



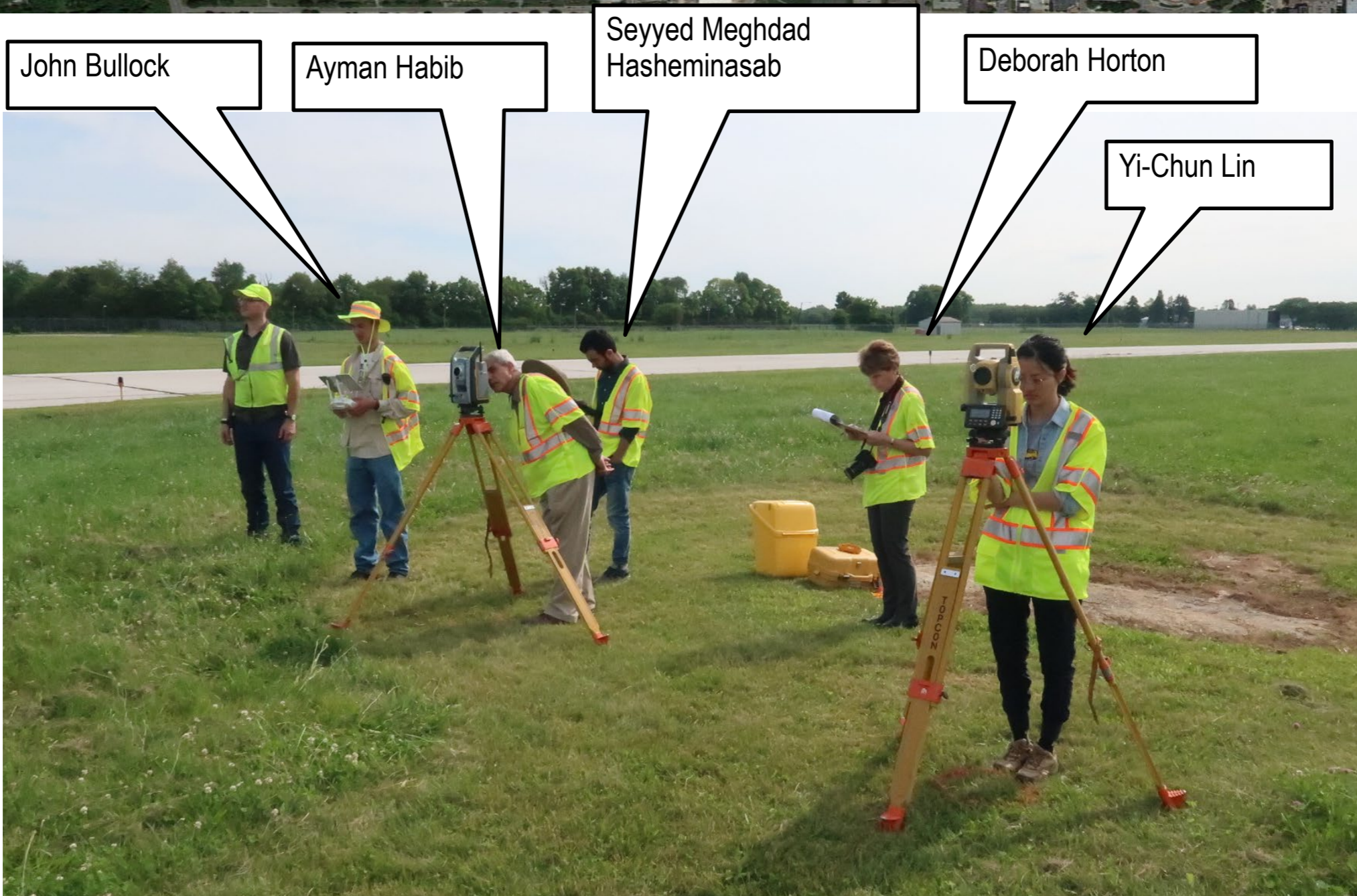
UAS Based Methodology for Measuring Glide Slope Angles of Airport Precision Approach Path Indicators (PAPI)

March 11, 2020

Yi-Chun Lin, Seyyed Meghdad Hasheminasab, John L. Bullock, Deborah Horton, Adam Baxmeyer, Ayman Habib, and Darcy M. Bullock

Lyles School of Civil Engineering
Purdue University

The Research Team



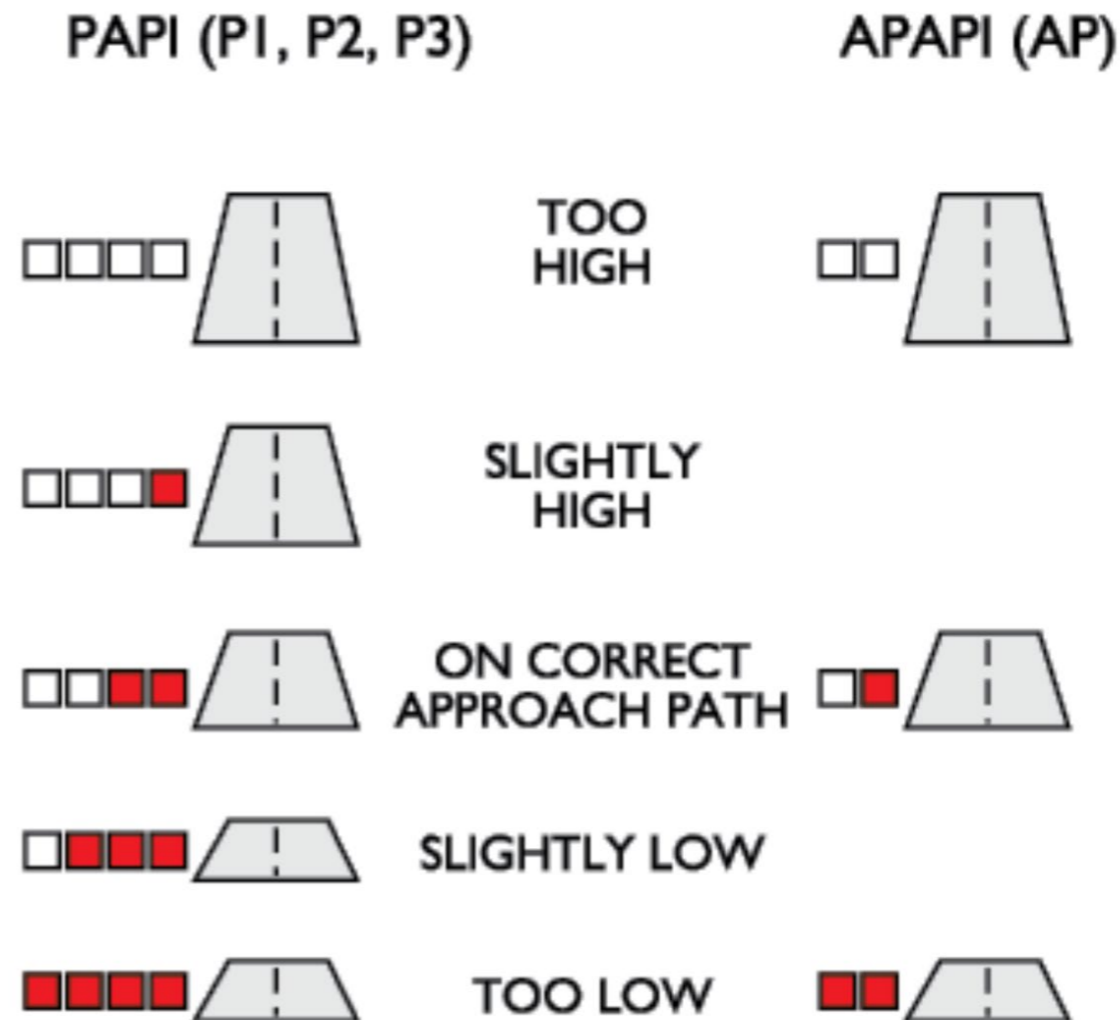
First Author Yi-Chün Lin (Jill)



Topics



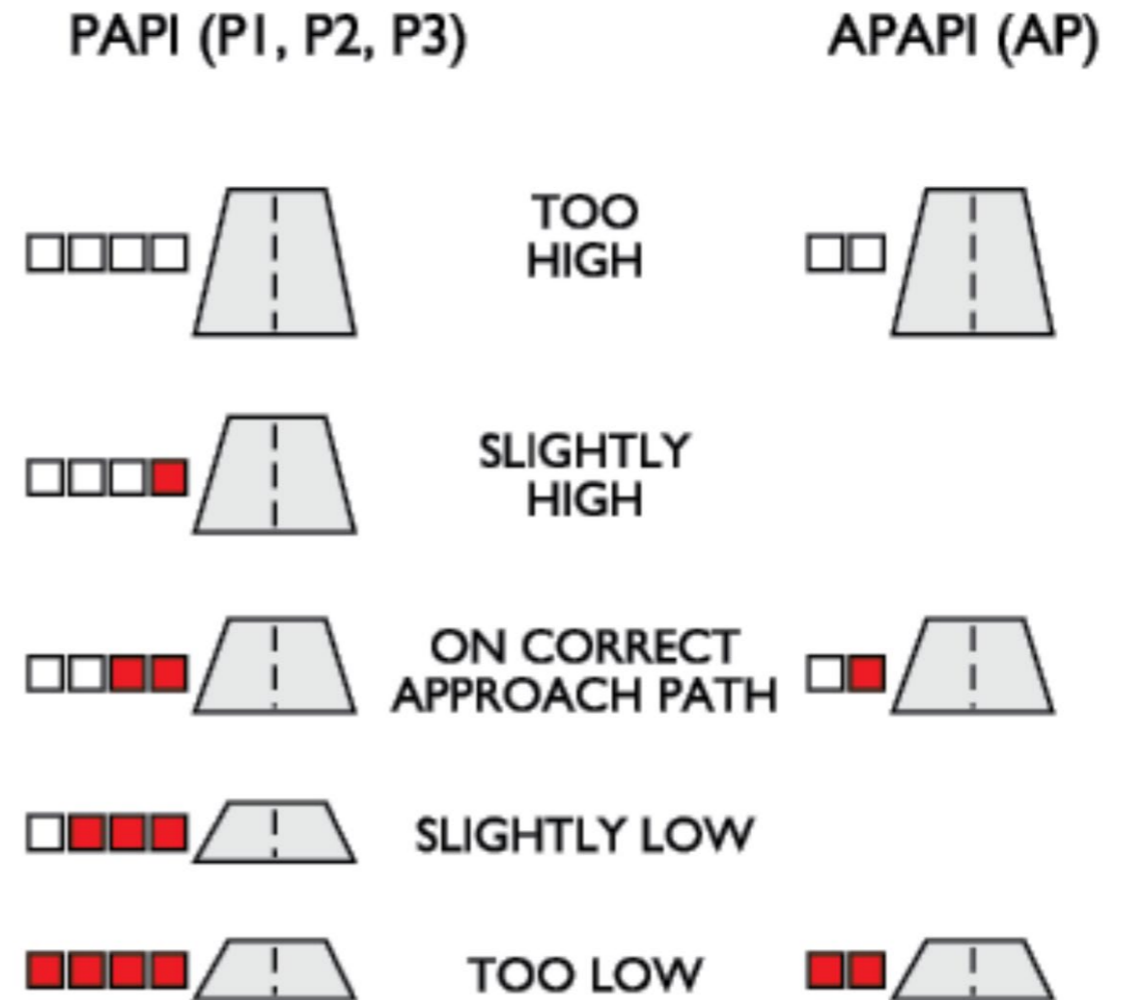
1. Research Team
2. **Problem Statement**
3. PAPI Light Concept
4. PAPI Light Images from Left Seat of Cessna 170
5. Surveying Procedures
6. PAPI Light Images from UAS
7. Glideslope Angle Estimate
8. Conclusion and Ongoing Implementation Activities



Problem Statement



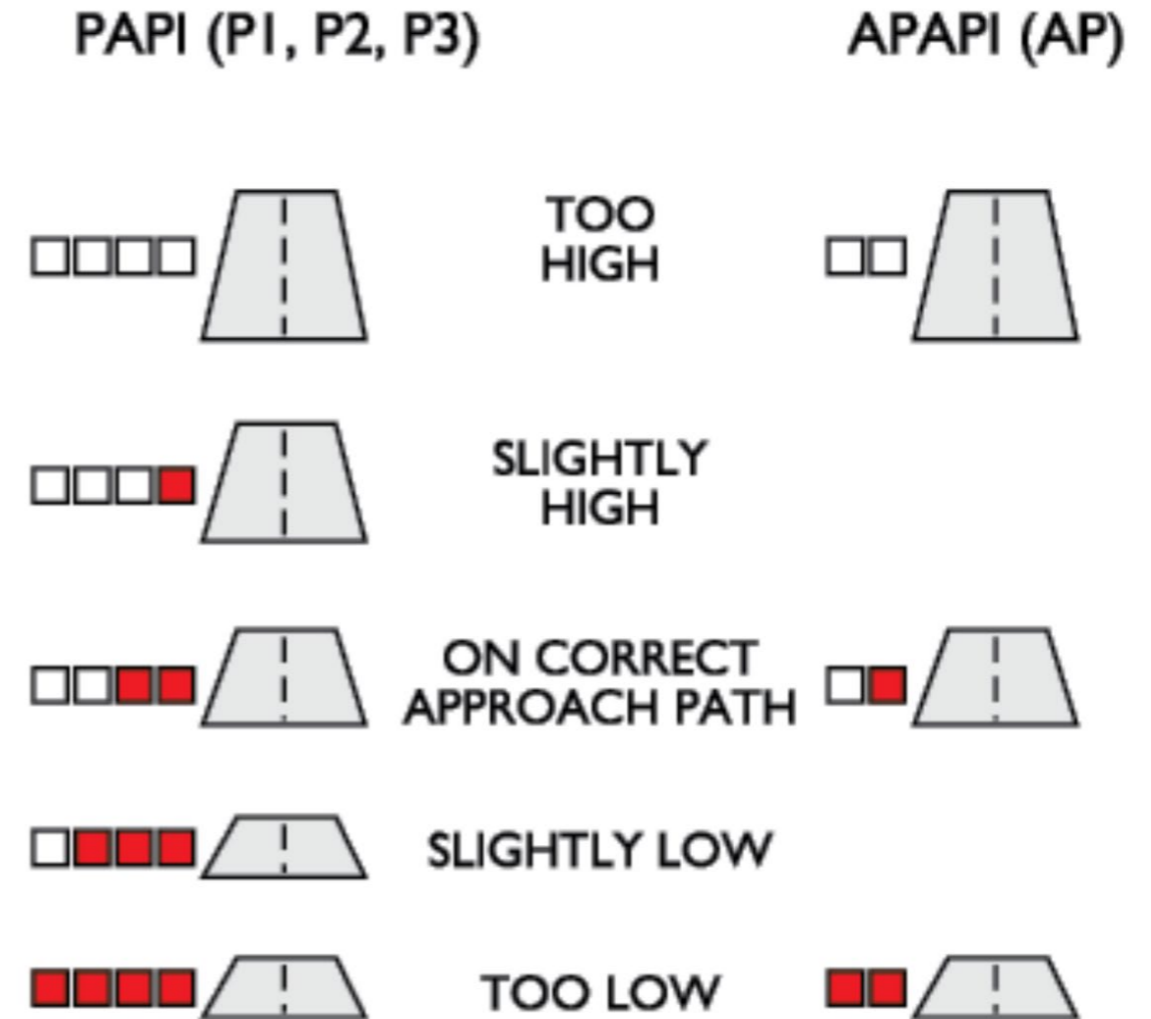
- Can we use UAS imagery and high quality positions to evaluate PAPI/APAPI



Topics (2)



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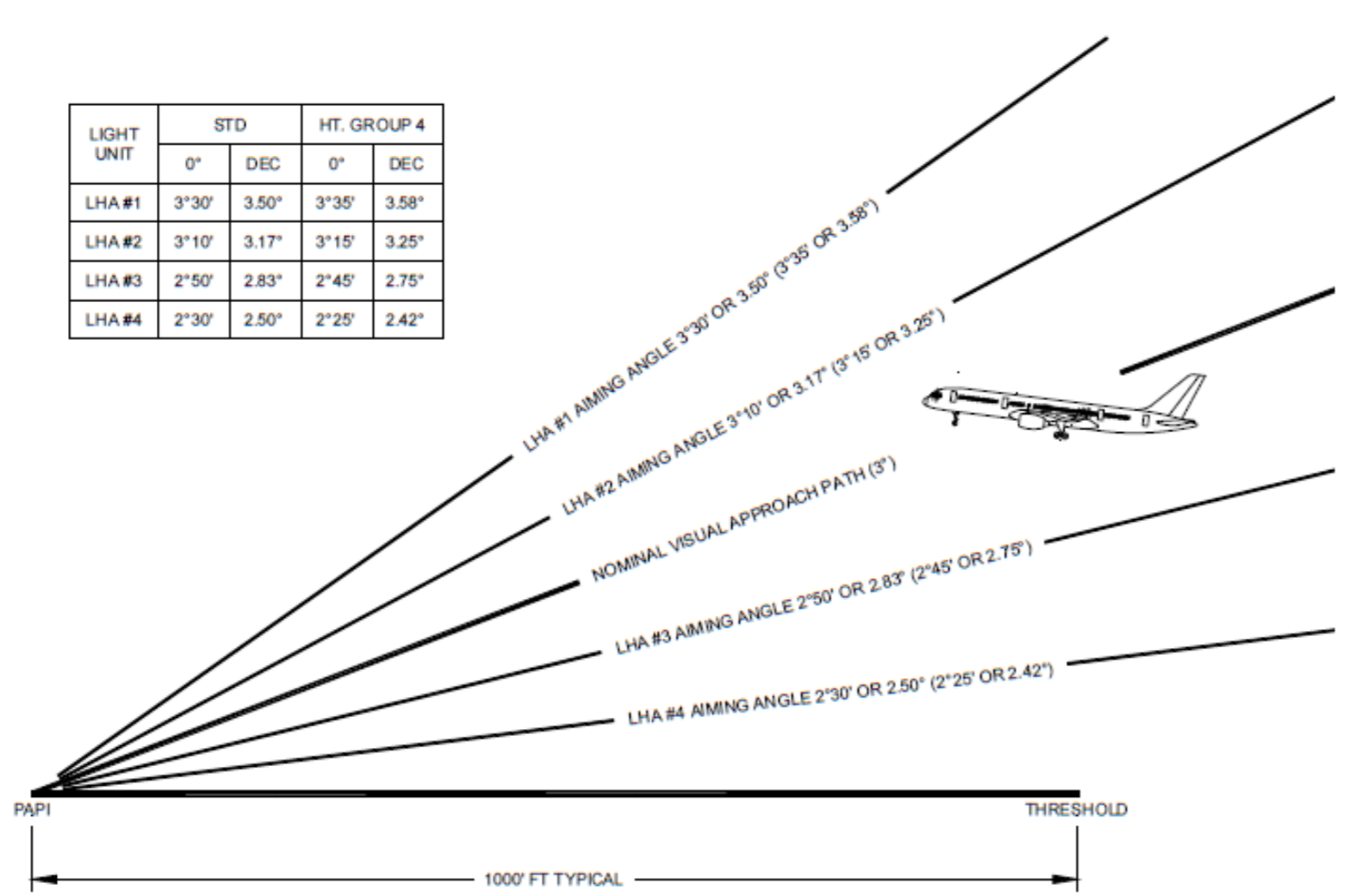


PAPI Light Concept



FIGURE 5-3. PAPI APPROACH PATH (SIDE VIEW)

LIGHT UNIT	STD		HT. GROUP 4	
	0°	DEC	0°	DEC
LHA #1	3°30'	3.50°	3°35'	3.58°
LHA #2	3°10'	3.17°	3°15'	3.25°
LHA #3	2°50'	2.83°	2°45'	2.75°
LHA #4	2°30'	2.50°	2°25'	2.42°



8/20/10

JO 6850.2B

NOTE: () IS THE AIMING ANGLE FOR HT. GROUP 4 AIRCRAFT ON ELECTRONIC GLIDE SLOPE RUNWAYS. SEE TABLE 5-2.



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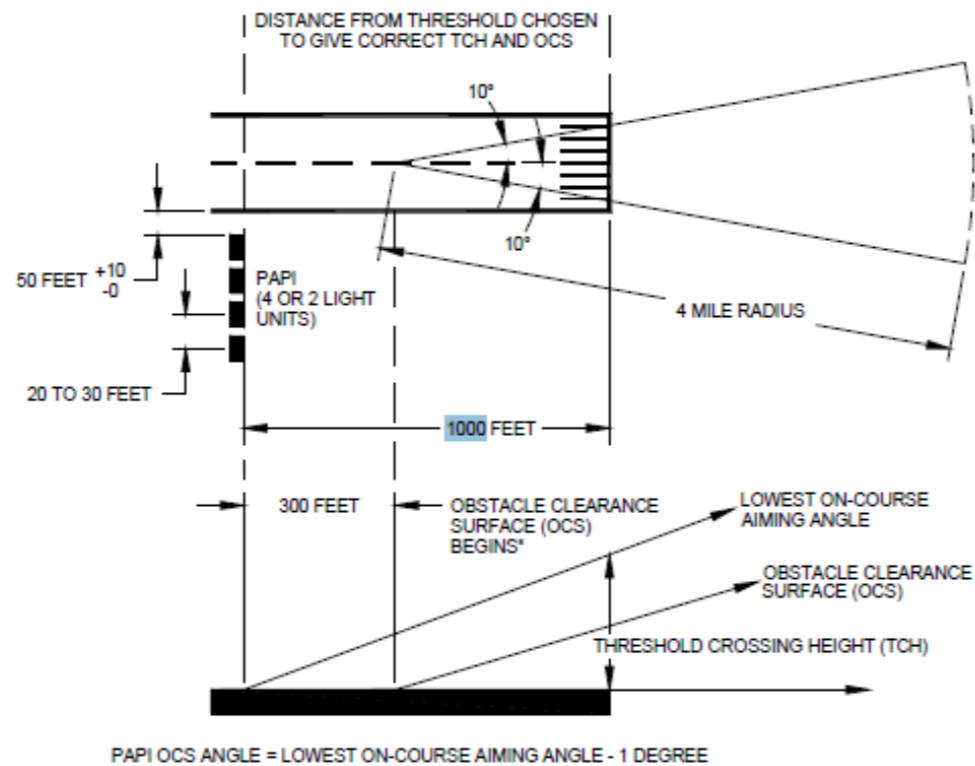
**ORDER
JO 6850.2B**

Effective Date:
8/20/10

SUBJ: Visual Guidance Lighting Systems

This order contains installation criteria for all visual guidance lighting systems installed under the Facilities and Equipment (F&E) Program. This order was revised to Revision B and includes Changes 1 through 4 from the previous version dated February 8, 1989.

Teri L. Bristol
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Vice President, Technical Operations Services



NOTES:

1. THE VISUAL GLIDE PATH ANGLE IS THE CENTER OF THE ON-COURSE ZONE, AND IS A NOMINAL 3 DEGREES WHEN MEASURED FROM THE HORIZONTAL SURFACE OF THE RUNWAY.
 - A. FOR NON-JET RUNWAYS, THE GLIDE PATH MAY BE RAISED TO 4 DEGREES MAXIMUM TO PROVIDE OBSTACLE CLEARANCE.
 - B. IF THE PAPI GLIDE PATH IS CHANGED TO A HIGHER ANGLE FROM THE NOMINAL 3 DEGREES, IT MUST BE COMMUNICATED IN A NOTICE TO AIRMAN (NOTAM) AND PUBLISHED IN THE AIRPORT FACILITY DIRECTORY.
2. PAPI OBSTACLE CLEARANCE SURFACE (OCS).
 - A. THE PAPI OCS PROVIDES THE PILOT WITH A MINIMUM APPROACH CLEARANCE.
 - B. THE PAPI MUST BE POSITIONED AND AIMED SO NO OBSTACLES PENETRATE ITS SURFACE.
 - (1) THE OCS BEGINS 300 FEET [90M] IN FRONT OF THE PAPI SYSTEM.
 - (2) THE OCS IS PROJECTED INTO THE APPROACH ZONE ONE DEGREE LESS THEN AIMING ANGLE OF THE THIRD LIGHT UNIT FROM THE RUNWAY FOR AN L-880 SYSTEM, OR THE OUTSIDE LIGHT UNIT FOR AN L-881 SYSTEM.



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5176

AIRPORT DIAGRAM

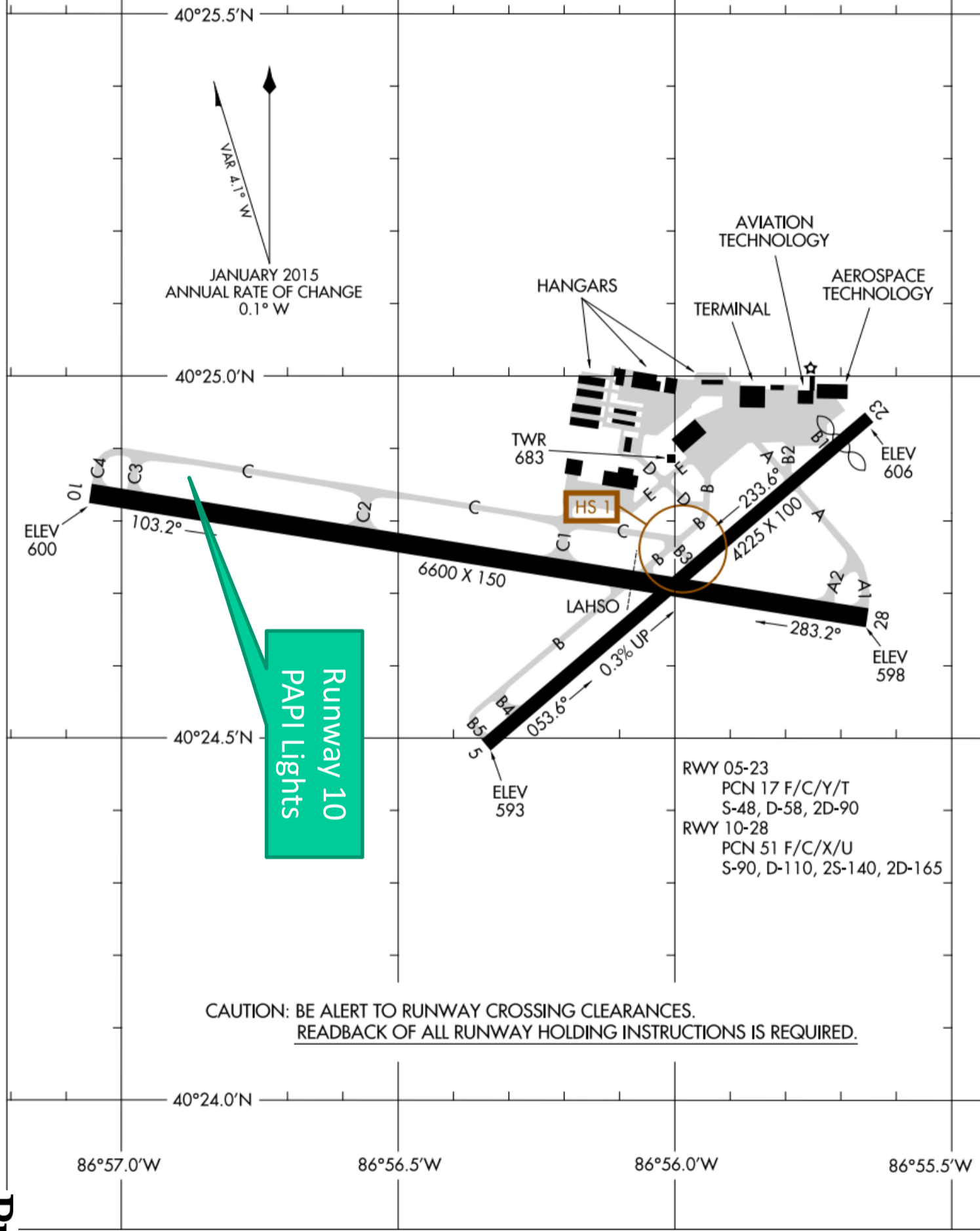
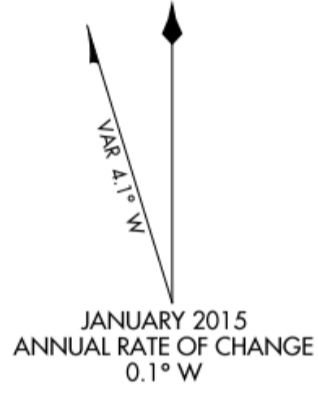
AL-220 (FAA)

PURDUE UNIVERSITY (LAF)
 LAFAYETTE, INDIANA

D
 METIS
 127.75
 LAFAYETTE TOWER ★
 119.6 393.0
 GND CON
 121.9 393.0

FIELD
 ELEV
 606

EC-2, 23 MAY 2019 to 20 JUN 2019



RWY 05-23
 PCN 17 F/C/Y/T
 S-48, D-58, 2D-90
 RWY 10-28
 PCN 51 F/C/X/U
 S-90, D-110, 2S-140, 2D-165

CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
READBACK OF ALL RUNWAY HOLDING INSTRUCTIONS IS REQUIRED.

86°57.0'W

86°56.5'W

86°56.0'W

86°55.5'W

AIRPORT DIAGRAM

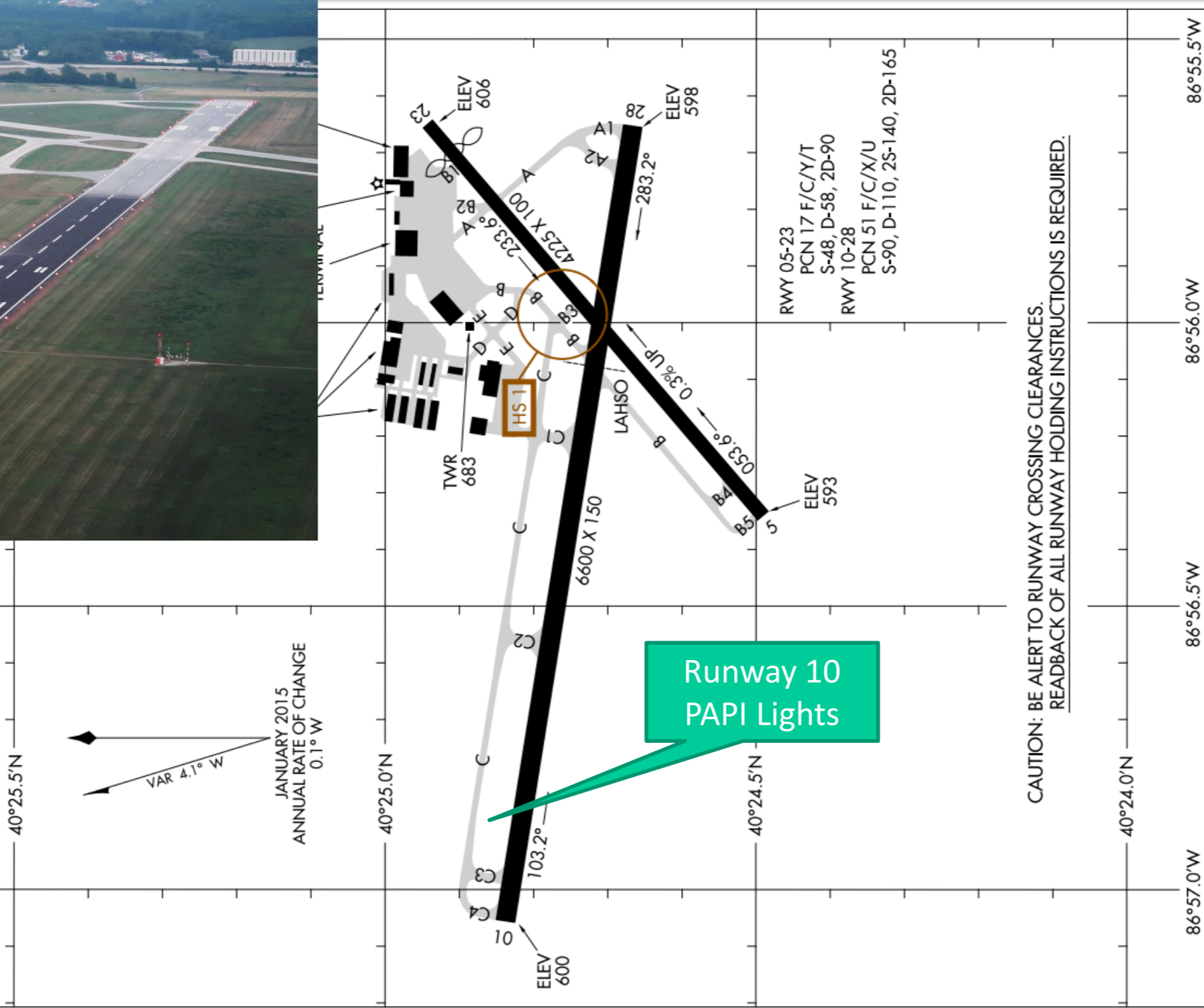
LAFAYETTE, INDIANA
 PURDUE UNIVERSITY (LAF)

5176



15176
AIRPORT DIAGRAM

127.75
LAFAYETTE TOWER ★
119.6 393.0
GND CON
121.9 393.0
D



JANUARY 2015
ANNUAL RATE OF CHANGE
0.1° W

VAR 4.1° W

RWY 05-23
PCN 17 F/C/Y/T
S-48, D-58, 2D-90
RWY 10-28
PCN 51 F/C/X/U
S-90, D-110, 2S-140, 2D-165

CAUTION: BE ALERT TO RUNWAY CROSSING CLEARANCES.
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40°25.5'N
40°25.0'N
40°24.5'N
86°57.0'W
86°56.5'W
86°56.0'W
86°55.5'W

15176
AIRPORT DIAGRAM



PAPI Light Concept (3)



Runway 10
PAPI Lights



Oblique air photo of Purdue Airport (KLAf)
Runway 10/28

PAPI Light Concept (4)



- Front Side of Runway 10 PAPI Lights



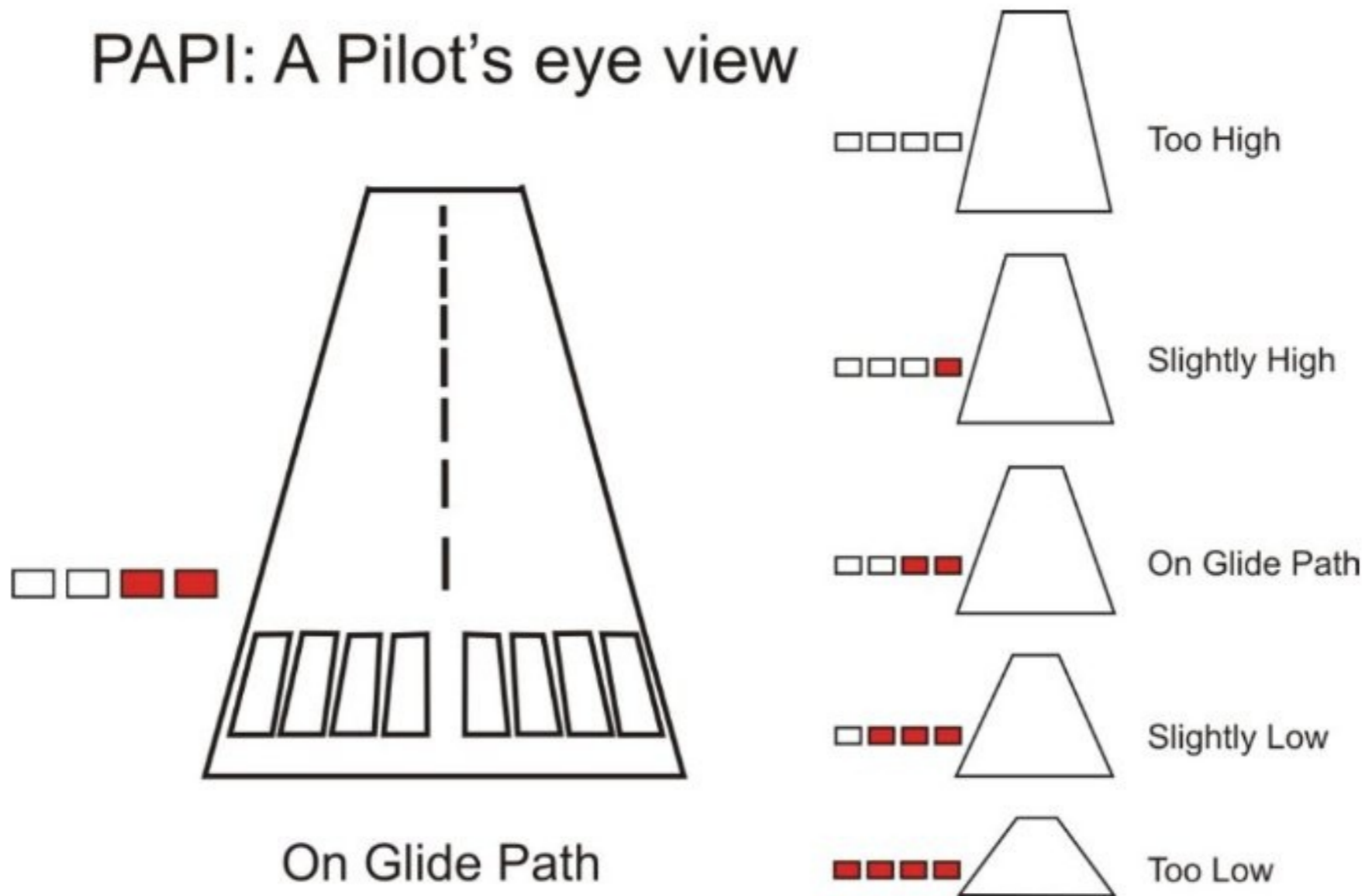
PAPI Light Concept (5)



PAPI Light Concept (6)



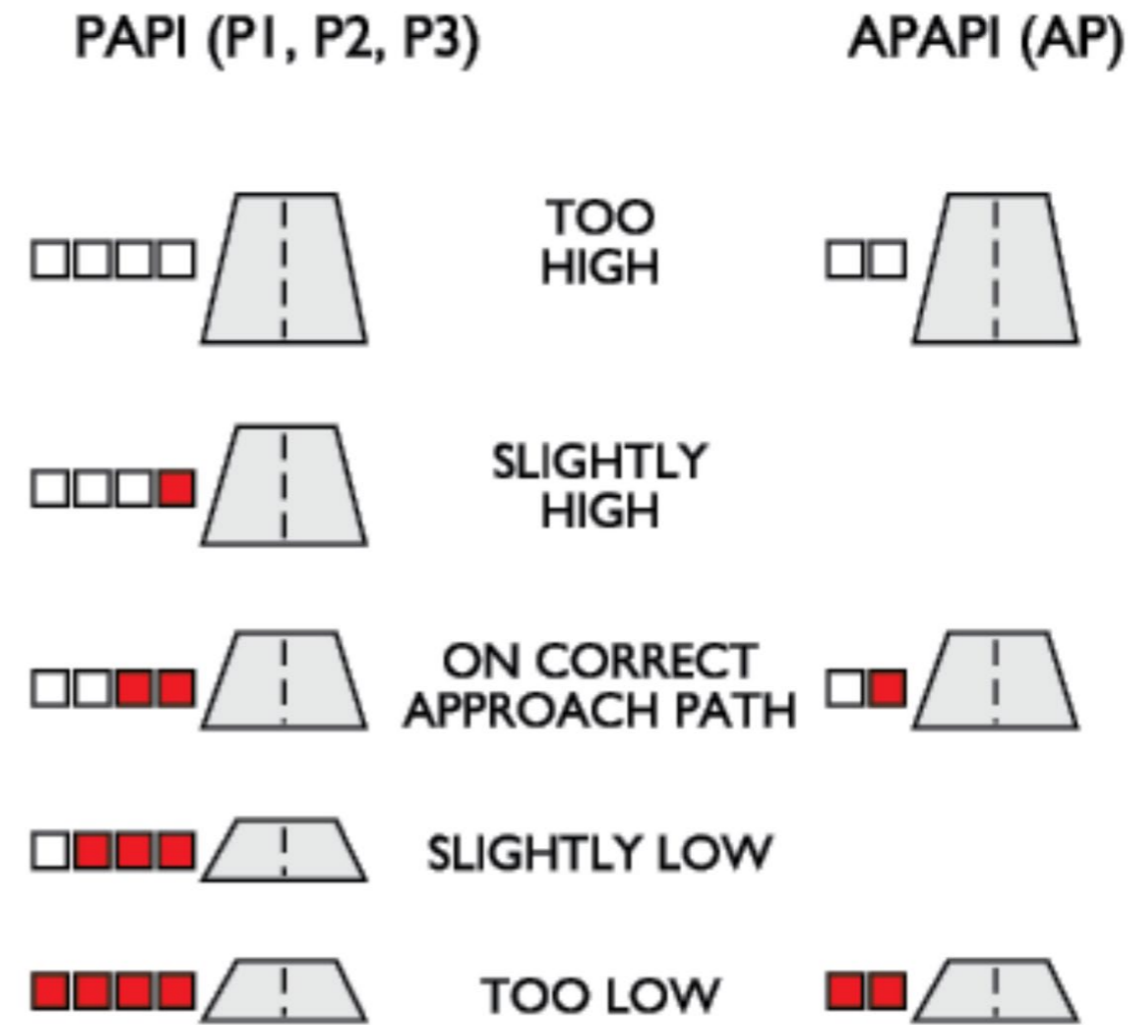
PAPI: A Pilot's eye view



Topics (3)



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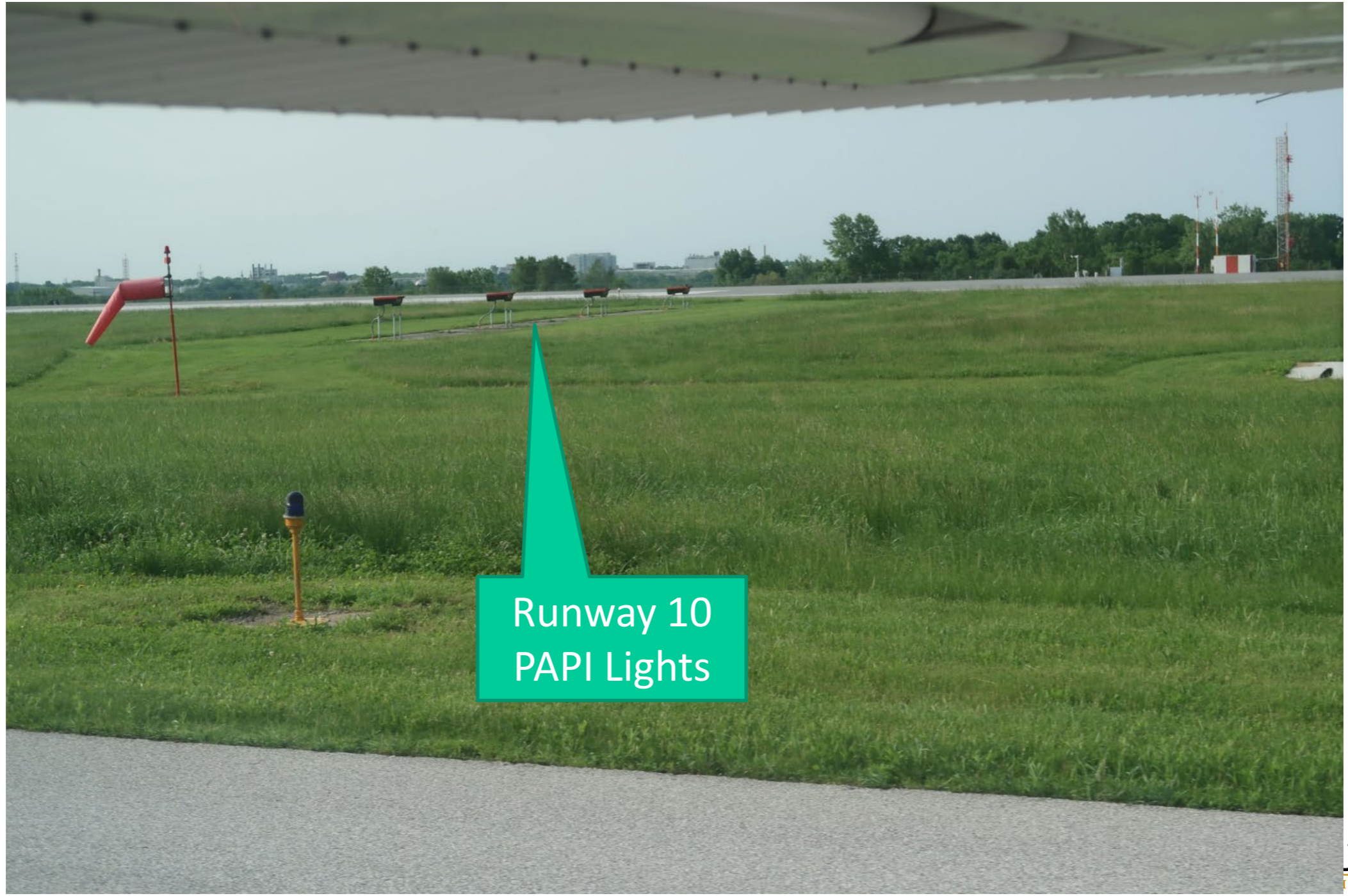
Example Aircraft View



Our Purdue Pilot



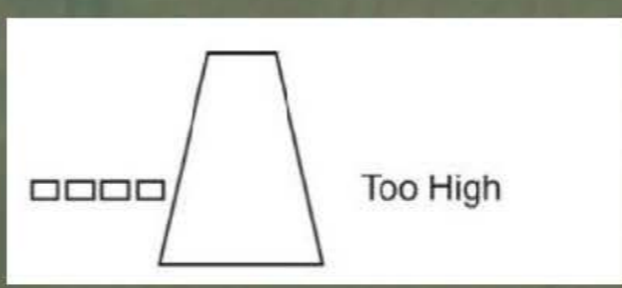
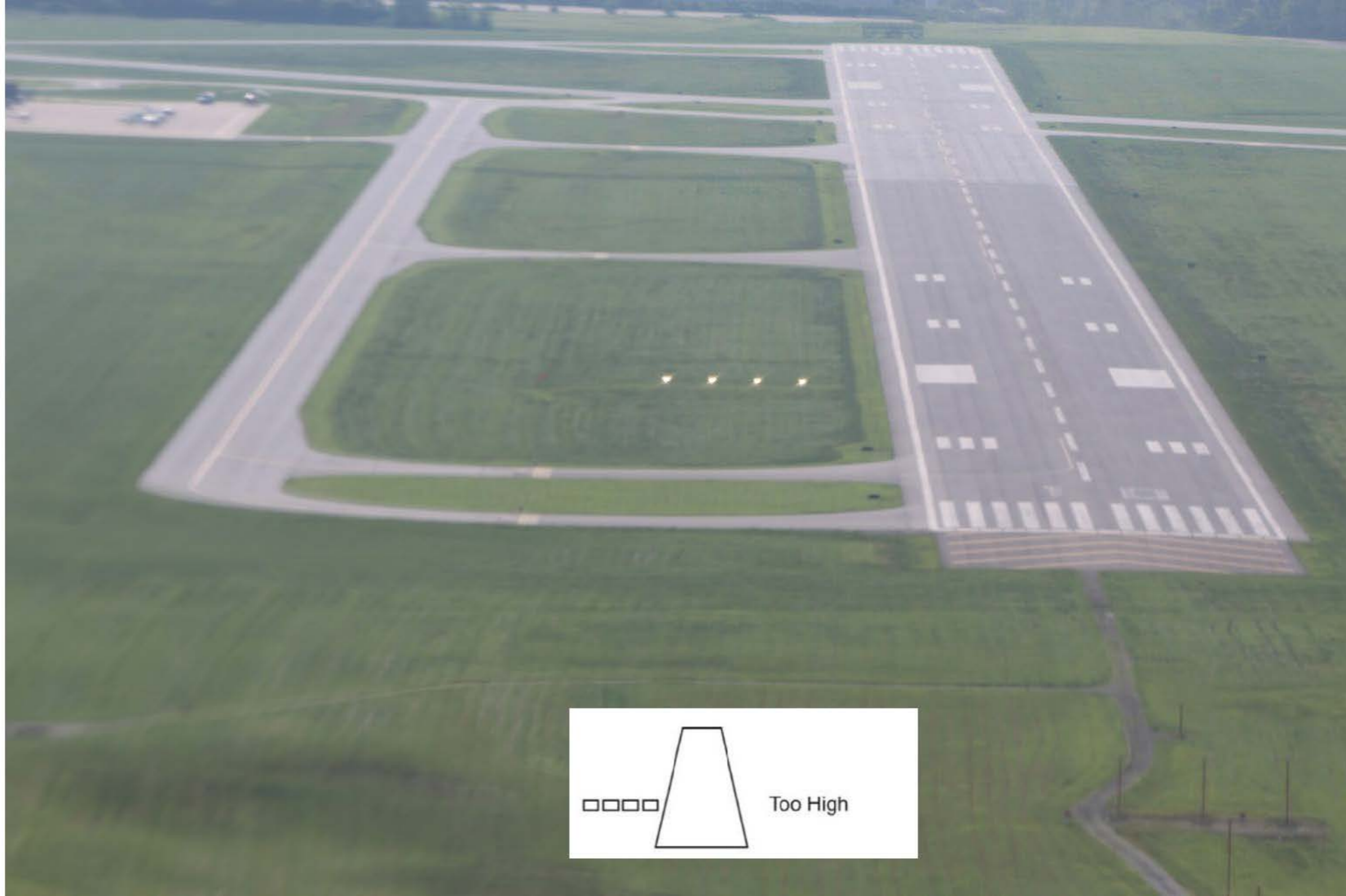
Runway 10 PAPI Lights




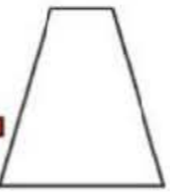
Runway 10
PAPI Lights

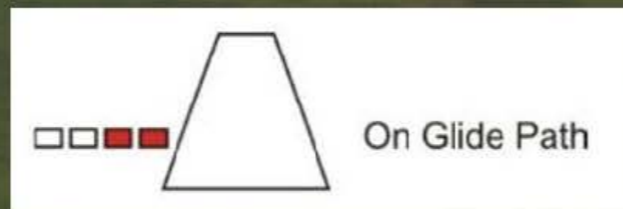
UAS with high quality position locates will be more cost effective and likely more robust over entire envelope





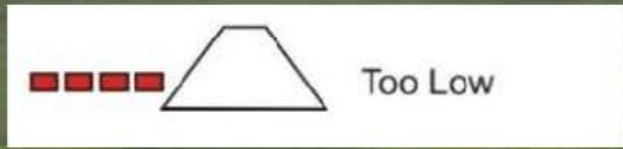


  Slightly High





Slightly Low

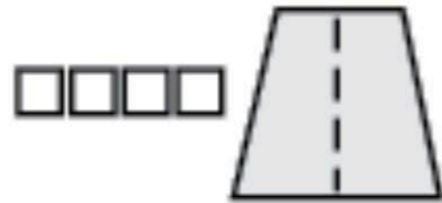


PAPI Light Concept (8)

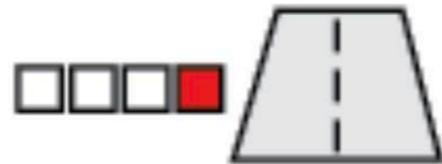
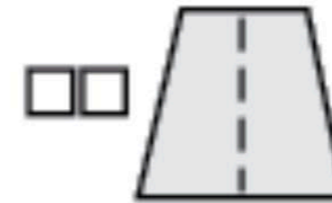


PAPI (P1, P2, P3)

APAPI (AP)



TOO HIGH



SLIGHTLY HIGH



ON CORRECT APPROACH PATH



SLIGHTLY LOW



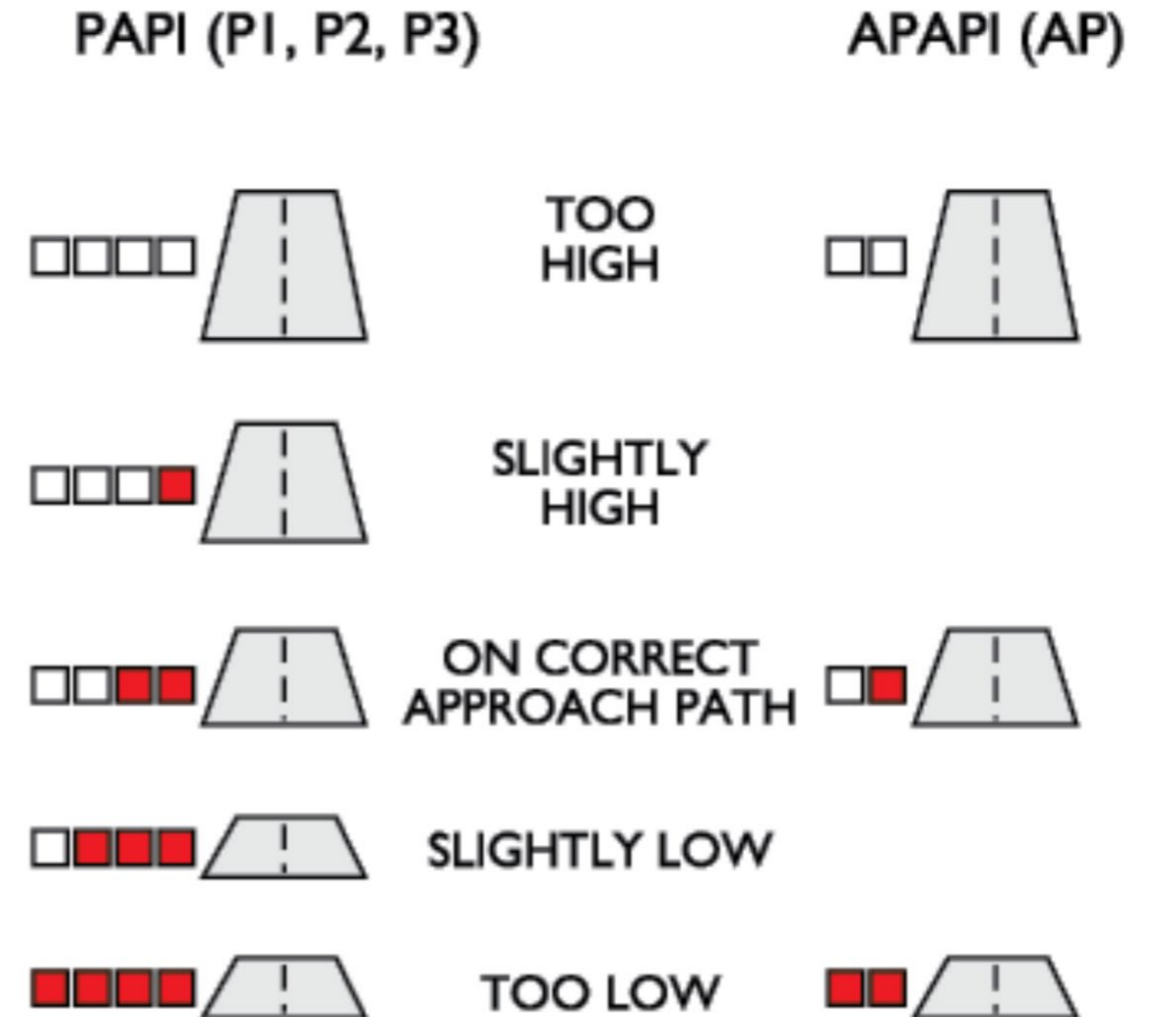
TOO LOW



Topics (4)



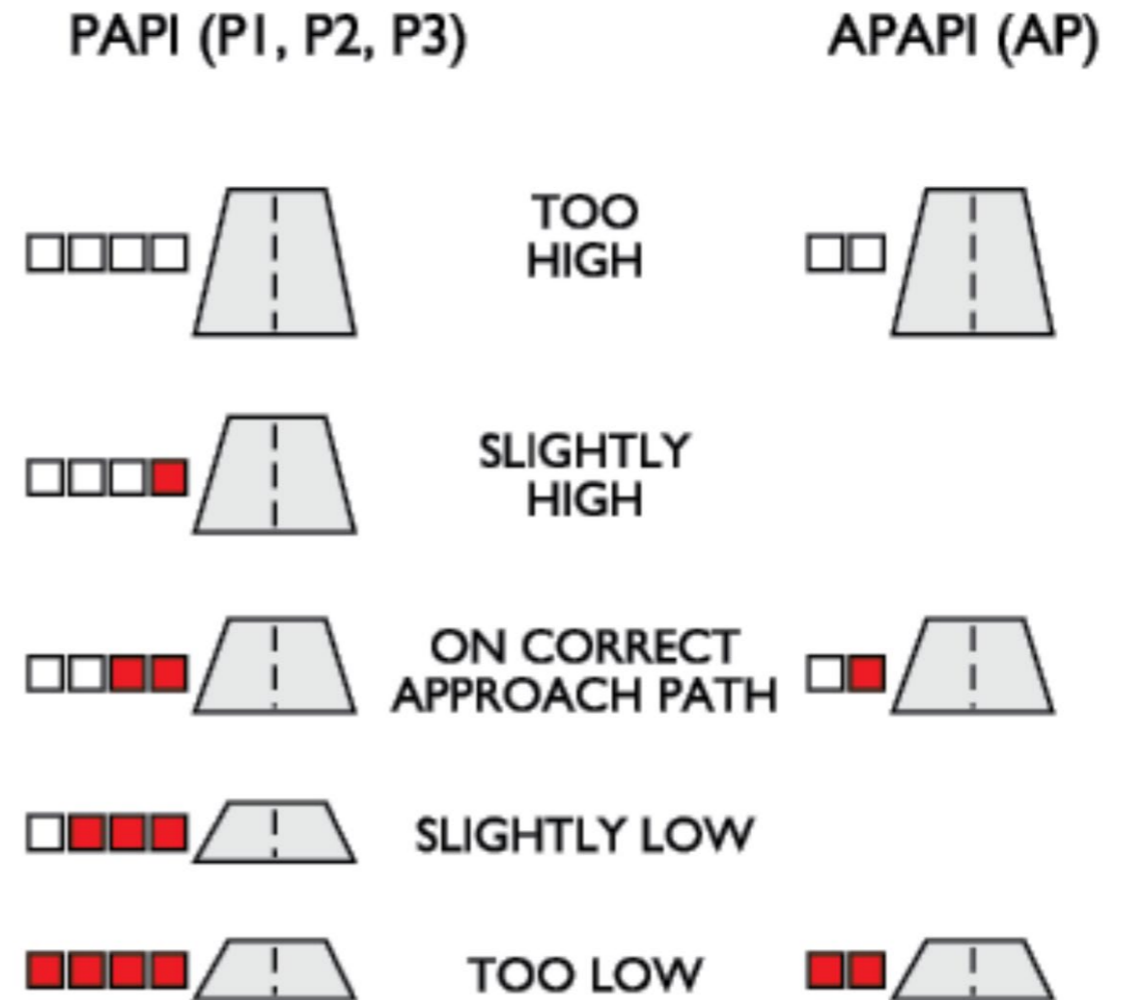
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Problem Statement (9)



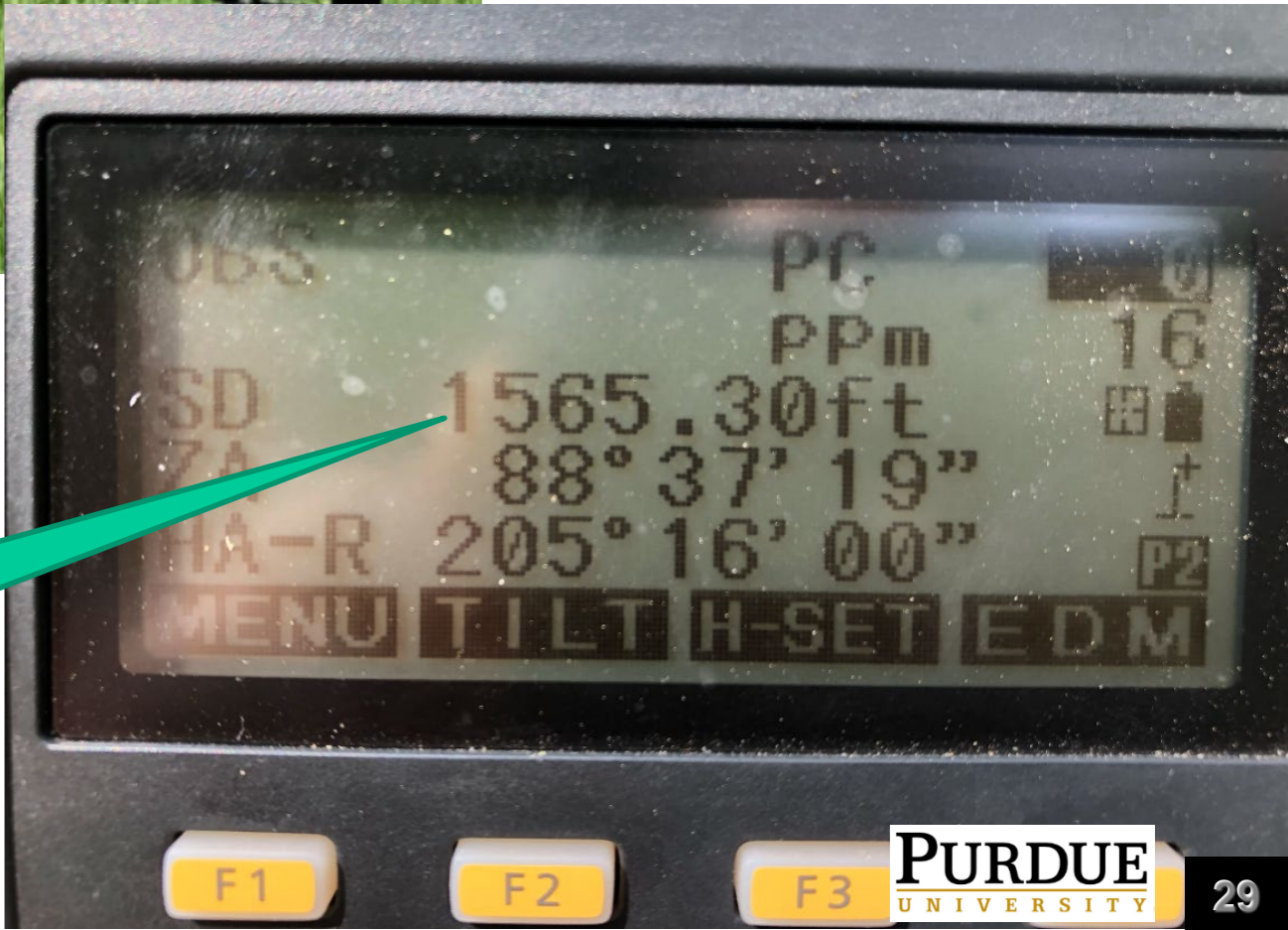
- Can we use UAS imagery and high-quality positions to evaluate PAPI/APAPI





Survey target
tape works to
about 800 ft.

Survey prism
works well up to
~ 1500 ft



Transition Elevations at 1000 ft and 2000 ft



Angle	Dec	1000	2000
3.5	0.061163	61.16	122.33
3.17	0.055383	55.38	110.77
3	0.052408	52.41	104.82
2.83	0.049433	49.43	98.87
2.5	0.043661	43.66	87.32



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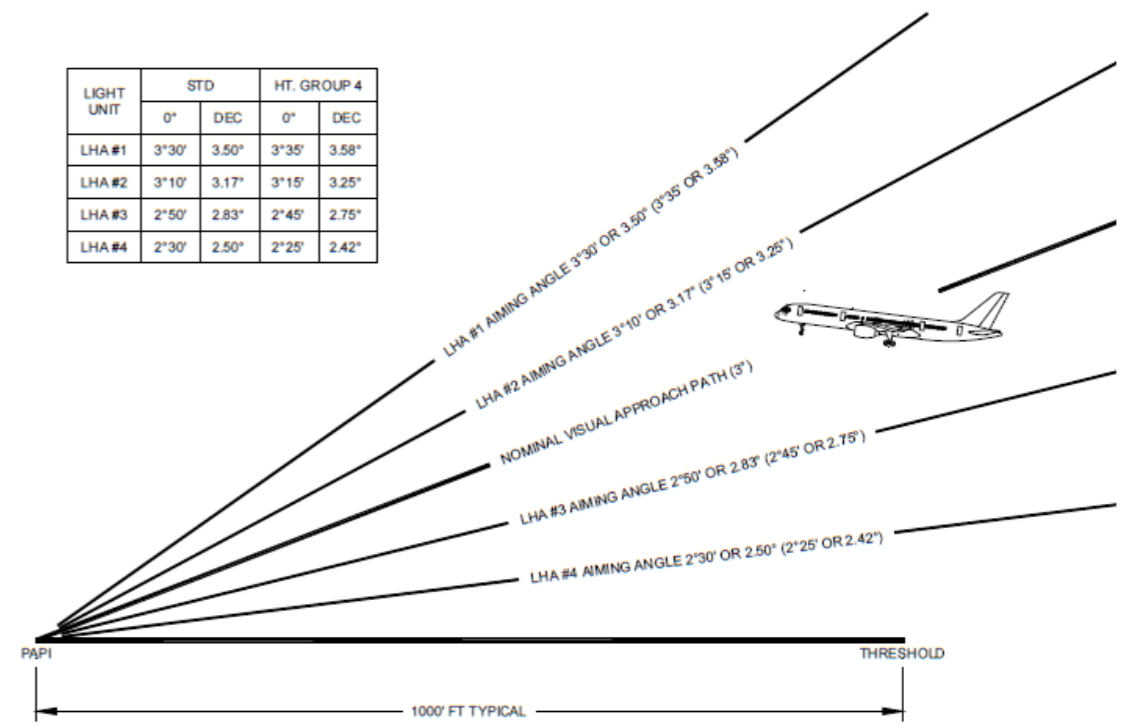
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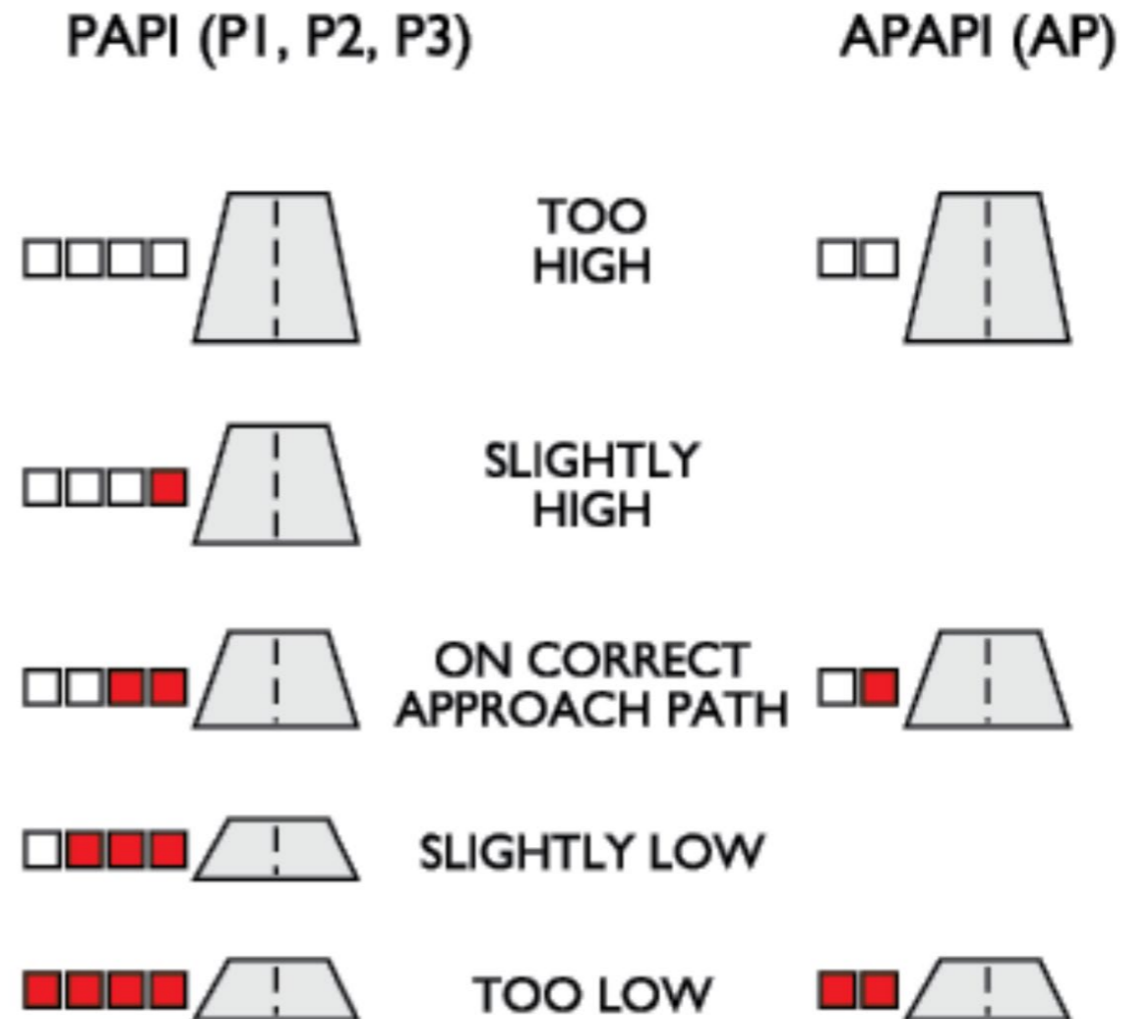
8/20/10

JO 6850.2B

Topics (5)



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LHA # 2



ON CORRECT
APPROACH PATH



LHA # 2



ON CORRECT
APPROACH PATH



LHA # 2



  SLIGHTLY HIGH



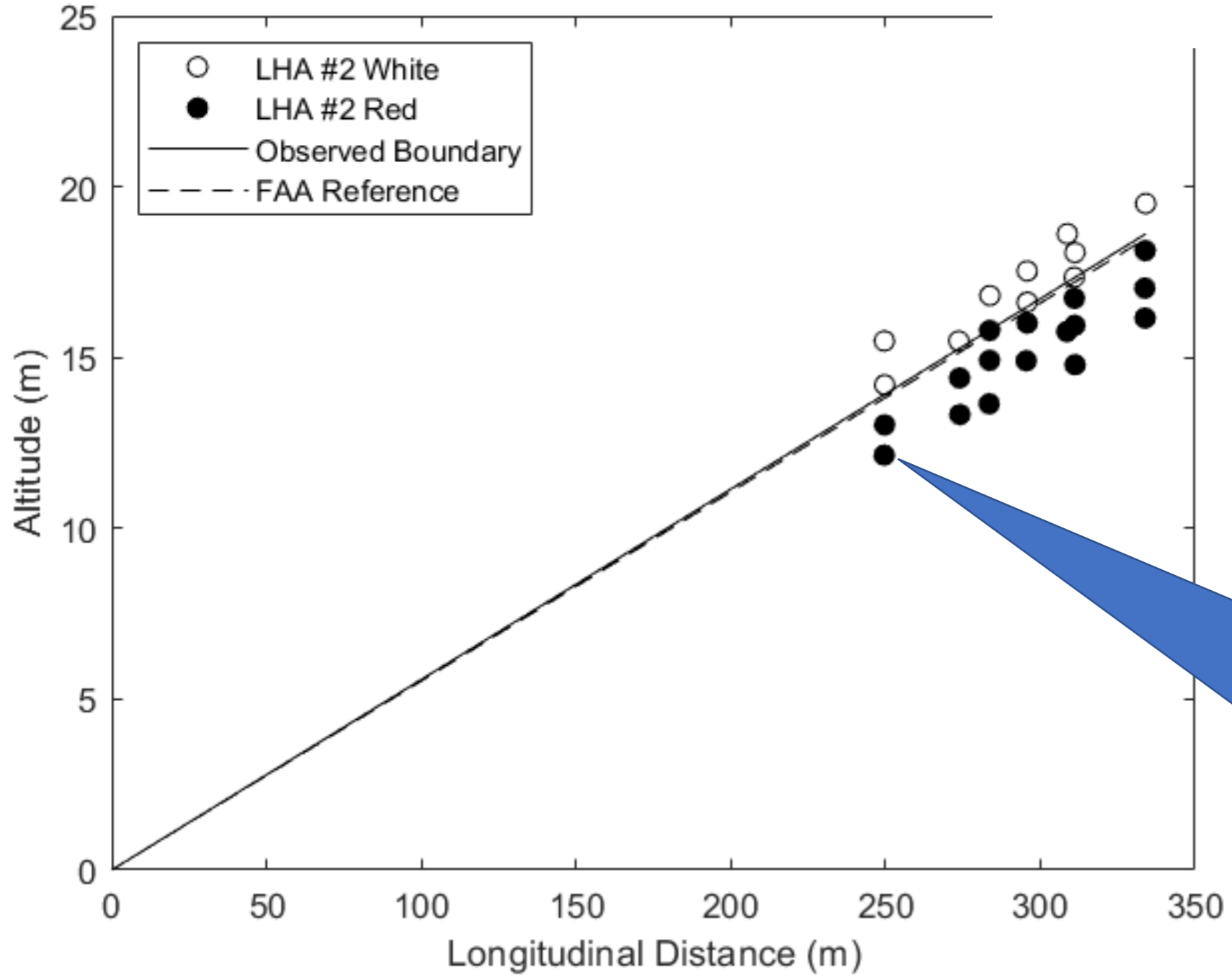
LHA # 2



  SLIGHTLY HIGH



**ON CORRECT
APPROACH PATH**

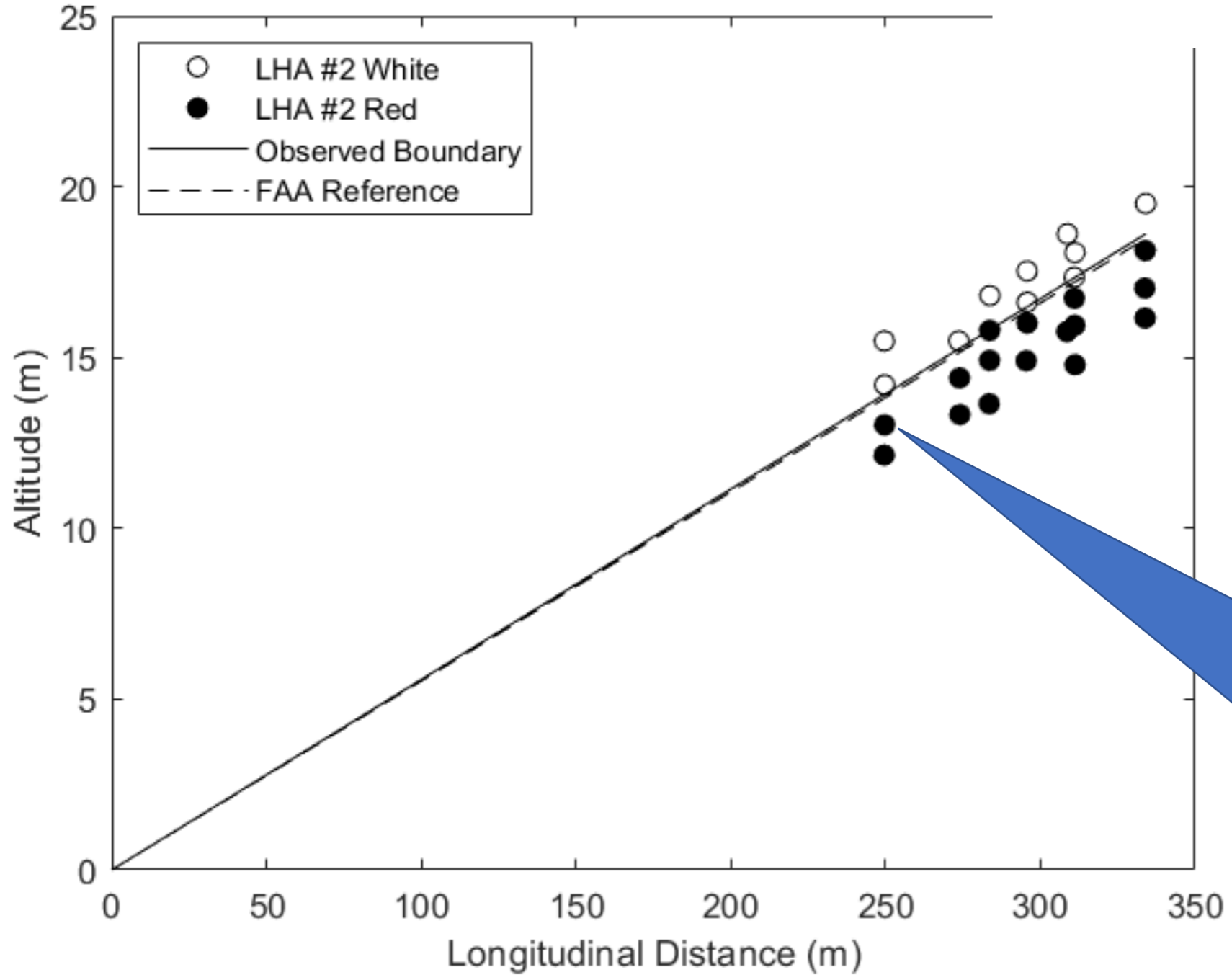


LHA # 2



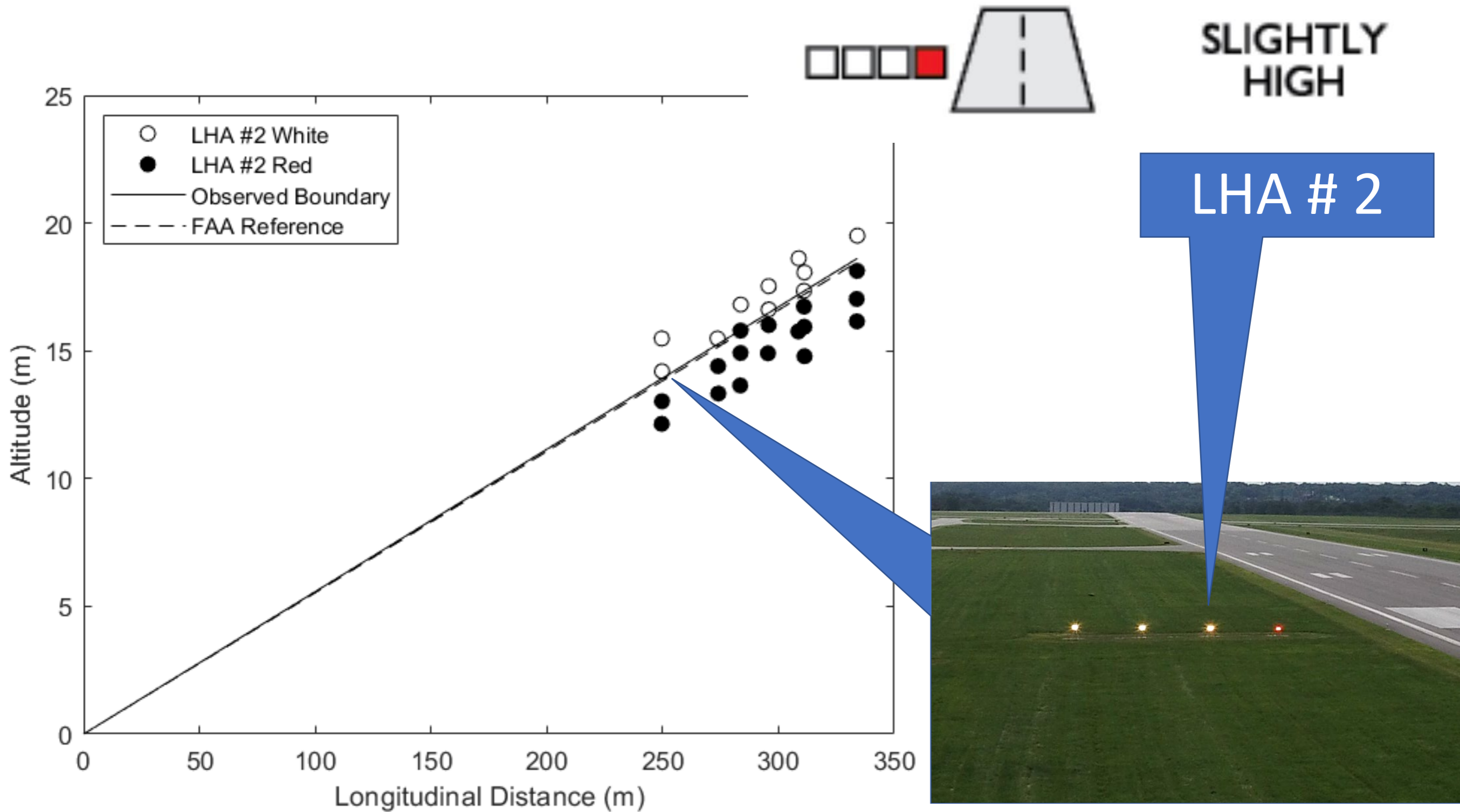


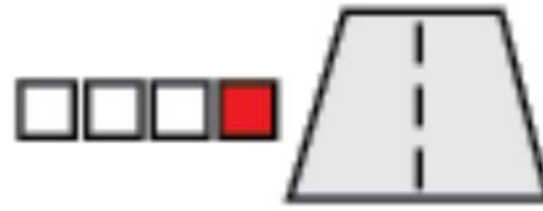
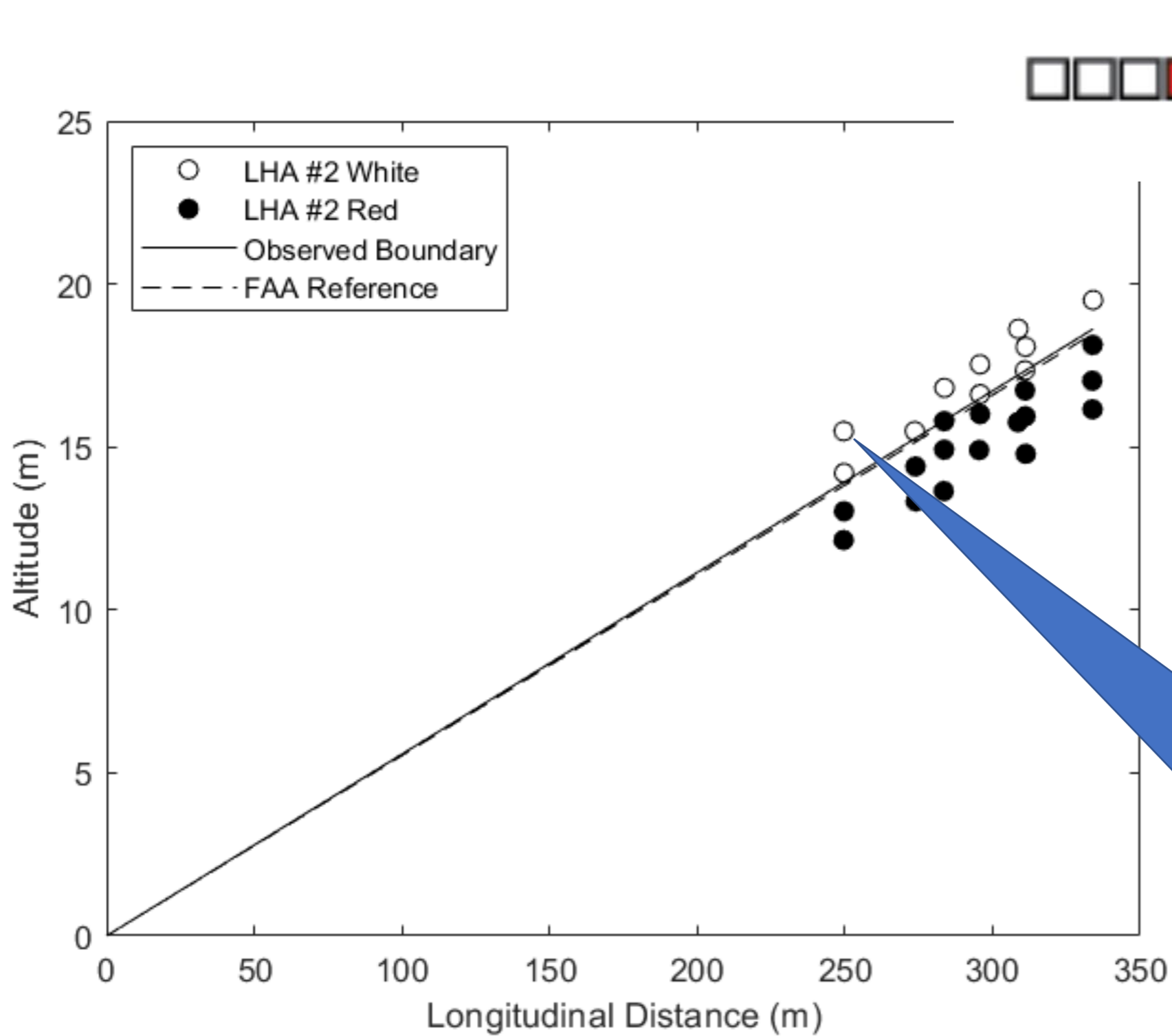
ON CORRECT
APPROACH PATH



LHA # 2





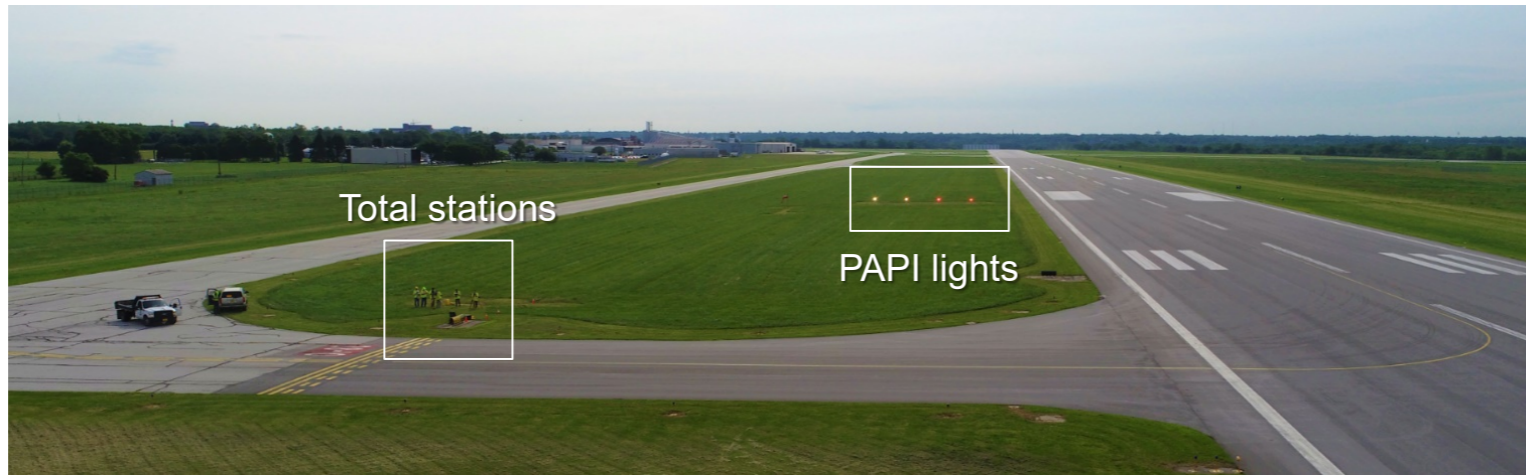


SLIGHTLY
HIGH

LHA # 2



- Fly the UAS at different locations and altitudes and take images of the PAPI system
- Survey the UAS positions using (two) independent total stations



UAS image shows the total stations and PAPI lights

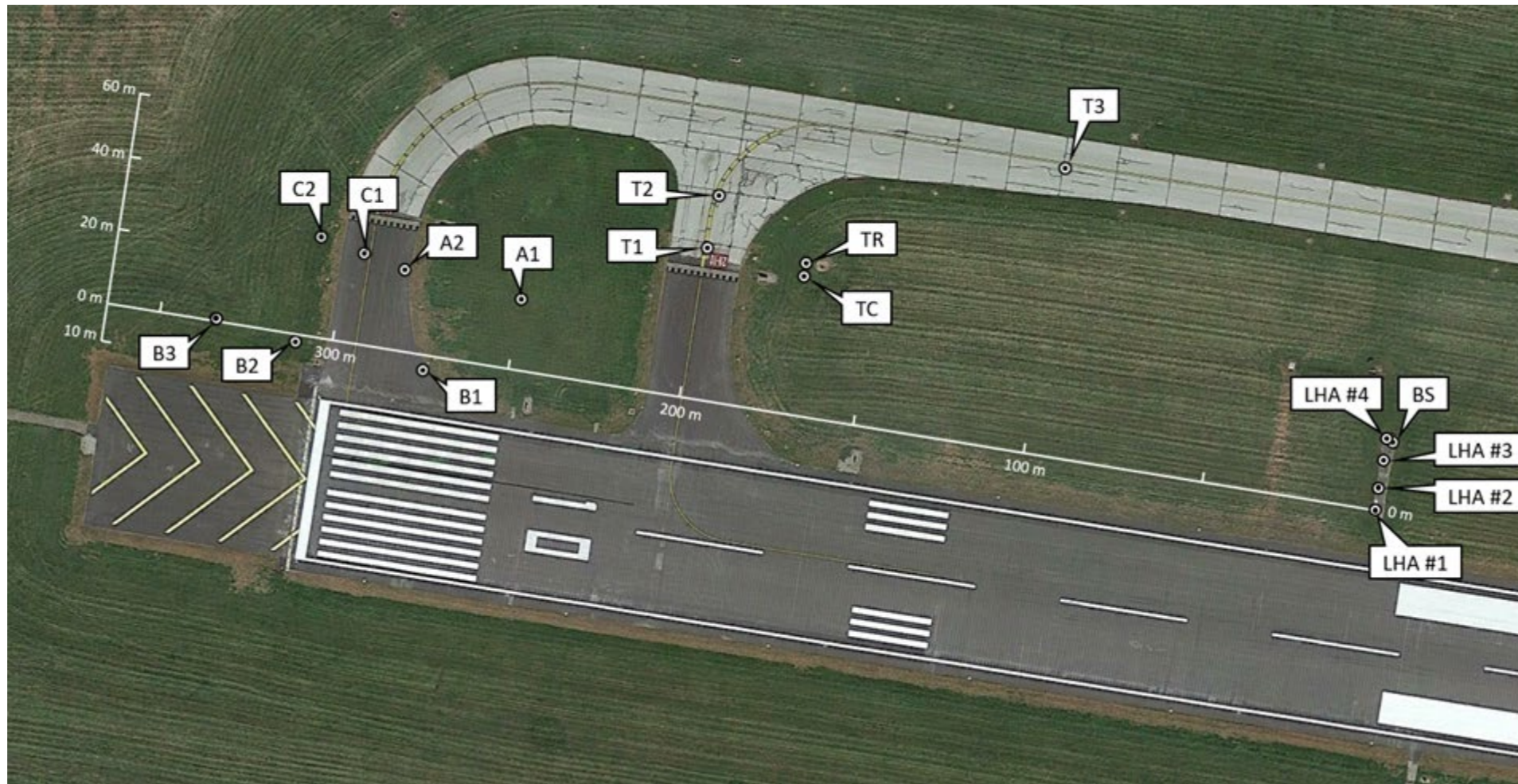


UAS with survey prism mounted



Total stations used to locate UAS

Top View of the Study Site



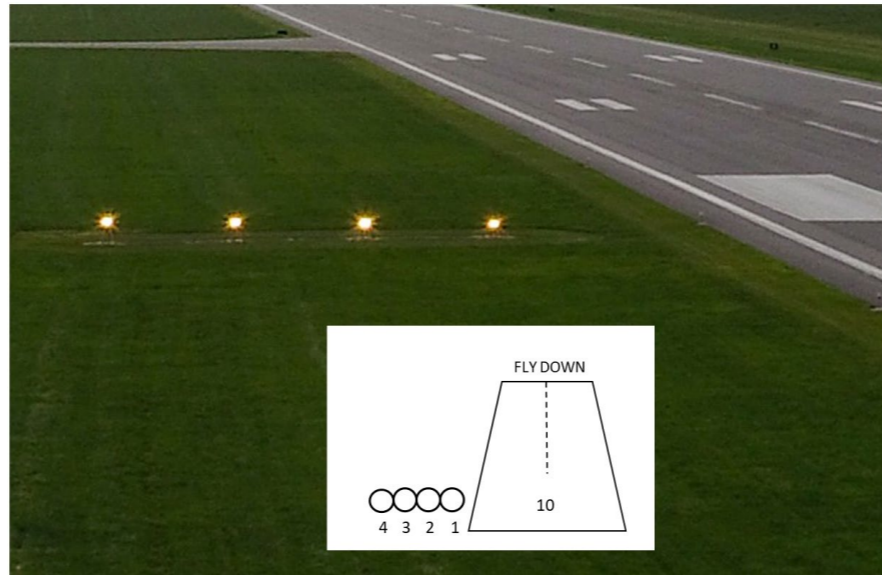
- LHA #1-LHA #4: the PAPI light units
- A1, A2, B1, B2, B3, C1 and C2: the locations where the UAS flew vertical profiles
- TC and TR: the locations of the Topcon and Trimble total stations
- BS: the location where a backsight prism was set up
- T1, T2, and T3: three control points which were surveyed using both total stations and RTK-GNSS

PAPI Indications and UAS Images

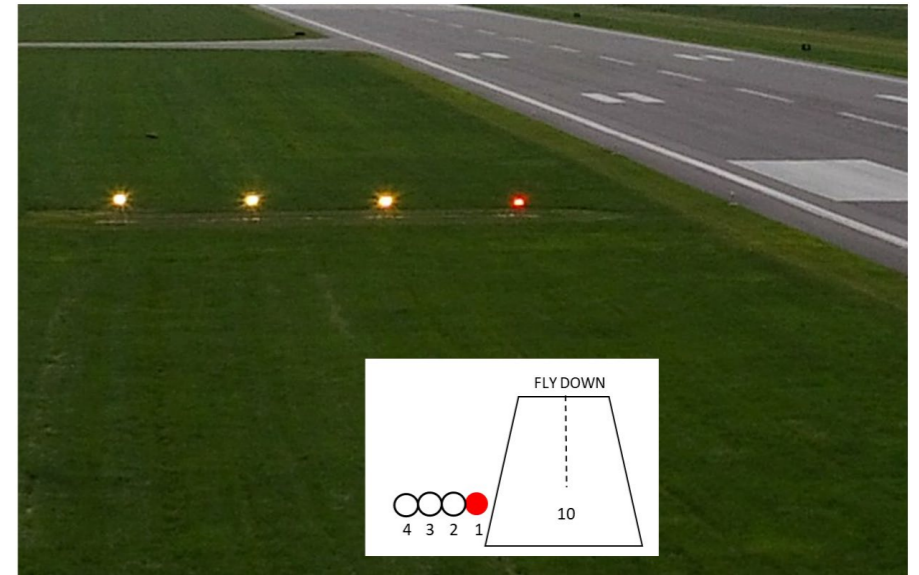
PAPI light housing assemblies



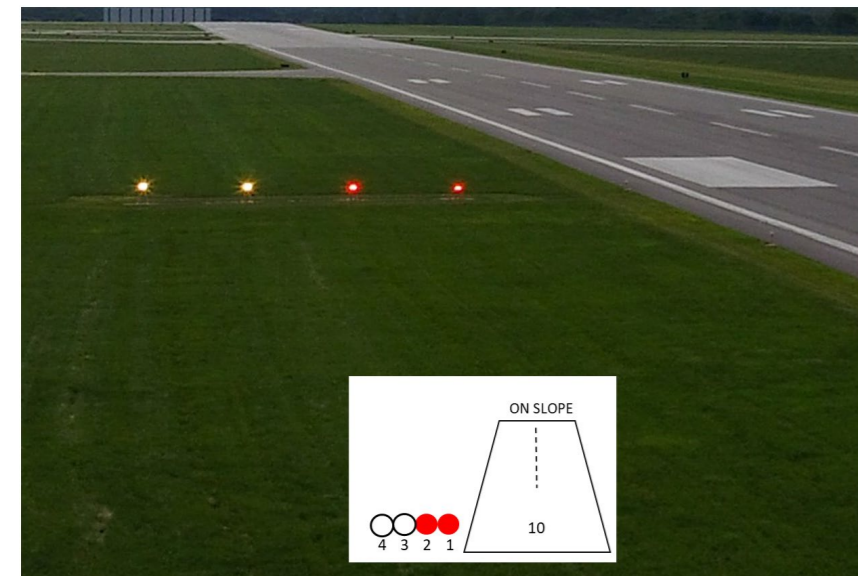
Four white PAPI indications



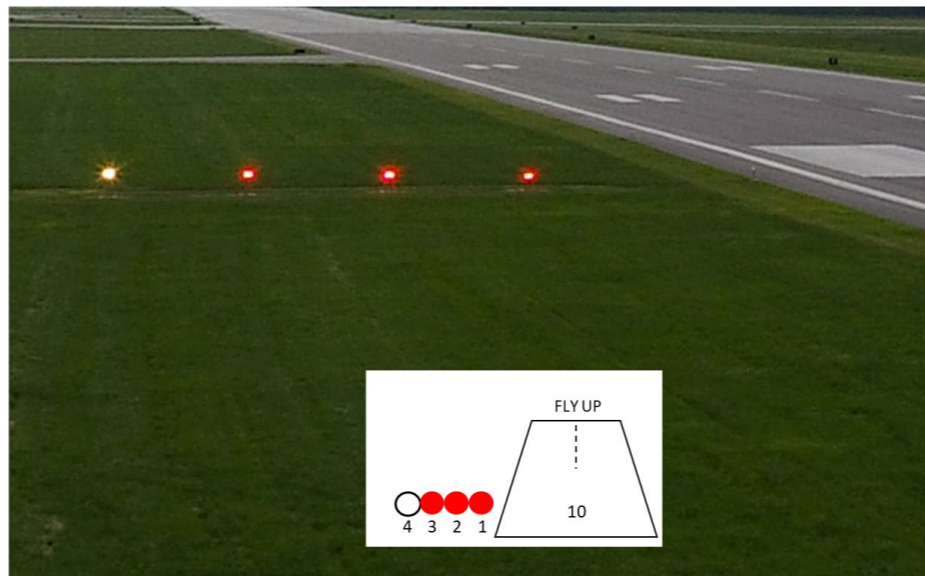
Three white, one red PAPI indications



Two white, two red PAPI indications



One white, three red PAPI indications



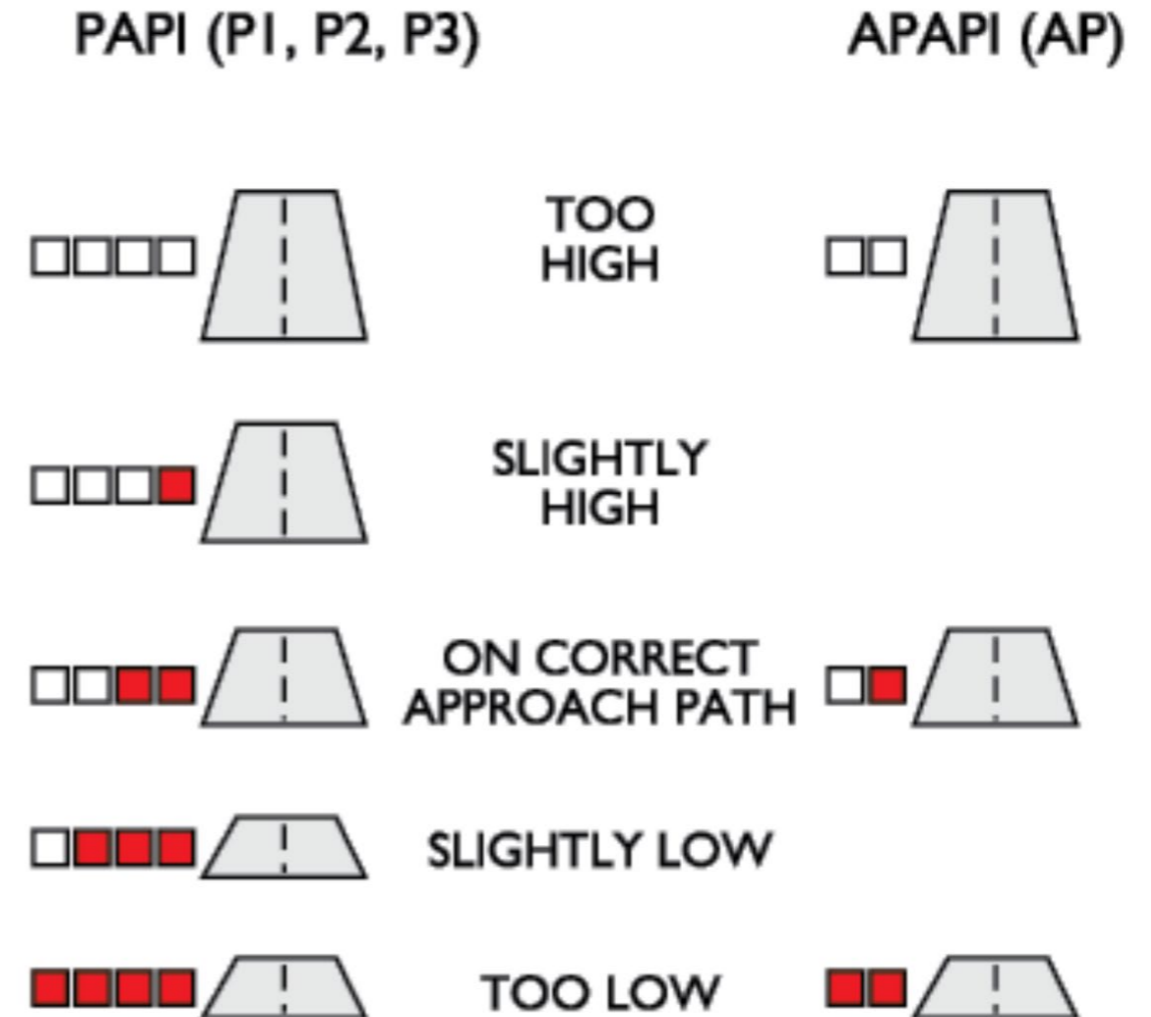
Four red PAPI indications



Topics (6)



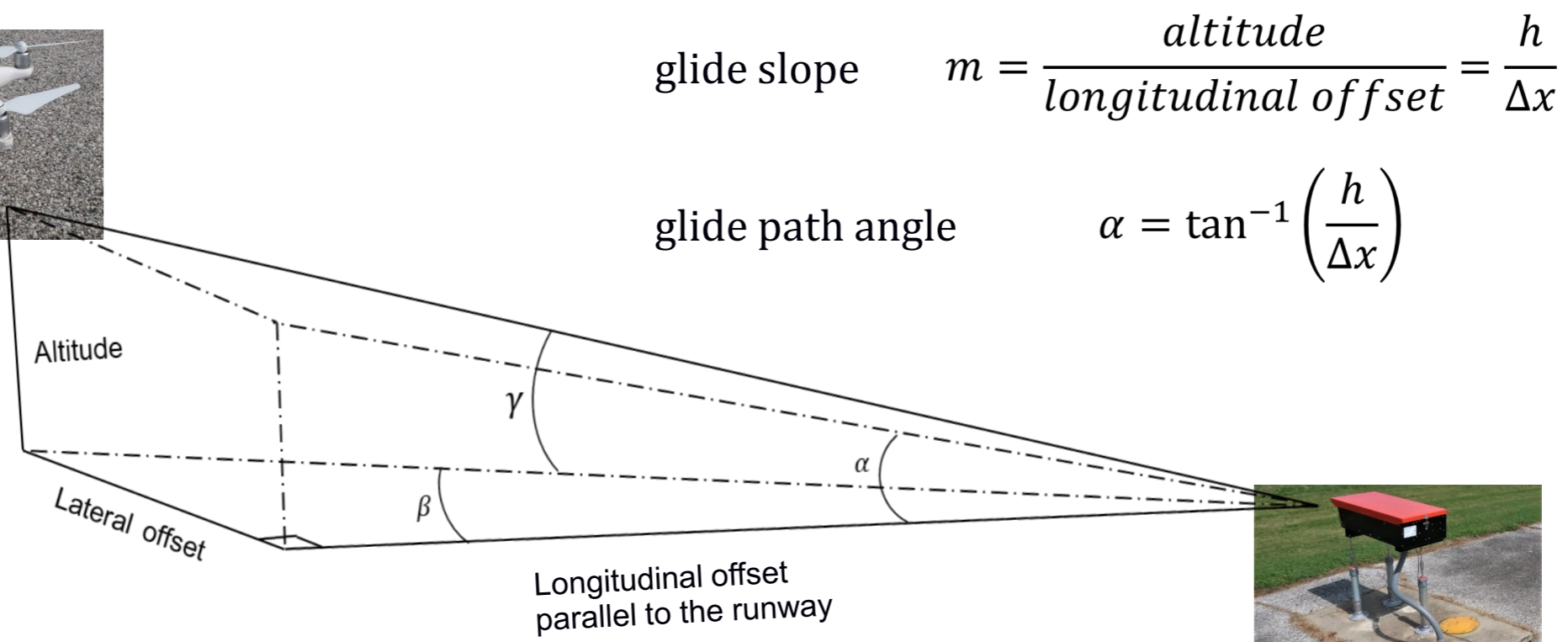
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Spatial Reference for Each UAS Image



- Georeference total station measurements to UTM coordinate system using ground control points
- Decompose the total station angle and distance measurements into longitudinal (parallel to the runway) and lateral components
- Calculate glide slope and glide path angle

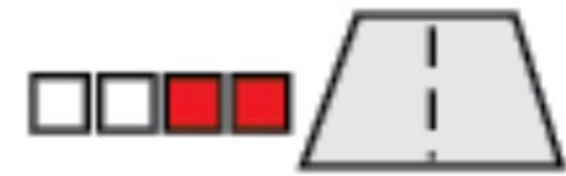


glide slope $m = \frac{\textit{altitude}}{\textit{longitudinal offset}} = \frac{h}{\Delta x}$ Eq. 1

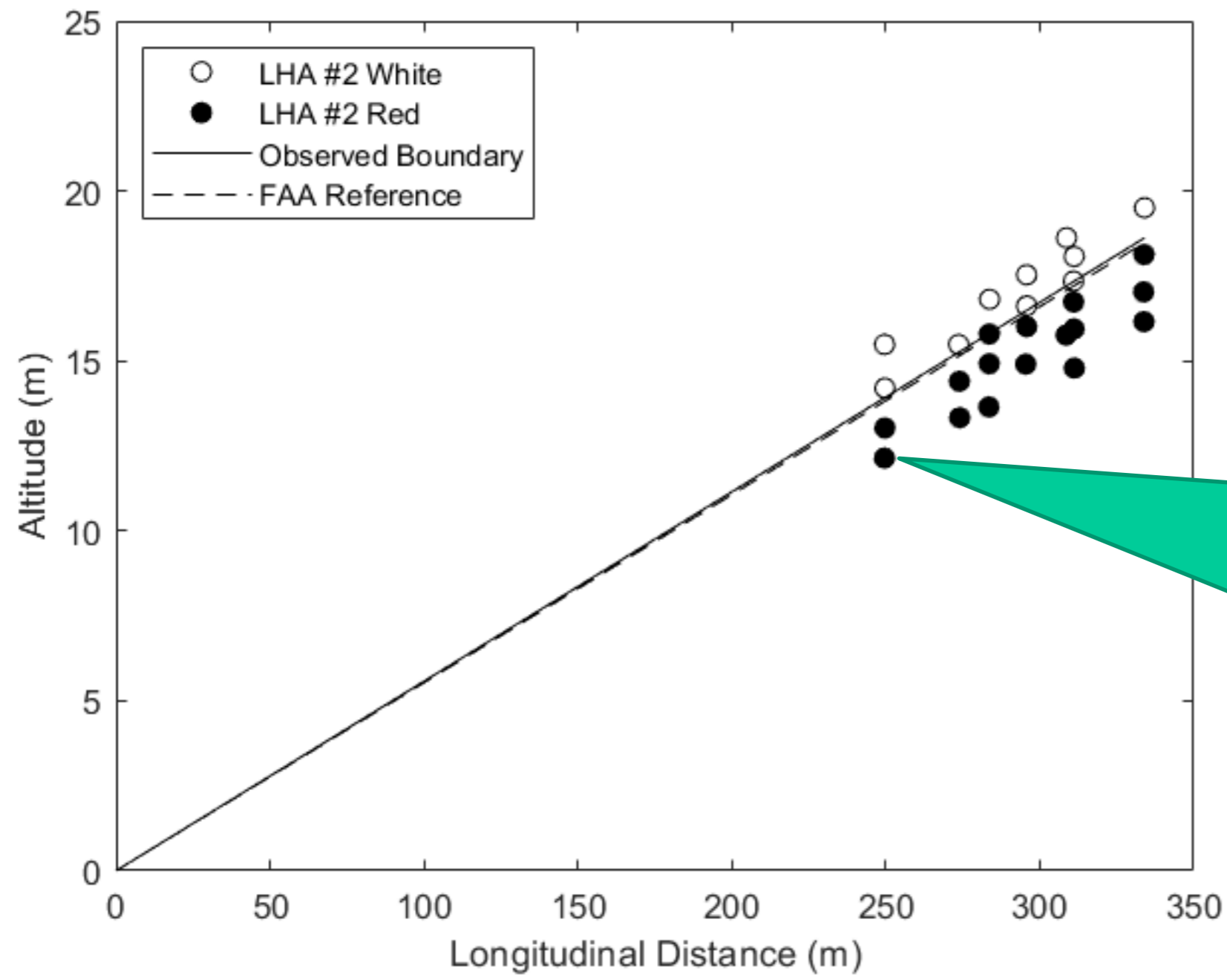
glide path angle $\alpha = \tan^{-1}\left(\frac{h}{\Delta x}\right)$ Eq. 2



Estimated Transition Angle



ON CORRECT
APPROACH PATH



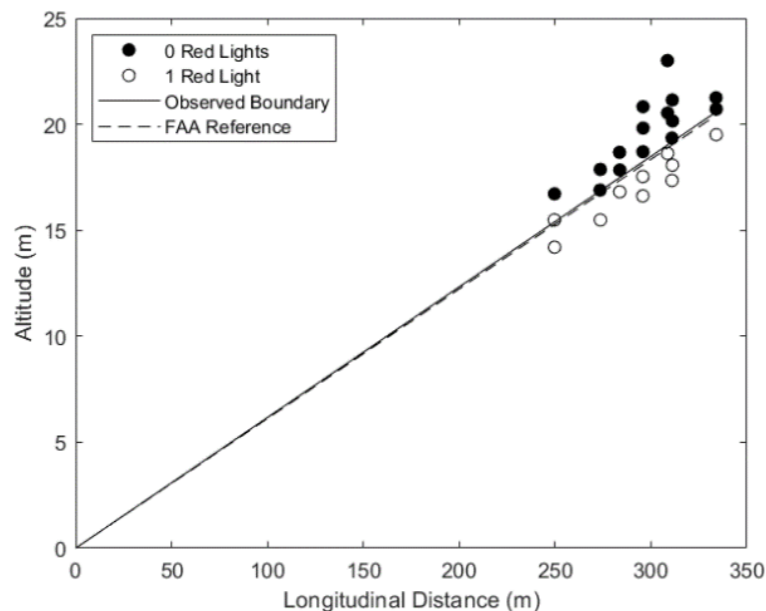
LHA # 2



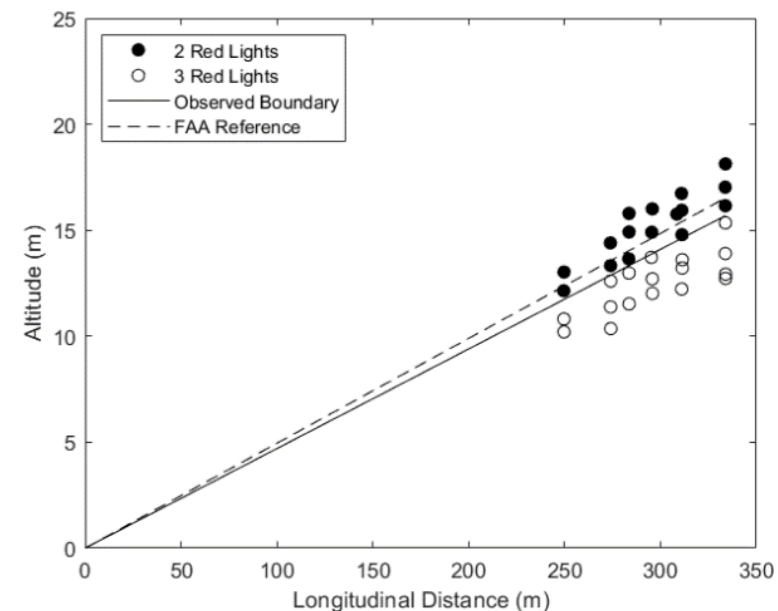
Estimated Transition Angle for PAPI Lights (4)



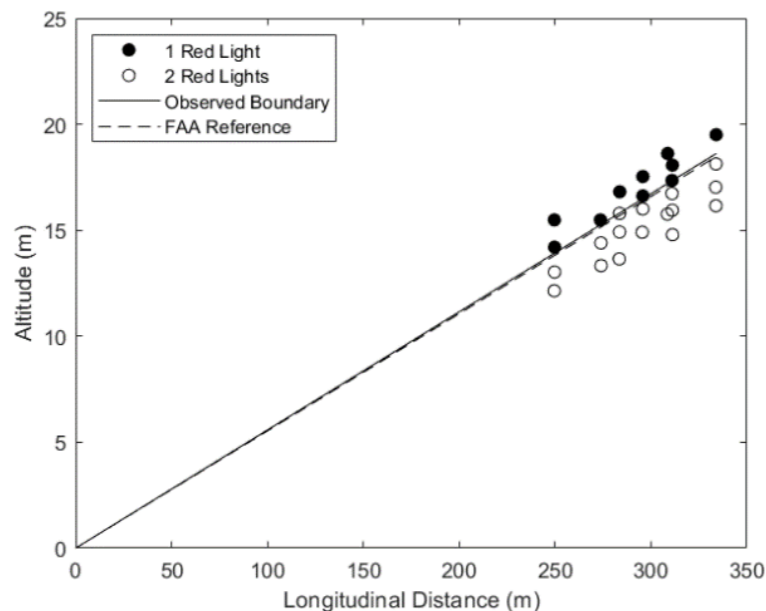
Boundary between 0 and 1 red lights (LHA #1)



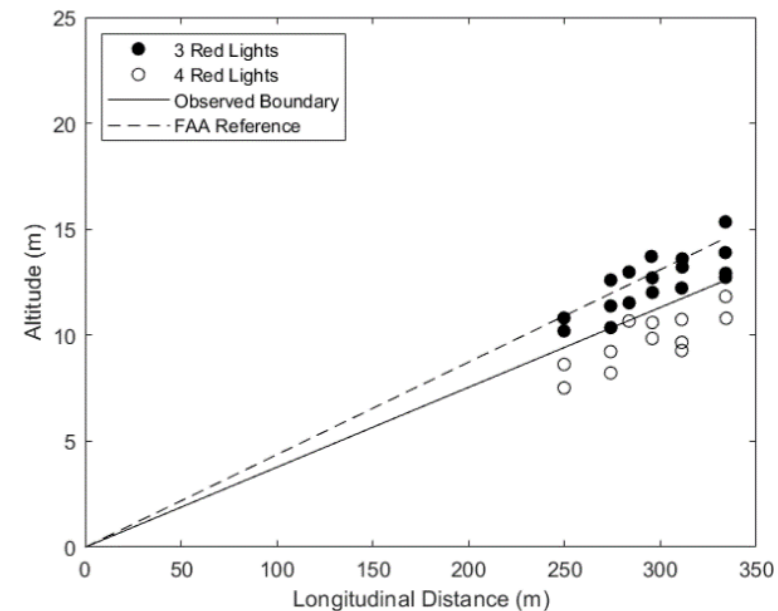
Boundary between 2 and 3 red lights (LHA #3)



Boundary between 1 and 2 red lights (LHA #2)



Boundary between 3 and 4 red lights (LHA #4)



Estimated Transition Angle for PAPI Lights

- **Small p-value: confidence that the model is effectively classifying the transition angle**
- **The transitions from 0 to 1 red PAPI lights and 1 to 2 red PAPI lights (correspond to LHA #1 and LHA #2) are within the allowable tolerance**
- **The transitions from 2 to 3 red PAPI lights and 3 to 4 red PAPI lights (correspond to LHA #3 and LHA #4) are outside of the allowable deviations → adjusted according to the manufacturer guidelines and FAA Advisory Circular 150/5340-26C**

Comparison of logit model estimate of red/white transition with expected transition glide slope

LHA	# Obs	A	p-value of A	B	p-value of B	UAS Calculated Glide Slope (deg)	Expected Glide Slope (deg)	Difference (°)	Difference (min)
#1	25	2947.7	0.029	-181.7	0.030	3.526	3.500	0.026	1.584
#2	26	86386.0	0.000	-4815.1	0.000	3.190	3.167	0.024	1.418
#3	33	71714.0	0.000	-3369.8	0.000	2.690	2.833	-0.143	-8.582
#4	29	90100.0	0.000	-3397.4	0.000	2.160	2.500	-0.341	-20.430

Allowable tolerance specified in FAA Order JO 6850.2B: 0.083° (5 arc-min)

Independent Check of Total Stations Locations



- The slope distances from PAPI light LHA #1 to UAS locations and the slope angles were calculated using both Topcon and Trimble measurements

Measurement	Mean	Standard Deviation	RMSE
Slope Distance	0.060 <i>m</i>	0.060 <i>m</i>	0.085 <i>m</i>
Alpha Angle	0.0058°	0.0219°	0.0225°

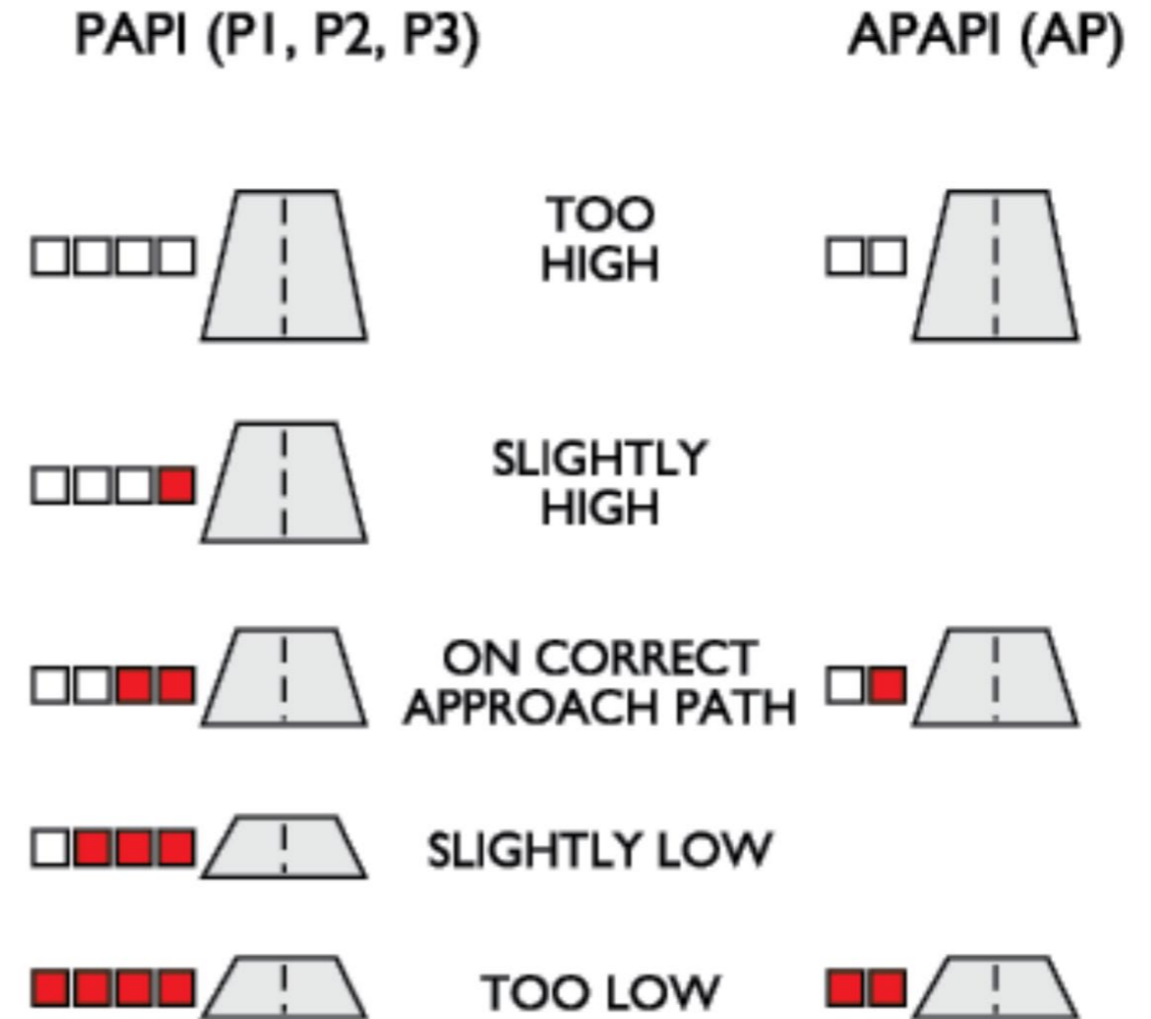
- The transition angles estimated using the Trimble data are 3.534°, 3.172°, 2.676° and 2.155°, for LHA #1, LHA #2, LHA #3 and LHA #4, respectively → the differences are within 1 arc-min when compared with the Topcon estimates
- These results suggest that the accuracy of the UAS location and glide path angle are ±0.0085 m and ±0.0225° (1.35 arc-min), respectively.

Smaller error than in how pilots sit in cockpit or adjust their seat

Topics (7)



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Ongoing Implementation Activities



High Fidelity GPS can provide couple cm location accuracy and eliminate need for total station(s).



Ongoing Implementation Activities (2)



- This also works well with 2 light APAP (marginally quicker)



Conclusions



- **UAS is used to measure the glide slope angle of a four-box PAPI system transitions from white to red to assess compliance with FAA Order JO 6850.2B**
- **The estimated transition angles of LHA #1 and LHA #2 are 3.53° and 3.19° , well within the 5 arc-min tolerance defined in FAA Order JO 6850.2B. The estimated transition angles of LHA #3 and LHA #4 are 2.69° and 2.16° , both outside of the tolerance**
- **These findings suggest that PAPI light glidepath angles can be quickly and cost effectively validated with low cost UAS's and commonly used surveying equipment**
 - This activity was done in partnership with the FAA and operations continued on runway 5/23 during missions.
 - With proper preparation, inspection can be done during a single 20 minute UAS flight..
- **Opportunities for Further work**
 - Instead of a \$1200 UAS and Surveying equipment, deploy a \$12,000 UAS with integrated IMU and higher fidelity GPS so that UAS position is recorded with a couple of cm accuracy.

Peru Airport APAPI Survey



Peru Team



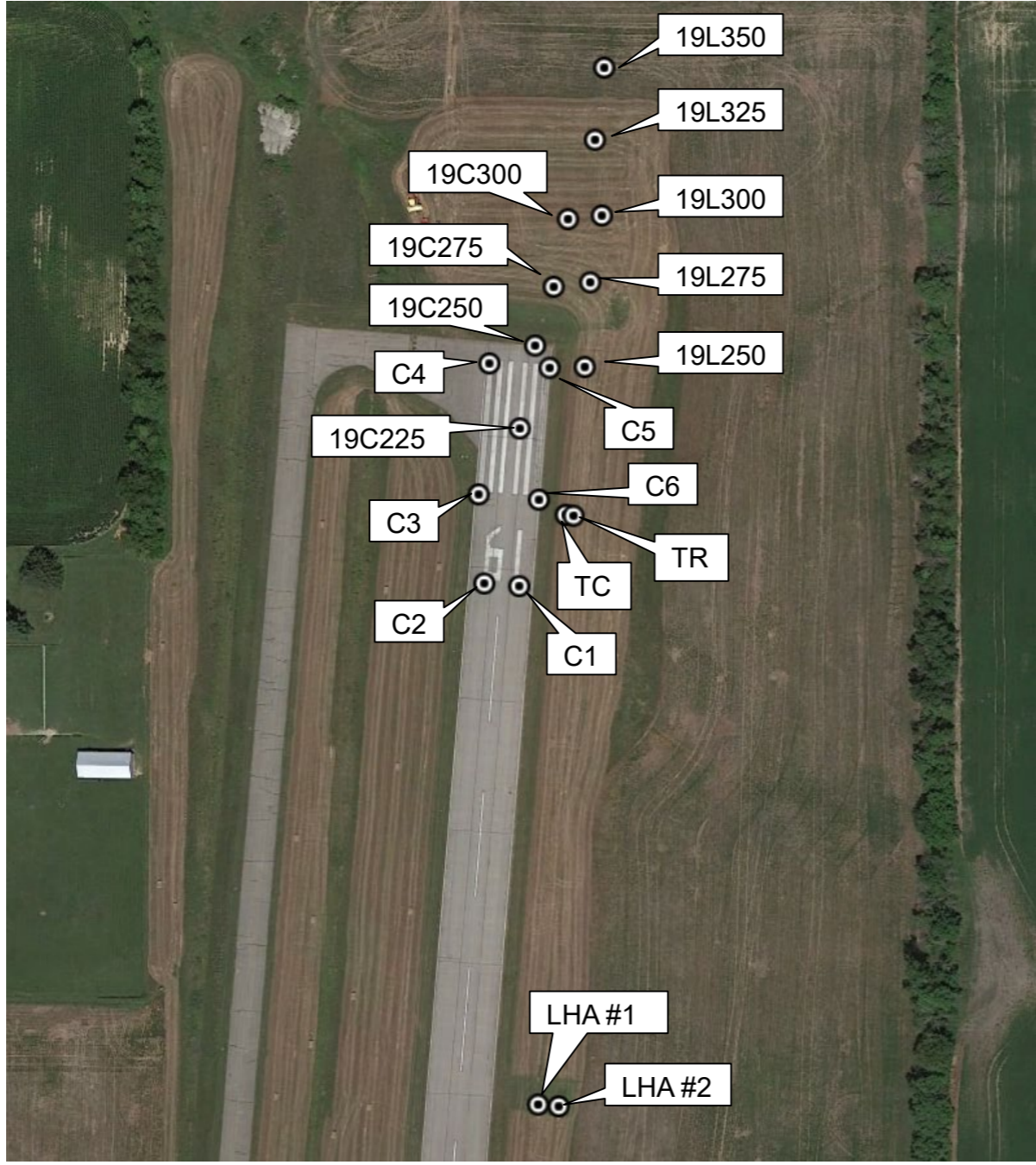
Total State Setup



Backsite



UAS Measurement Locations



- LHA #1, LHA #2: the PAPI light units
- 19L350, 19L325, 19L300, 19L275, 19L250, 19C300, 19C275, 19C250, and 19C225: the locations where the UAS flew vertical profiles
- TC and TR: the locations of the Topcon and Trimble total stations
- C1, C2, C3, C4, C5 and C6: six control points which were surveyed using both total stations and RTK-GNSS

Sample Photo from Phantom (1 red, 1 white)



1 Red, 1 White



ICAO Standard for APAPI Cutoff Angles

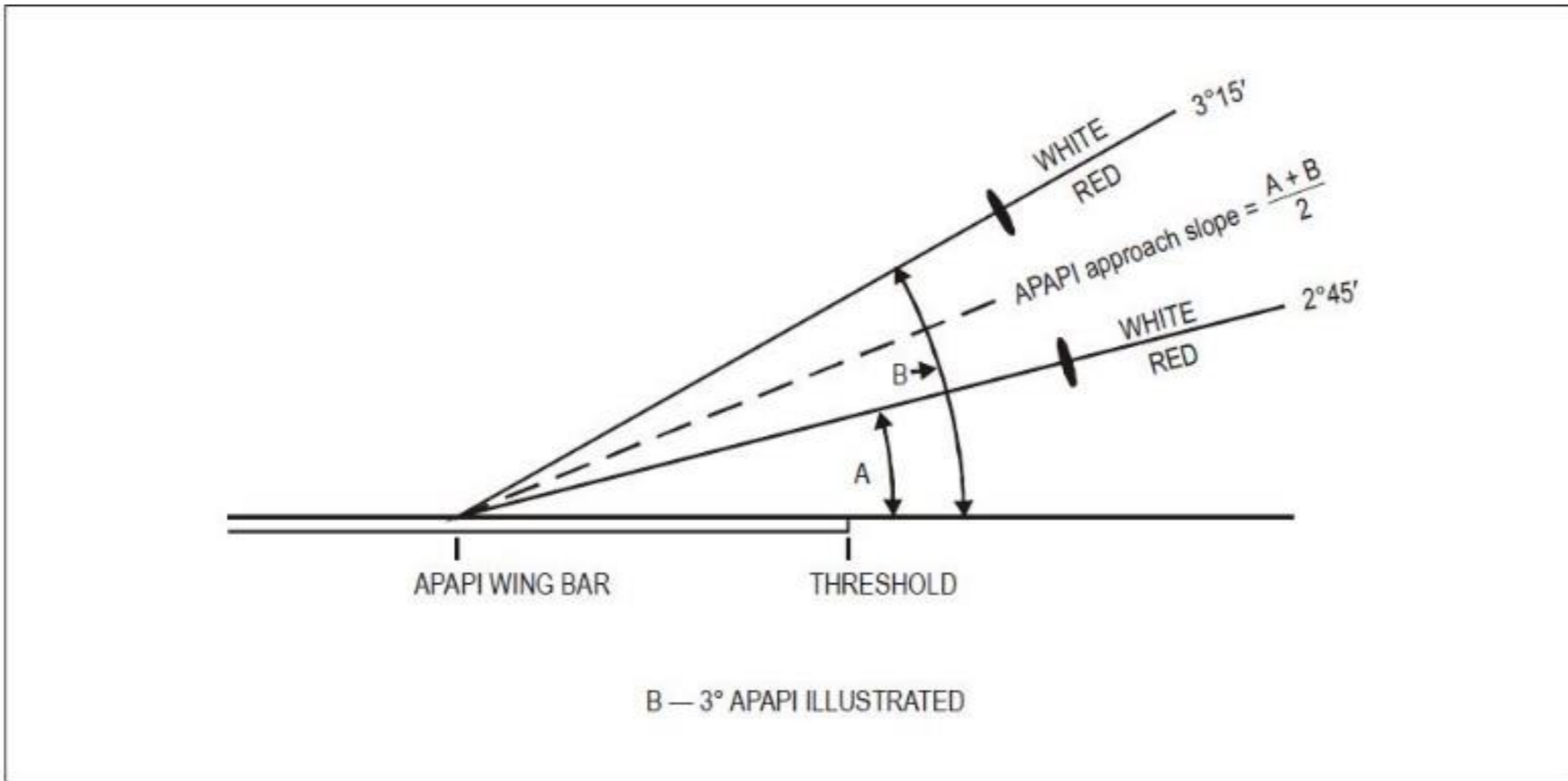


Figure 5-20. Light beams and angle of elevation setting of PAPI and APAPI

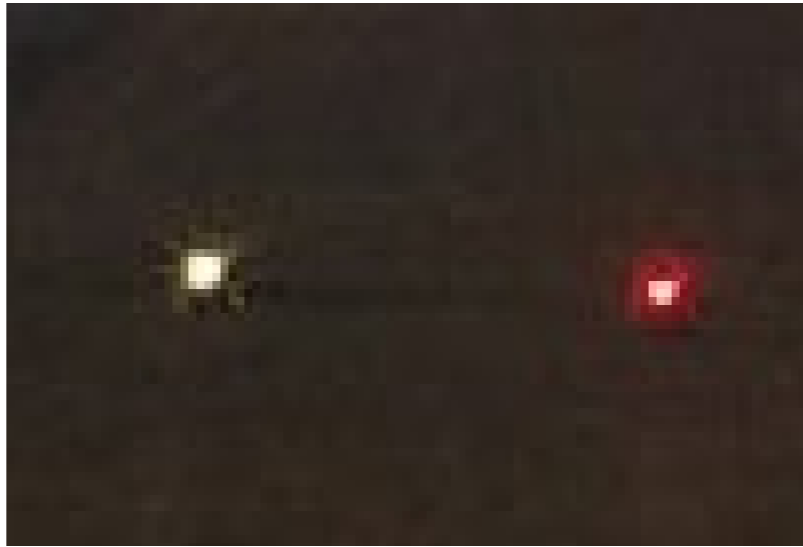
APAPI Light Configurations



2 red (DJI_0025.JPG)



1 red, 1 white (DJI_0027.JPG)

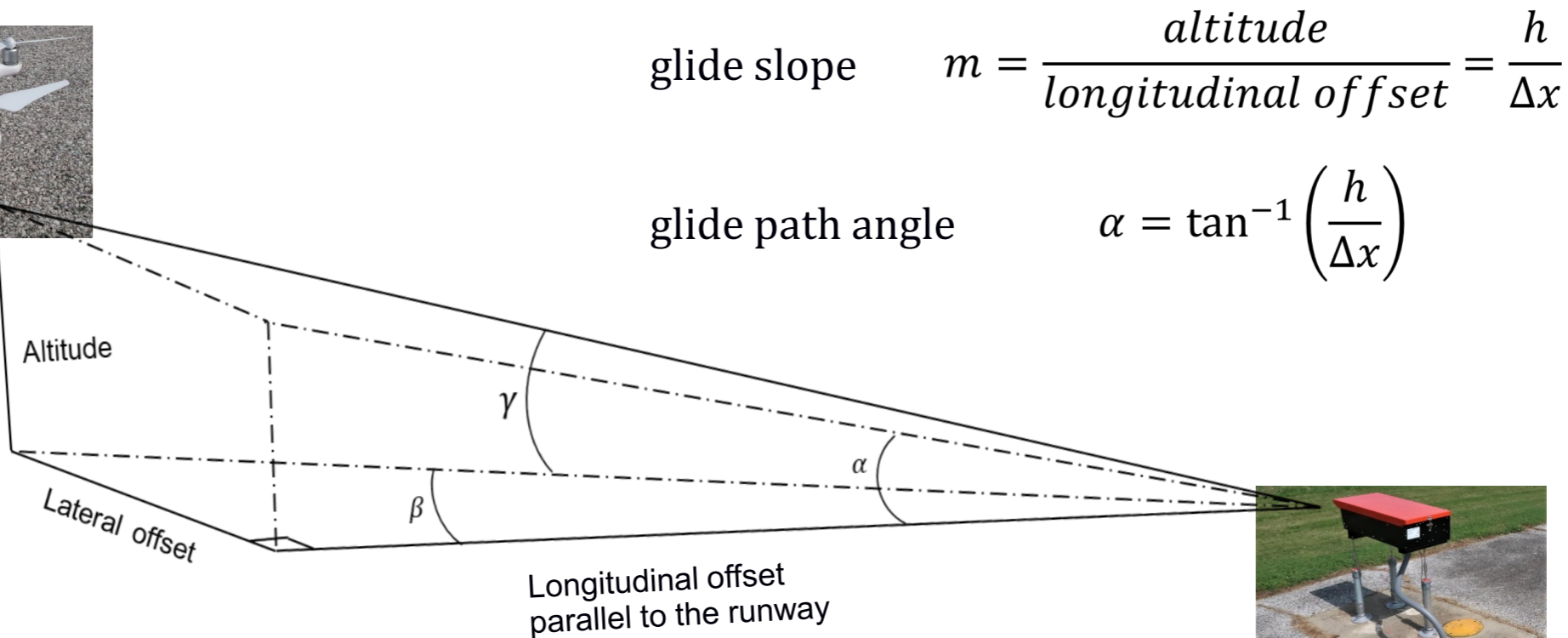


2 white (DJI_0029.JPG)



Spatial Reference for Each UAS Image (2)

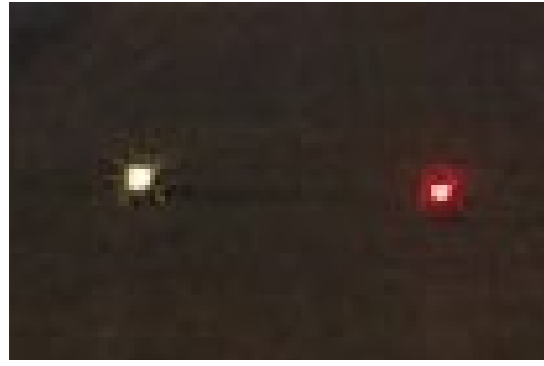
- Georeference total station measurements to UTM coordinate system using ground control points
- Decompose the total station angle and distance measurements into longitudinal (parallel to the runway) and lateral components
- Calculate glide slope and glide path angle



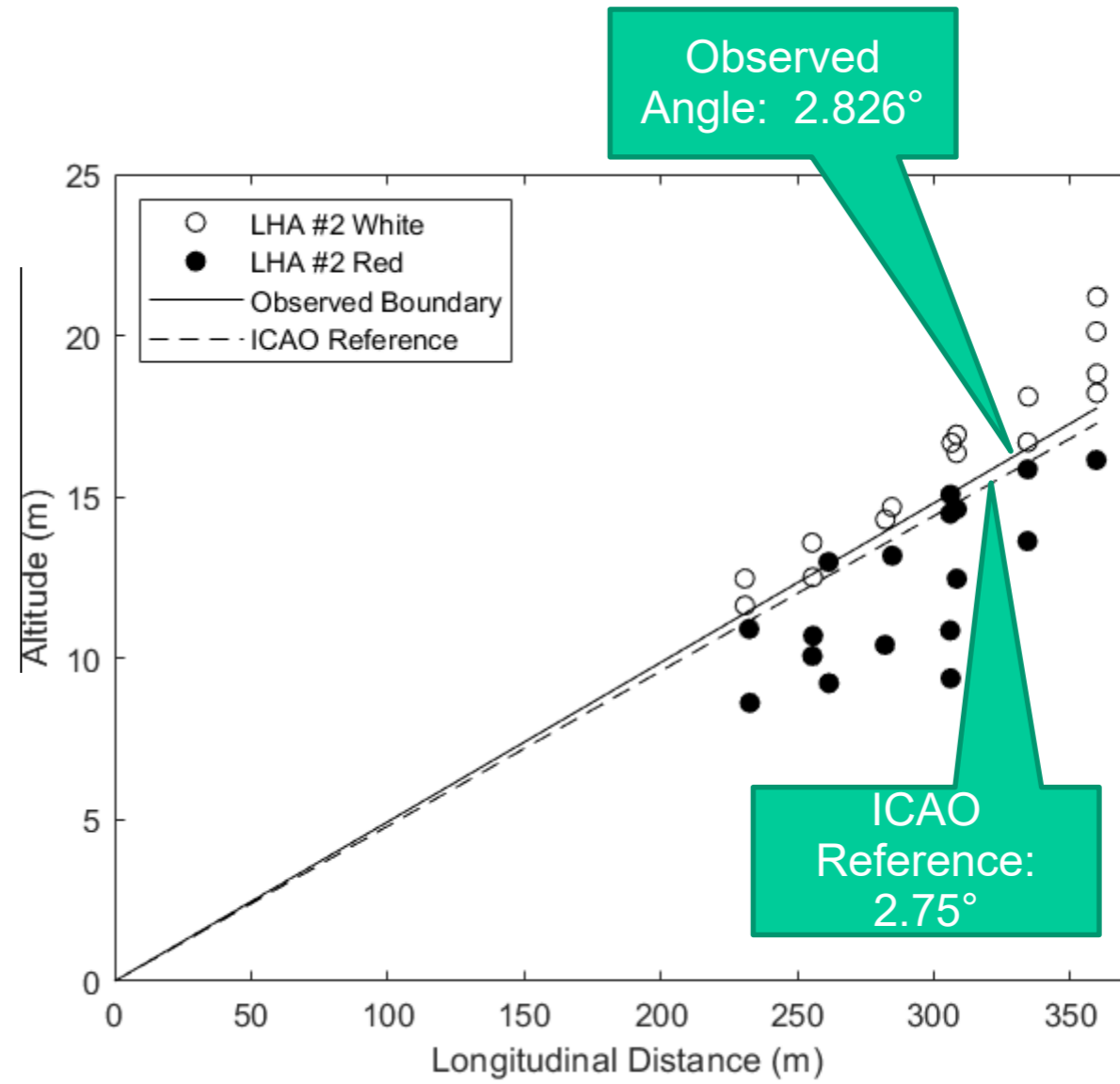
LHA #2 Results



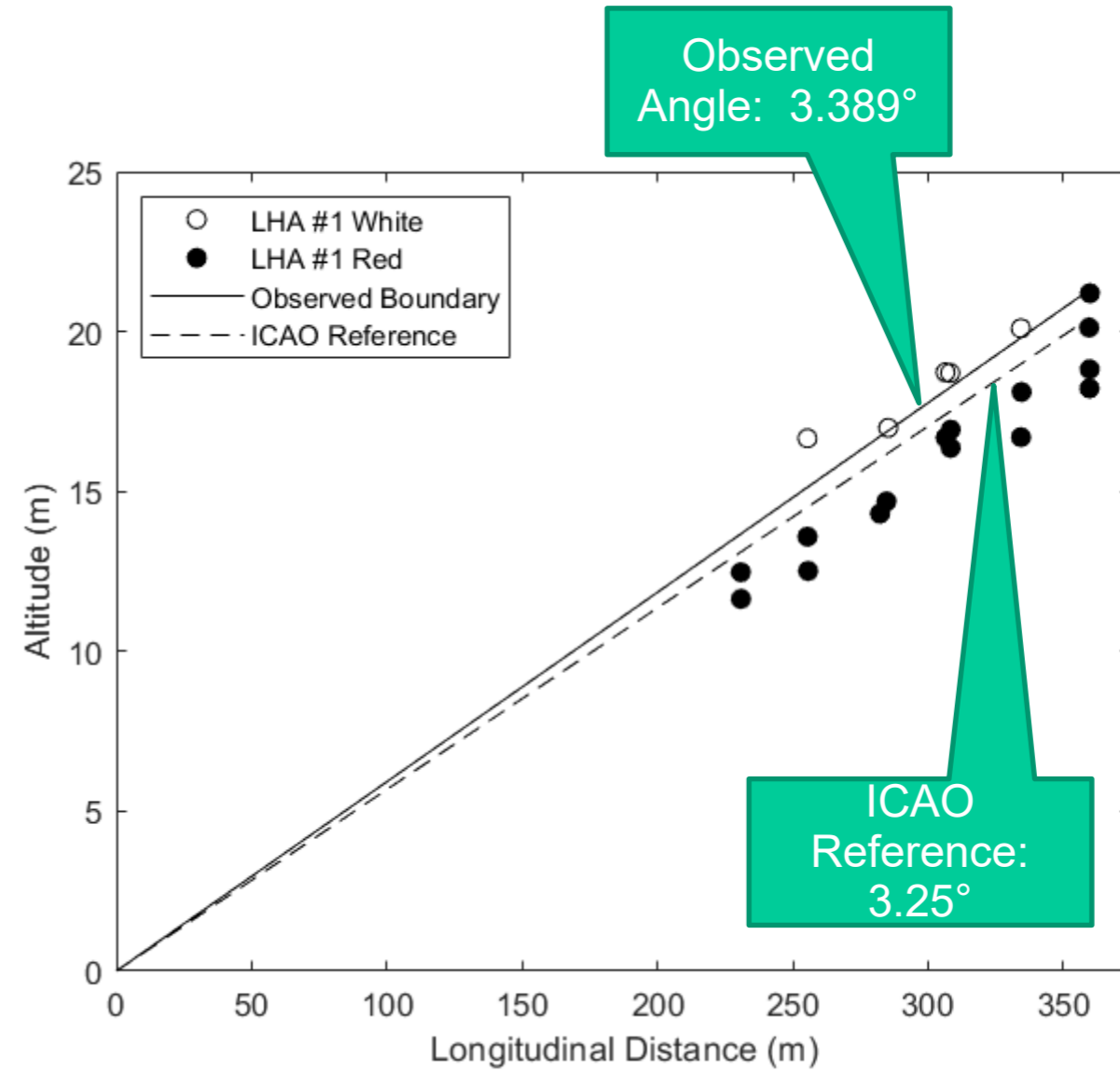
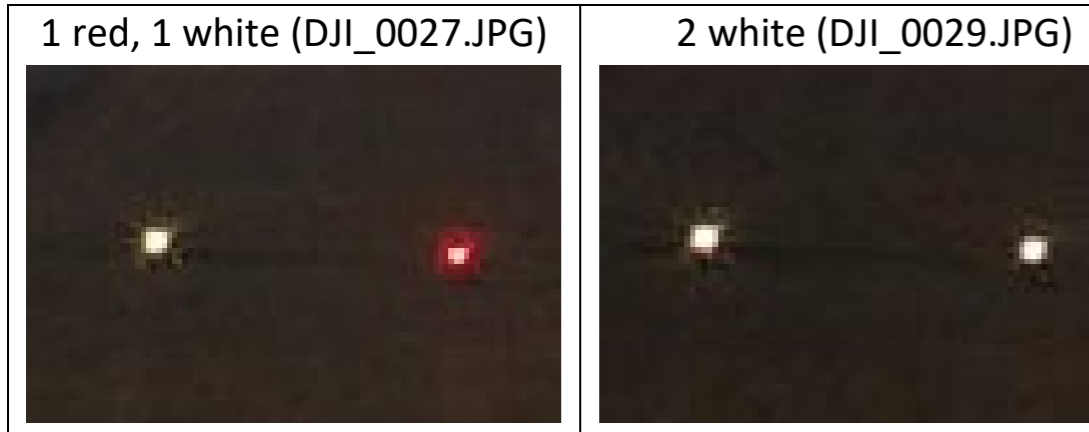
1 red, 1 white (DJI_0027.JPG)



2 white (DJI_0029.JPG)



LHA #1 Results



Allowable tolerance specified in FAA Order JO 6850.2B: 0.083° (5 arc-min)

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