# Transportation CPS Workshop

## CPS for Aviation: Looking Forward

## Controller Design for Safety Critical Systems

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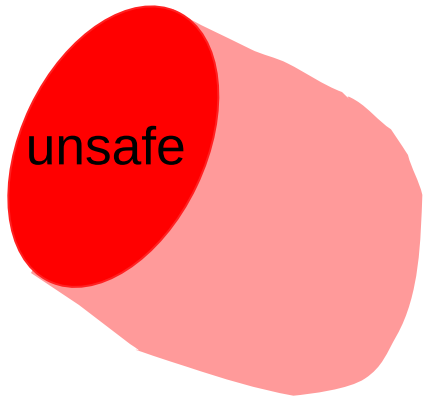
**with Ian Mitchell (UBC), Alex Bayen (UCB), Jerry Ding (UCB), Rodney Teo (DSO), and Jung Soon Jang (Boeing)**

# Controller Design for Safety Critical Systems

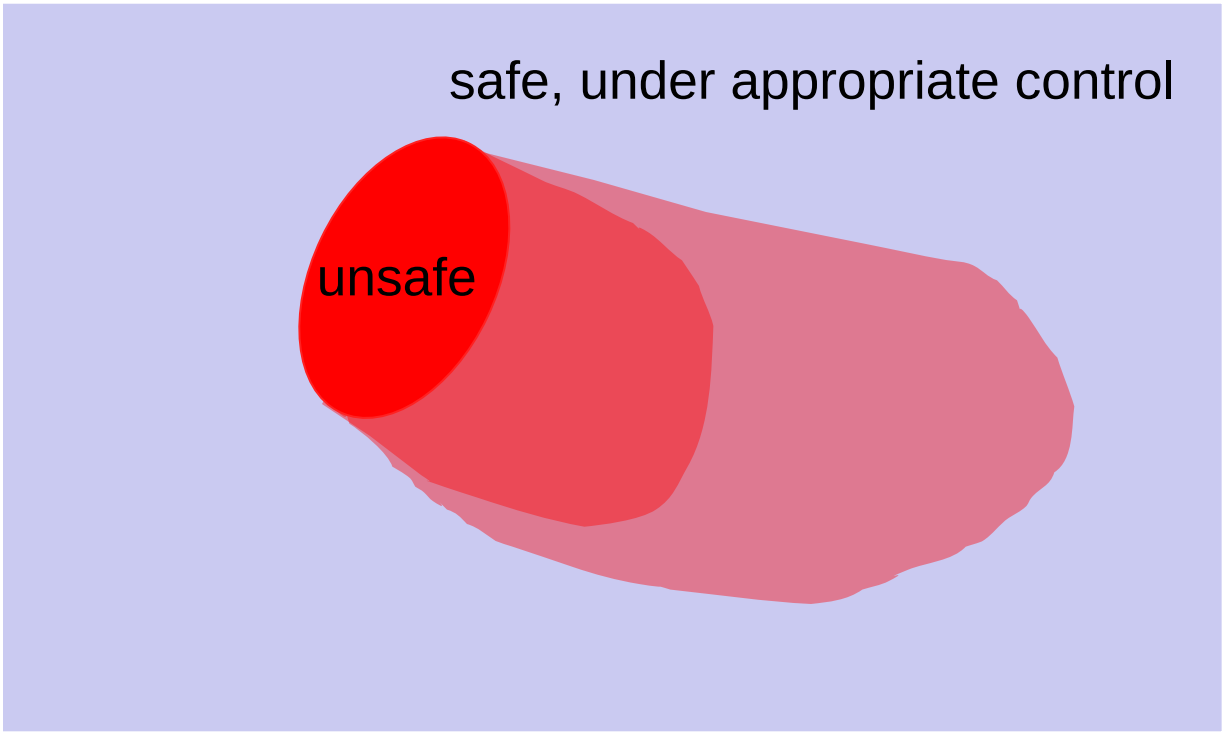

**Controller synthesis:** to guarantee that a system satisfies a safety property

# Controller Design for Safety Critical Systems

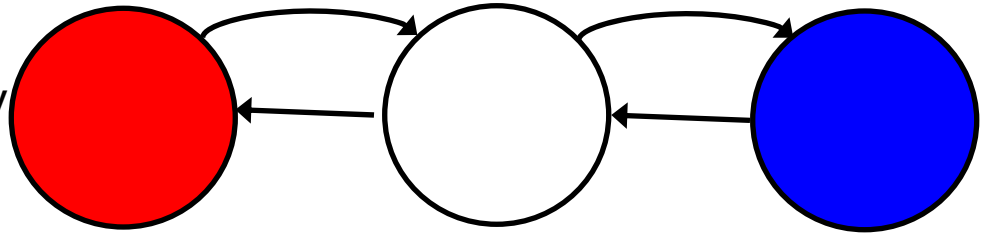



**Controller synthesis:** to guarantee that a system satisfies a safety property

# Controller Design for Safety Critical Systems




**Safety Property** can be encoded as a condition on the system's **reachable set of states**

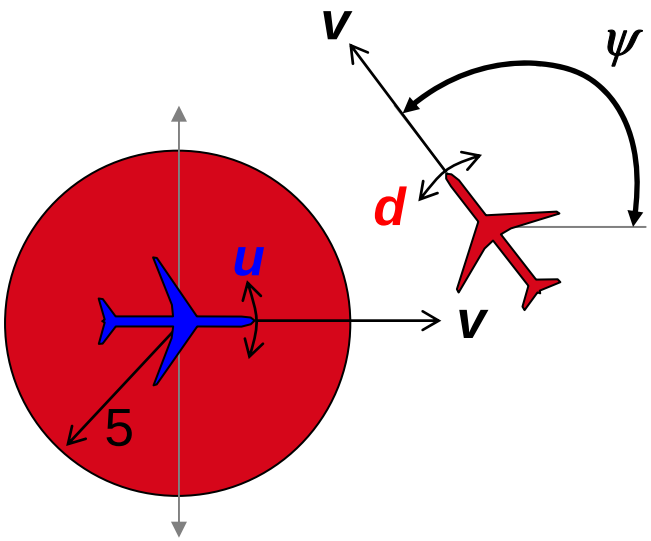


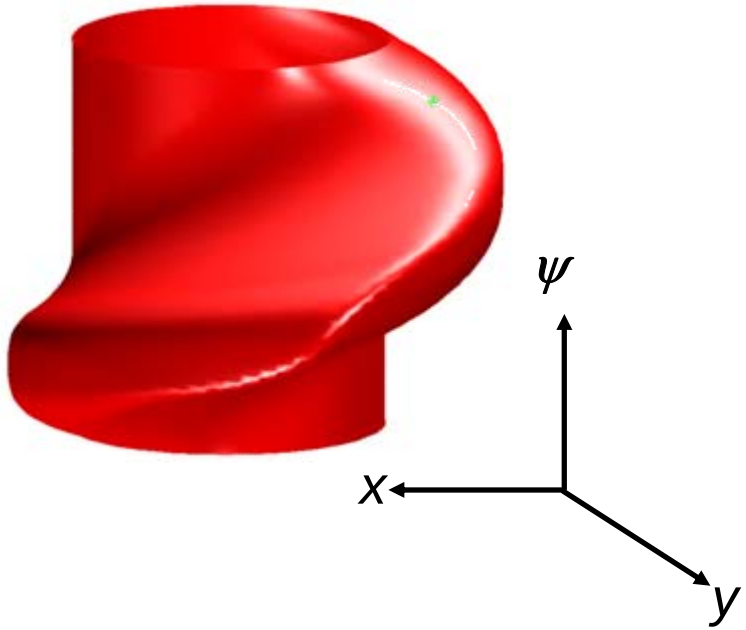
In red, system may become unsafe

In blue, system will stay safe

On boundary, apply control to stay out of red

# Example 1: Collision avoidance control

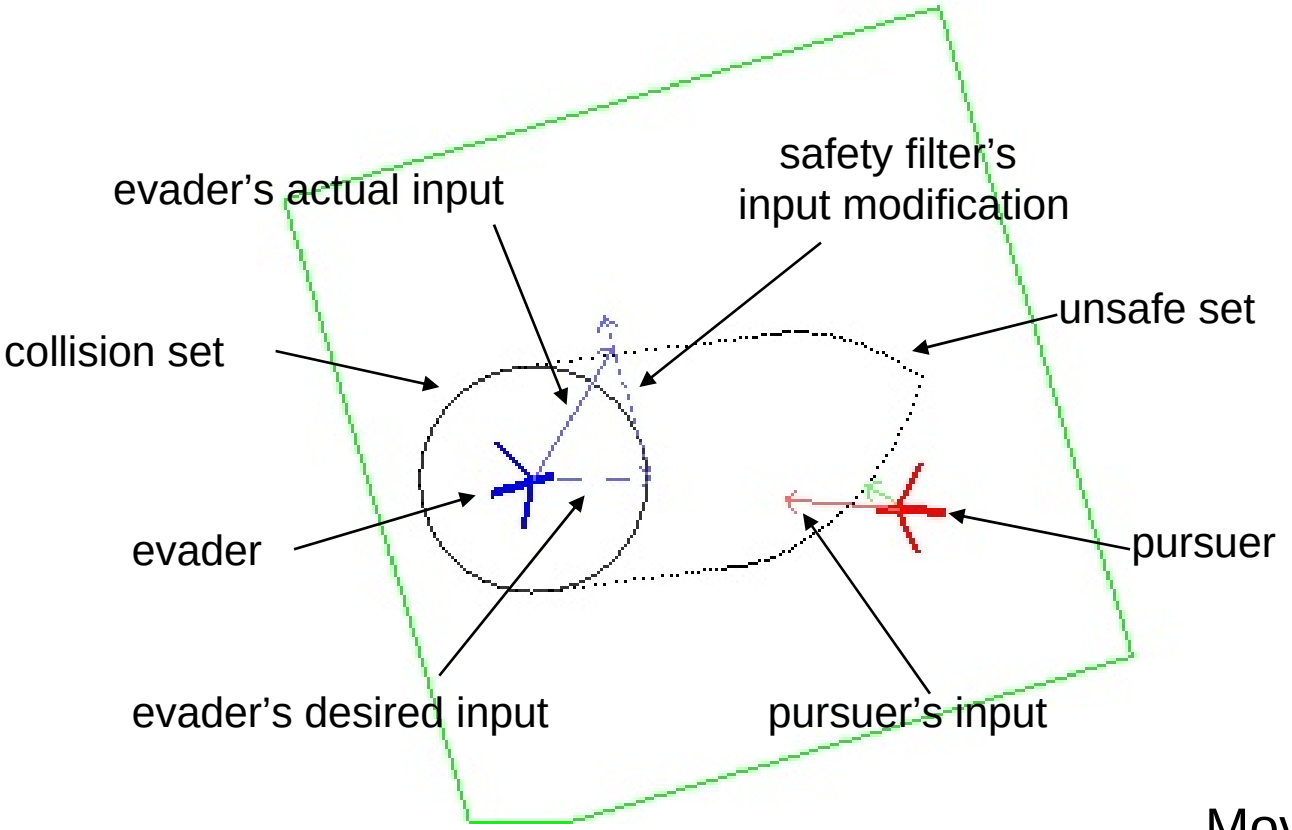


# Collision Avoidance Control

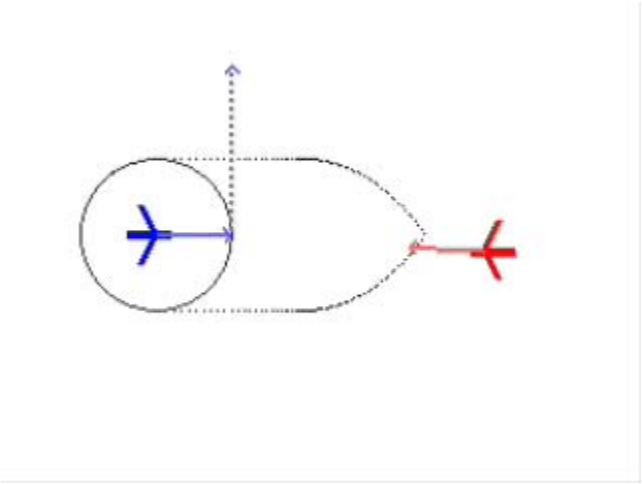
Simple demonstration

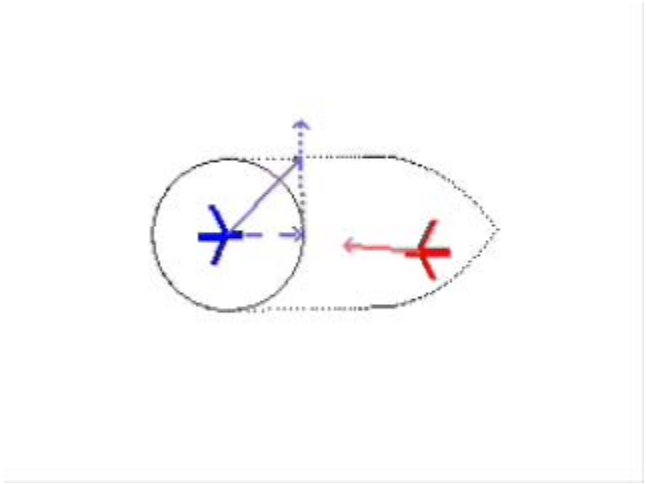
- Pursuer: turn to head toward evader
- Evader: turn to head right




Movies…

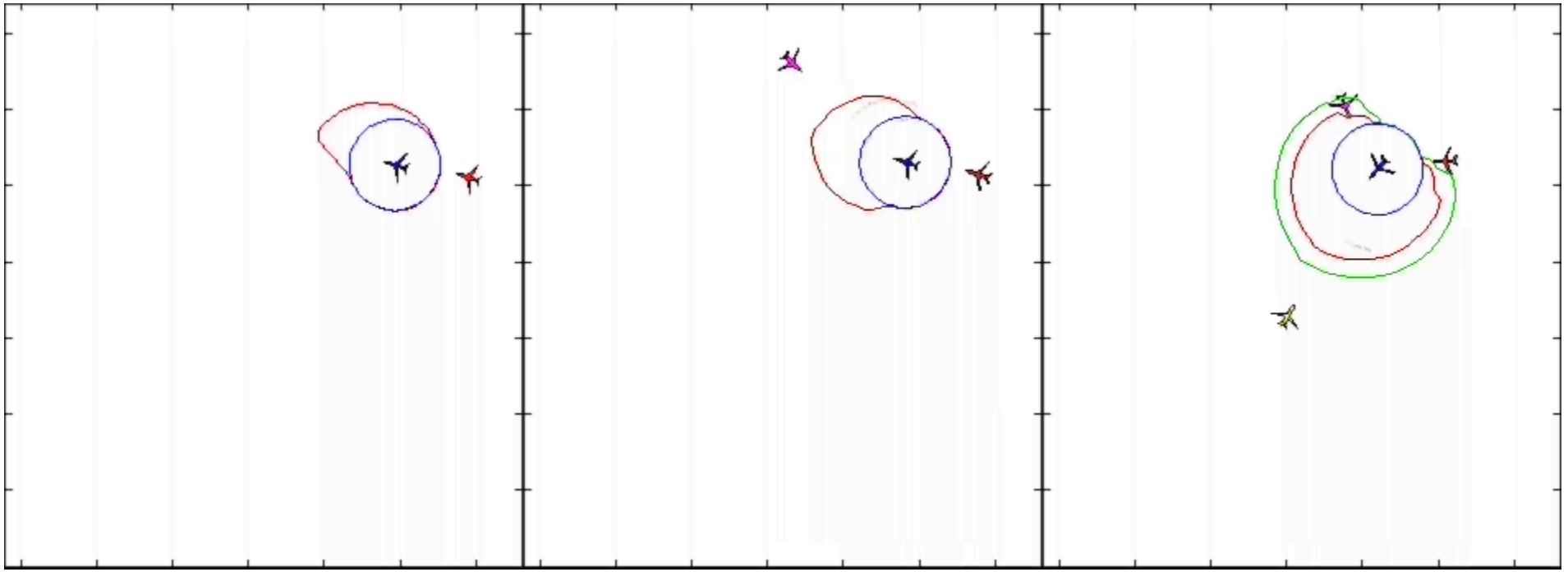
# Collision Avoidance Control



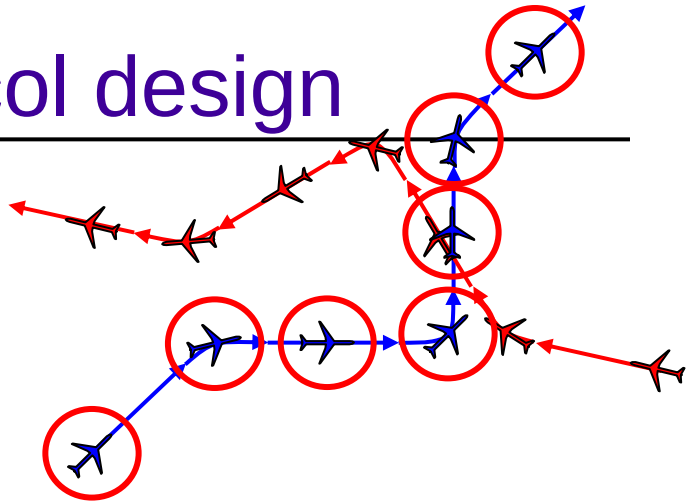


http://www.cs.ubc.ca/~mitchell/ToolboxLS/

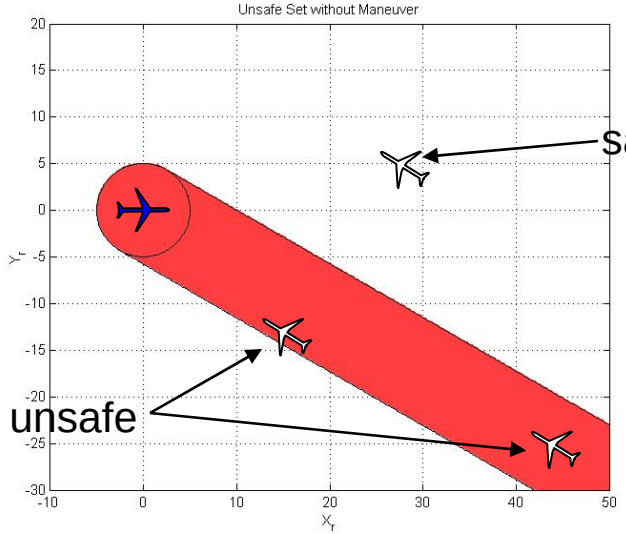
# Extending to multiple aircraft

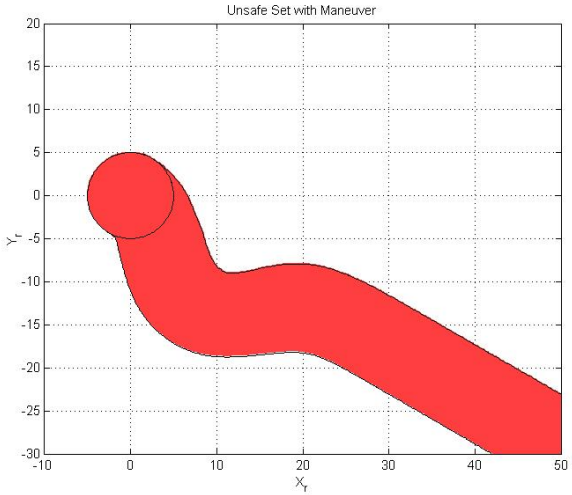


# Example 2: Protocol design



unsafe set without maneuver

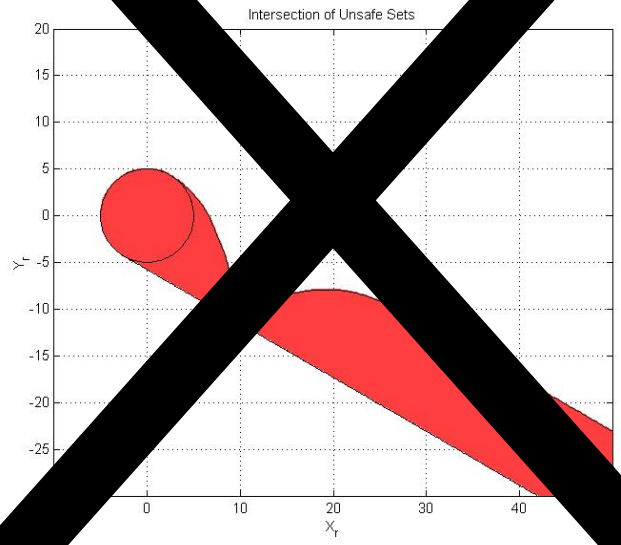



unsafe set with maneuver

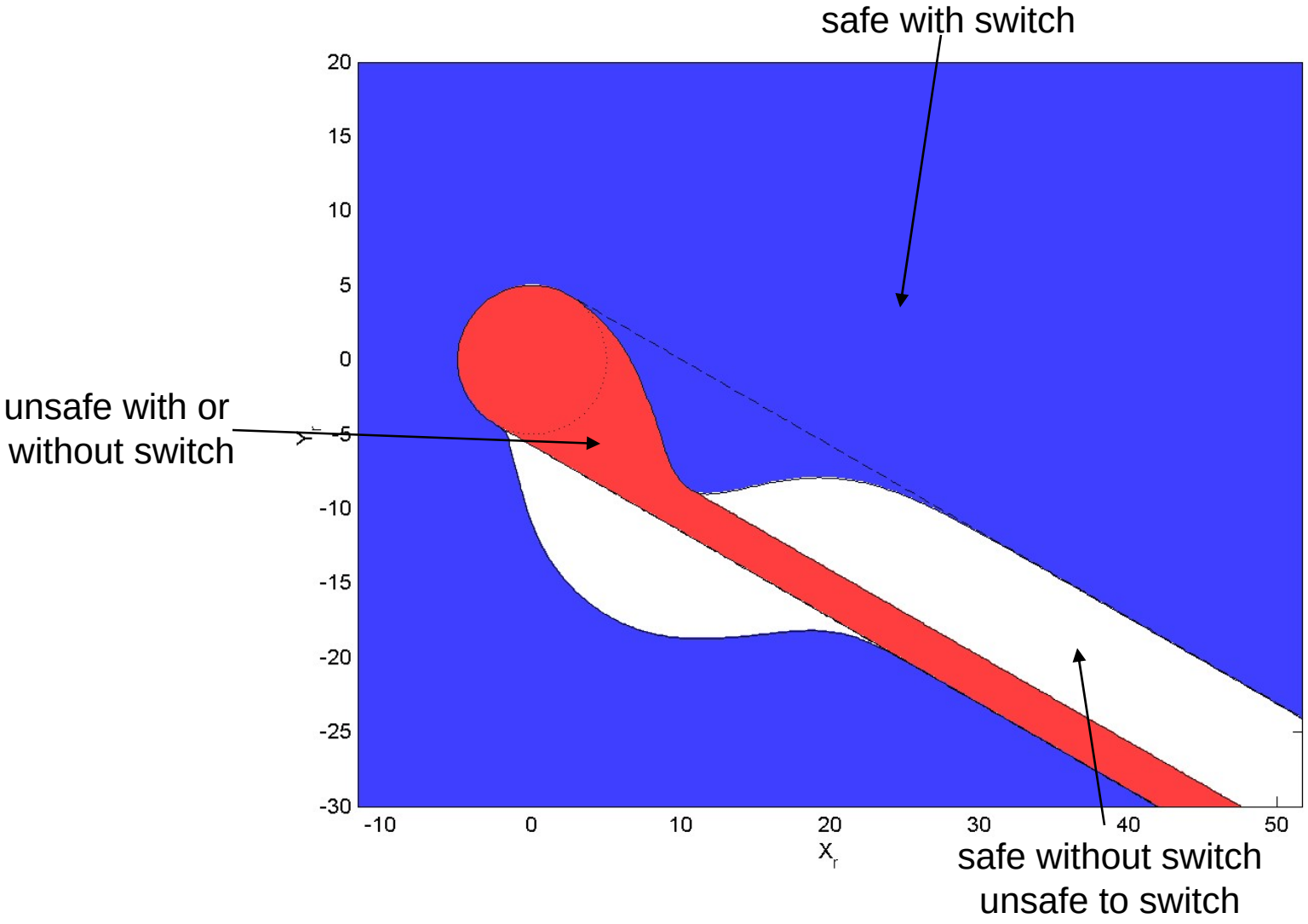
?

unsafe set with choice
maneuver or no



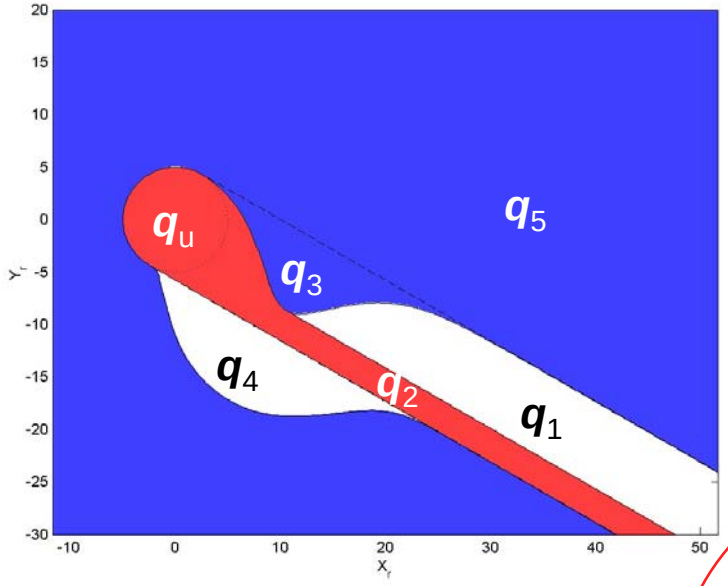
# Protocol Design

- Ability to choose maneuver start time further reduces unsafe set

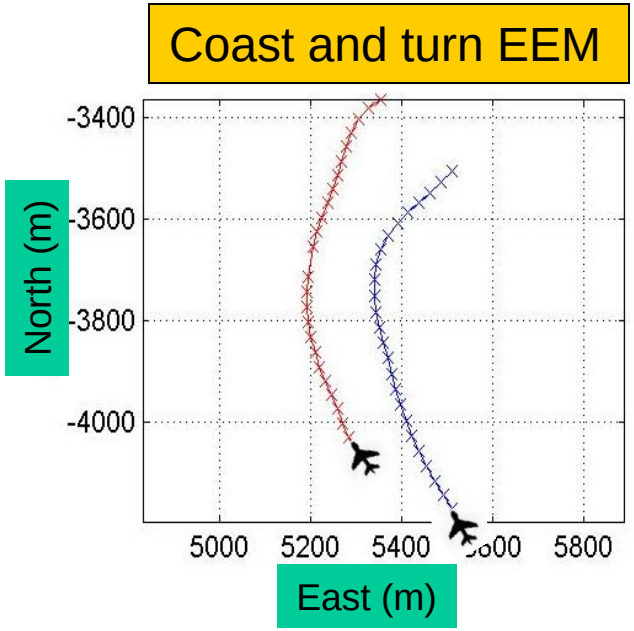


# Implementation: a finite automaton

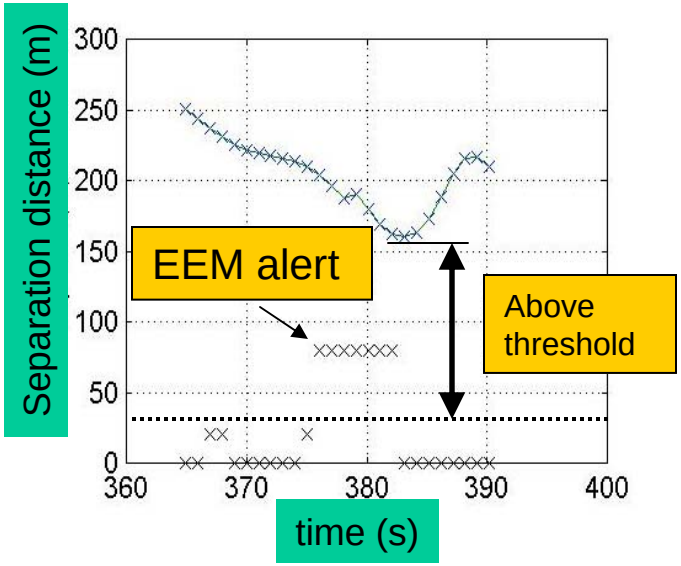
- It can be easier to analyze discrete systems than continuous: use reachable set information to abstract away continuous details

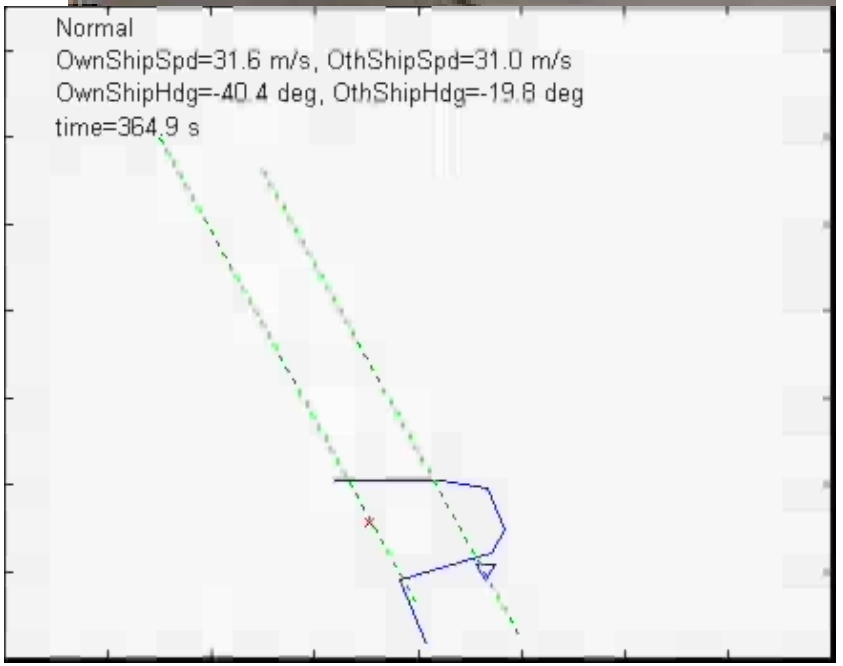


# Tested at Moffett Federal Airfield



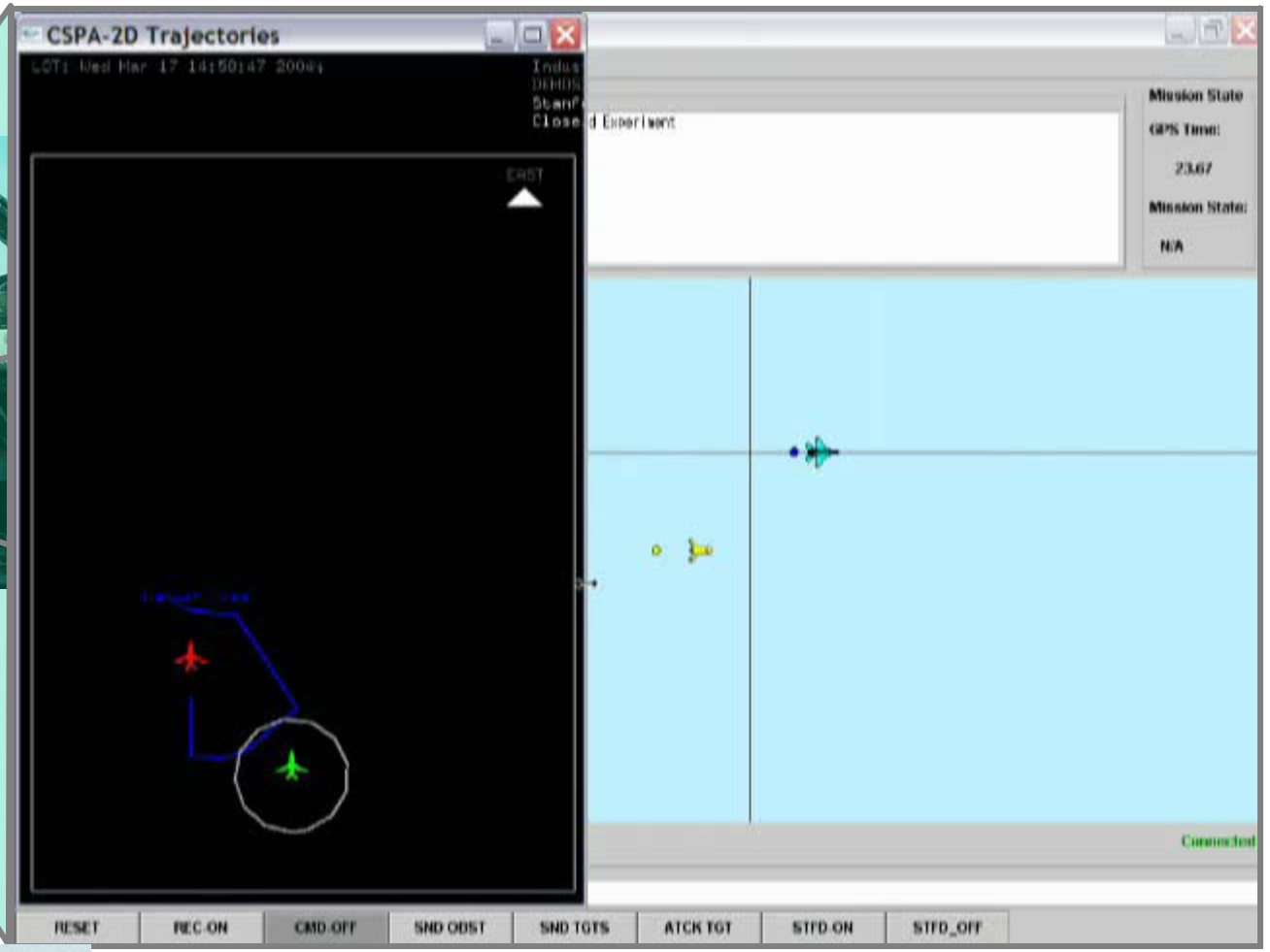




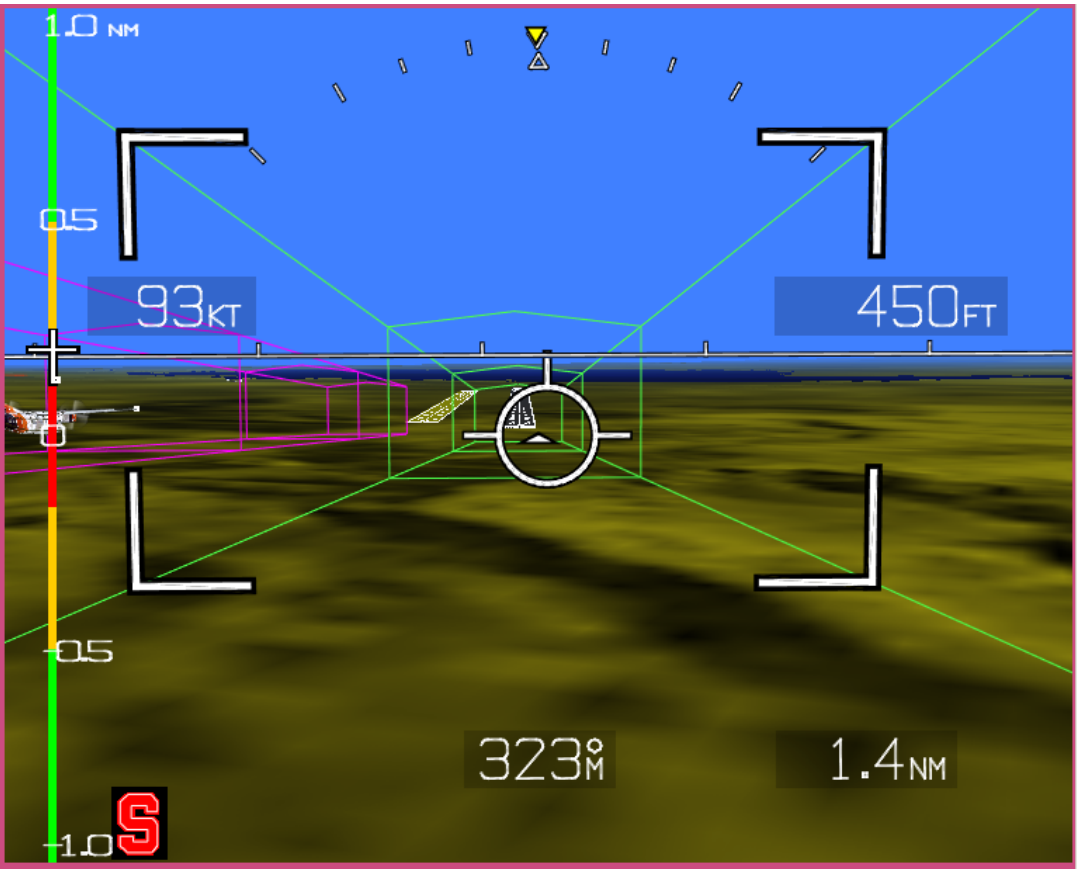



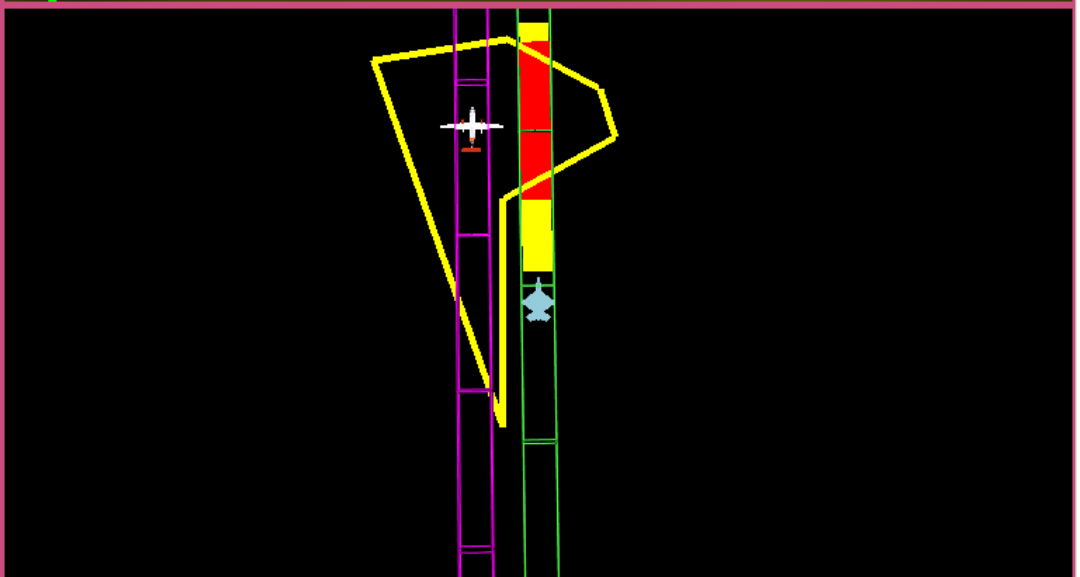
# Tested at Edwards Air Force Base

**T-33 Cockpit**




[DARPA/Boeing SEC Final Demonstration:
F-15 (blunderer), T-33 (evader)]

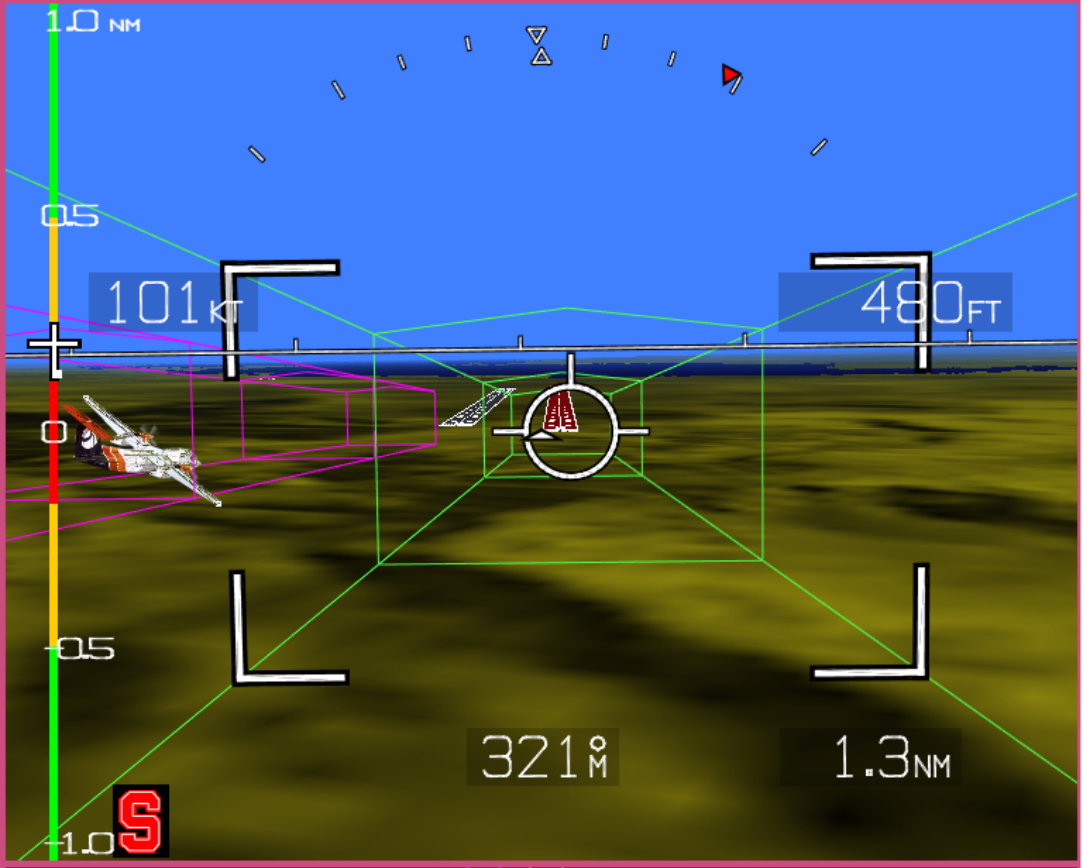


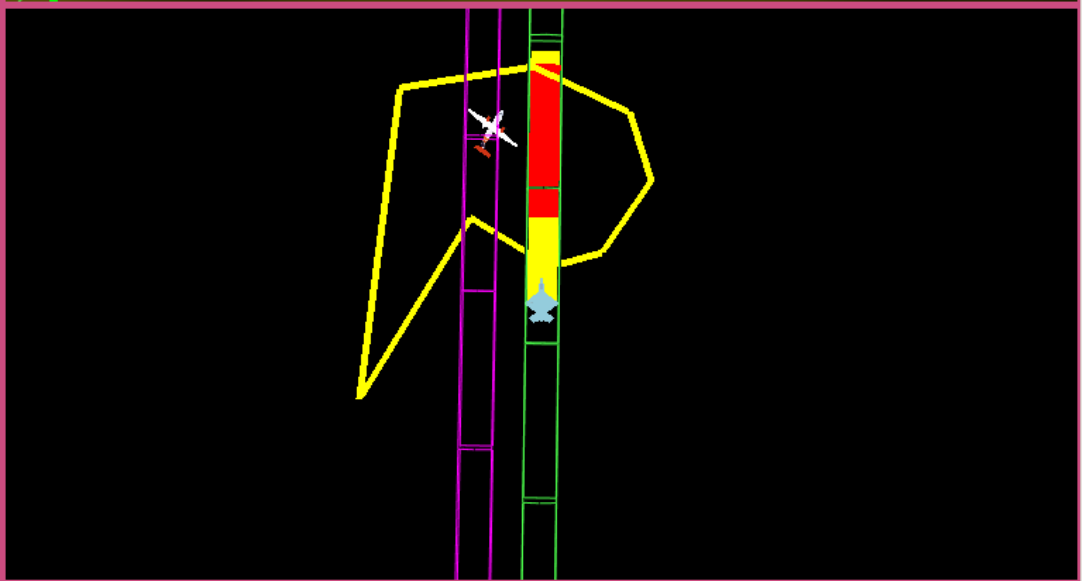



Blunder Zone is shown by the yellow contour

Red Zone in the green tunnel is the intersection of the BZ with approach path.

The Red Zone corresponds to an assumed 2 second pilot delay. The Yellow Zone corresponds to an 8 second pilot delay



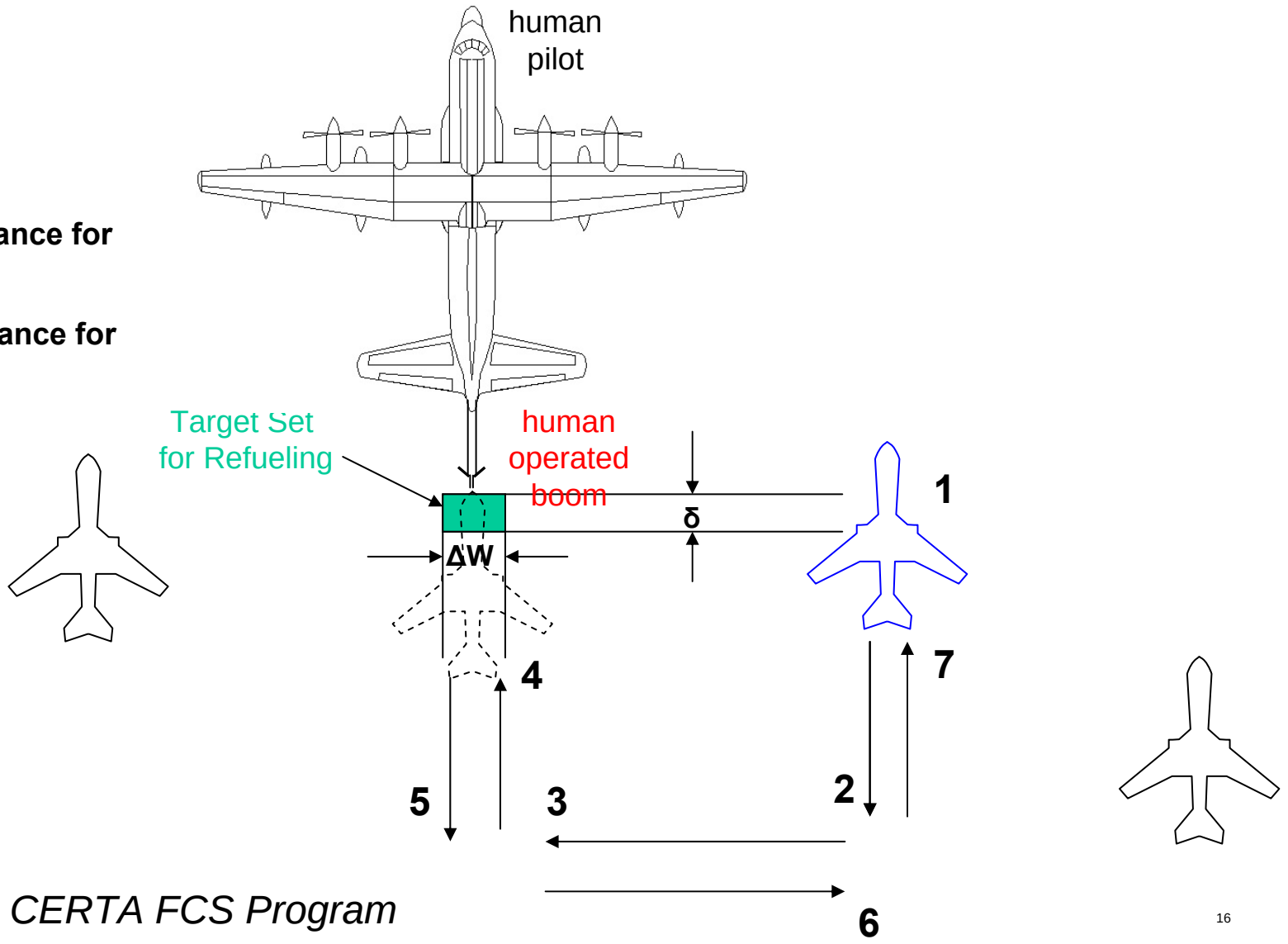
Map View showing a blunder

The BZ calculations are performed in real time (40Hz) so that the contour is updated with each video frame.

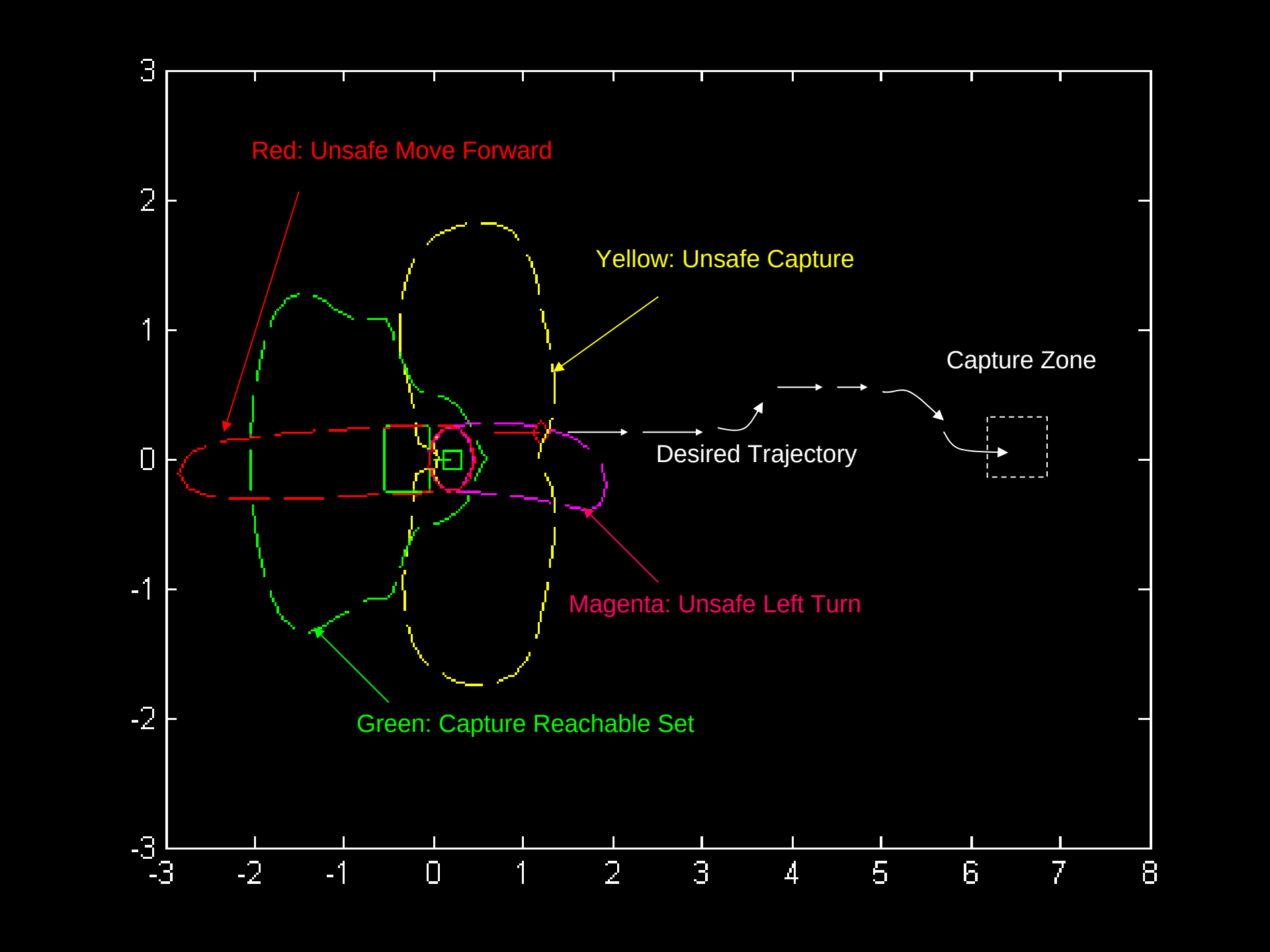
# Example 3: Automated Aerial Refueling

**δ = Long. Tolerance for Catching Boom**

**ΔW = Lat. Tolerance for Catching Boom**




*Boeing, AFRL CERTA FCS Program*


Red: Unsafe Move Forward
Yellow: Unsafe Capture
Capture Zone
Desired Trajectory
Magenta: Unsafe Left Turn
Green: Capture Reachable Set
3
2
1
0
-1
-2
-3
-3
-2
-1
0
1
2
3
4
5
6
7
8

# Directions

- AFOSR MURI:  from controller design to code
- NASA:  integrating short term collision avoidance methods with long term separation assurance schemes
- NASA:  Super-dense regions (Hansman and Balakrishnan)
- AFRL:  G-CAS, A-CAS, AAR