Egg-shaped conflict envelopes with Fuzzy logic for airspace Collision Risk Modelling

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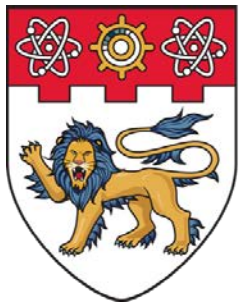

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Acknowledgment

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Motivation

- To increase airspace capacity, aircraft separation can be reduced.
- Therefore, how are the current separation standards derived?
- Can a different conflict envelope lead to the acceptance of a reduced separation requirement?

Target Level of Safety (TLS)

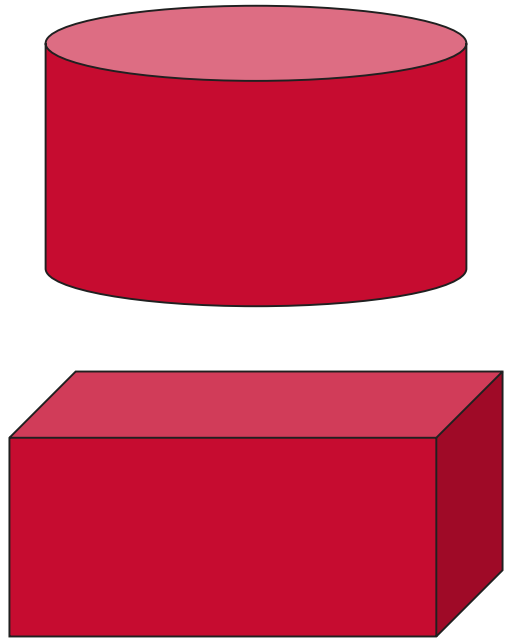
- TLS is specific to type of flight (recreational, military, commercial, etc.), and phase of flight (cruise, approach, etc.).
- TLS is usually defined as number of accidents per flight hour.
- There are multiple TLS around the world. Generally, they are in the order of 10^{-8} to 10^{-9} accidents per flight hour.

Collision Risk Models

- No single unified CRM
- EUROCONTROL
  - CRM developed by Mathematical Drafting Group
  - Includes ADS-B and 4D radar information
- Africa & Middle-East
  - CRM based on ICAO's Rice Formula

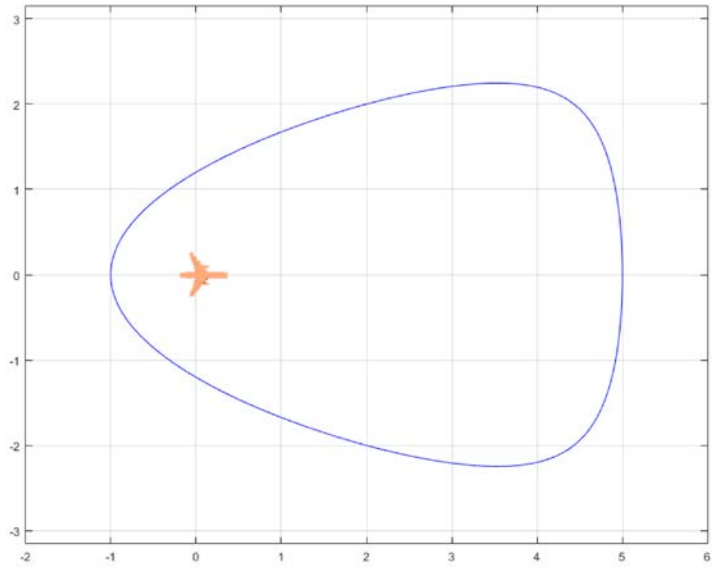
Conflict Envelope (or Region of Conflict)

- Existing 3D conflict envelopes
  - Cylindrical
  - Cuboid

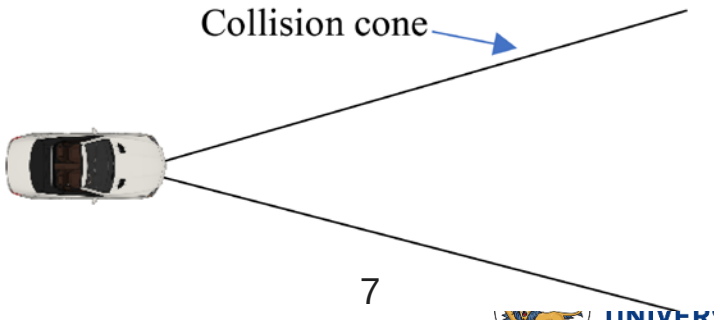


Egg-shaped Conflict Envelopes

- 2D Conflict Envelope of similar geometry derived from the shape of an egg
- Gives conflict attention to forward direction
- Conflict status is not transposable ($A \cap B \nLeftrightarrow B \cap A$)



- Inspired from the collision cone in automobile collision detection technology



Geometrical formulation

- Standard ellipse

$$\frac{(x-k)^2}{a}+\frac{(y-m)^2}{b}=1$$

- Modified ellipse with asymmetric x-values

$$\frac{(x-k)^2}{a}+\frac{(y-m)^2}{b}\cdot g(x)=1$$

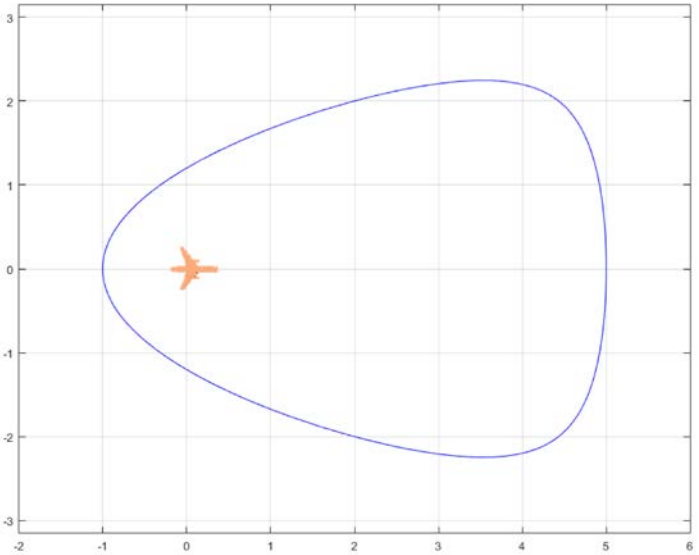
$$g(x)=1-px$$

- Parametrized

$$x=t+k$$

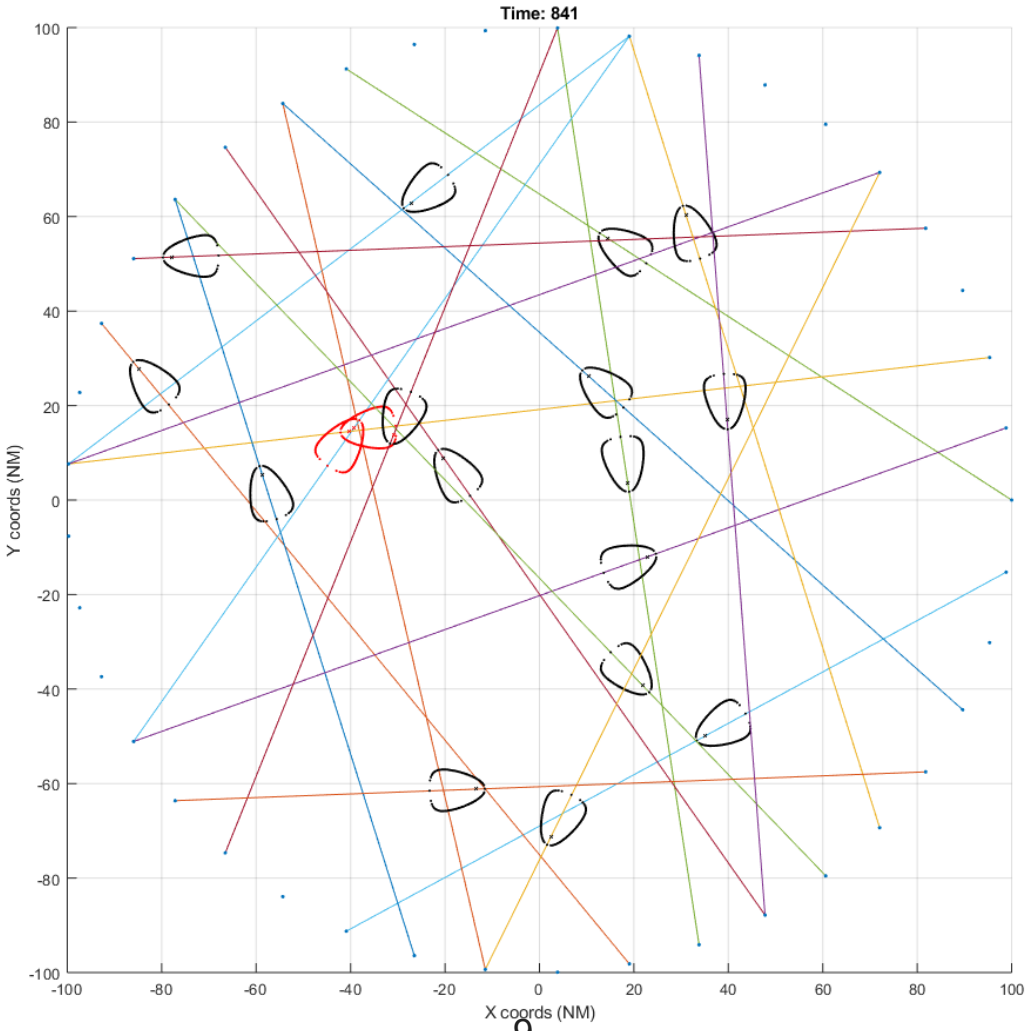
$$y=\pm\sqrt{\frac{b(a-t^2)}{a(1-pt)}}$$

$$a,b>0,k\geq 0,t^2\leq a$$

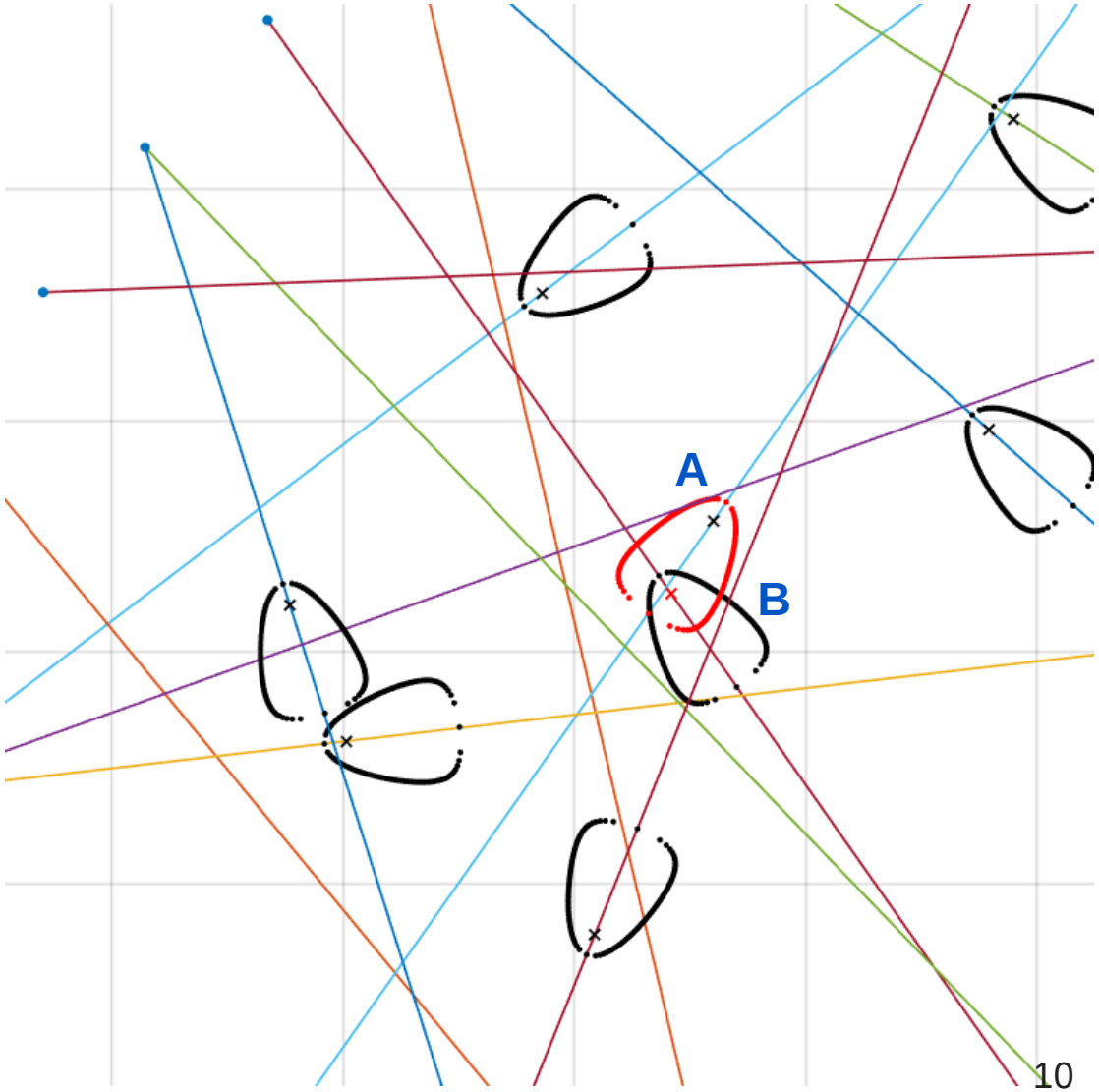


Some early results

- Simulated using entry and exit points on the circumference of a circular 2D airspace.
- 300 runs, each with randomized entry/exit points and time



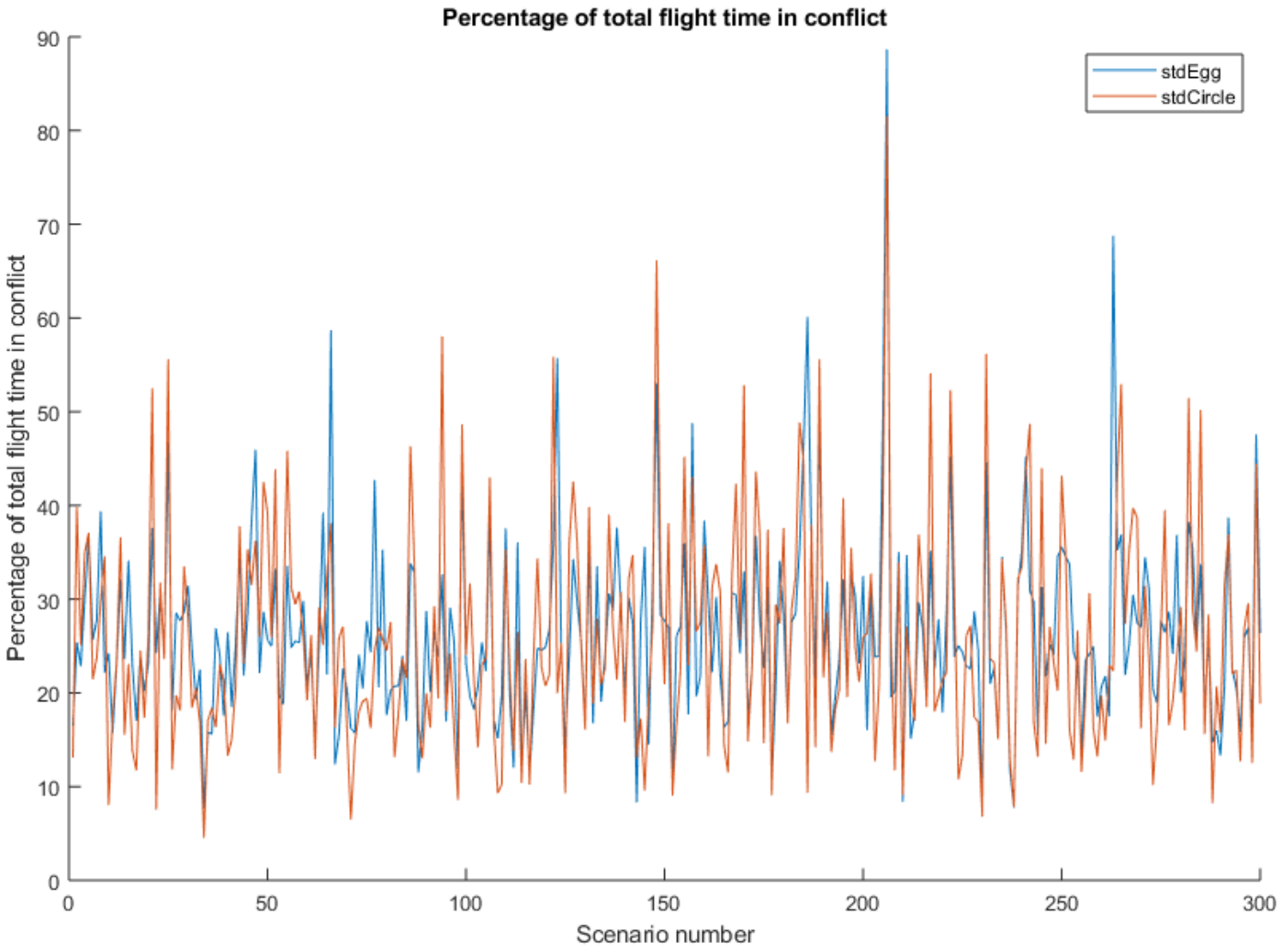
Non-transposable conflict logic ($A \cap B \nLeftrightarrow B \cap A$)



Aircraft B is in conflict with aircraft A.

Aircraft A is NOT in conflict with aircraft B

Some results



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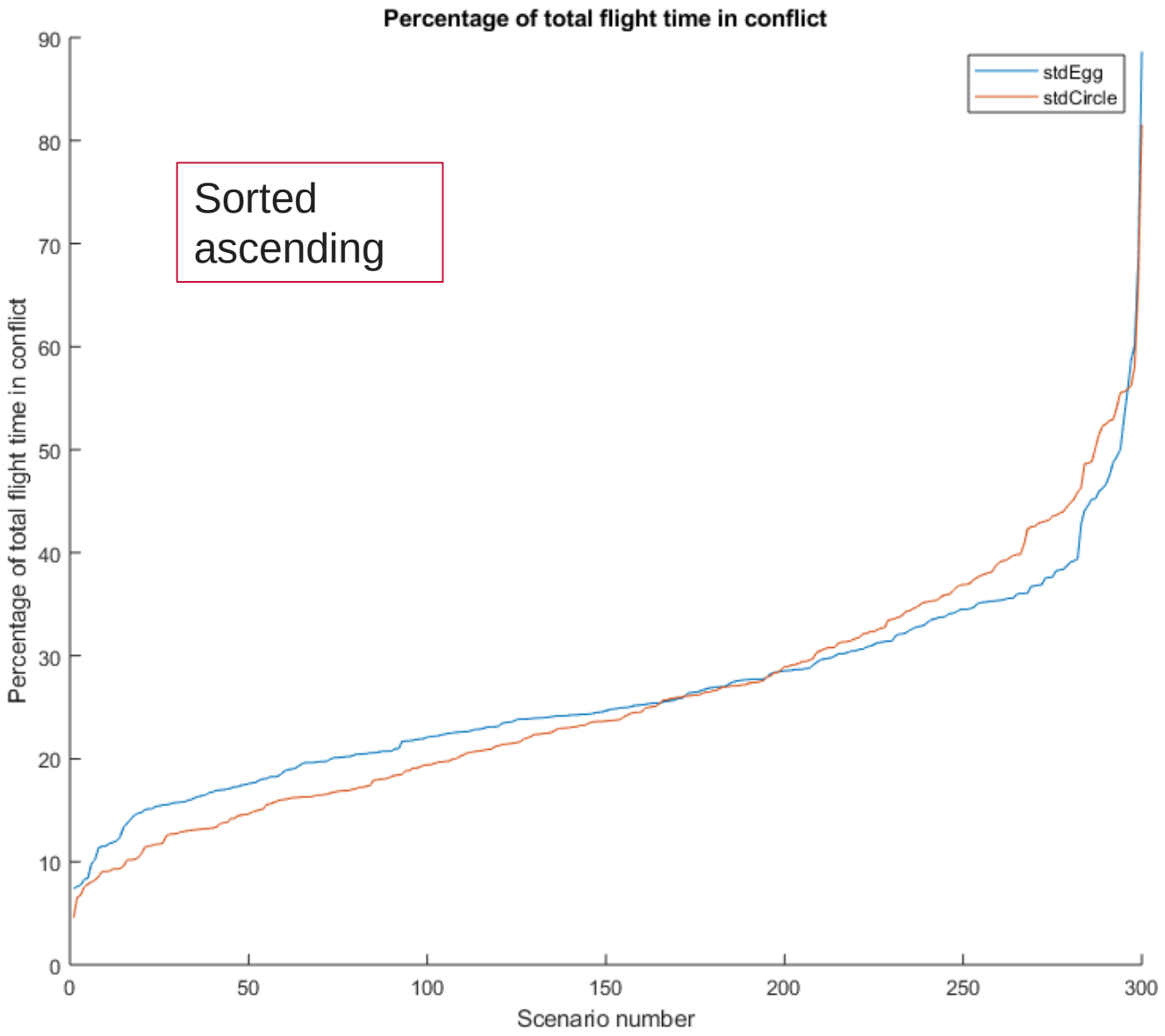
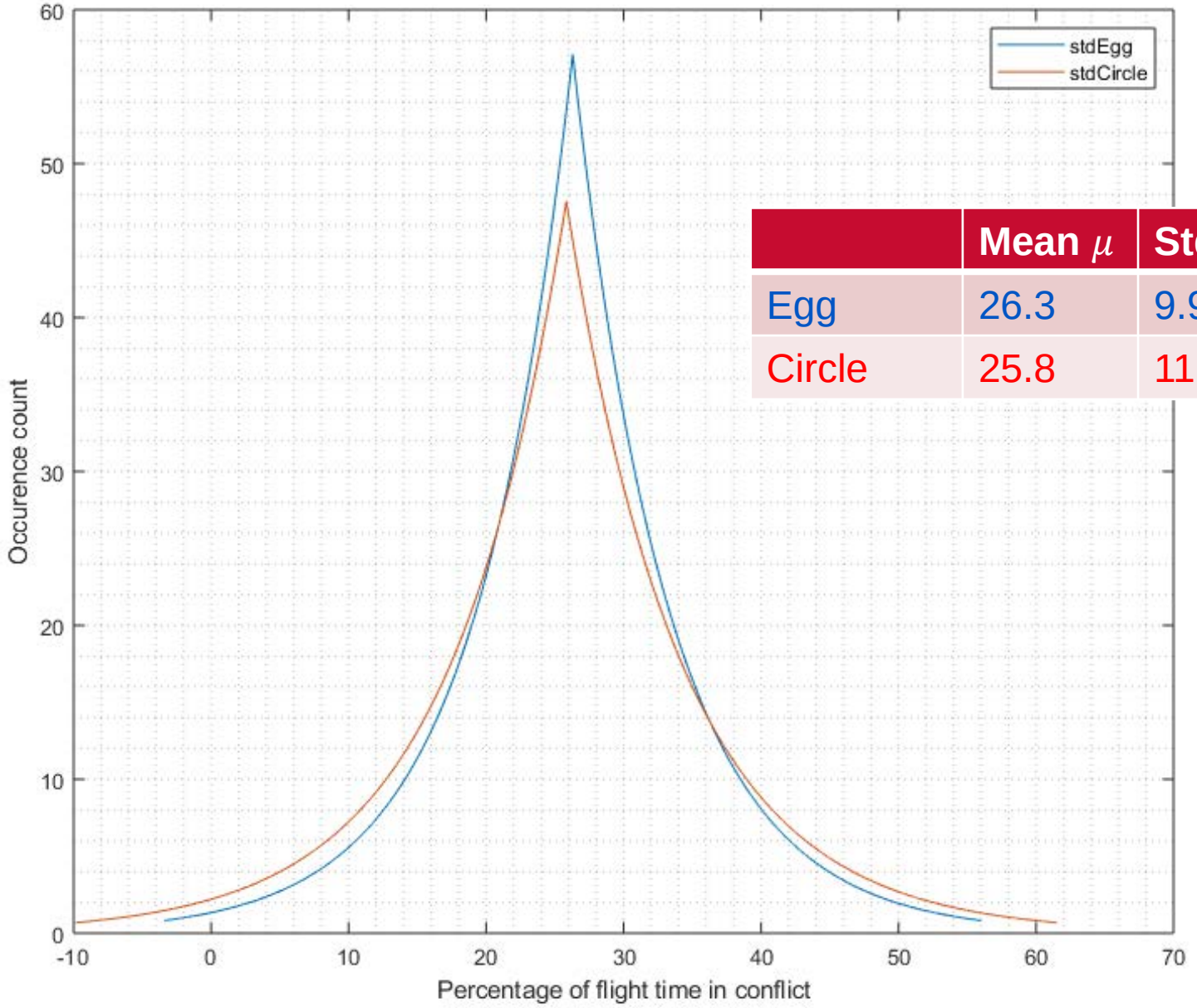


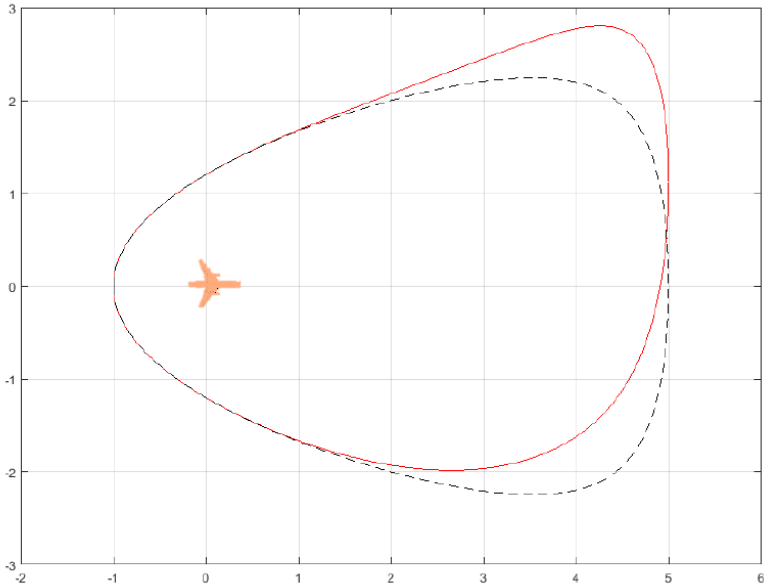
Histogram fit using Laplace distribution



	Mean μ	Std Dv σ
Egg	26.3	9.9
Circle	25.8	11.9

Tilt of Conflict Envelope

- Conflict envelope tilts with aircraft intention
- Intention may be acquired from flight plan or ATC queries
- Reflects where a conflict is more likely to happen



$$y' = y + \alpha x^n, x > 0$$

Fuzzy Logic vs Boolean Logic

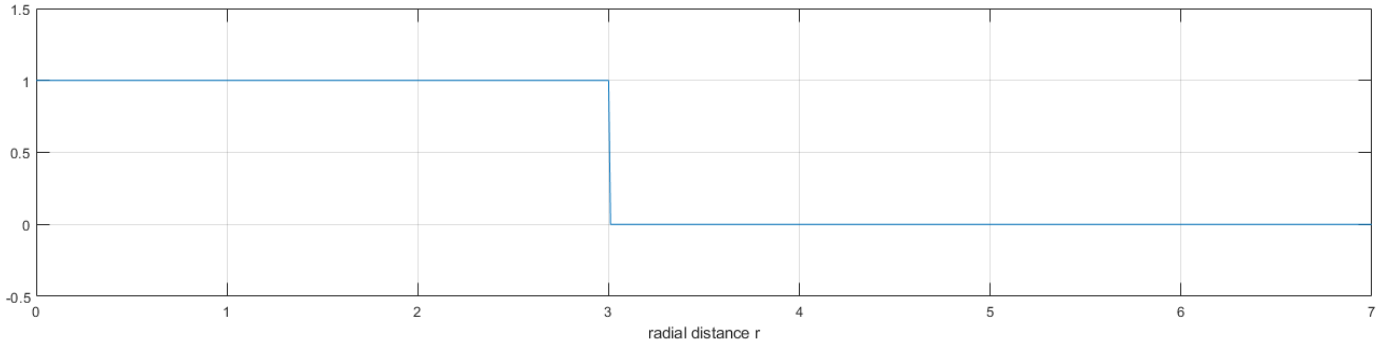
- Boolean Logic: Yes (1) or No (0)
- Fuzzy Logic: Yes (1), No (0), or any real value between 1 and 0.
  - Infinite number of values
- $\text{Logical output} = f(\text{inputs})$

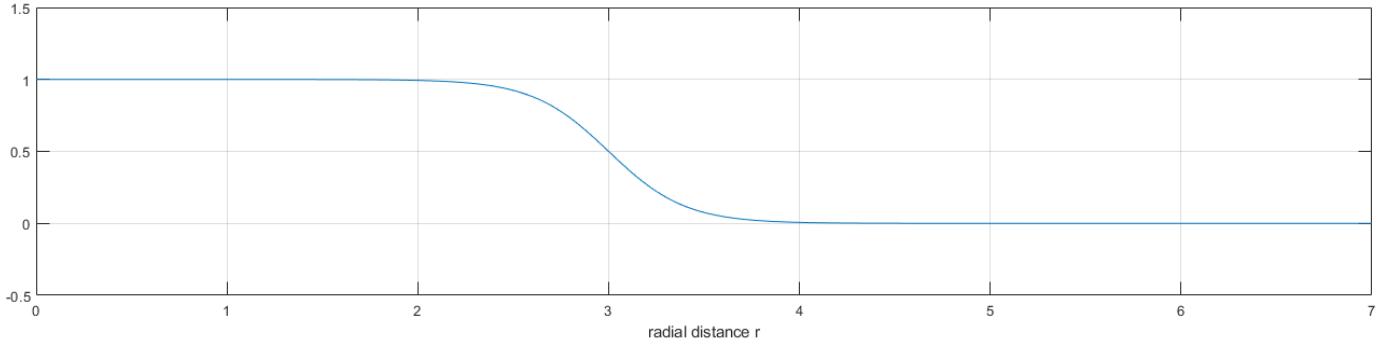
Membership Functions (MF) in Fuzzy Logic

- MFs are functions that assign an input to a degree of membership between 0 to 1. Common functions include
- Trapezoid
- Gaussian
- Cauchy
- Laplace
- Logistic (Sigmoid) ← Used for implementation

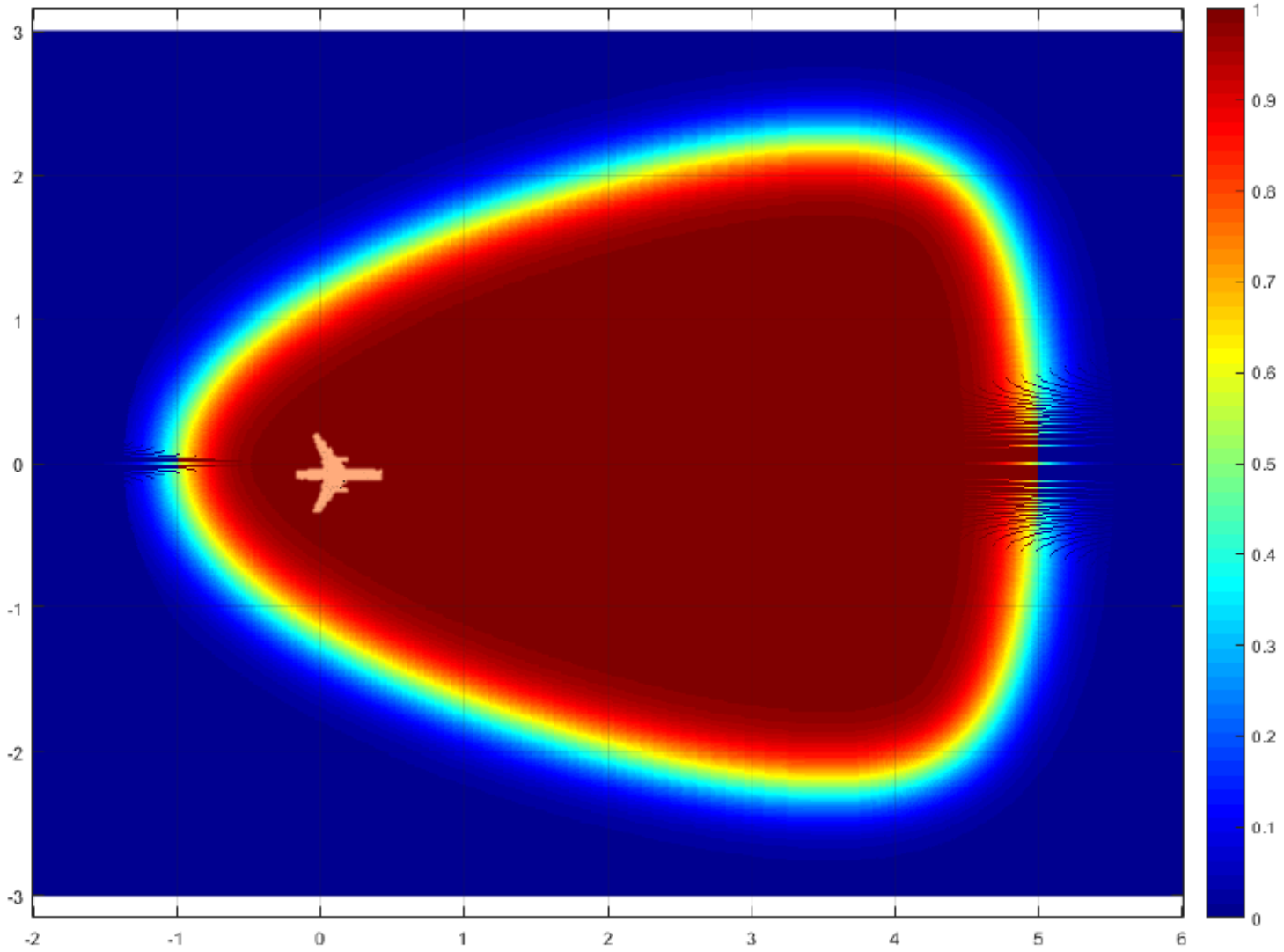
Conflict Status at the Boundary

- *Conflict* [1 or 0] will change from Boolean to Fuzzy → *Degree of Conflict* [1,0]





Heatmap of Fuzzy Conflict Envelope



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Between Fuzziness and Randomness

- Both concepts can easily be confused since they take on values between 0 and 1.
  - Fuzziness: Degree to which an event occurs
  - Randomness: Certainty of an event occurring

- Eg:
  - Fuzziness: Will it be a thunderstorm, or a light shower, or anything in between.
  - Randomness: How likely will it rain

Challenges

- How can the *level of safety* parameter be
  - **Evaluated** in a simulation,
  - **Compared** with existing standards/models,
  - **Verified** in a real-world setting.

- How can the optimal shape/size of the egg-shape be determined, such that it does not over or under estimate the collision probabilities

- What concept in reality can the *degree of conflict* parameter really represent?

Conclusion

- Presented a non-symmetrical conflict enveloped which prioritizes forward of aircraft.
- Briefly demonstrated a tilted conflict envelope which may vary with the aircraft intent
- Integrated Fuzzy logic to the boundary of the conflict envelope

Thank you for your attention!