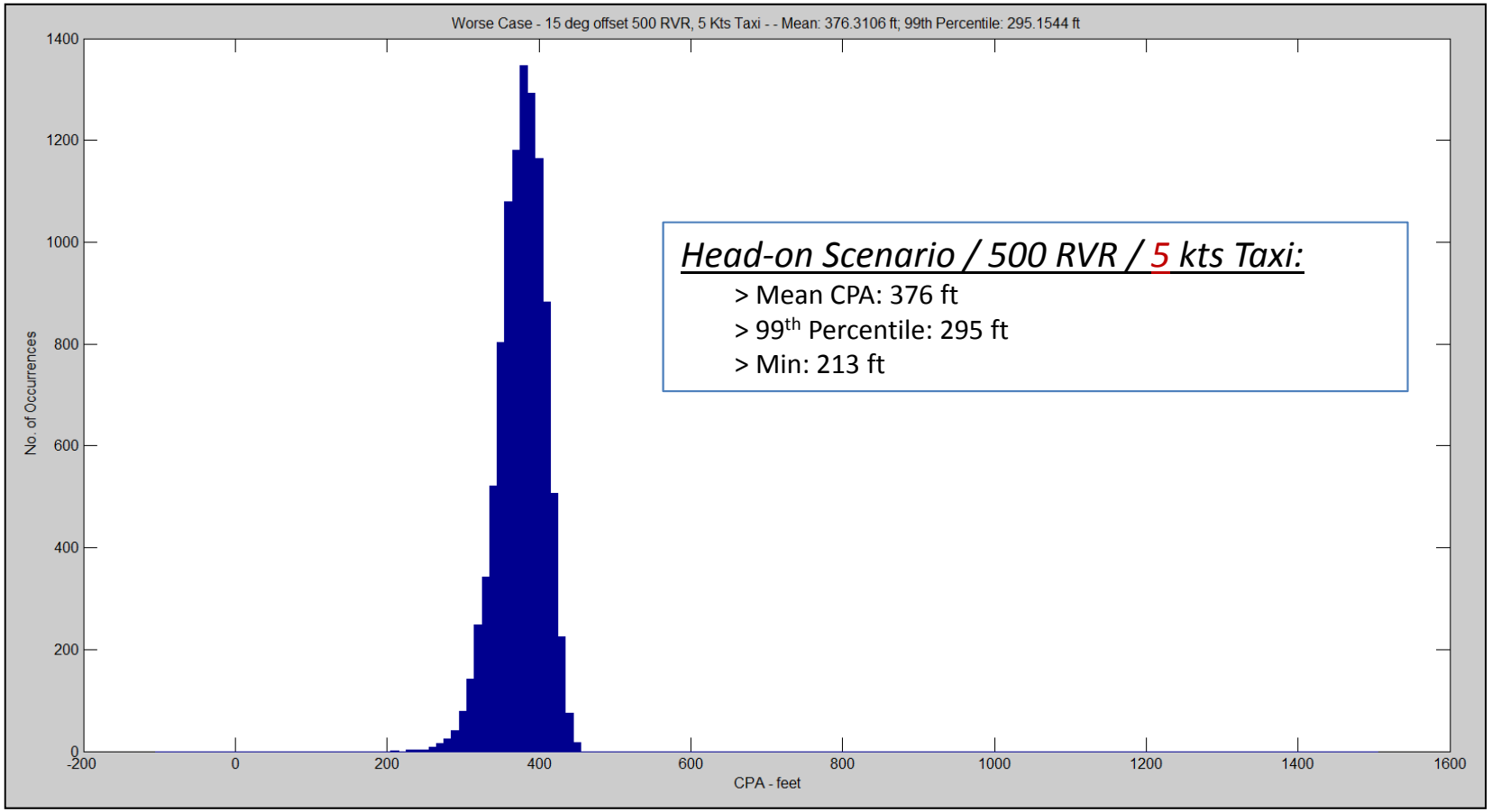
- In 1200 RVR, see-and-avoid is possible at 15 kts taxi speed

CPA Results: EFVS Worse-case, 500 RVR, 15 kts



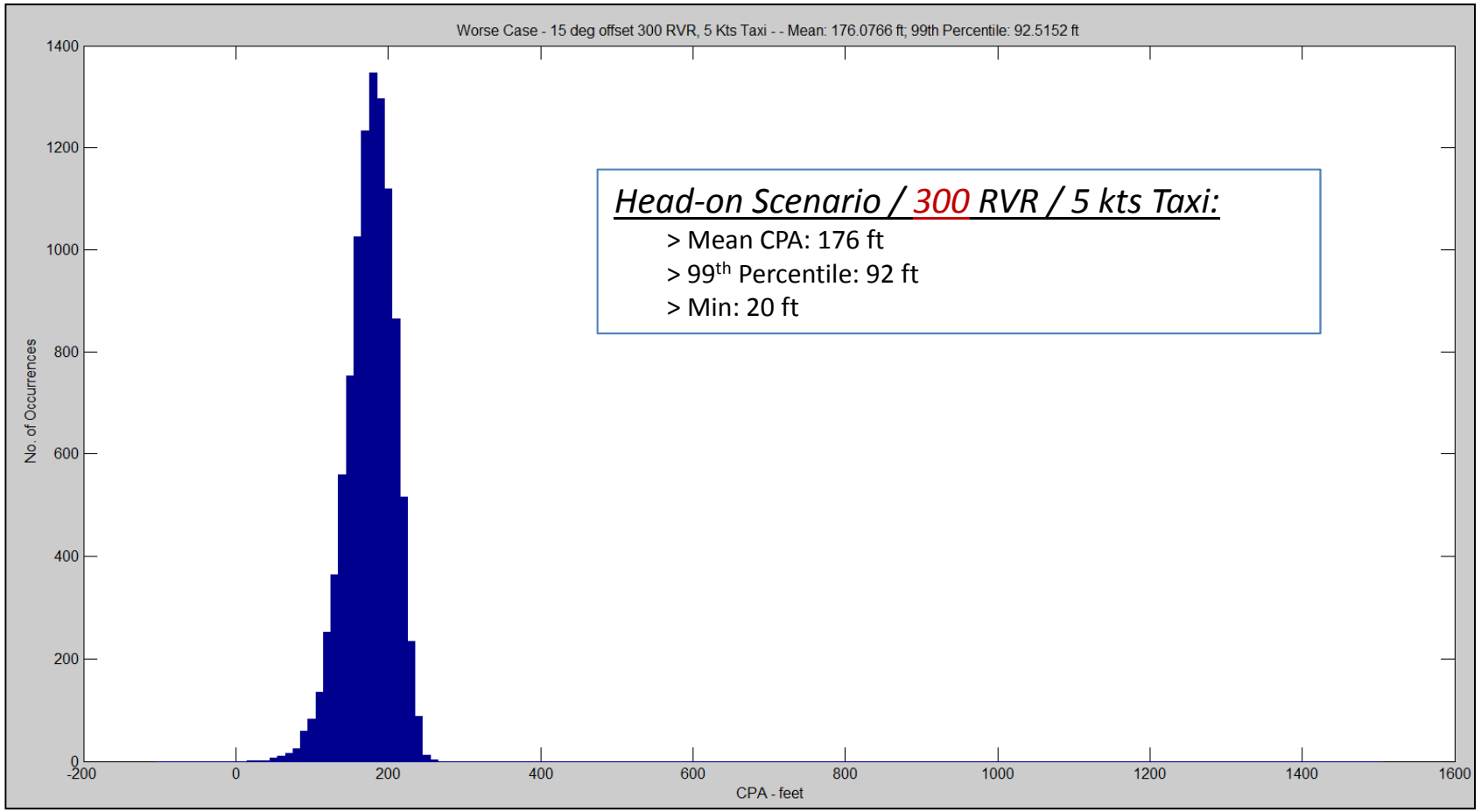
- In 500 RVR, see-and-avoid is *not* possible at 15 kts taxi speed

CPA Results: EFVS Worse-case, 500 RVR, 5 kts



- In 500 RVR, see-and-avoid is possible at 5 kts taxi speed

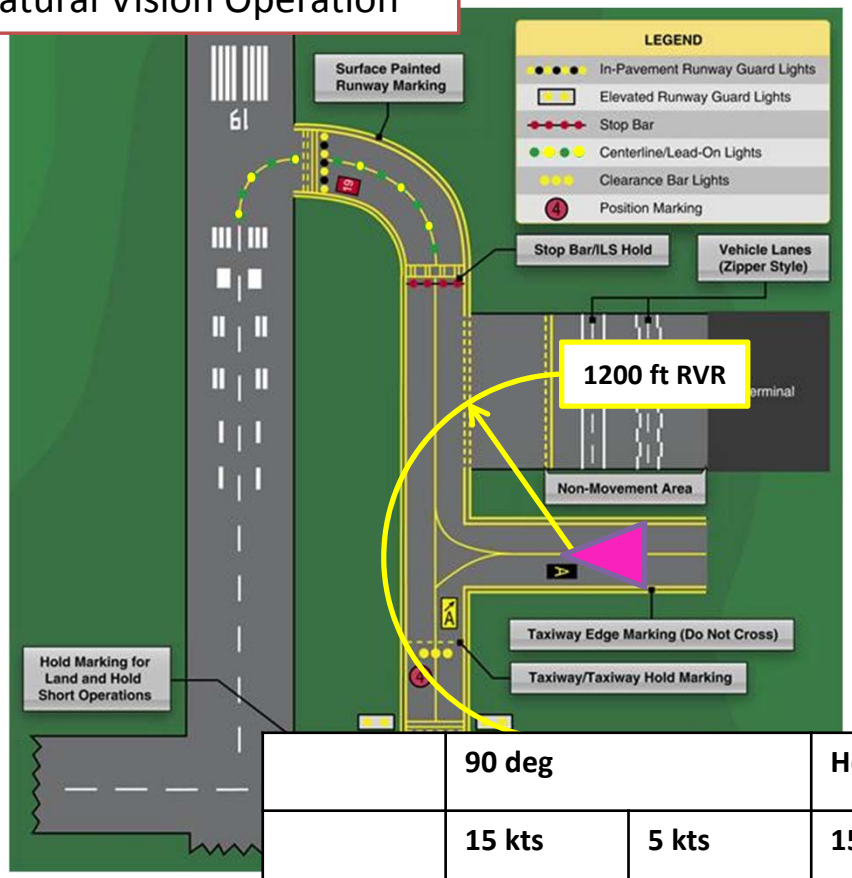
CPA Results: EFVS Worse-case, 300 RVR, 5 kts



- In 300 RVR, see-and-avoid is possible but not sufficient margins at 5 kts taxi speed

Concluding Remarks

Natural Vision Operation



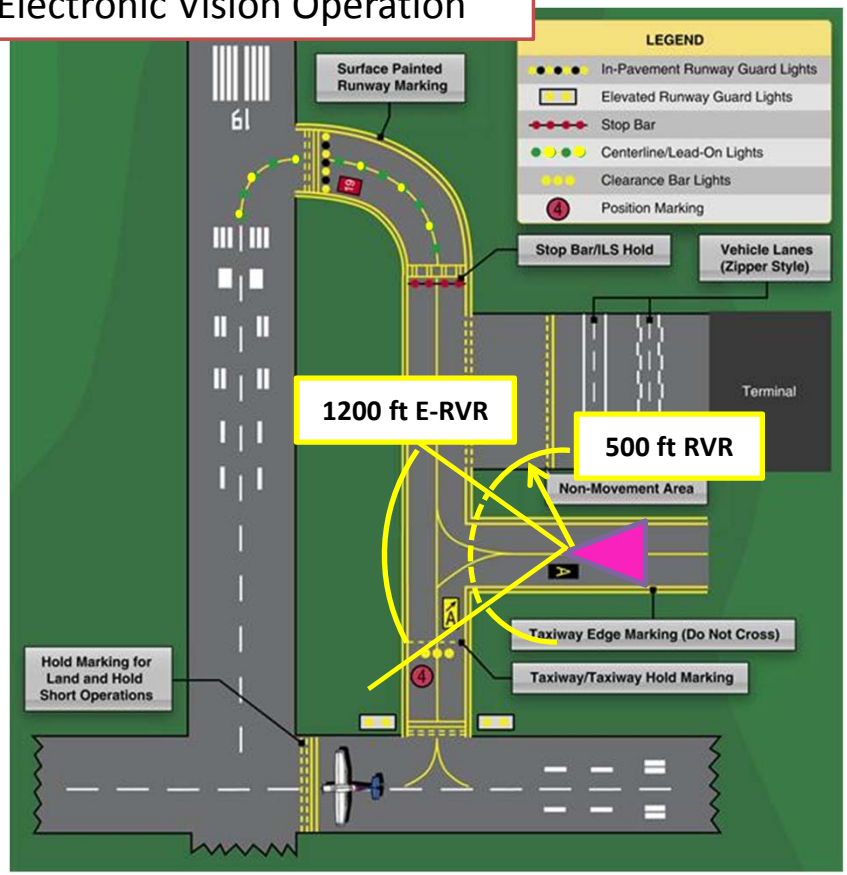
- Analysis conducted of "see-and-avoid" in surface ops
  - Using assumed reaction times; braking
- Analysis results match existing LVO/SMGCS guidance
  - Surface see-and-avoid >500 ft RVR
  - See-and-avoid problematic for < 500 ft RVR
- Taxi speed extremely influential to results

	90 deg		Head-on		EFVS Worse case	
	15 kts	5 kts	15 kts	5 kts	15 kts	5 kts
1200 RVR	●		●		●	
500 RVR	●	●	●	●	●	●
300 RVR		●		●		●

Implications for EFVS Operational Credit

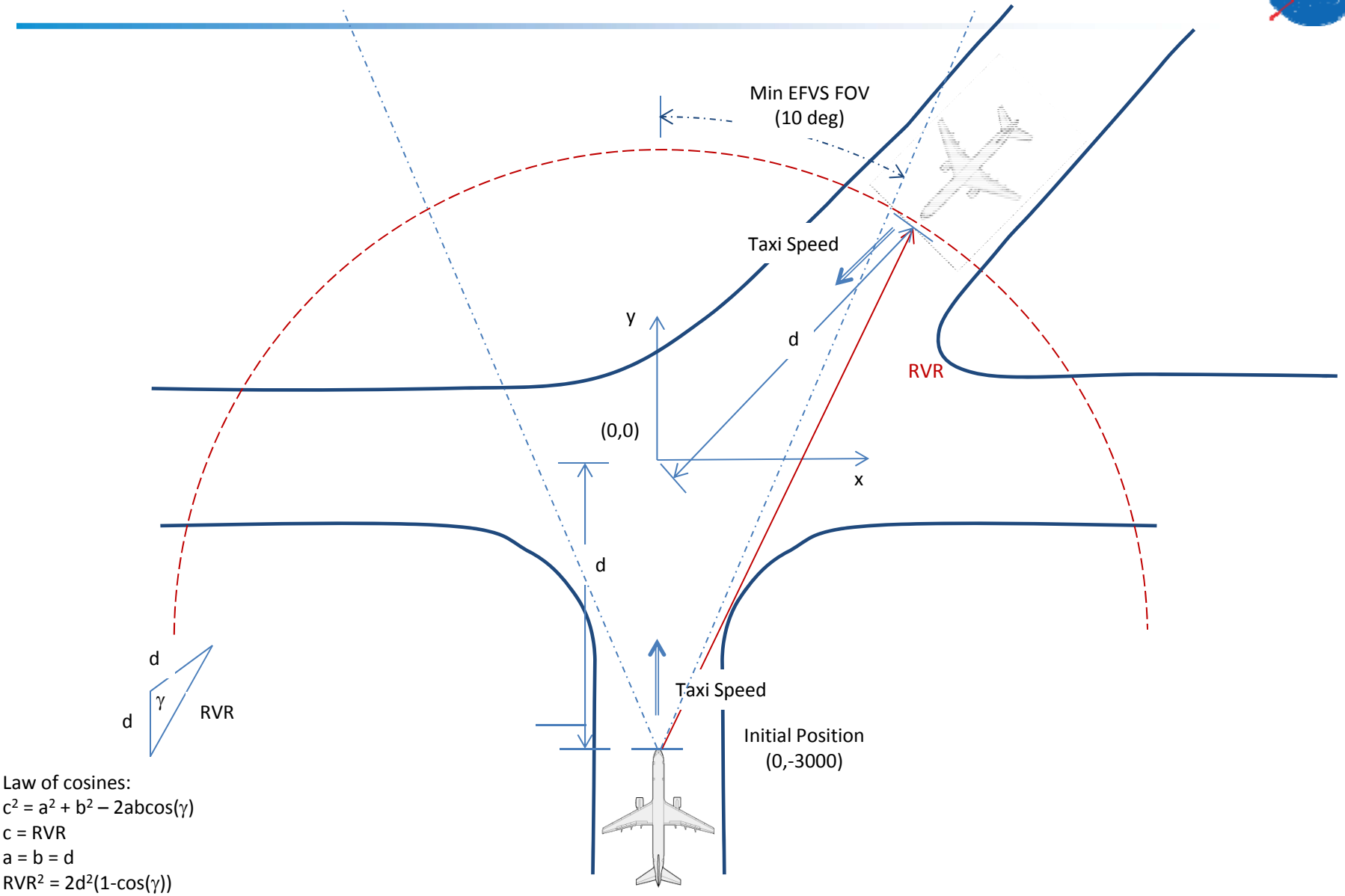
- EFVS surface ops are no less safe than non-EFVS surface ops
  - Better safety if EFVS provides visual advantage (i.e., head-on)
  - No worse than natural vision (i.e., can turn off EFVS if performance is degraded)
- Cannot use E-RVR (Visibility Provided by EFVS) for taxi speed
  - Taxi at speeds appropriate for prevailing natural vision
- Currently, ANSP Responsible for Separation <500 ft (Surface Radar)

Electronic Vision Operation



- **To Operate at Higher Speeds than Prudent for the Prevailing Natural Visibility or Below 500 ft RVR Will Require Other Technologies (Larger FOV EFVS, Cockpit Display of Traffic Information, Flight Deck-based Surface Conflict Detection & Resolution)**

Questions?



Law of cosines:

$c^2 = a^2 + b^2 - 2ab\cos(\gamma)$

$c = RVR$

$a = b = d$

$RVR^2 = 2d^2(1-\cos(\gamma))$

if we assume α = (FOV off-boresight) = 15 deg, then γ = 150 deg