

Uncrewed Aircraft System Lost Command and Control Link Procedures with Simulated Air Traffic Control Resolution Maneuvers

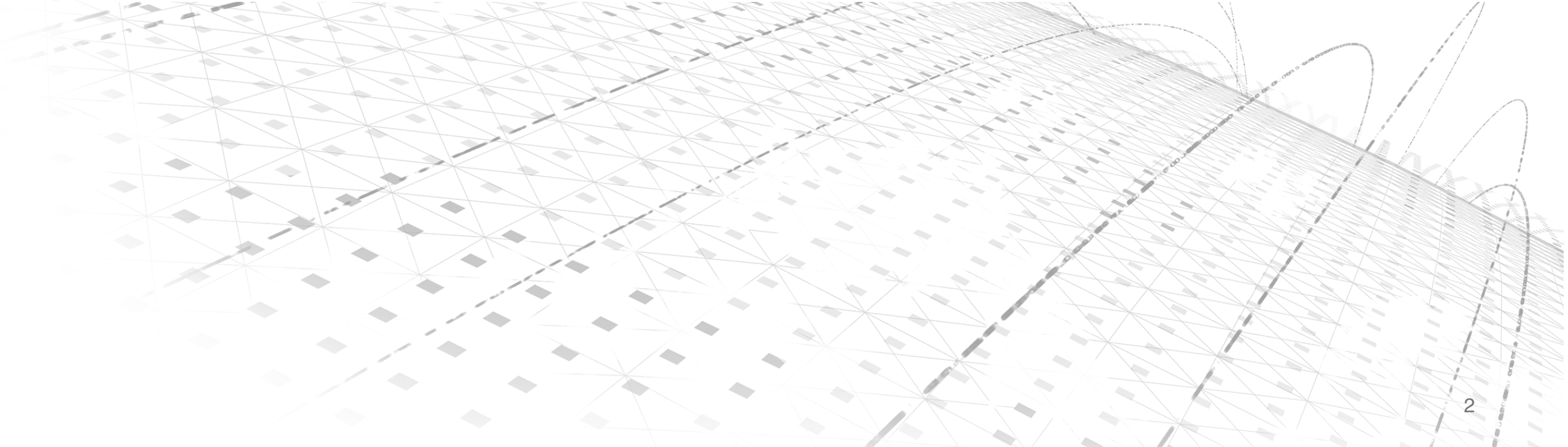
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James D. Phillips – Crown Innovations Inc.

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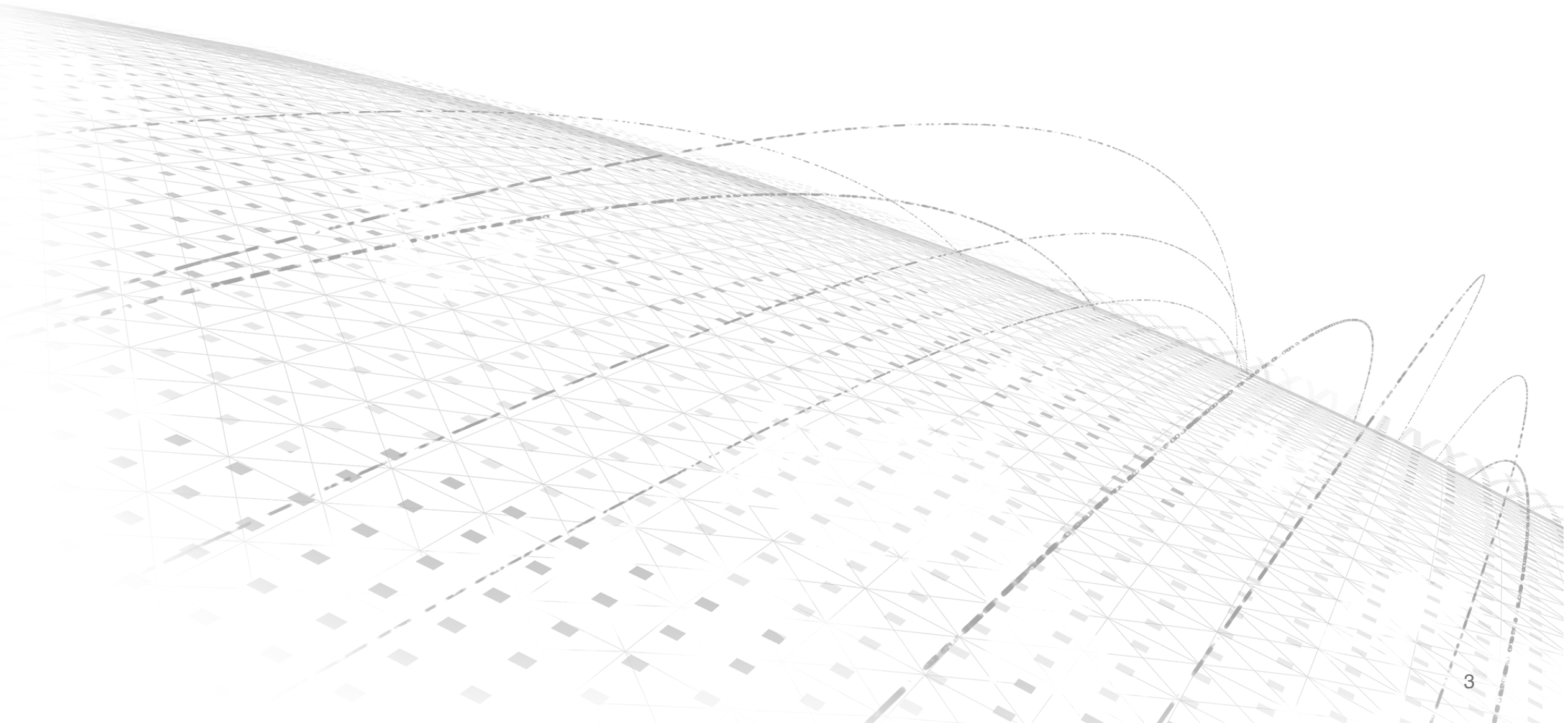
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Overview

- Introduction and Background
- Modeling the Problem
- Results and Discussion
- Conclusions



Introduction



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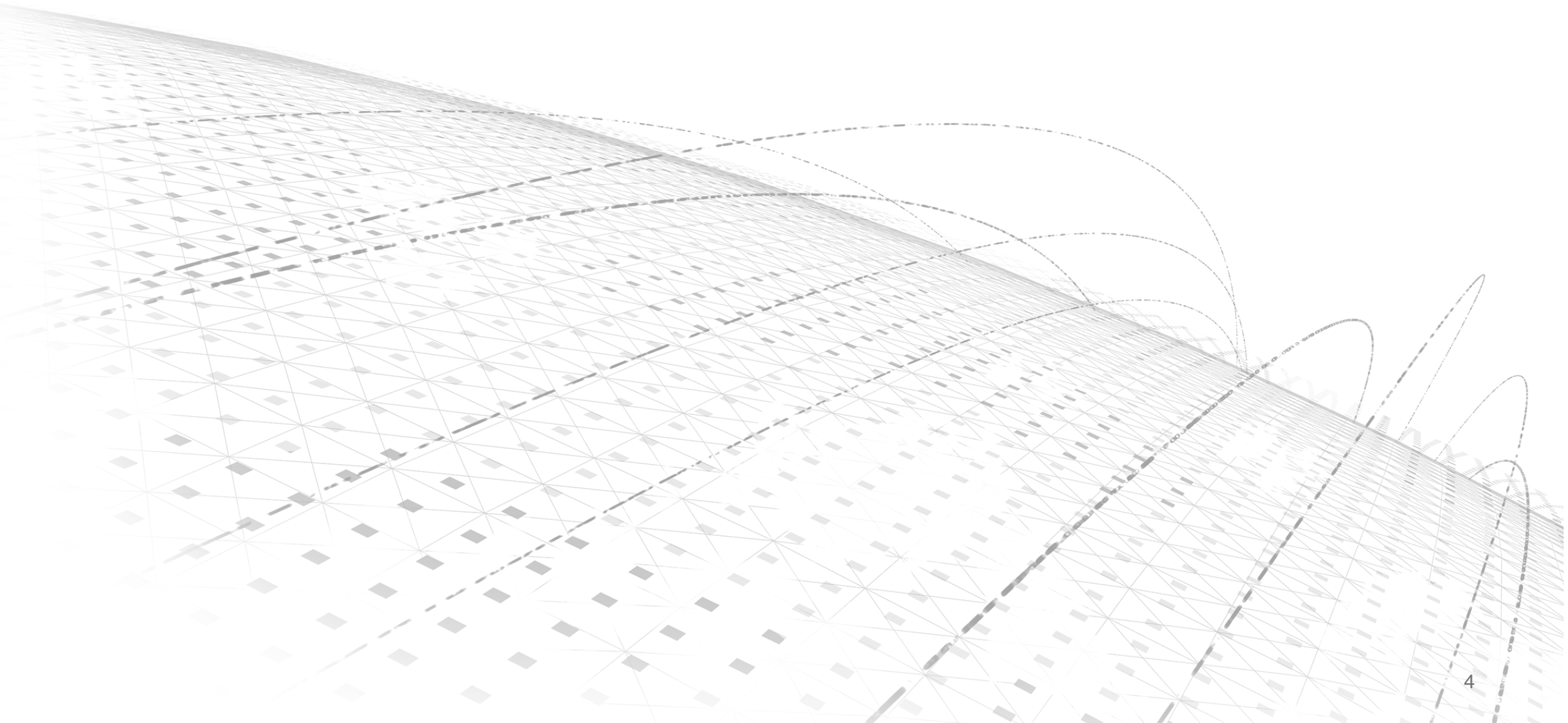
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- **Initial Use Case:** Large, fixed-wing UAS (e.g., C208) operating from conventional airports to deliver regional cargo (~200,000 UAS flights per year in the United States)
- **The Challenge:** Achieving scale and satisfying business cases requires robust procedures for off-nominal events

Lost Command and Control Link



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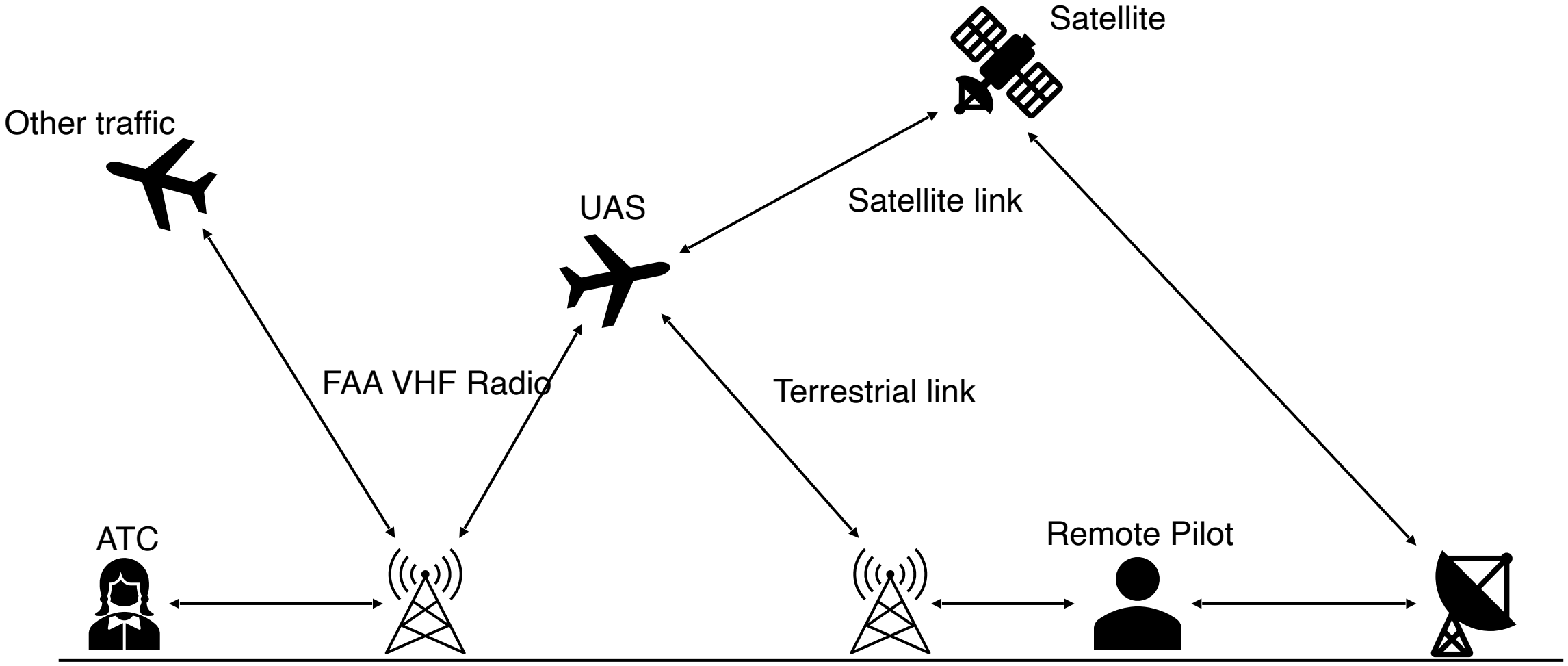
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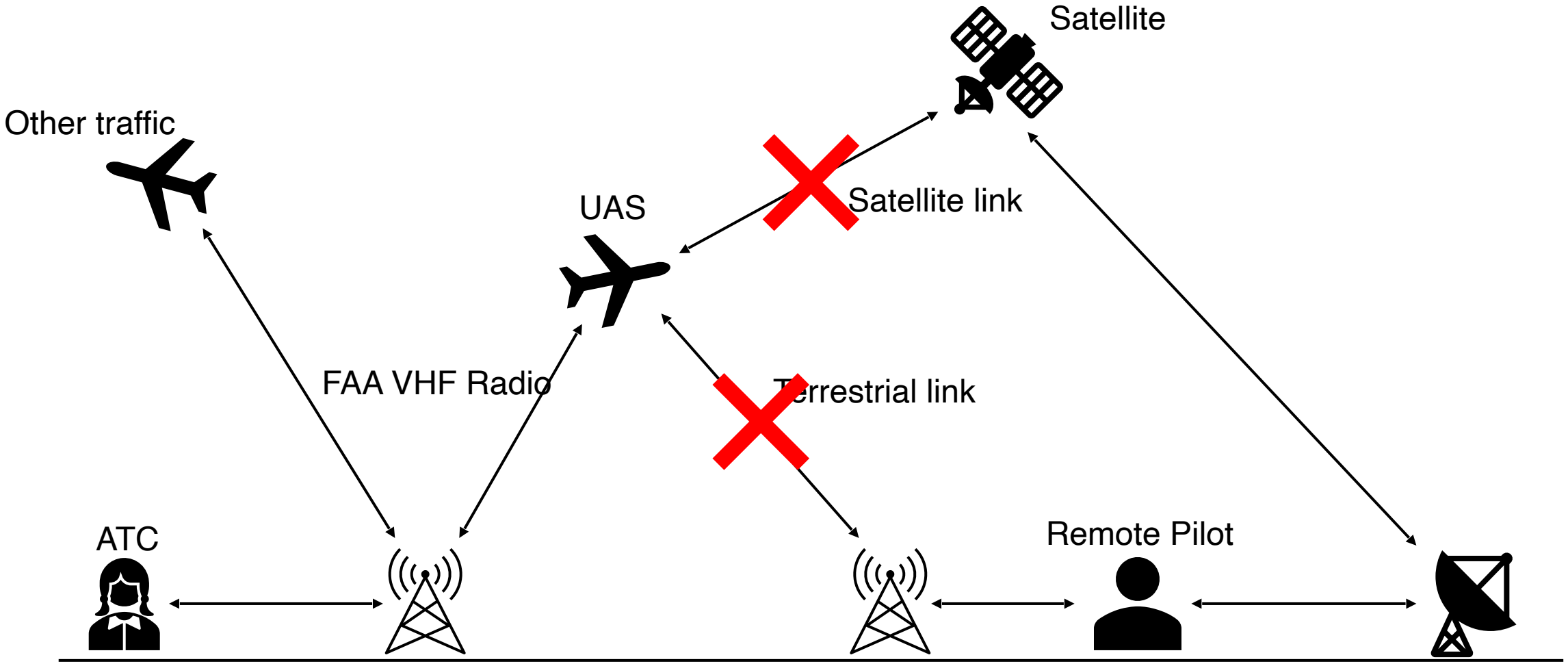
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- The ATCO will not be able to issue actionable control instructions to the UAS when the C2 link is severed

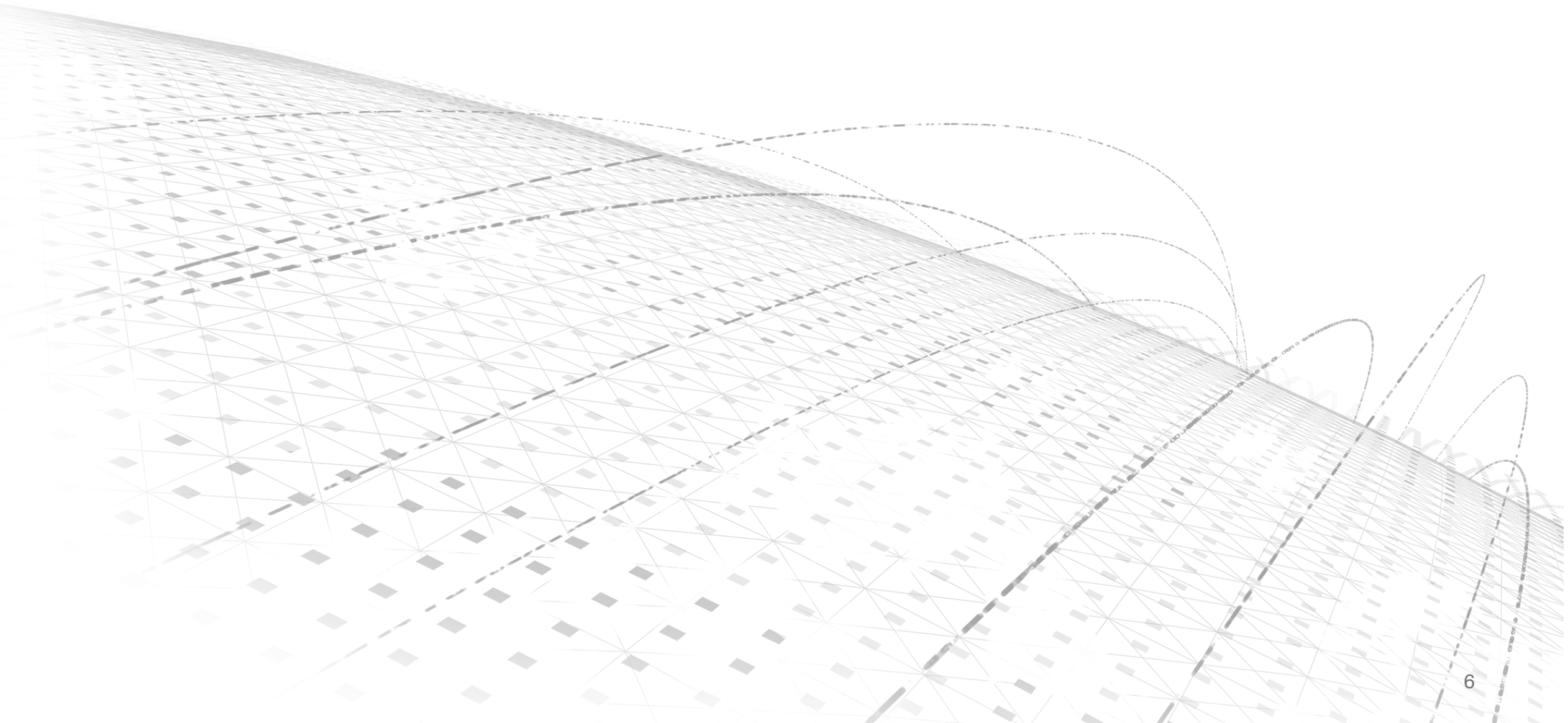
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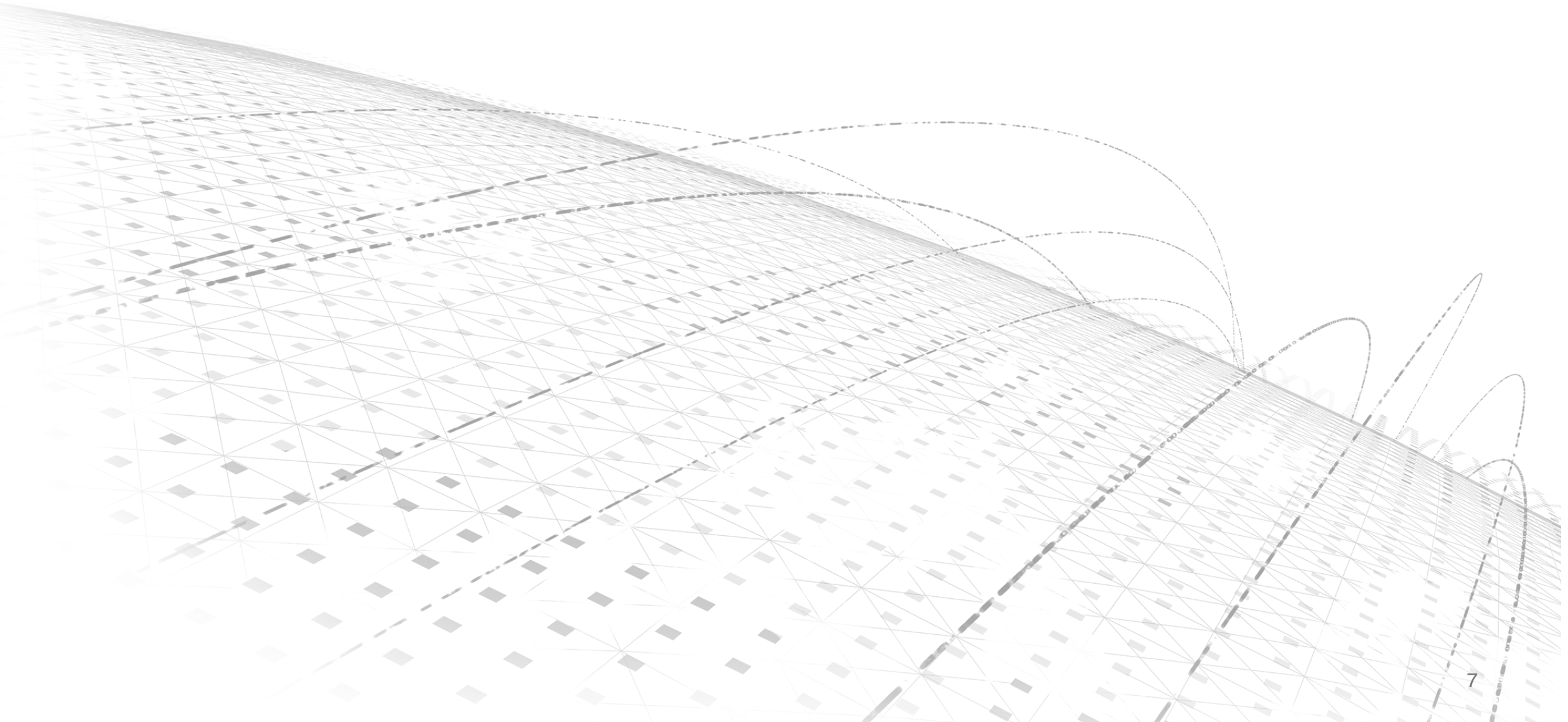
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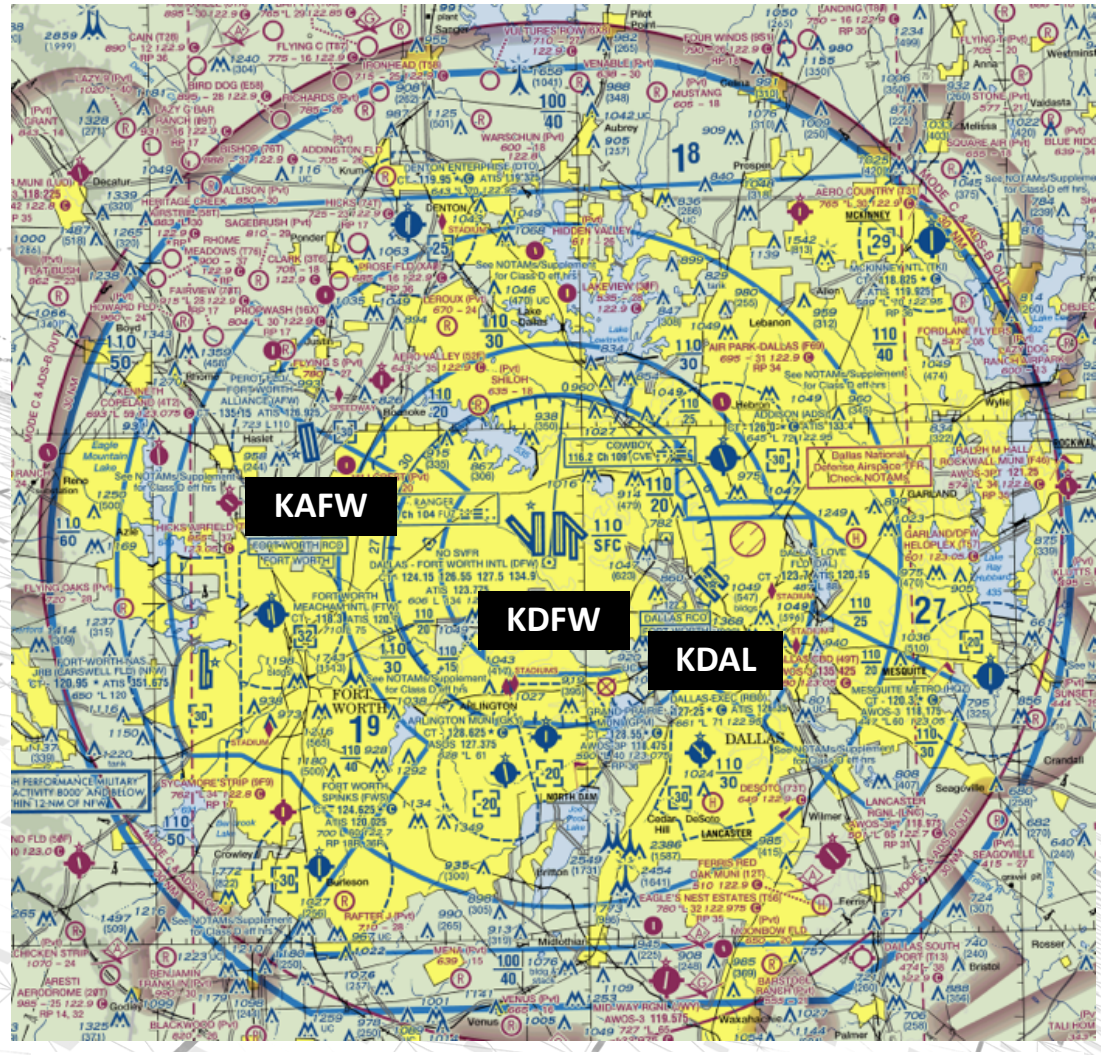
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- **Need:** Assessment of LC2L procedures in a realistic airspace environment
- **Contribution:** Developed a realistic environment for assessment with simulated air traffic control resolution maneuvers

Modeling the Airspace + Routes

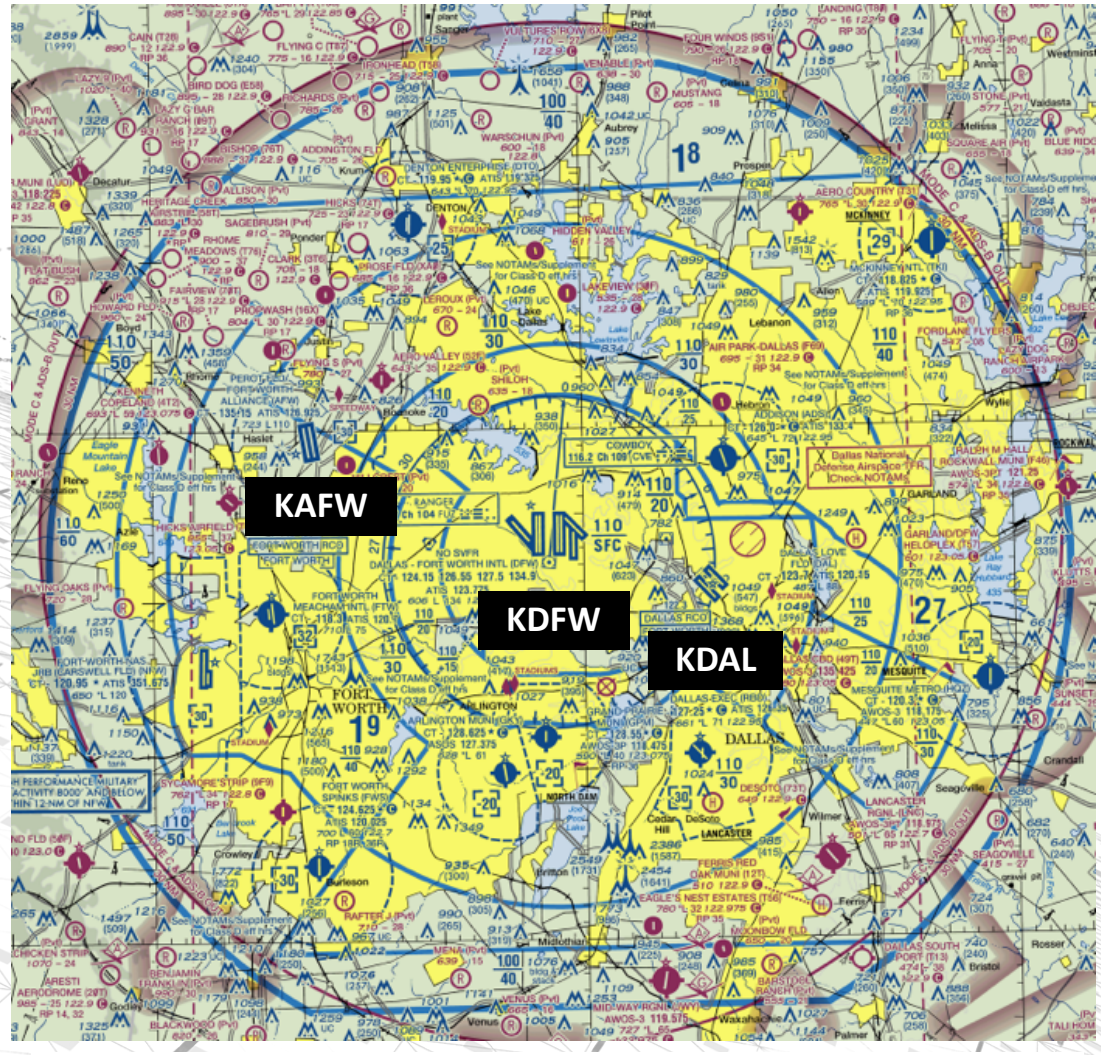
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FAA VFR Sectional Chart of Dallas-Fort Worth, TX

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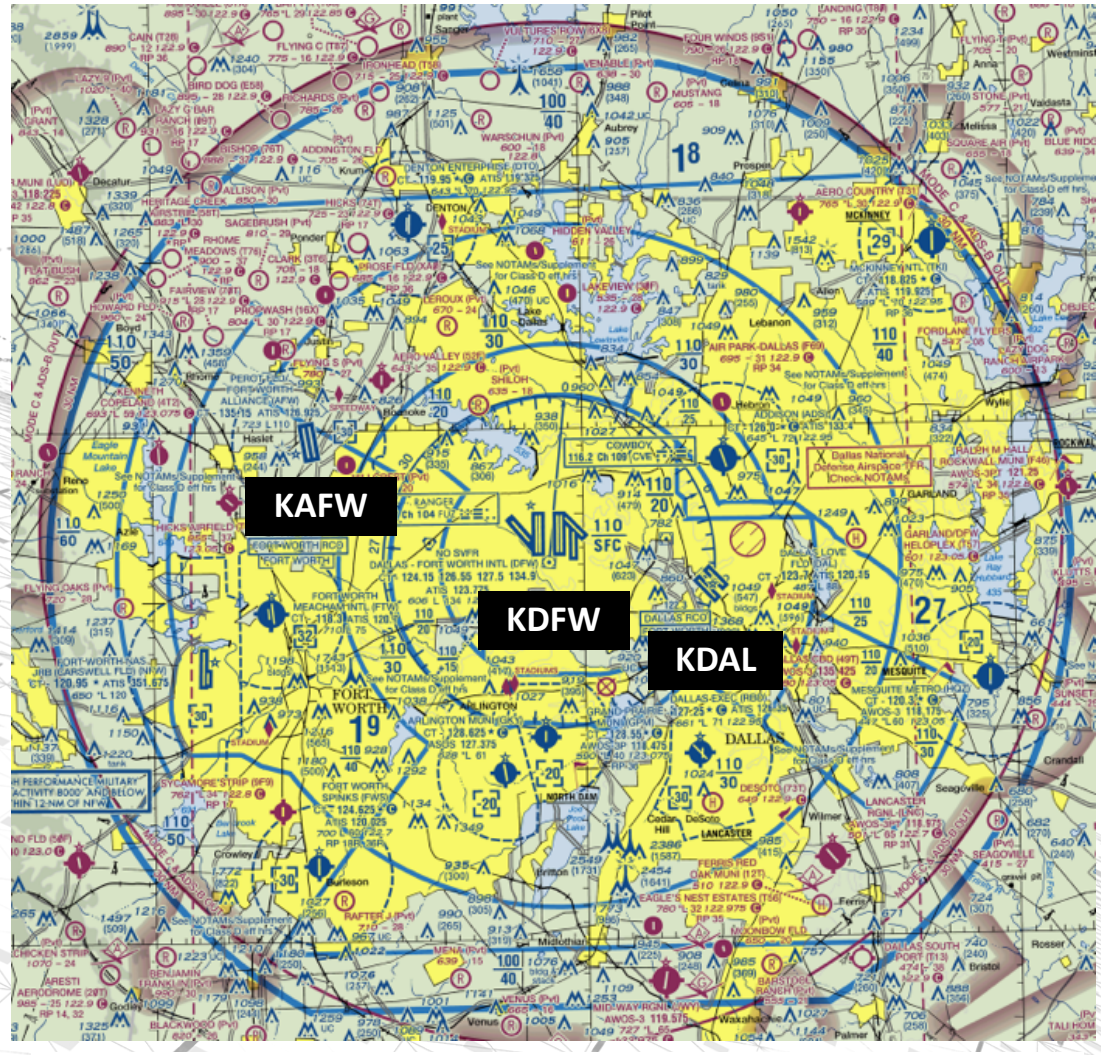
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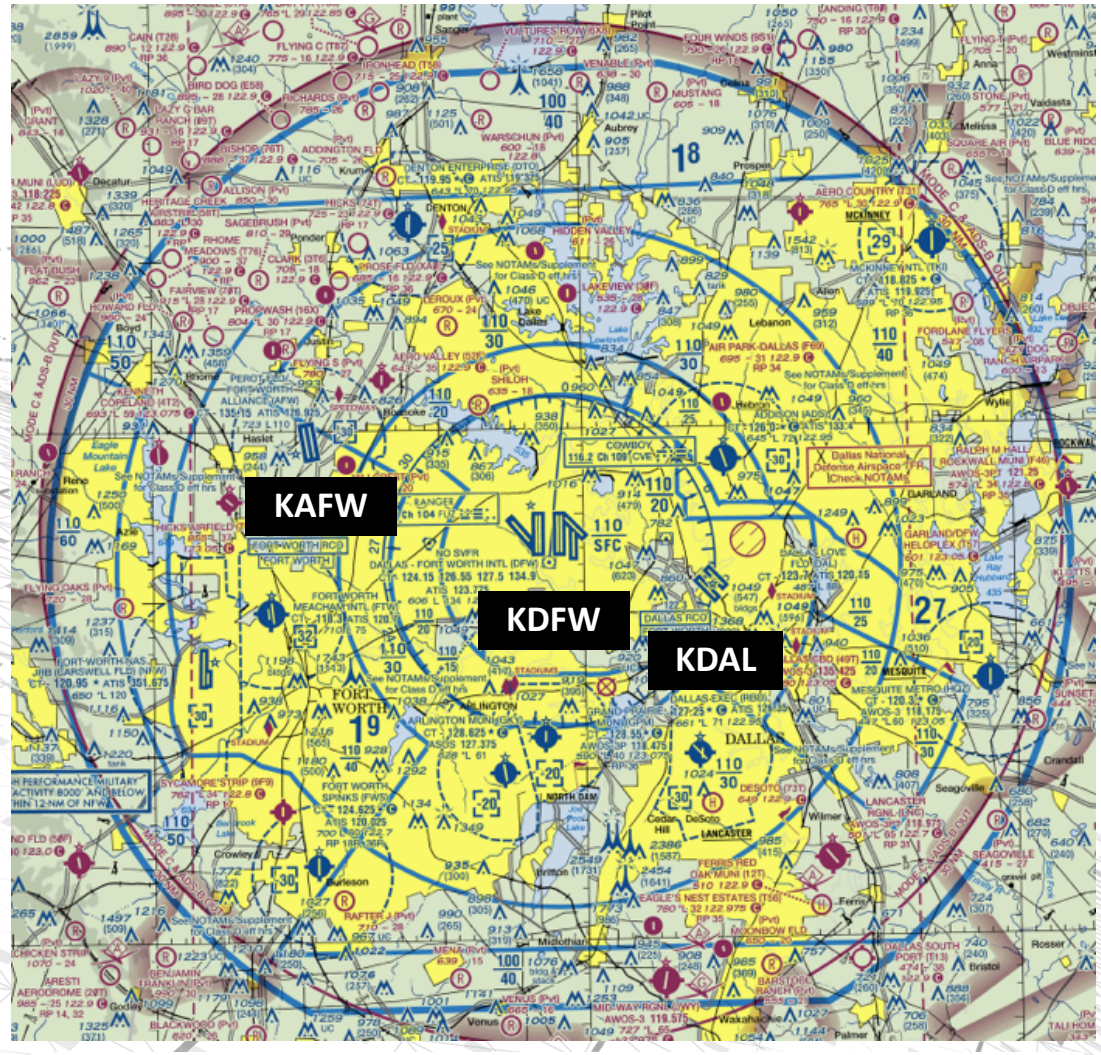
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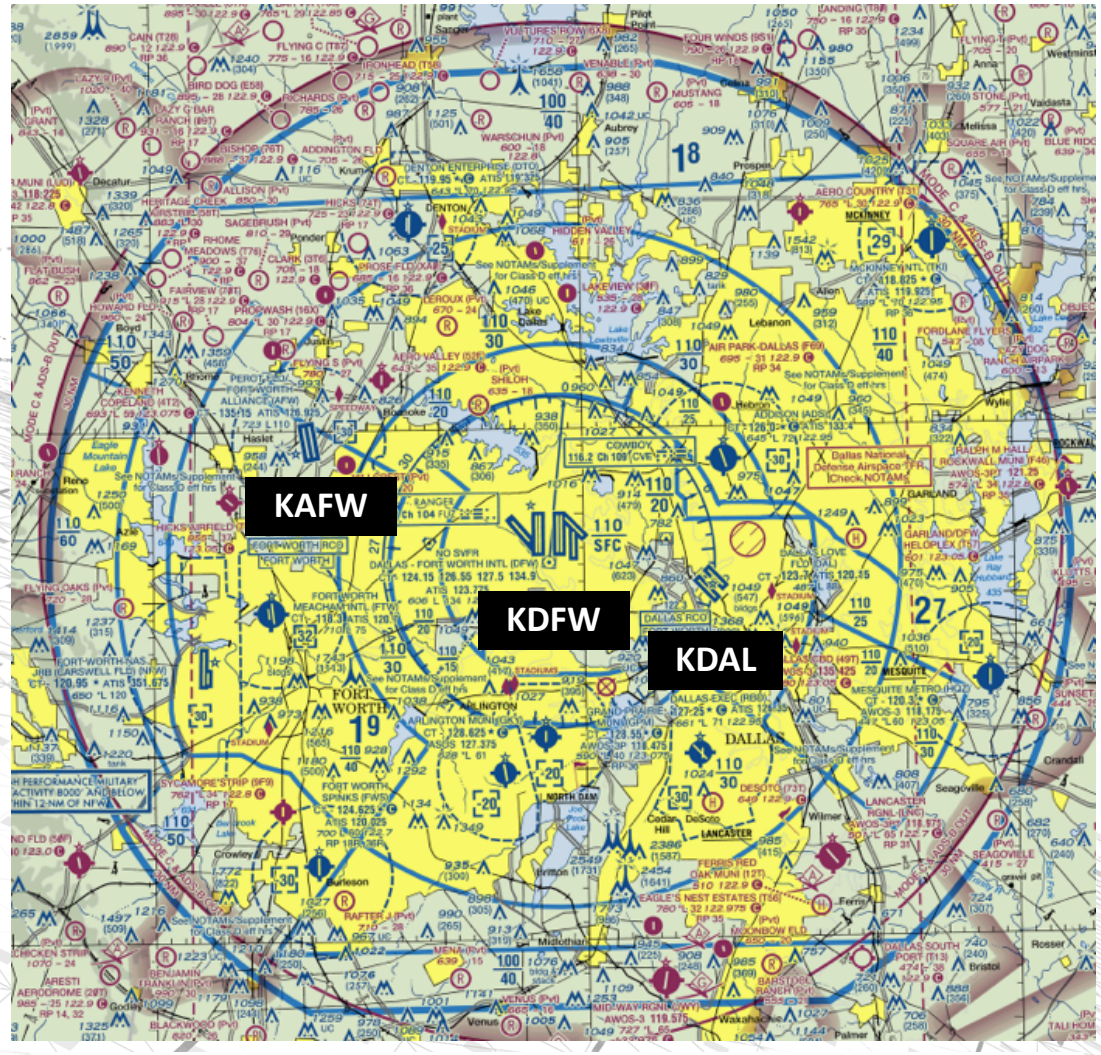
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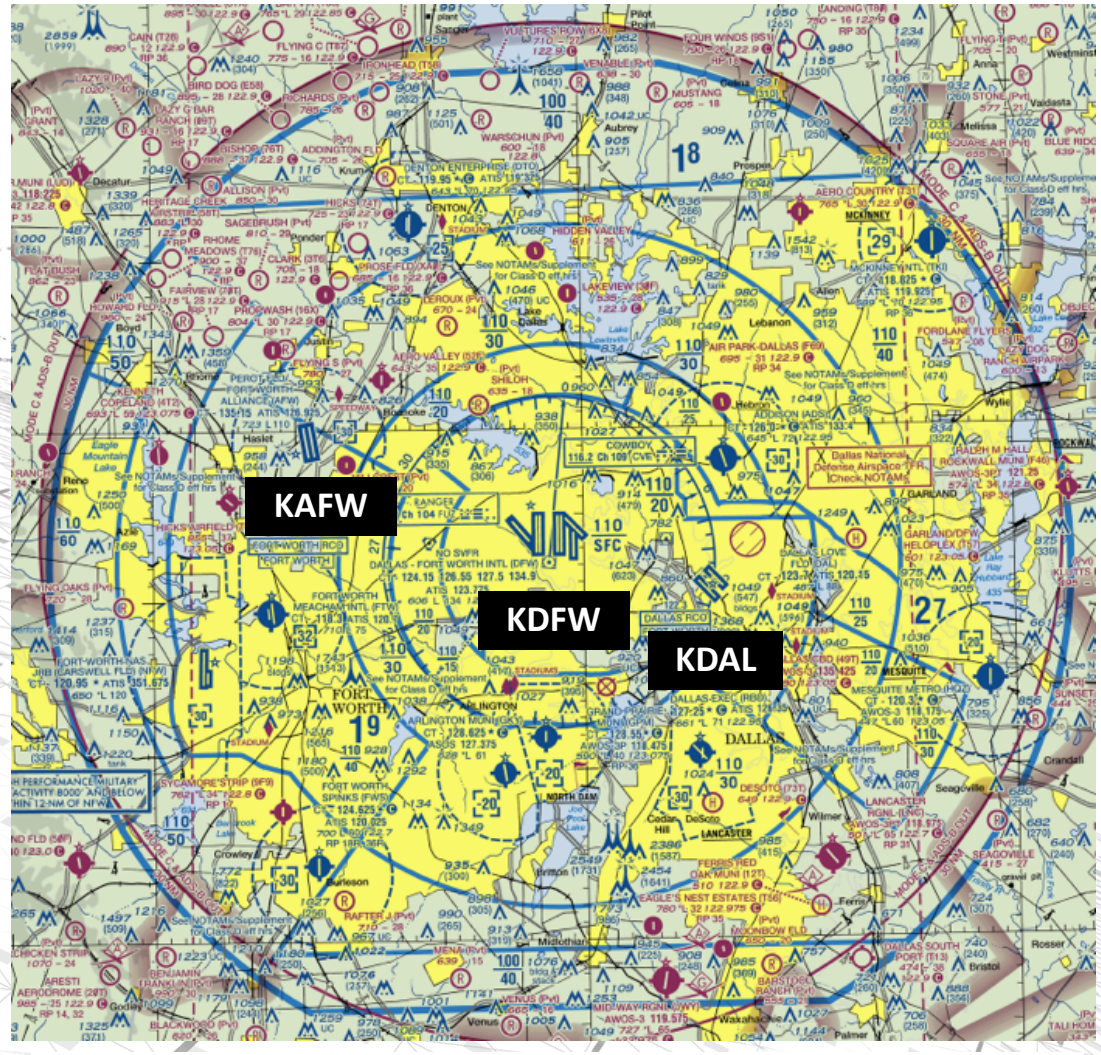
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  - Instrument Approach Procedures (IAP)
  - Played back recorded background traffic



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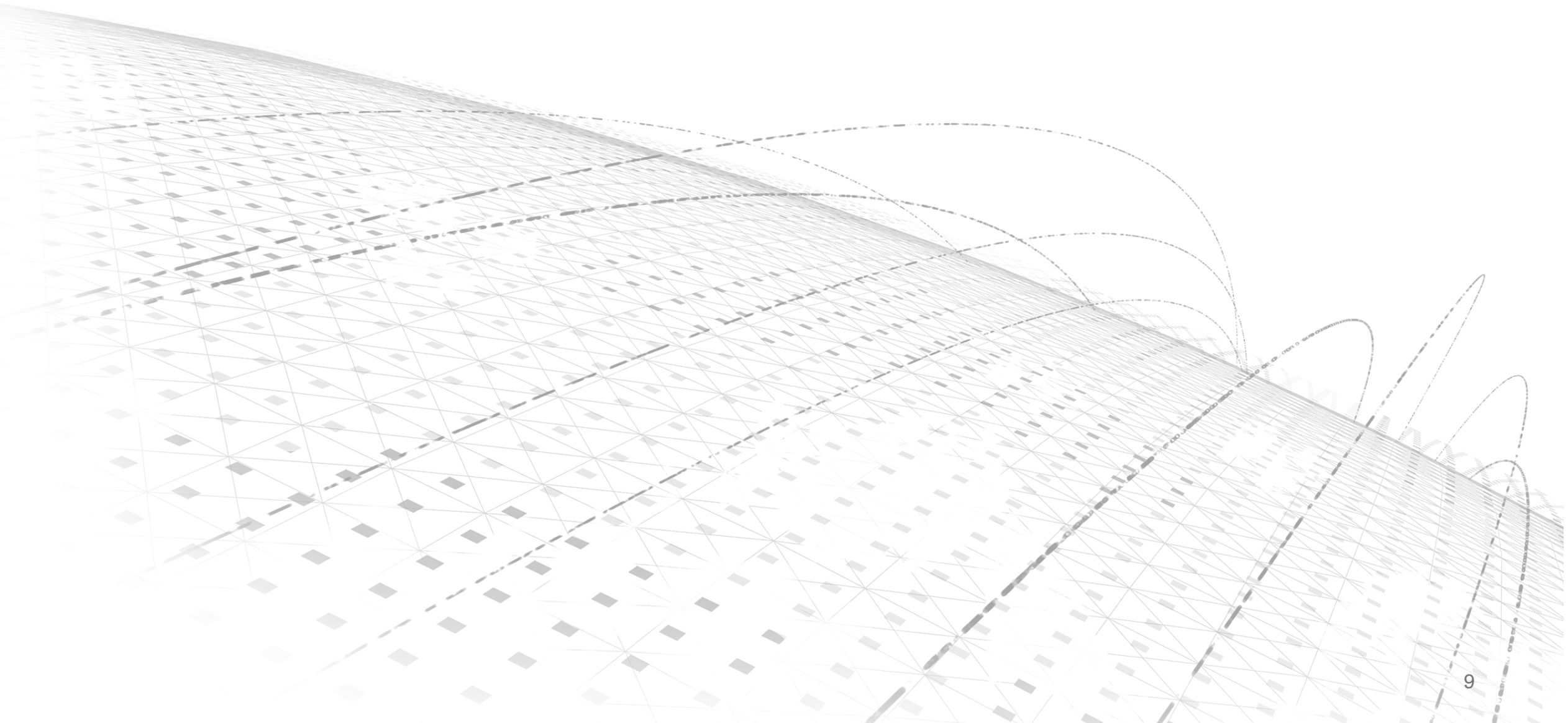
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- Flights into DFW cargo hub Fort Worth Alliance (KAFW)



FAA VFR Sectional Chart of Dallas-Fort Worth, TX

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- Nominal (remain on route):
  - Identified real flights that flew between airports of interest
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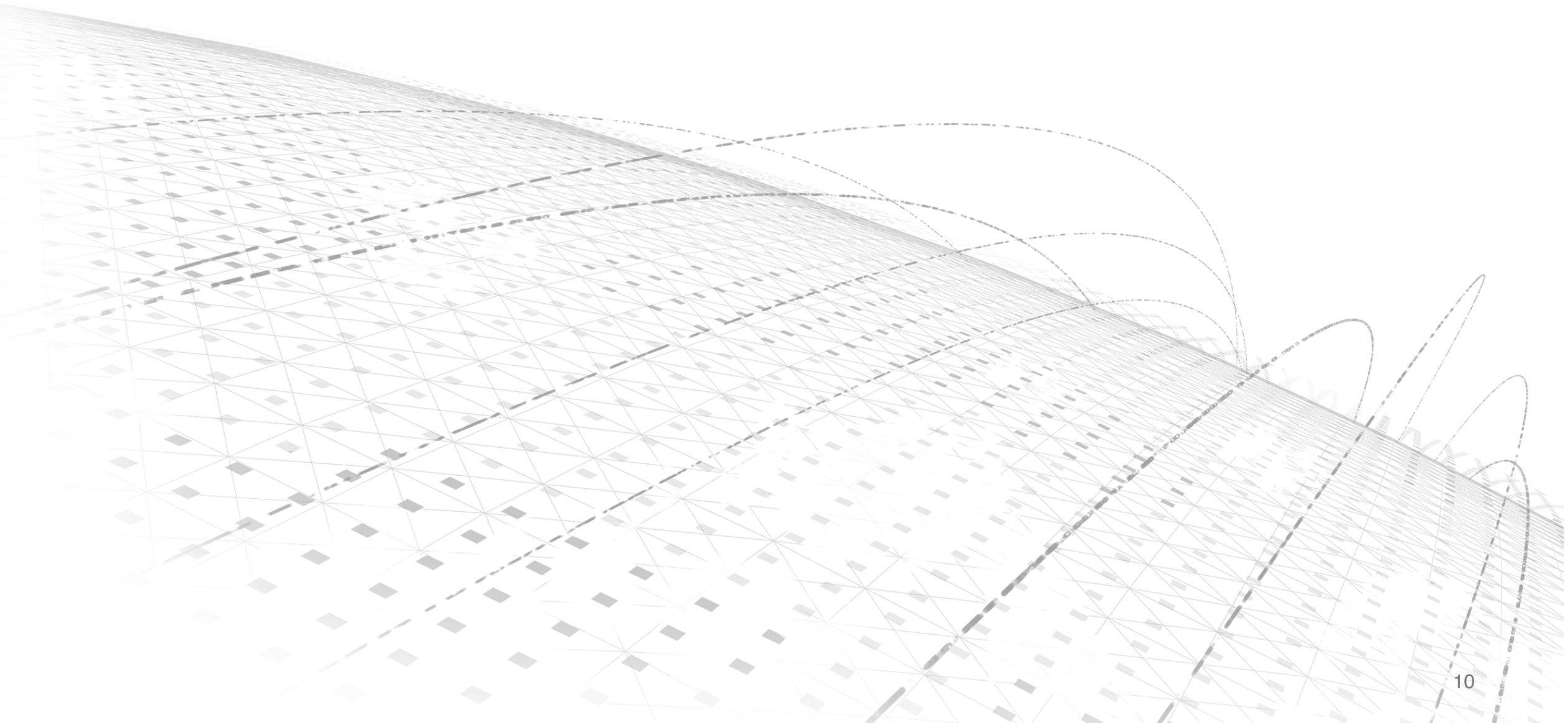
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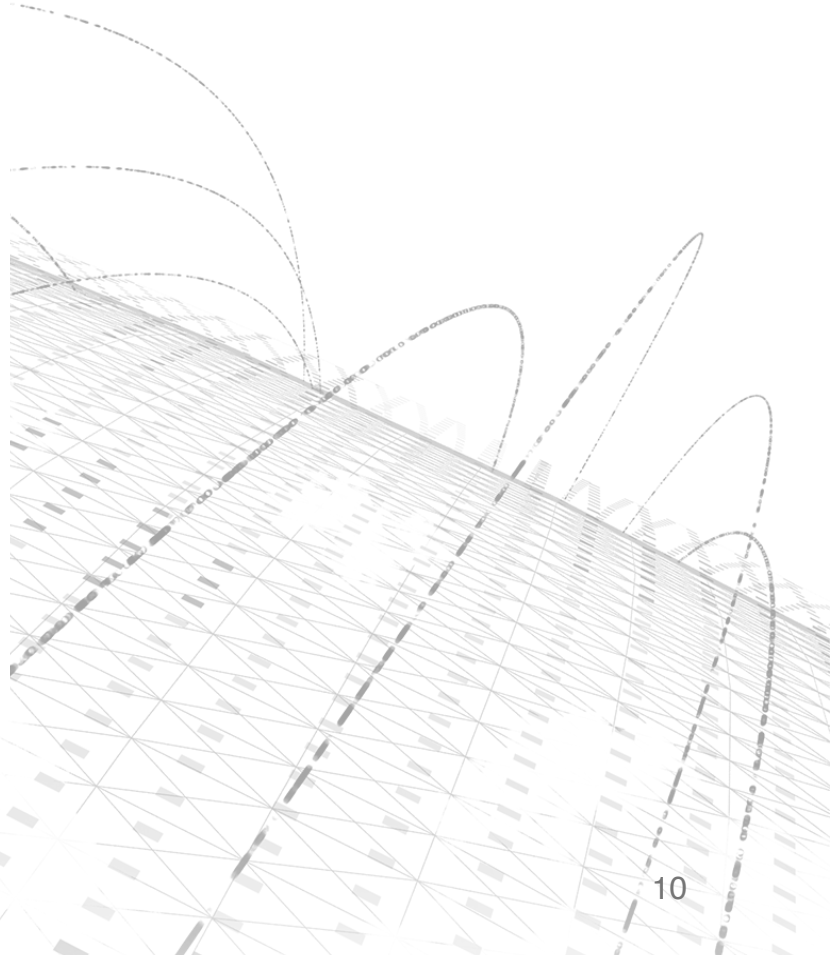
- Off-Nominal (RTCA DO-400):
  1. The UAS flies to its last clearance (e.g., end of STAR)
  2. The UAS then proceeds directly to the Initial Approach Fix of the published approach
  3. The UAS then executes the published approach

Traffic Scenario in the Dallas-Fort Worth Terminal



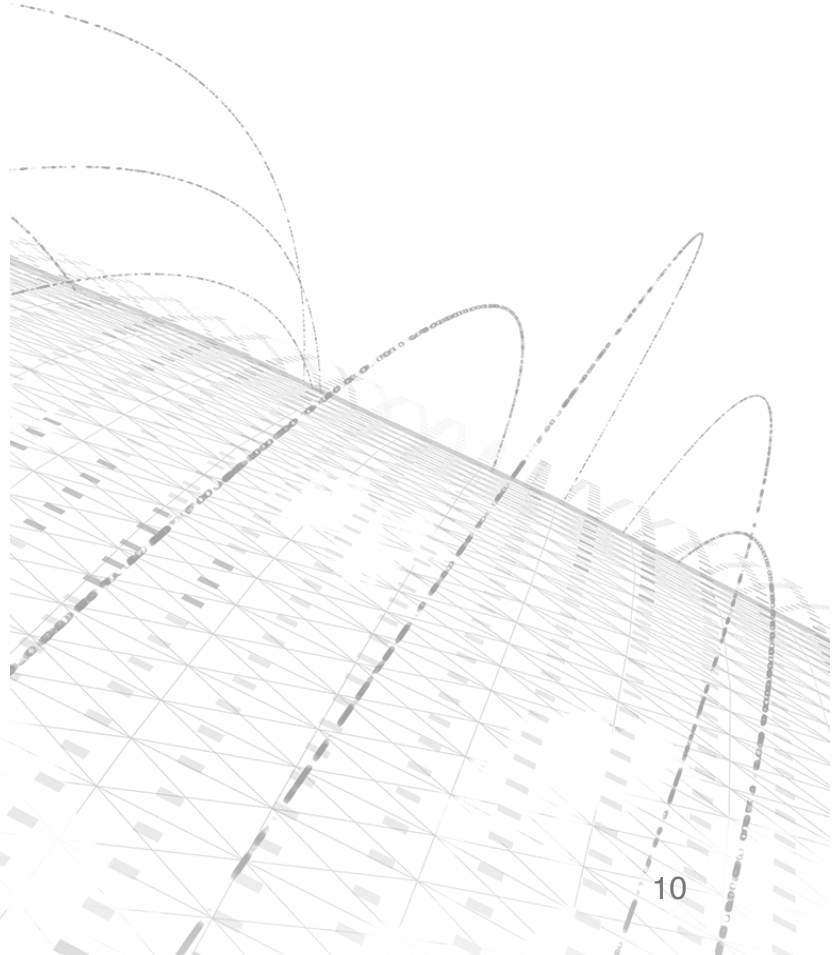
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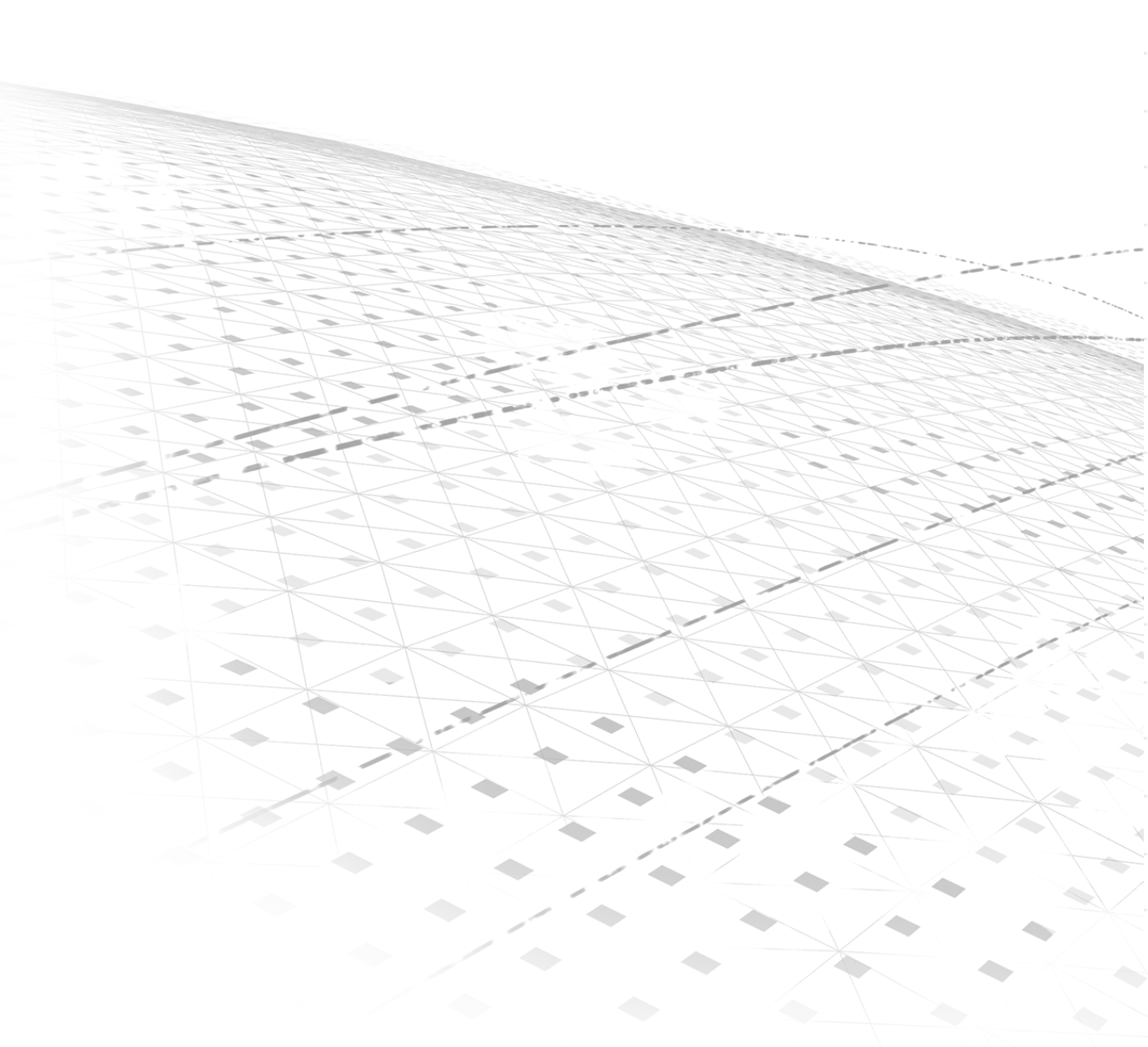
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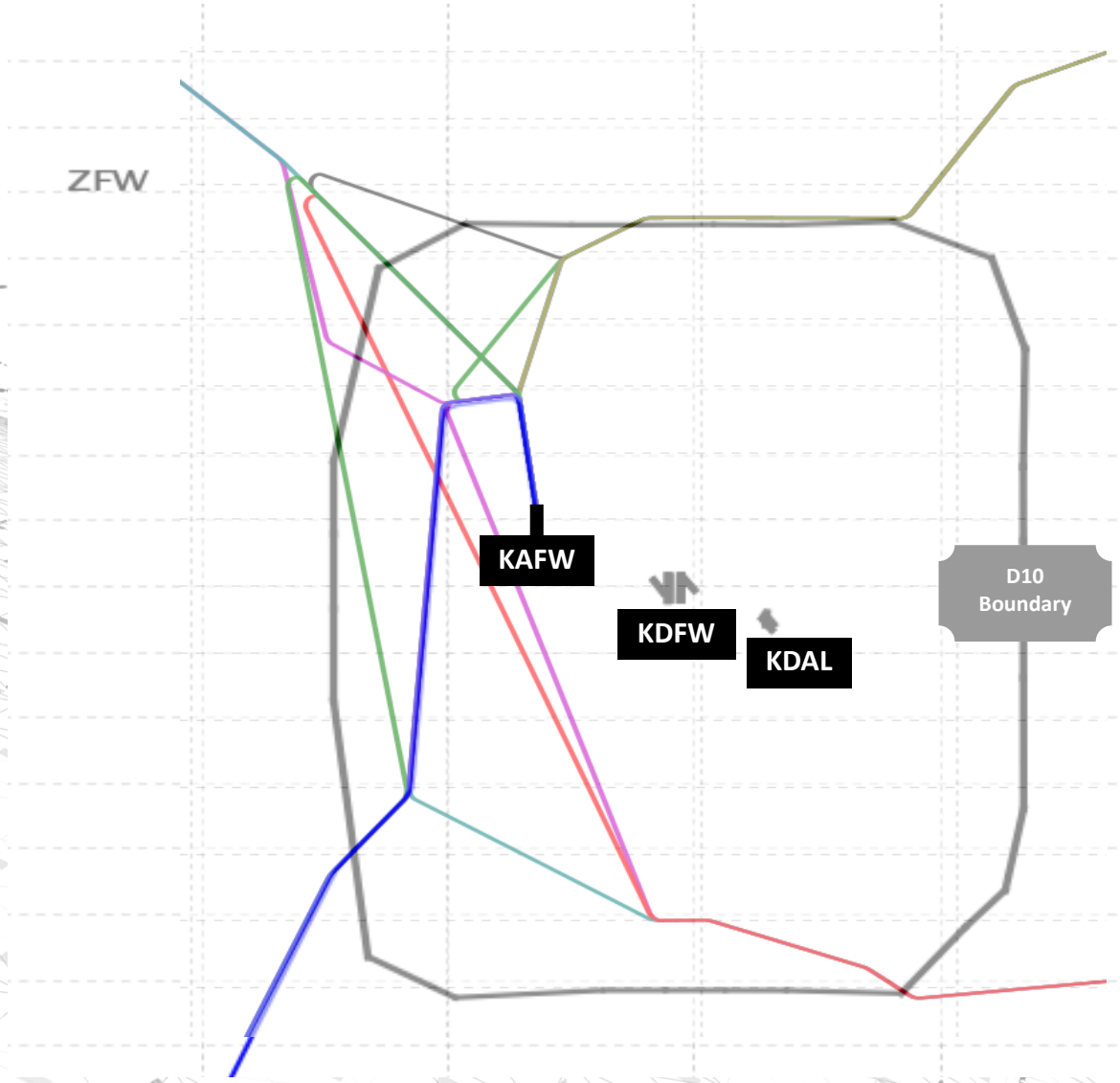
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Aircraft: Cessna 208 Grand Caravan © 2023 Textron Aviation

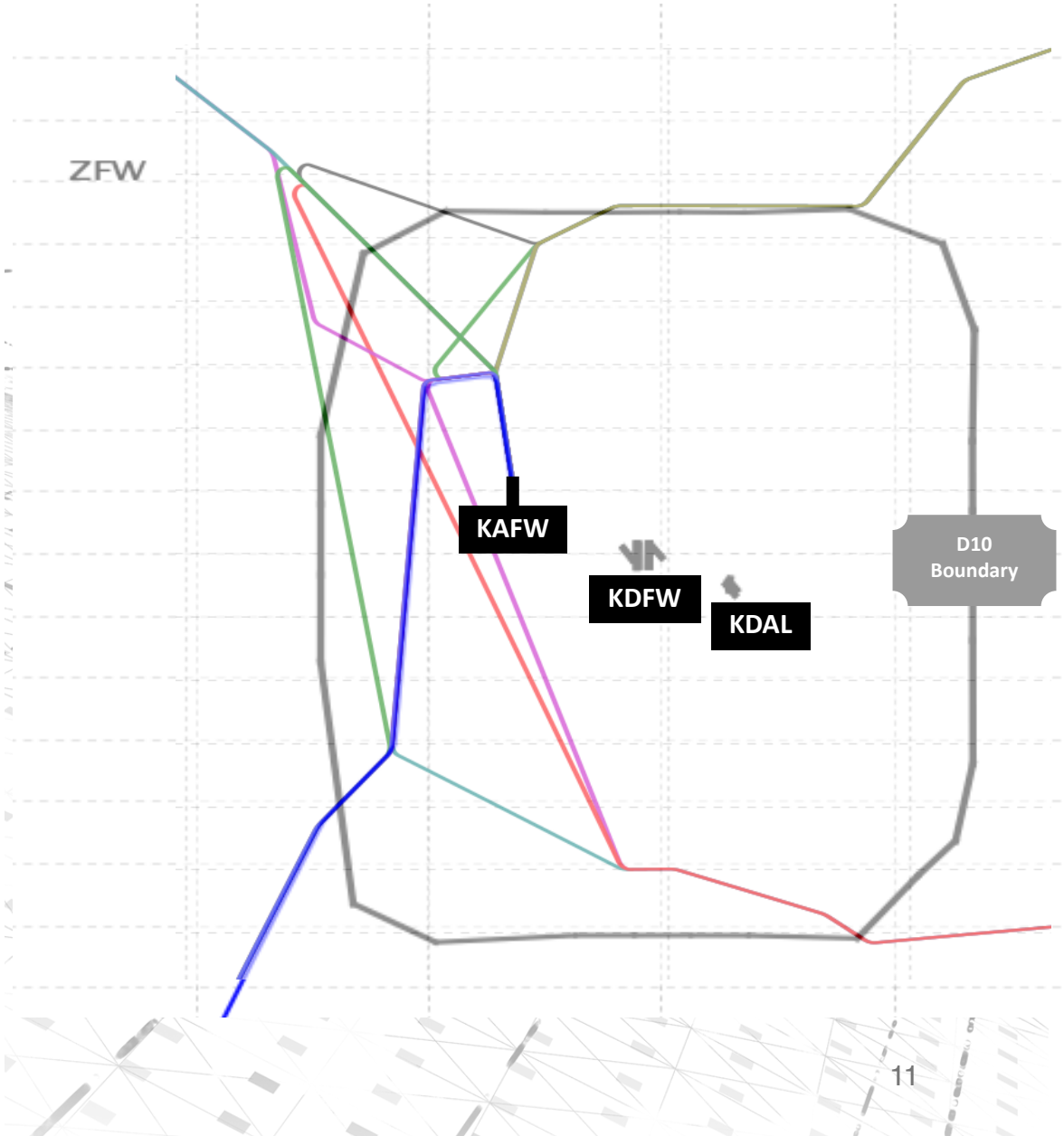
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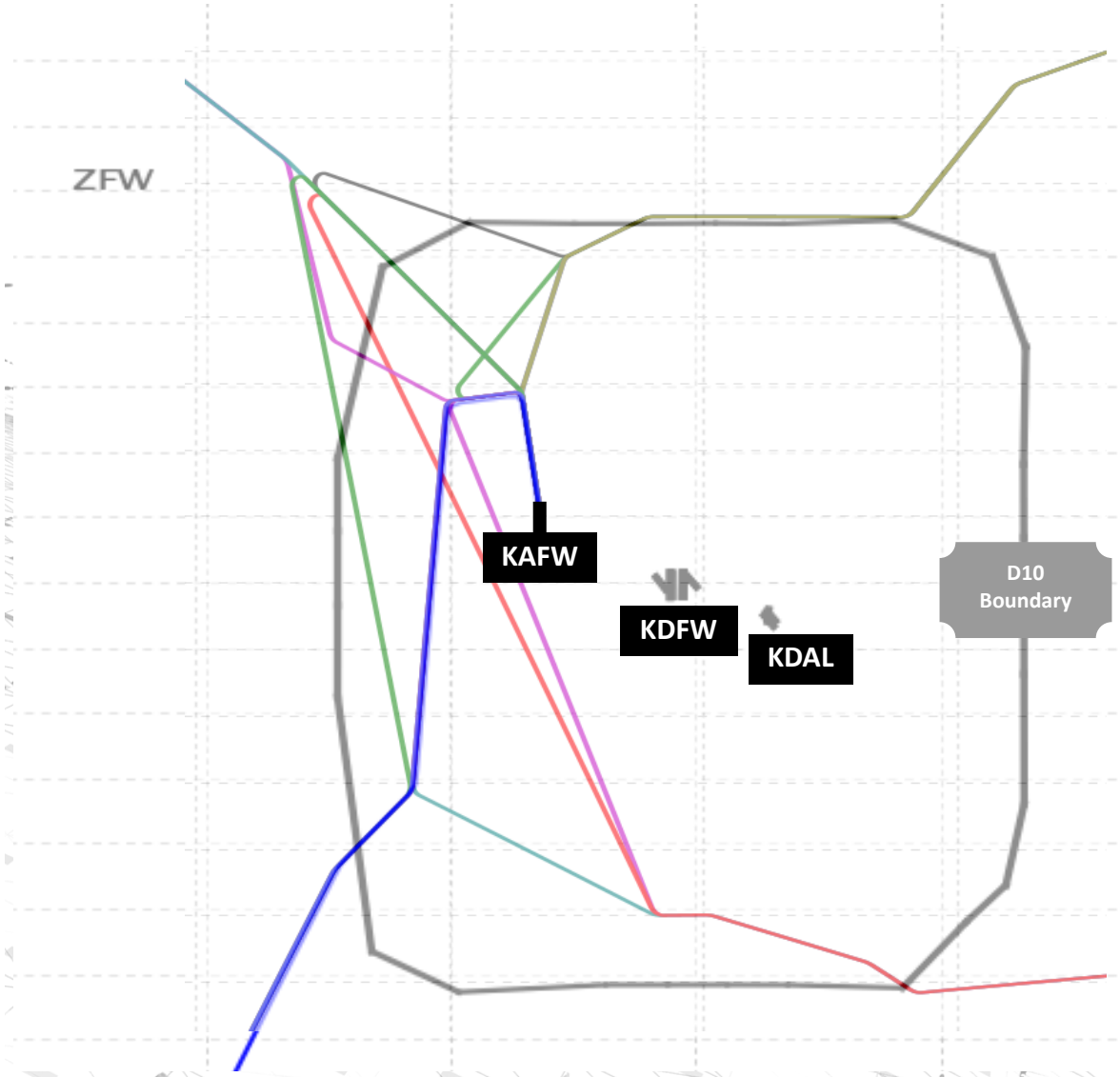
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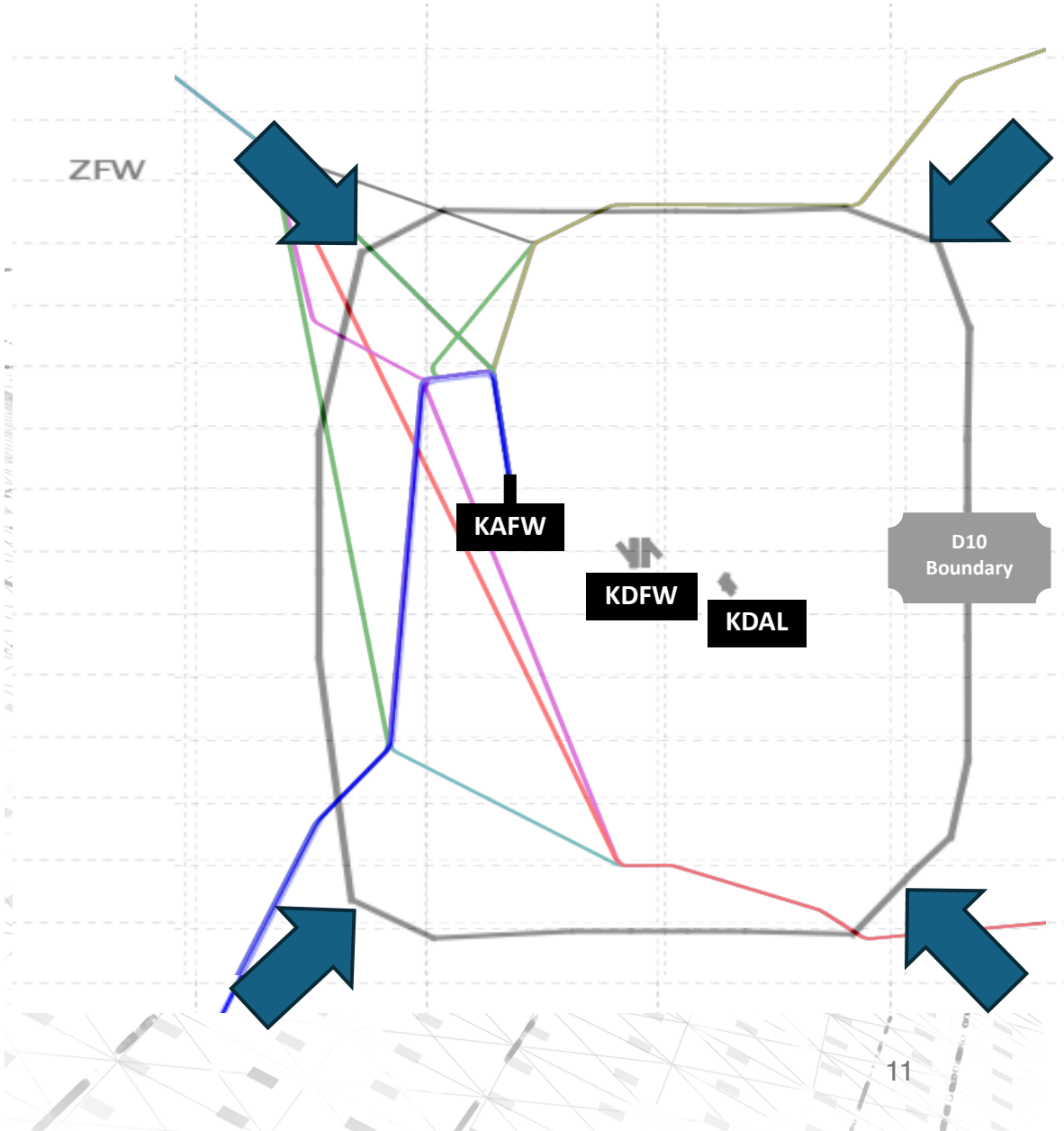
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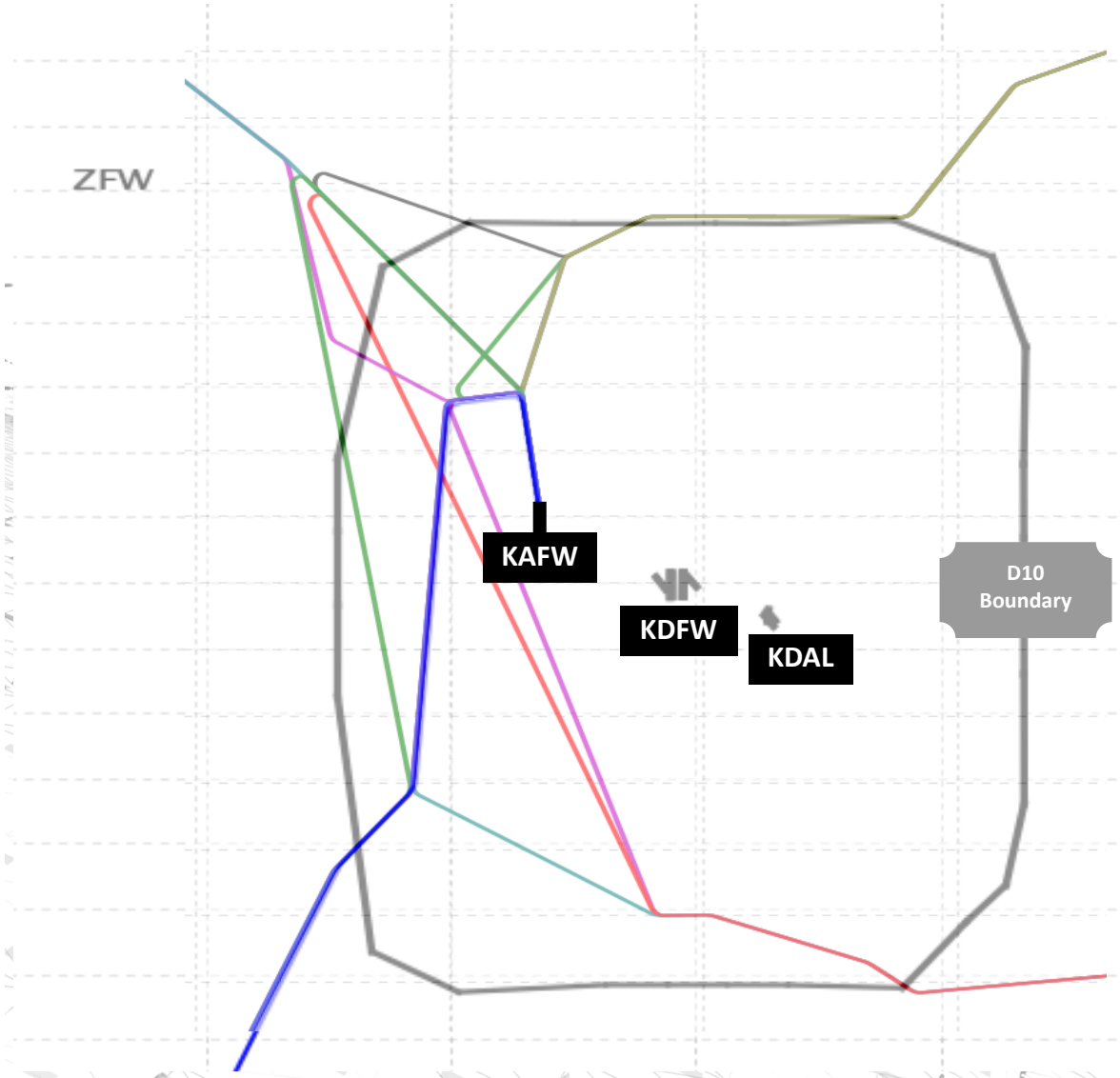
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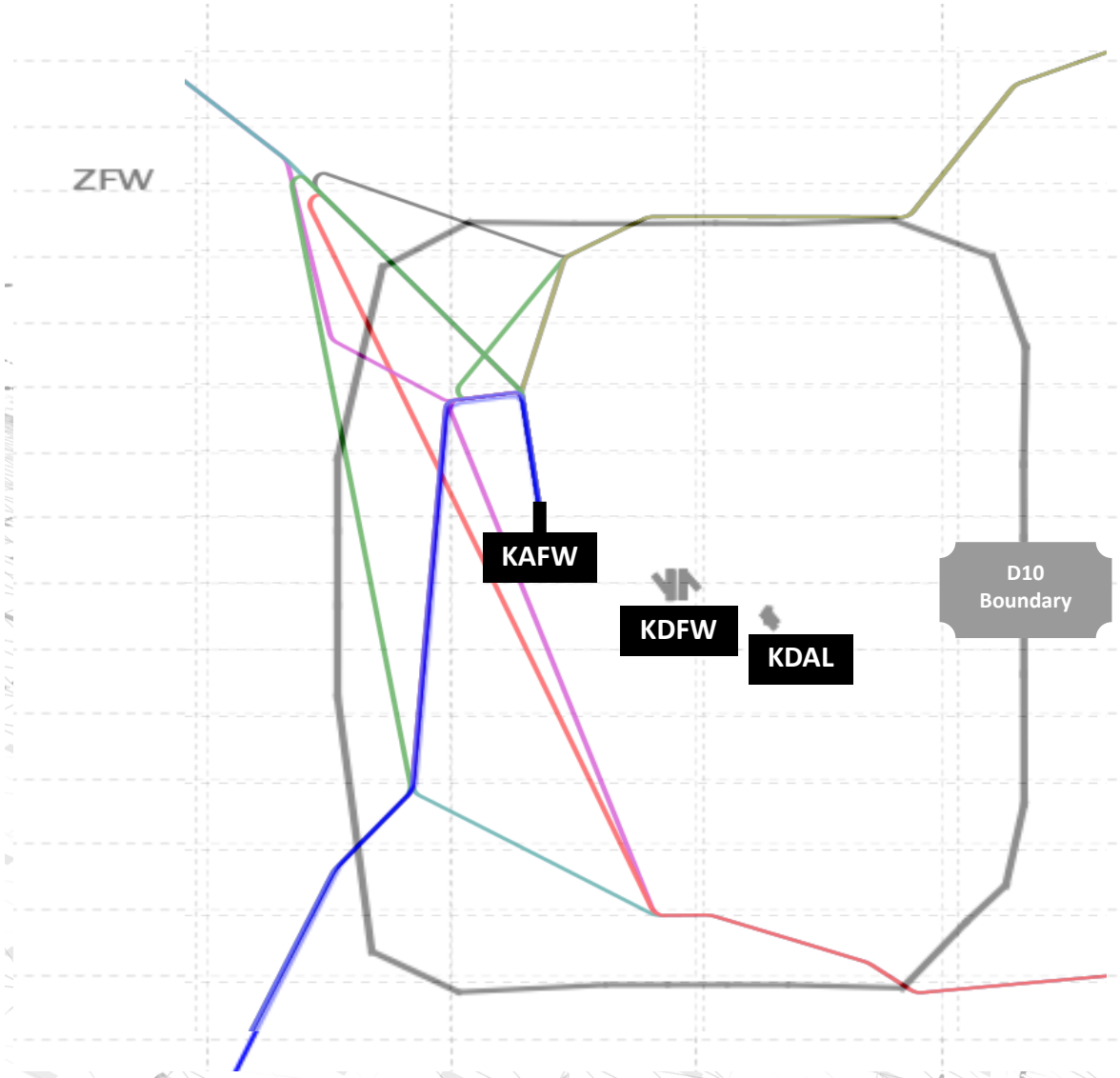
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- Two Instrument Approach Procedures to KAFW Runway 16L



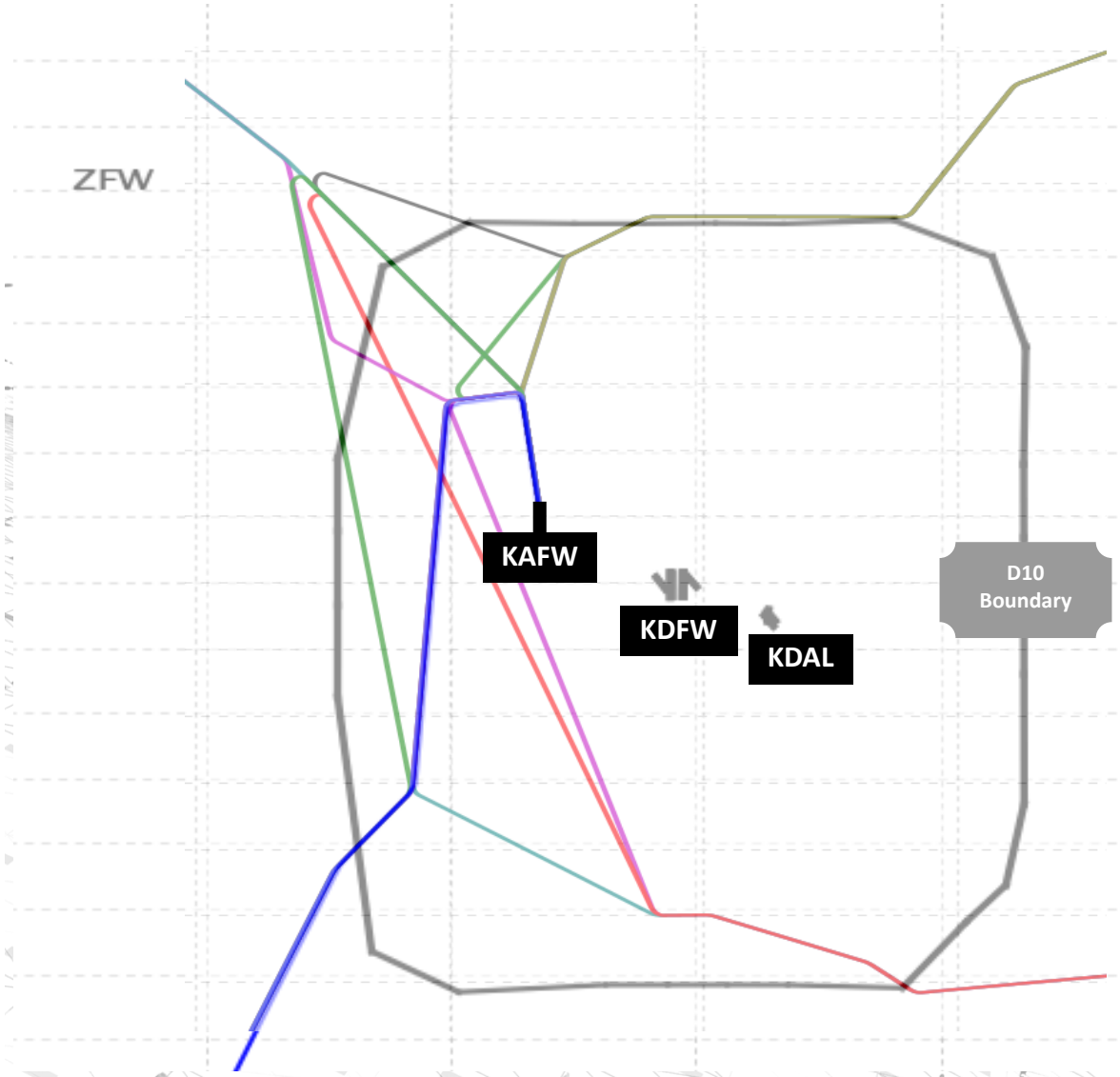
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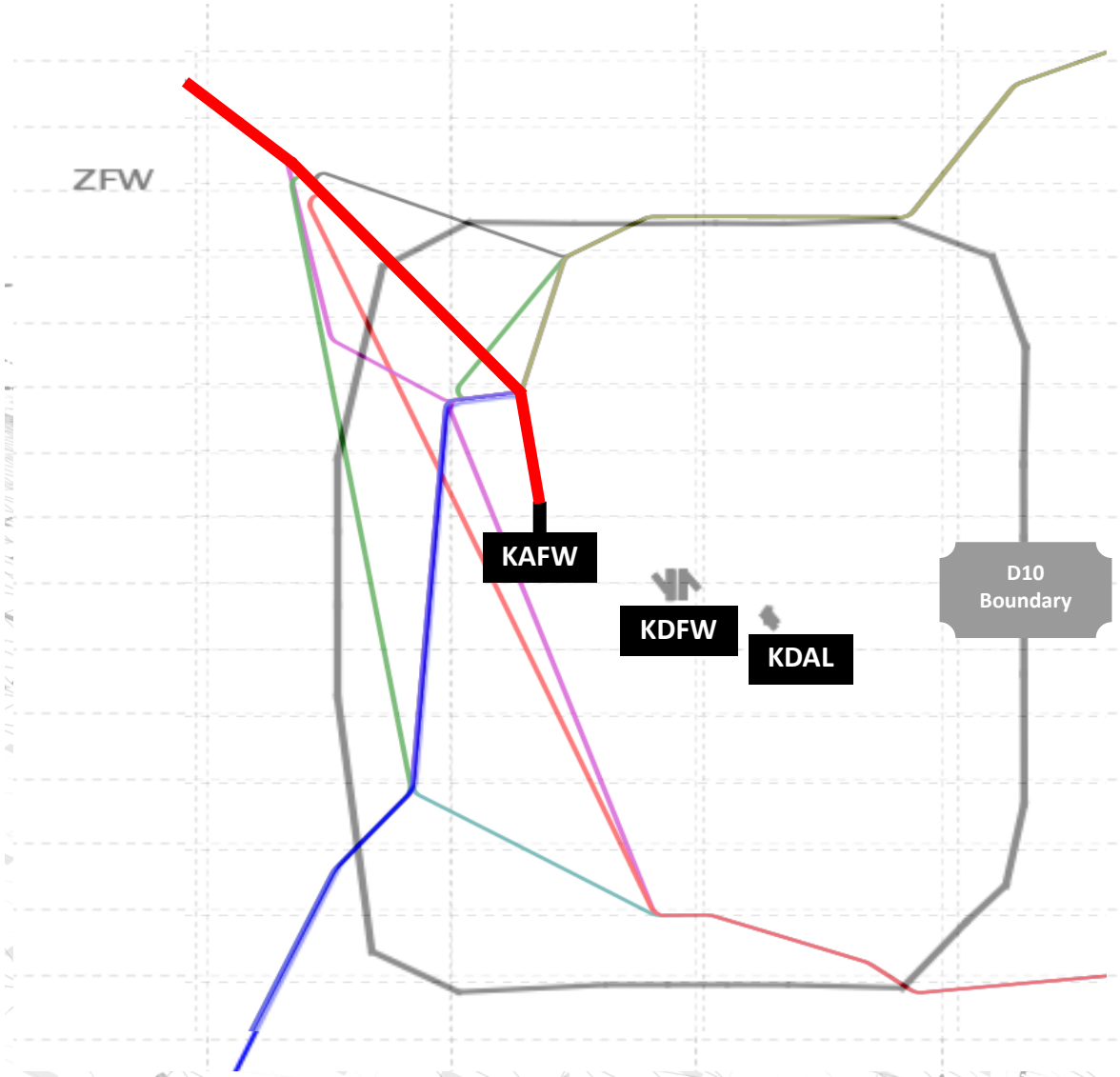
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  - Area Navigation (RNAV (GPS))



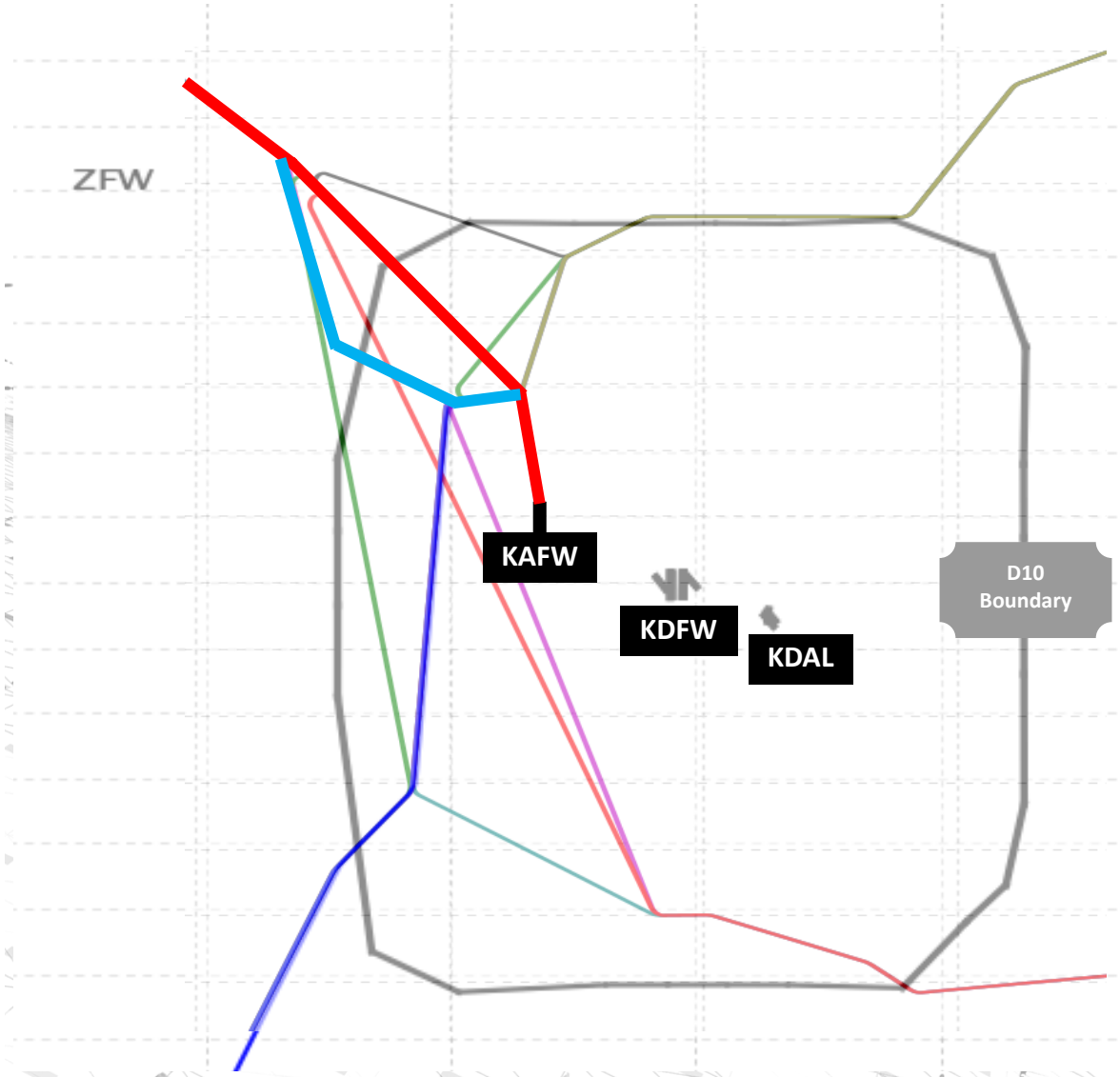
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  - Instrument Landing System (ILS)
  - Area Navigation (RNAV (GPS))
- Four origin airports
  - KLBB: Lubbock, TX (2 routes, northwest)



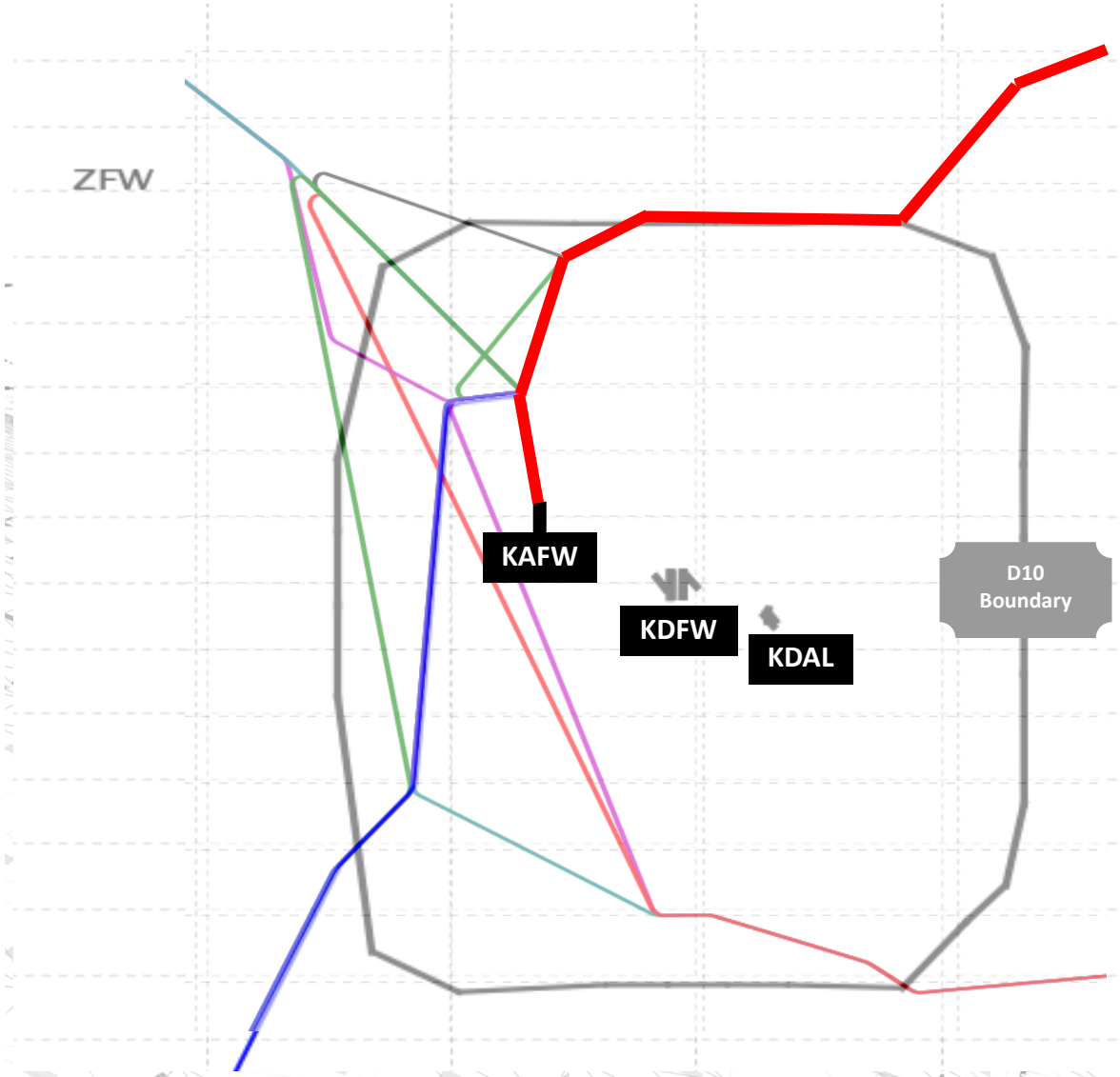
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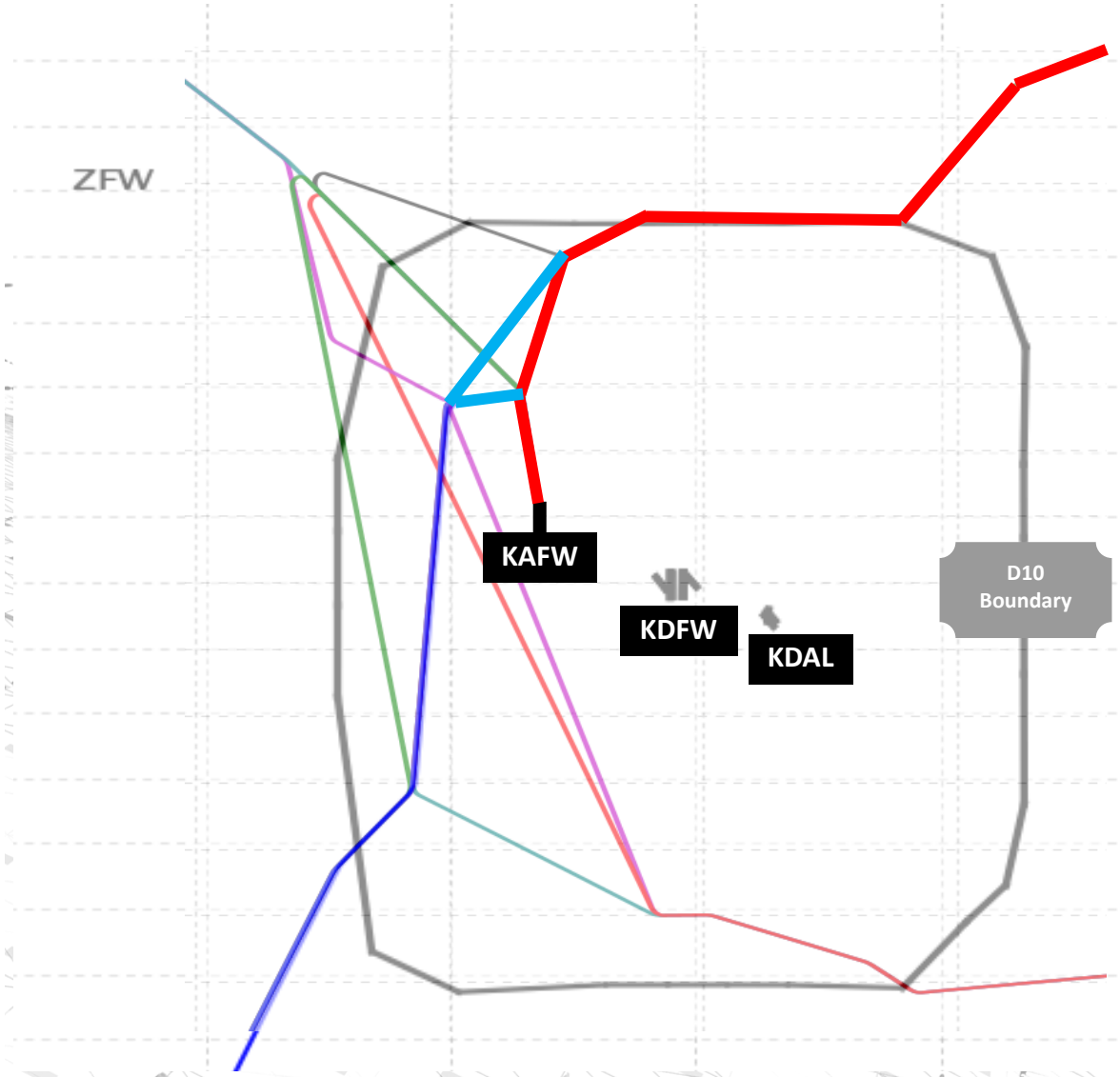
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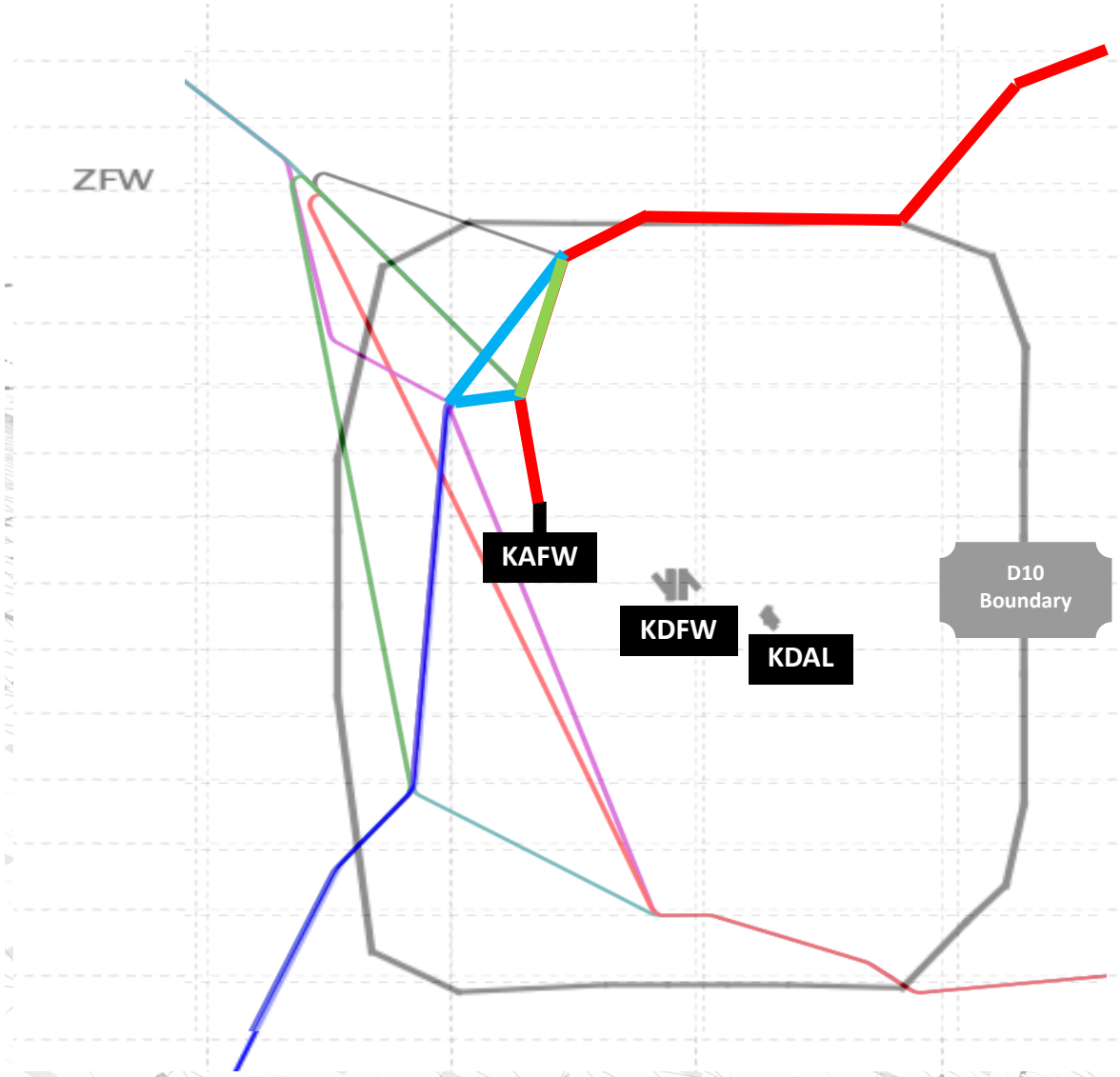
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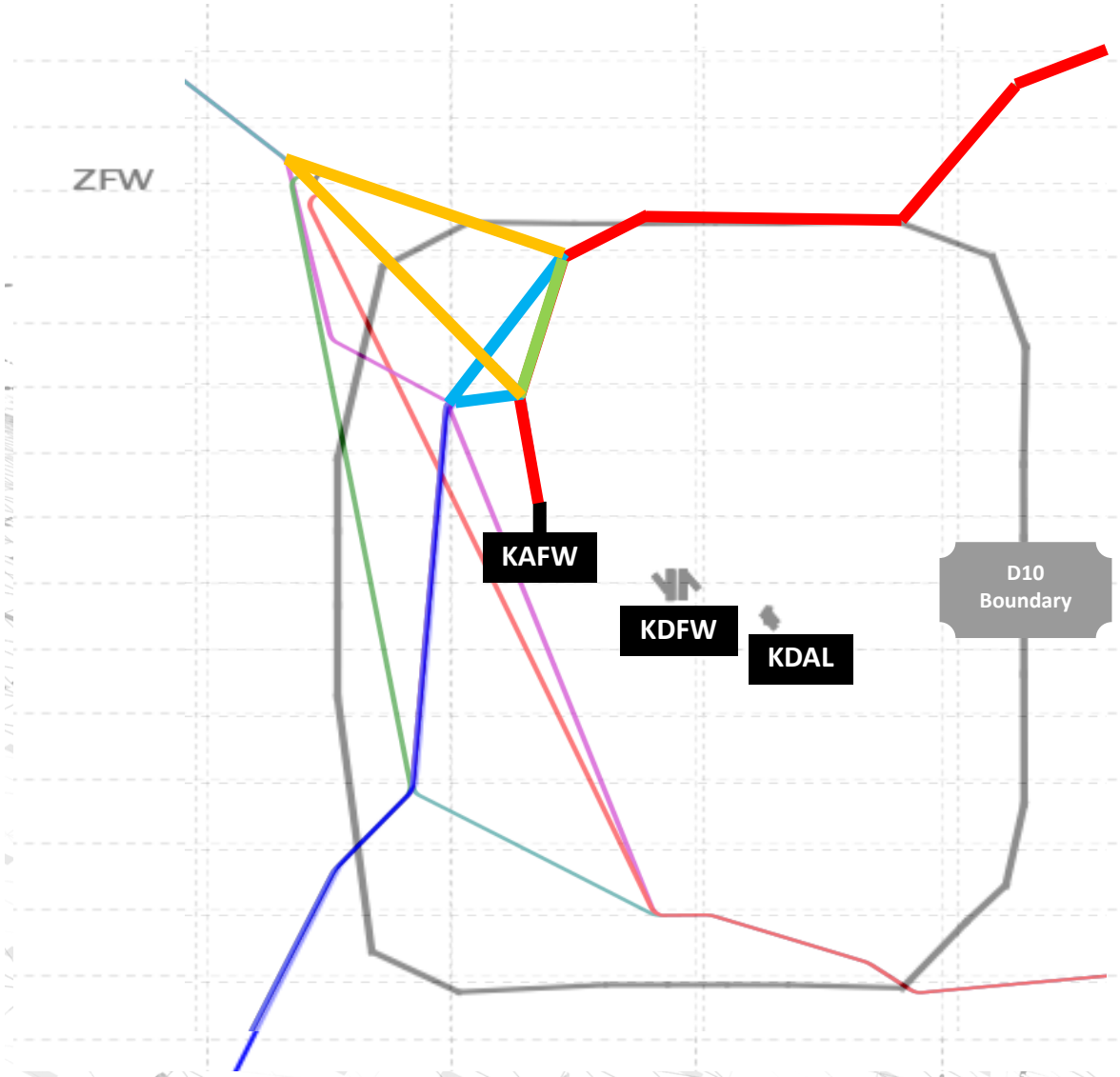
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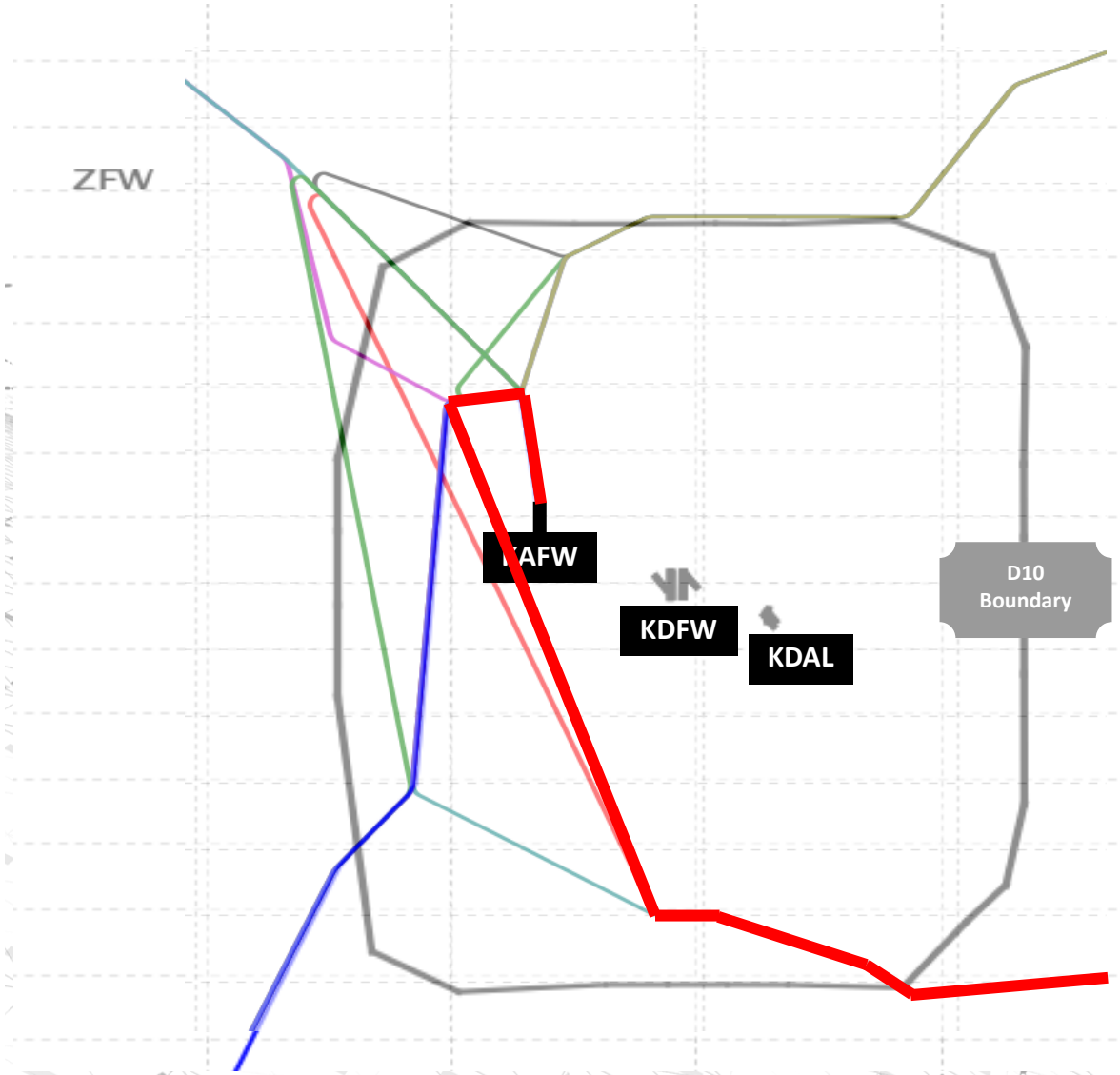
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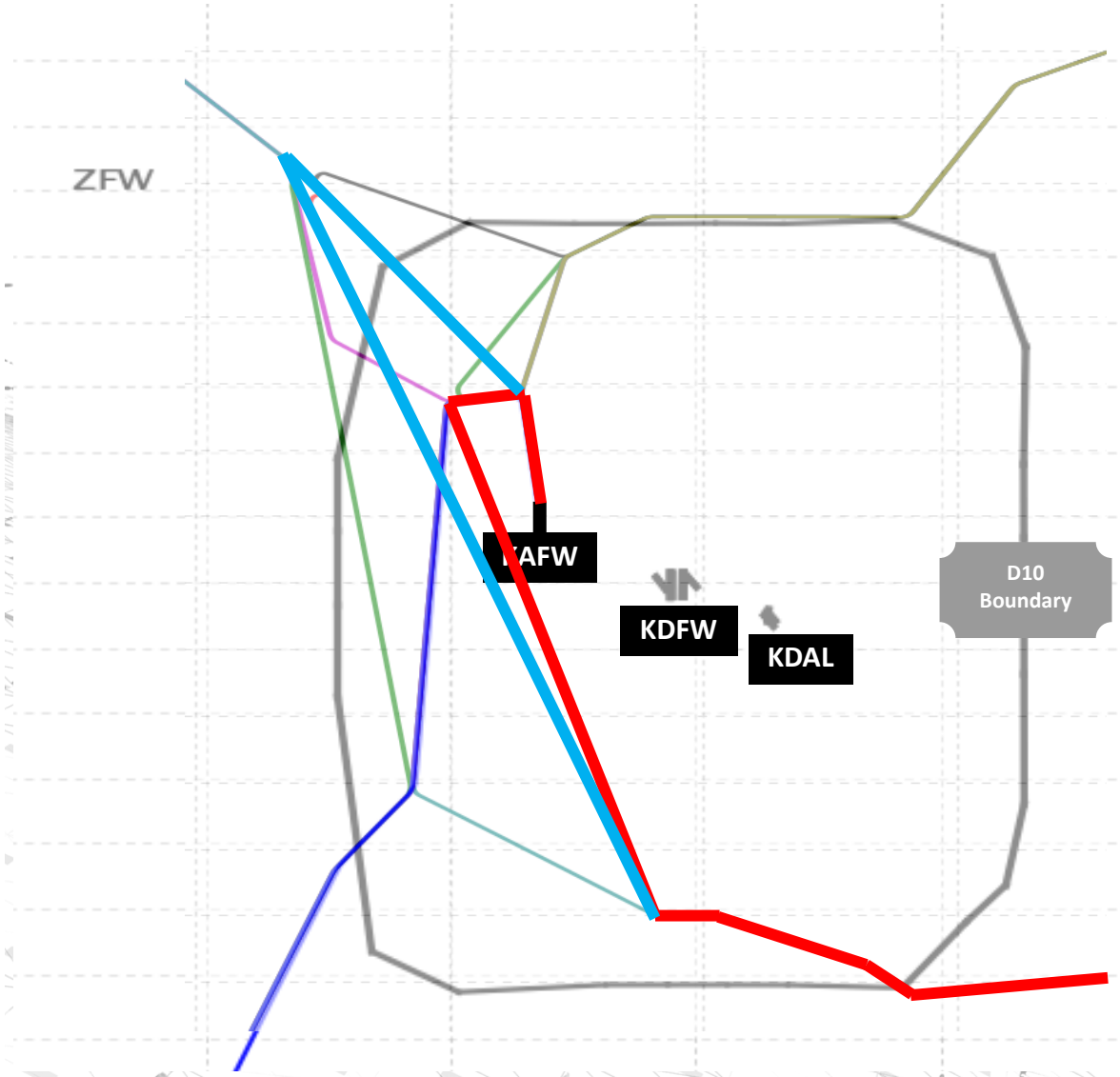
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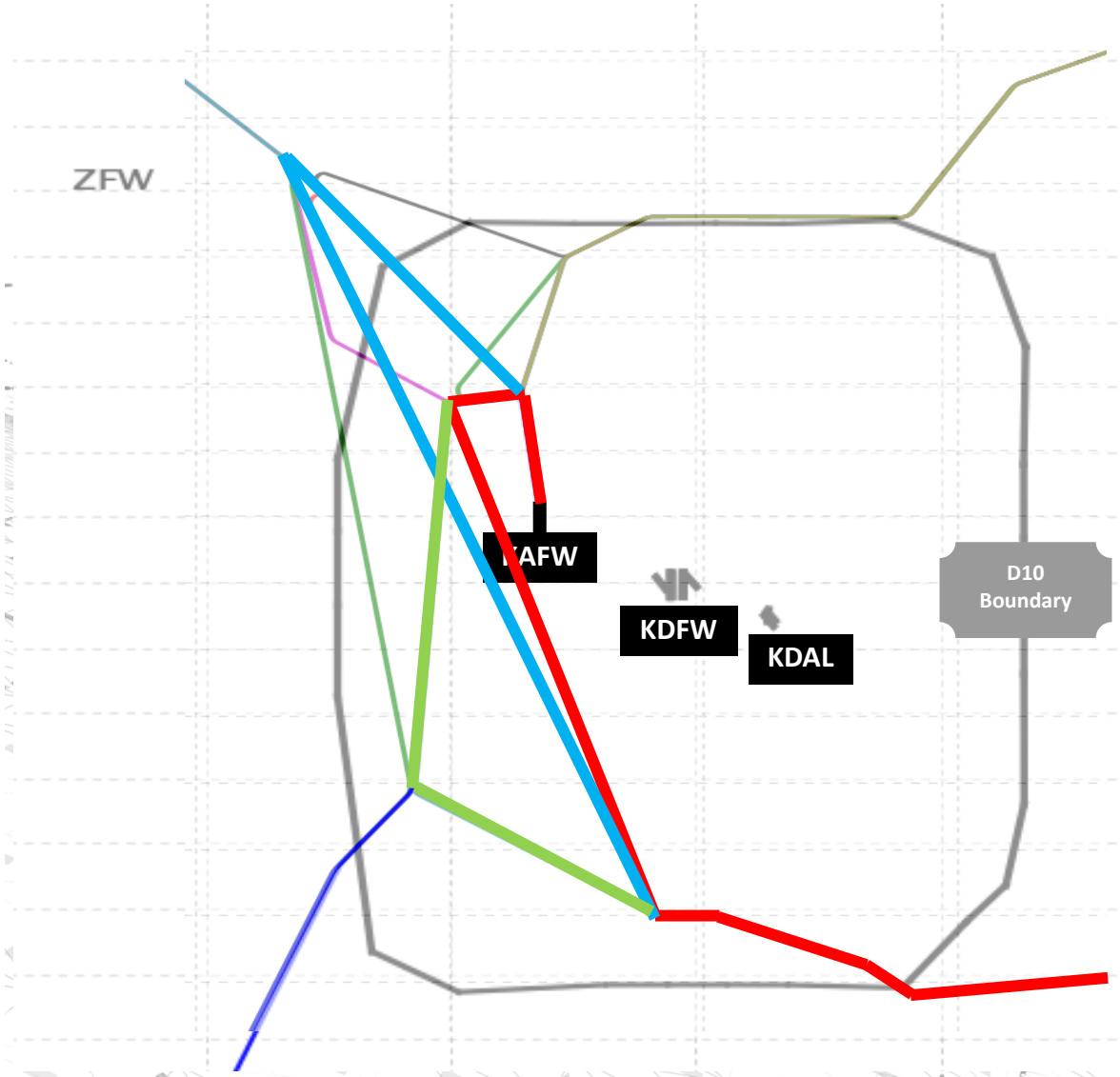
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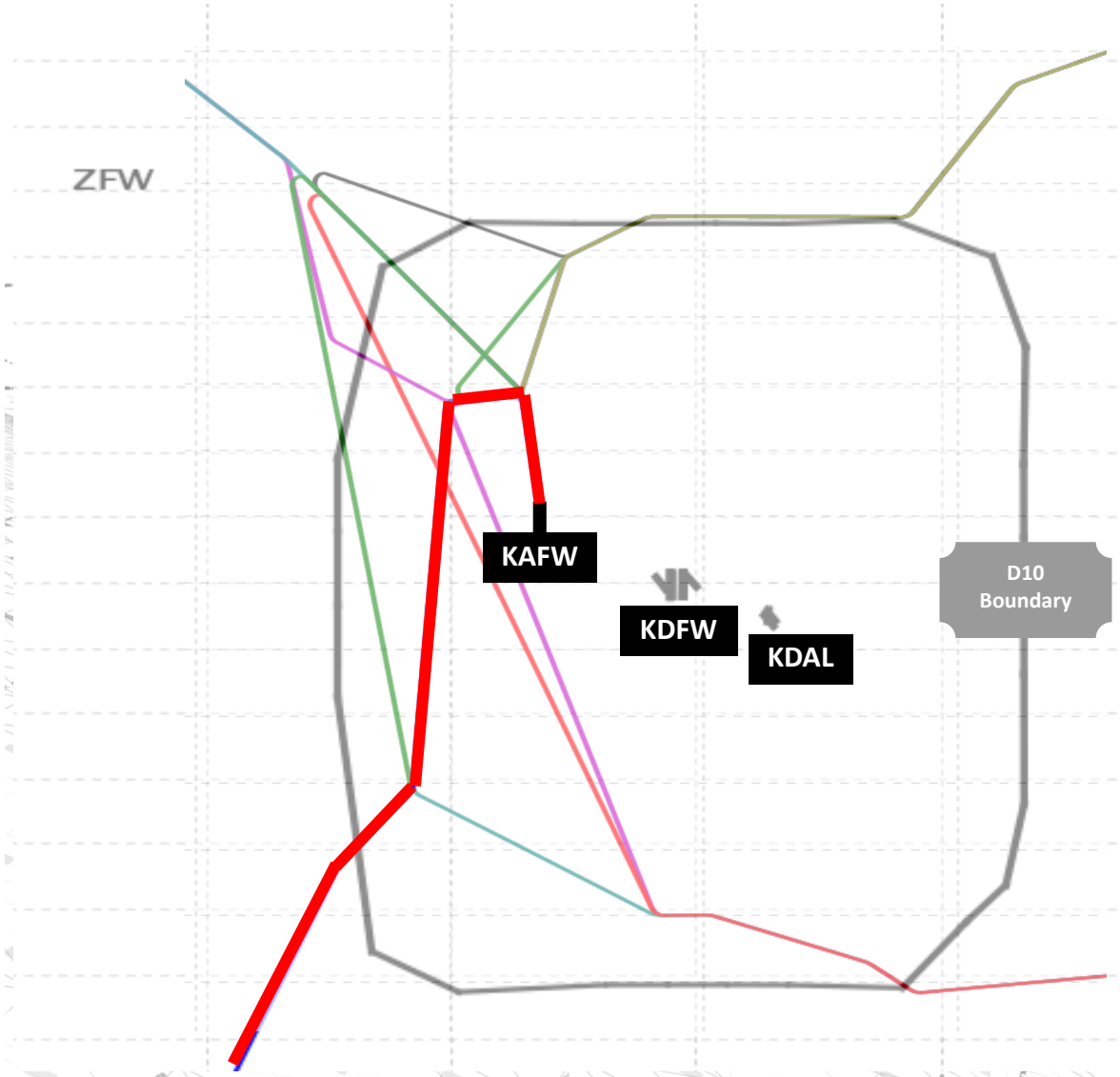
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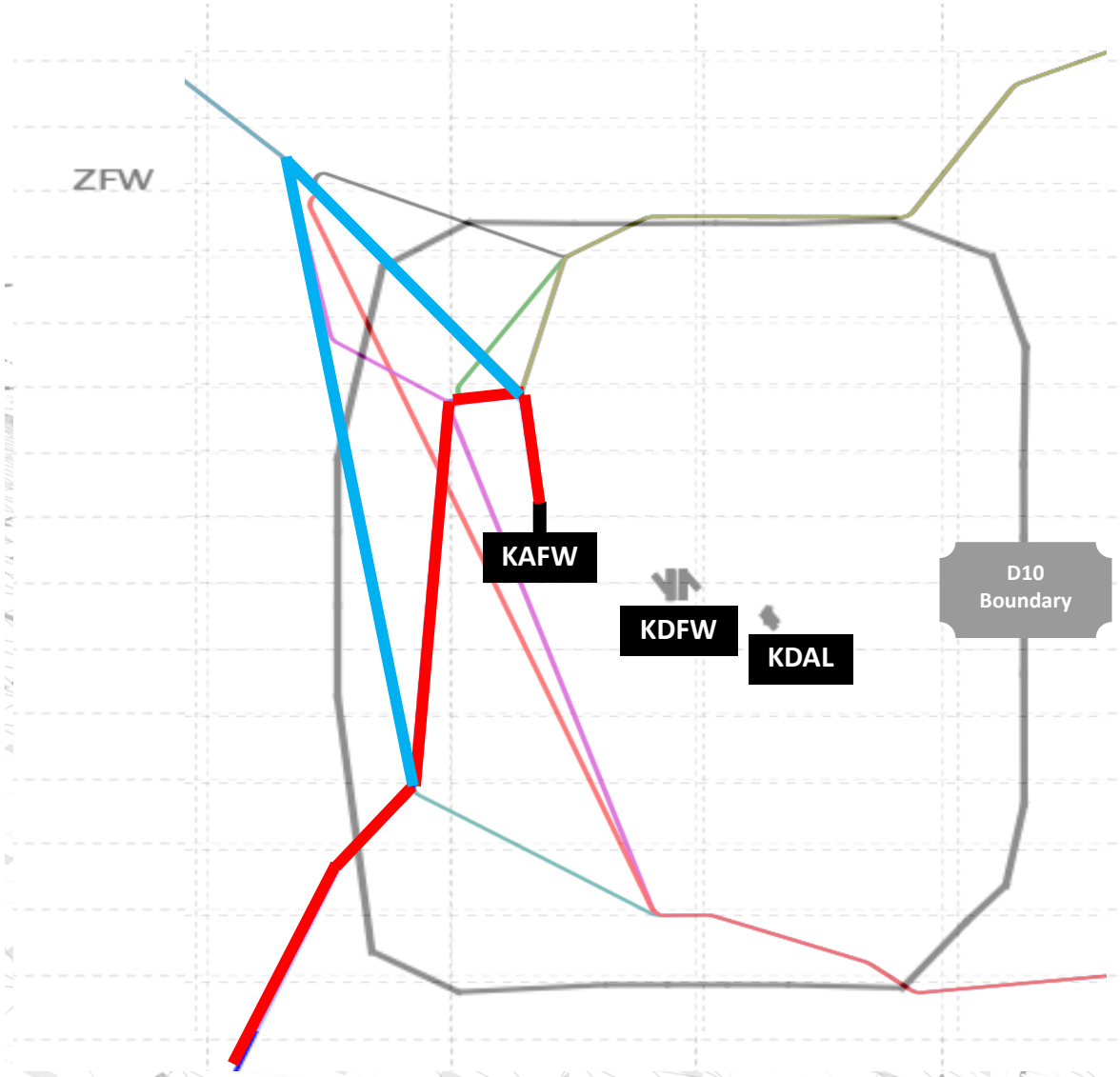
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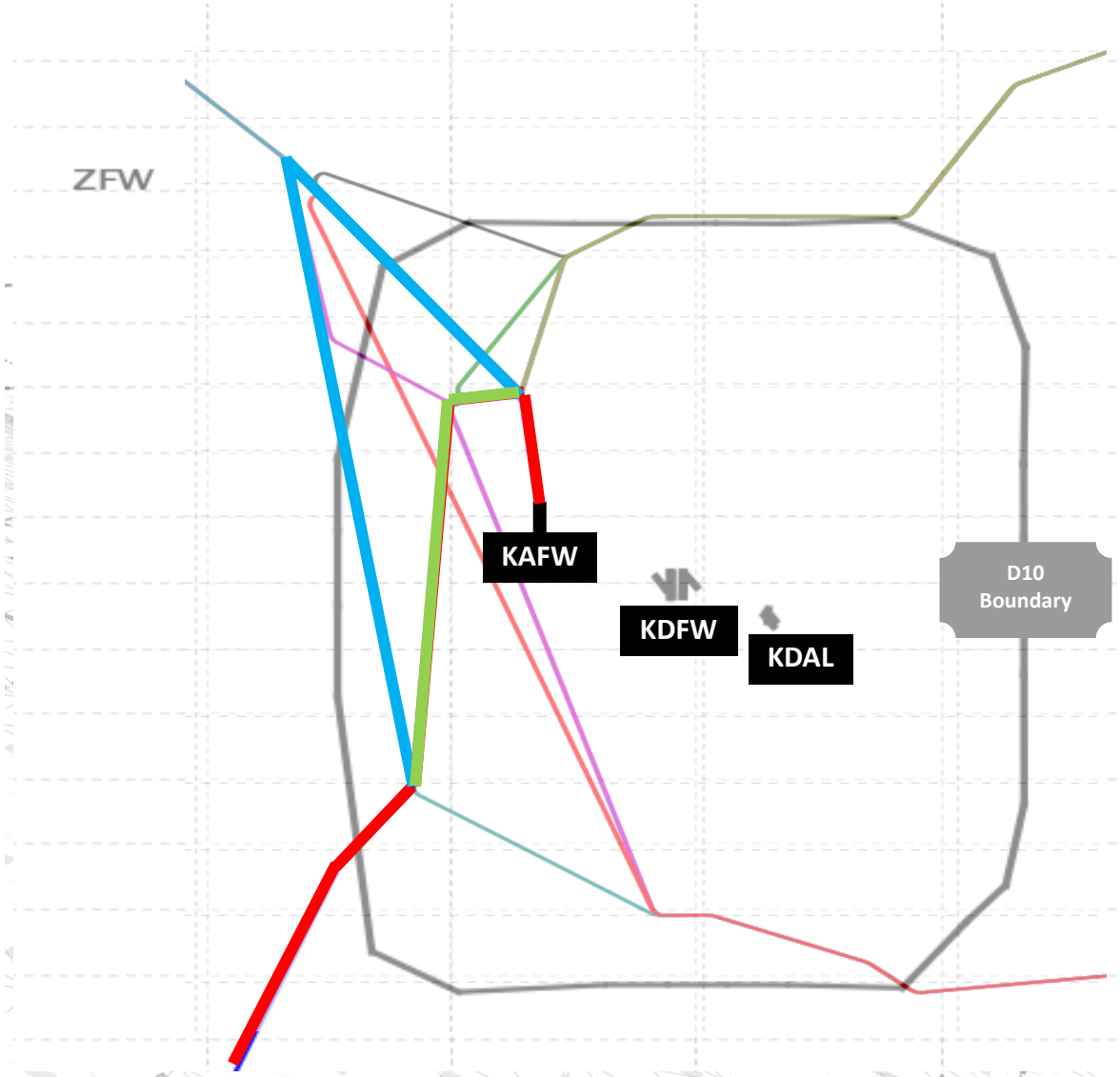
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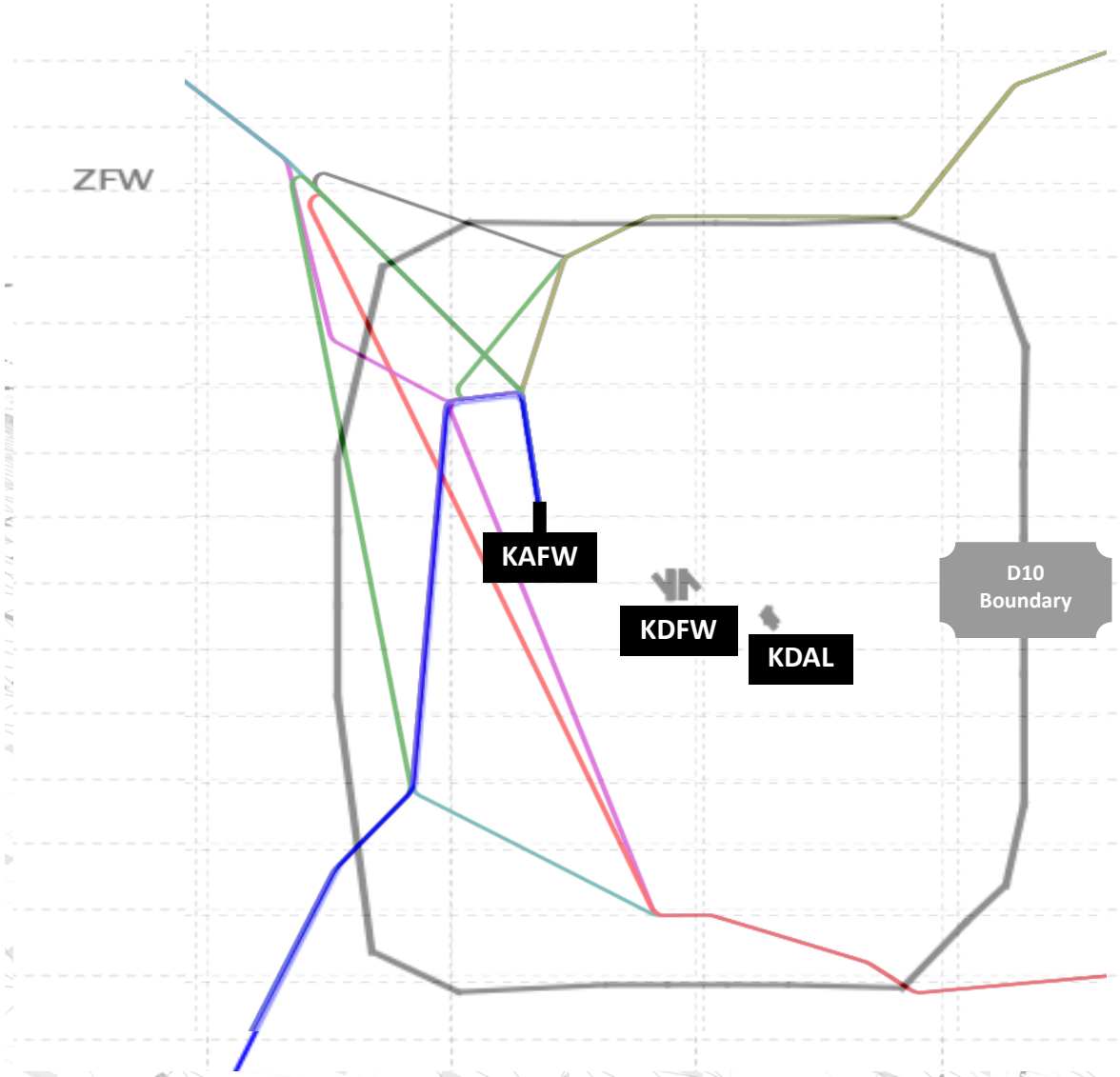
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- 12 total unique routes + four overlapping routes

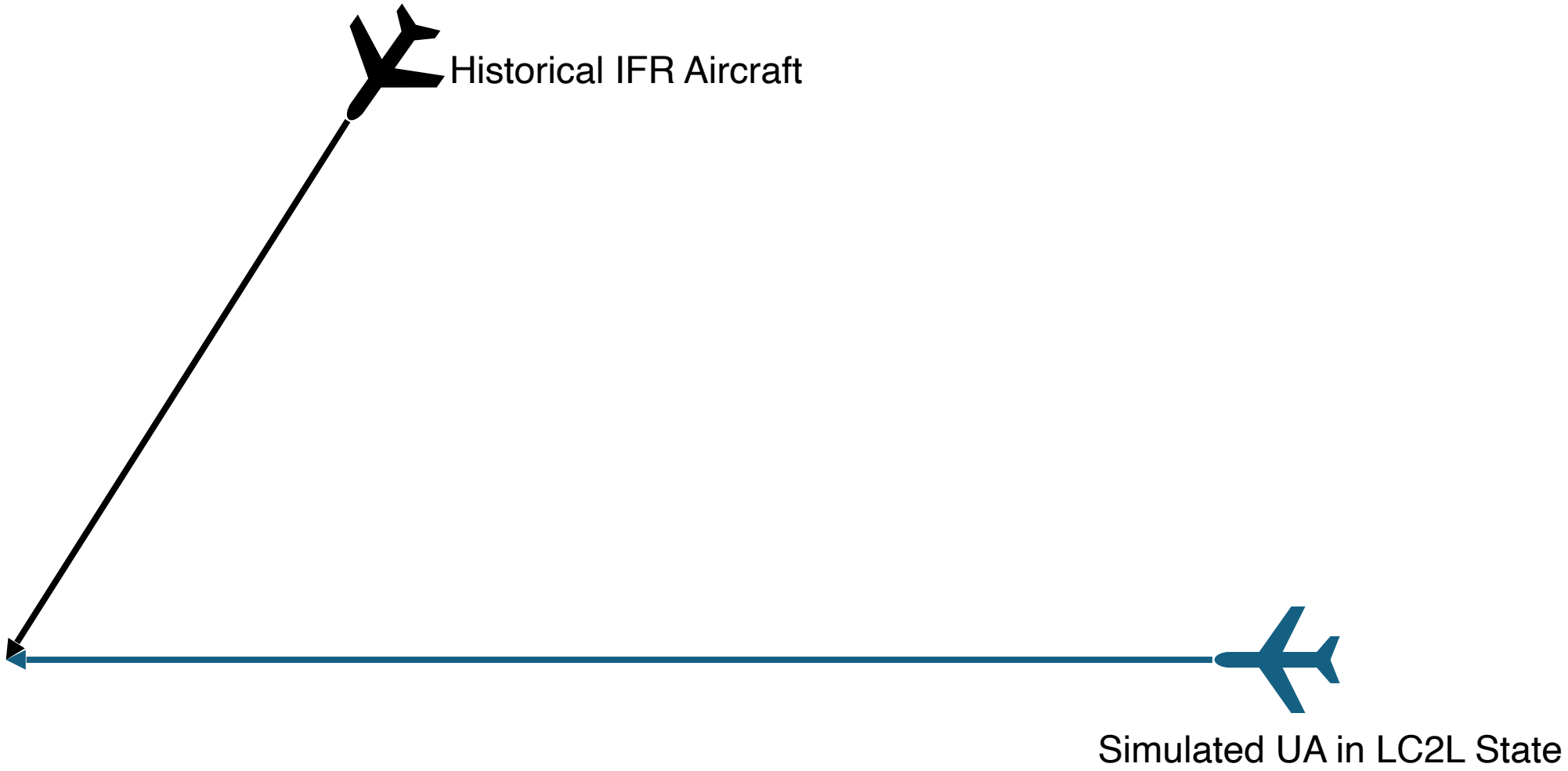


Simulated ATC Conflict Resolution Maneuvers

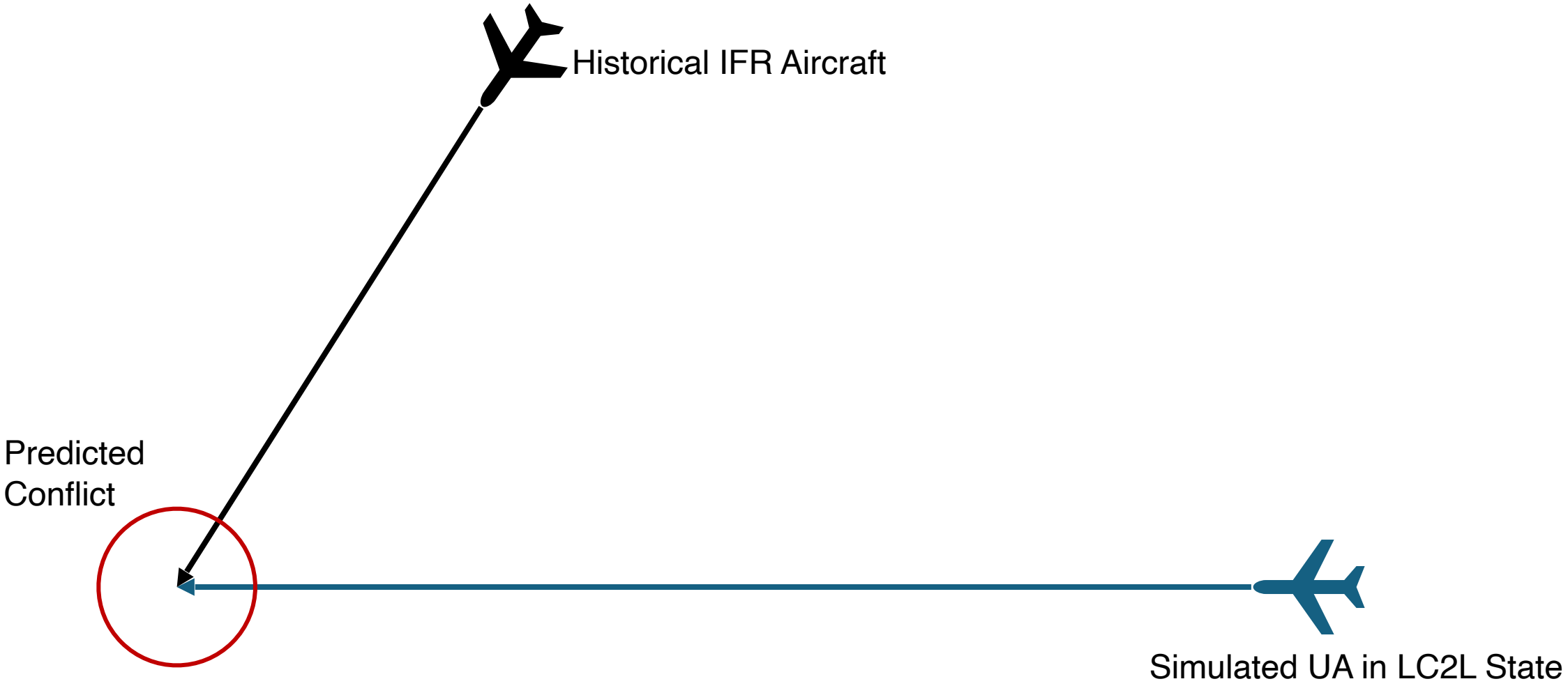


Simulated UA in LC2L State

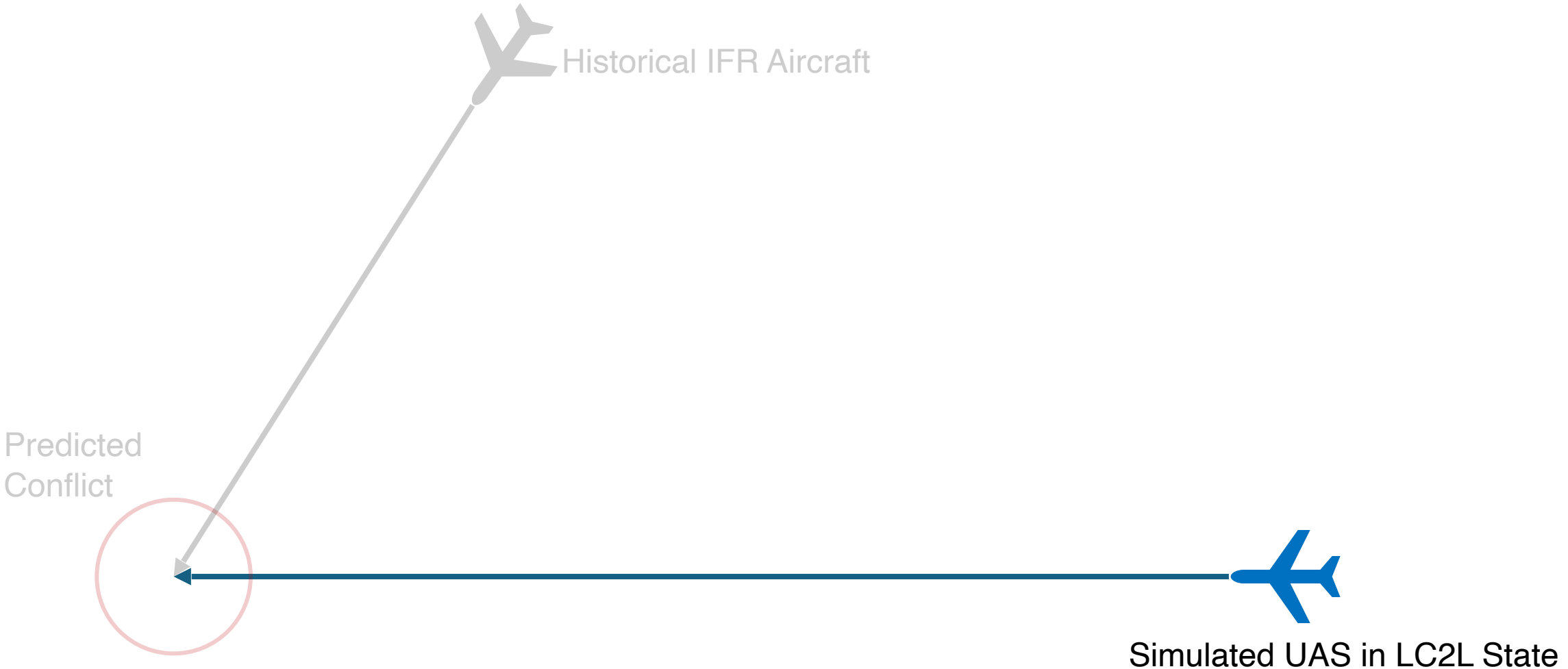
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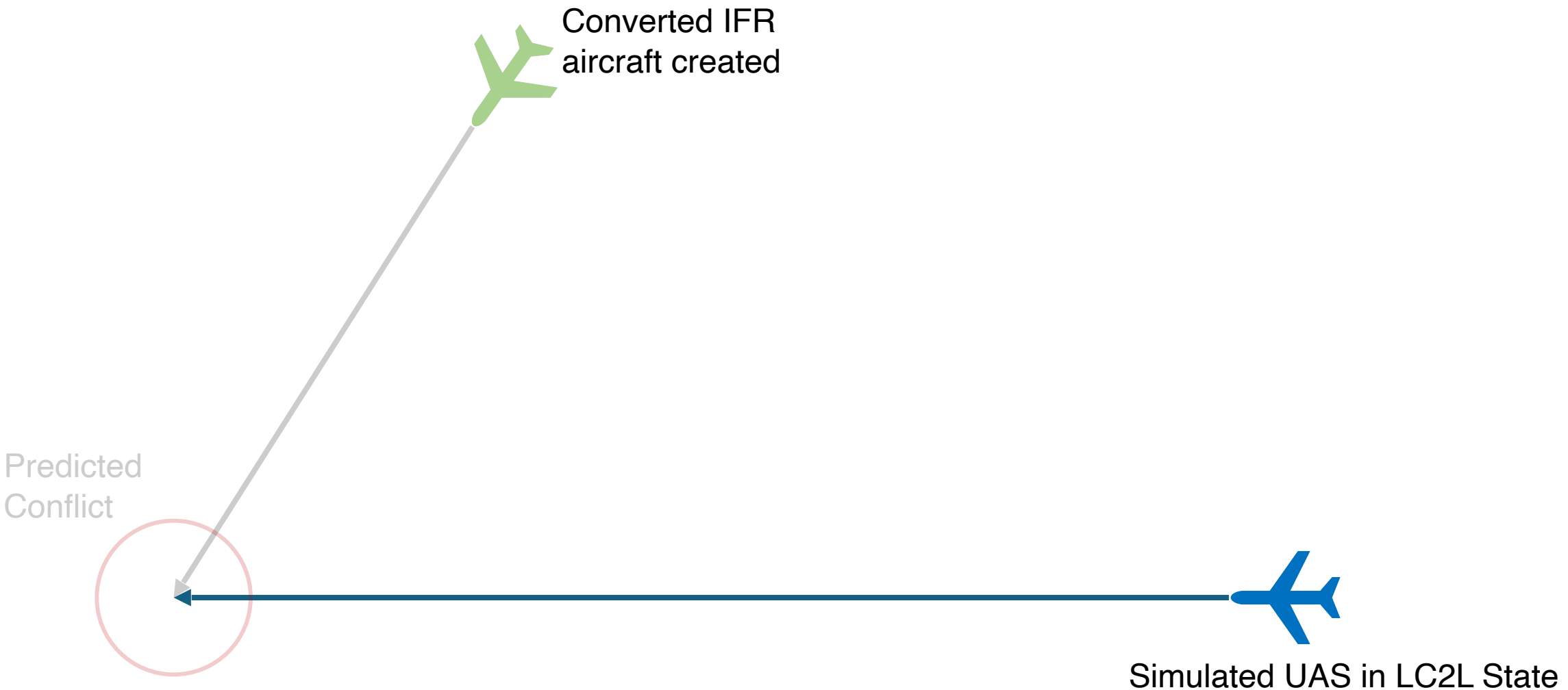
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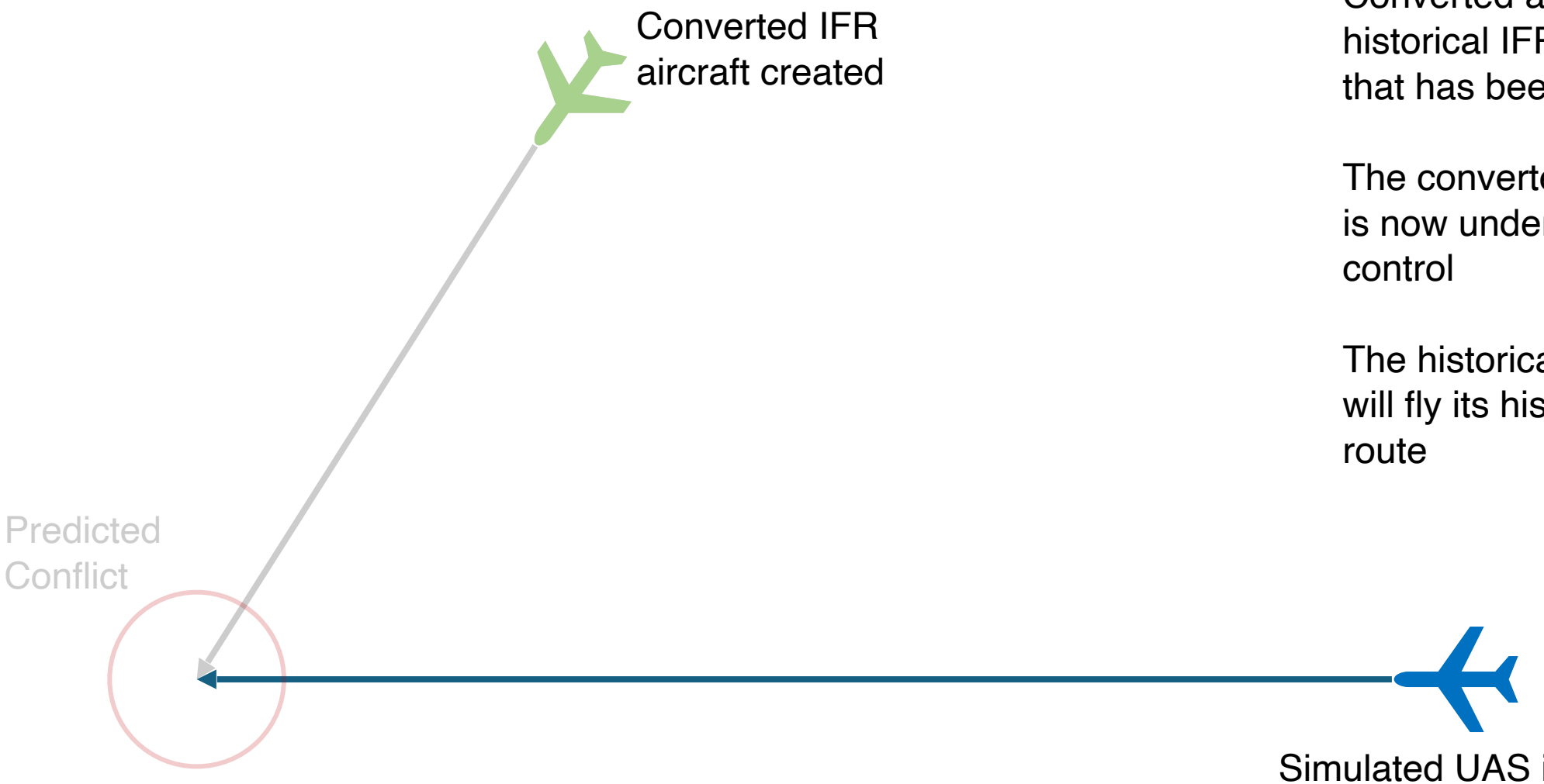
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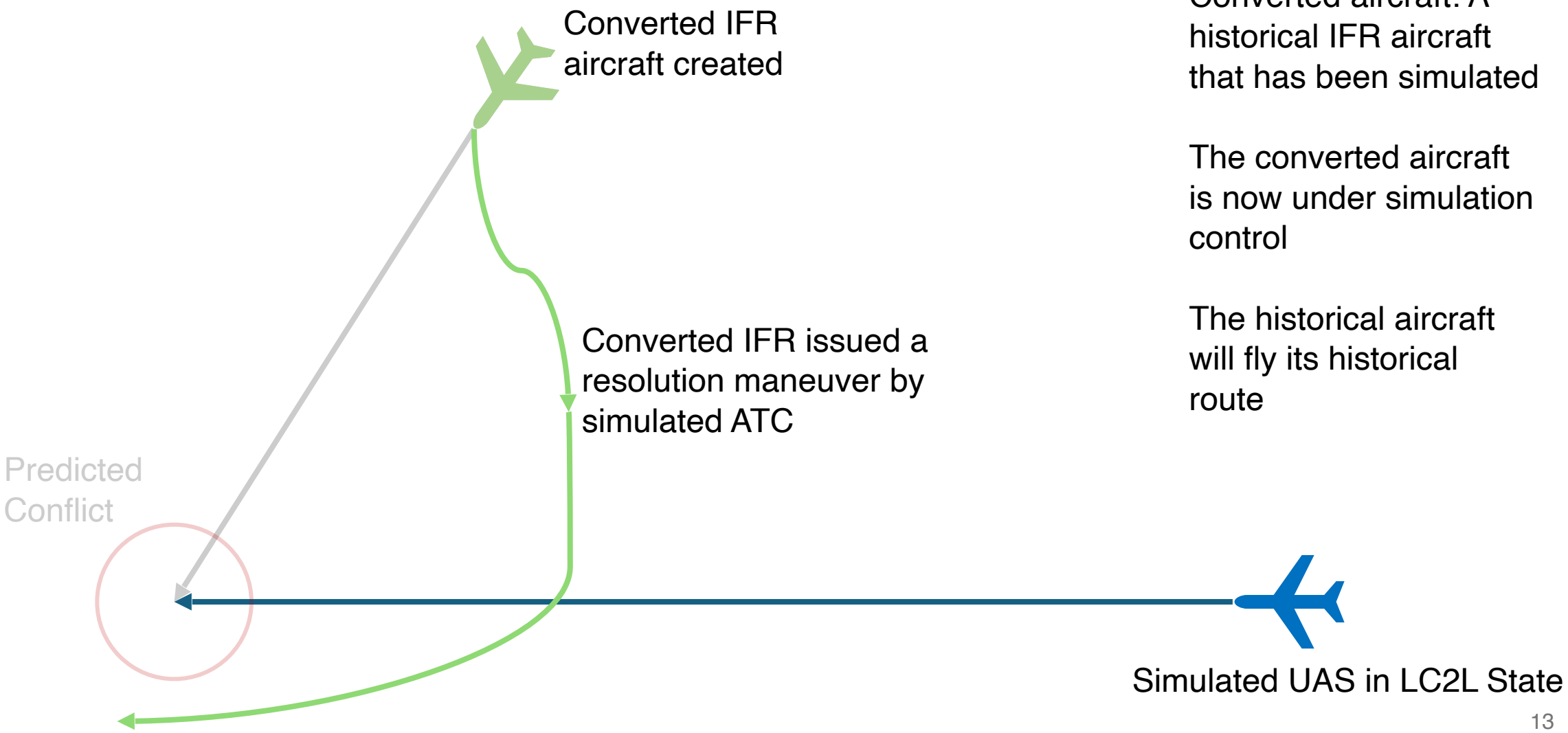


Converted aircraft: A historical IFR aircraft that has been simulated

The converted aircraft is now under simulation control

The historical aircraft will fly its historical route

Simulated ATC Conflict Resolution Maneuvers



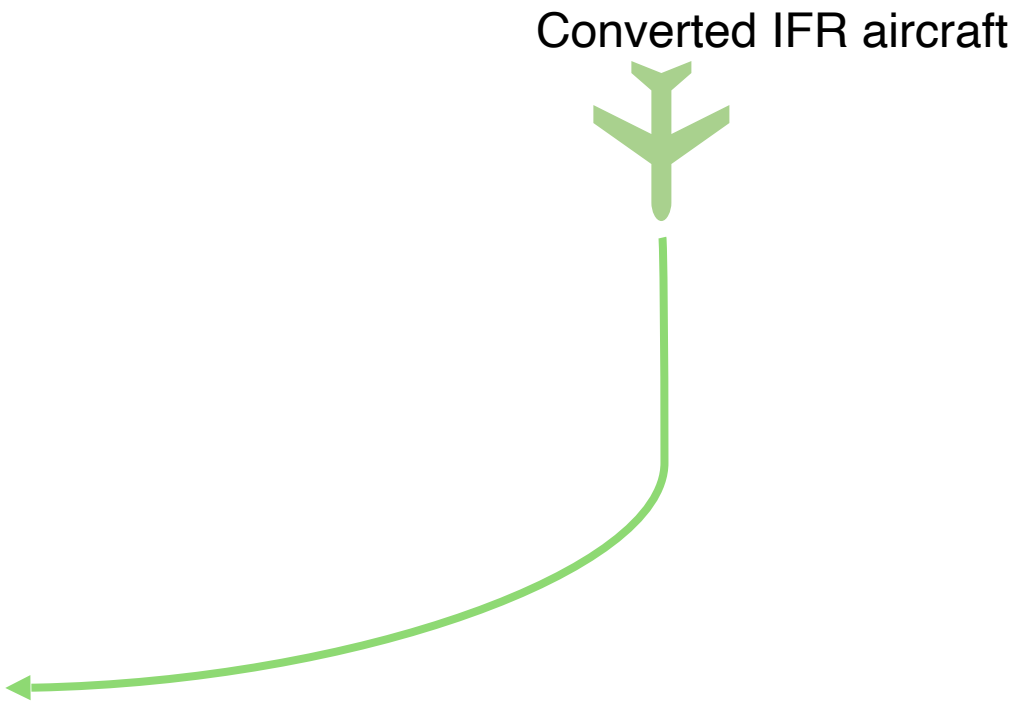
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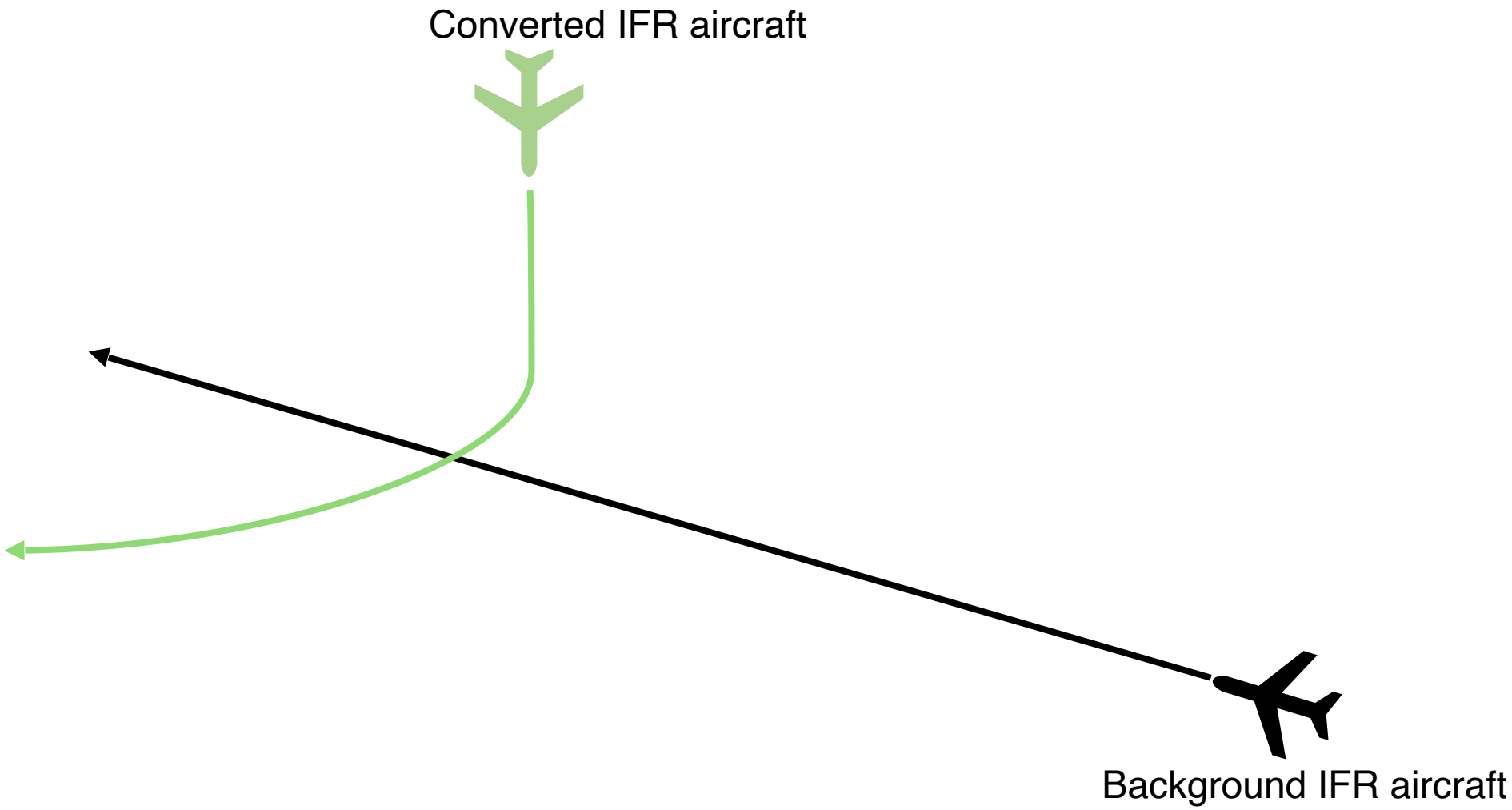
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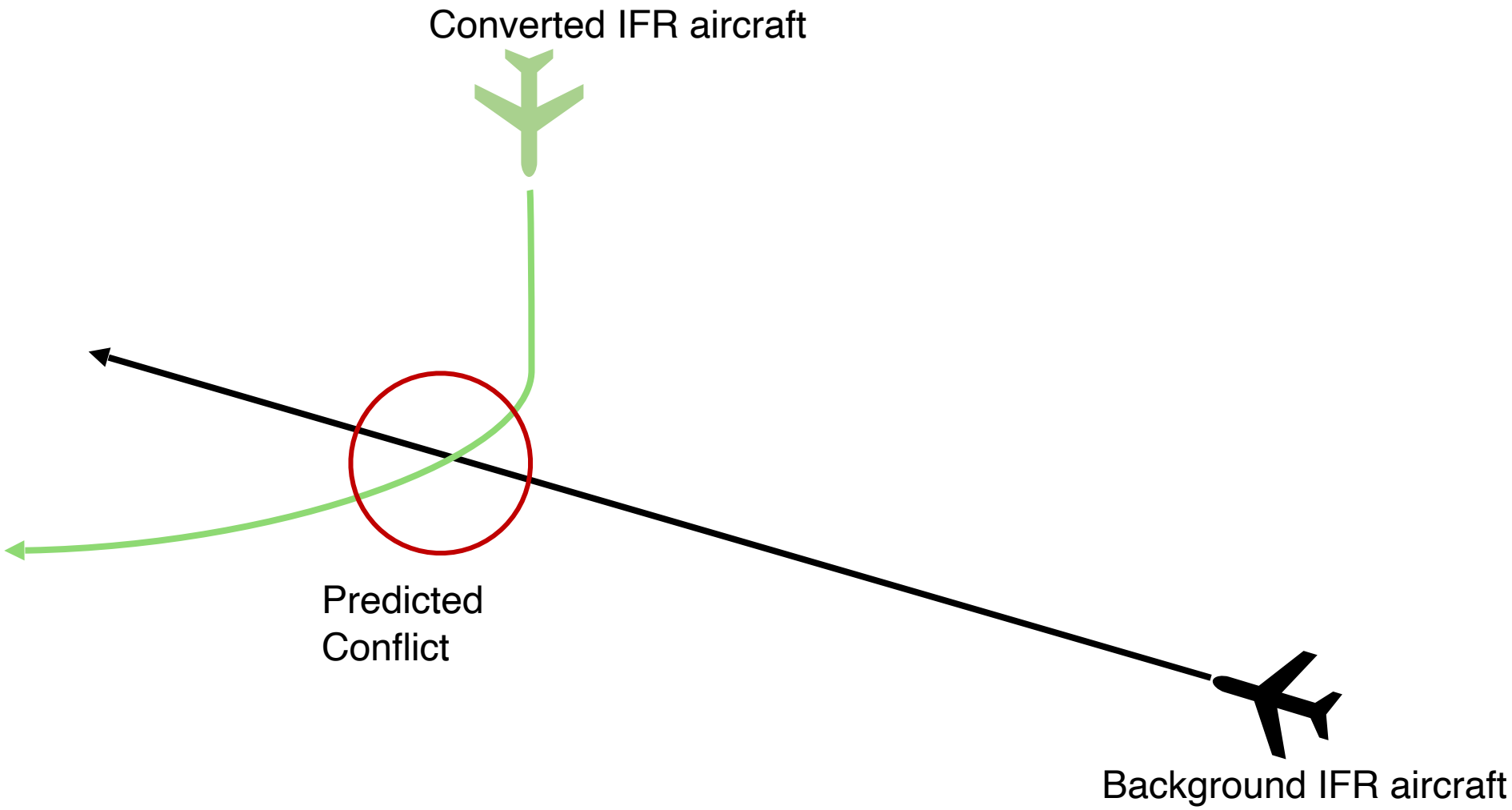
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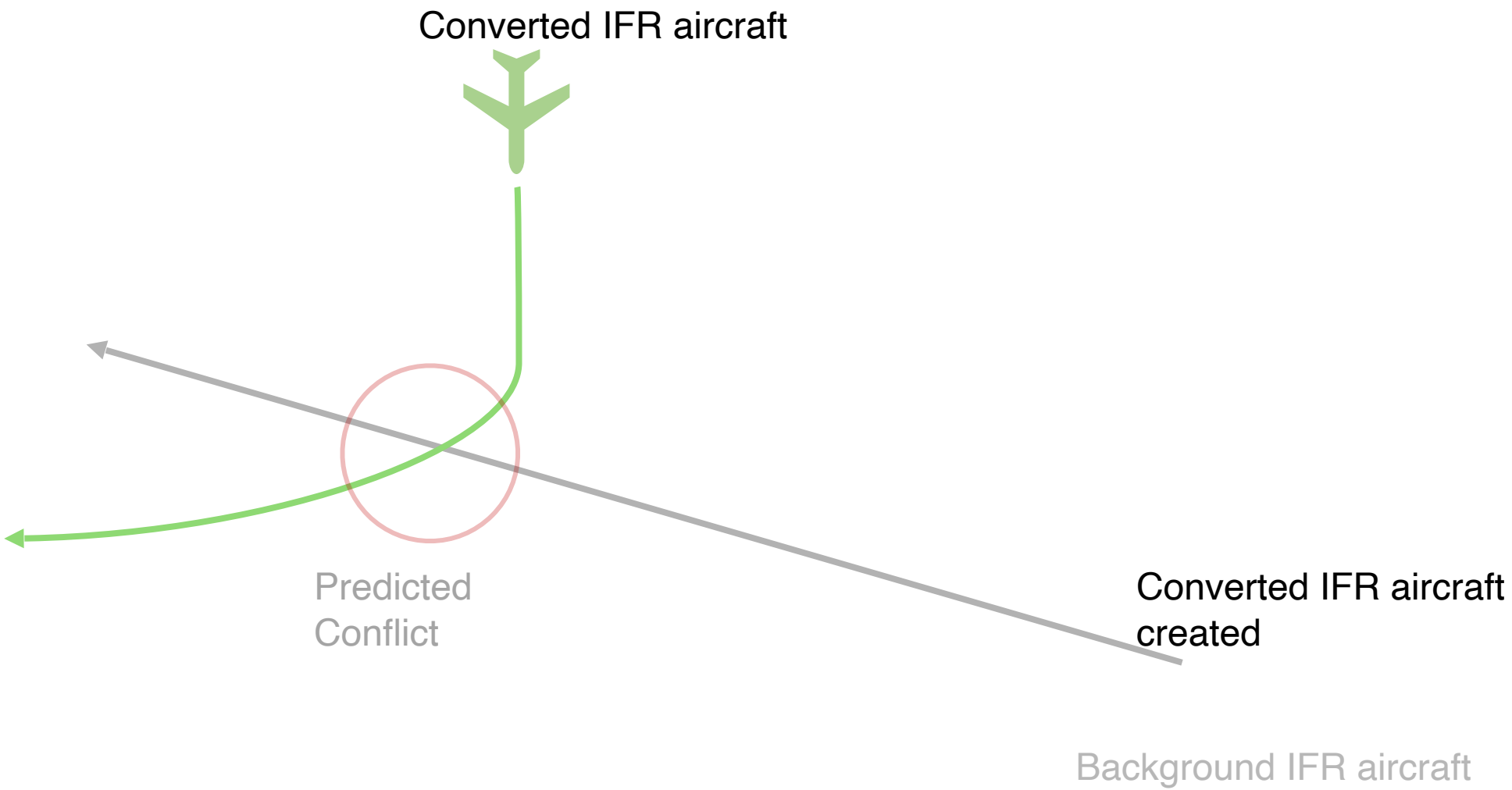
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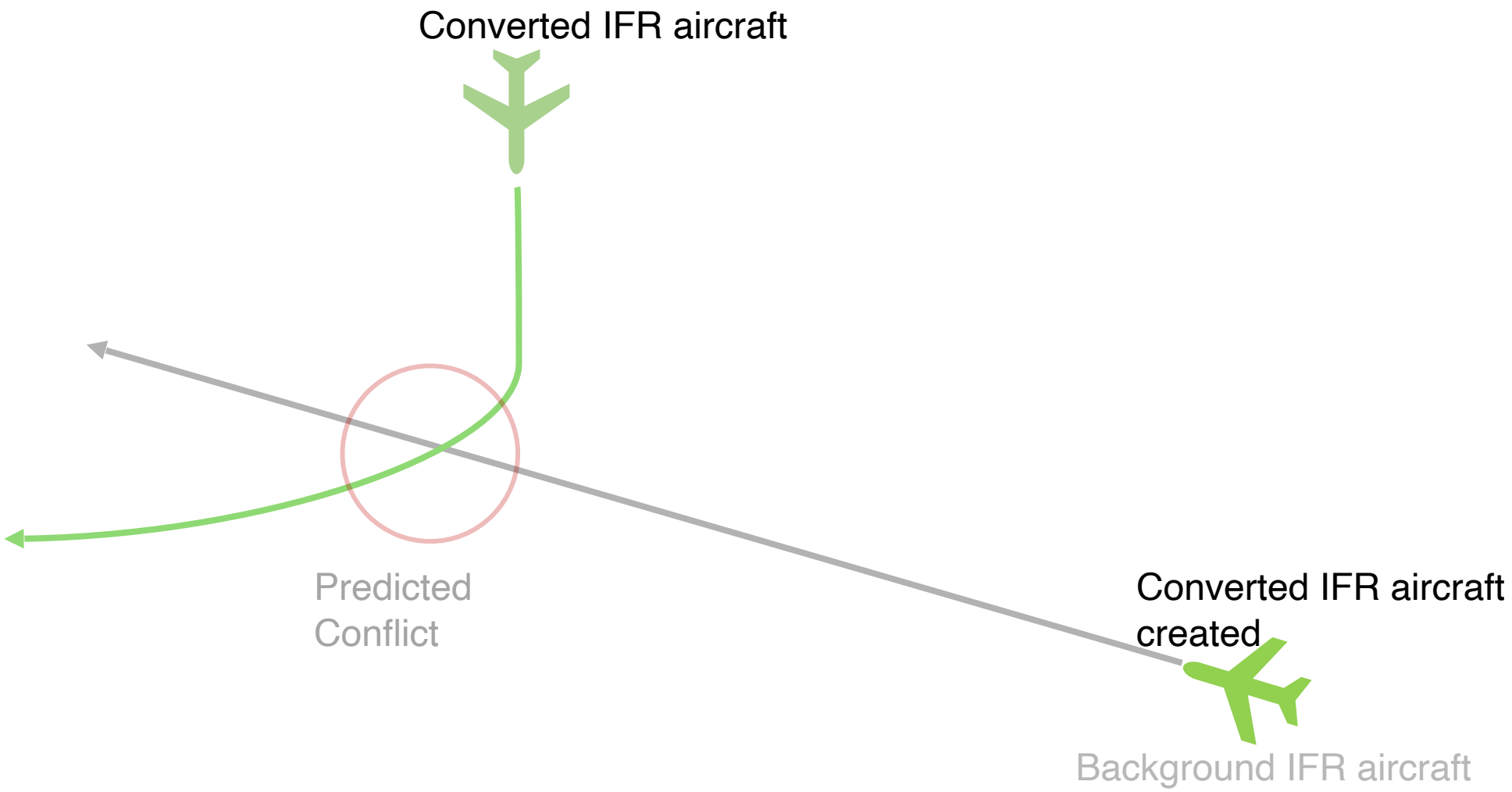
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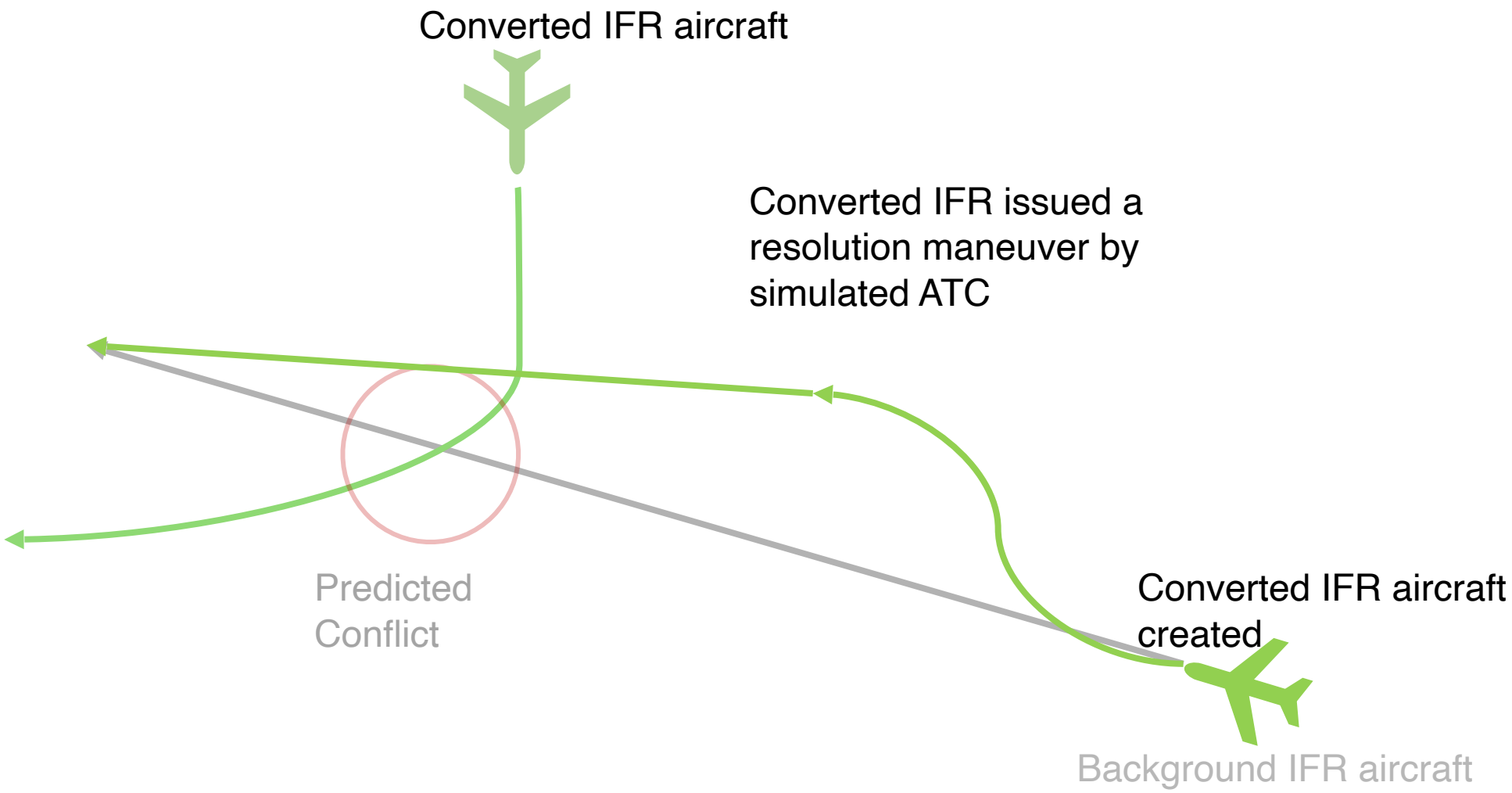
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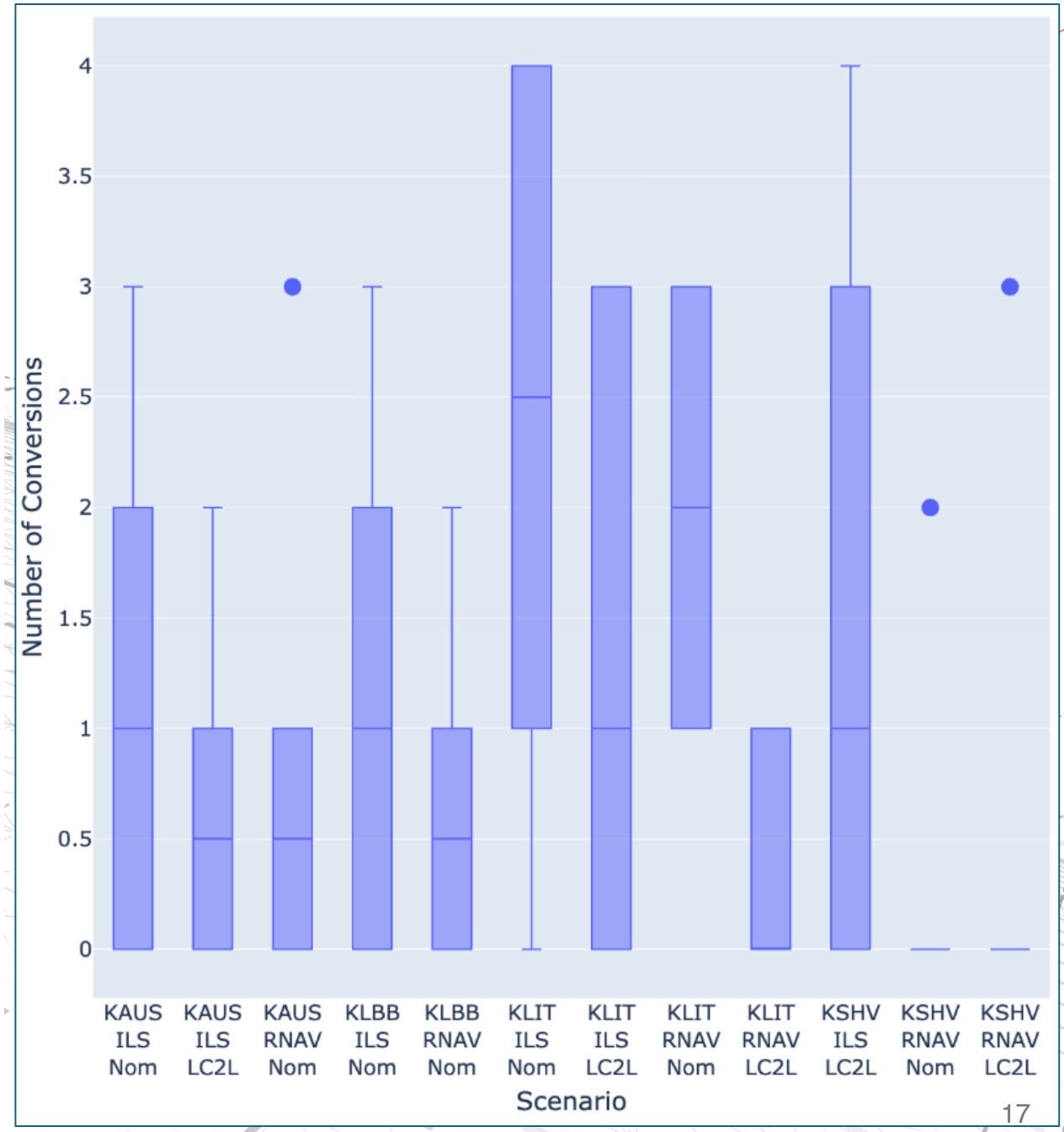
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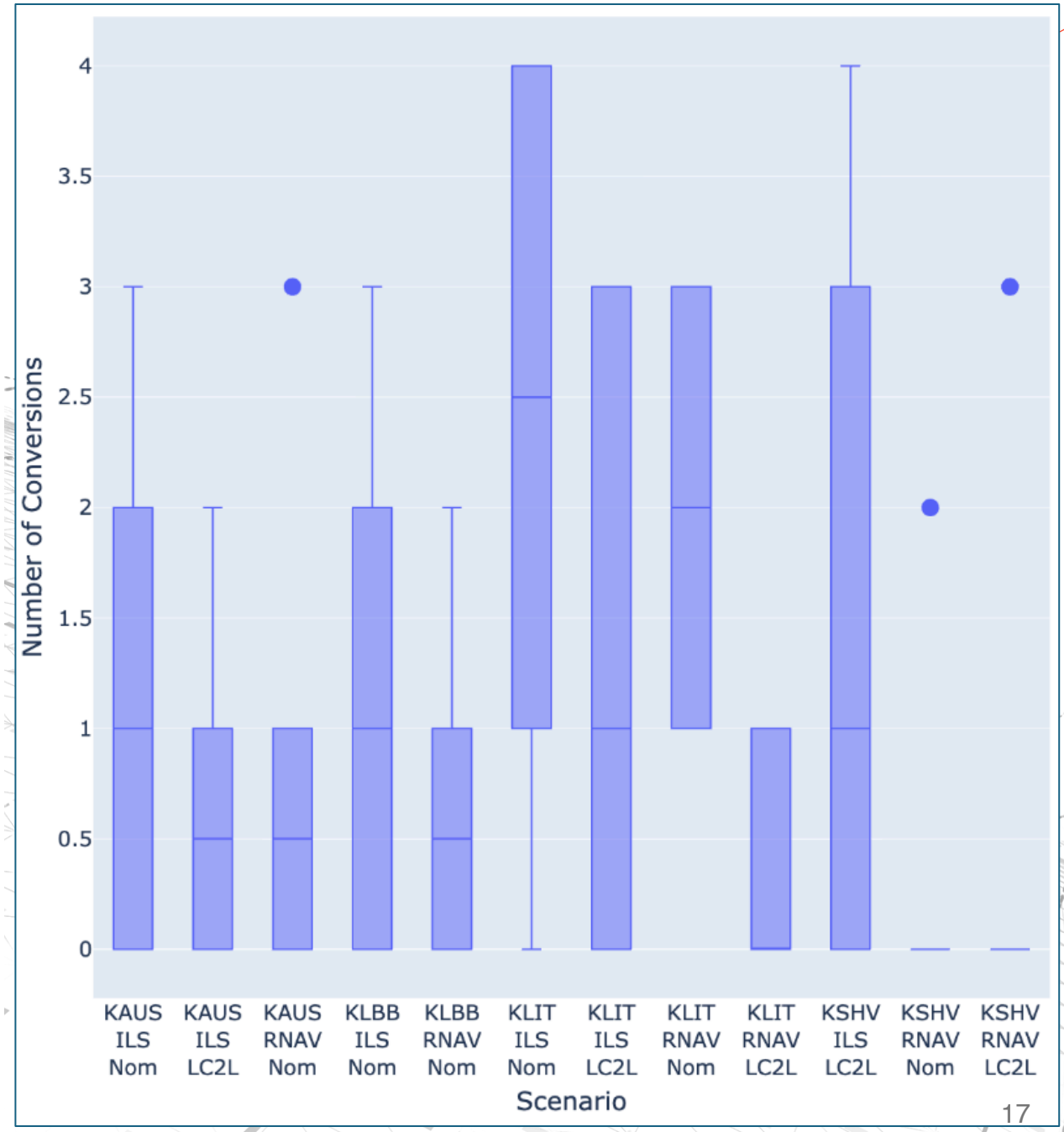
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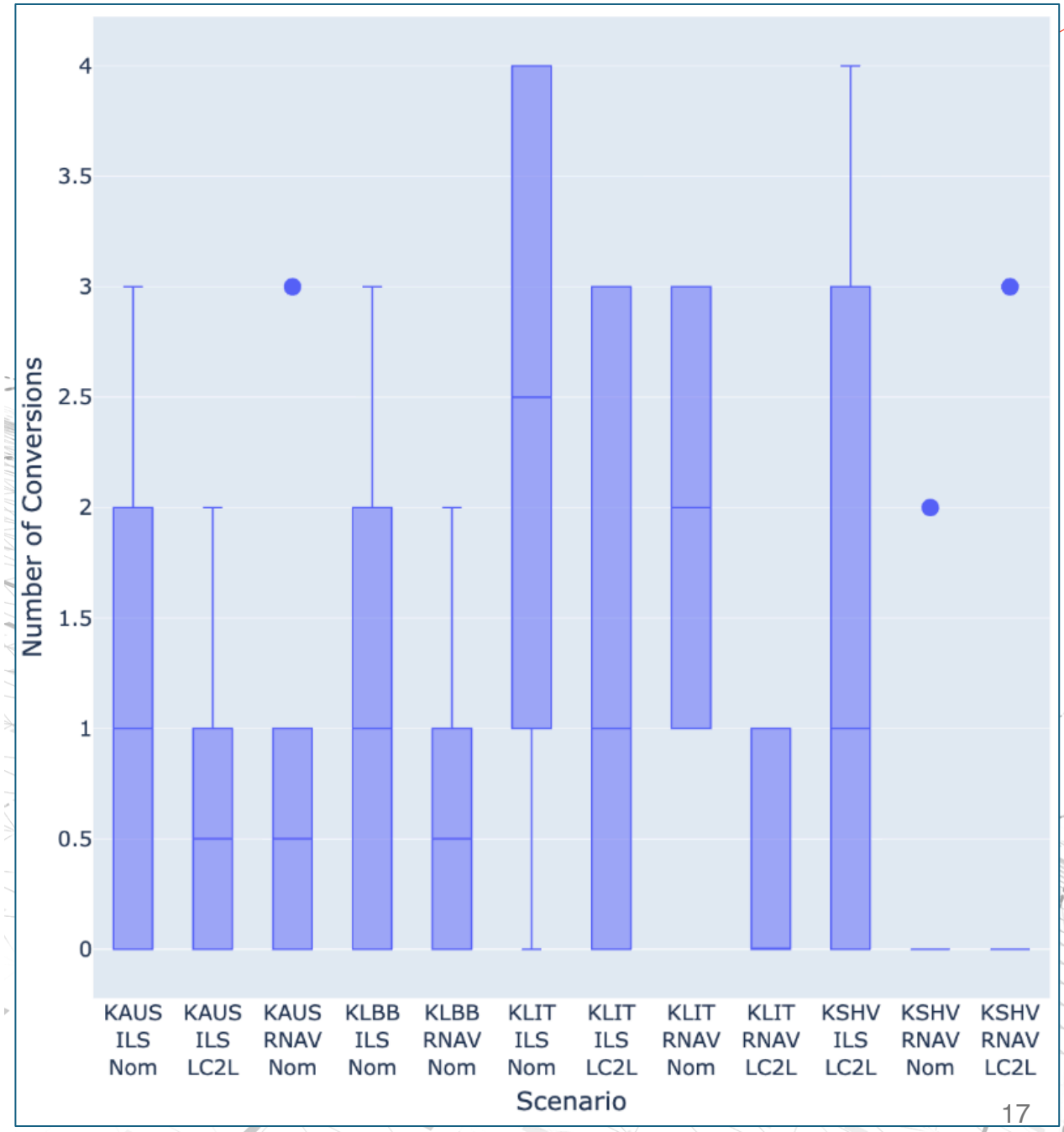
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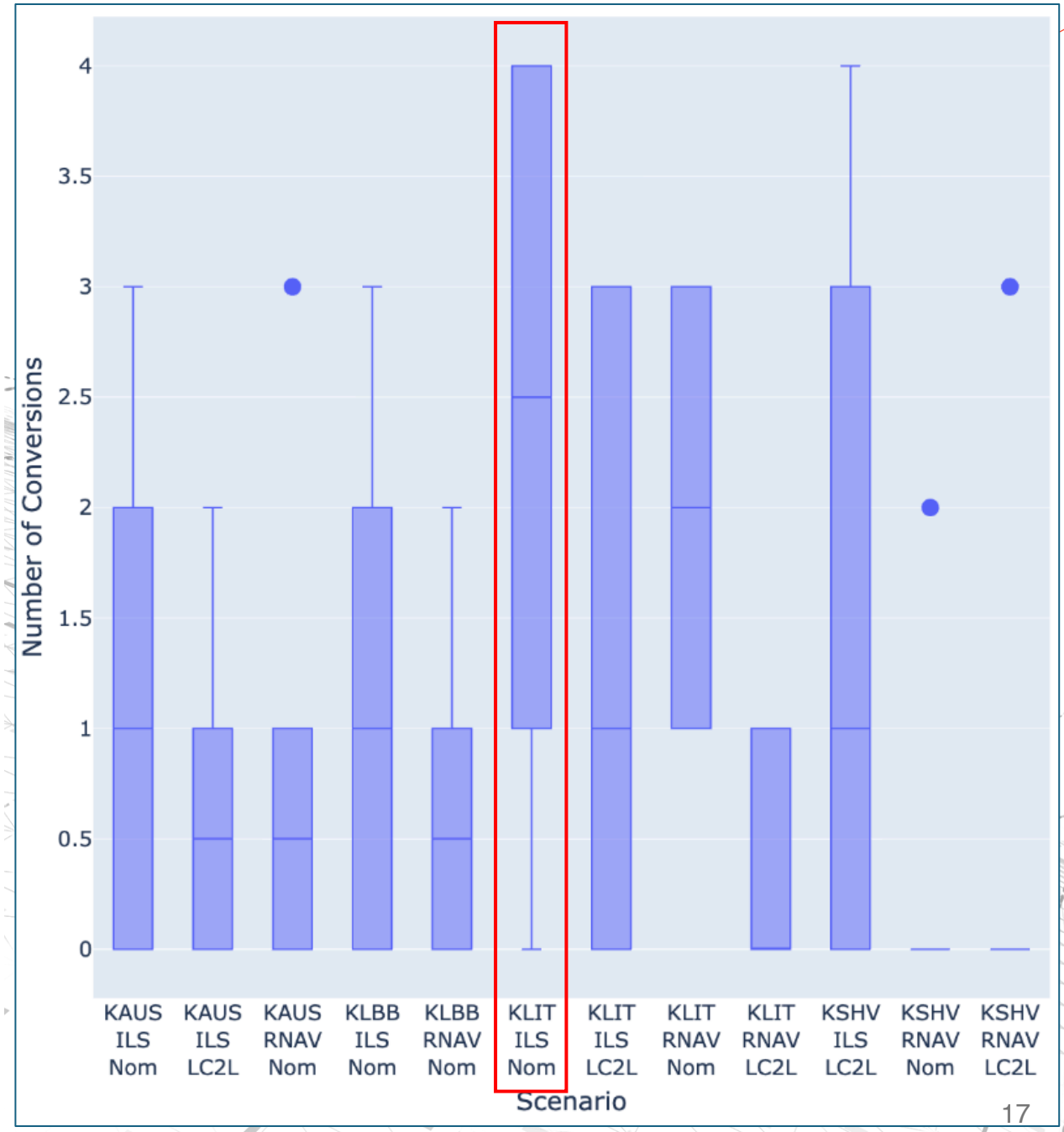
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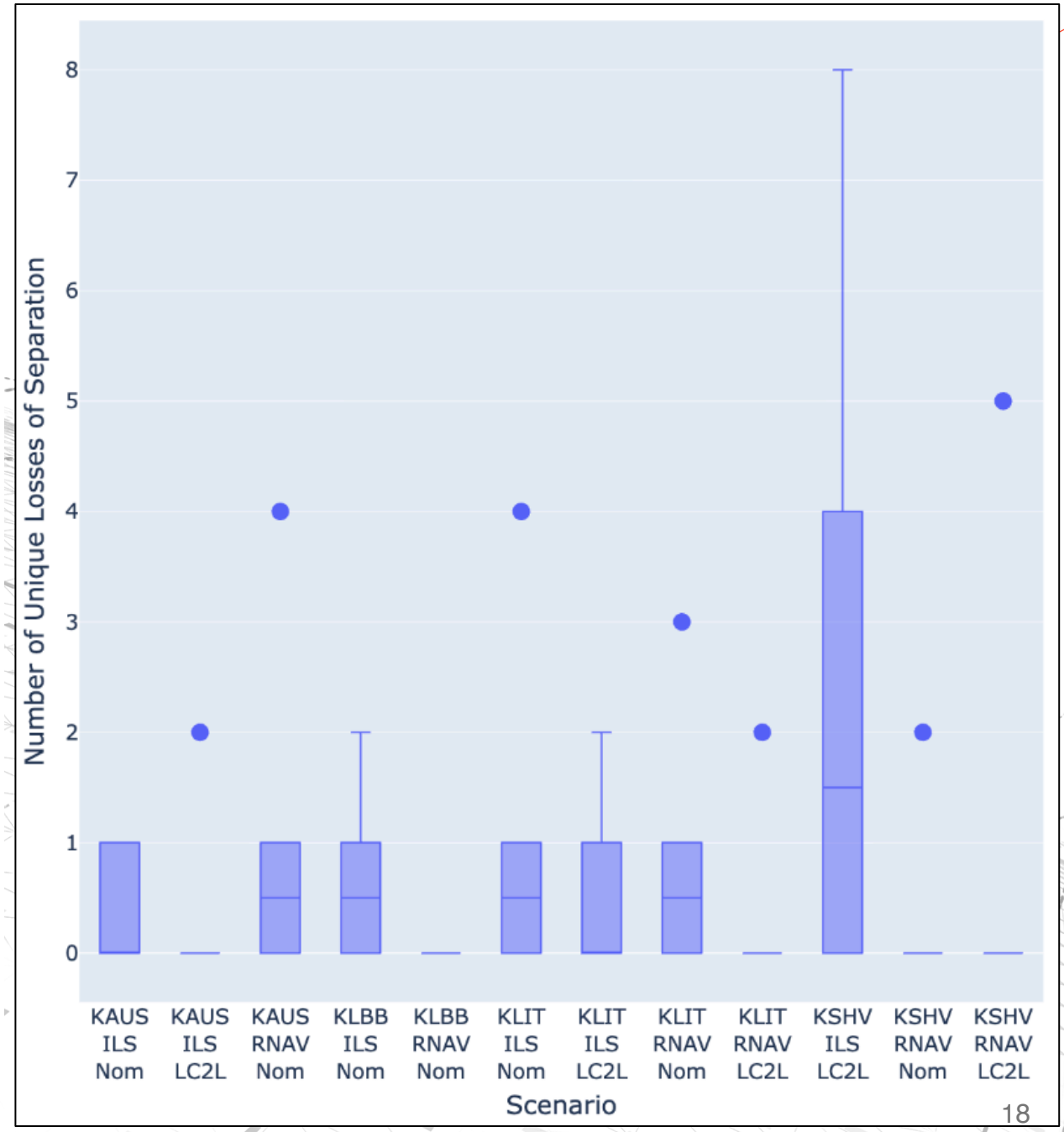
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- KLIT ILS Nominal: matched intuition (transits busy airspace) -> quantifiable



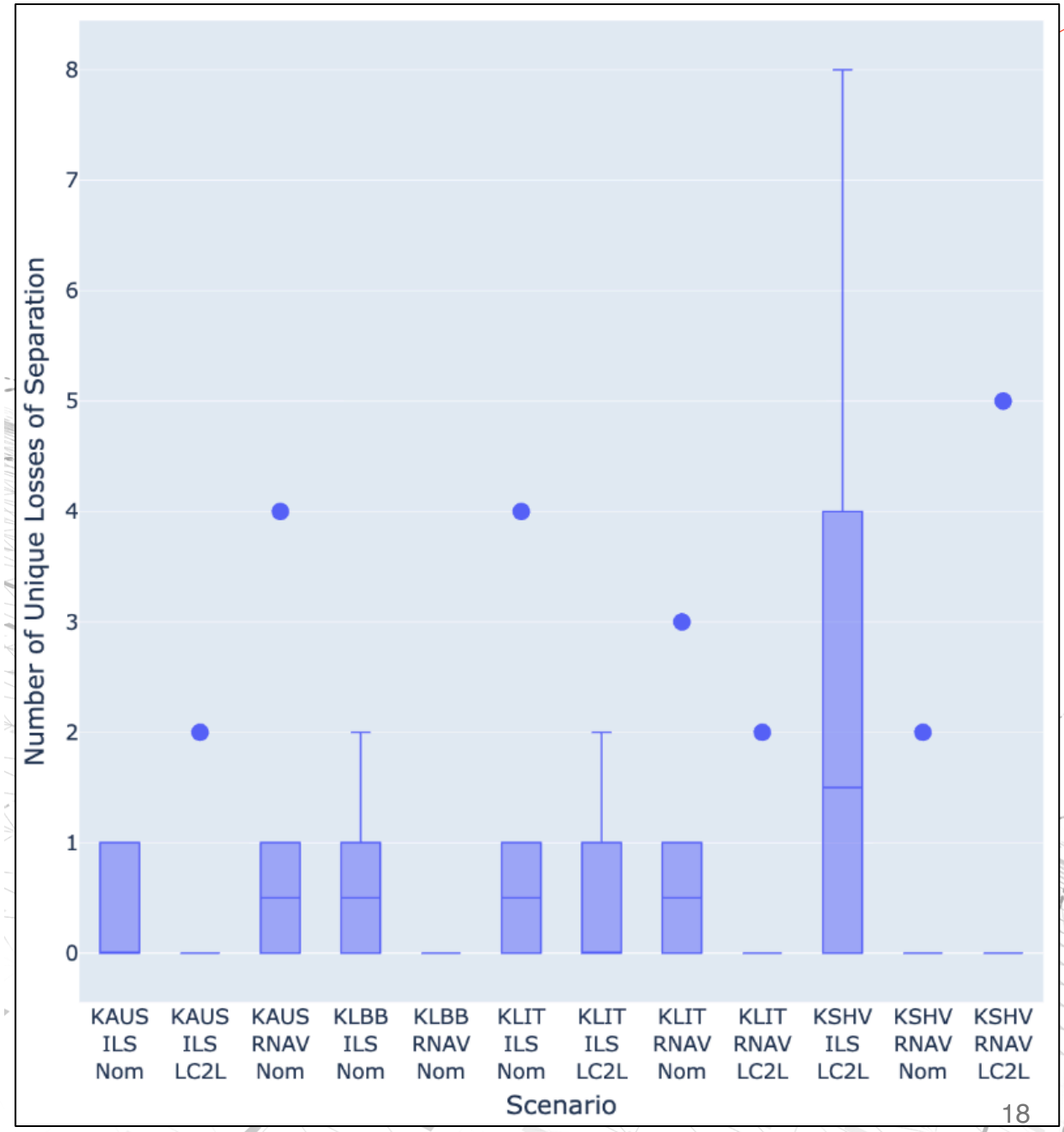
Losses of Separation (LOS)

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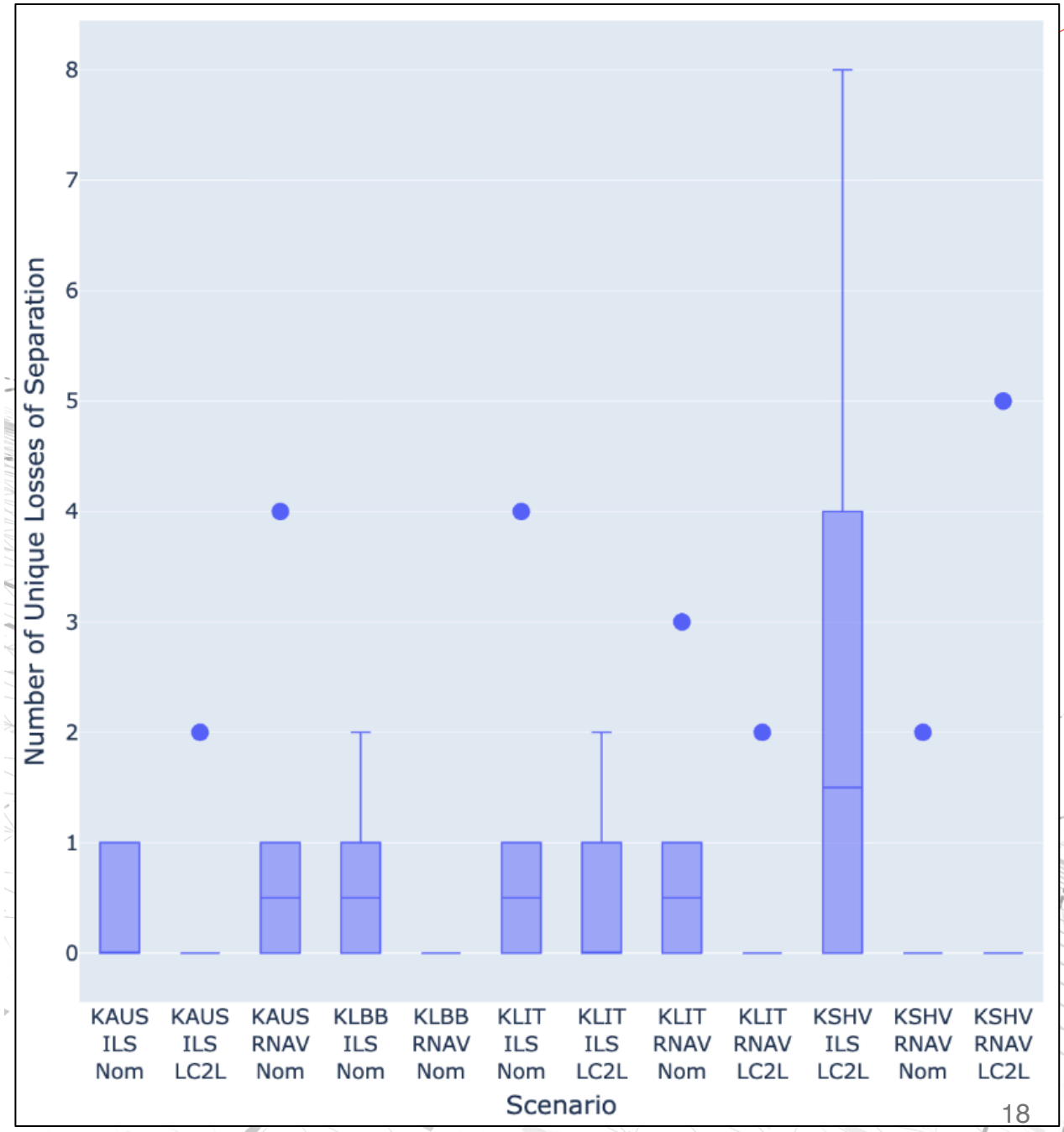
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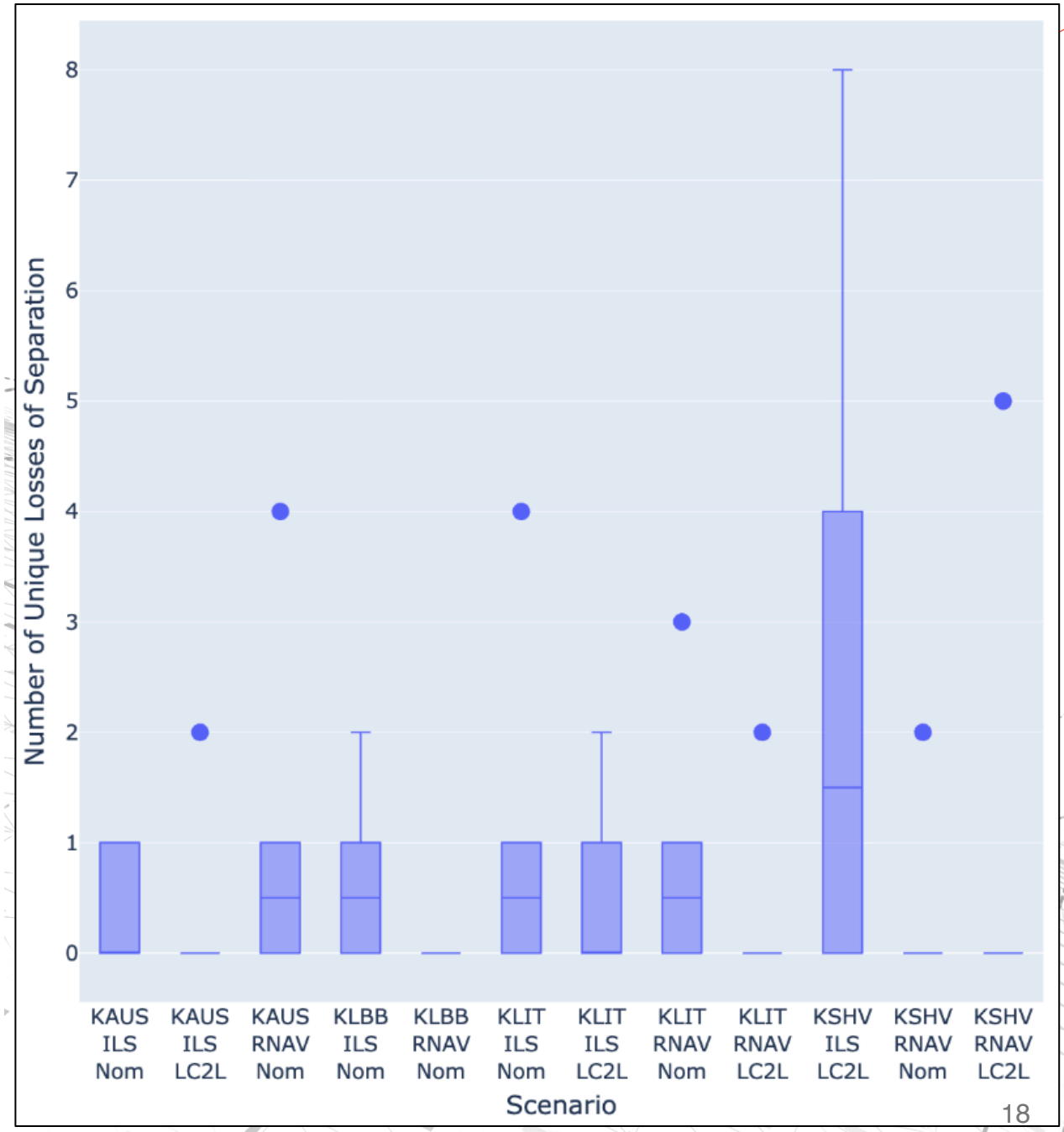
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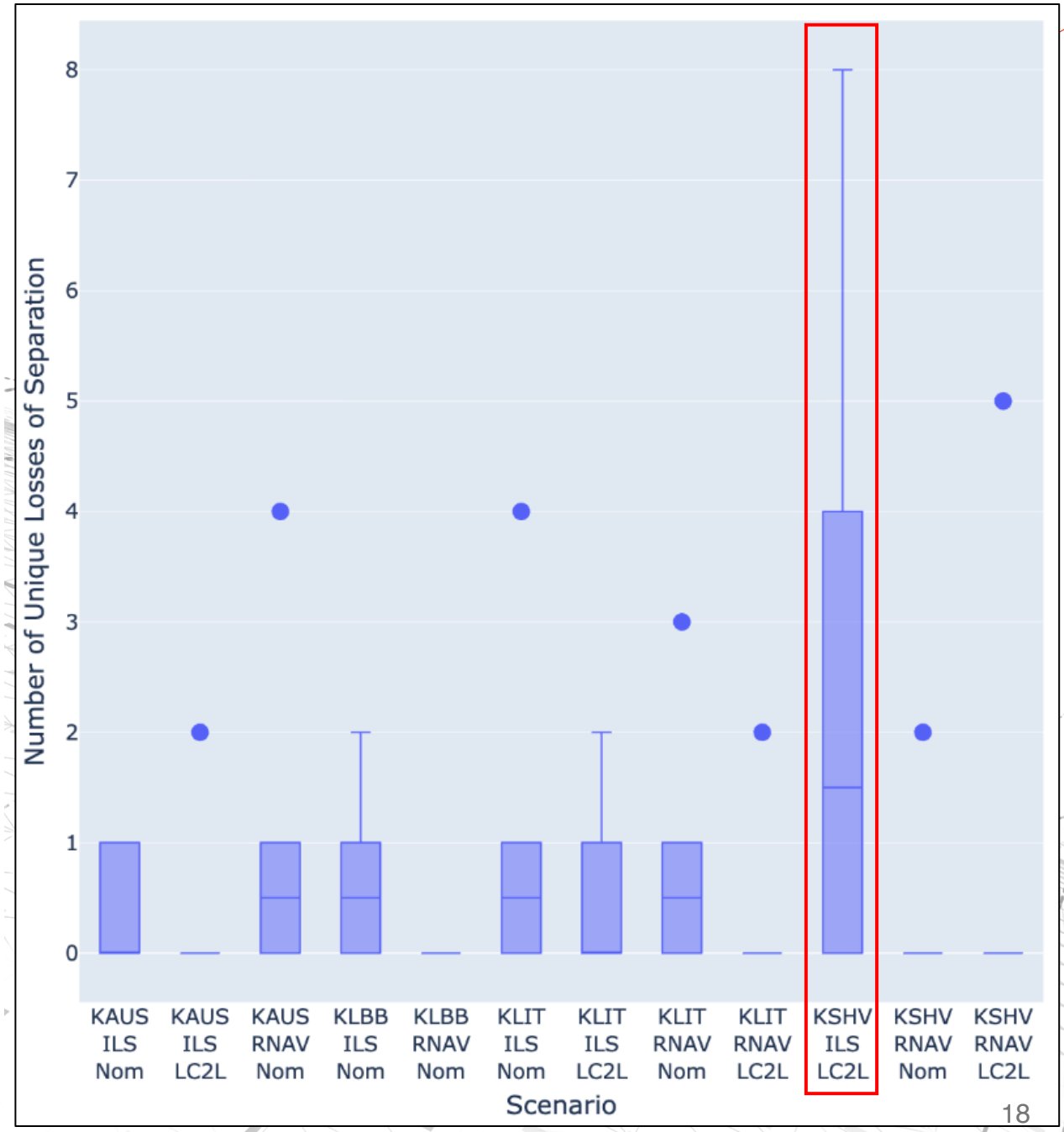
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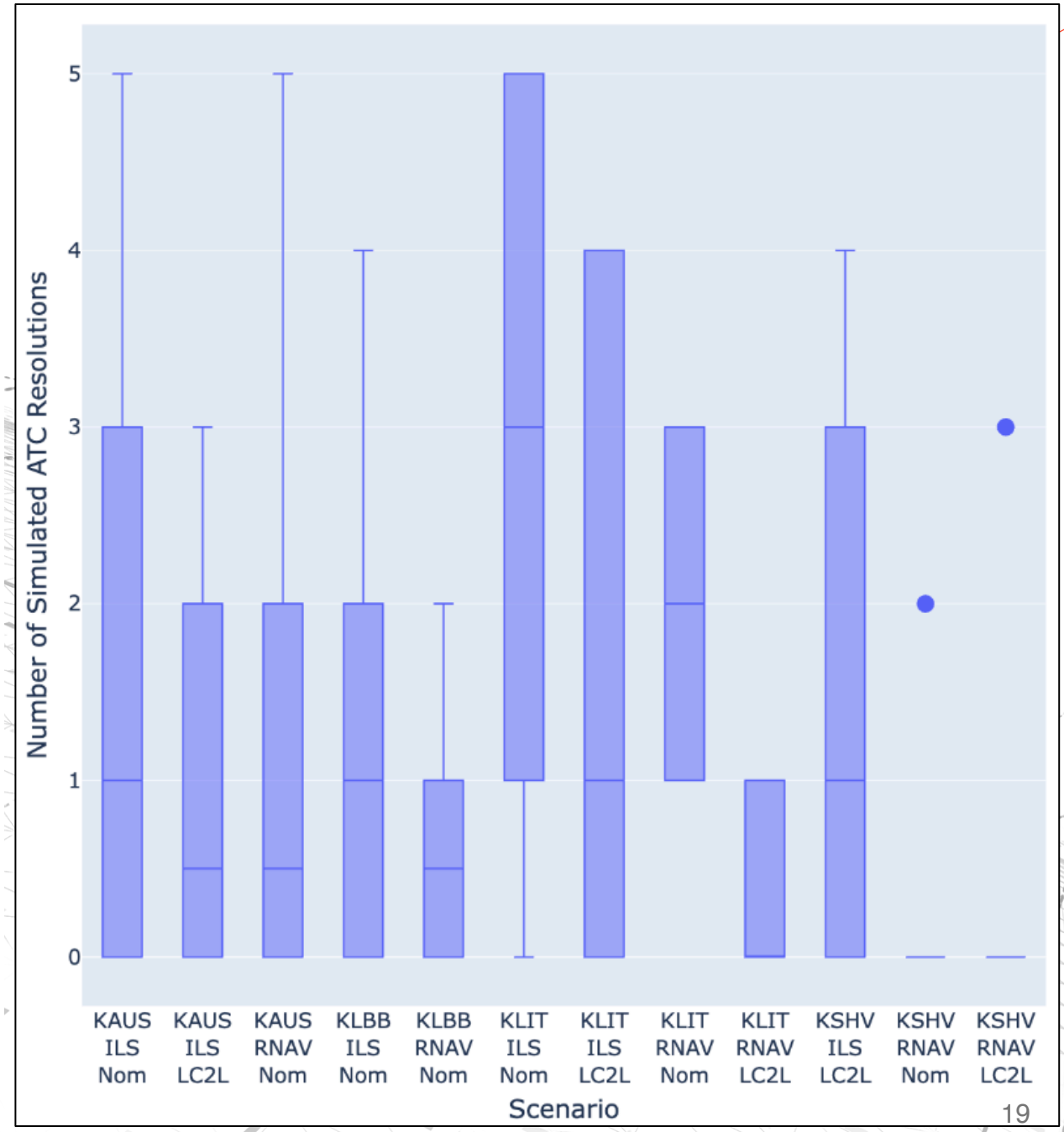
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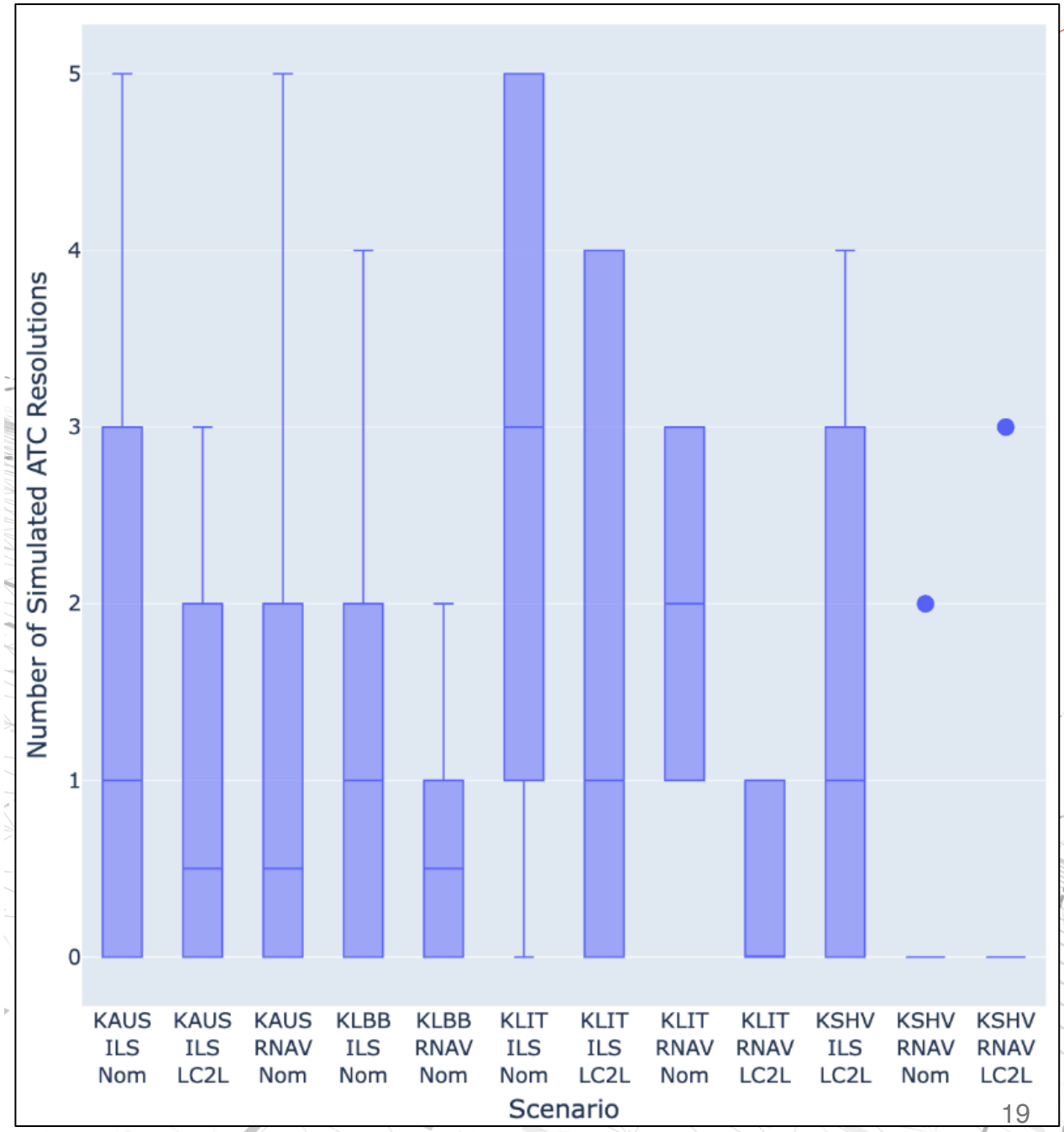
Resolution Maneuvers

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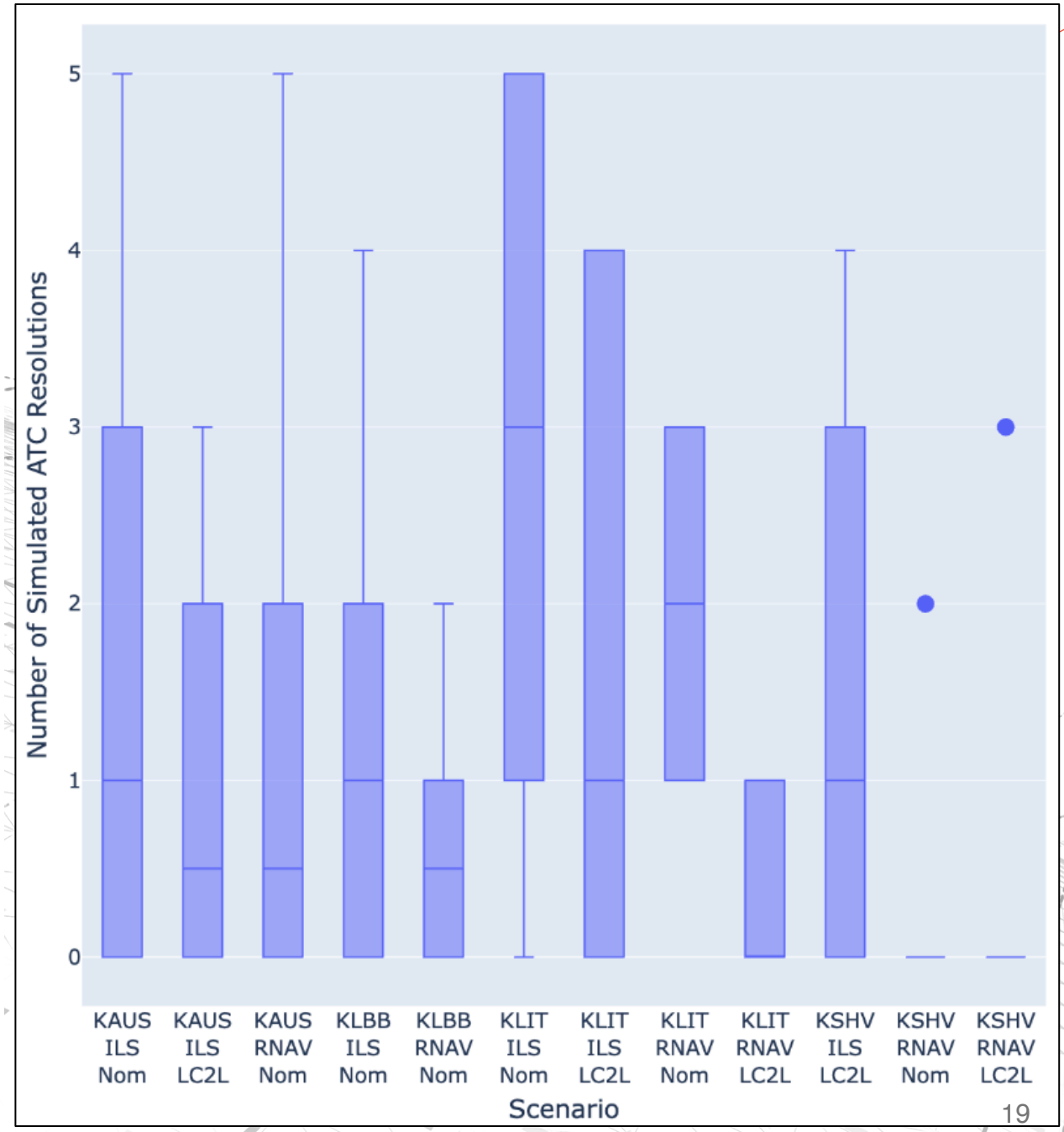
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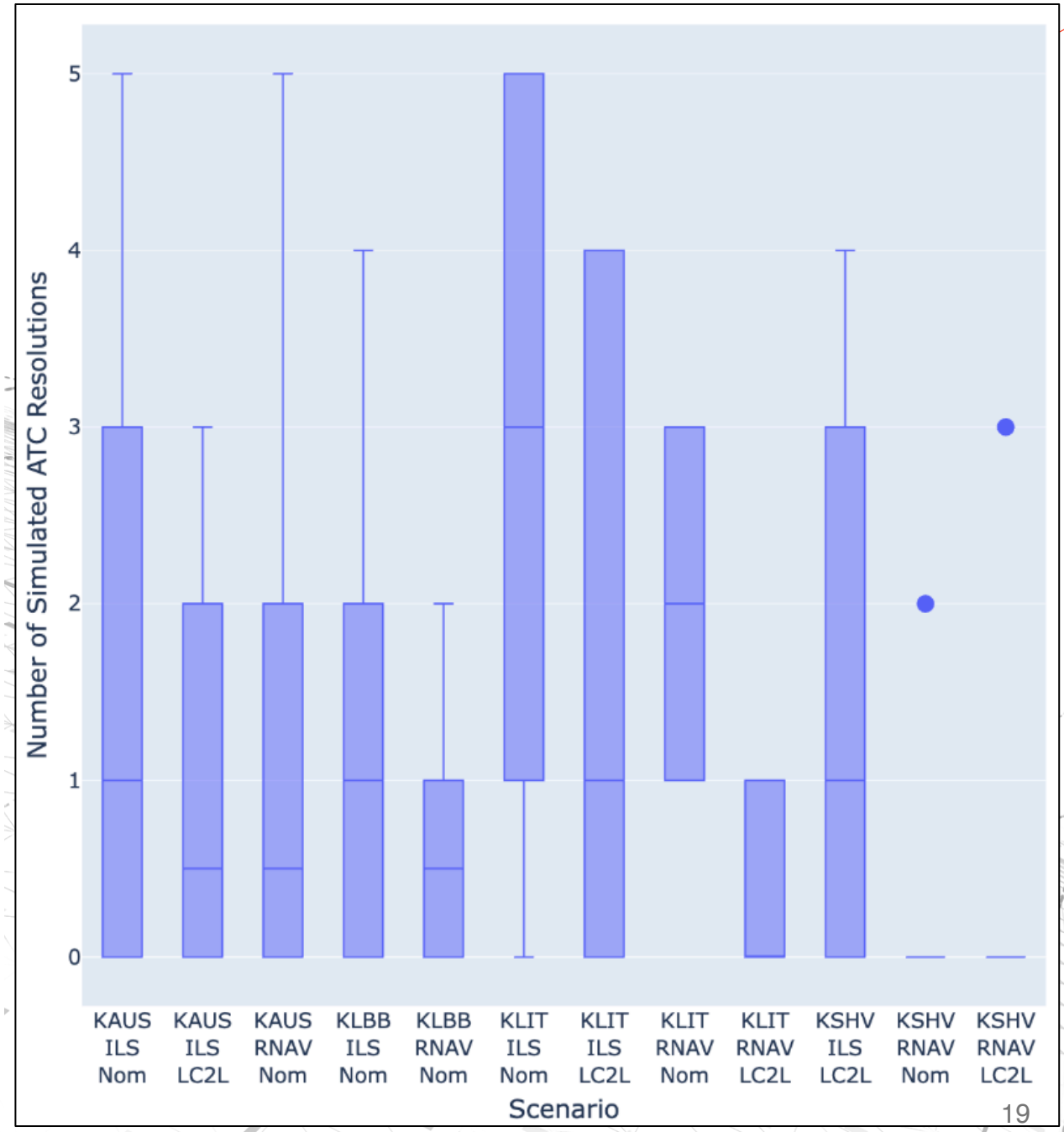
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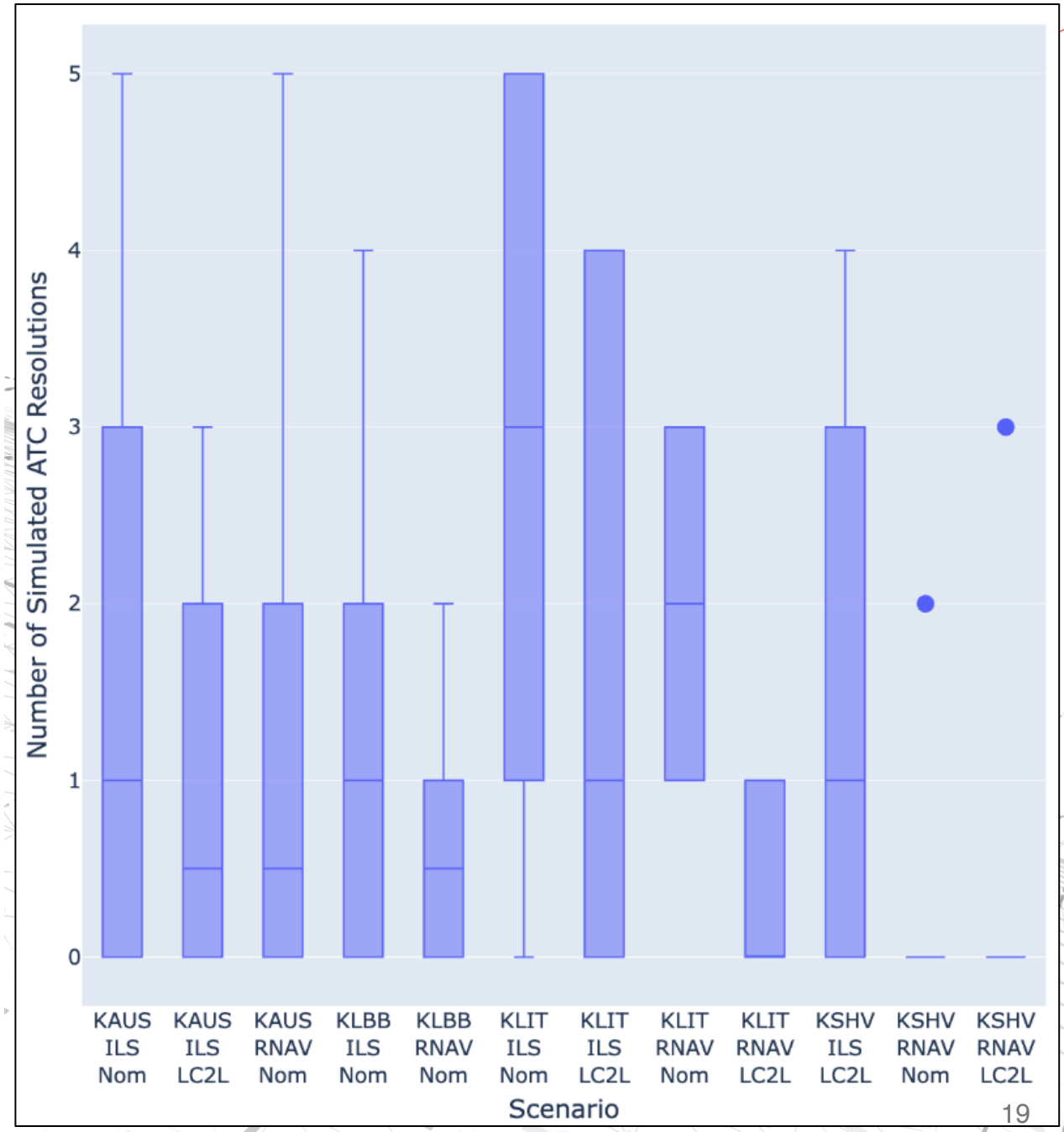
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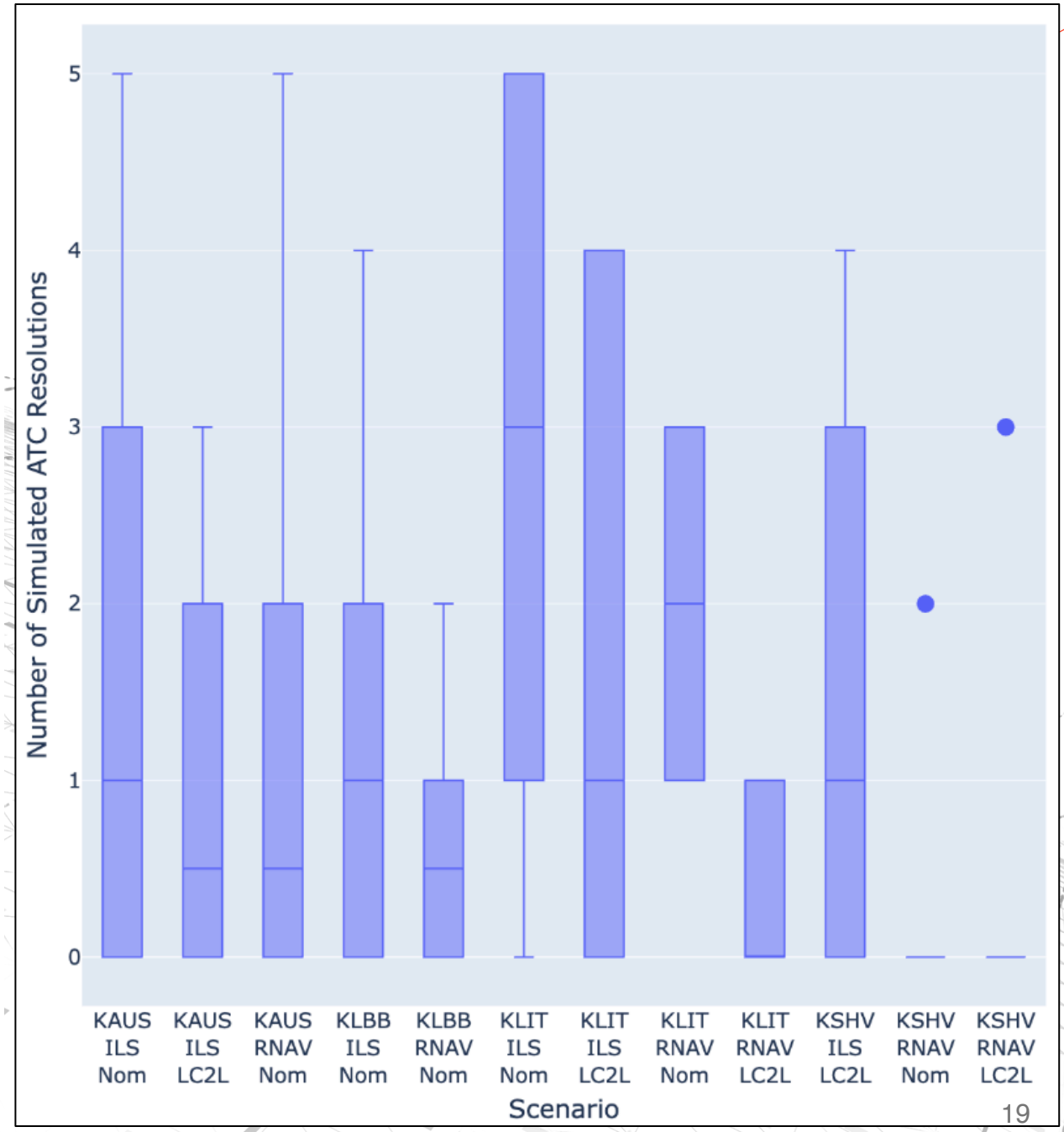
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- Highlights the need for future human ATC-in-the-loop testing



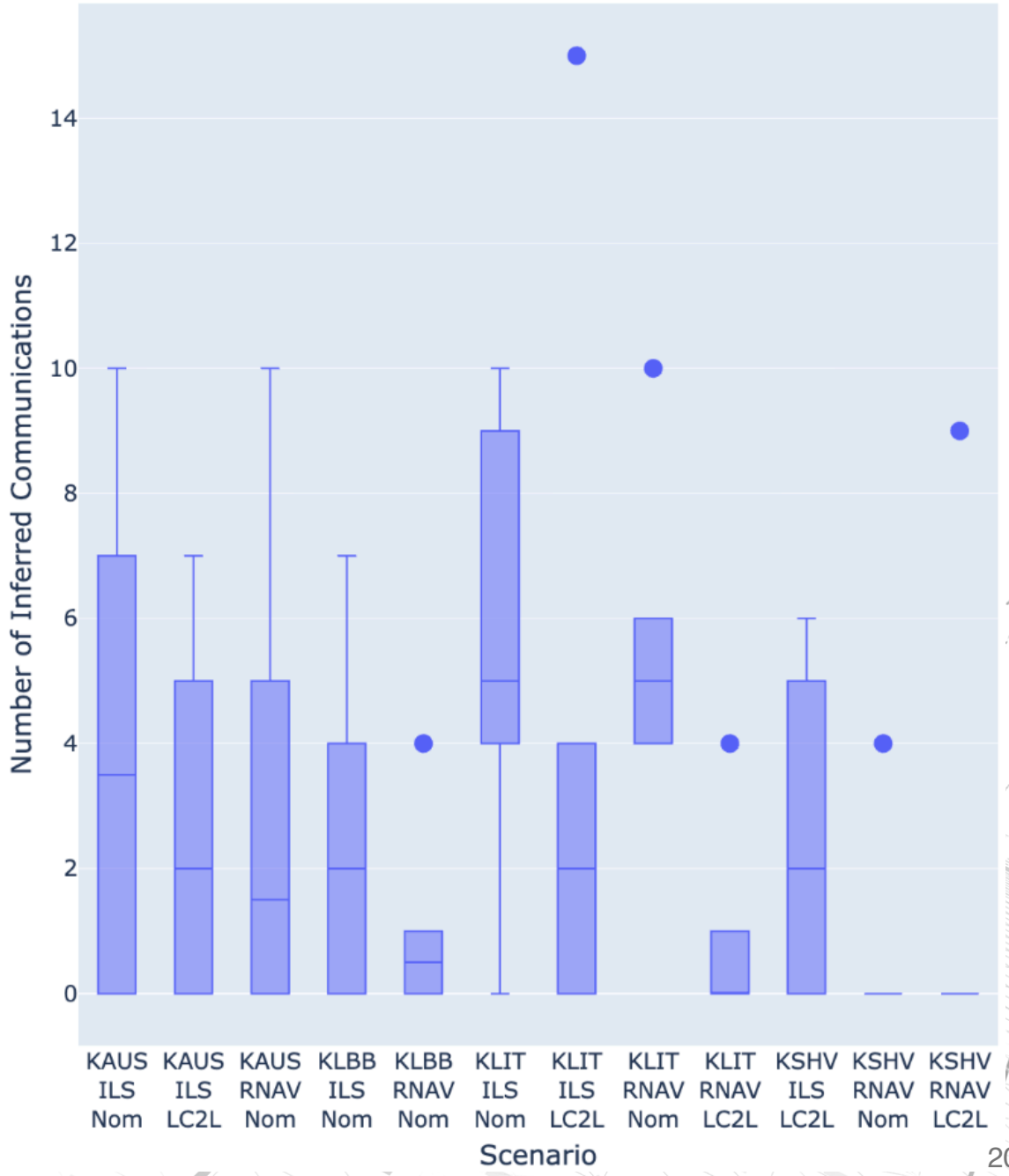
Resolution Maneuvers

- Number of simulated ATC resolutions enacted by air traffic control surrogate
- Conversion of a historical aircraft and additional control resolution maneuvers (e.g., path stretch)
- Minimum number of communications the simulated ATCO would have to convey due to Lost Link UAS
- Likely an underestimate of the real number of communications
- Highlights the need for future human ATC-in-the-loop testing
- Same trend as Conversions metric



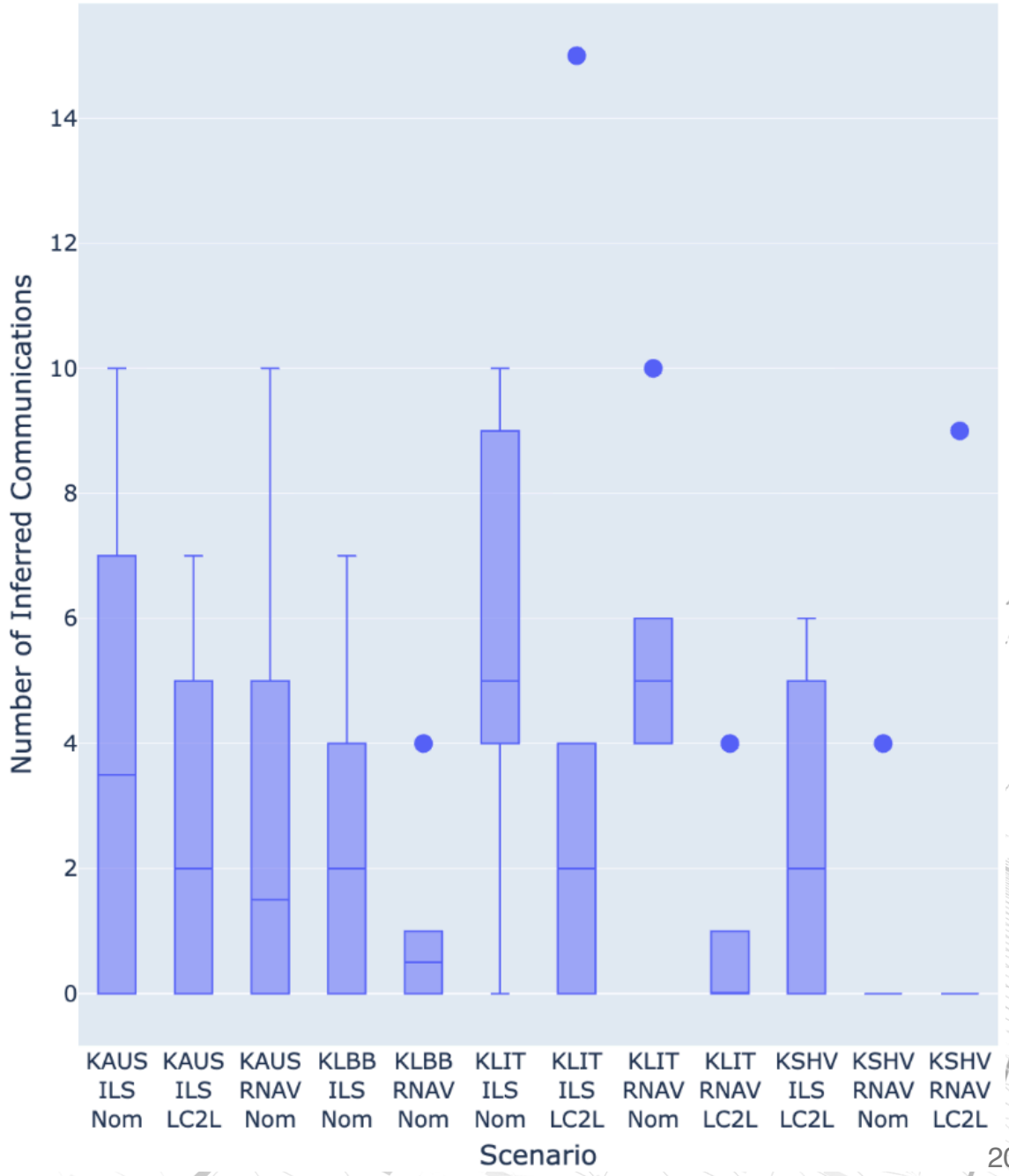
Inferred Communications

- Number of inferred communications



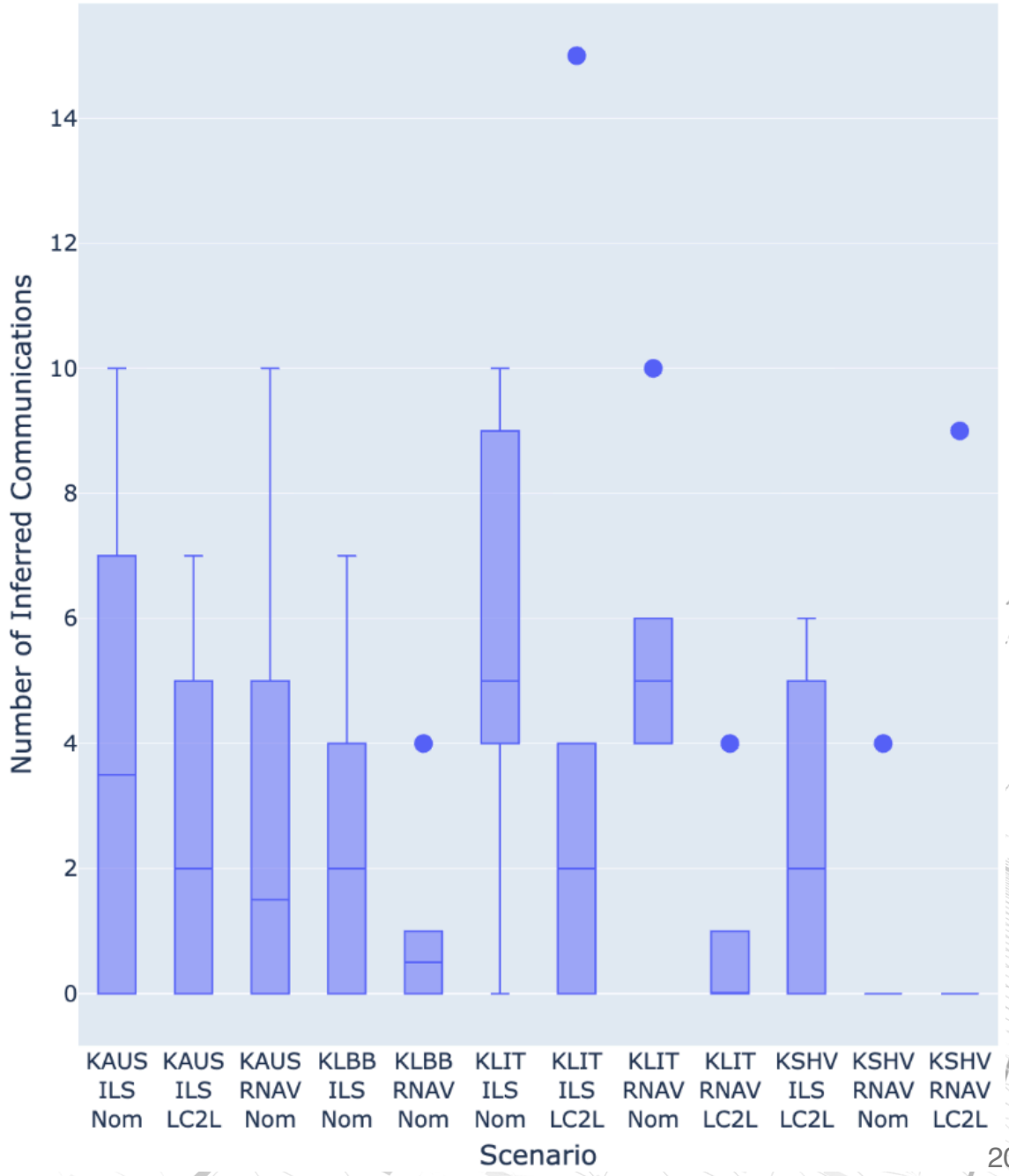
Inferred Communications

- Number of inferred communications
- Δ between the historical aircraft and the converted aircraft trajectories



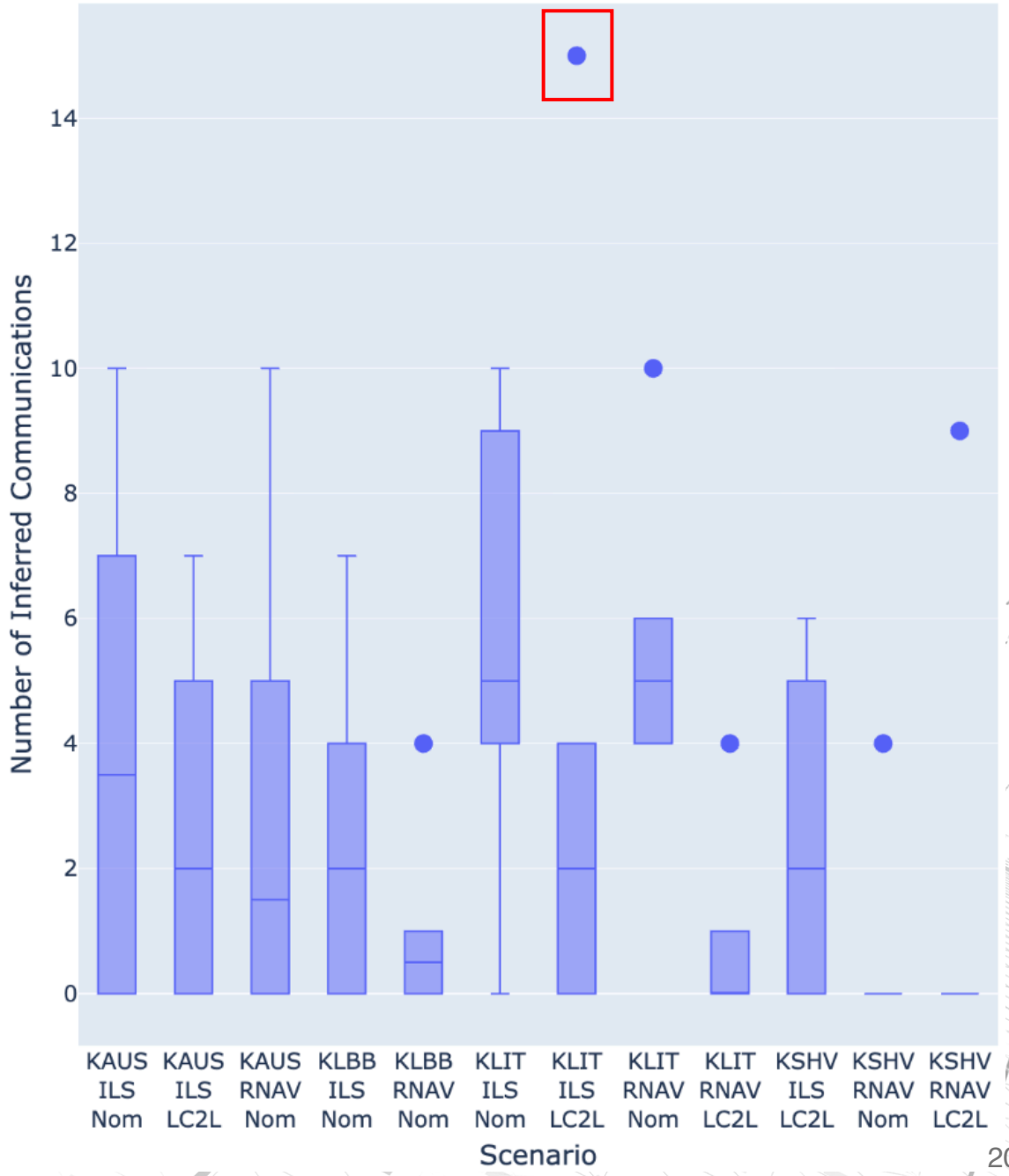
Inferred Communications

- Number of inferred communications
- Δ between the historical aircraft and the converted aircraft trajectories
- Inferred from trajectory data
  - >3.3 ft/sec (1 m/s) altitude
  - >2 deg/sec heading

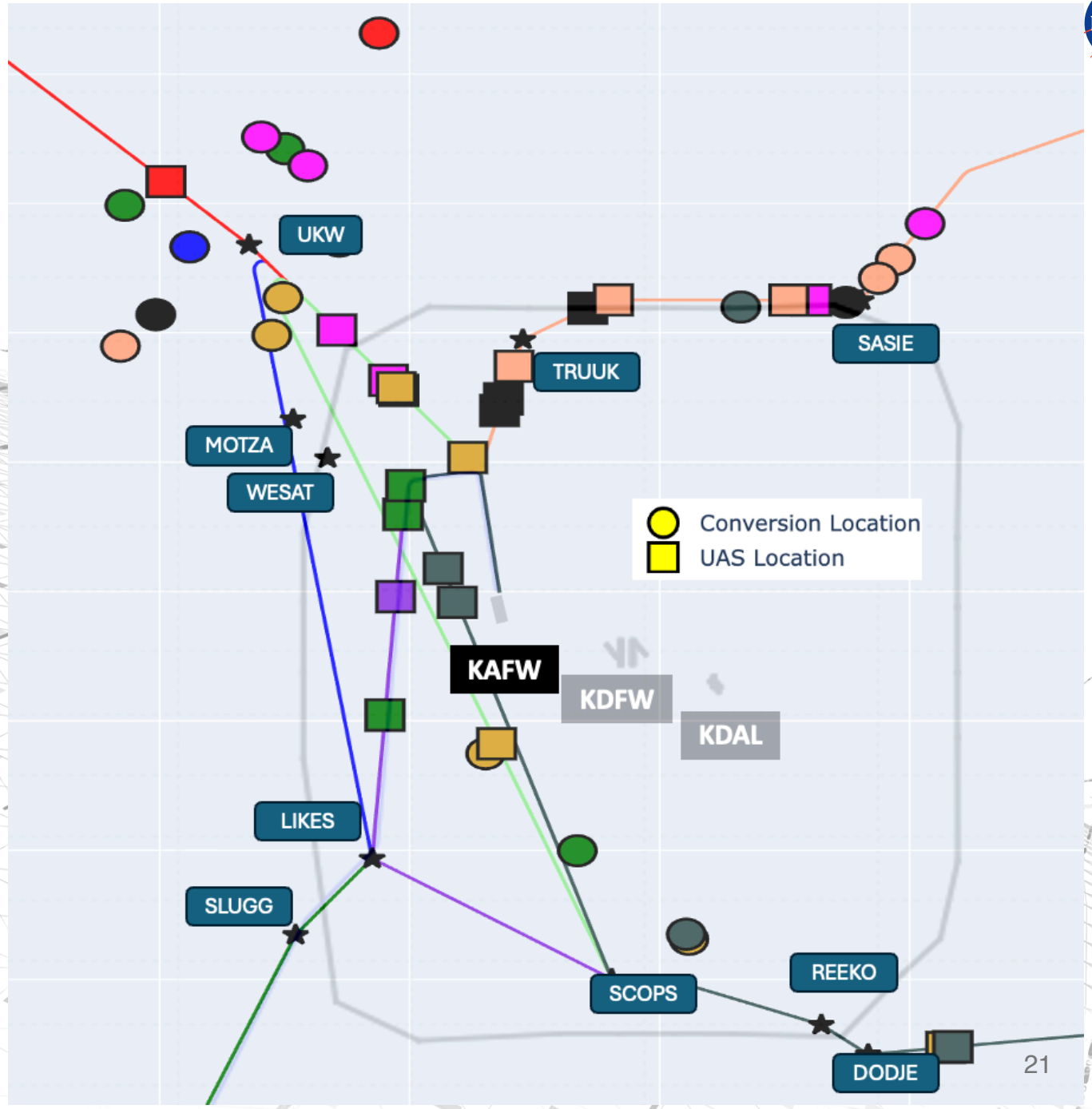


Inferred Communications

- Number of inferred communications
- Δ between the historical aircraft and the converted aircraft trajectories
- Inferred from trajectory data
  - >3.3 ft/sec (1 m/s) altitude
  - >2 deg/sec heading
- 9am KLIT RNAV LC2L had 15 additional inferred communications

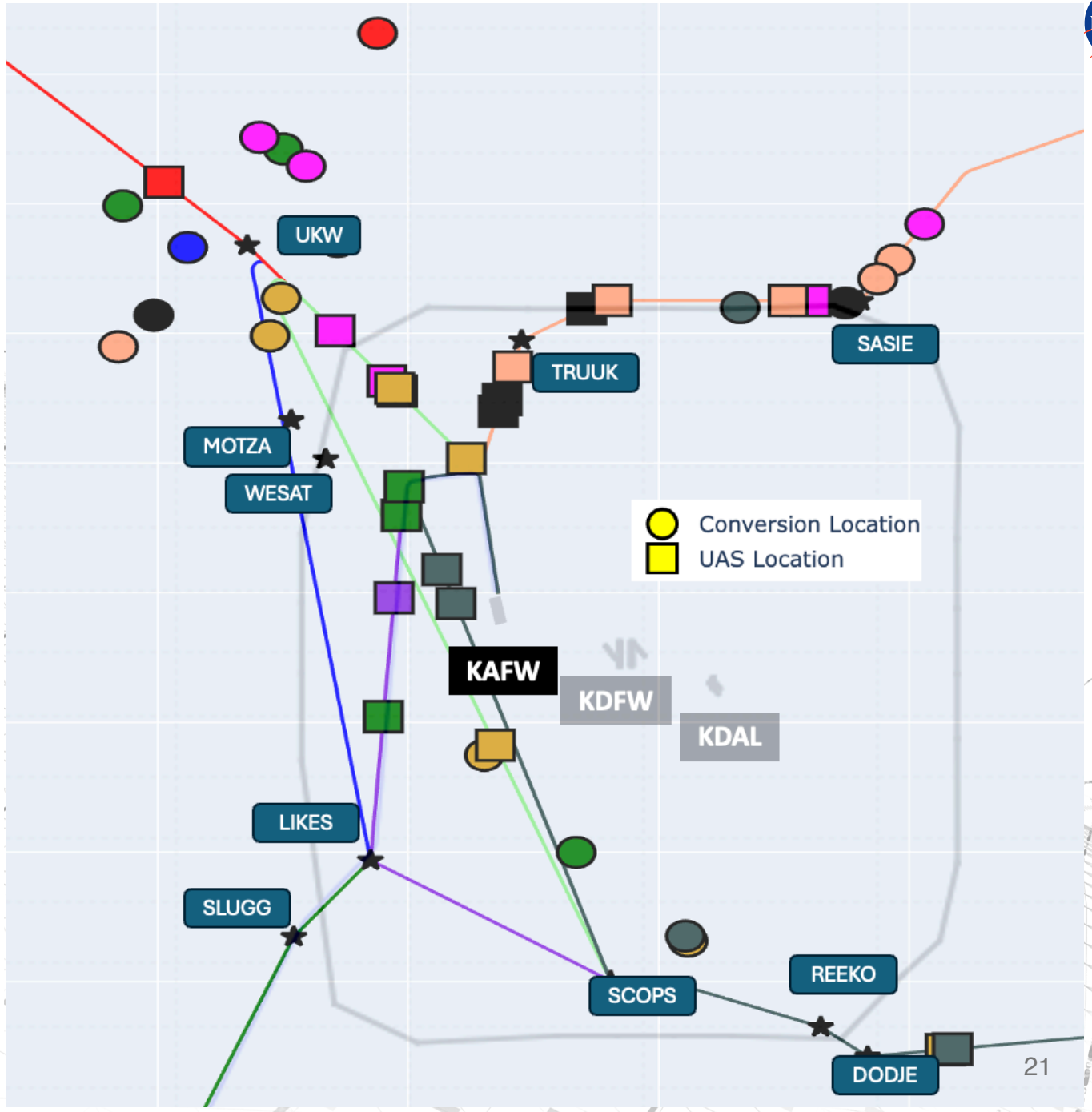


9am Conversion Locations



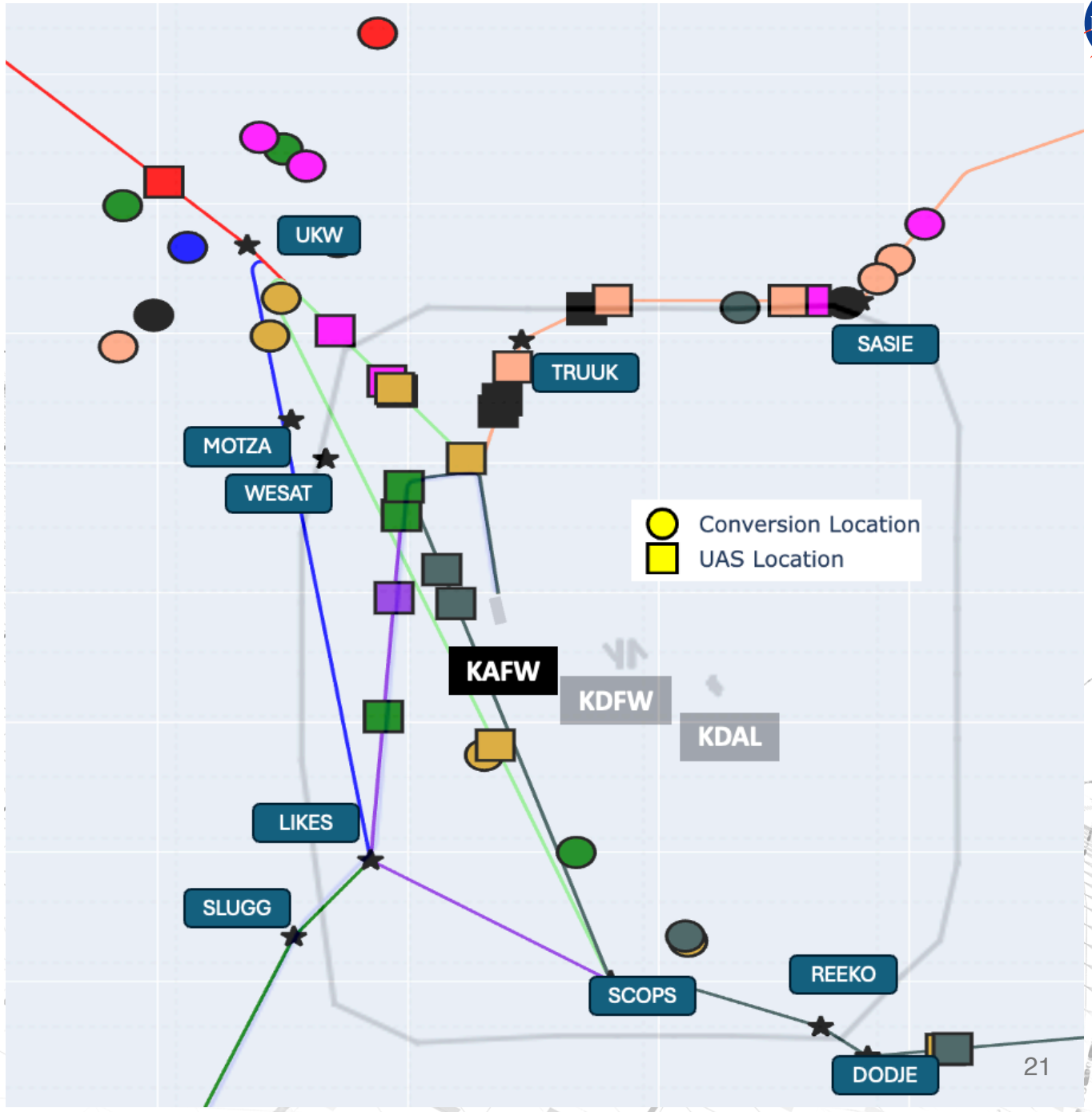
9am Conversion Locations

- Busiest hour: Same trend, locations mapped



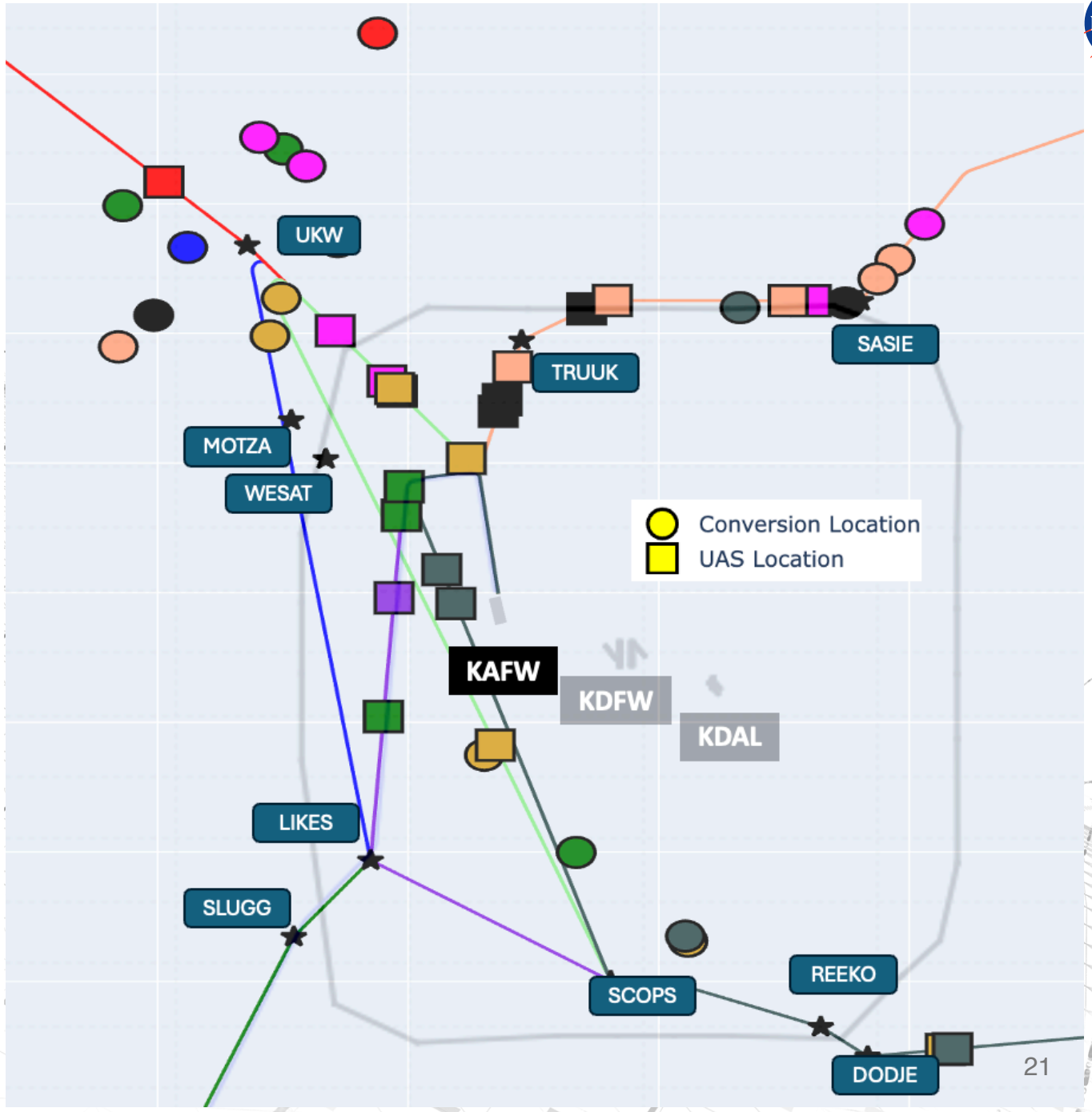
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- Busiest hour: Same trend, locations mapped
- Location of UAS (square) when a conflict was detected with an IFR aircraft (circle)



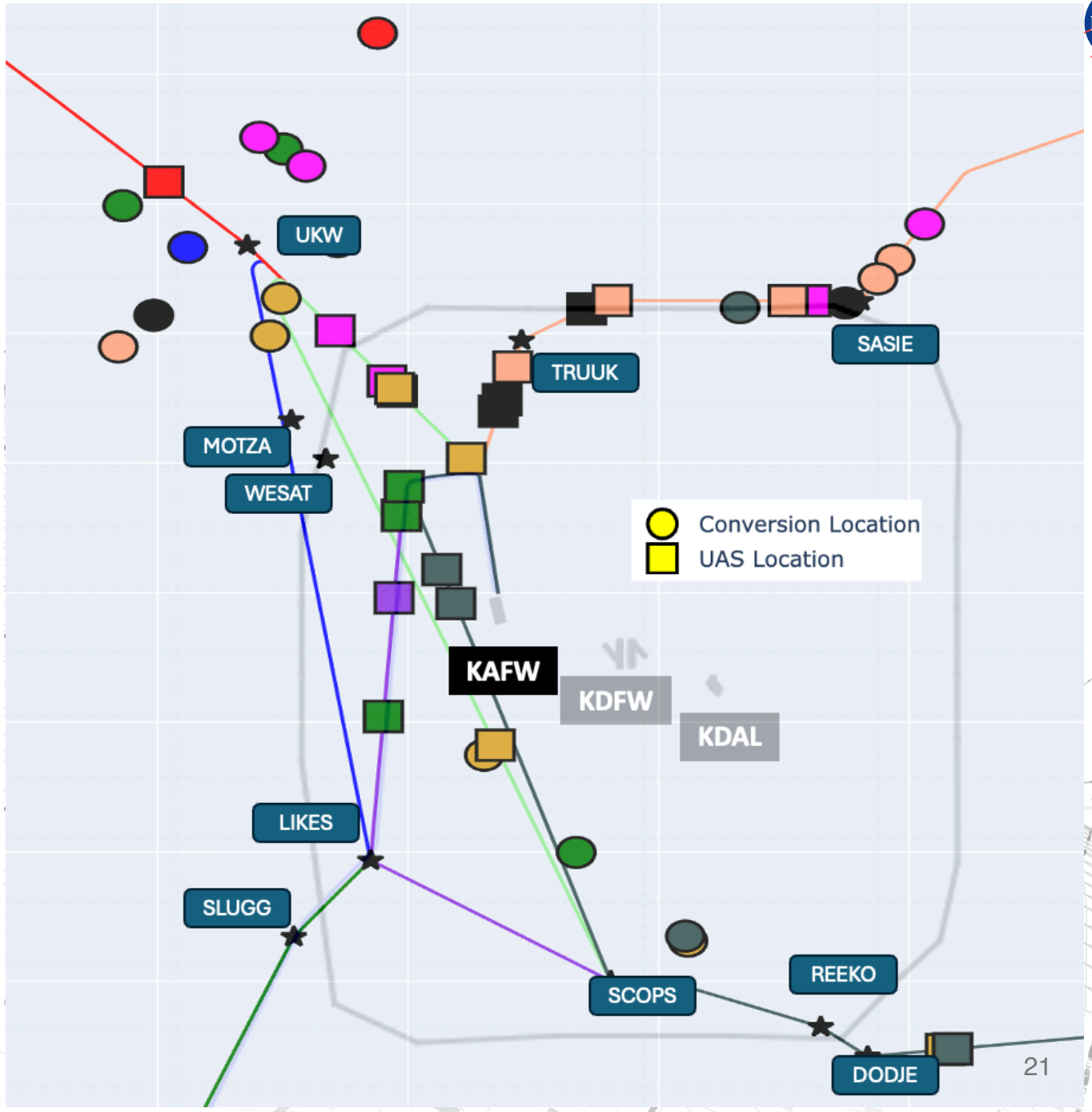
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- Busiest hour: Same trend, locations mapped
- Location of UAS (square) when a conflict was detected with an IFR aircraft (circle)
- IFR aircraft was then converted and issued a simulated resolution maneuver



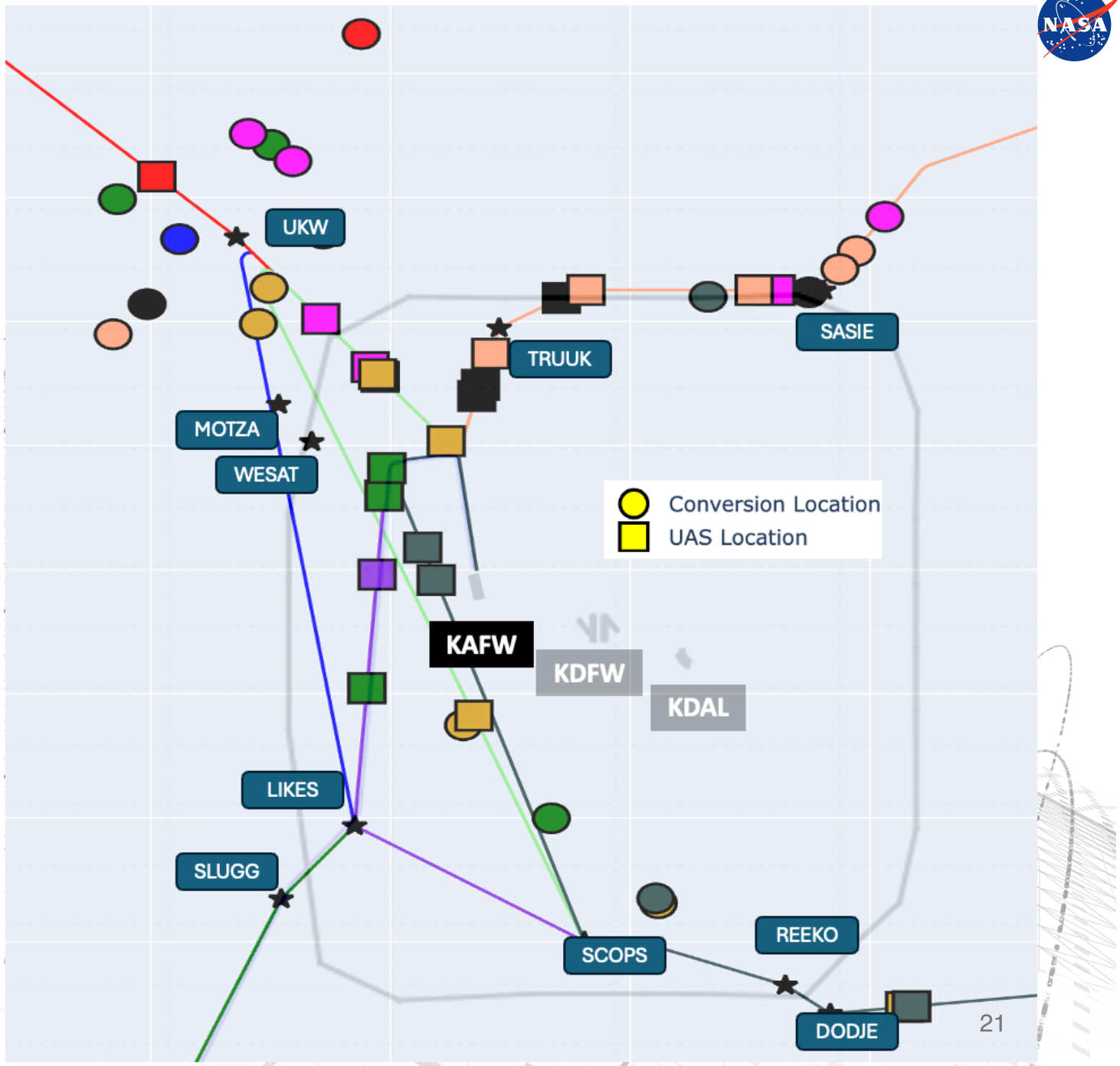
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- Location of UAS (square) when a conflict was detected with an IFR aircraft (circle)
- IFR aircraft was then converted and issued a simulated resolution maneuver
- 27 conversions across 10 simulations

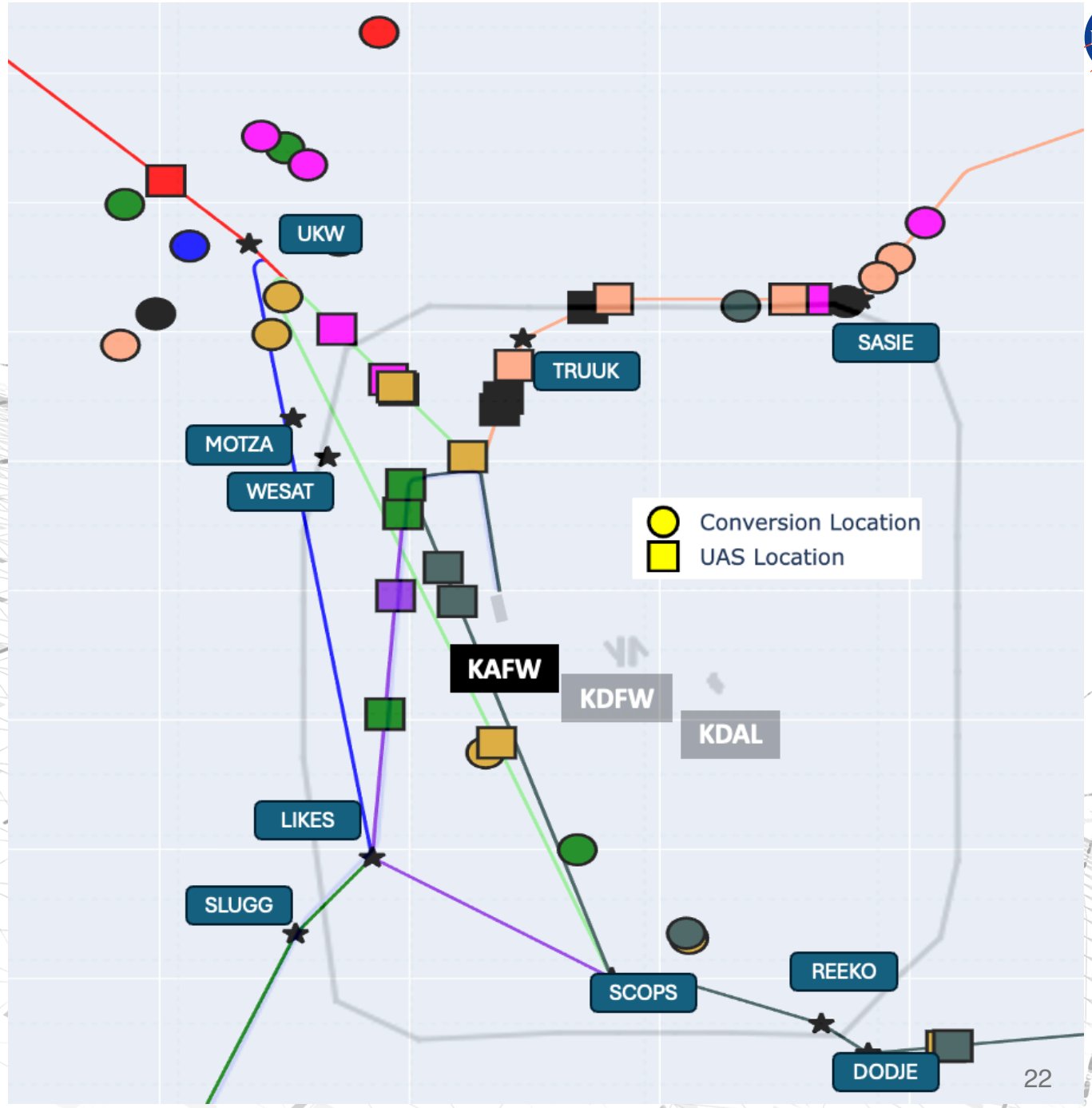


9am Conversion Locations

- Busiest hour: Same trend, locations mapped
- Location of UAS (square) when a conflict was detected with an IFR aircraft (circle)
- IFR aircraft was then converted and issued a simulated resolution maneuver
- 27 conversions across 10 simulations
- RTCA DO-400
  - Complete STAR
  - Go direct to Initial Approach Fix
  - Execute Instrument Approach Procedure

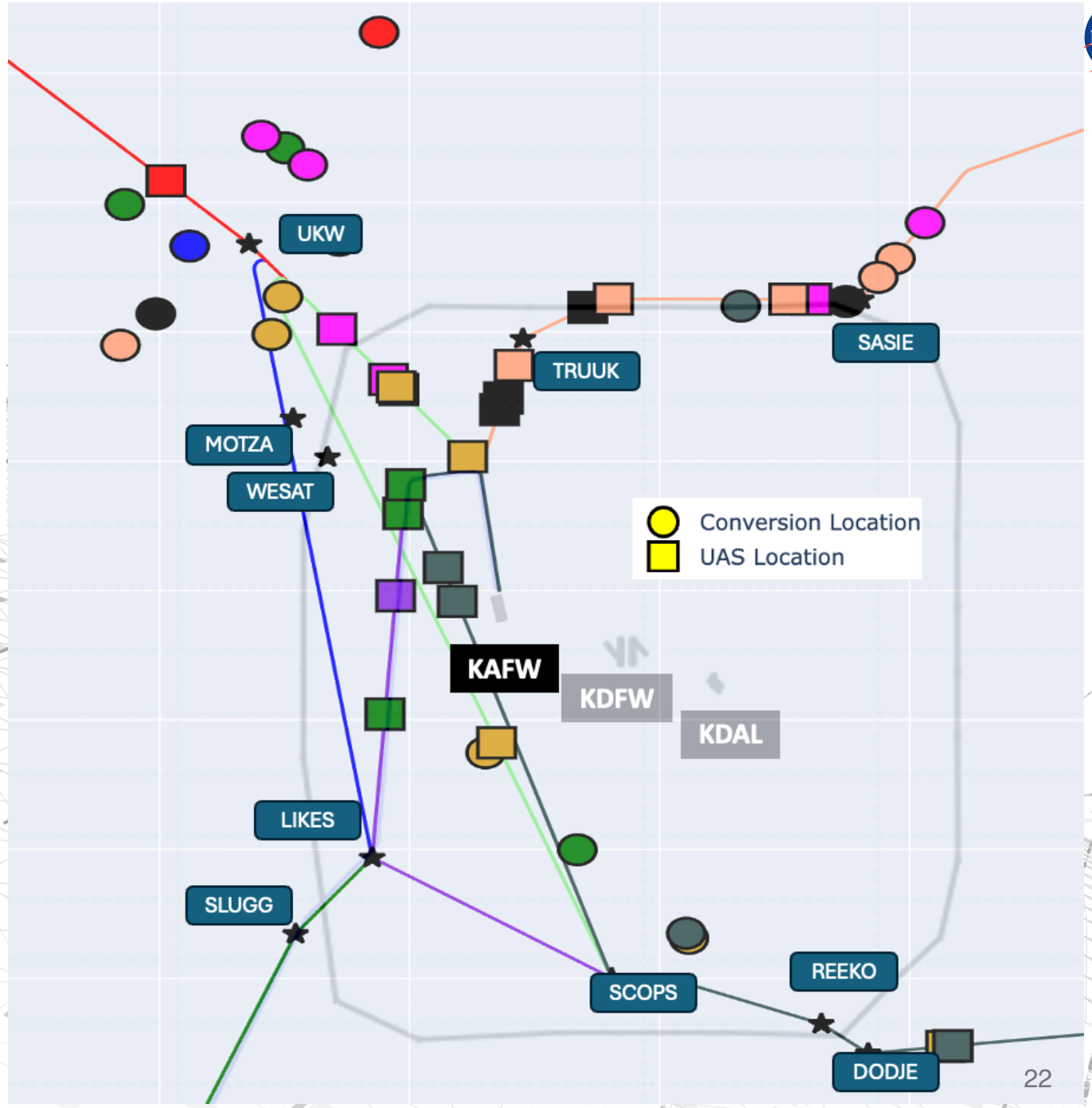


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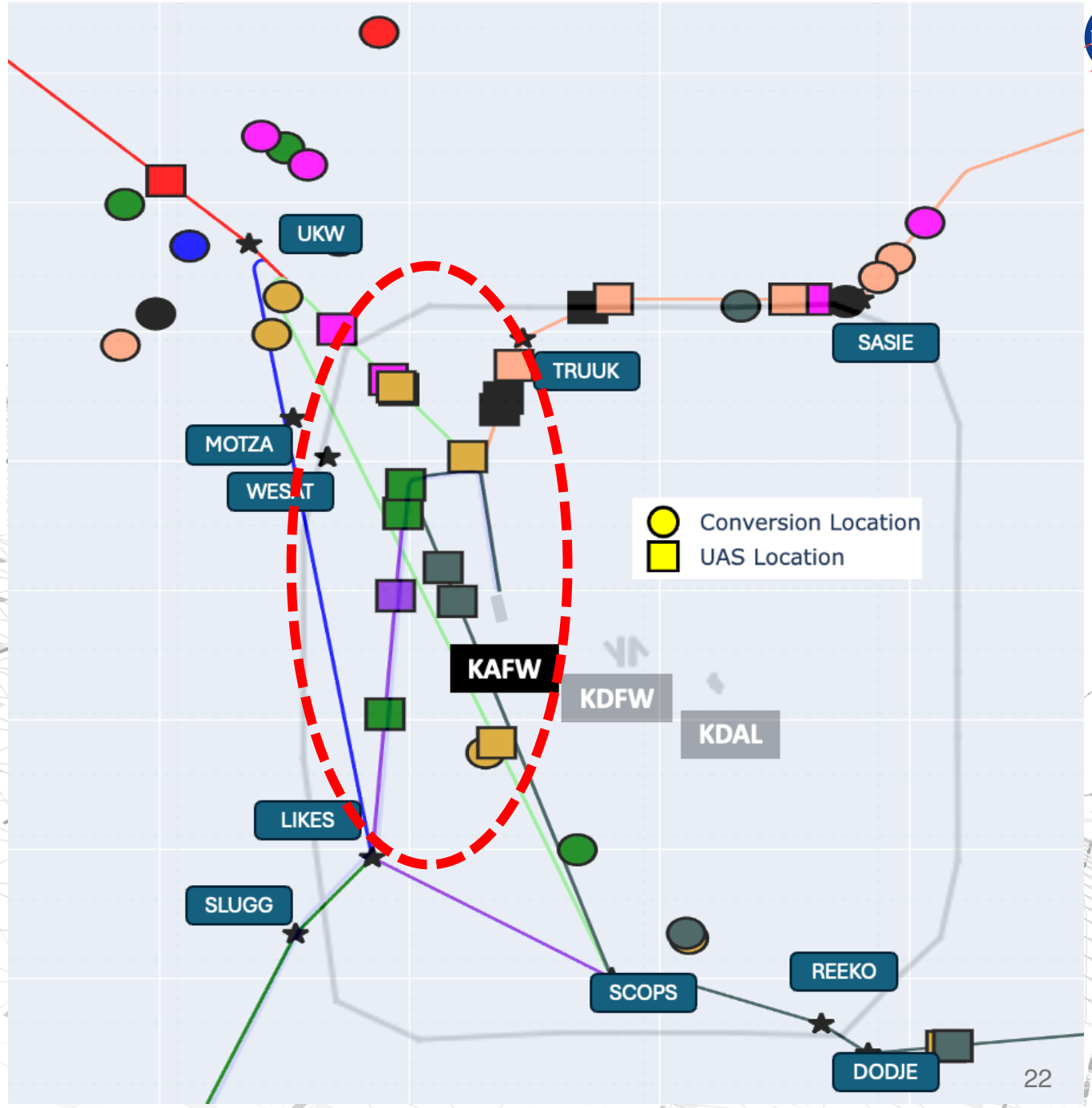
9am Conversion Locations

- 9/27 conversions occur while the UAS is on a STAR



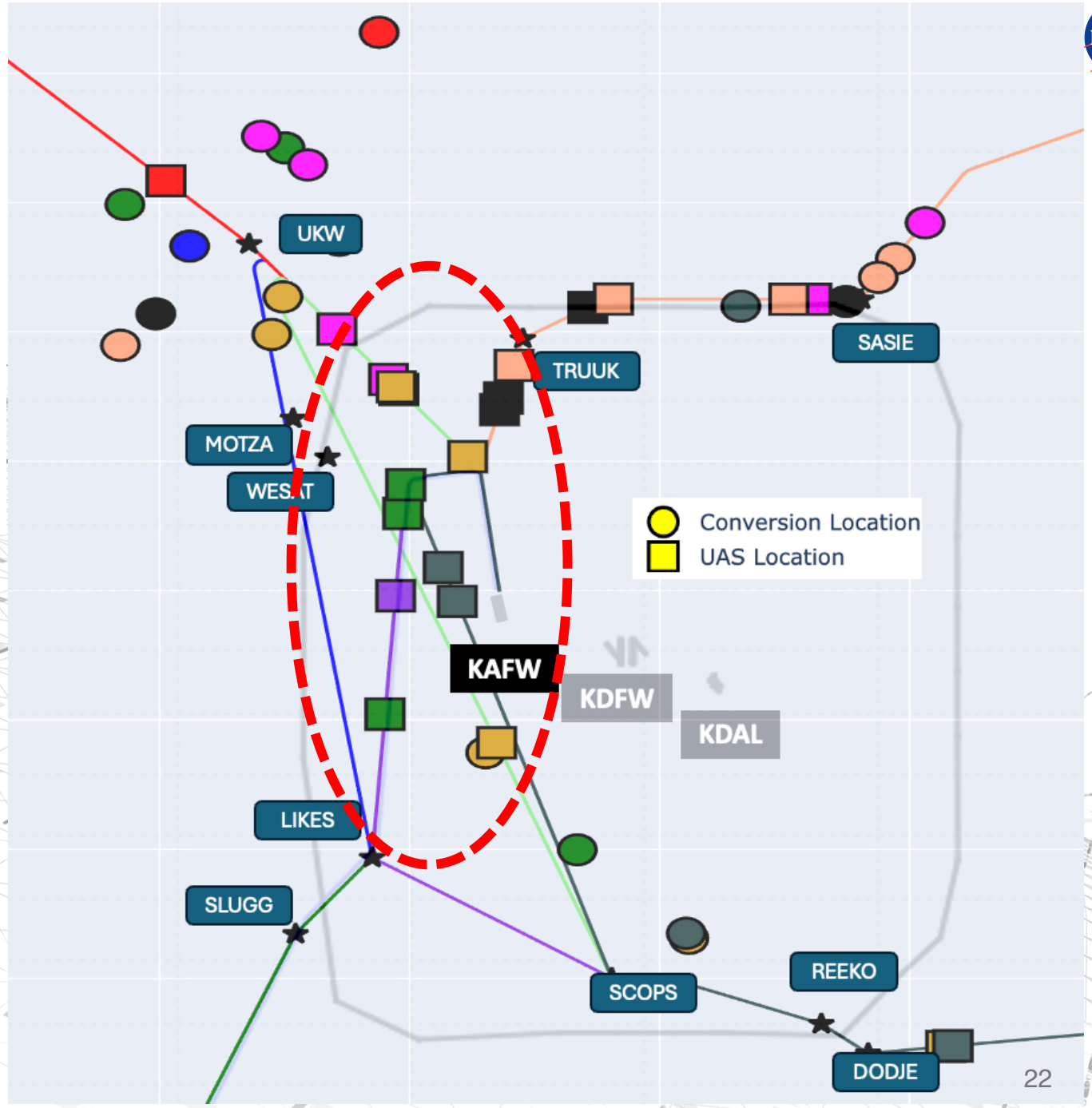
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- 9/27 conversions occur while the UAS is on a STAR
- 18/27 conversions occur after the UAS has completed the STAR

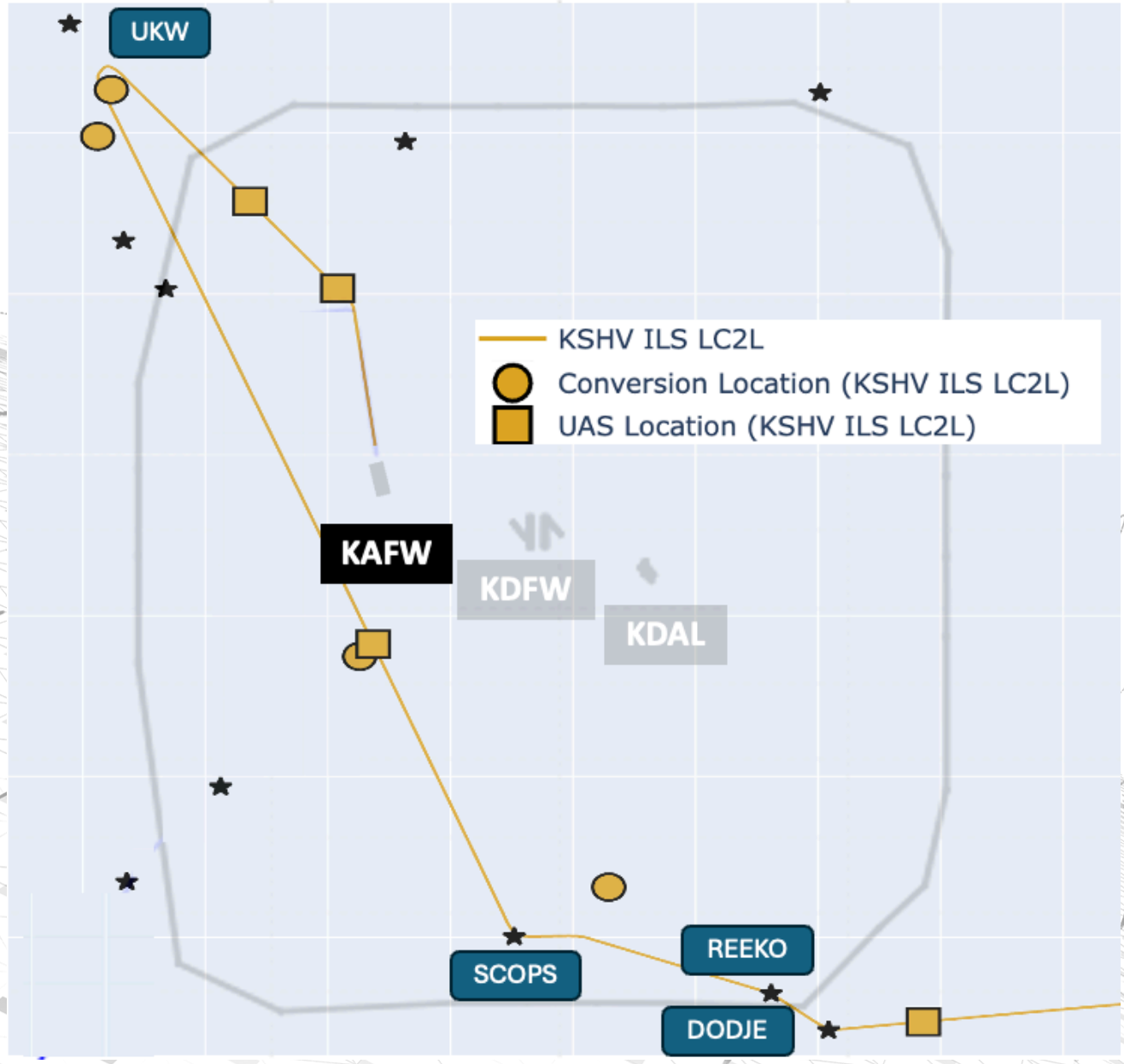


9am Conversion Locations

- 9/27 conversions occur while the UAS is on a STAR
- 18/27 conversions occur after the UAS has completed the STAR
- UAS would normally be receiving vectored control instructions

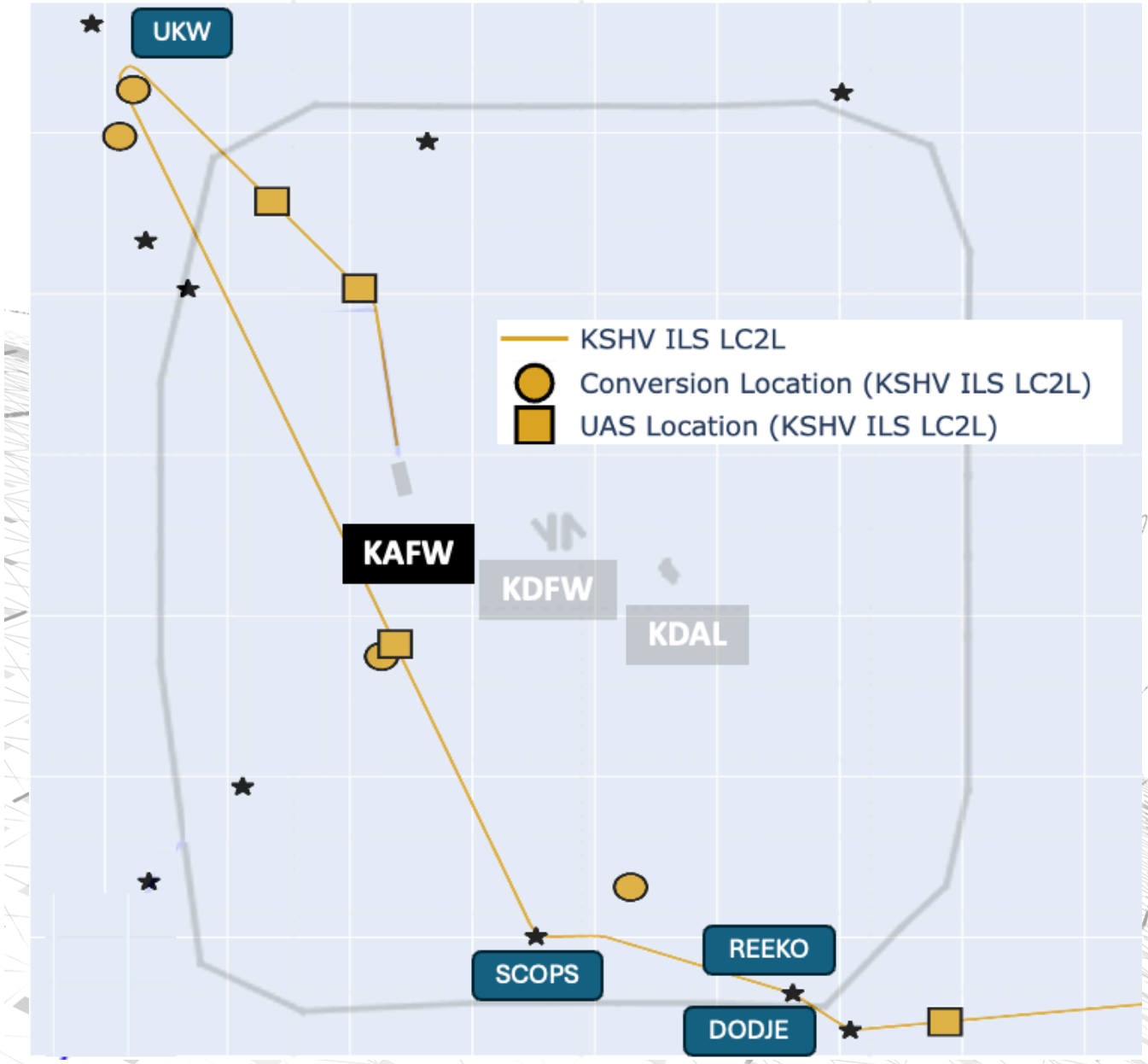


9am KSHV ILS LC2L



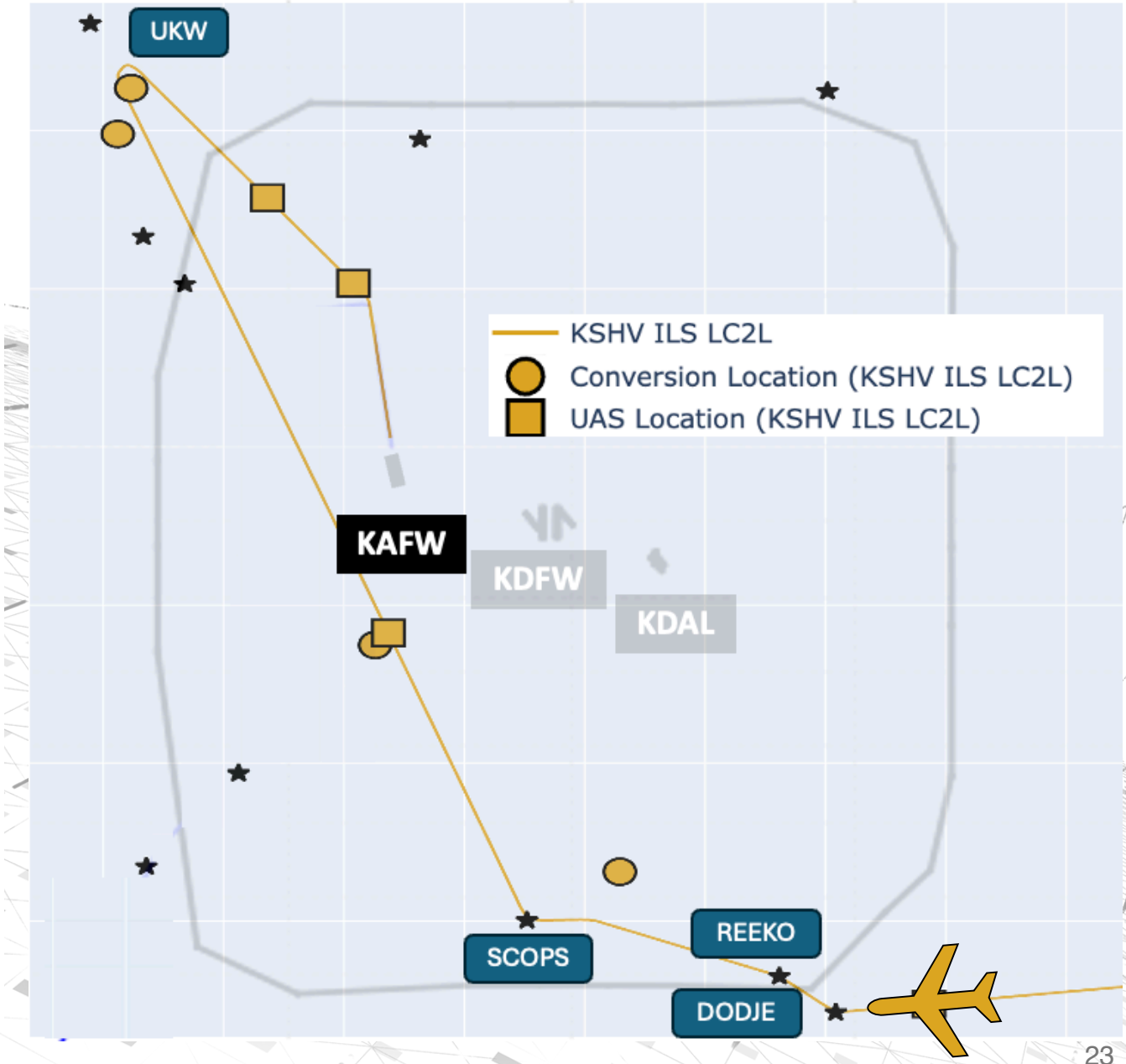
9am KSHV ILS LC2L

- UAS on STAR, IFR departing



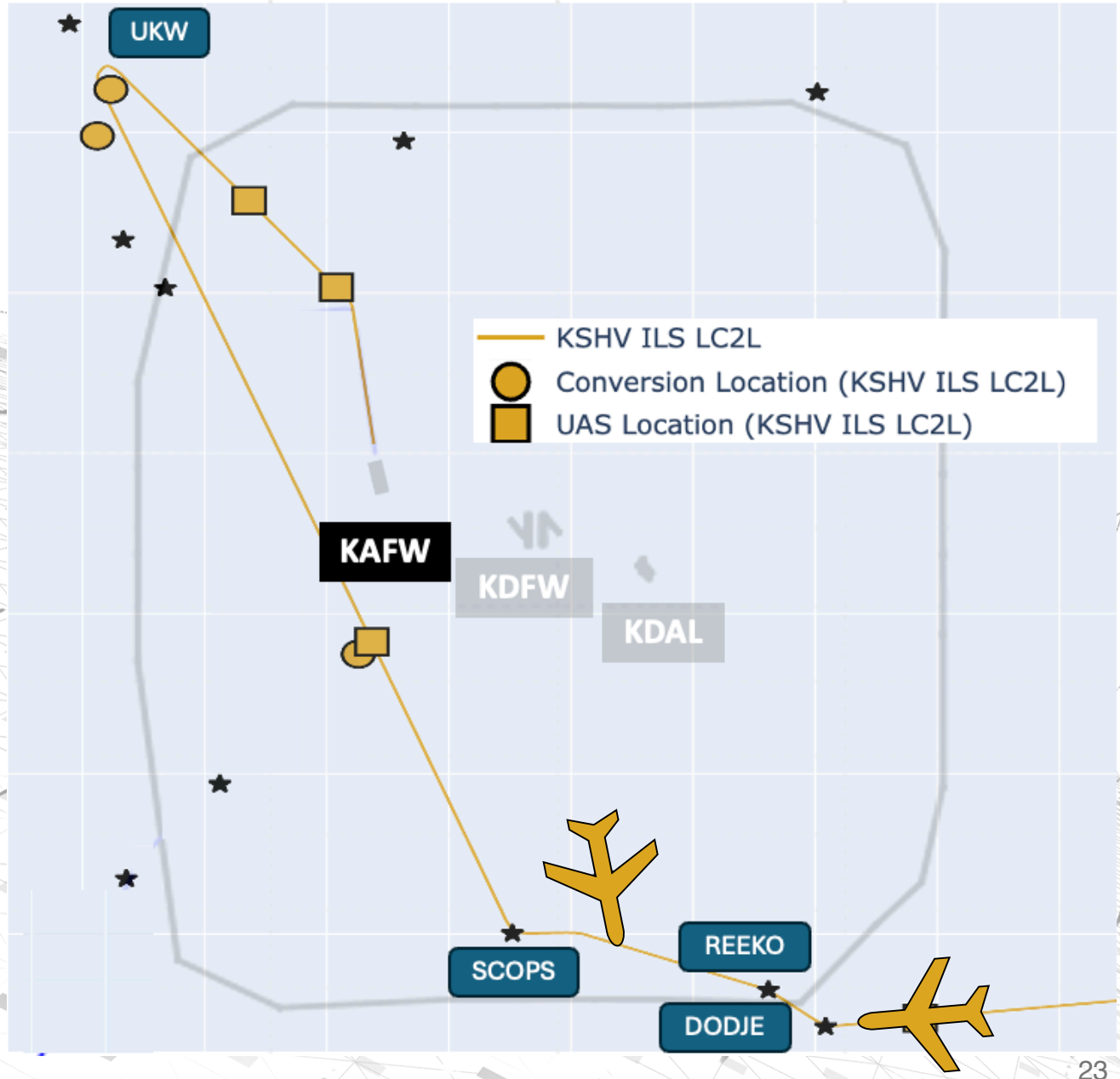
9am KSHV ILS LC2L

- UAS on STAR, IFR departing
  - UAS in Center



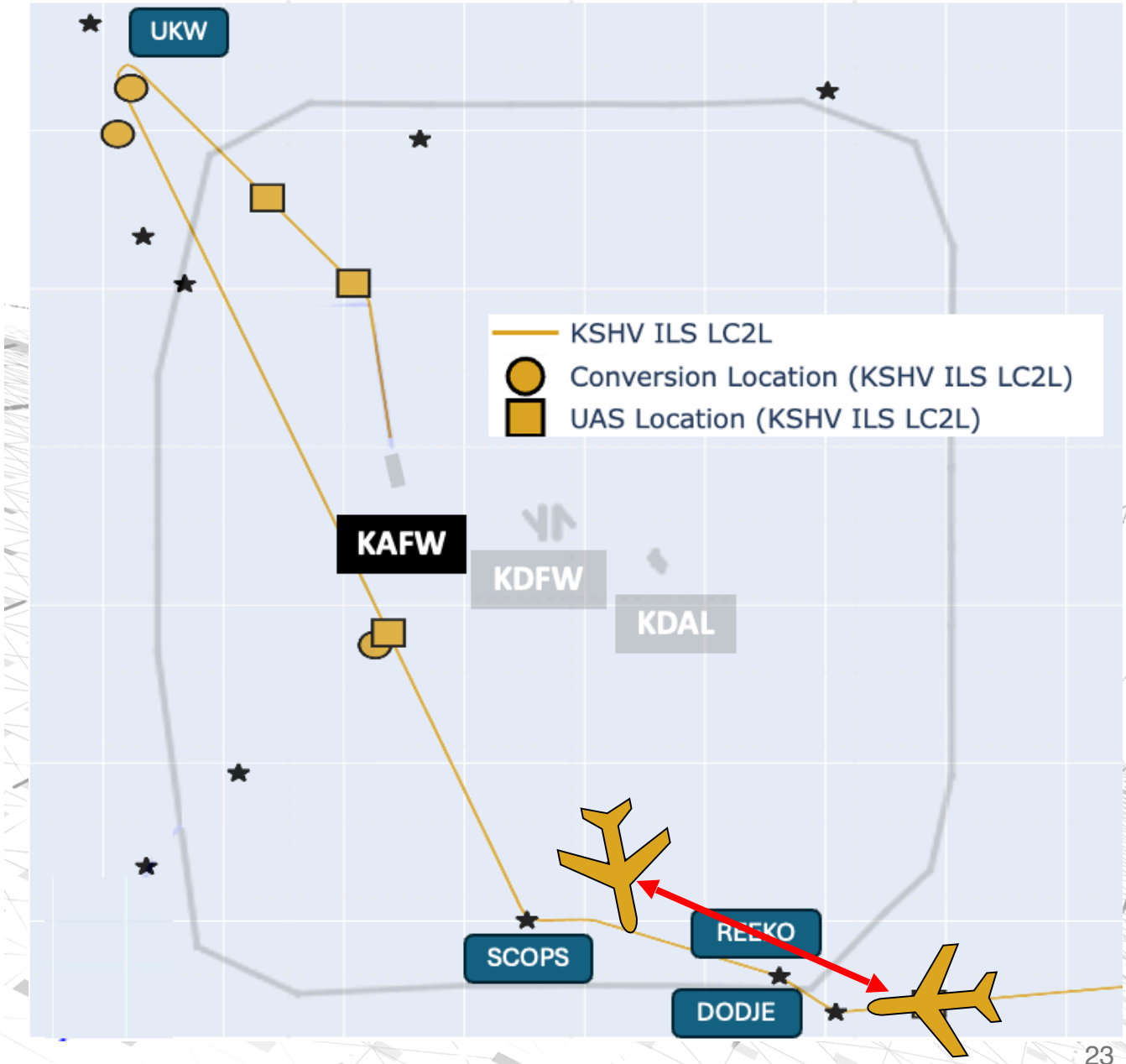
9am KSHV ILS LC2L

- UAS on STAR, IFR departing
  - UAS in Center
  - IFR inside Terminal



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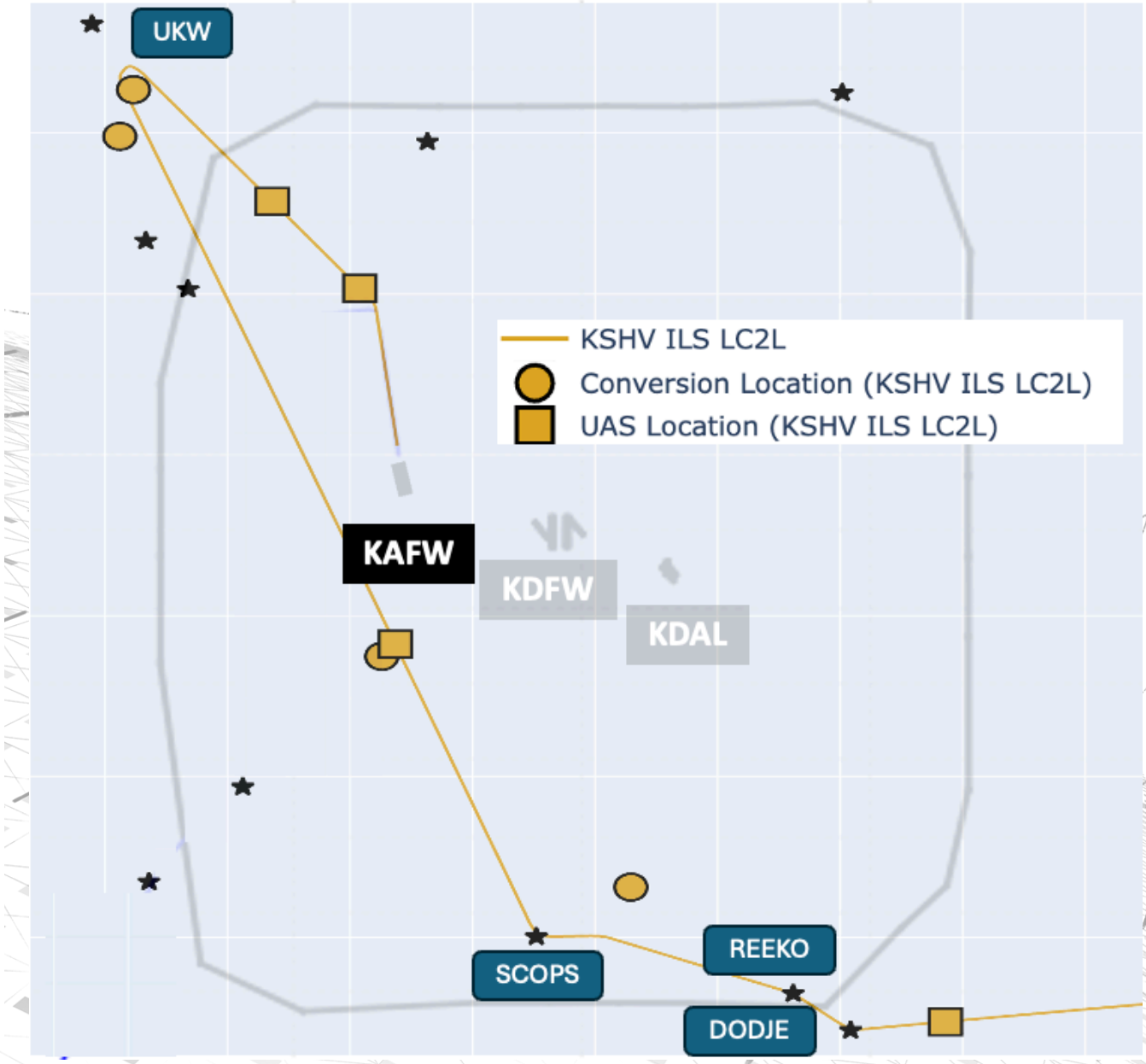
- UAS on STAR, IFR departing
  - UAS in Center
  - IFR inside Terminal
  - Could necessitate communication between Terminal and Center controllers



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  - UAS in Center
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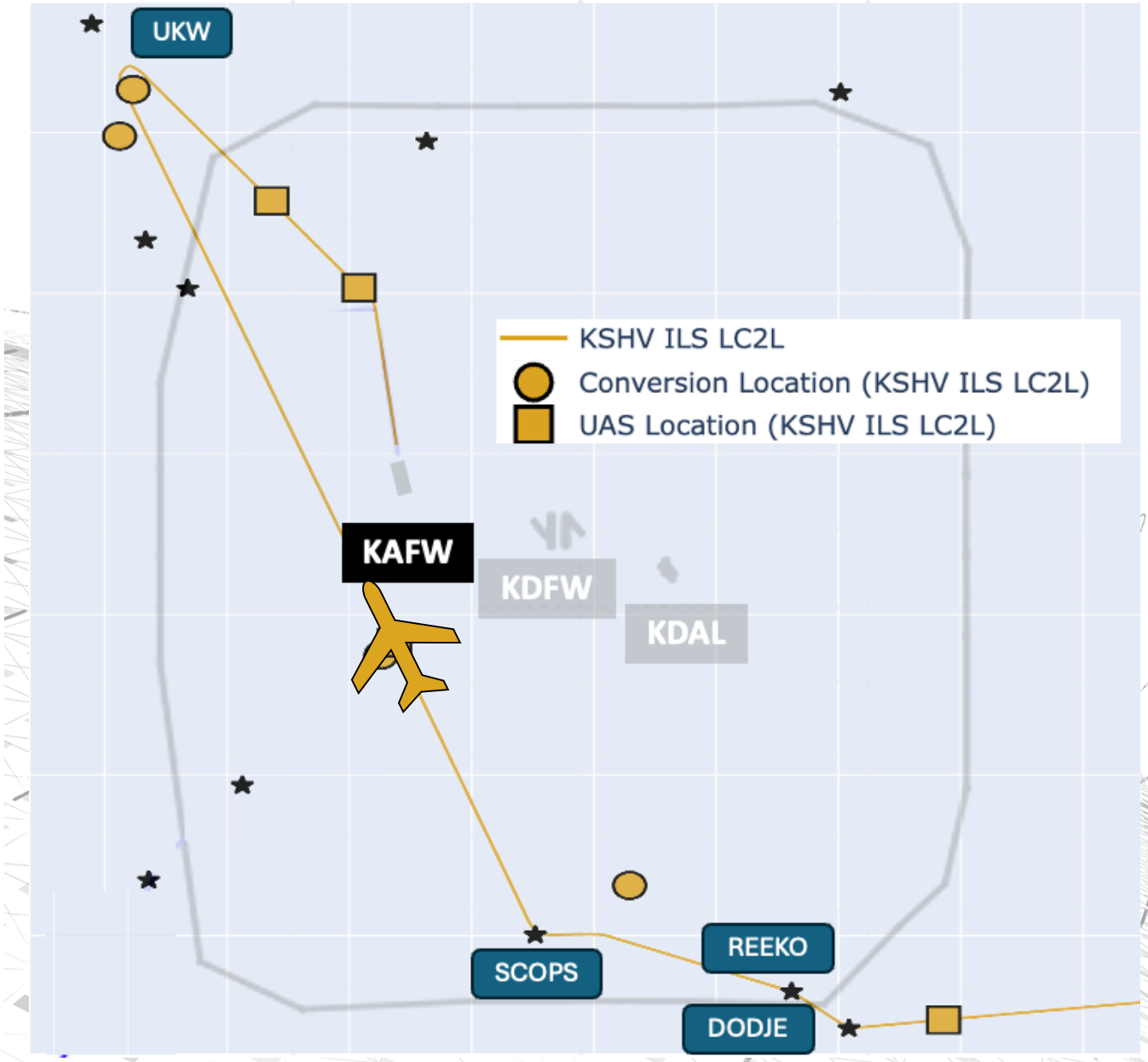
- UAS heading direct to UKW (where UAS would be receiving vectored control instructions)



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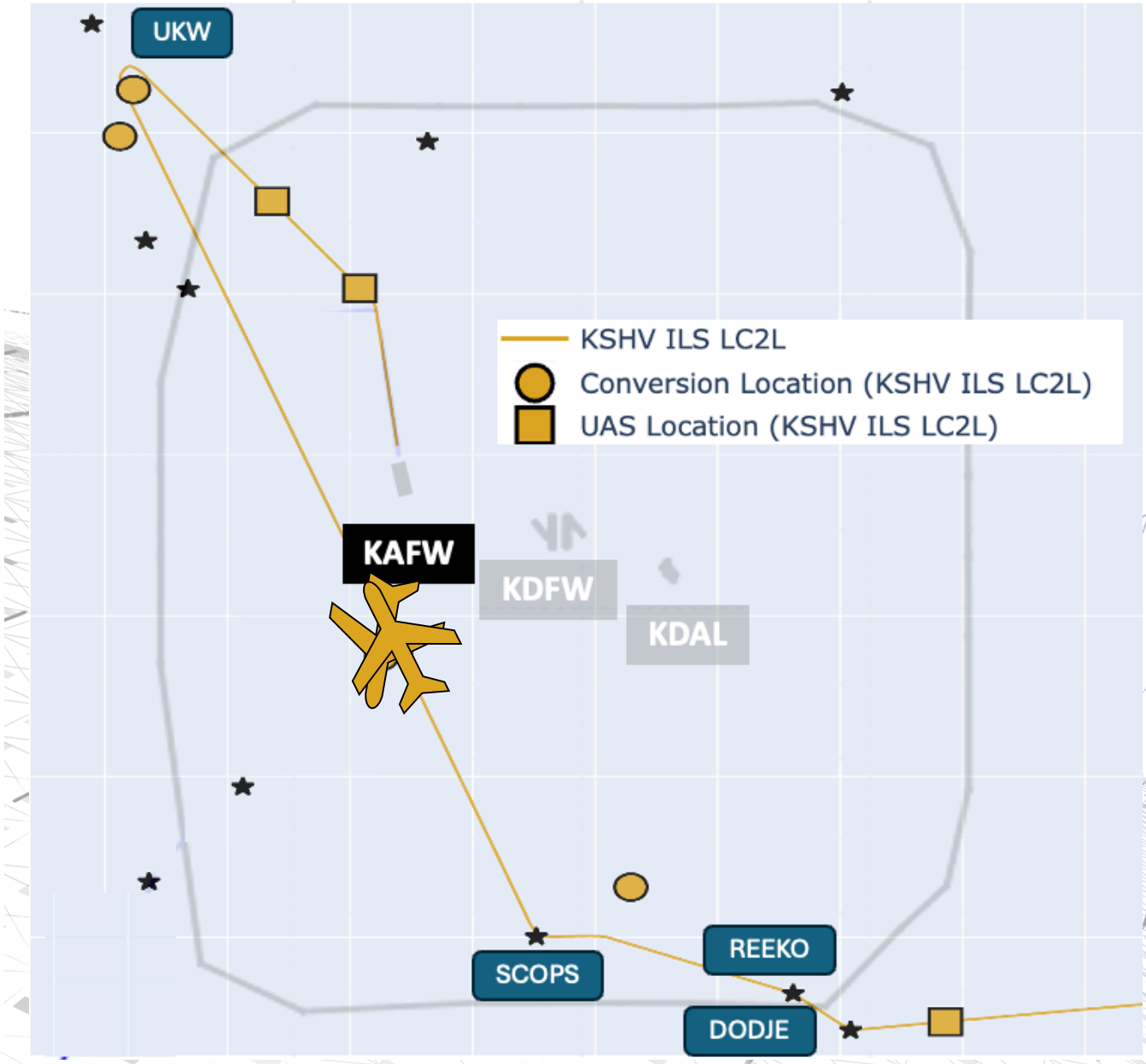
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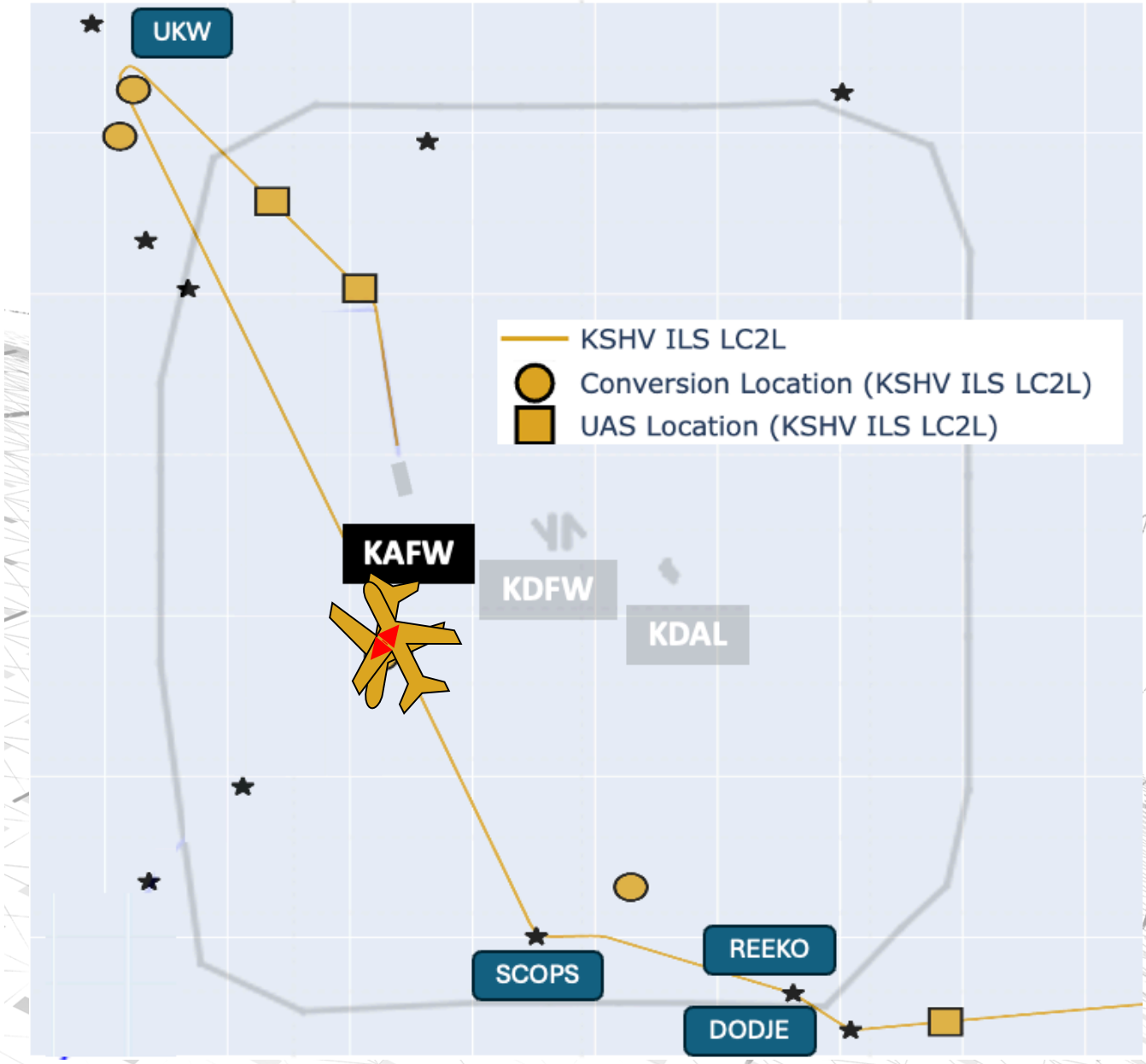
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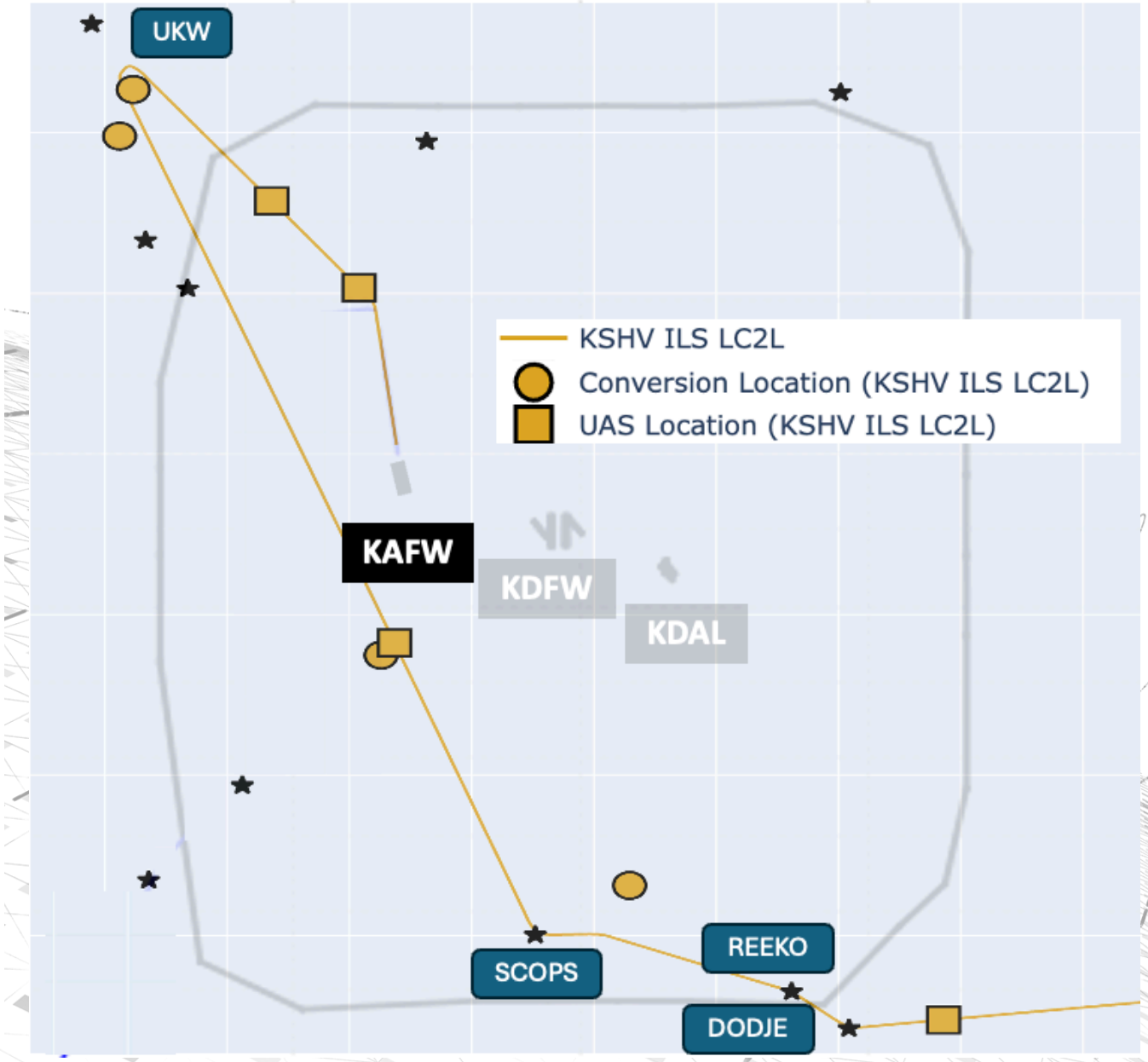


9am KSHV ILS LC2L

- UAS on STAR, IFR departing
  - UAS in Center
  - IFR inside Terminal
  - Could necessitate communication between Terminal and Center controllers

- UAS heading direct to UKW (where UAS would be receiving vectored control instructions)

- UAS being overtaken while on IAP

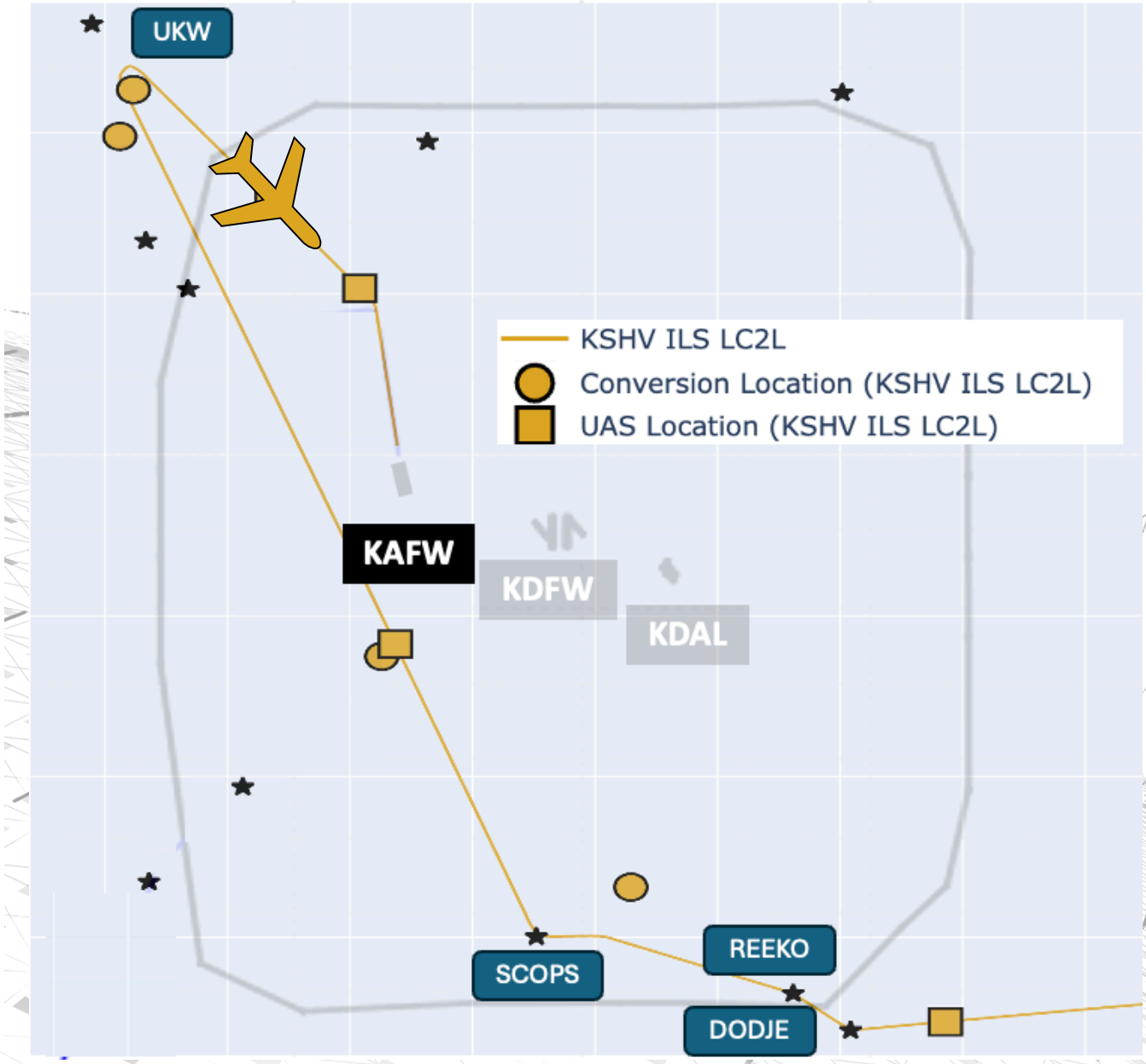


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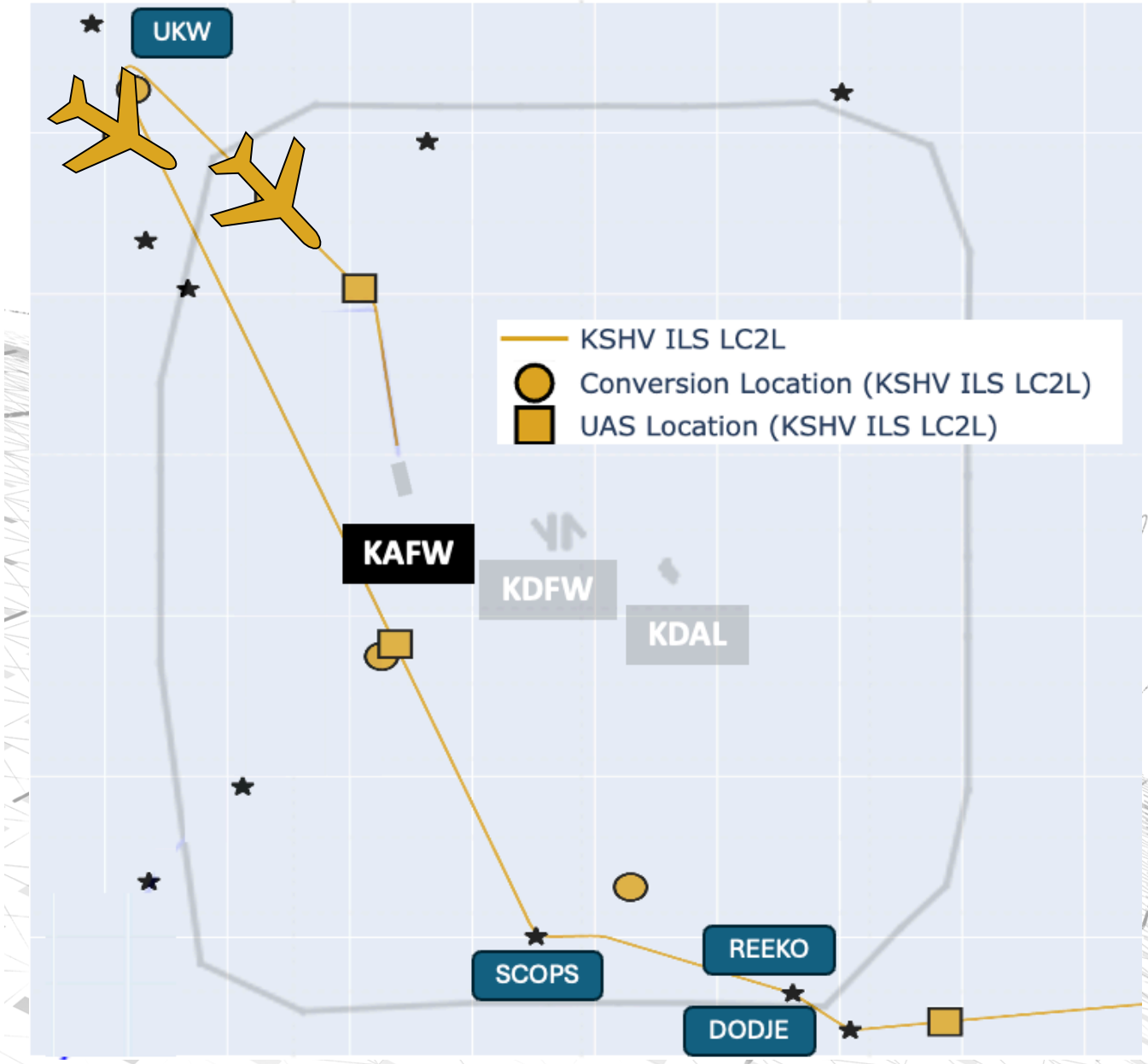


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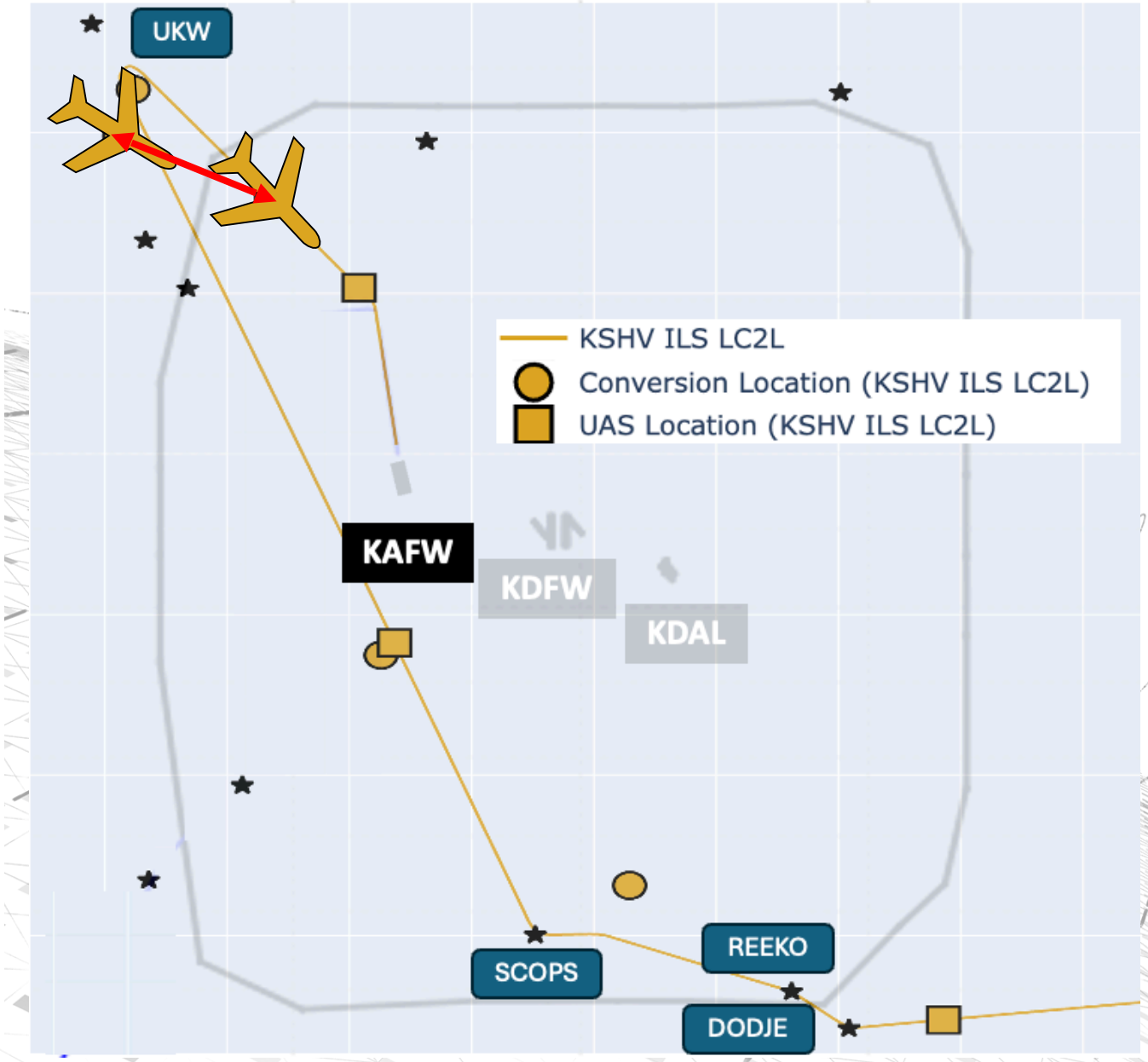


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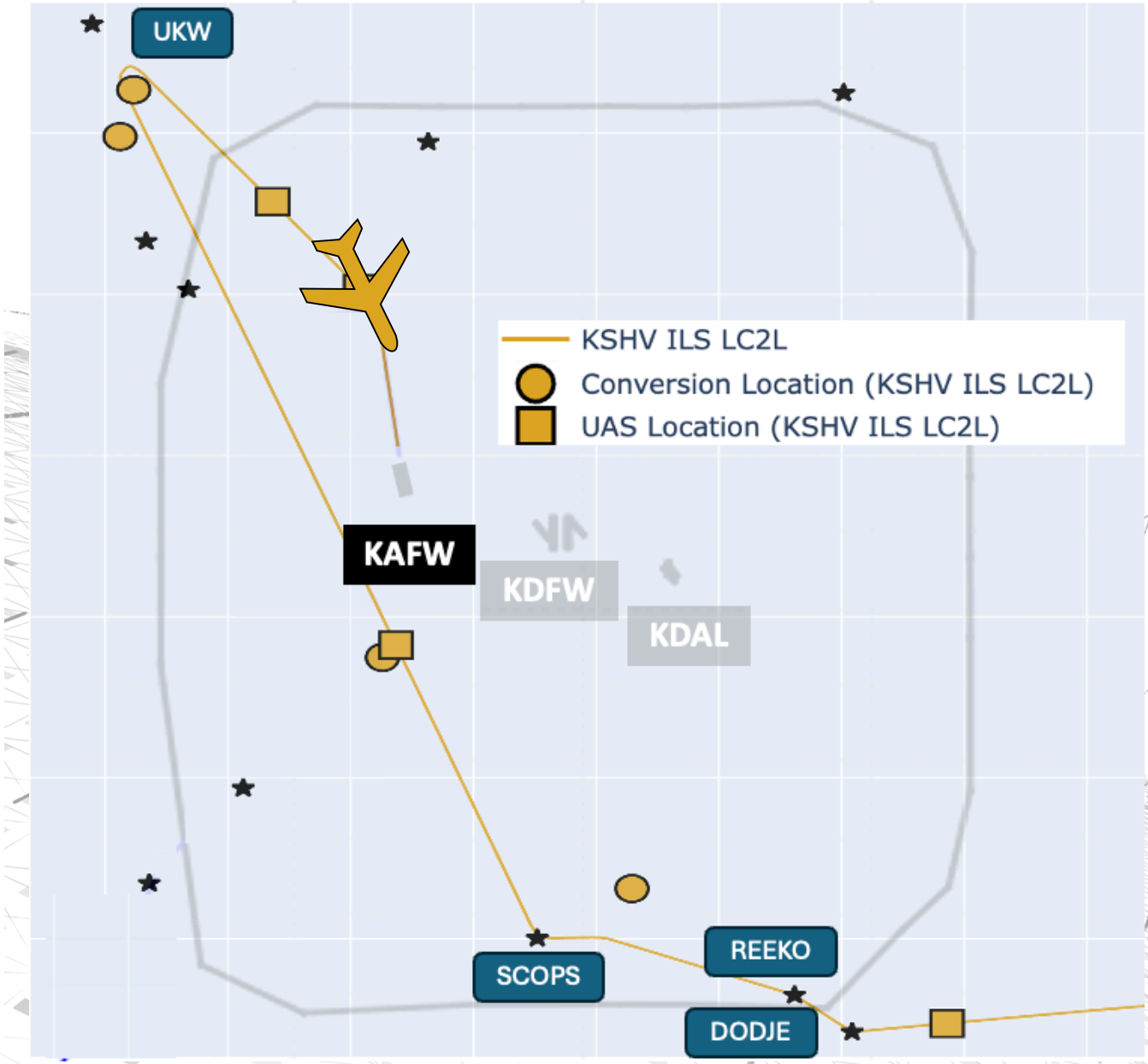


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  - UAS inside Terminal
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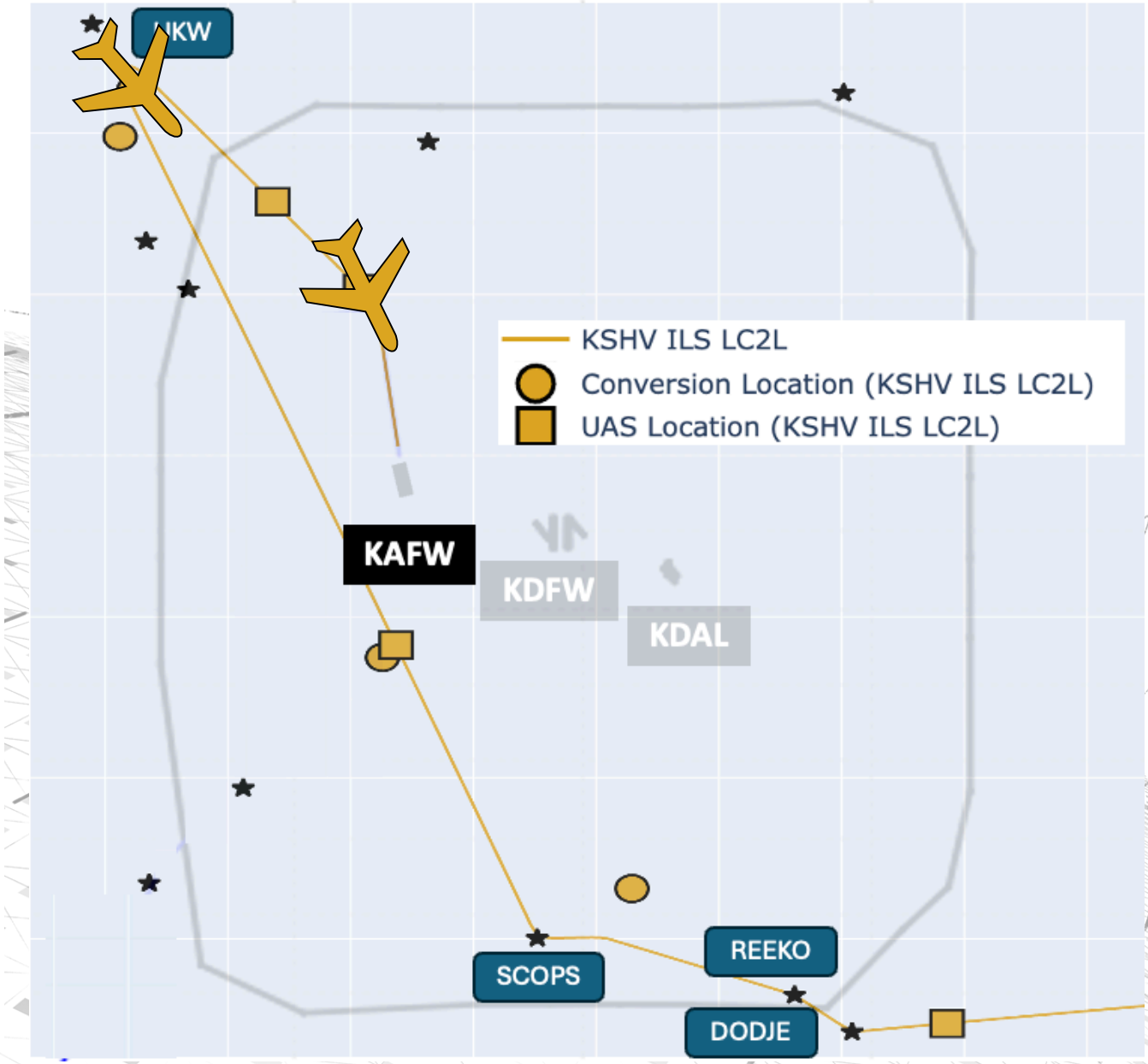


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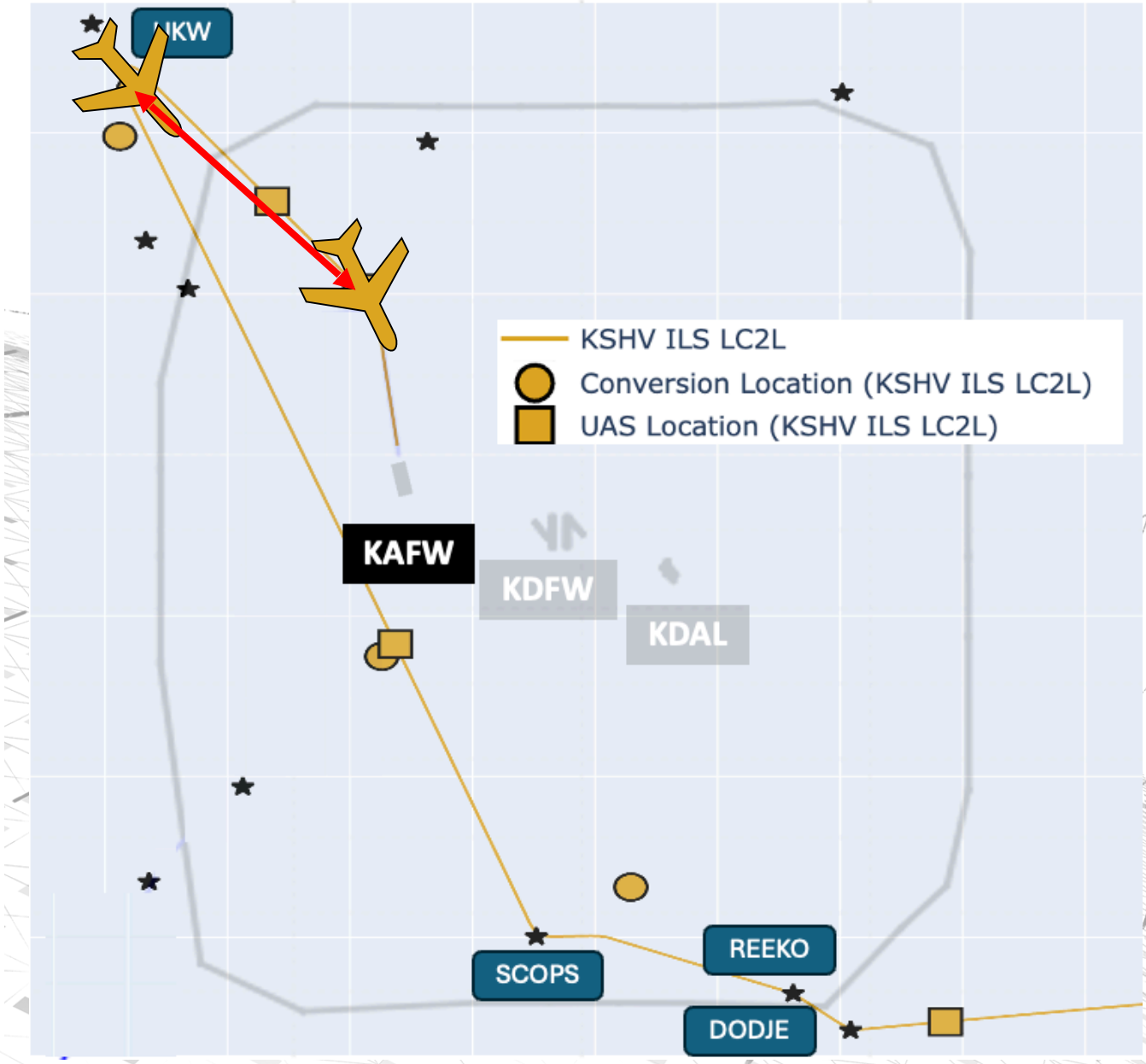


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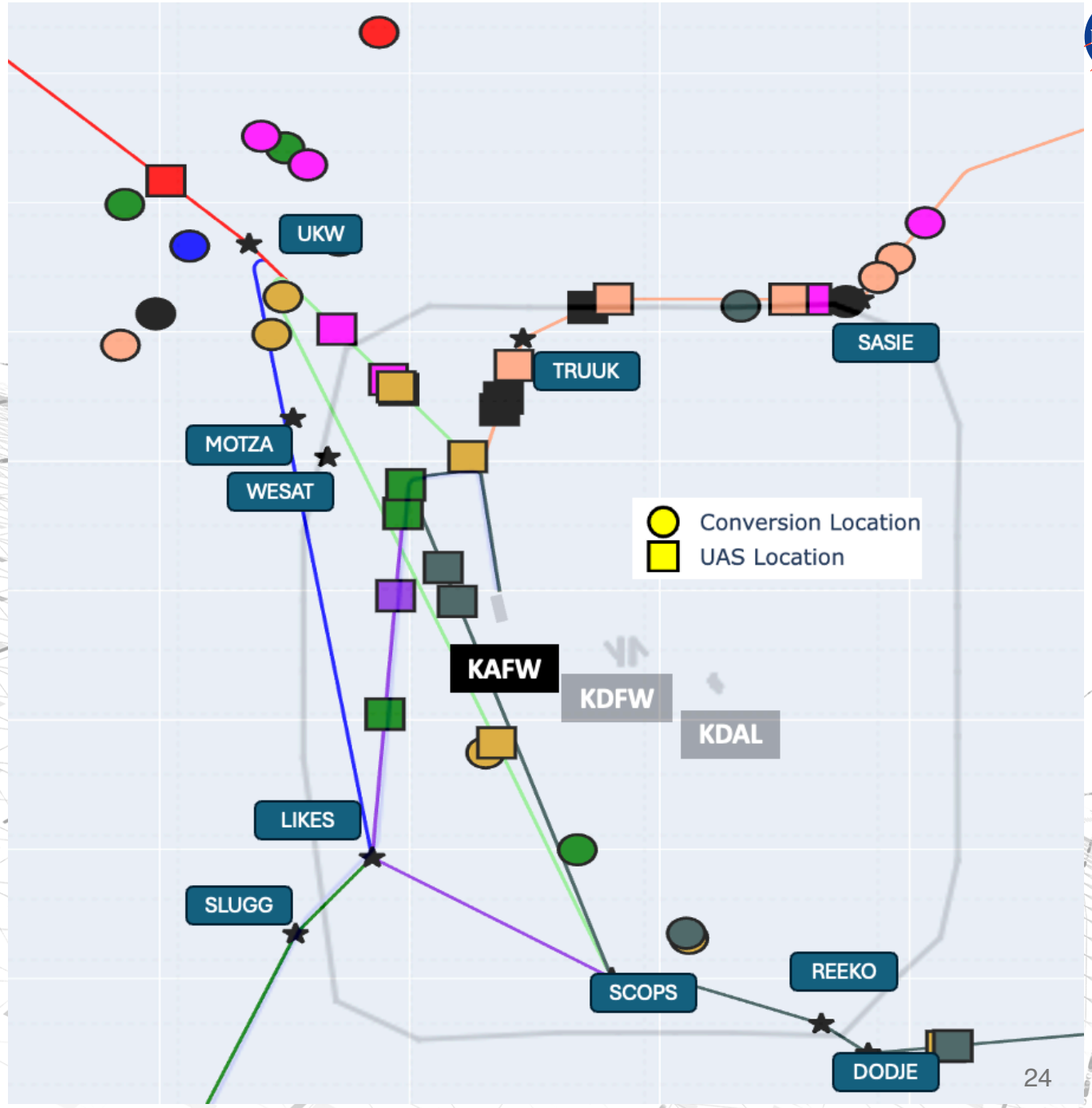
- UAS on STAR, IFR departing
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- UAS heading direct to UKW (where UAS would be receiving vectored control instructions)

- UAS being overtaken while on IAP
  - UAS inside Terminal
  - IFR in Center
  - Could necessitate communication between Terminal and Center controllers
  - Highlights speed differences

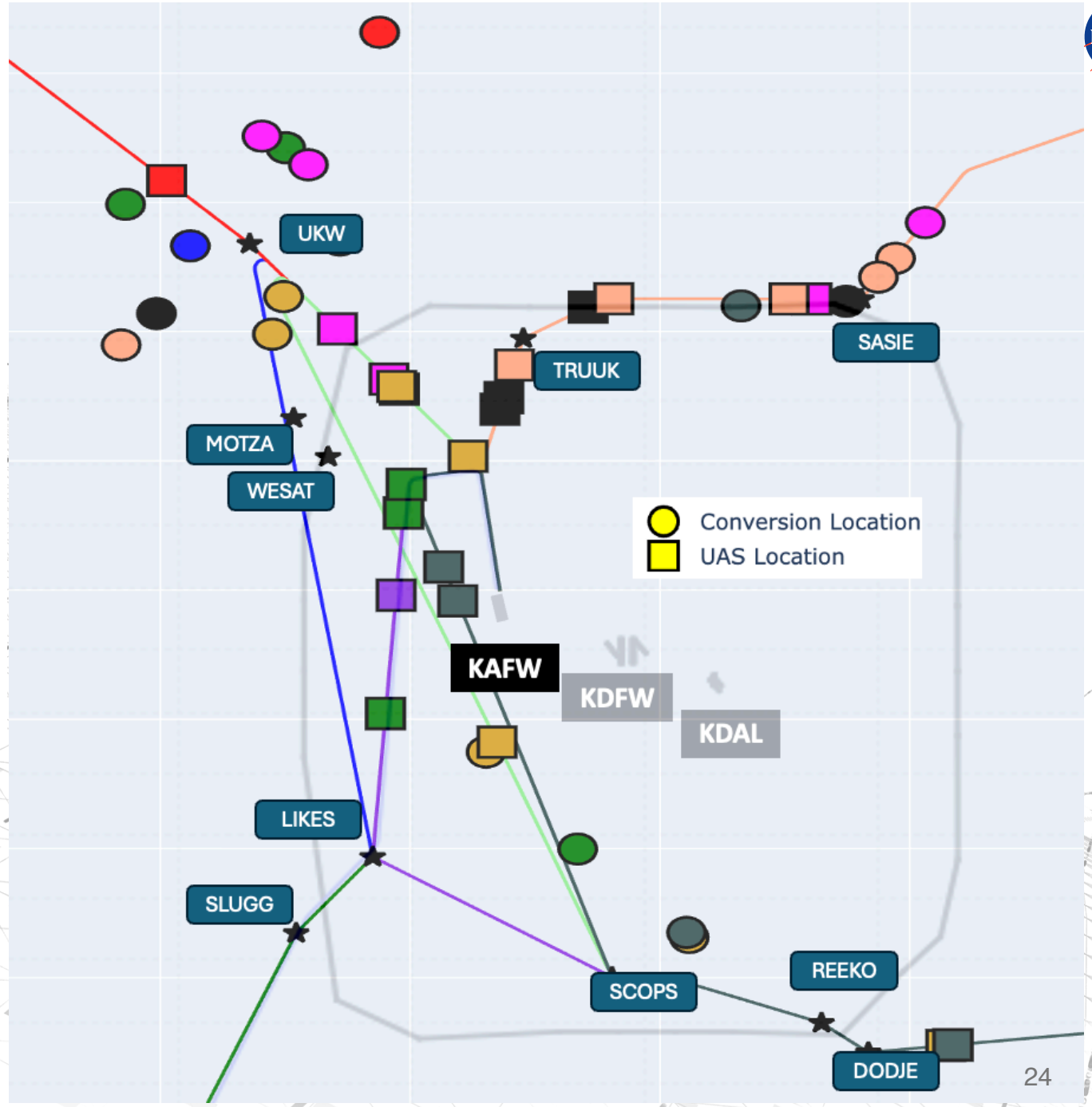


9am Conversion Locations



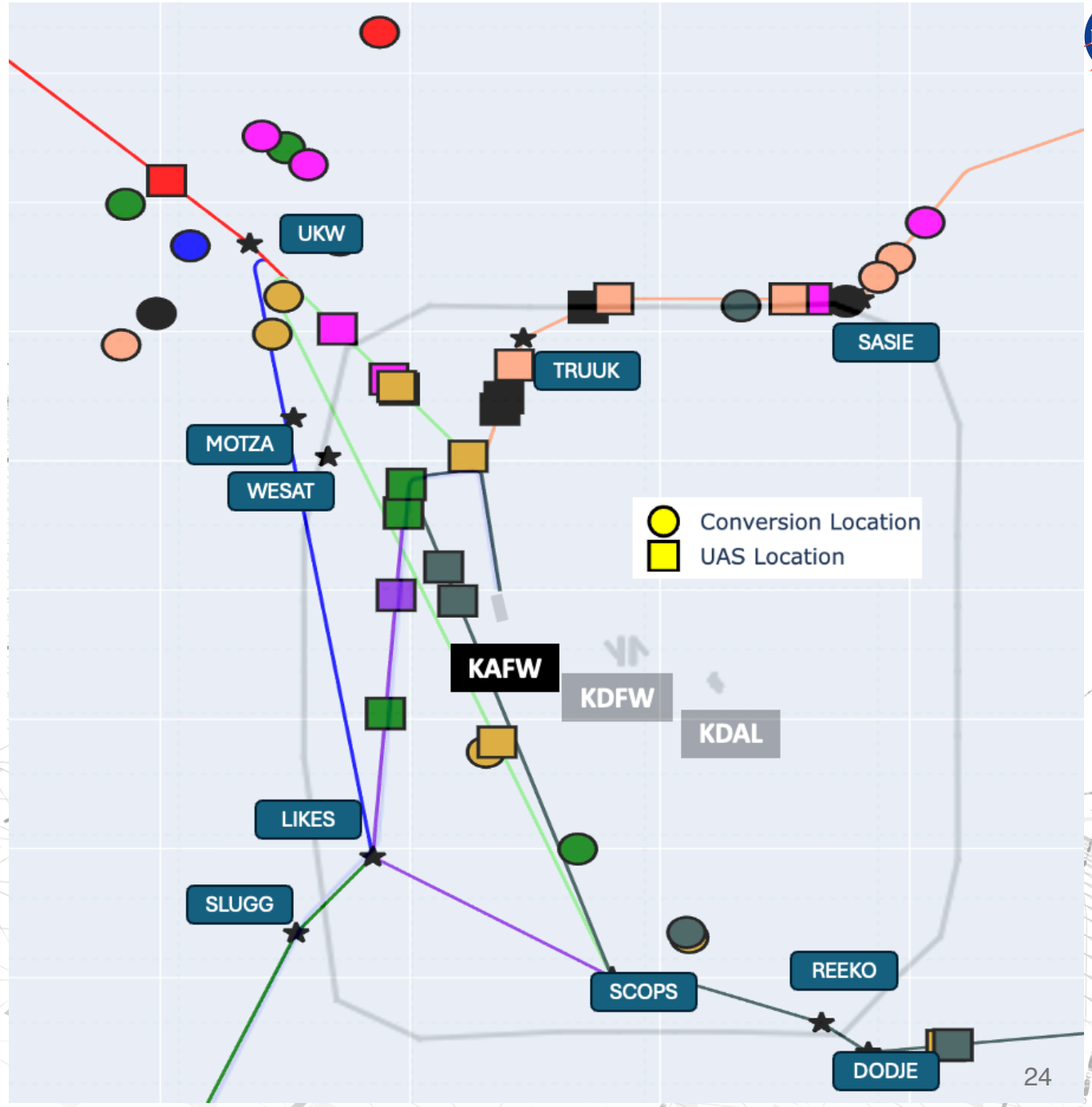
9am Conversion Locations

- Majority of conversions clusters in the northeast and northwest corners of D10



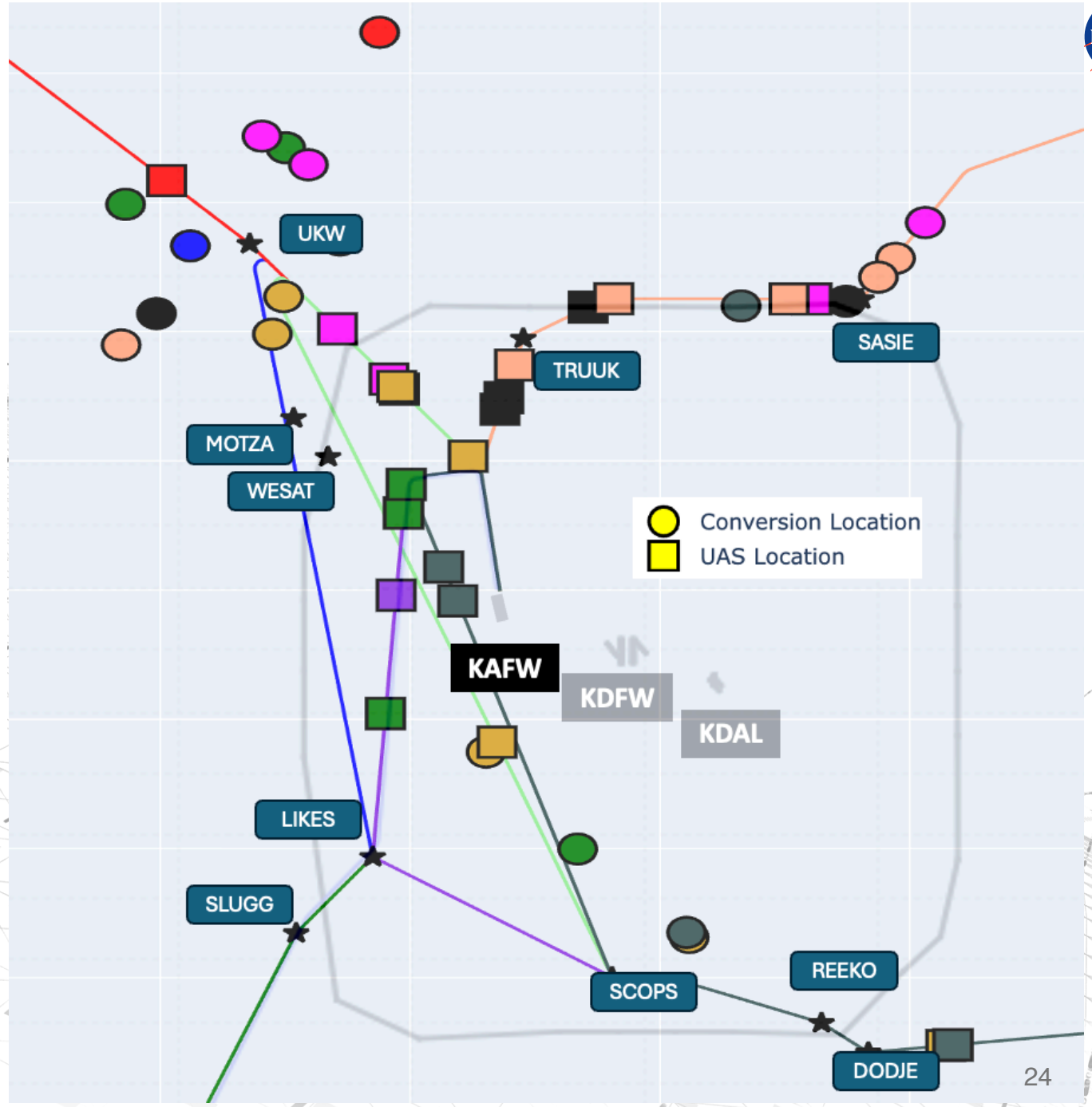
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- Many conversions are overtake conflicts (~100 kts speed difference between C208 and commercial jets)

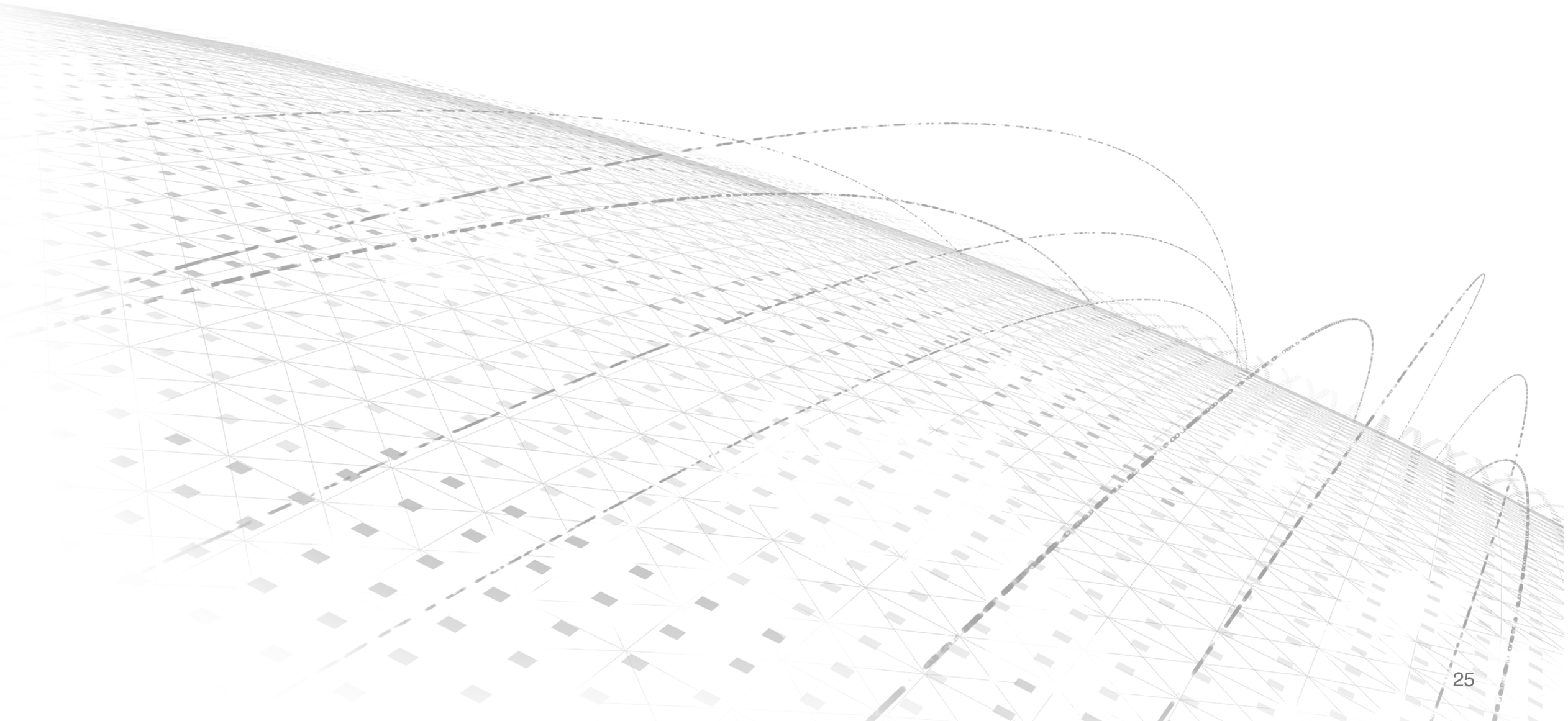


9am Conversion Locations

- Majority of conversions clusters in the northeast and northwest corners of D10
- Many conversions are overtake conflicts (~100 kts speed difference between C208 and commercial jets)
- Conversions the occur when the UAS and IFR aircraft are not in the same airspace could require additional communications between ATCOs



Discussion



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- **Research Question: How do LC2L UAS procedures impact air traffic control (ATC) and surrounding air traffic in a busy terminal environment to enable scalable use cases?**

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  - Quantified:
    - Up to 5 simulated ATC resolution maneuvers

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    - Up to 15 additional inferred communications in these scenarios

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  - Major Takeaways:
    - Most conflicts were detected between the end of the STAR and the beginning of the IAP, precisely when ATC gives vectors over voice (along arrival routes)
    - UAS and conflicting IFR aircraft were often in the terminal and center airspace, respectively, meaning ATC would have additional coordination concerns

Moving Forward

- **What are some mitigations to those concerns?**

Moving Forward

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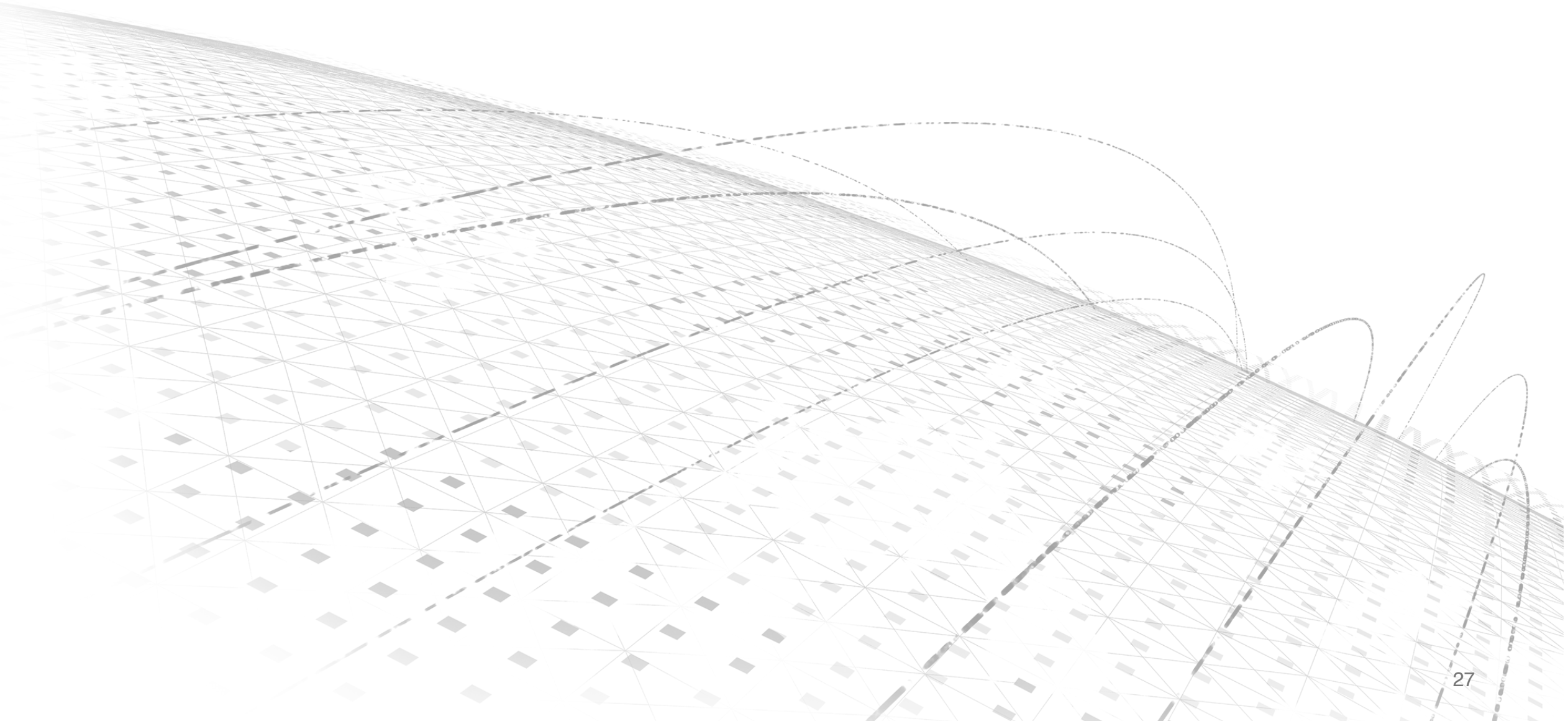
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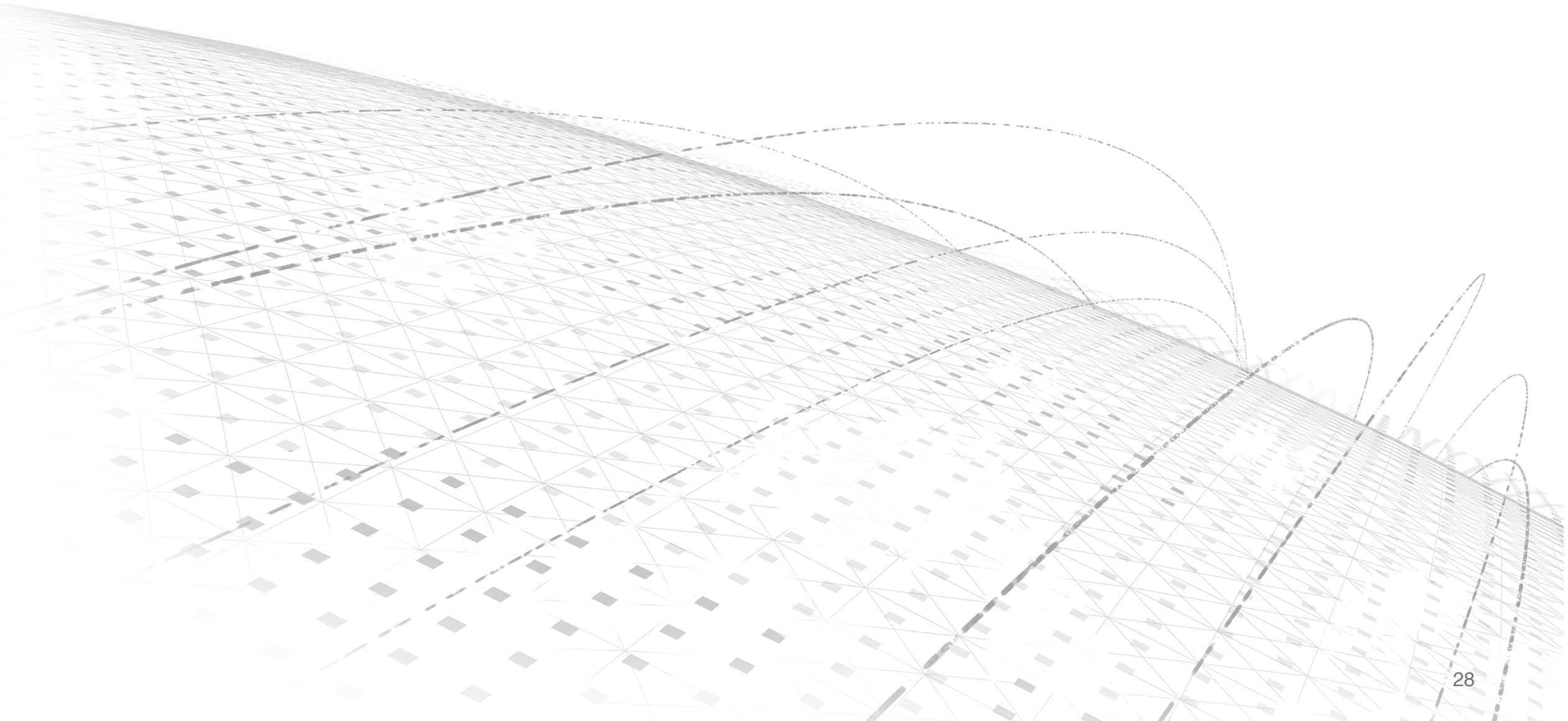
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- This work can be used to provide data for Lost Link procedure development

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Questions

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