NASA Aeronautics Research Institute

Intelligent UAS Sense-and-Avoid Utilizing Global Constraints

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Unmanned Aircraft Systems

Wide range of sizes – tiny to large

Widely varying capabilities

Many potential uses

- SAR
- traffic monitoring
- wildlife surveys
- cropdusting
- package delivery
- fire monitoring

Require operation in the NAS

The SAA Problem

Sense and Avoid other aircraft

Maintain safe "separation"

ATC:

- IFR traffic – 3nm, 1000ft
- VFR traffic – 1.5nm, 500ft

Visual separation not clearly defined

- 500 ft from person, vehicle, structure
- should be time-based

Aspects of SAA

Sensor technology – visual, radar, IR, electro-optical

Sensor Integration

Communication technology

Integrity/Robustness

Threat Recognition

Threat Avoidance

Aspects of SAA

Sensor technology

Sensor Integration

Communication technology

Integrity/Robustness

Threat Recognition

Threat Resolution

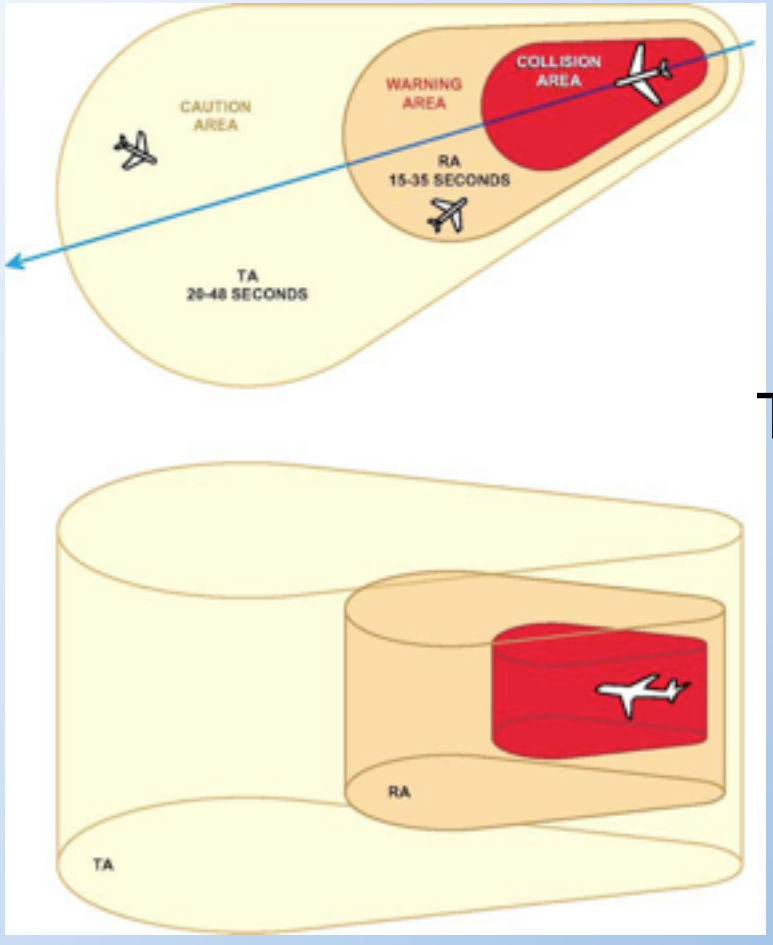
Recognition & Avoidance work

TCAS

ACAS X

JOCA

TCAS



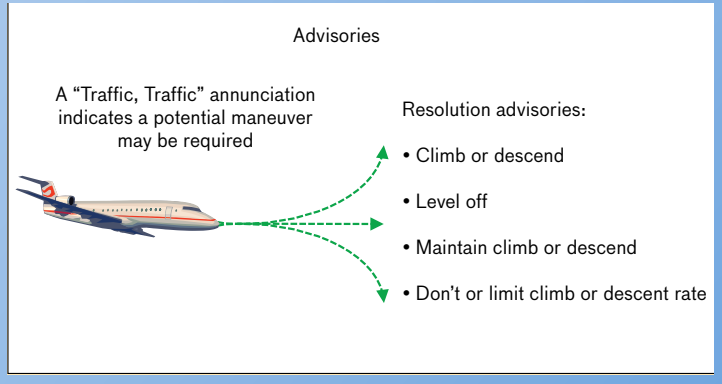
Text

Transport aircraft

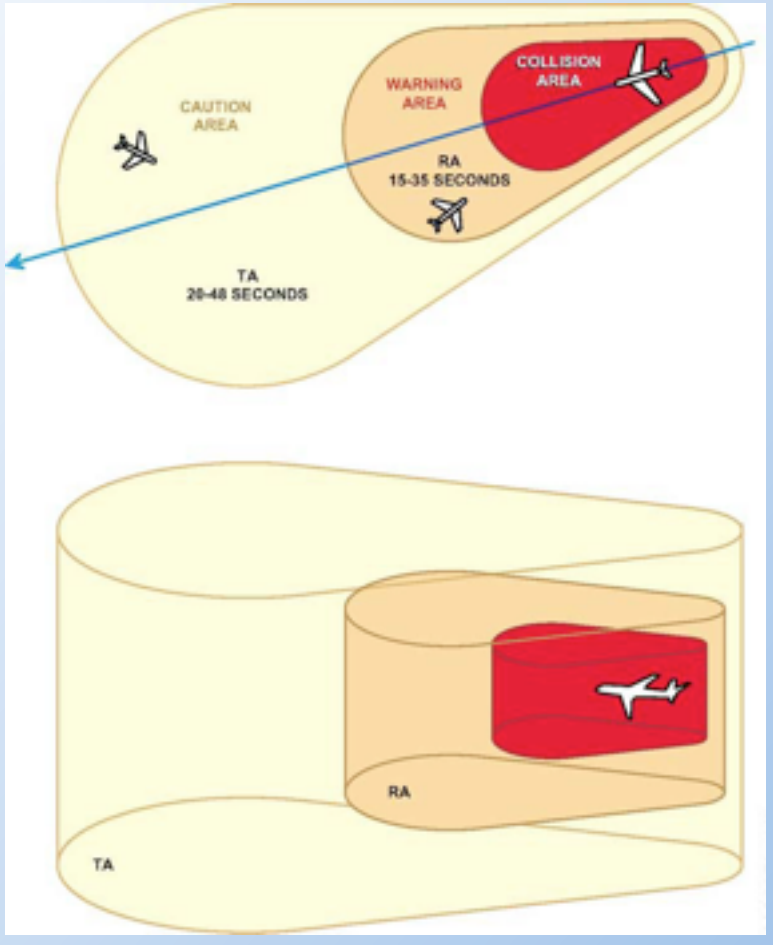
Near term encounters

Logic:

- Deterministic trajectories
- Ad Hoc rules
- Altitude Resolutions
- Compliance



ACAS X

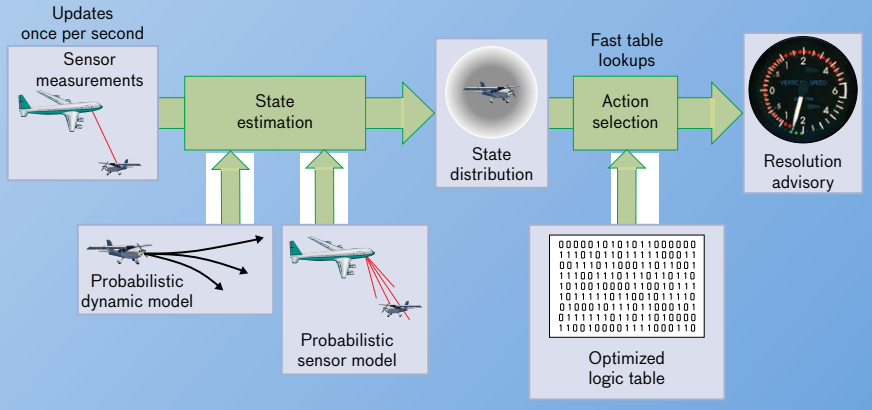


Wider applicability

Near term encounters

Logic:

- **Trajectory distribution**
- **MDP decision table**
- Altitude Resolutions
- ~~Compliance~~



Next-generation airborne collision avoidance system, Kochenderfer et al., Lincoln Labs J.19(1), 2012

What's Different?

Emphasis:

- small UAS
- VFR
- low altitude
- medium term

Issues

- traffic trajectory is less predictable
- medium/long term prediction is harder
- terrain
- weather

Approach

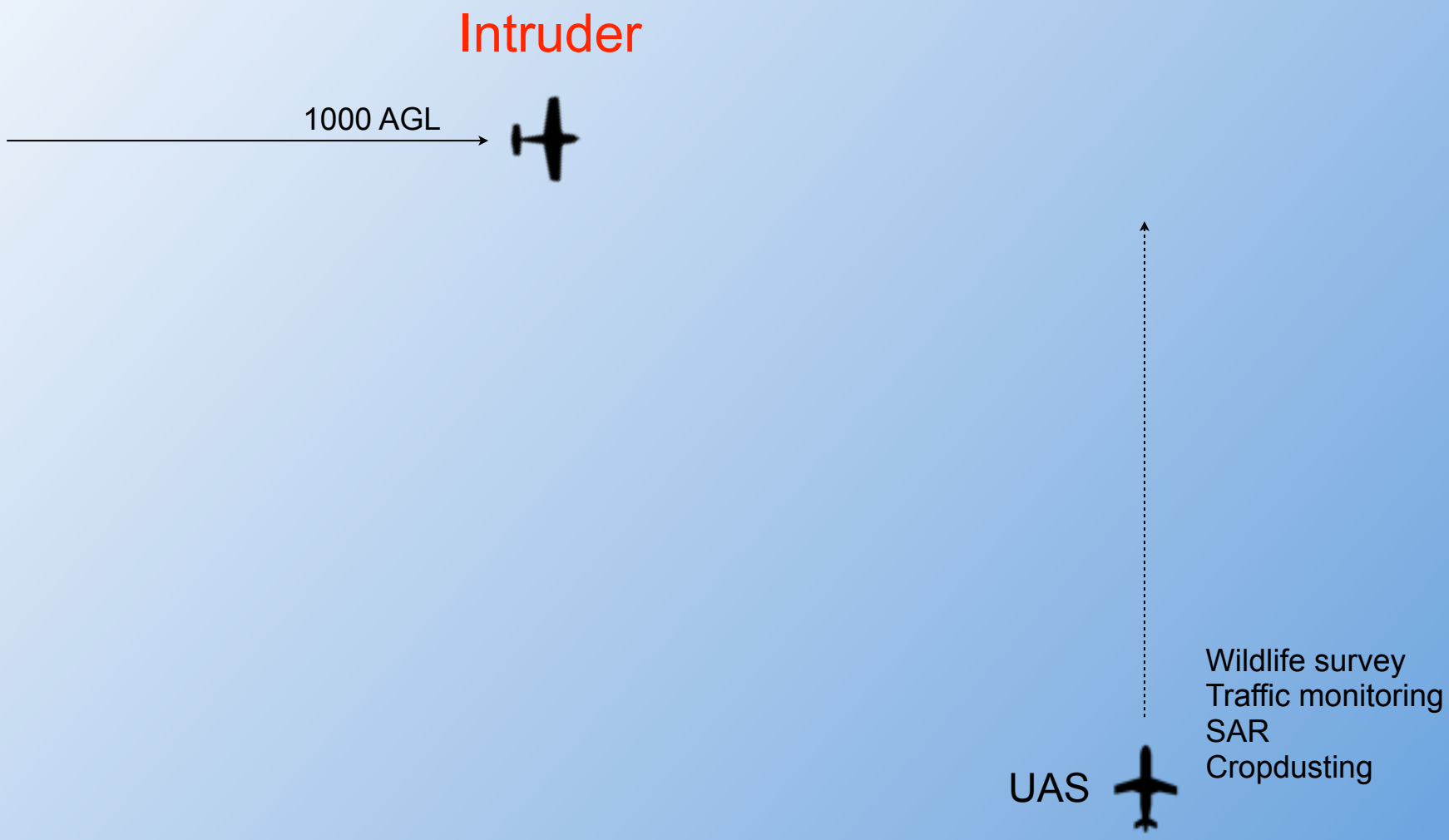
Threat Recognition

- probabilistic plan recognition
- knowledge intensive

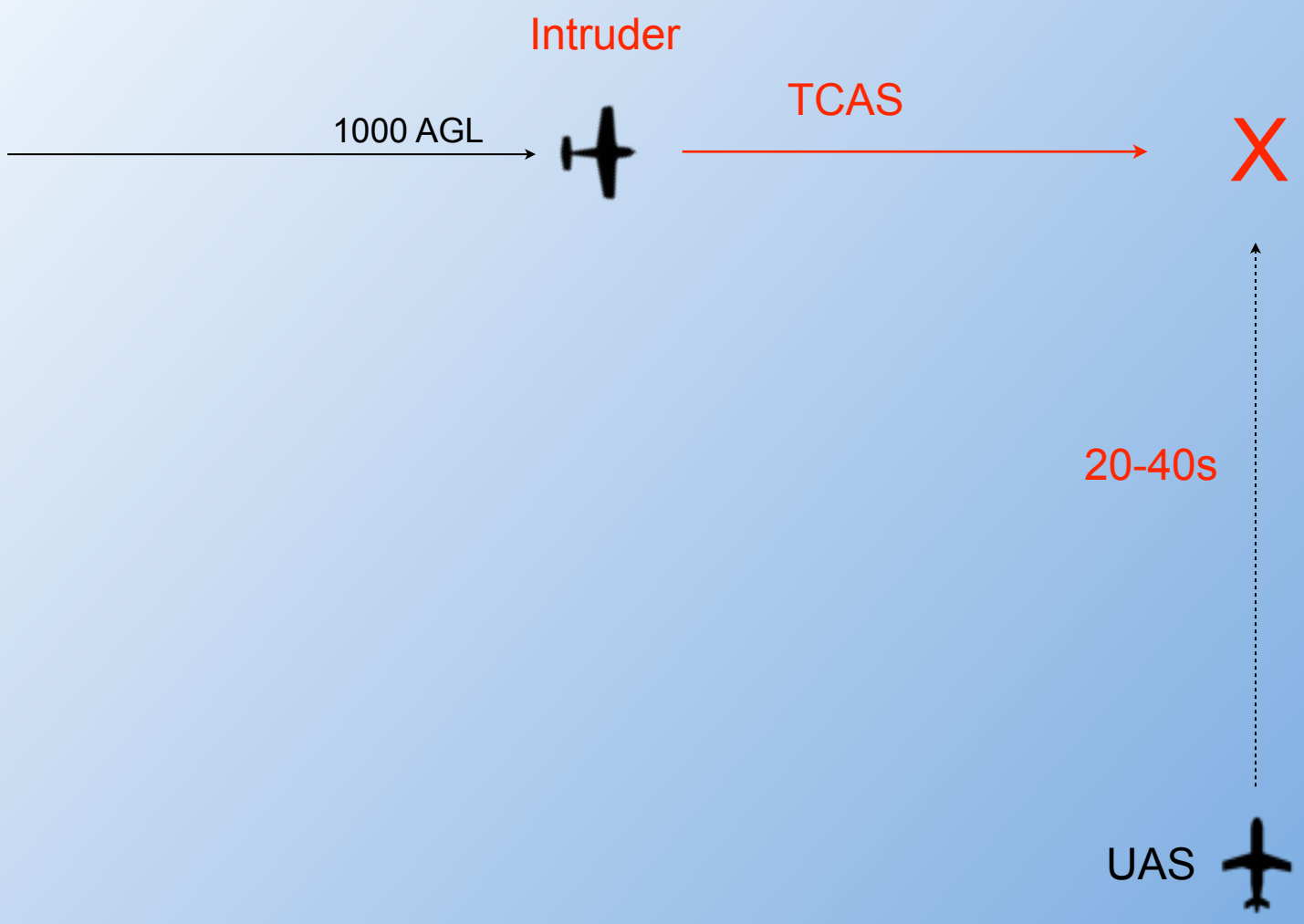
Threat Resolution

- probabilistic planning
- take objective into account

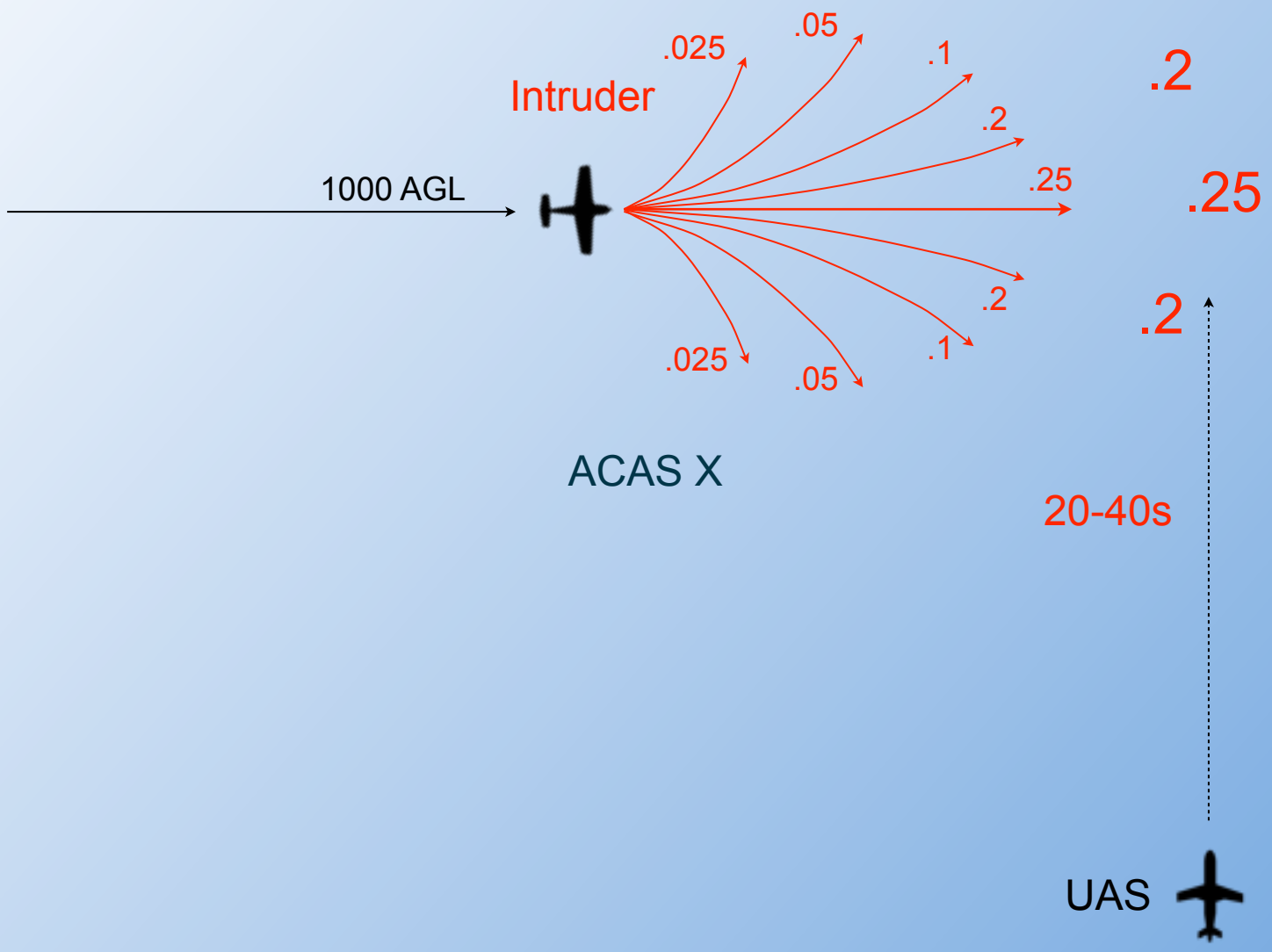
Example


Intruder
1000 AGL
UAS
Wildlife survey
Traffic monitoring
SAR
Cropdusting

Example



Example



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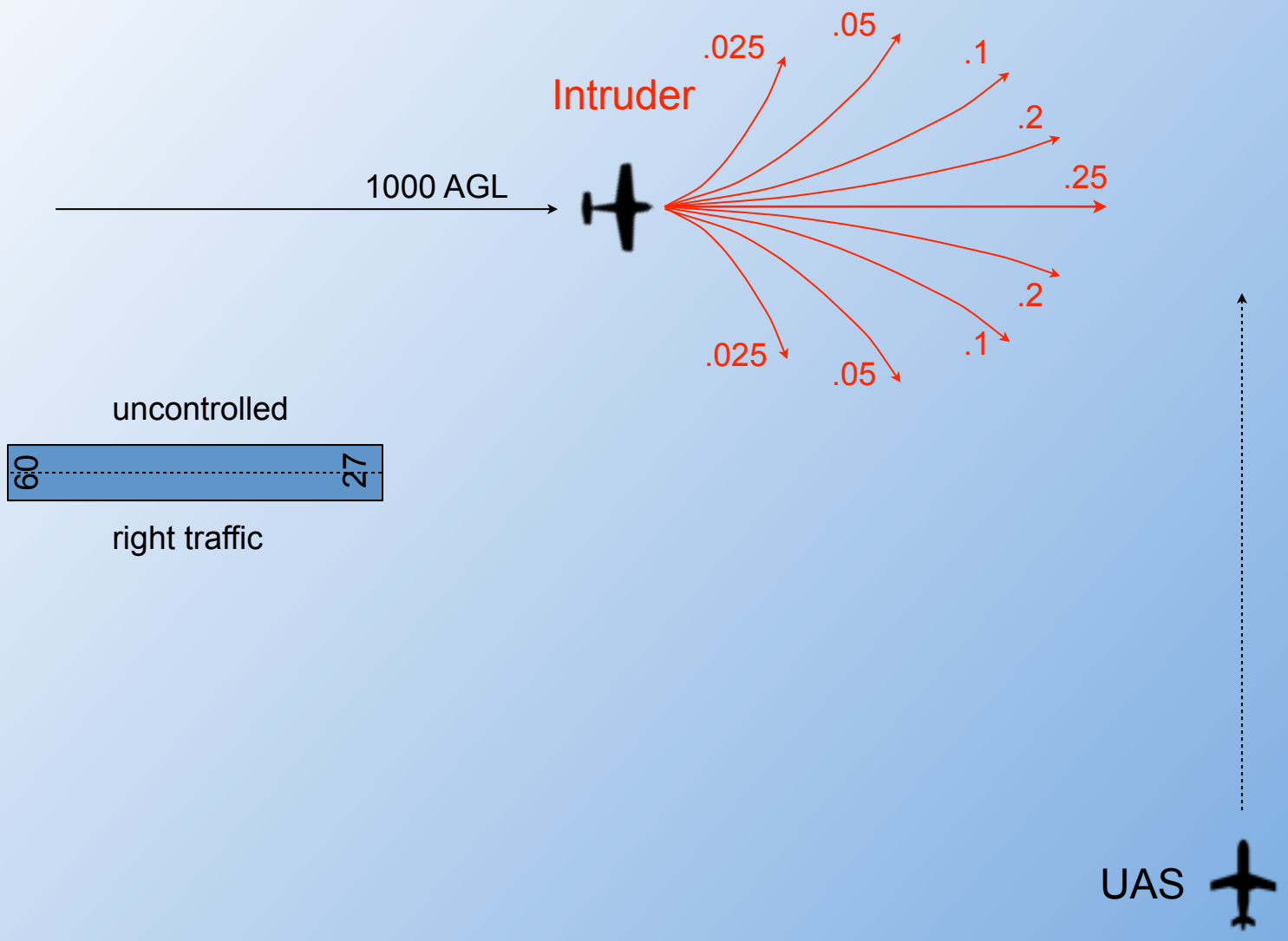
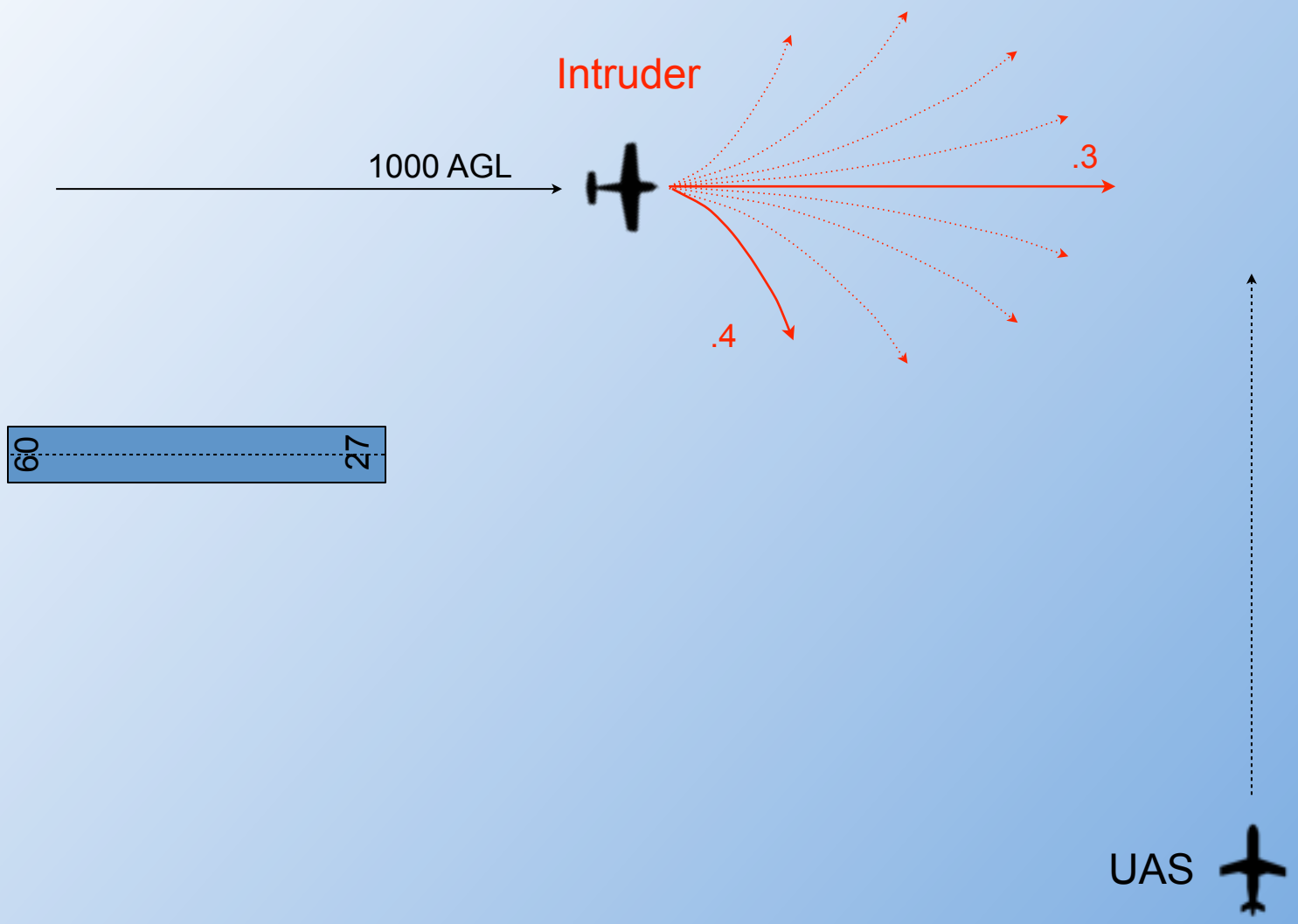

.025
.05
.1
Intruder
.2
1000 AGL
.25
.2
.025
.1
.05
uncontrolled
6i0
27
right traffic
UAS

Example



Example

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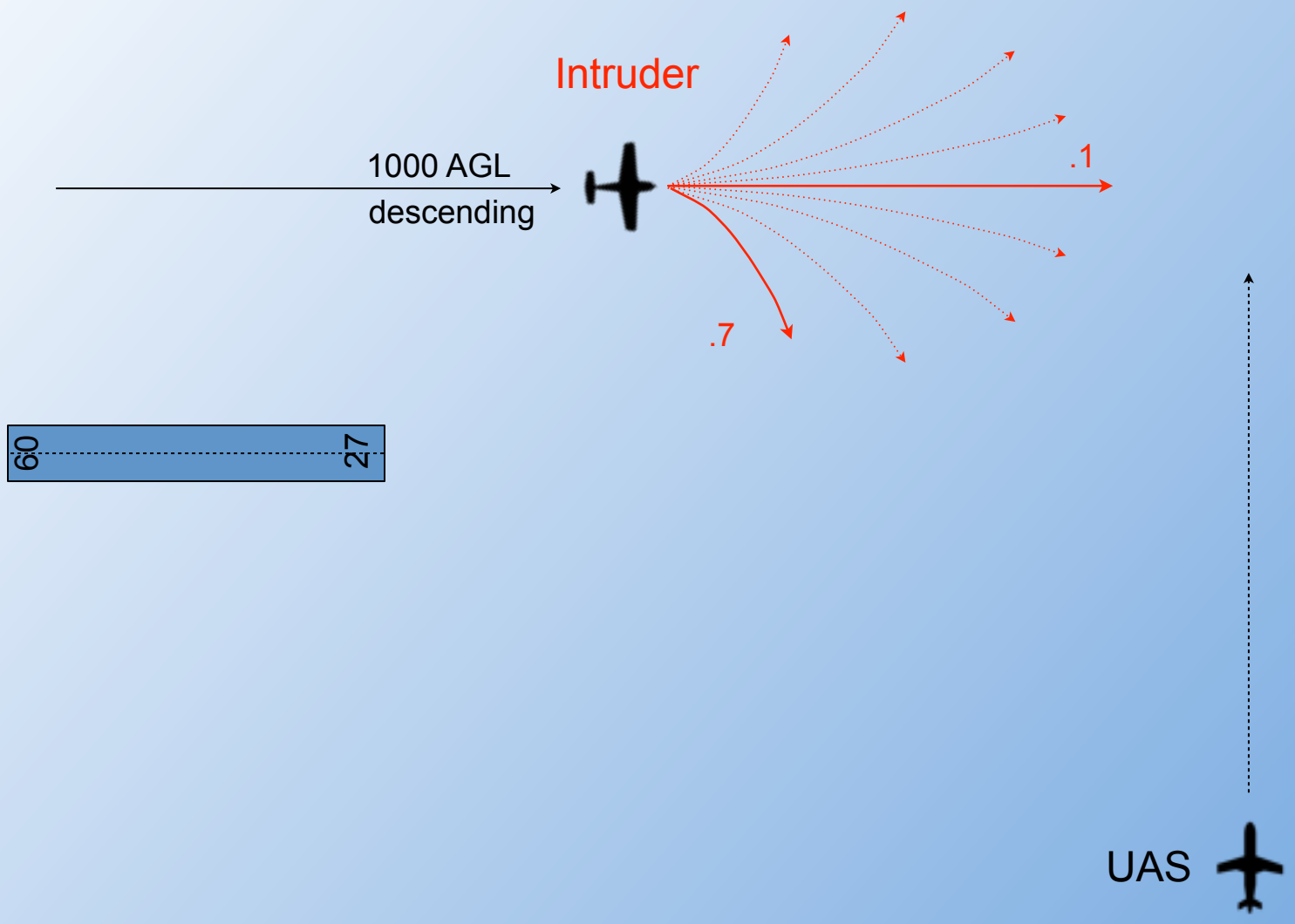

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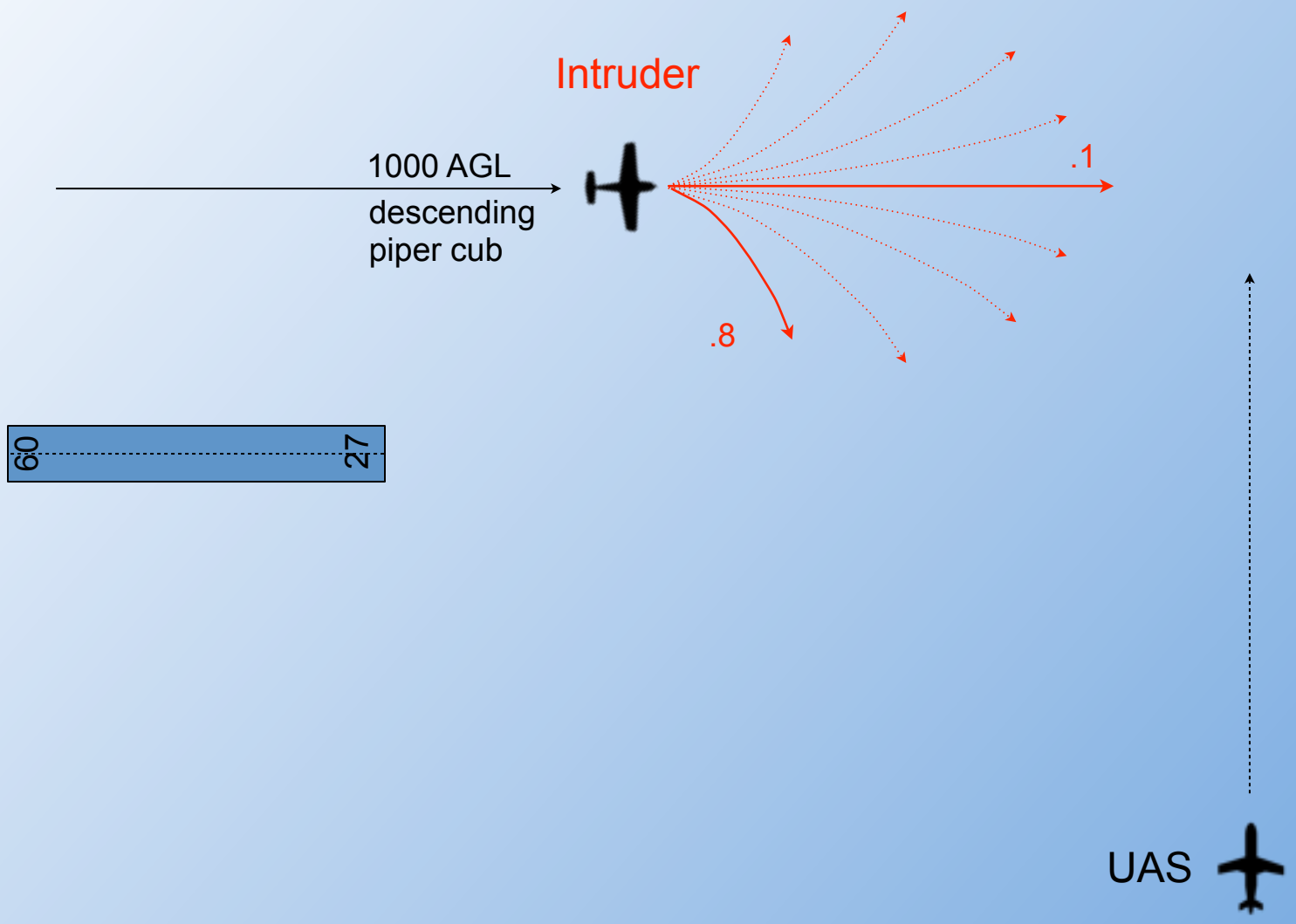

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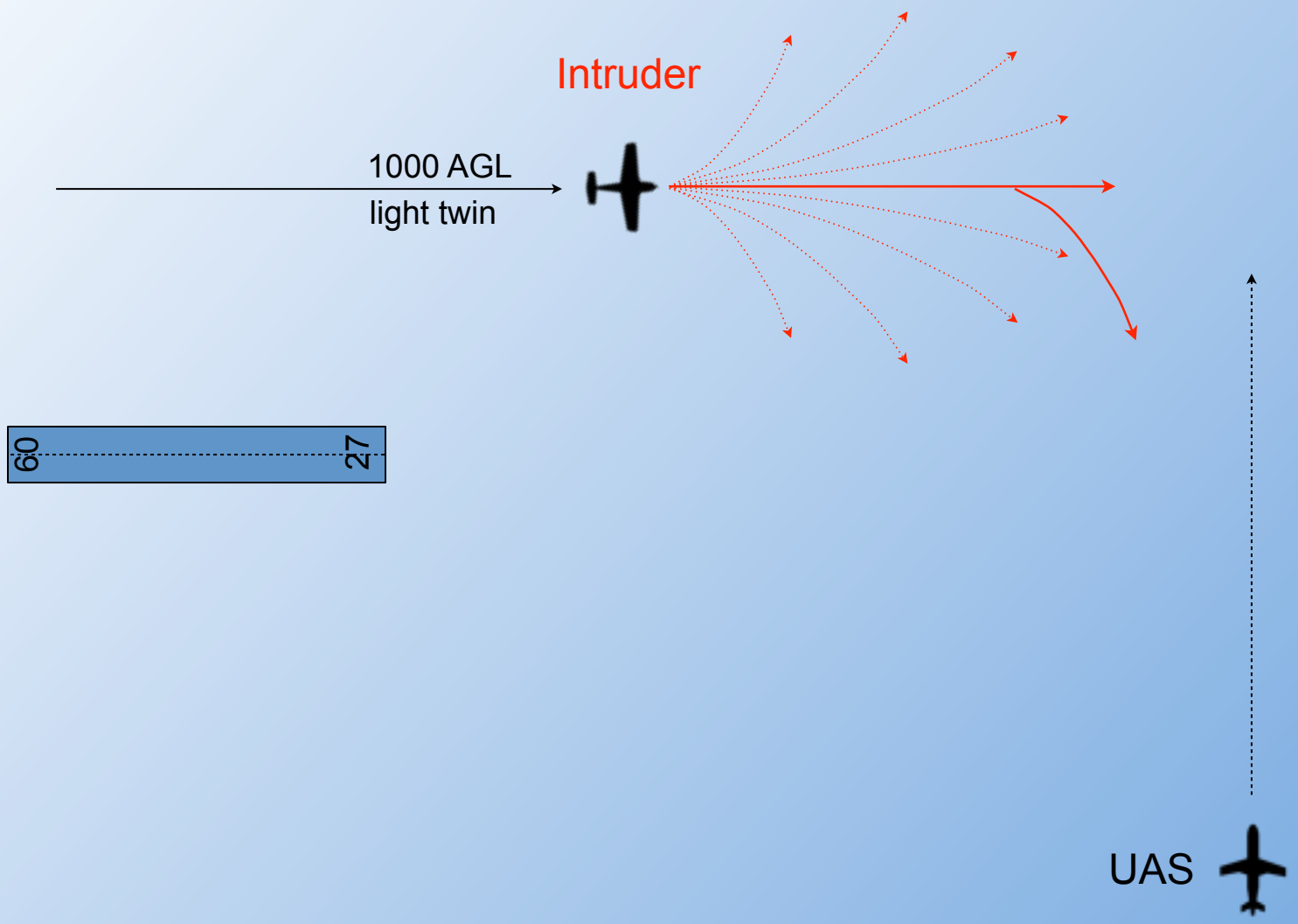

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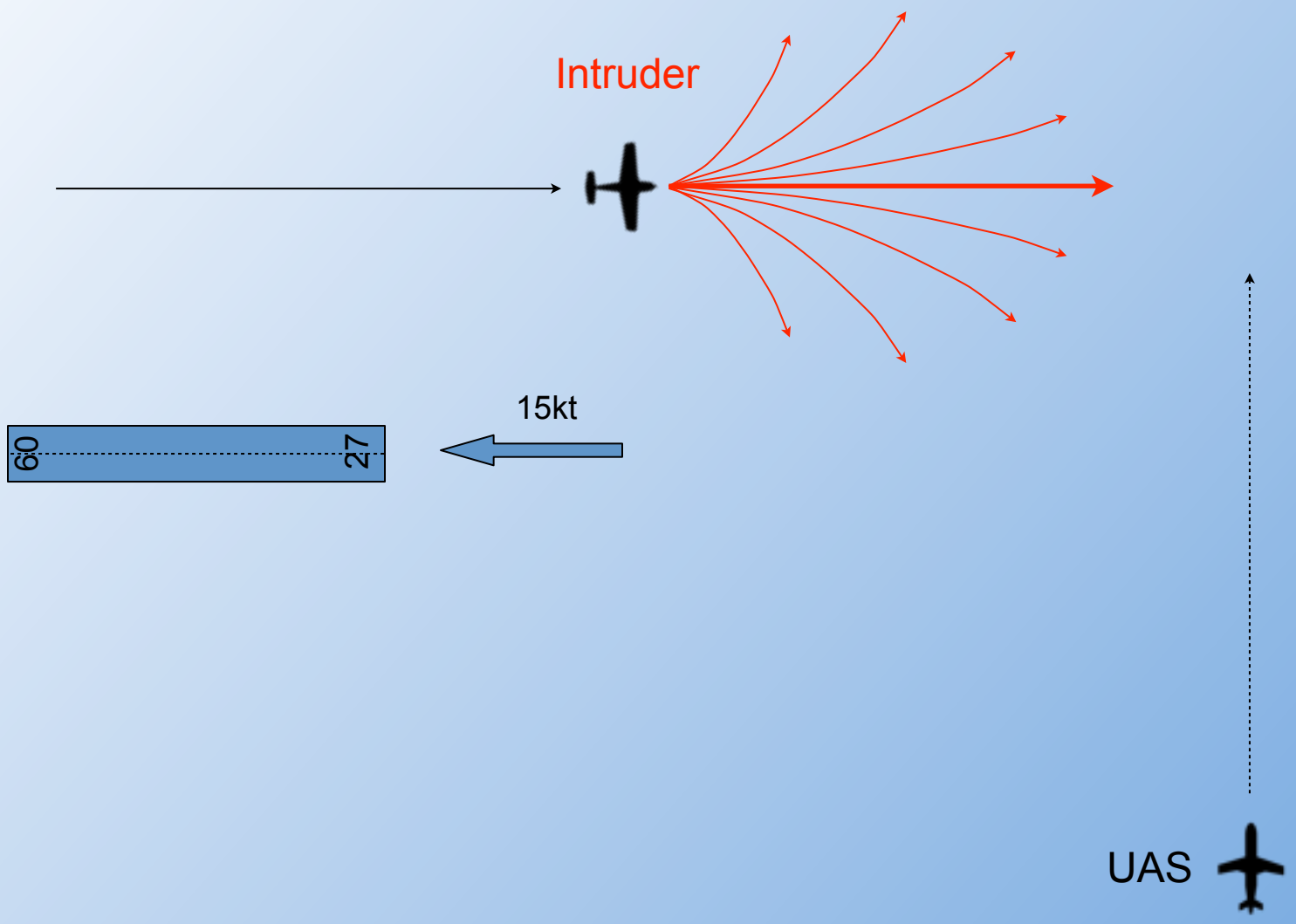

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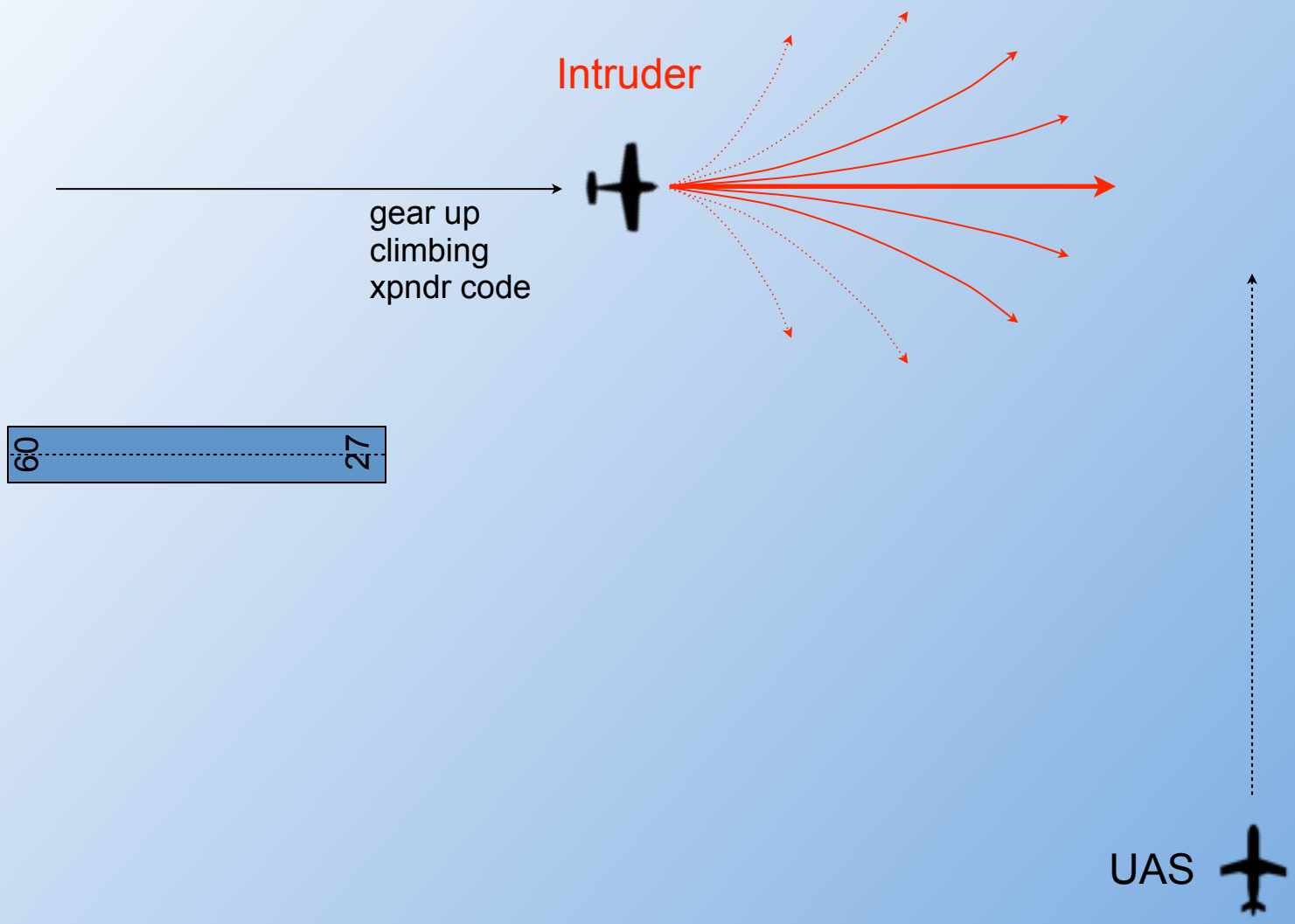

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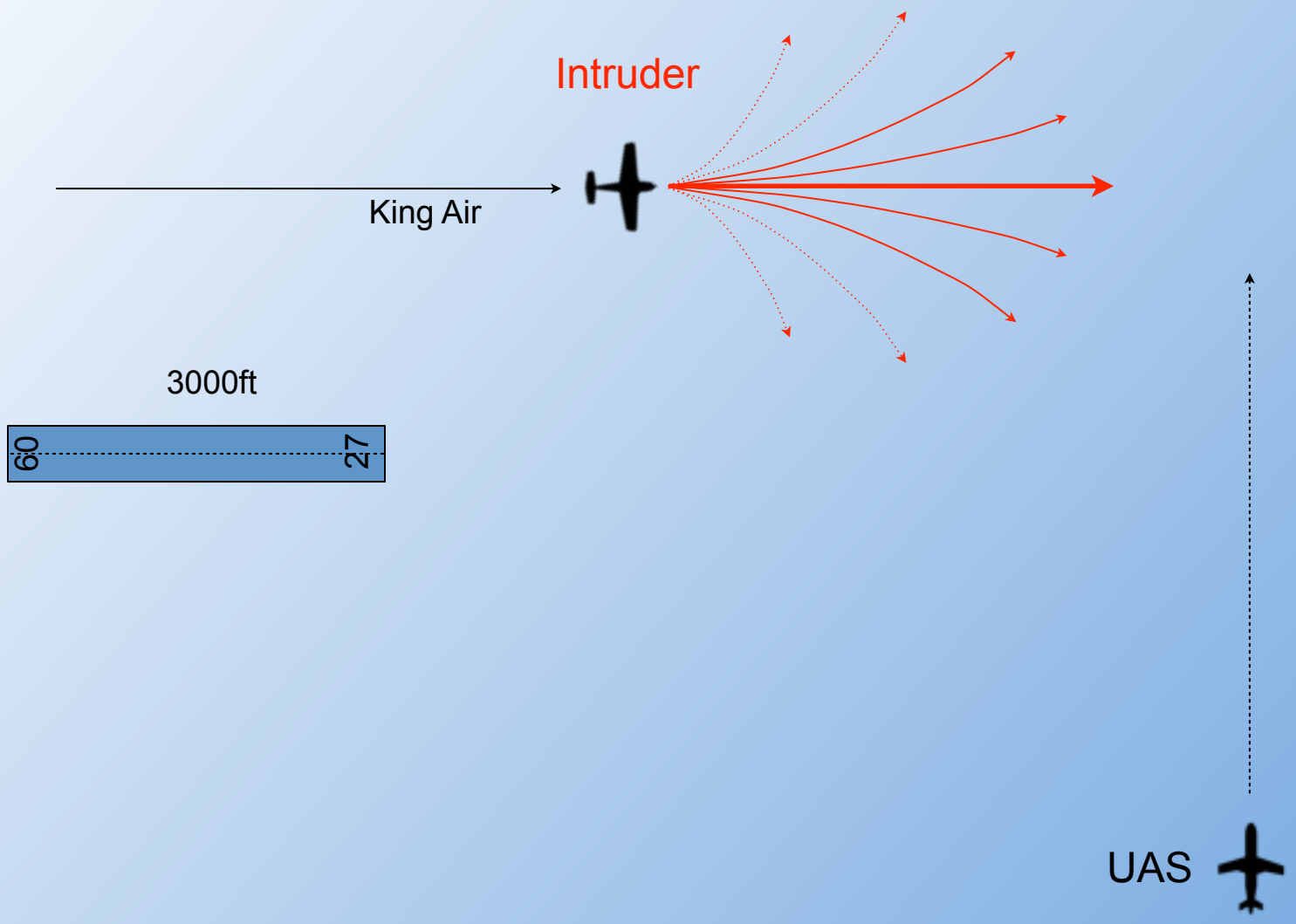

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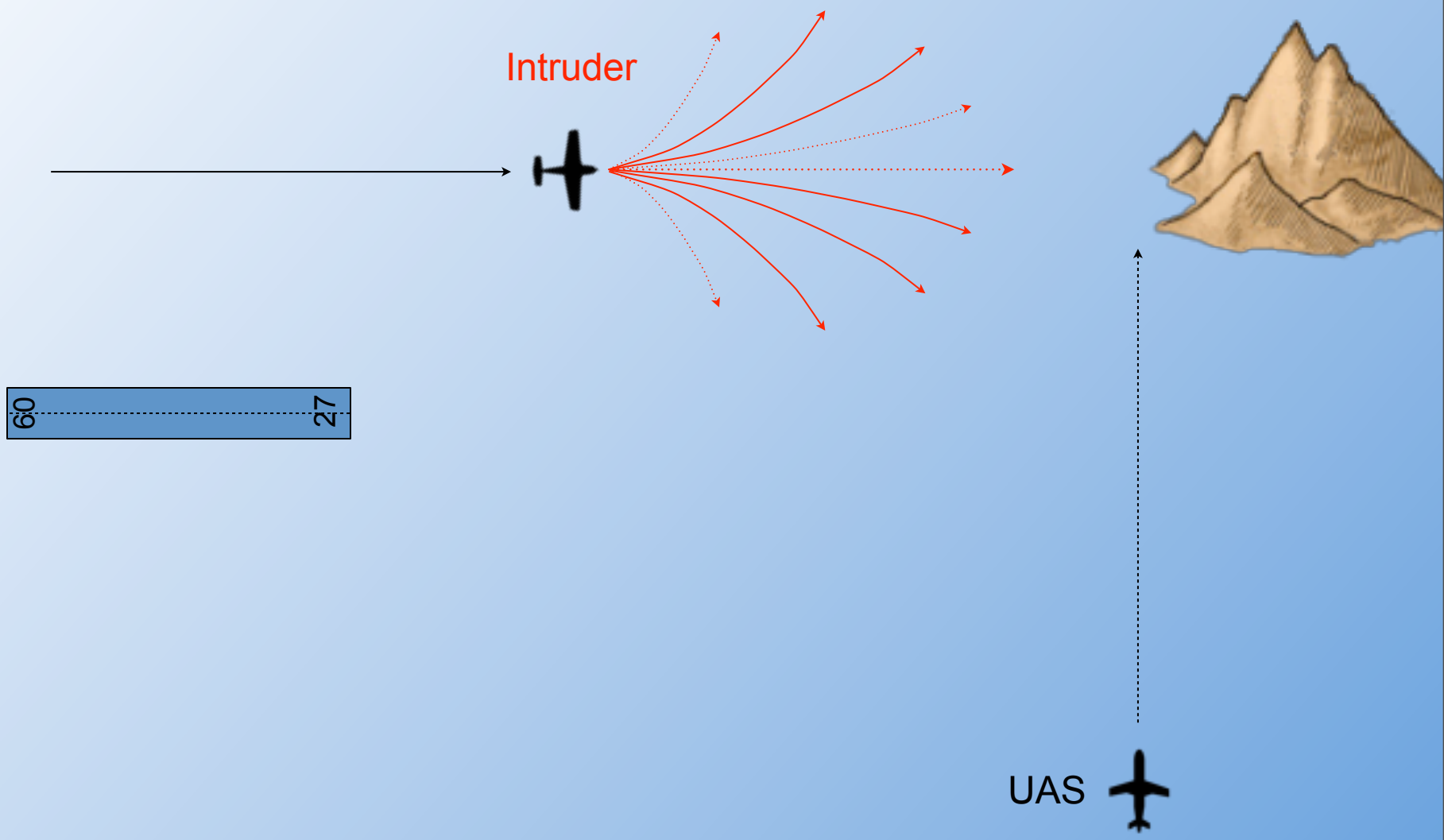

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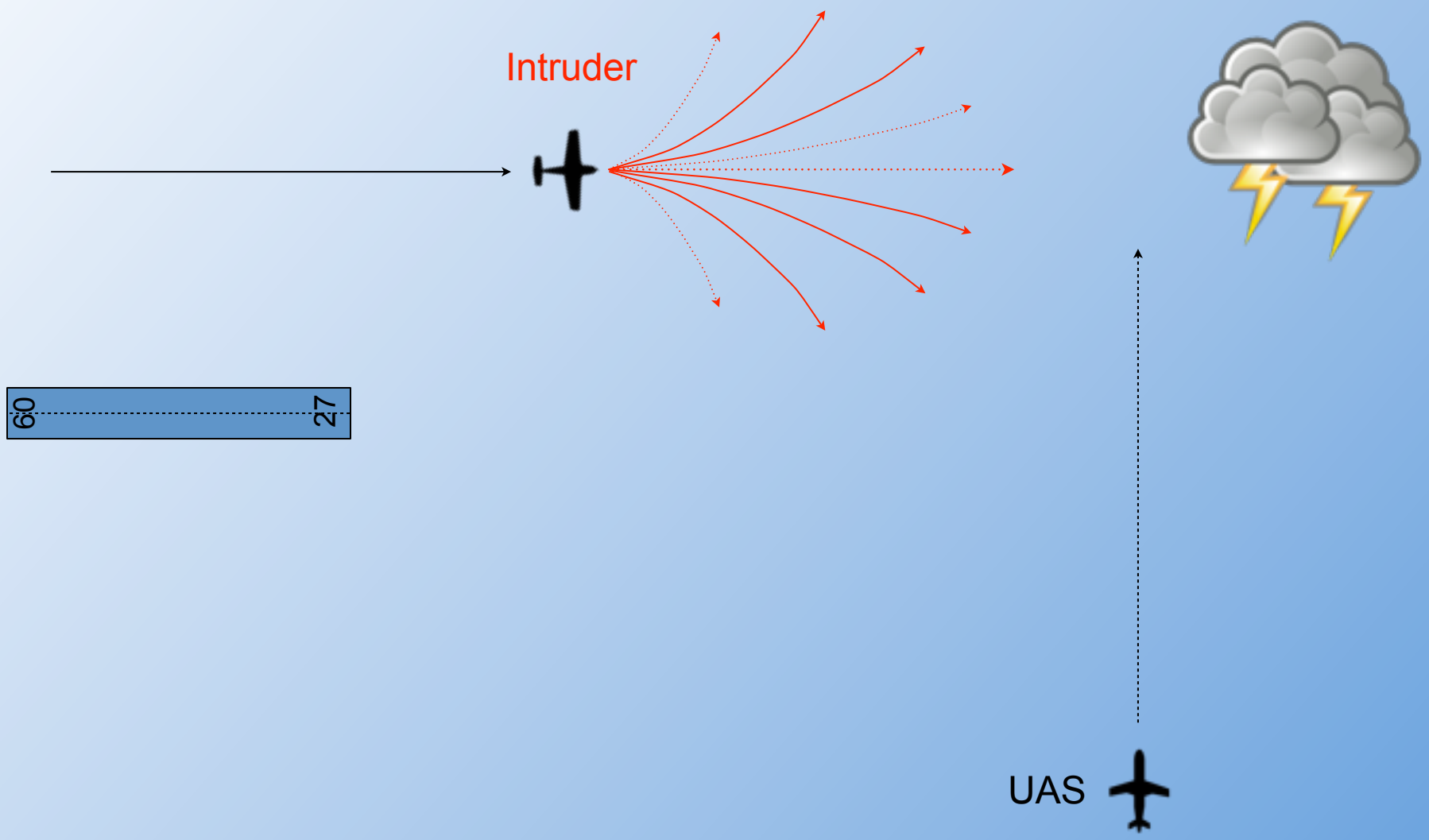

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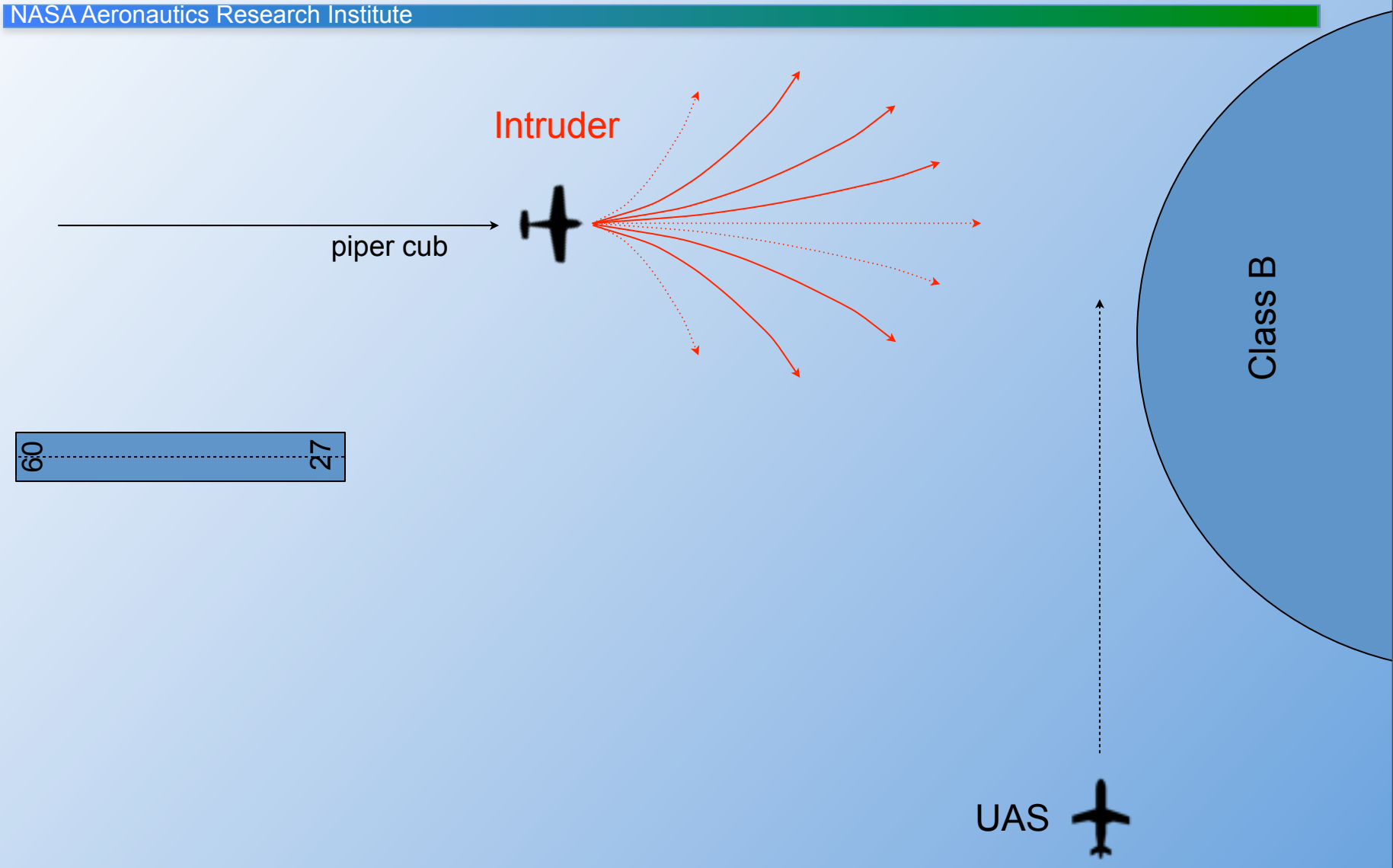


Intuition

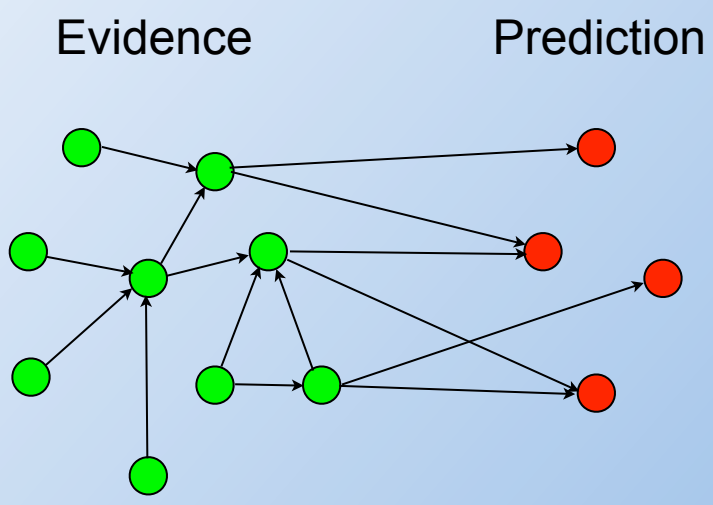
Trajectory Prediction is a knowledge-intensive task

- heading, velocity, acceleration (lateral, vertical)
- aircraft type
- transponder
- communication
- airports
- traffic patterns
- airspace
- airways, arrival/departure routes
- terrain
- weather

Given evidence, what is the intruder likely to do?

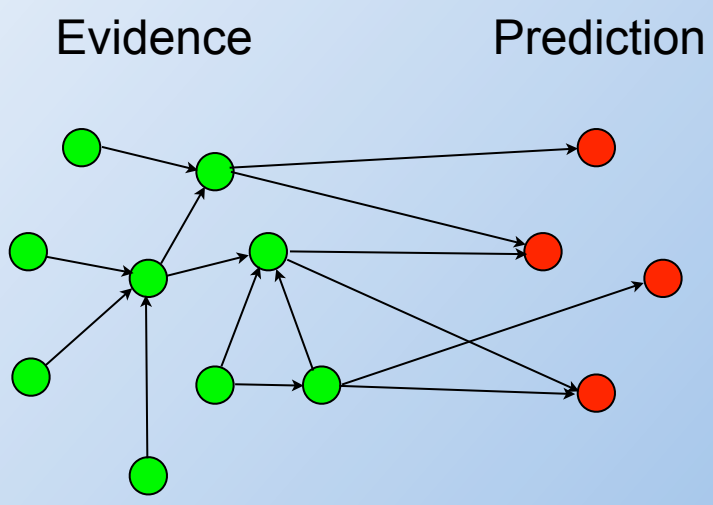
Technical Approach

Model the prediction problem as a Dynamic Bayesian Network



Technical Approach

Model the prediction problem as a Dynamic Bayesian Network



ACAS X

v, v', ψ', h, h'

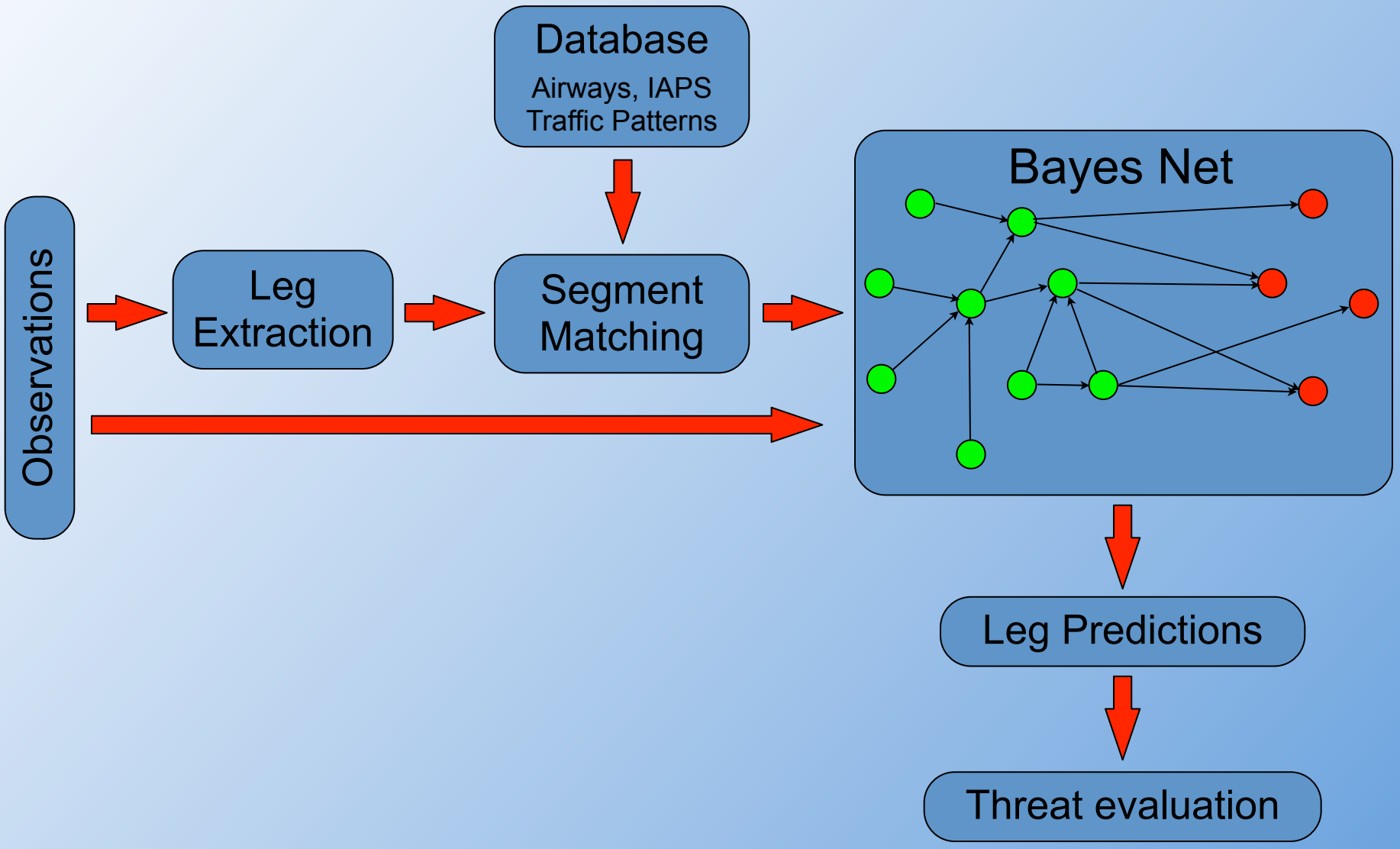
Here

v, v', ψ', h, h'
type, transponder, wx
legs, intent

Bayes Net

Aircraft-make
Aircraft
instruments
Engines
Aircraft_size
Engine-type
WingType
RetractableGear
Flight_Rules
Wing
TailType
LandingGearType
GearPosition0
Comm-CTAF
Comm-app
PossibleLegs0
leg0
leg+1
Comm-CTAF-intentions
Transponder
leg0-type
Visibility
MetConditions
Climb/Descent
Ceiling

Architecture



Route Segments

Airways, IAPS from ARINC 424 database

ACES's SAA-integrated new Java classes:

- Store route segments: track with lateral tolerance, altitude range, heading with tolerance
- Multiple segments make up an airway/IAP/traffic-pattern.

Trajectory Leg Generator

- New Java classes integrated with ACES's SAA and utilize ACES's basic classes.
- Analyze the observed history of an intruder by breaking it into unique legs based on:
  - **Speed**: constant, accelerating, decelerating
  - **Altitude**: constant, climbing, descending
  - **Heading**: constant, turn-left, turn-right

Route Segment Matching

- Match observed trajectory legs with route database
  - All points within a given leg are within the 3D boundary of the route segment.
  - Aircraft heading for each point in a leg should be within the pre-specified tolerance of the segment's heading.

Intentions

Build probabilistic predictor

Evaluation using ACES

- create mix of small aircraft trajectories
- compare ACES-SAA to iSAA

Accomplishments

Build probabilistic predictor

✓ – leg extraction

✓ – segment matching

✓ – dynamic bayes net predictor

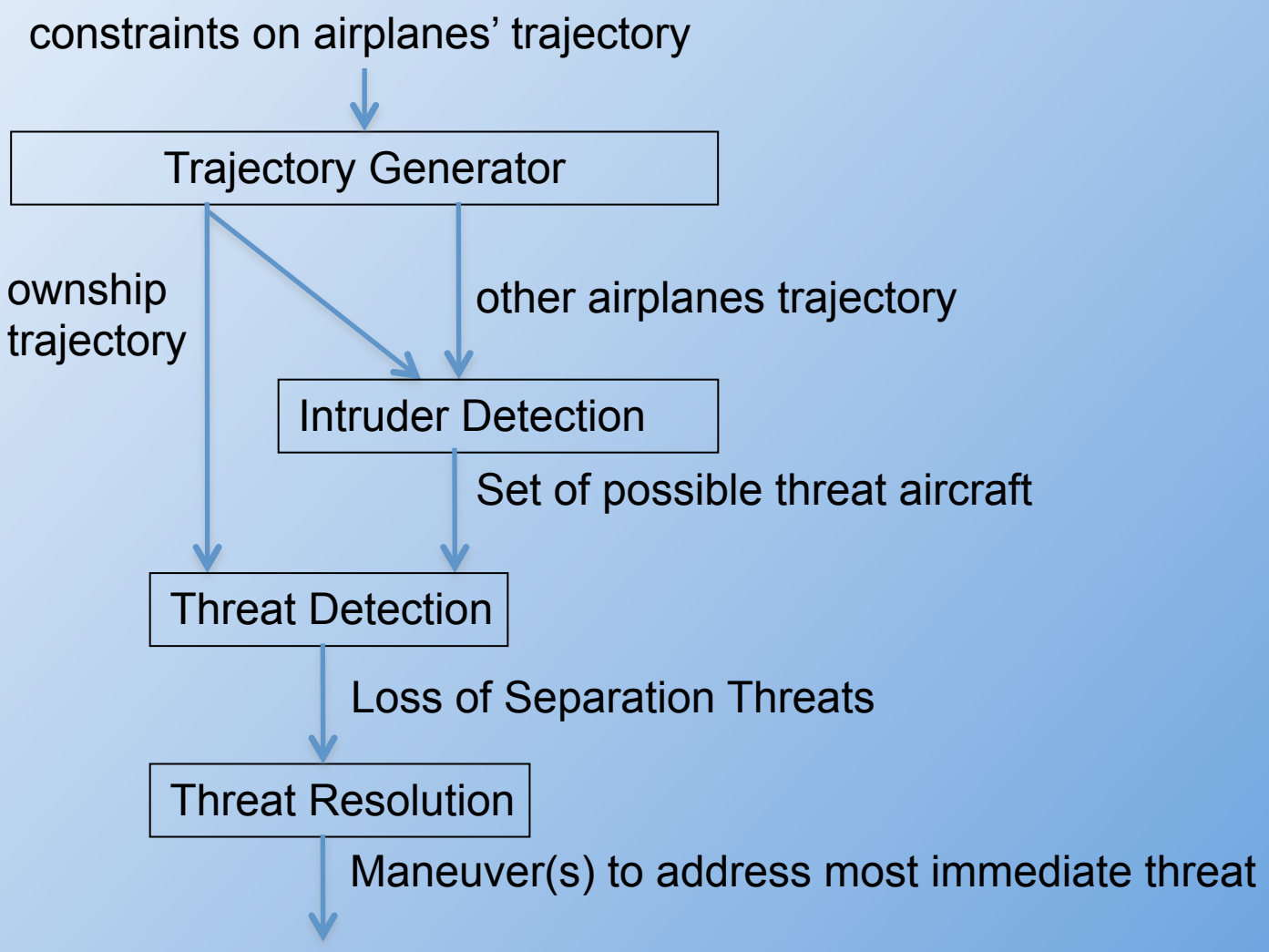
✓ – Hand evaluation of Bayes Net on characteristic examples

Evaluation using ACES

– create mix of small aircraft trajectories

X – compare ACES-SAA to iSAA

ACES SAA Architecture



ACES Threat Detection

- Trajectories for ownship and intruders are discretized and mapped to a lat/long grid called the DynMap.
- Loss-of-separation threats are evaluated on the DynMap. Start and End Times are computed for each threat.
- Threats that are beyond a minimum vertical separation threshold are discarded.

ACES Threat Resolution

- Only the Threat with minimum start time addressed.
- Algorithm deterministically tries a set of pre-specified steps to change one of {Horizontal position, Altitude, Speed} until it either resolves all the conflicts, or runs out of pre-specified changes to try.
- Each of the selected changes is translated into a corresponding maneuver.
- Result of Threat resolution is the set of Maneuvers that eliminates most immediate threat

ACES SAA Limitations

- No support for representing terrain and weather data
- Limited representation of aircraft type and capability information
- Does not support flight at different altitudes
- No support for information sources such as existing airways, IAPs, Traffic Patterns
- Does not utilize history of intruder's trajectory
- No good visualization capability
- Threat resolution assumes deterministic prediction
- intruder trajectories do not seem to respect heading & waypoint constraints

SAA Visualization

- Interactive discrete time simulation
- Incremental addition of intruders
- For each discrete time step, automatic display of:
  - 2D threat detection graph
  - Detected threats
  - Computed resolution maneuvers
- Saved history to support debugging/ verification

SAA Visualization

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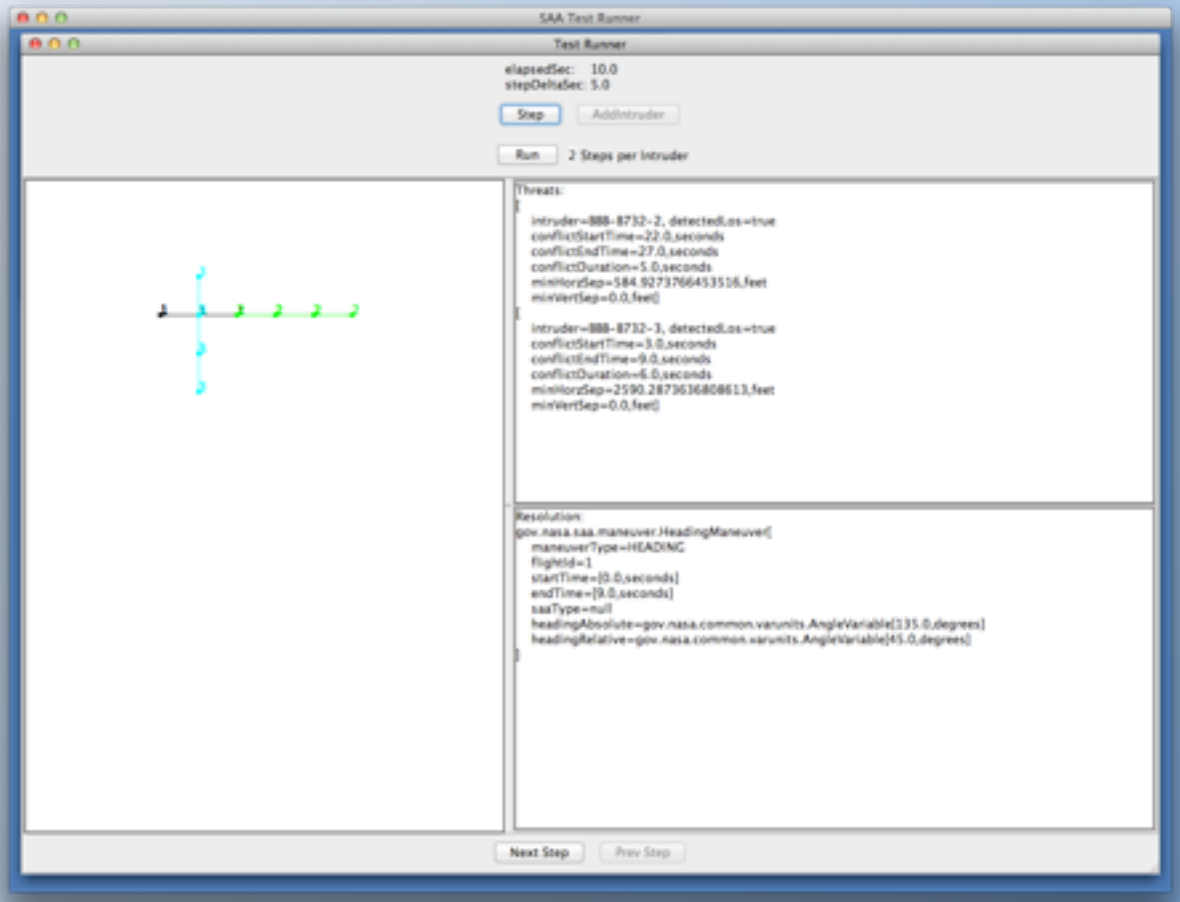
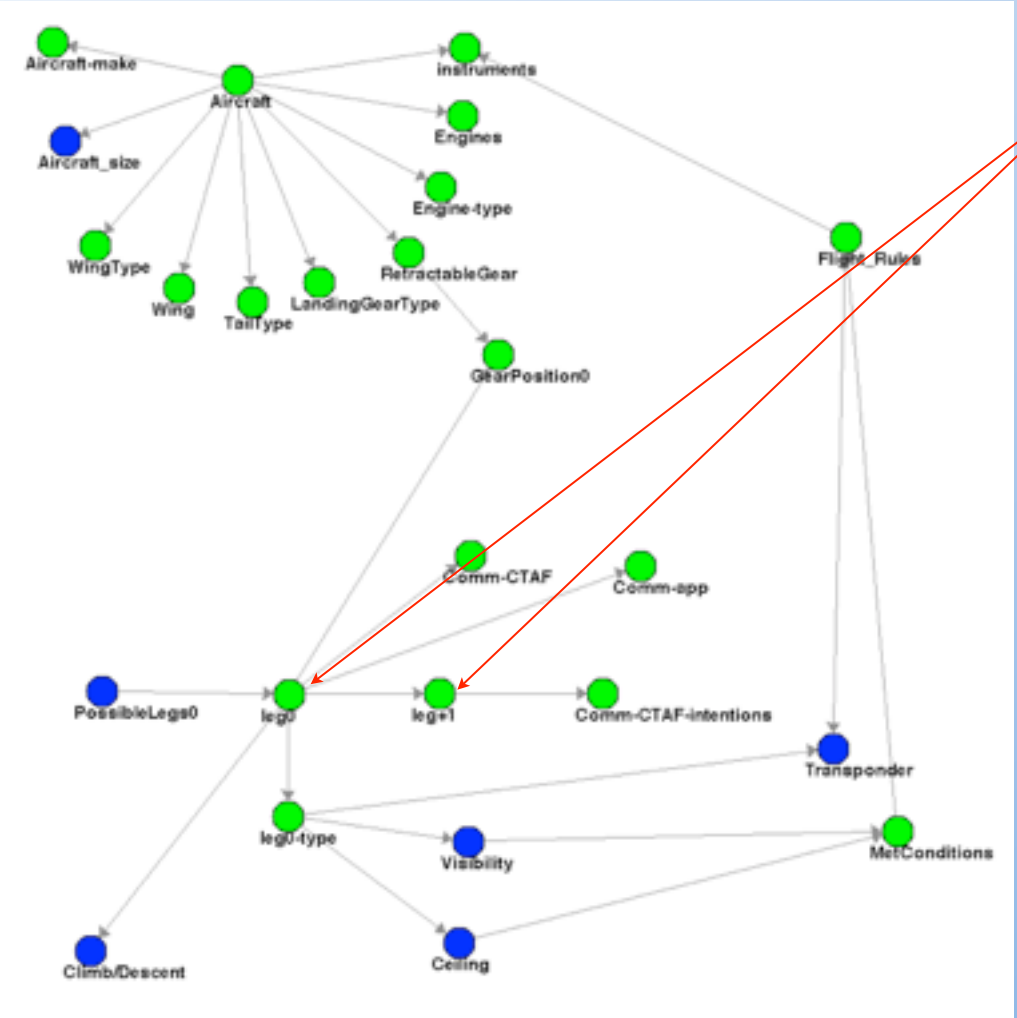


Challenges

Bayes Net Size and Encoding



Large CP tables

- very sparse
- painful to construct
- probabilistic automata

Area Instantiation

- relevant routes

Procedure Automata

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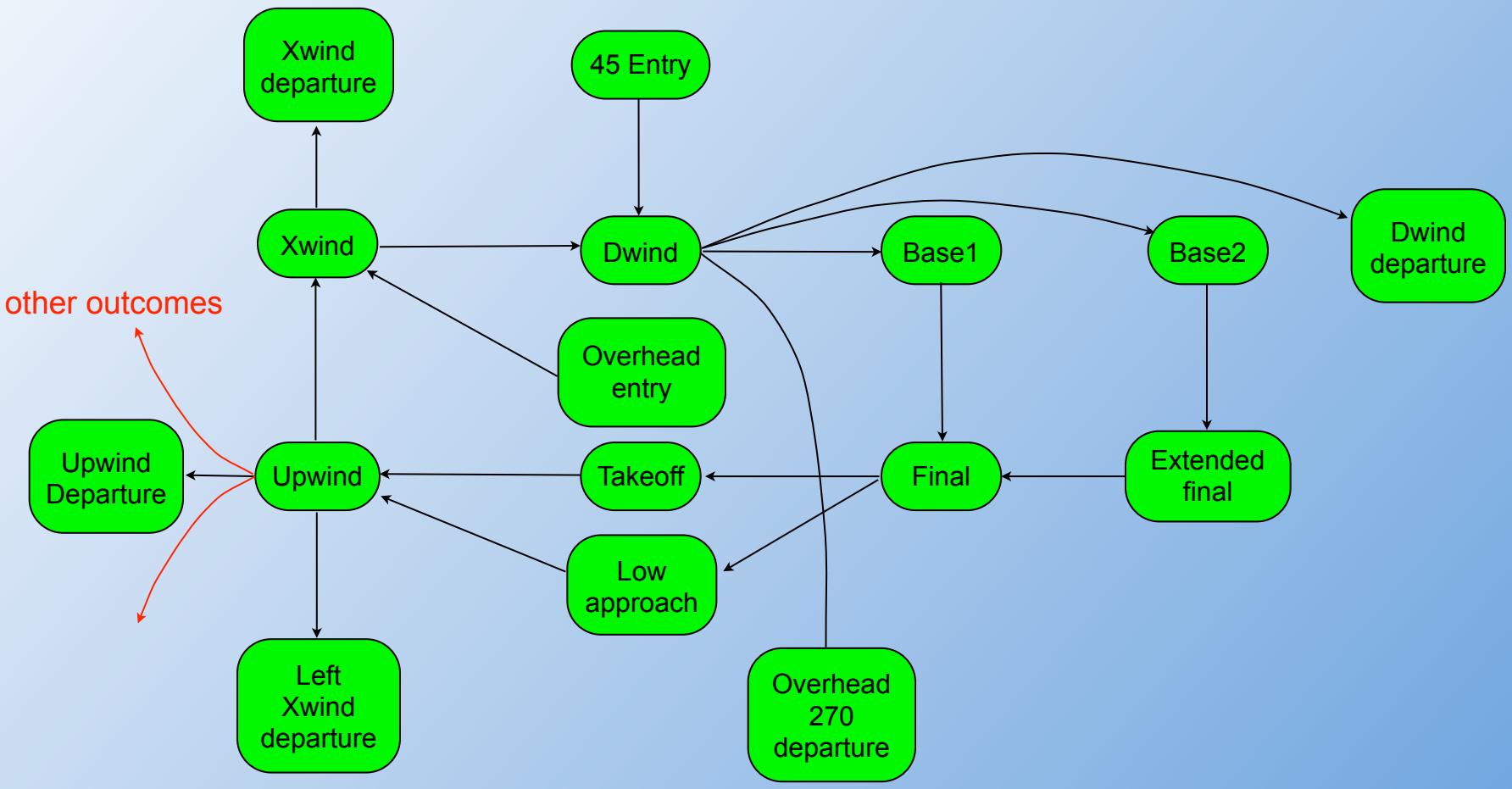

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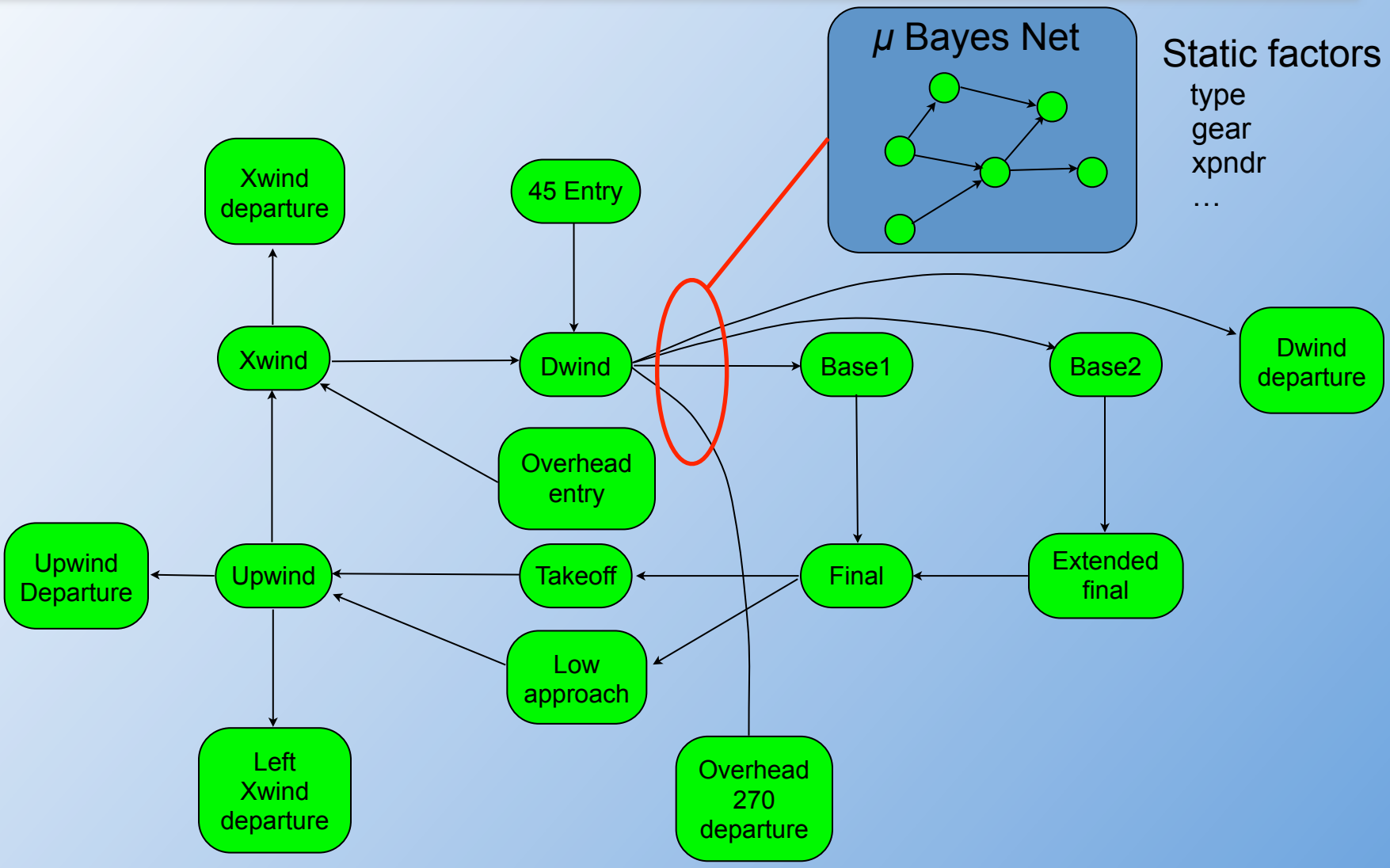
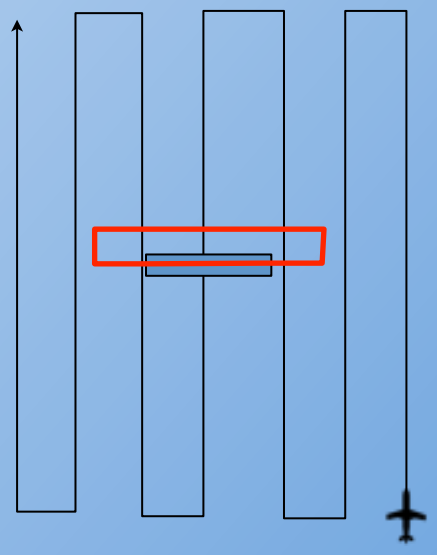


Next Steps

- Integration and testing with ACES
- More compact & robust representation of Bayes Net
- Automatic generation of Routes from NFD
- Probabilistic Threat Resolution
  - ACAS X approach
  - POMDPS are location specific
  - goals, wx, terrain, etc.



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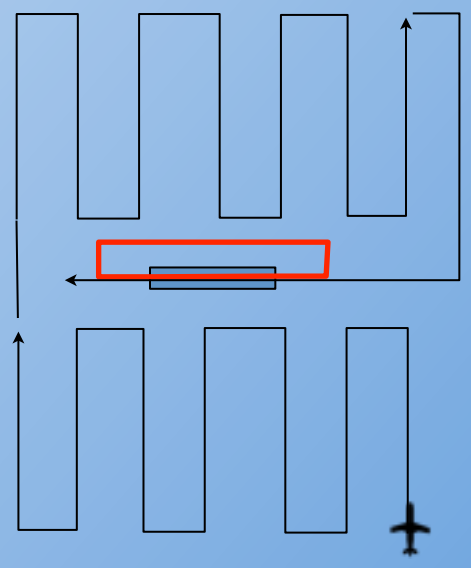
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