Contrail Observation and Detection Using Ground-Based Cameras

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1. Context

Contrails are a significant non-CO_2 contributor to aviation-related warming.

Challenges:

- Changing all aircraft's trajectories is difficult in a saturated airspace.
- Changing the engine properties is hard to enforce.

Opportunity: About 80% of contrail cirrus are caused by only 5% of flights.

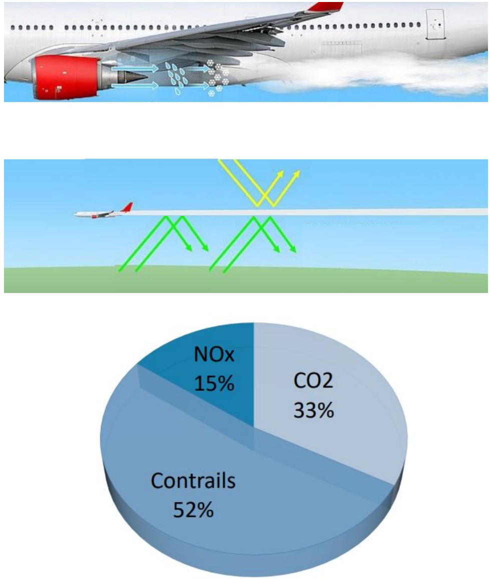

Figure 1. Contrails and their contribution to aviation's climate impact

1. Context

New European regulation on non-CO2 (contrails) impacts:

- Reporting in 2025
- Taxation in 2028

European Commission

SII Research contributes to industrial research projects of international corporations on this topic.

CICONIA (Airbus)

CONCERTO (THALES)

1. Context

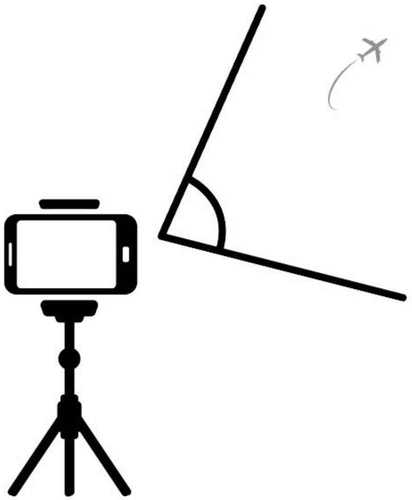

Figure 2. Ground-based observation

- Satellite observation faces *uncertainties* (trail identification accuracy, spatial and temporal limitations …)

- Ground observation studies exist but are *costly* and *focus on specific areas.*

→ Focus on *low-tech* ground observation

2. Contrail Observation

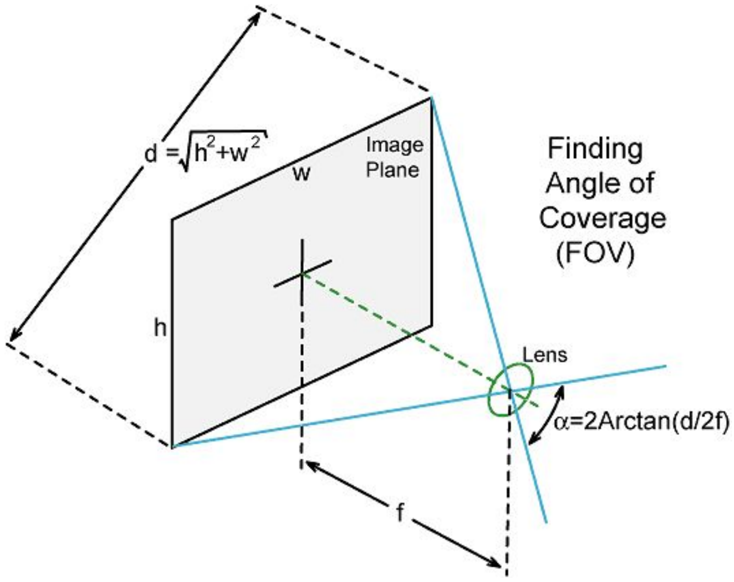

Figure 3. Field of View (FOV) calculation

$$\mathrm{FOV} = 2 \cdot \arctan\left(\frac{\text{sensor size}}{2 \cdot \text{focal length}}\right)$$

FOV of the main camera on **Samsung Note 20 Ultra** at *16:9* aspect ratio:

- Horizontal FOV: *41.05°*
- Vertical FOV: *67.30°*

2. Contrail Observation

- Current GPS coordinates: *(43.5707, 1.4683)*
- Center orientation: *214.5° SW*

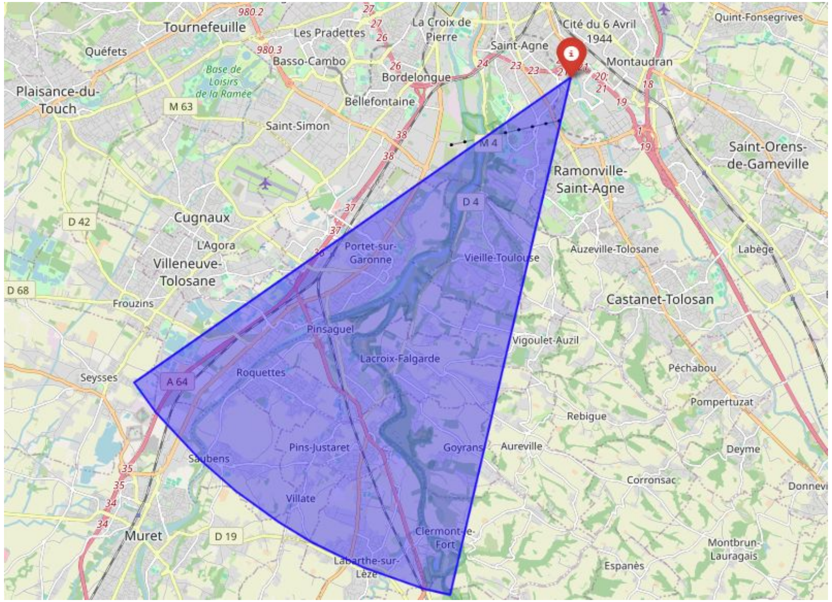

Figure 4. Observation area of camera 1

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2. Contrail Observation

Question: *What is the ideal distance between two cameras?*

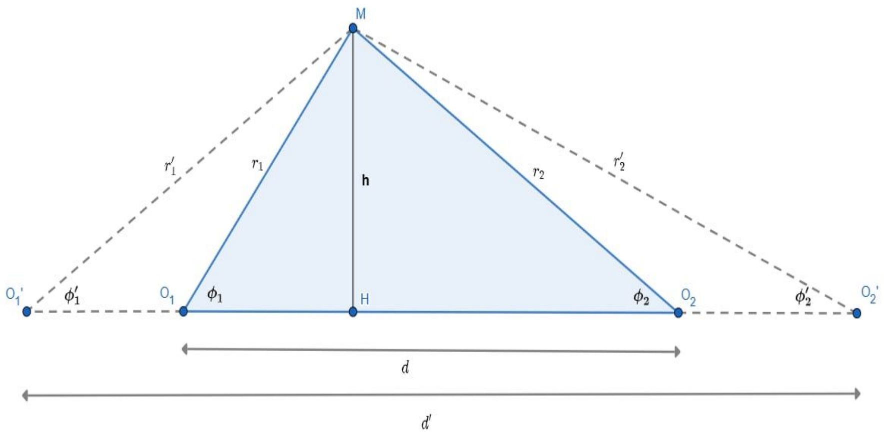

Figure 5. Modeling the problem to determine the optimal distance

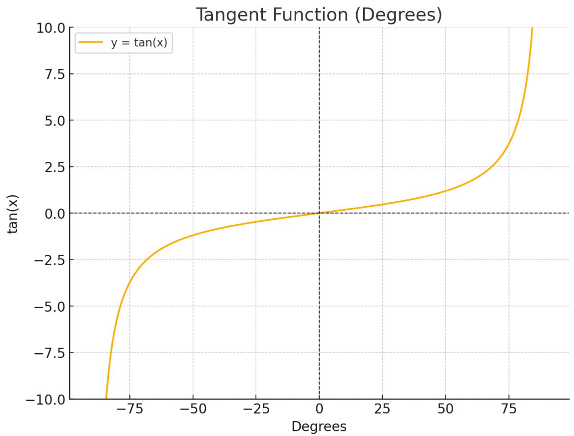

Figure 6. Graph of the tangent function in degrees

Balance two criteria: **object clarity in images** and **calculation accuracy**.

2. Contrail Observation

Contrail clarity in the images

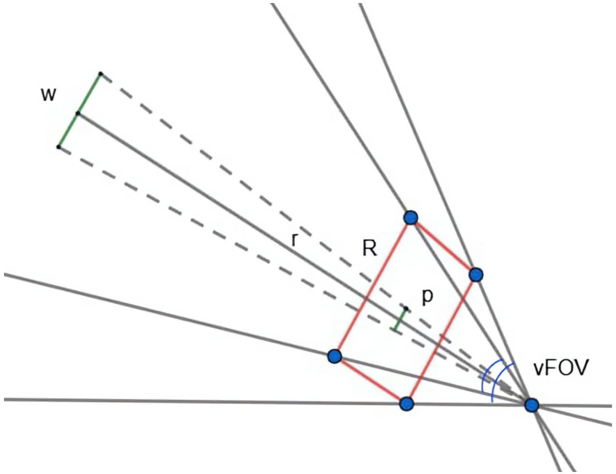

Figure 7. Calculating the number of pixels p representing the contrails

$$p = \frac{w}{r} \cdot \frac{R}{2\tan\left(\frac{\text{vFOV}}{2}\right)}$$

where:

- r: camera-contrail distance
- w: contrail width, range within *200-400* m
- R: vertical resolution, R = *3840* for 4K camera
- $vFOV$: vertical field of view, $vFOV$ = 67.3°

- Increase d ⇔ Increase r ⇔ Reduce p ⇔ Contrails will not be clear.
- We need a small enough distance d.

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2. Contrail Observation

Height calculation accuracy

To simplify the calculation, we assume $\phi_1 = \phi_2 = \phi$

$$h = \frac{d}{2} \cdot \tan(\phi)$$

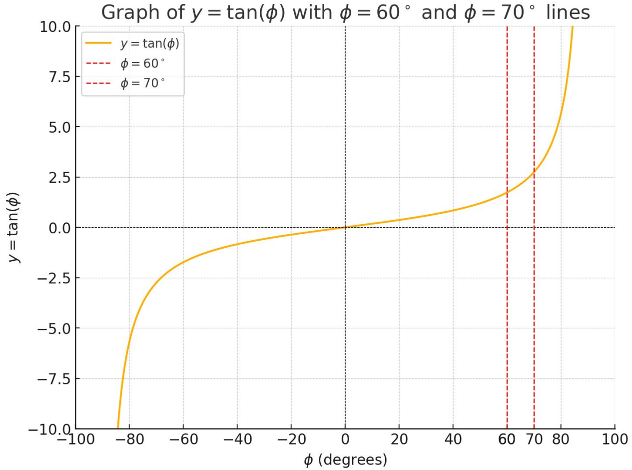

Figure 8. Graph of the Tangent Function and Boundary Values

- When $\phi > 70°$, the **tan(ϕ)** function curve increases rapidly.
- To avoid errors in calculation h , **limit** the value of ϕ ⇔ **Increase** d

2. Contrail Observation

Question: *What is the ideal distance between two cameras?*

- Increasing d ⇔ reducing contrail clarity in images
- Decreasing d ⇔ potentially causing large errors when $\phi > 70°$

Table 1. Values of distance, number of pixels, and error range with different ϕ values

Angle ϕ	Distance d (m)	Number of Pixels p	Error Range (%) (for a 1° deviation)
60°	13856	42	4.07 - 4.16
65°	11191	44	4.59 - 4.73
70°	8735	45	5.47 - 5.70

Balance two criteria: **calculation accuracy** and **object clarity in images**.
We choose ϕ **= 65° ⇔ d = 11191m**

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2. Contrail Observation

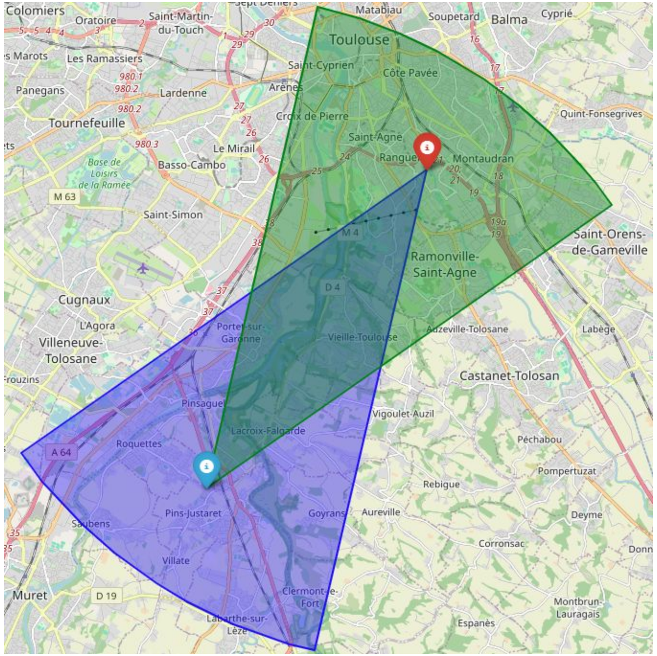


Figure 9. Proposed second camera position

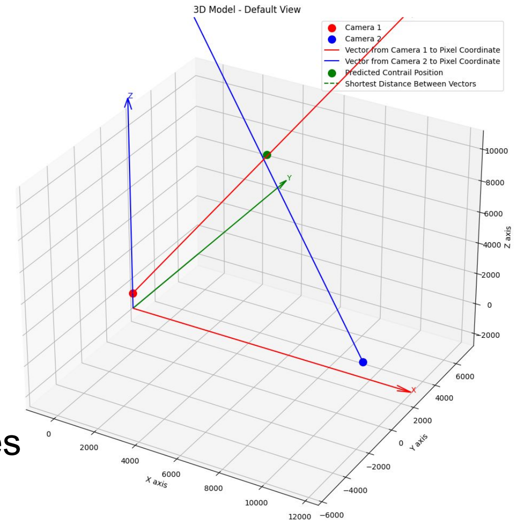
- Camera 2 GPS coordinates: *(43.4878, 1.3896)*
- Center orientation: *34.5° NE*

3. Approximate the GPS coordinate of the contrail

Input → Algorithm → Contrail's position in $Oxyz$

What we need (Input):

- Geographic coordinates of 2 cameras
- Camera specifications:
  - Resolution of images
  - Horizontal and vertical FOV
  - Tilt angle of the camera
- Pixel coordinates of the contrail on the images



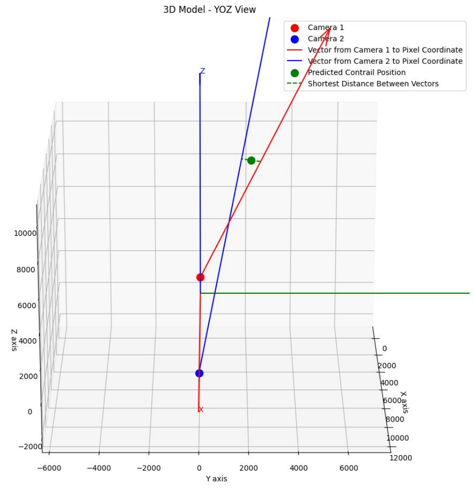


Figure 10. Estimate the contrail’s position in Oxyz

3. Approximate the GPS coordinate of the contrail

Input → Algorithm → Contrail's position in $Oxyz$

Algorithm to determine contrail coordinates:

1. Model the problem in $Oxyz$ coordinates

2. Determine the equations of the contrail-camera vectors

3. The contrail's position is the closest point to these two vectors (ideally, is the intersection)

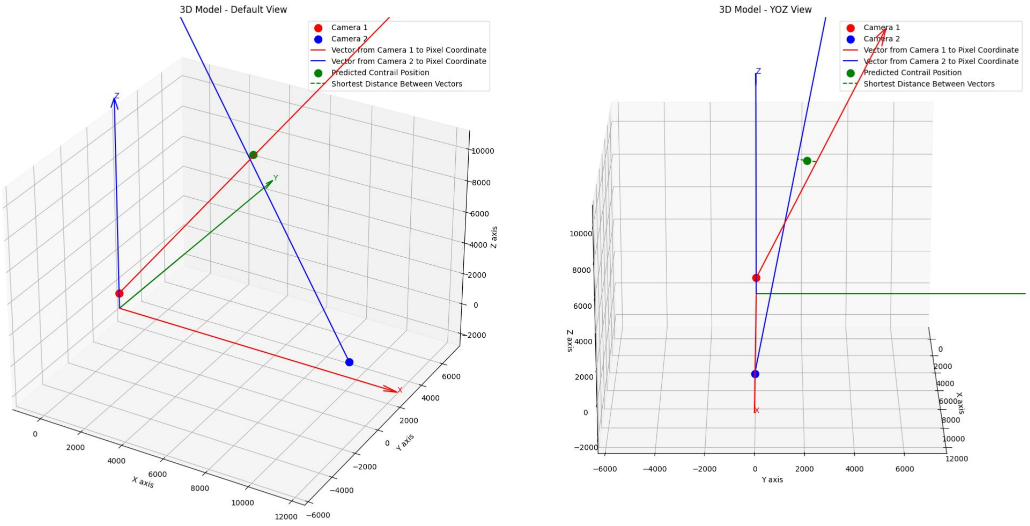


Figure 10. Estimate the contrail's position in Oxyz

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3. Approximate the GPS coordinate of the contrail

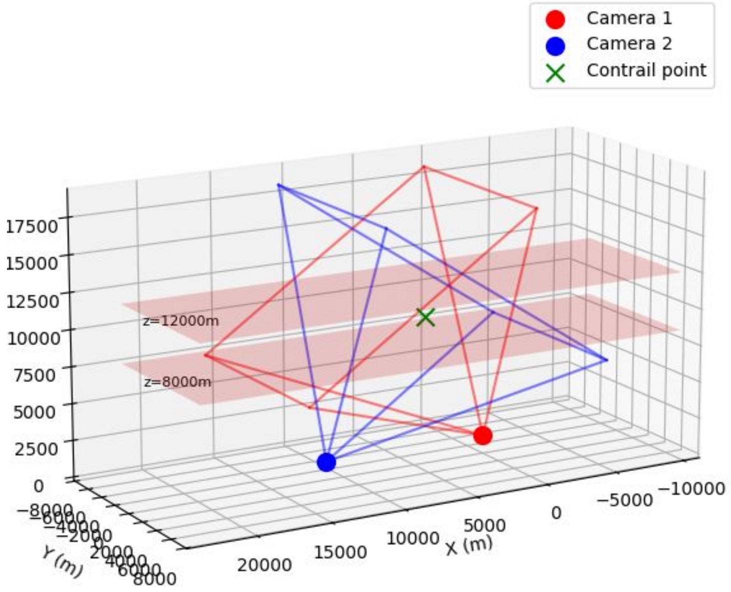

Figure 11. Predicted Oxyz coordinates of the contrail point, FOV of the two cameras, and limiting altitude for contrail appearance

Predicted Oxyz coordinates of the contrail point:
(5477.39, 1574.07, 10227.52)

3. Approximate the GPS coordinate of the contrail

Formula for changes in longitude and latitude:

$$\Delta \text{lat} = \frac{D}{R}\cos(\theta)$$

$$\Delta \text{lon} = \frac{D}{R\cos(\text{latitude})}\sin(\theta)$$

where:

- D: Distance between the camera and the contrail
- R: Earth radius *(6,371,000 m)*
- Θ: Geographic angle of the contrail-camera vector
- $latitude$: Current latitude of the camera

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3. Approximate the GPS coordinate of the contrail

Predicted GPS coordinates of the contrail point:
(43.5241, 1.4389, 10227.52)

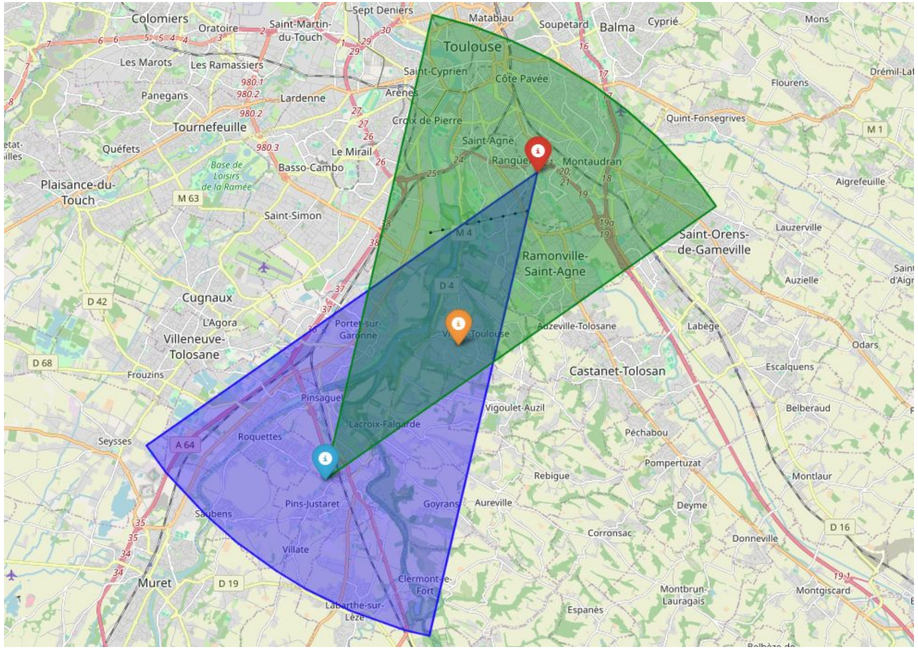

Figure 12. Predicted GPS coordinates of the contrail point

4. Detecting and classifying the contrails

Image annotation → Model training → Prediction

Image annotation: Create an oriented bounding box for each object

Model training: YOLOv8n-OBB model

Prediction: Detection on new images

4. Detecting and classifying the contrails

Classification criteria: *shape*, *width*, *blur*, *formation time*, and *color*

6 classes: young contrail, old contrail, very old contrail, parasite, sun, unknown

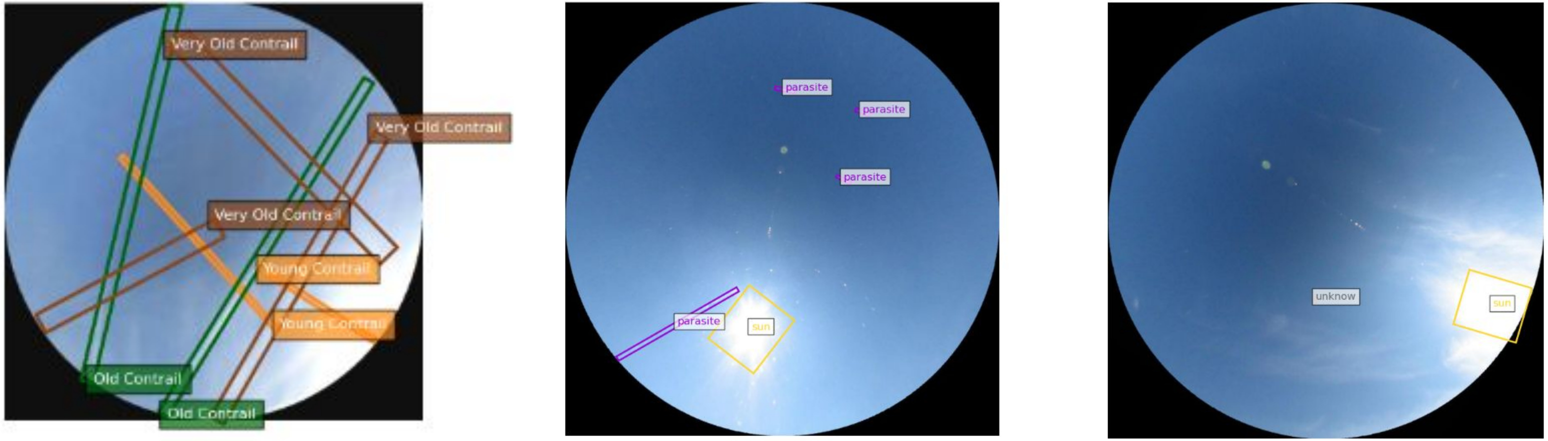

Figure 13. Samples in an open-source dataset on Roboflow

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4. Detecting and classifying the contrails

Table 2. Performance metrics of the YOLOv8n model on the validation set

Class	Images	Instances	Precision	Recall	mAP50
all	810	1789	0.858	0.833	0.896
old contrail	124	162	0.760	0.821	0.863
very old contrail	248	497	0.876	0.932	0.961
young contrail	306	388	0.803	0.631	0.759
parasite	202	323	0.866	0.762	0.883
sun	348	348	0.986	0.994	0.993
unknown	63	71	0.857	0.859	0.914

Young contrails (harder to detect) → Old contrails (easier) → Very old contrails (best detected)

4. Detecting and classifying the contrails

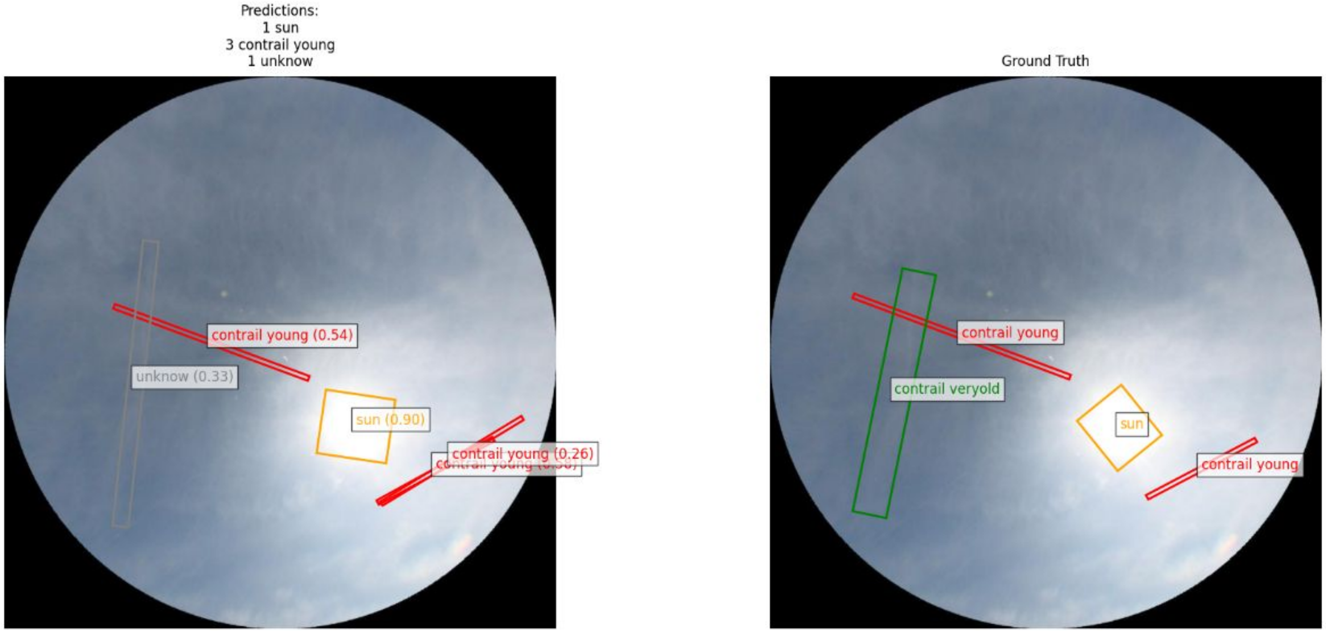

Figure 14. Visualization of predictions and ground truth on the test set

5. Achievements and Future direction

Achievements:

1. Proposed an optimal distance of approximately 11 km between the two cameras.
2. Calculated GPS coordinates of the contrail based on pixel coordinates of images.
3. Trained a Yolov8n-OBB model on an open source dataset, achieving Precision, Recall, mAP50 metrics mostly above 0.8.

Future direction:

1. Collect and label data to create our own dataset.
2. Track contrail persistence to identify Ice-Supersaturated Regions (ISSR).
3. Match contrails to their corresponding aircraft types.

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