Airborne Evaluation of Retro-Reflective Beads

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16. Abstract

This project was undertaken by the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Sub-Team as part of an effort to determine the relative conspicuity, from an aircraft on approach, of Type I and Type III retro-reflective beads. Retro-reflective beads are designed to redirect and return light back to its source. The inclusion of retro-reflective beads in painted surface markings can increase their conspicuity. It has been suggested that Type III retro-reflective beads, which have a higher index of refraction (IOR) compared to Type I beads, will substantially increase the conspicuity of paint markings and could help prevent runway incursions. The FAA uses Federal Specification TT-B-1325D, “Beads (Glass Spheres) Retro-Reflective,” to specify retro-reflective beads.

Previous studies by the United States Air Force and the FAA have shown that in cases where the light source is not in close proximity to the observer’s line of sight, the benefit of using higher IOR beads is negligible. Since 1994, all research on retro-reflective beads has been focused on surface markings from the ground to improve the conspicuity of taxiway hold position markings, which aid in the prevention of runway incursions. Due to advances in bead technology, it has been suggested that additional tests be conducted from the pilot’s perspective on approach to a runway.

Type I and Type III retro-reflective beads were installed on the same type of airport pavement markings at opposite ends of Runway 13/31 at Atlantic City International Airport (ACY) for a period of 8 months and side by side on Runway 10 at Savannah/Hilton Head International Airport (SAV) for a period of 2 months. Subjective data was collected in the form of questionnaires completed by test subjects from aircraft approaching the runway at both locations. The test subjects were queried concerning ease of marking detection and conspicuity. Objective measurements were taken at the beginning and the end of the evaluation.

The majority of the test subjects involved in the tests at both ACY and SAV stated they do not use runway markings as a visual cue on approach to a runway at night. They focus on the runway lights. Of the subjects participating, all but one reported no difference in ease of detection between Type I and Type III bead markings.

The chromaticity and retro-reflectivity characteristics of the bead markings were acceptable following initial application and throughout the evaluation period. While the Type III beads had a greater retro-reflectivity reading after initial installation, the effects on conspicuity from a pilot’s perspective on approach to the runway were minimal. Also, the higher retro-reflectivity readings of the Type III beads only lasted a few months at ACY then leveled out to the same retro-reflectivity values as the Type I beads for the remainder of the markings’ useful life.

This study revalidates the airborne research performed in 1994 and is consistent with other ground-based research performed to date including research completed in 2009.

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LIST OF ACRONYMS

AC	Advisory Circular
ACY	Atlantic City International Airport
CIE	Commission on Illumination
DOT	Department of Transportation
FAA	Federal Aviation Administration
HMA	Hot-mix asphalt
ICAO	International Civil Aviation Organization
IOR	Index of refraction
R&D	Research and development
RWY	Runway
SAV	Savannah/Hilton Head International Airport
USAF	United States Air Force

EXECUTIVE SUMMARY

This project was undertaken by the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Sub-Team as part of an effort to determine the relative conspicuity, from an aircraft on approach, of Type I and Type III retro-reflective beads. Retro-reflective beads are designed to redirect and return light back to its source. The inclusion of retro-reflective beads in painted surface markings can increase their conspicuity. It has been suggested that Type III retro-reflective beads, which have a higher index of refraction (IOR) compared to Type I beads, will substantially increase the conspicuity of paint markings and could help prevent runway incursions. The Federal Aviation Administration (FAA) uses "Federal Specification TT-B-1325D, "Beads (Glass Spheres) Retro-Reflective," for retro-reflective beads.

Previous studies by the United States Air Force and the FAA have shown that in cases where the light source is not in close proximity to the observer's line of sight, the benefit from using higher IOR beads is negligible.

Since 1994, all research on retro-reflective beads has been focused on pavement markings from the ground to improve the conspicuity of taxiway hold position markings, which aid in the prevention of runway incursions. Due to advances in bead technology, it has been suggested that more tests be conducted from the pilot's perspective on approach to a runway.

Type I and Type III retro-reflective beads were installed on the same type of airport pavement markings at opposite ends of Runway 13/31 at Atlantic City International Airport (ACY) for a period of 8 months and side-by-side on Runway 10 at Savannah/Hilton Head International Airport (SAV) for a period of 2 months. Subjective data was collected in the form of questionnaires completed by test subjects from aircraft approaching the runway at both locations. The test subjects were queried concerning ease of marking detection and conspicuity. Objective measurements were taken at the beginning and end of the evaluation.

The majority of the test subjects at both ACY and SAV stated they do not use runway markings as a visual cue on approach to a runway at night. They focus on the runway lights. Of the subjects participating, all but one reported no difference in ease of detection between Type I and Type III bead markings.

The chromaticity and retro-reflectivity characteristics of the bead markings were acceptable following initial application and throughout the evaluation period. While the Type III beads, with a higher IOR had a greater retro-reflectivity reading after initial installation, the effects on conspicuity from a pilot's perspective on approach to the runway were minimal. Also, the higher retro-reflectivity readings of the Type III beads only lasted a few months at ACY then leveled out to the same retro-reflectivity values as the Type I beads for the remainder of the marking's useful life.

This study revalidates the airborne research performed in 1994 and is consistent with other ground-based research performed to date, including research completed in 2009.

INTRODUCTION

PURPOSE.

This project was undertaken by the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development (R&D) Visual Guidance Sub-Team as part of an effort to determine the relative conspicuity, from an aircraft on approach, of Type I and Type III retro-reflective beads. Type I and Type III retro-reflective beads are currently recommended in FAA Advisory Circular (AC) 150/5340-1J [1].

BACKGROUND.

Retro-reflective beads are designed to redirect and return light back to its source. The inclusion of retro-reflective beads in pavement markings can increase their conspicuity. It has been suggested that Type III retro-reflective beads, which have a higher index of refraction (IOR) compared to other beads, will substantially increase the conspicuity of paint markings and could help prevent runway incursions. The FAA uses Federal Specification TT-B-1325D [2] for retro-reflective beads. Type I (1.5 IOR) low-index, recycled retro-reflective beads have less density, roughly 1570 grams per liter. Type III (1.9 IOR) high-index virgin glass beads have a larger density, roughly 2670 grams per liter. In August 2007, a revision to specification TT-B-1325D included a nonmandatory note that stated “Type III - high index glass beads for drop-on applications is intended for applications where increased retro-reflectivity is needed.” It further clarifies that the “increased retro-reflective values obtained from use of high IOR glass beads are only apparent to the observer in cases where the observer’s line of sight is in close proximity to the path of the light source used to illuminate the markings.”

Previous studies by the United States Air Force and the FAA have shown that in cases where the light source is not in close proximity to the observer’s line of sight, the benefit from using higher IOR beads is negligible.

To date, the only other study conducted, from the perspective of a pilot on approach, by the FAA is documented in reference 3.

These tests showed that the conspicuity of both Type I and Type III retro-reflective beads was adequate to complete aircraft operations safely. It also showed that Type III retro-reflectivity was initially higher than Type I retro-reflective beads; however, after a few months, the readings deteriorated to a Type I retro-reflectivity level for the remainder of the pavement marking’s useful life.

Since 1994, all research on retro-reflective beads had been focused on the ground to improve the conspicuity of taxiway hold position markings, which aid in the prevention of runway incursions.

Due to advances in bead technology, it was suggested that additional tests be conducted from the pilot’s perspective on approach to a runway.

SCOPE.

For this evaluation, Type I and Type III retro-reflective beads were tested in actual airport runway environments from November 2008 through December 2009.

OBJECTIVES.

The objectives of this project were:

- Determine the effectiveness of beads over the useful life of a pavement marking at ACY only.

- Determine if the visual cues provided to pilots on approach to a runway by pavement markings with either Type I or Type III retro-reflective beads are adequate to safely perform the intended operation.

- Compare the conspicuity of Type I and Type III retro-reflective beads.

RELATED DOCUMENTATION.

- ICAO Annex 14, Volume I, “Aerodrome Design and Operation,” August 9, 2000.

- Cyrus, H., “Paint and Bead Durability Study,” FAA report DOT/FAA/AR-02/128, March 2003.

EVALUATION APPROACH

The evaluation of Type I and Type III beads was conducted in two airport locations: phase one at Atlantic City International Airport (ACY) and phase two at Savannah/Hilton Head International Airport (SAV).

The color white was selected for this evaluation since white is one of the colors used for airport runway systems. All retro-reflective beads were applied to the same Type III, TT-P-1952E, HD-21A, high-build resin waterborne white paint material at an application depth of 14-mil wet film thickness at a paint application rate of 115 ft^2/gal, per AC 150/5370-10D [4].

Retro-reflective beads were installed in the same type of airport pavement markings at opposite ends of Runway 13/31 at ACY for 8 months and side by side on Runway 10 at SAV for 2 months. Subjective data was collected in the form of questionnaires completed by test subjects from aircraft approaching the runway at both locations. Because different painting contractors applied the markings at each test site, objective measurements were taken at the beginning of the evaluation to determine if the application at both test sites produced approximately the same retro-reflectivity and chromaticity readings, which should be obtained in a “typical” installation. These readings were taken again at both sites at the end of the evaluation, which was 8 months after installation at ACY and 2 months after installation at SAV.

PHASE ONE—ATLANTIC CITY INTERNATIONAL AIRPORT.

Phase one was conducted using the opposite ends of Runway 13/31 at ACY in November 2008. Type I and Type III retro-reflective beads were applied to standard waterborne paint at an application depth of 14-mil wet film thickness. Threshold Markings, Threshold Bar, Runway Designation Number, Runway Centerline, Touchdown Zone, Aiming Point, and Runway Edge markings were evaluated. Throughout the evaluation, objective data were collected to determine the chromaticity and retro-reflectivity readings. Figure 1 shows an airport diagram of ACY indicating where the Type I and Type III retro-reflective beads were applied to the runway markings.

Subjective data were collected during the flight tests to determine the adequacy of the visual cues. Test subjects were given an in-flight questionnaire, as well as postflight debriefs, to collect subjective data as to conspicuity and adequacy of the markings evaluated.

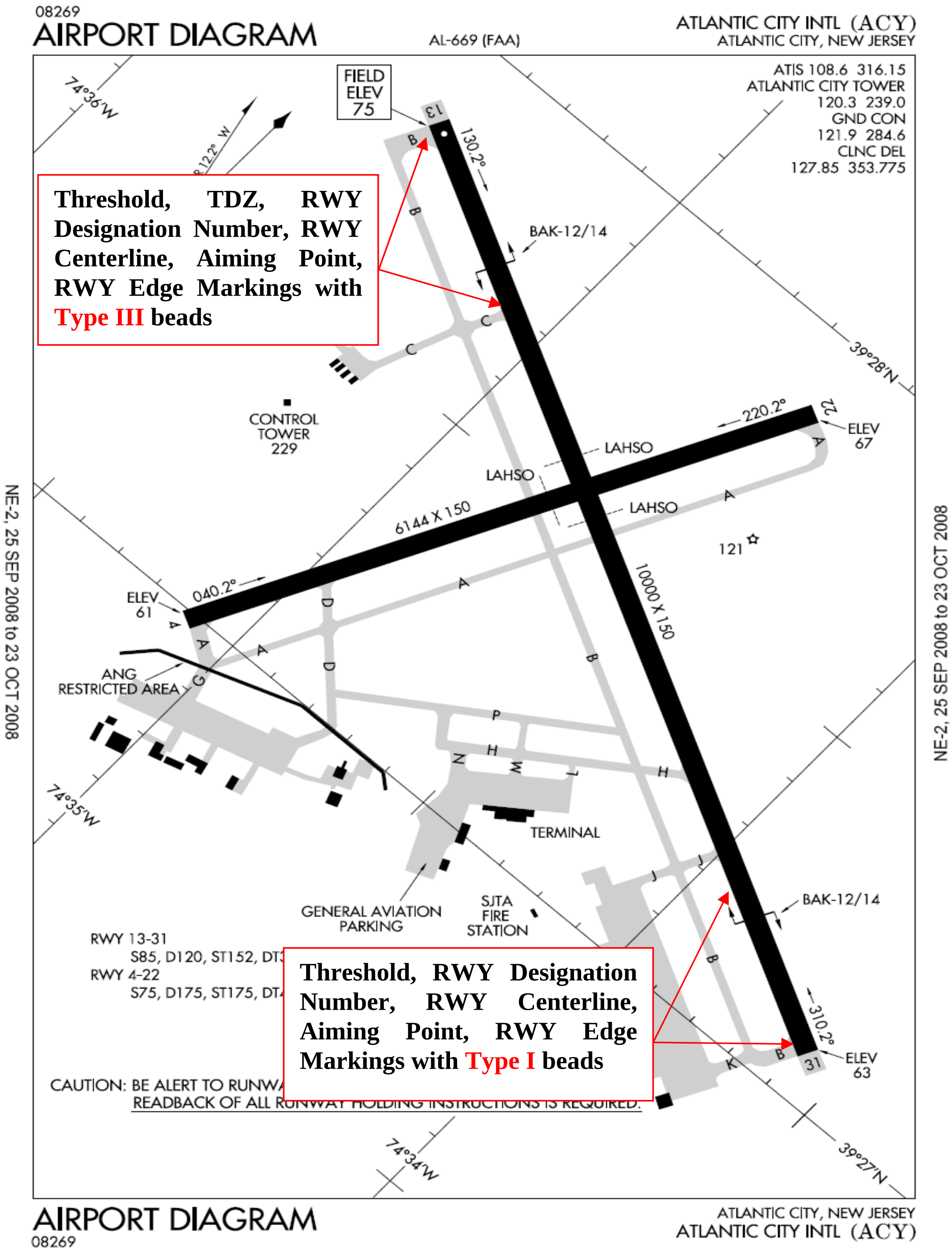

Figure 1. Atlantic City International Airport Diagram

PHASE TWO—SAVANNAH/HILTON HEAD INTERNATIONAL AIRPORT.

Phase two was conducted on Runway 10 at SAV in September 2009. Type I and Type III retro-reflective beads were applied to the same Type III, TT-P-1952E, HD-21A high-build resin waterborne white paint material at an application of 14-mil wet film thickness at a paint application rate of 115 ft^2/gal. per AC 150/5370-10D [4]. Threshold Markings, Threshold Bar, Runway Centerline, Touchdown Zone, Aiming Point, and Runway Edge markings were evaluated. Type I retro-reflective beads were applied to one side (i.e., north) of the runway and Type III retro-reflective beads were applied to the opposite side (i.e., south) of the runway. Subjective data was collected during flight tests to determine the adequacy of the visual cues. Figure 2 shows an airport diagram of SAV showing where the Type I and Type III retro-reflective beads were applied to the runway (RWY) markings. General aviation and military transport aircraft were used during this 2-month evaluation.

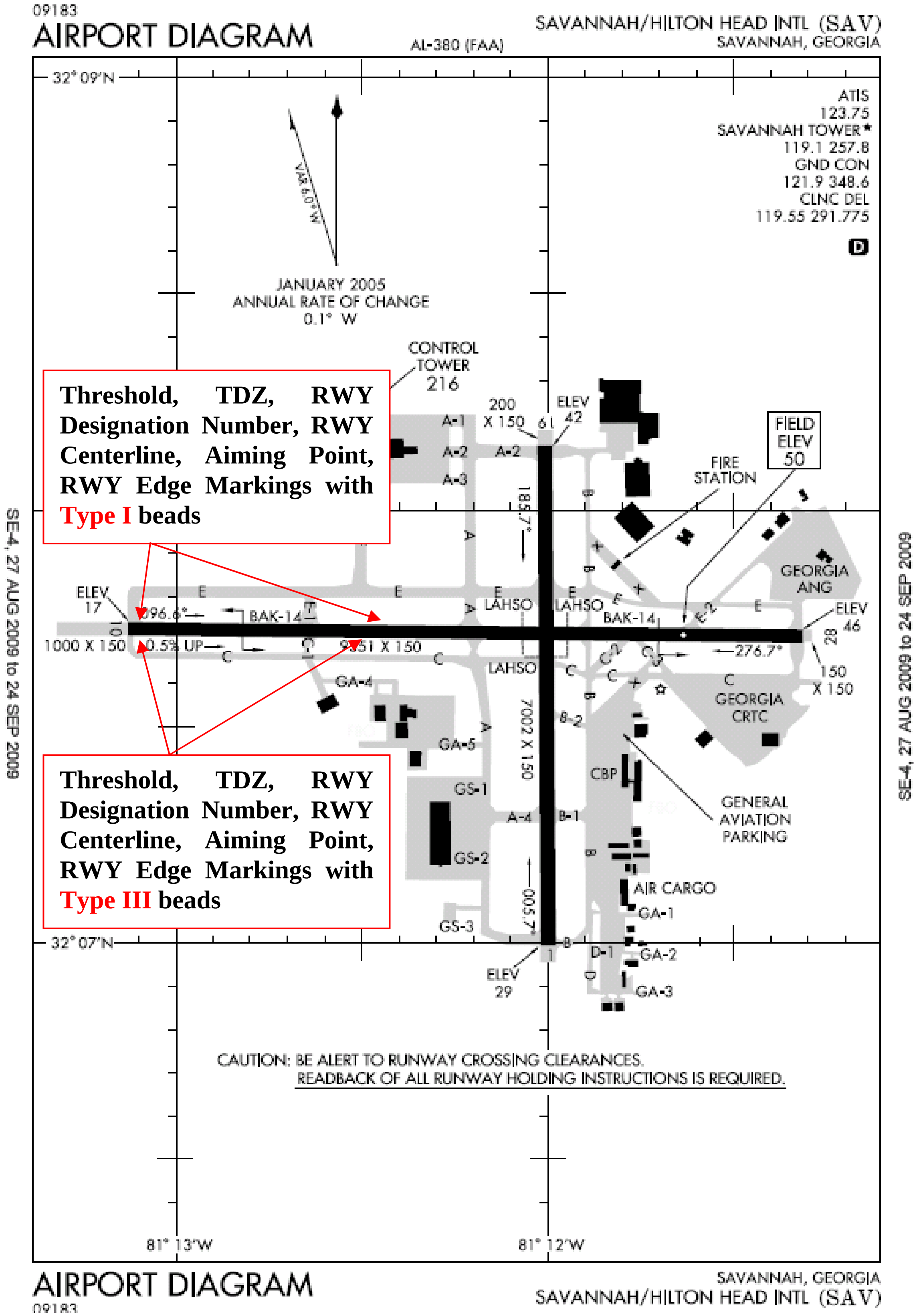

Figure 2. Savannah/Hilton Head International Airport Diagram

DATA COLLECTION

Chromaticity and retro-reflectivity test procedures were the same for both ACY and SAV and are described below.

CHROMATICITY TEST.

Color readings were taken with a Spectro-Guide 45/0 Spectrophotometer, BYK-Gardner USA, which produces three coordinates (Y = depth, x = width, y = height) for its readouts (figure 3). The Spectro-Guide was setup for the standard coordinate system CIE 1931 XYZ color space, created by the International Commission on Illumination (CIE). The readings obtained were then compared to the color coordinate boundaries for white, as shown in figure 4.

Figure 3. Airport Safety Technology R&D Sub-Team Member Taking Chromaticity Readings

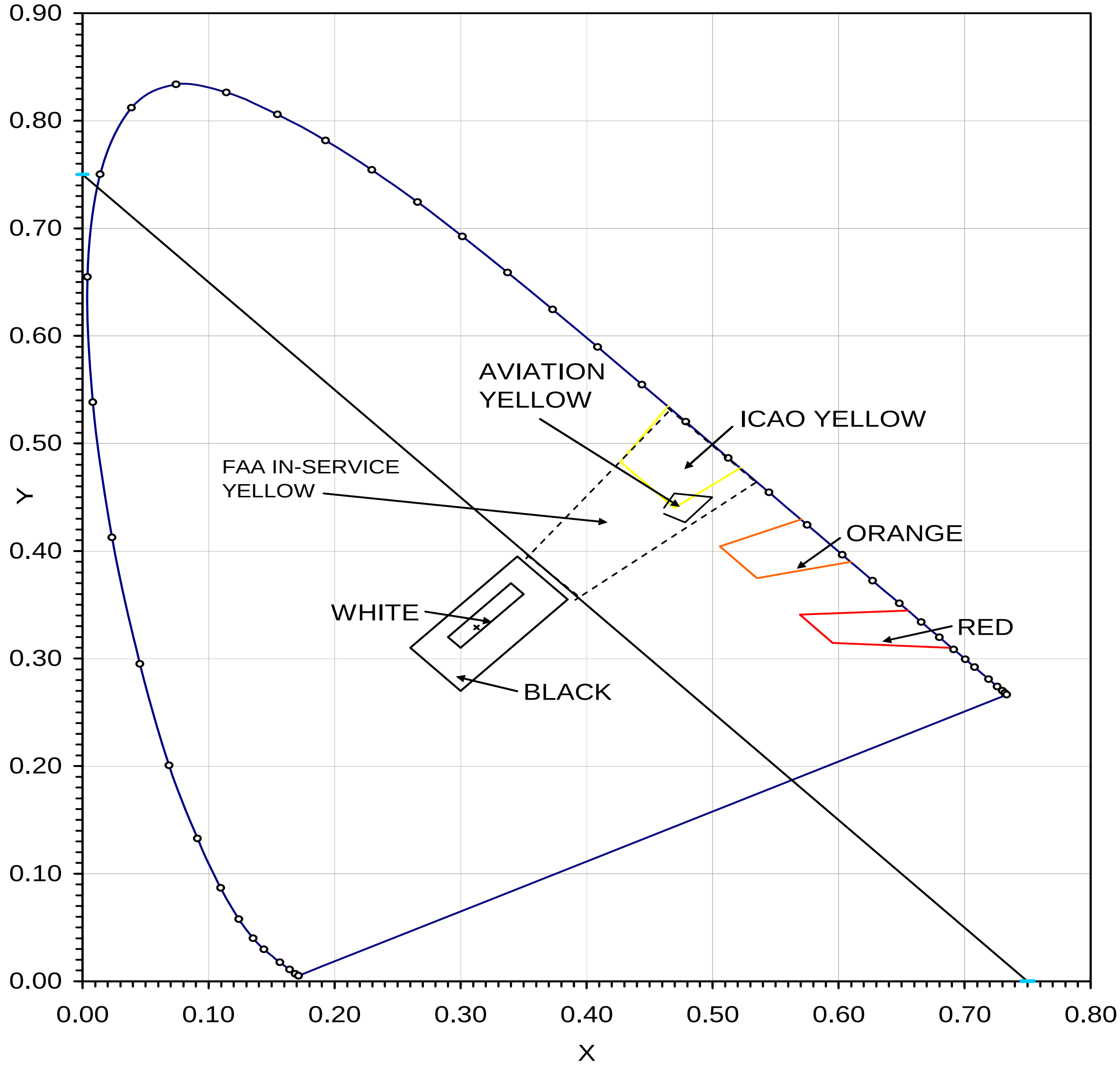

Figure 4. Sample Standard Illuminant D_{65} Color Chart

<u>RETRO-REFLECTIVITY TEST</u>.

The LTL-X Retrometer used in this evaluation produced millicandela per meter squared per lux readings. Currently, the FAA has no standard for retro-reflectivity limits. In a previous pavement marking study conducted by the FAA Airport Safety Technology R&D Sub-Team [5], it was recommended that the minimum retro-reflectivity for the color white should be $100 mcd/m^2/lx$.

The 30-meter geometry for retro-reflectivity, which is distance from the headlights to the pavement markings, is the standard used by the highway departments, as shown in figure 5. The National Institute of Standards and Technology does not have a reference standard for retro-reflectometers. No standard has been developed for aircraft due to variability of cockpit heights. Therefore, the standards for the highway department are used.

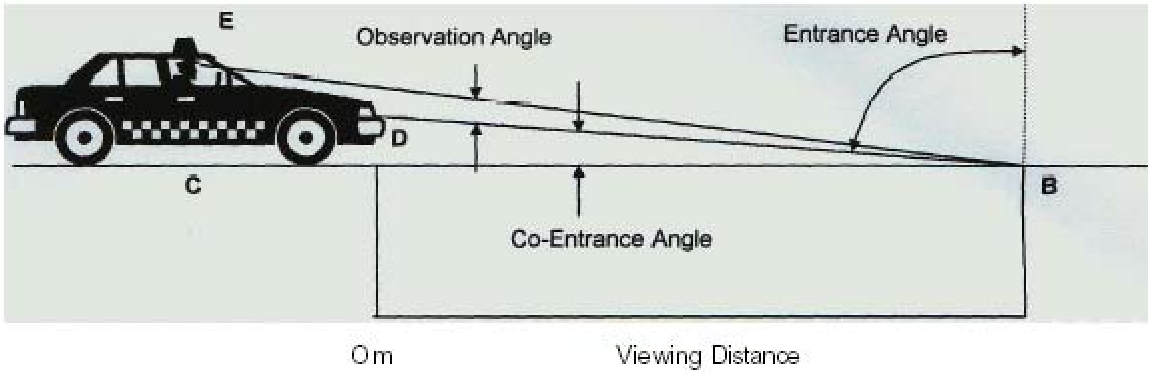

Figure 5. Thirty-Meter Geometry Measurement for Retro-Reflectivity

Using the LTL-X Retrometer built by Delta Lights and Optics of Denmark, six readings per marking were taken, as shown in figure 6. Prior to each use, the instrument was calibrated.

Figure 6. Airport Safety Technology R&D Sub-Team Members Taking Retro-Reflectivity Readings

SUBJECTIVE TEST.

The conspicuity of the runway markings was evaluated using aircraft on approach to Runway 13/31 at ACY.

An evaluation questionnaire was given to each test subject for approaches to Runway 13. This process was then repeated for Runway 31. Standard 3° approaches to each runway were flown. Flights were flown toward the runway markings until the test subject deemed them visible and conspicuous.

The SAV-based general aviation and military transport aircraft test subjects evaluated the conspicuity of the runway markings during approaches to Runway 10 at SAV.

An evaluation questionnaire was filled out by each test subject for approaches to Runway 10. Flights were flown towards the runway markings until the test subject deemed them visible and conspicuous.

RESULTS

CHROMATICITY TESTS.

For the chromaticity or color check, the BYK Gardner Spectro-Guide 45/0 Spectrophotometer was used in conjunction with a CIE D_{65} chart. This device shows if the paint is fading. The data points are graphed on the CIE D_{65} chart, then checked to see if they fall within the International Civil Aviation Organization white region. A white data point falling outside the white region was considered failed. (See appendix A for additional data.)

The first chromaticity readings for all runway markings at ACY were within the acceptable chromaticity range. During the 8-month evaluation at ACY:

- one data point from Type I beads on the Threshold Bar marking was outside the region. (Refer to figure A-1 in appendix A).
- three data points from Type I beads on the Centerline marking were outside the region. (Refer to figure A-4 in appendix A).
- one data point from Type I beads on the Aiming Point marking was outside the region. (Refer to figure A-6 in appendix A).
- two data points from Type III beads on the Aiming Point marking were outside the region. (Refer to figure A-13 in appendix A).

The first and last chromaticity readings (with only a few points outside the region) for all runway markings at SAV were acceptable. (See appendix A for additional data.)

Tables 1 and 2 provide side-by-side comparisons of the Type I and Type III retro-reflective beads on hot-mix asphalt (HMA) at both airports. (See appendix A for additional data.)

Table 1. Initial Chromaticity Readings of Type I Retro-Reflective Beads on Aged HMA

Runway Marking	ACY Runway 31	SAV Runway 10
Threshold Bar	Acceptable	Acceptable
Threshold Line	Acceptable	Acceptable
Designator	Acceptable	Acceptable
Centerline	Acceptable	Acceptable
Touch Down Zone	Acceptable	Acceptable
Aiming Point	Acceptable	Acceptable
Edge Line	Acceptable	Acceptable

Table 2. Initial Chromaticity Readings of Type III Retro-Reflective Beads on Aged HMA

Runway Marking	ACY Runway 13	SAV Runway 10
Threshold Bar	Acceptable	Acceptable
Threshold Line	Acceptable	Acceptable
Designator	Acceptable	Acceptable
Centerline	Acceptable	Acceptable
Touch Down Zone	Acceptable	Acceptable
Aiming Point	Acceptable	Acceptable
Edge Line	Acceptable	Acceptable

RETRO-REFLECTIVITY TESTS.

The first retro-reflectivity readings for all runway markings were above the recommended minimum retro-reflectivity of 100 mcd/m^2/lx for the color white.

Figure 7 shows the initial overall average of retro-reflectivity readings for runway markings at ACY and SAV taken immediately after installation. Two different contractors applied the markings at the test sites, and the readings indicated the application of the paint markings were "typical" installations. (See appendix B for additional data.)

The ACY evaluation provided the length of time necessary to capture the rate of retro-reflective degradation. Figure 8 shows that, initially, markings with Type III beads were more retro-reflective; however, after 4 months, both Type I and Type III beads leveled out at essentially the same value, which was above the recommended level of 100 mcd/m^2/lx. All the retro-reflective bead evaluations that were conducted up to this point have demonstrated the same leveling out aspect.

Figure 9 shows the SAV data for a 2-month period.

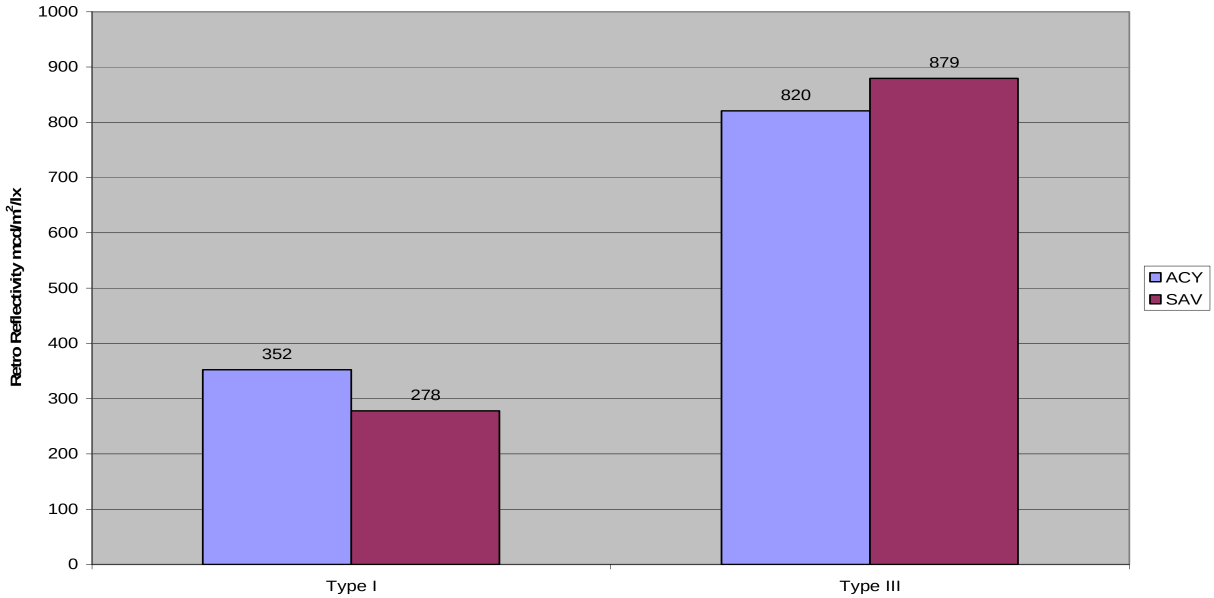

Figure 7. Overall Average of Retro-Reflectivity Readings at Start of Evaluation

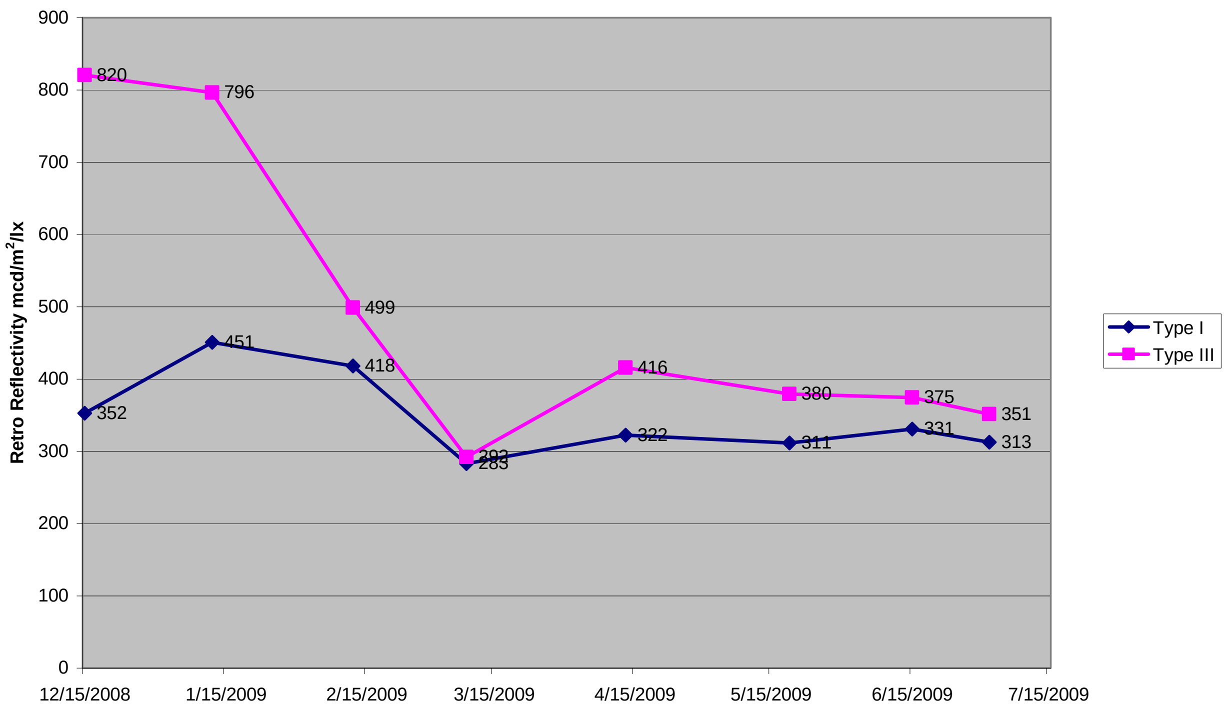

Figure 8. Overall Average of Retro-Reflectivity Readings at ACY Over 8 Months

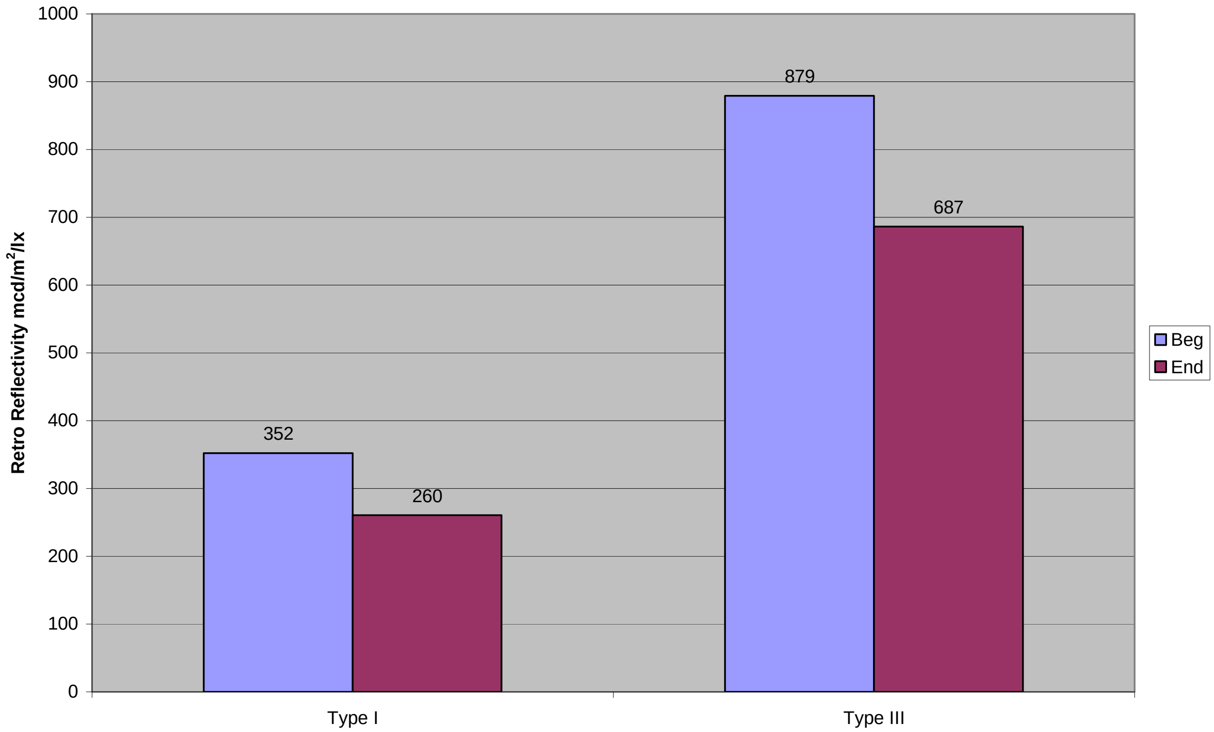

Figure 9. Overall Average of Retro-Reflectivity Readings at SAV Over 2 Months

SUBJECTIVE TEST.

The conspicuity of the ACY runway markings was evaluated using an aircraft approaching Runway 13/31 at ACY.

An evaluation questionnaire was filled out by each test subject for approach to Runway 13. This process was then repeated for Runway 31. Standard 3° approaches to each runway were flown. Flights were flown towards the runway markings until the test subject deemed them visible and conspicuous.

Figure 10 shows a comparison of Type I and Type III retro-reflective beads in relation to the statements “Were the markings easy to detect?” and “Were the runway markings adequate in regards to conspicuity to complete the landing operation safely?” (labeled “Ease of Acquisition” and “Adequate for Operation,” respectively, in the figure.) Using a seven-point Likert scale where 1 implied “Not Very Easy” and 7 implied “Very Easy,” observers noted that ease of detection for Type I retro-reflective beads had an average response of 5.2, and Type III retro-reflective beads had an average response of 5.1. Conspicuity to complete the landing operation safely had an averaged response of 5.3 for Type I retro-reflective beads and 5.5 for Type III retro-reflective beads.

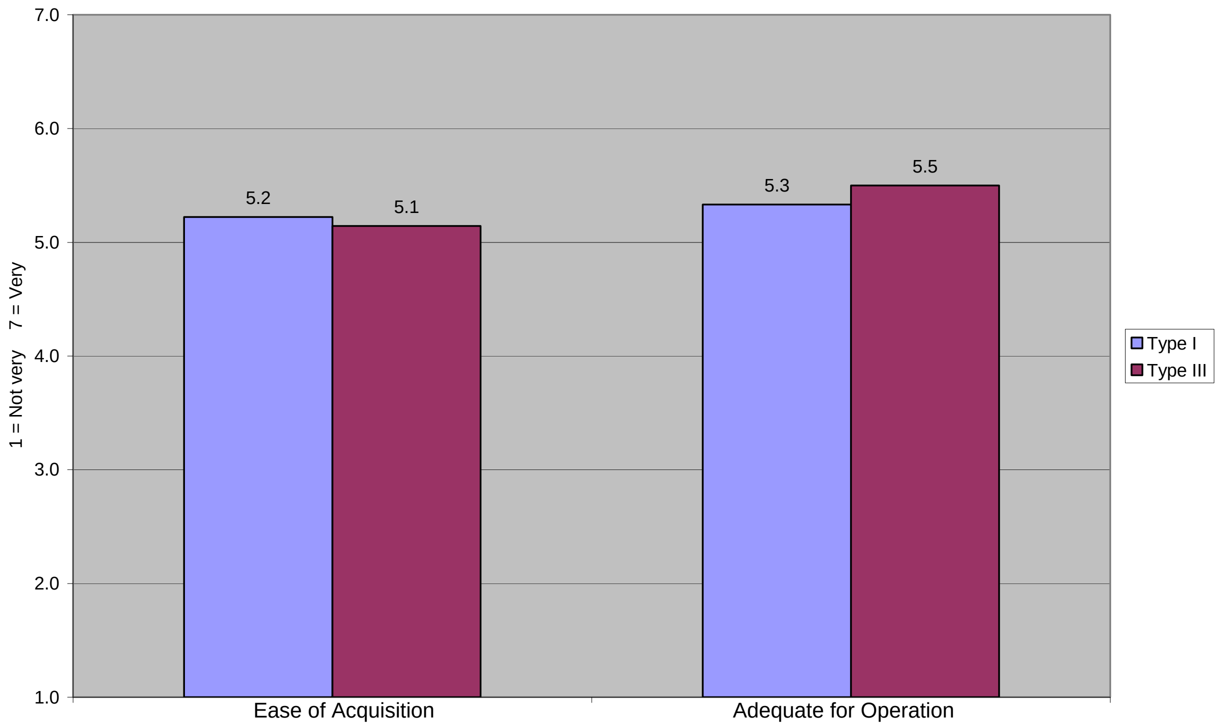

Figure 10. Comparison of ACY Type I and III Retro-Reflective Beads Regarding Ease of Runway Marking Detection and Adequacy Regarding Conspicuity

The subject pilots at SAV evaluated the conspicuity of the runway markings during approaches to Runway 10 at SAV.

An evaluation questionnaire was filled out by each test subject after completing approaches to Runway 10. Flights were flown toward the runway markings, and the test subject would indicate (on the postflight questionnaire) when the markings were visible and conspicuous.

Based on the subjective information obtained from the test subjects, it was determined that the average distance from the runway threshold that both Type I and Type III bead markings were visible and conspicuous was 3.9 miles. Of the ten test subjects, one did not list a distant measuring equipment reading, regarding visibility and conspicuity. A comment was made that "markings on the right (south Type III) side of the runway became visible just slightly before the left (north Type I)." Figure 11 shows the responses from the subjects at SAV regarding the markings' visibility and conspicuity.

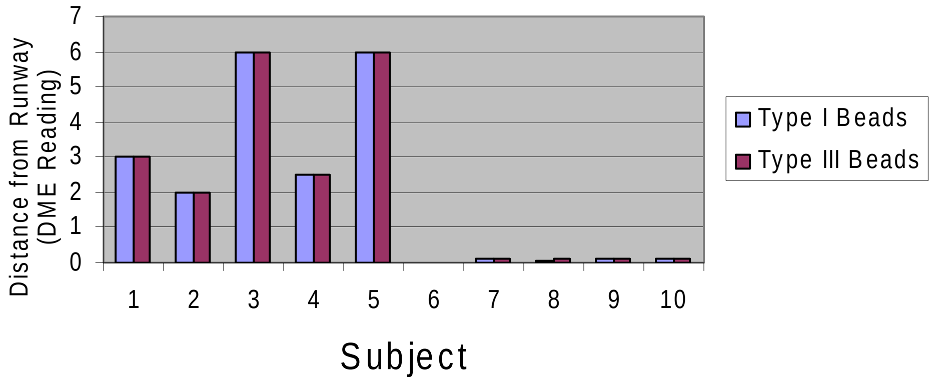

Figure 11. Test Subject Responses Regarding Visibility and Conspicuity of Runway Markings at SAV

The test subjects were asked whether the runway markings on the left (north) or right (south) side of Runway 10 were easier to detect. Ninety percent of the test subjects indicated that there was no difference between Type I and Type III beads (table 3). Only one test subject indicated that the Type III bead markings appeared brighter.

Table 3. Runway Side Identified by the Test Subjects as Easier to Detect at SAV

Subject	Ease of Detection		
	Left Side (North) (Type I)	Right Side (South) (Type III)	No Difference
1			X
2			X
3			X
4			X
5			X
6		X	
7			X
8			X
9			X
10			X

CONCLUSIONS AND RECOMMENDATIONS

While Type III beads have a higher retro-reflectivity reading after initial installation than Type I beads, the effects on conspicuity for a pilot on approach to the runway is minimal. The higher retro-reflectivity readings of the Type III beads only lasted a few months, as the readings leveled out to the same retro-reflectivity values as the Type I beads for the remainder of the markings' useful life.

This study revalidates the airborne research performed in 1994 and is consistent with other ground-based research performed to date, including research completed in 2009. Type I and Type III beads both performed adequately in providing the visual cue intended.

The majority of the test subjects at both Atlantic City International Airport and Savannah/Hilton Head International Airport stated they do not use runway markings as visual cues on approach to a runway at night, but instead focus on the runway lights. The test subjects indicated they had to really concentrate (for this evaluation) on looking for runway markings and then, only noted a very slight difference, if any, between Type I and III retro-reflective beads.

The difference between Type I and Type III beads from the pilot's perspective on approach is negligible.

The test subjects indicated that they use the markings after touchdown and that all the markings appeared the same on both sides.

If an airport has a surface area that requires higher retro-reflectivity for a shorter duration, a bead with a higher index of refraction, such as Type III, would provide that benefit.

REFERENCES

1. AC 150/5340-1J Change 2, "Standards for Airport Markings," June 6, 2008.

2. Federal Specification TT-B-1325D, "Beads (Glass Spheres) Retro-Reflective," August 6, 2007.

3. Bagot, K., "Evaluation of Retro-Reflective Beads in Airport Pavement Markings," FAA report DOT/FAA/CT-94/120, December 1994.

4. AC 150/5370-10D, "Standards for Specifying Construction of Airports," Item P-620, "Runway and Taxiway Painting," September 30, 2008.

5. Cyrus, H., "Development of Methods for Determining Airport Pavement Marking Effectiveness," FAA report DOT/FAA/AR-TN03/22, March 2003.

APPENDIX A—CHROMATICITY READINGS

Table A-1. Initial Chromaticity Readings of ACY Type I Beads on Aged Hot-Mix Asphalt

Runway Marking	Y = depth coordinate	x = width coordinate	y = height coordinate
Threshold Bar	71.45	0.3208	0.3416
Threshold Line	68.01	0.3202	0.3399
Designator	57.95	0.3262	0.3465
Centerline	65.14	0.3174	0.3390
Touch Down Zone	69.42	0.3190	0.3389
Aiming Point	63.69	0.3172	0.3370
Edge Line	69.63	0.3217	0.3404

Table A-2. Initial Chromaticity Readings of ACY Type III Beads on Aged Hot-Mix Asphalt

Runway Marking	Y = depth coordinate	x = width coordinate	y = height coordinate
Threshold Bar	77.08	0.3236	0.3424
Threshold Line	60.12	0.3186	0.3359
Designator	61.59	0.3226	0.3404
Centerline	58.21	0.3244	0.3454
Touch Down Zone	7083	0.3201	0.3383
Aiming Point	67.21	0.3218	0.3398
Edge Line	71.38	0.3291	0.3496

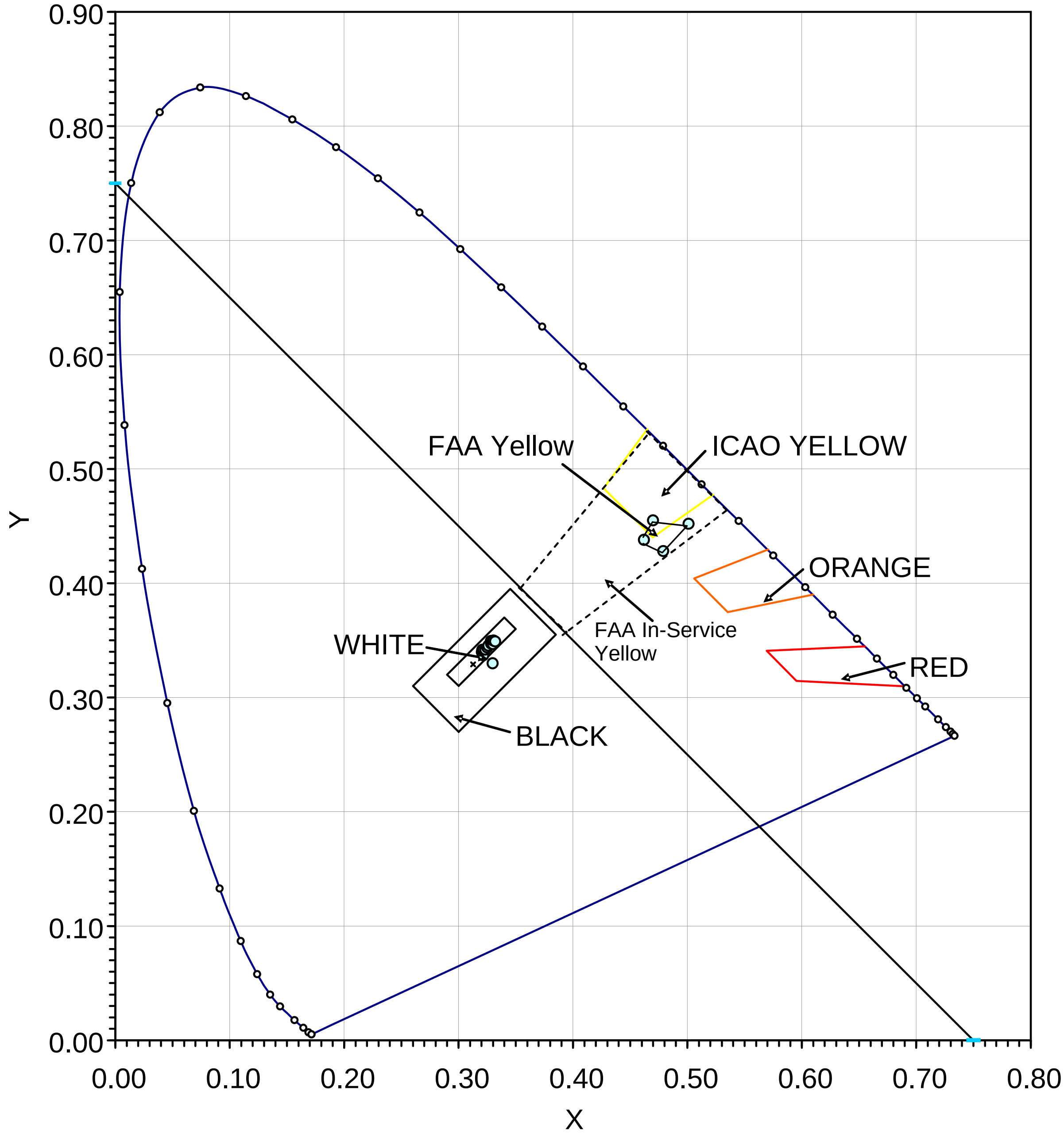

Figure A-1. Chromaticity Readings of Type I Bead on ACY Threshold Bar

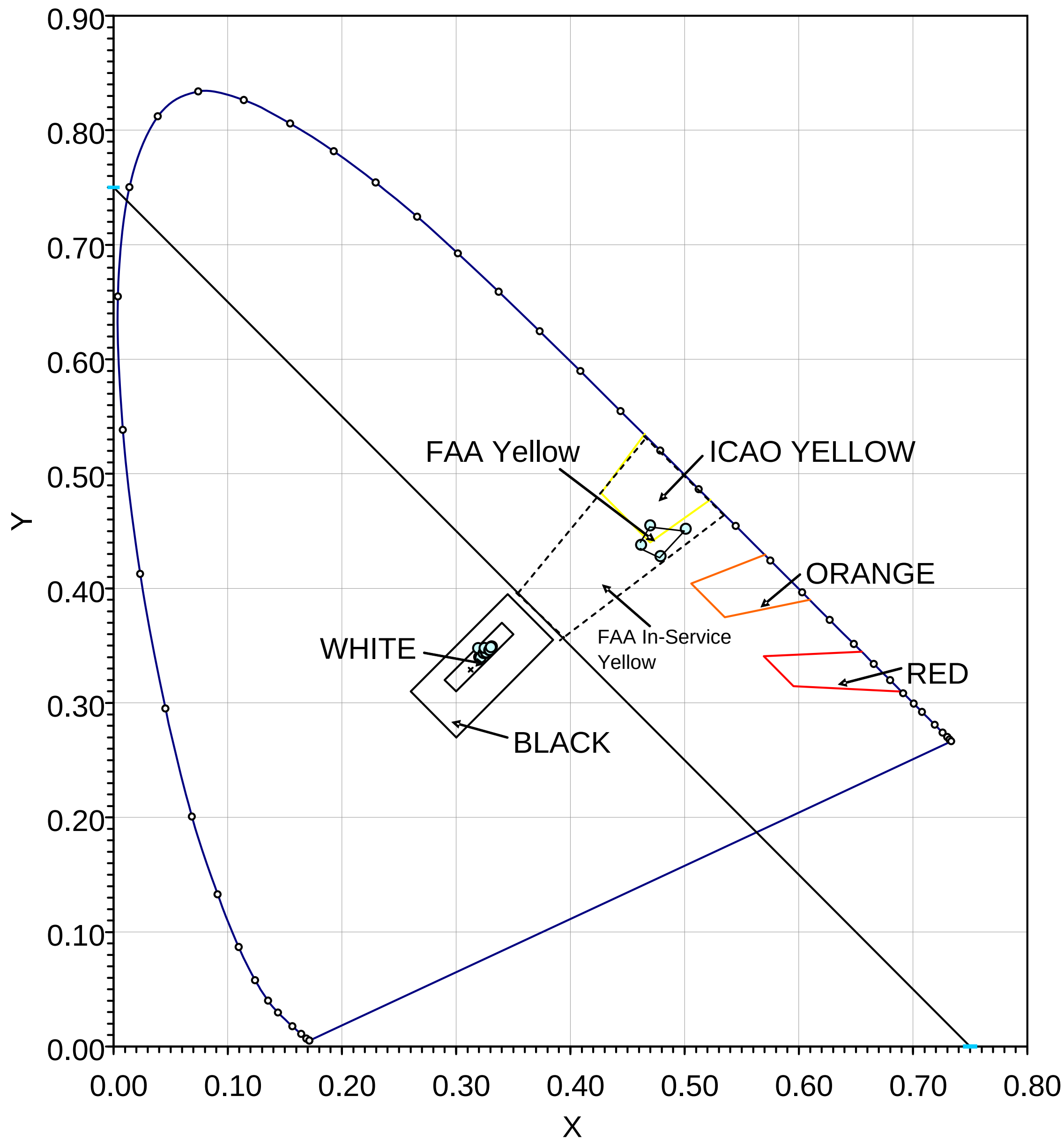

Figure A-2. Chromaticity Readings of Type I Bead on ACY Threshold Line

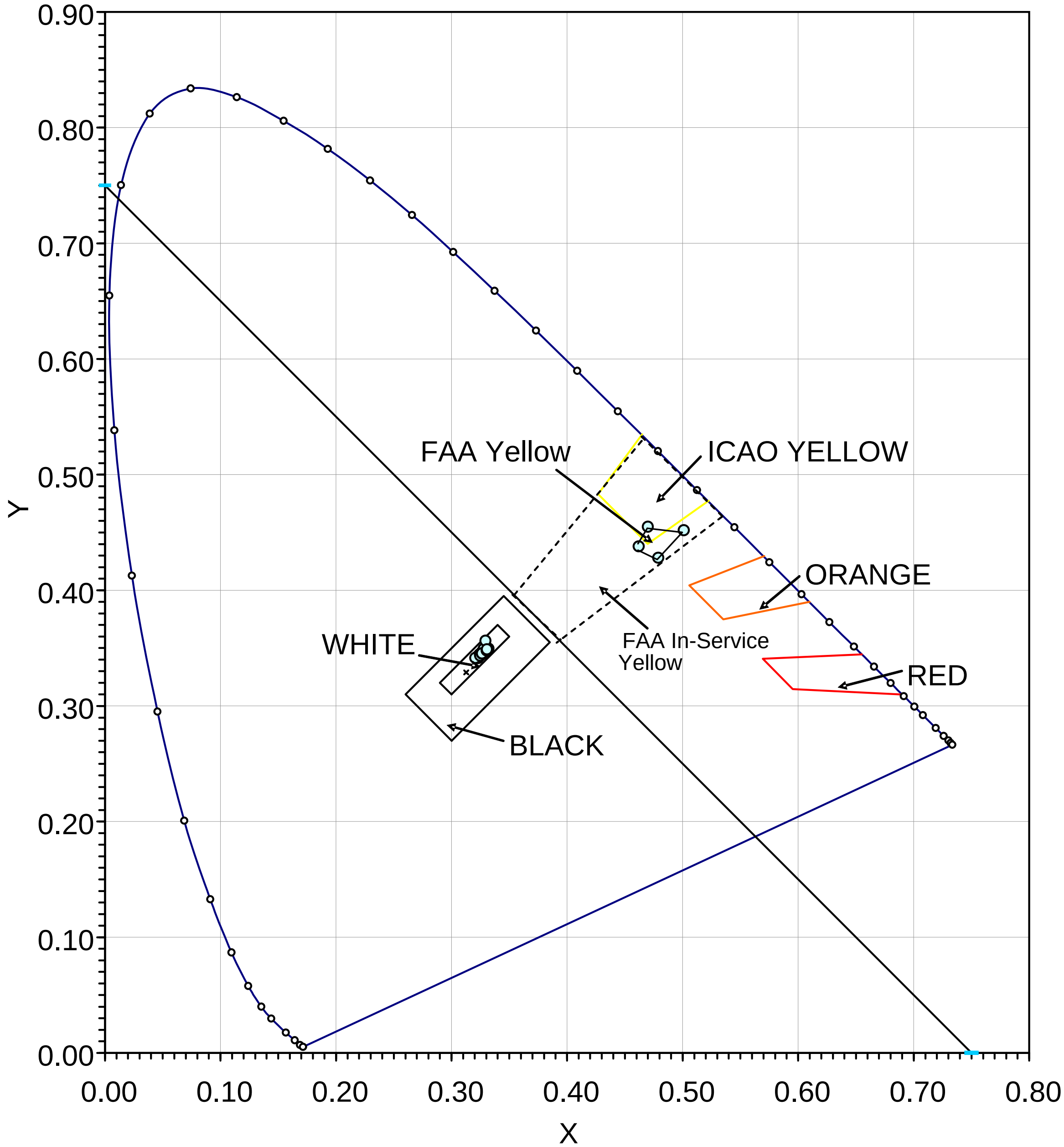

Figure A-3. Chromaticity Readings of Type I Bead on ACY Runway Designator

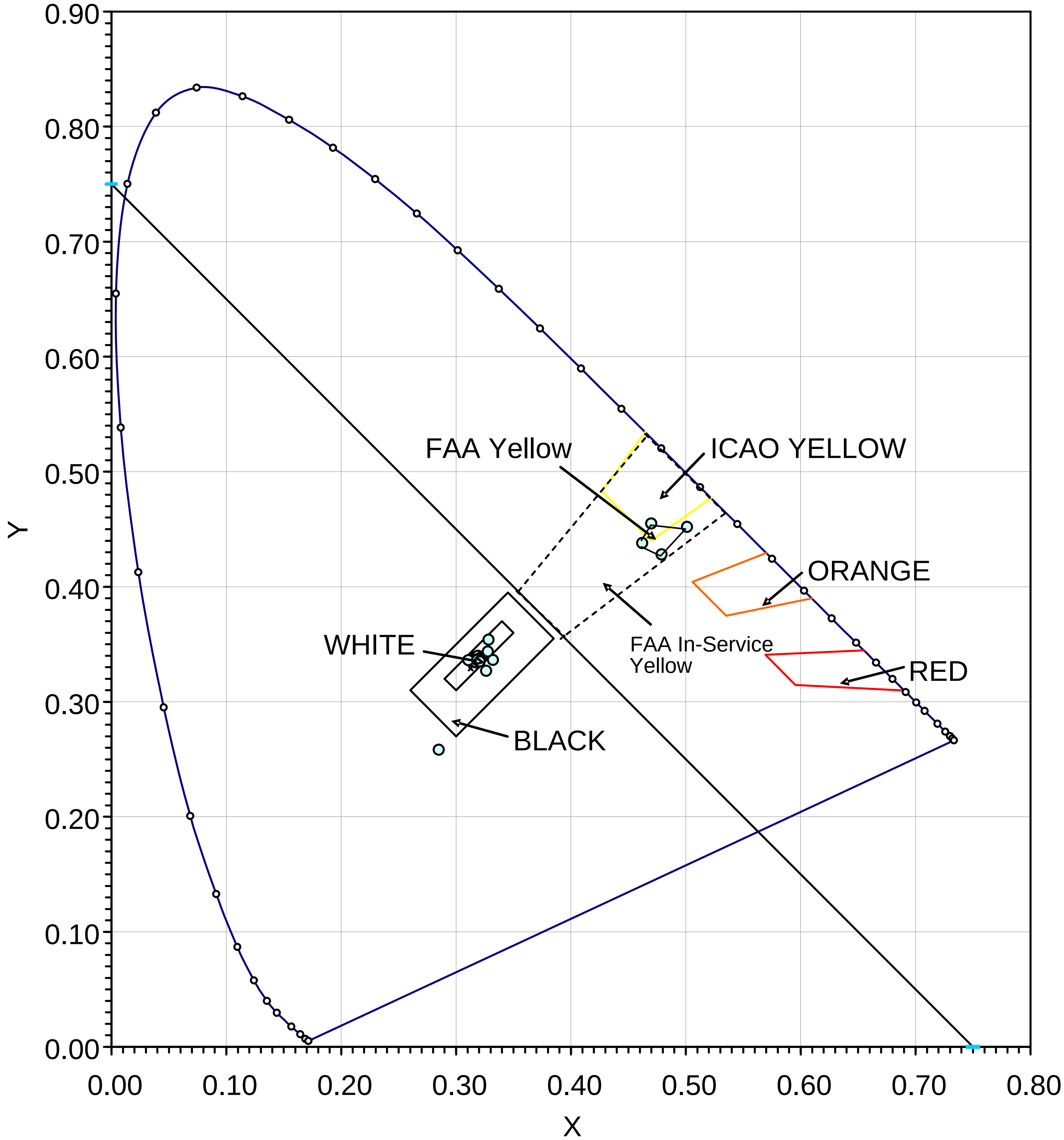

Figure A-4. Chromaticity Readings of Type I Bead ACY on Runway Centerline

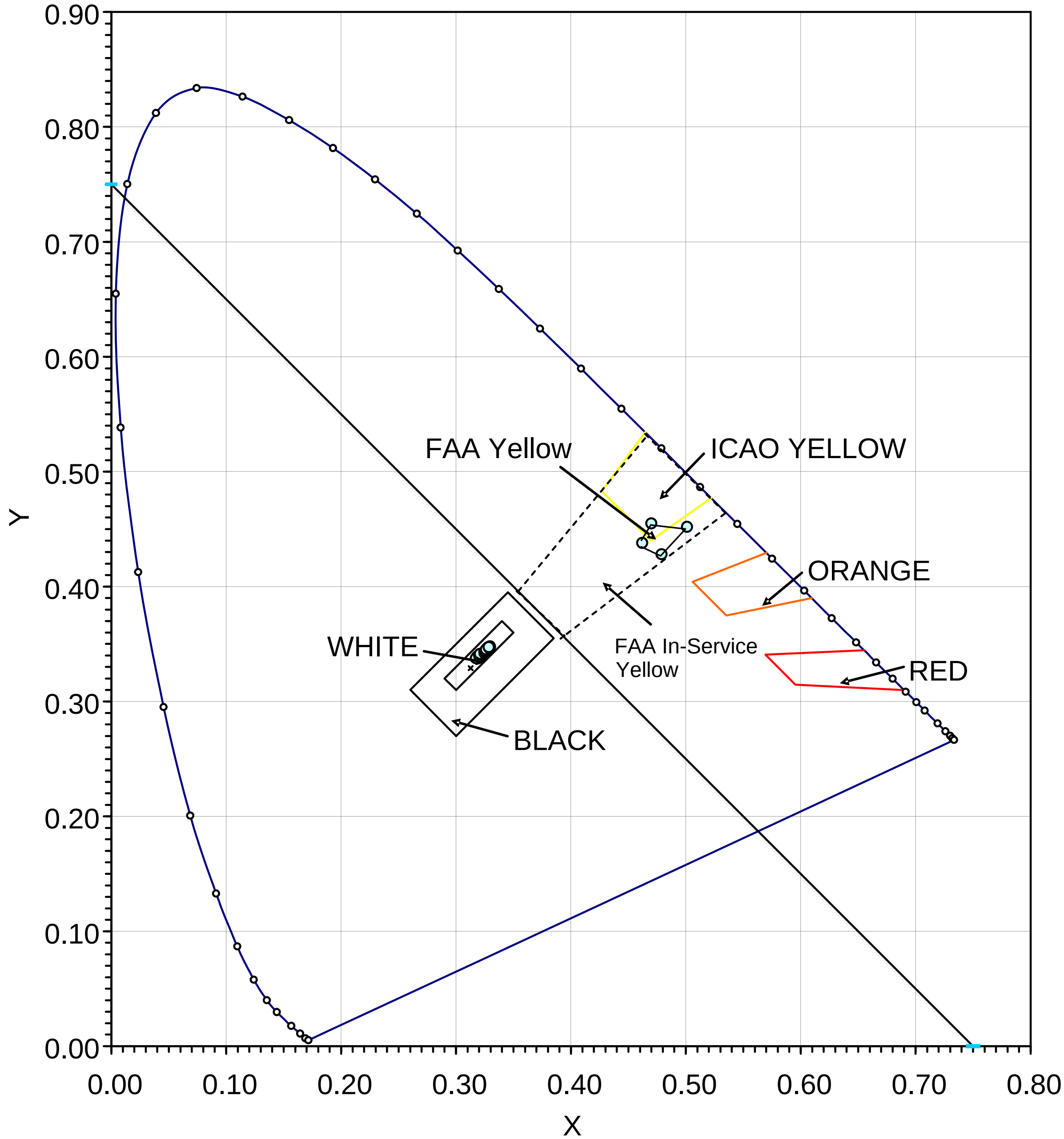

Figure A-5. Chromaticity Readings of Type I Bead on ACY Runway Touch Down Zone

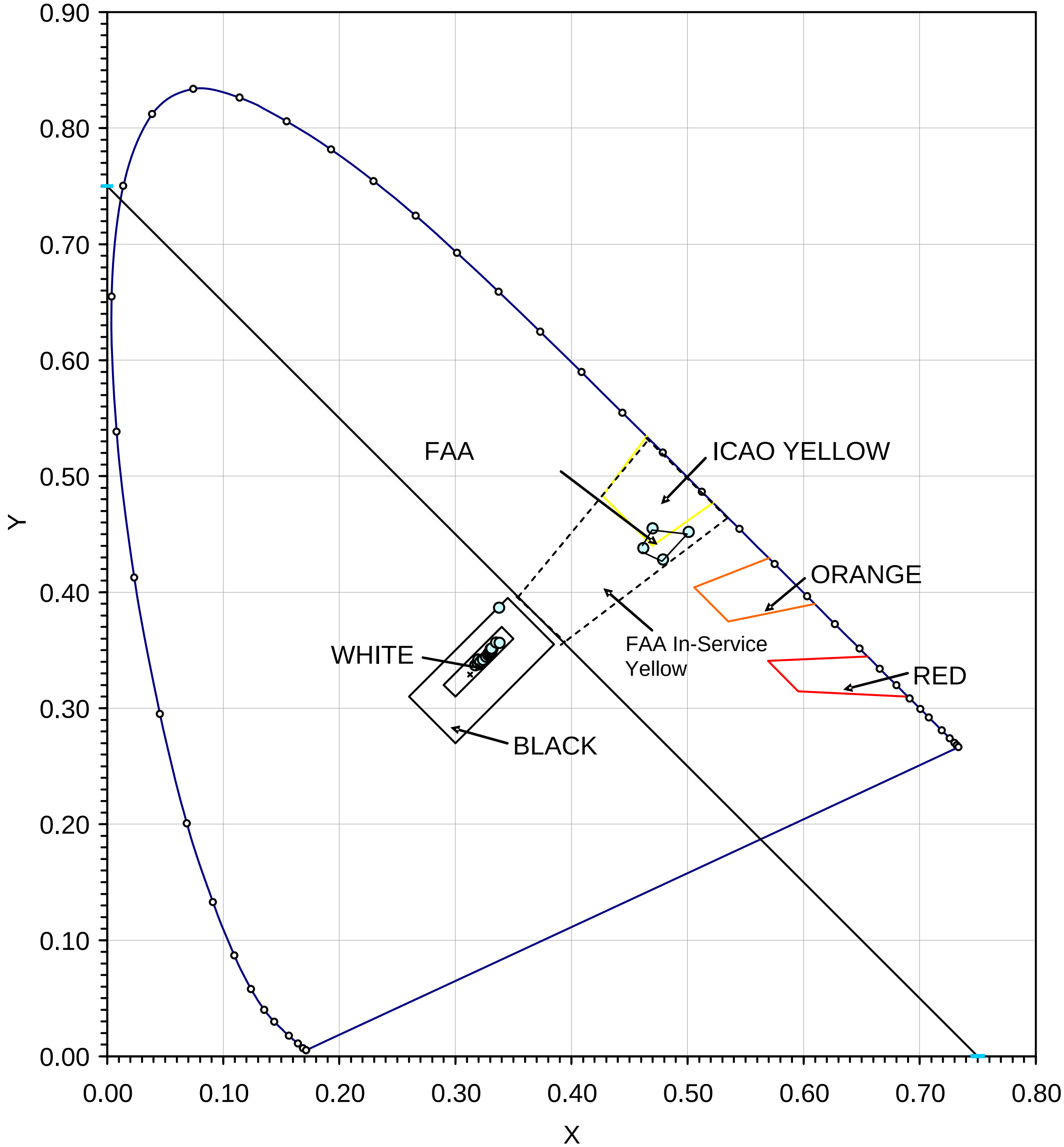

Figure A-6. Chromaticity Readings of Type I Bead on ACY Runway Aiming Point

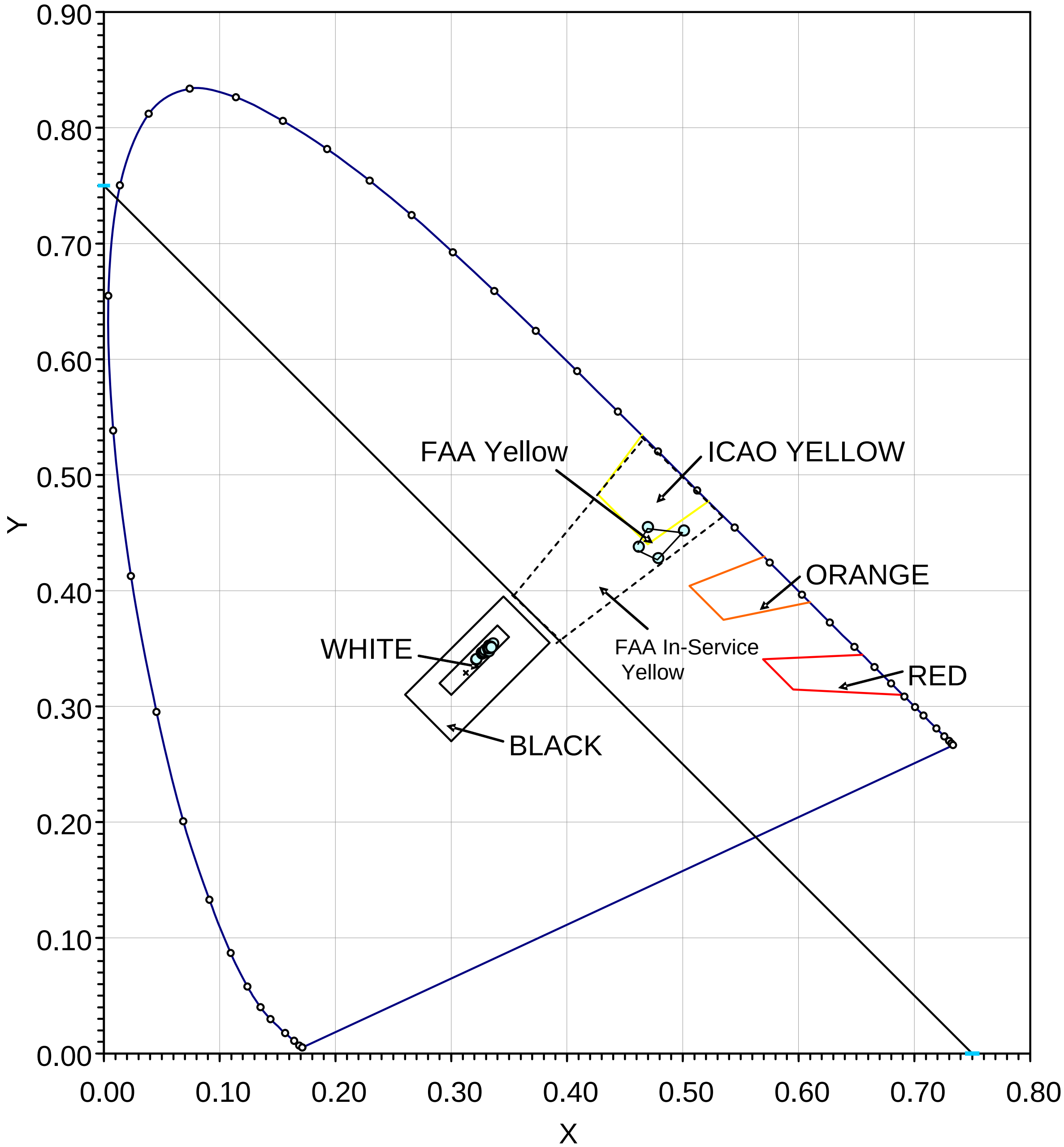

Figure A-7. Chromaticity Readings of Type I Bead on ACY Runway Edge Line

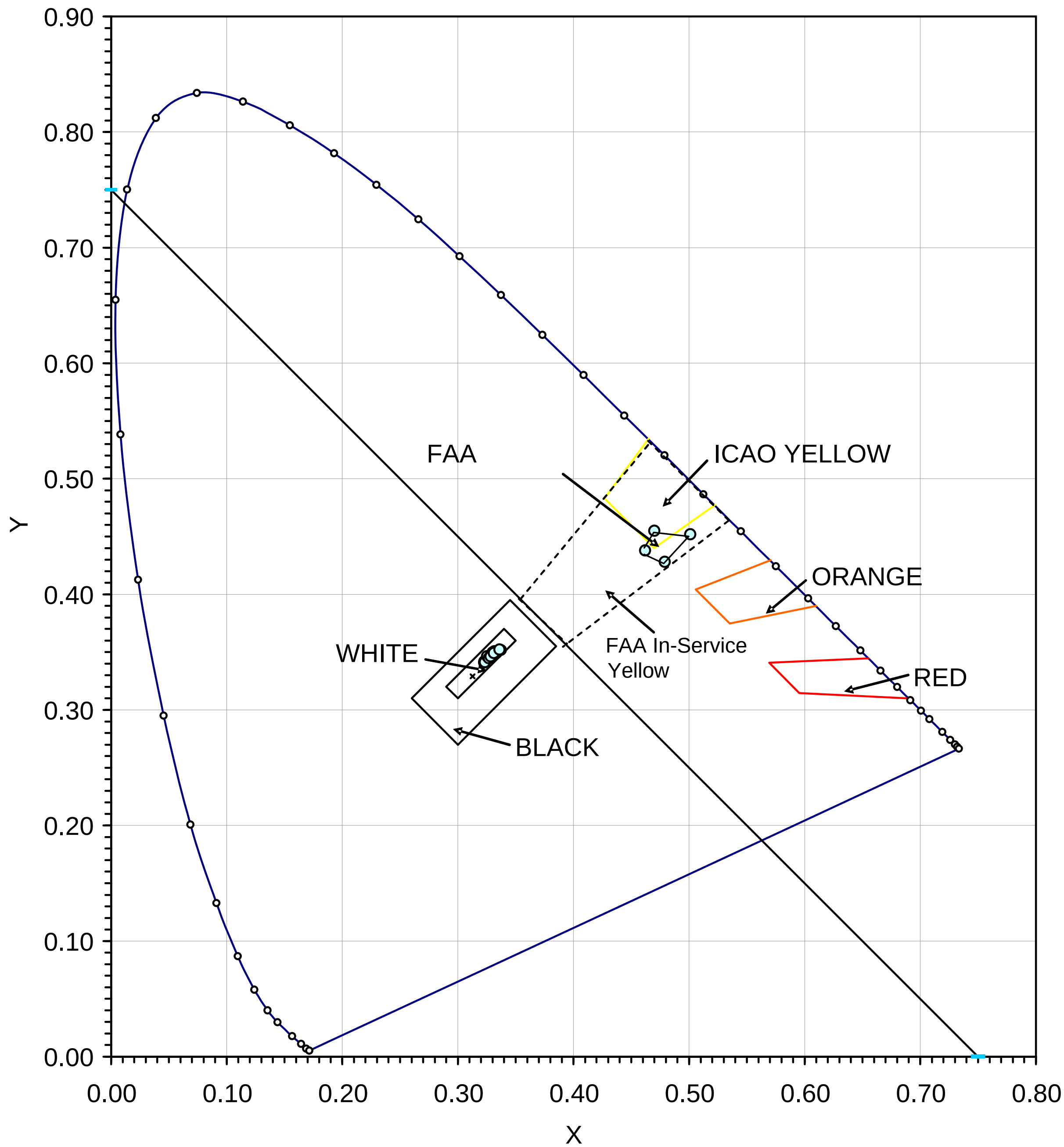

Figure A-8. Chromaticity Readings of Type III Bead on ACY Runway Threshold Bar

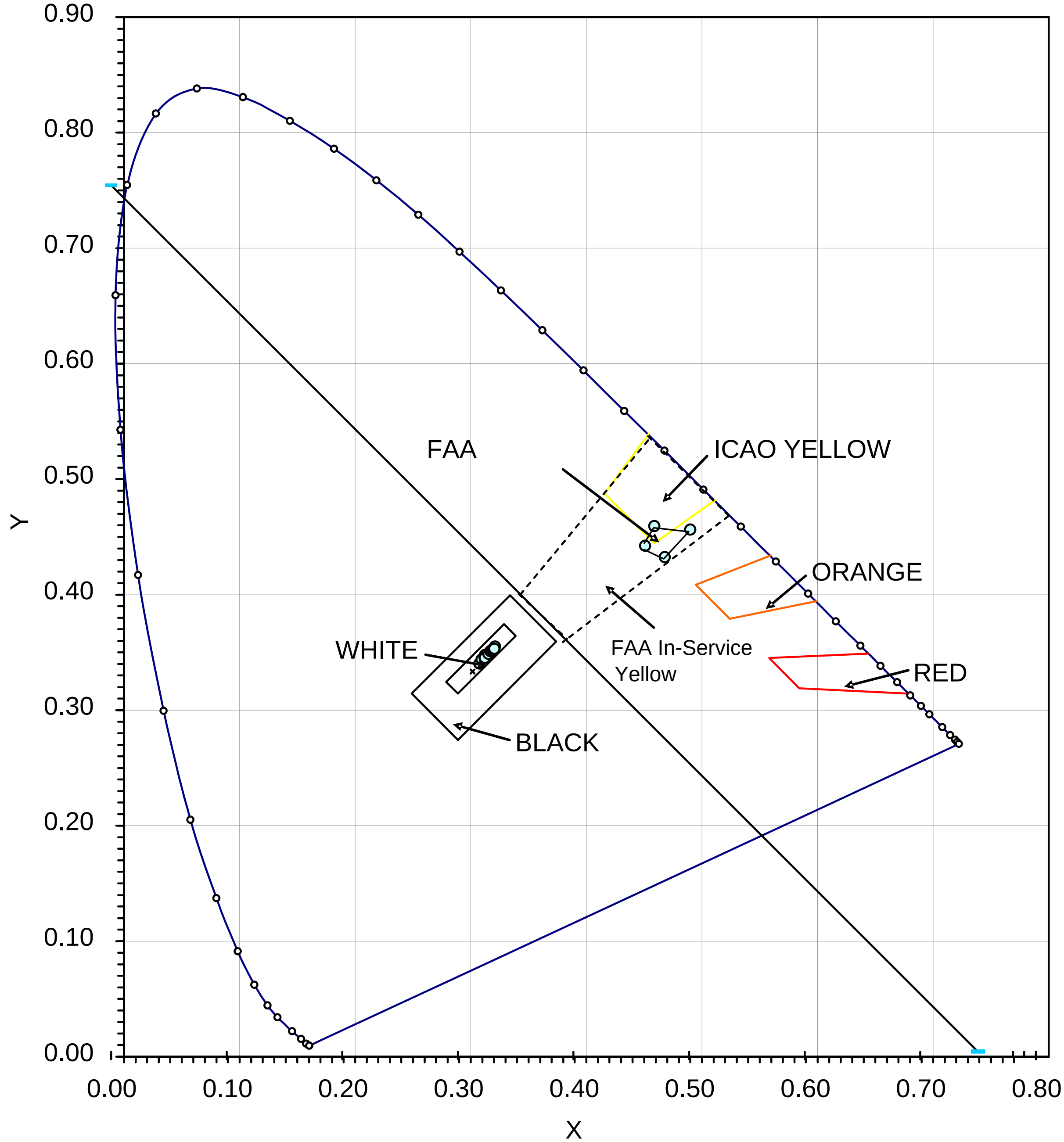

Figure A-9. Chromaticity Readings of Type III Bead on ACY Runway Threshold Line

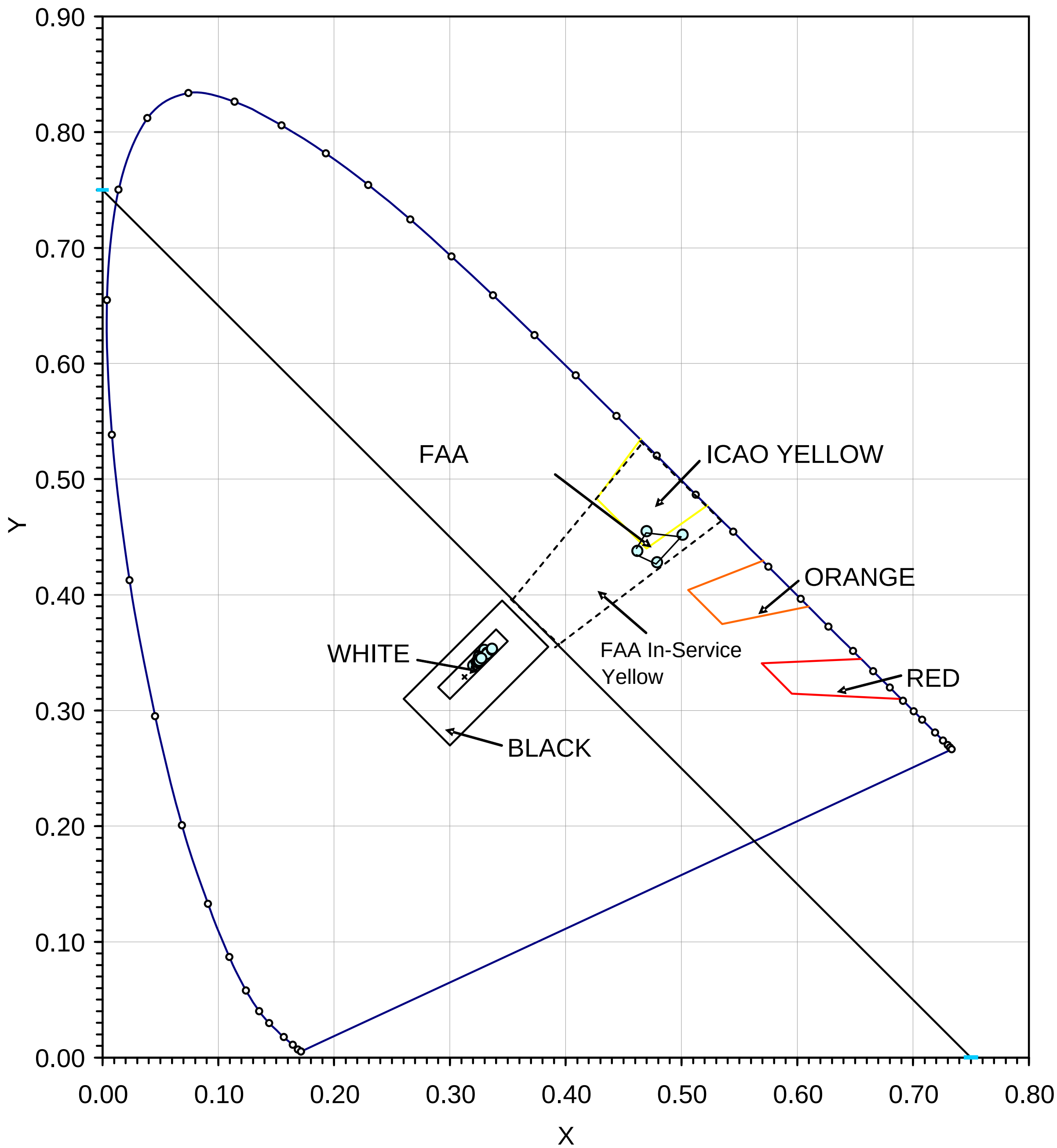

Figure A-10. Chromaticity Readings of Type III Bead on ACY Runway Designator

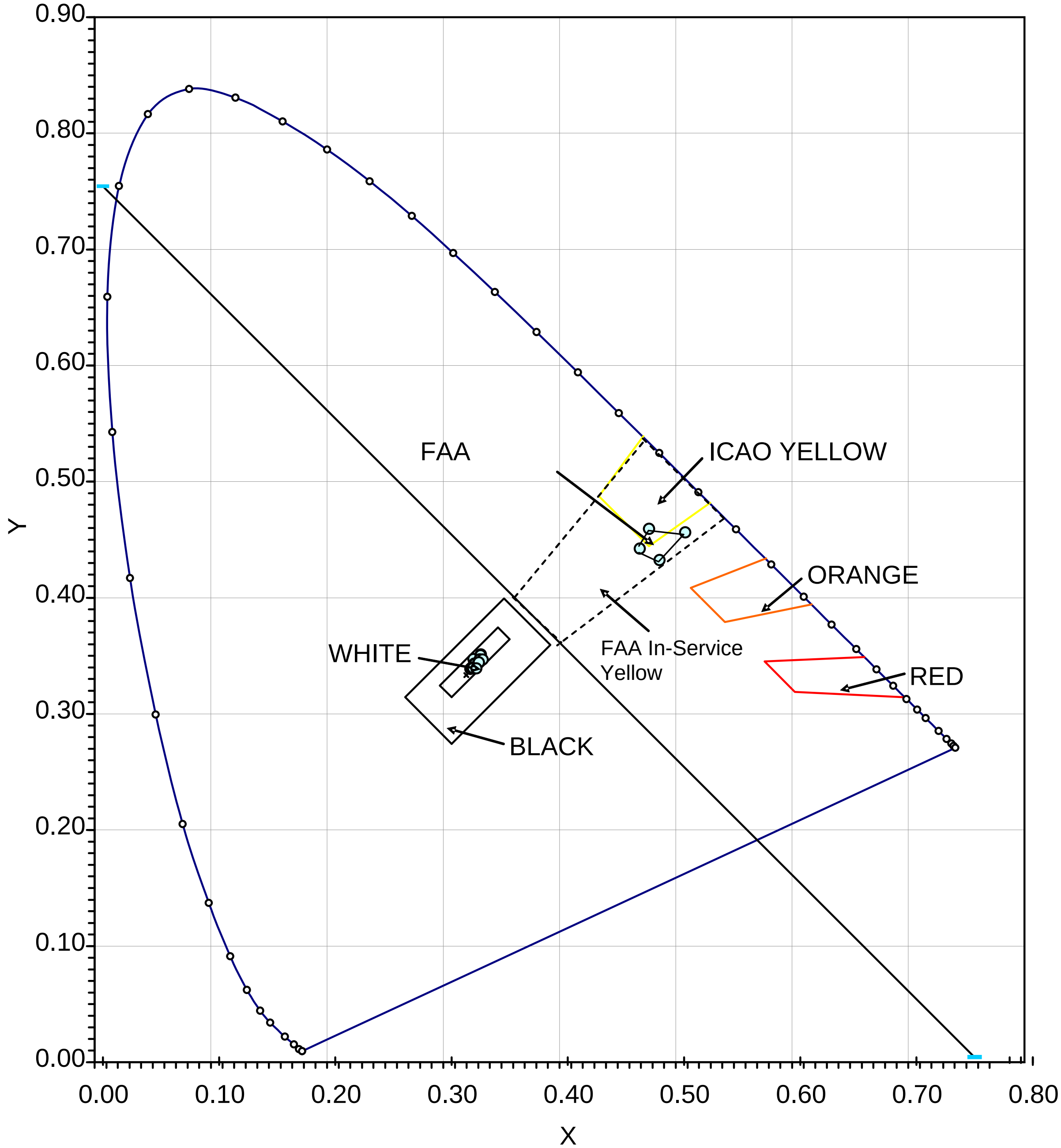

Figure A-11. Chromaticity Readings of Type III Bead on ACY Runway Centerline

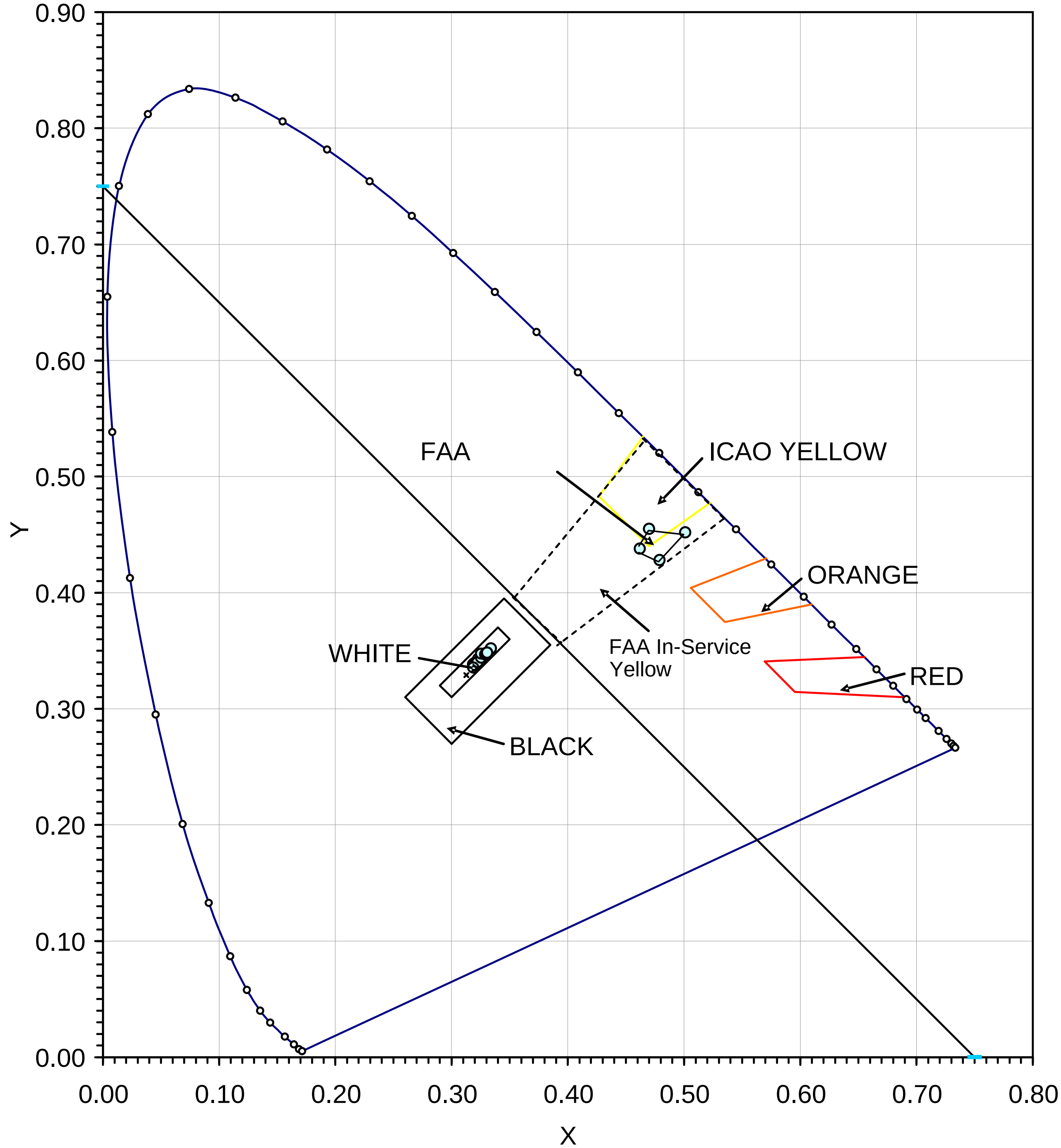

Figure A-12. Chromaticity Readings of Type III Bead on ACY Runway Touch Down Zone

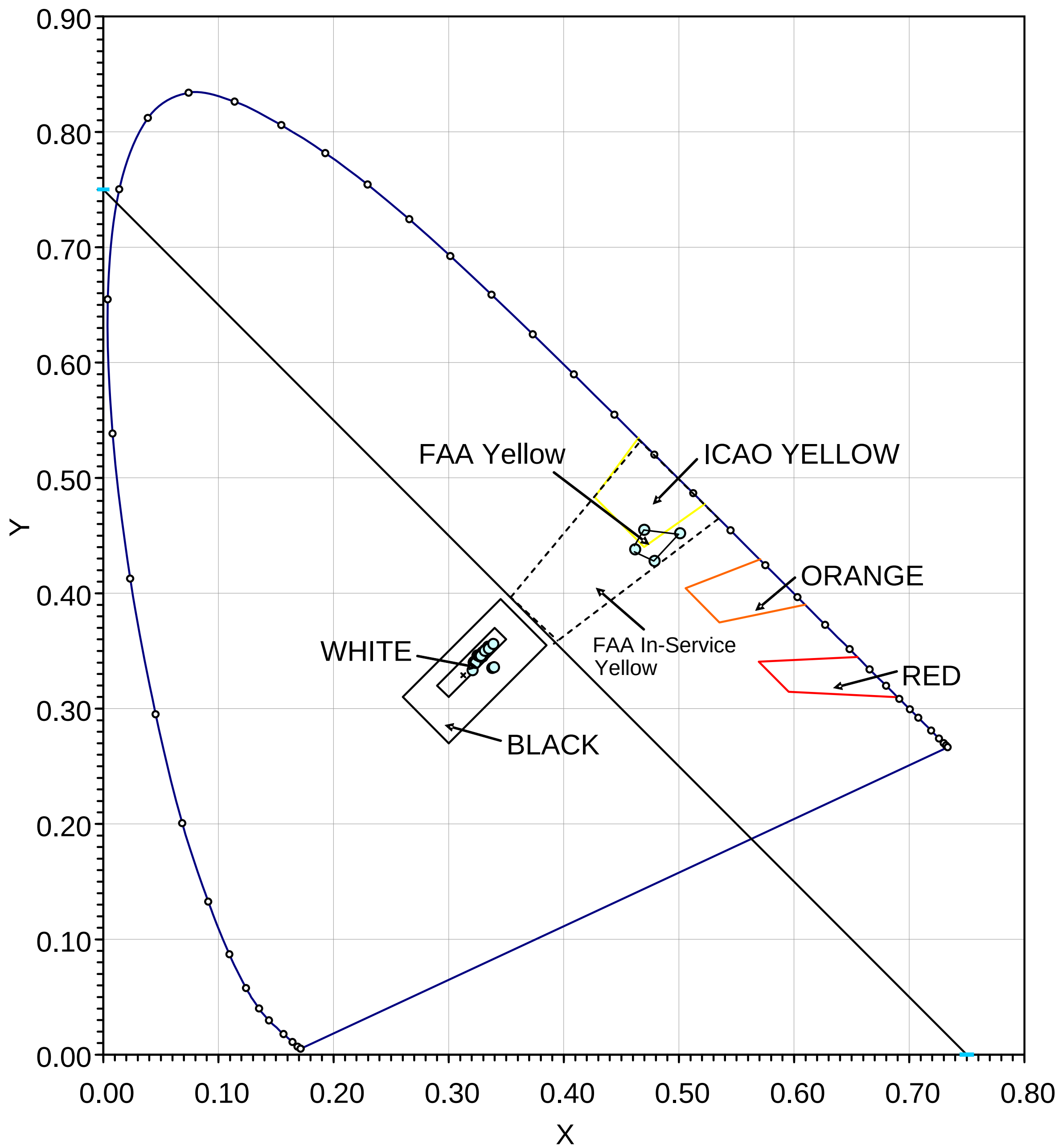

Figure A-13. Chromaticity Readings of Type III Bead on ACY Runway Aiming Point

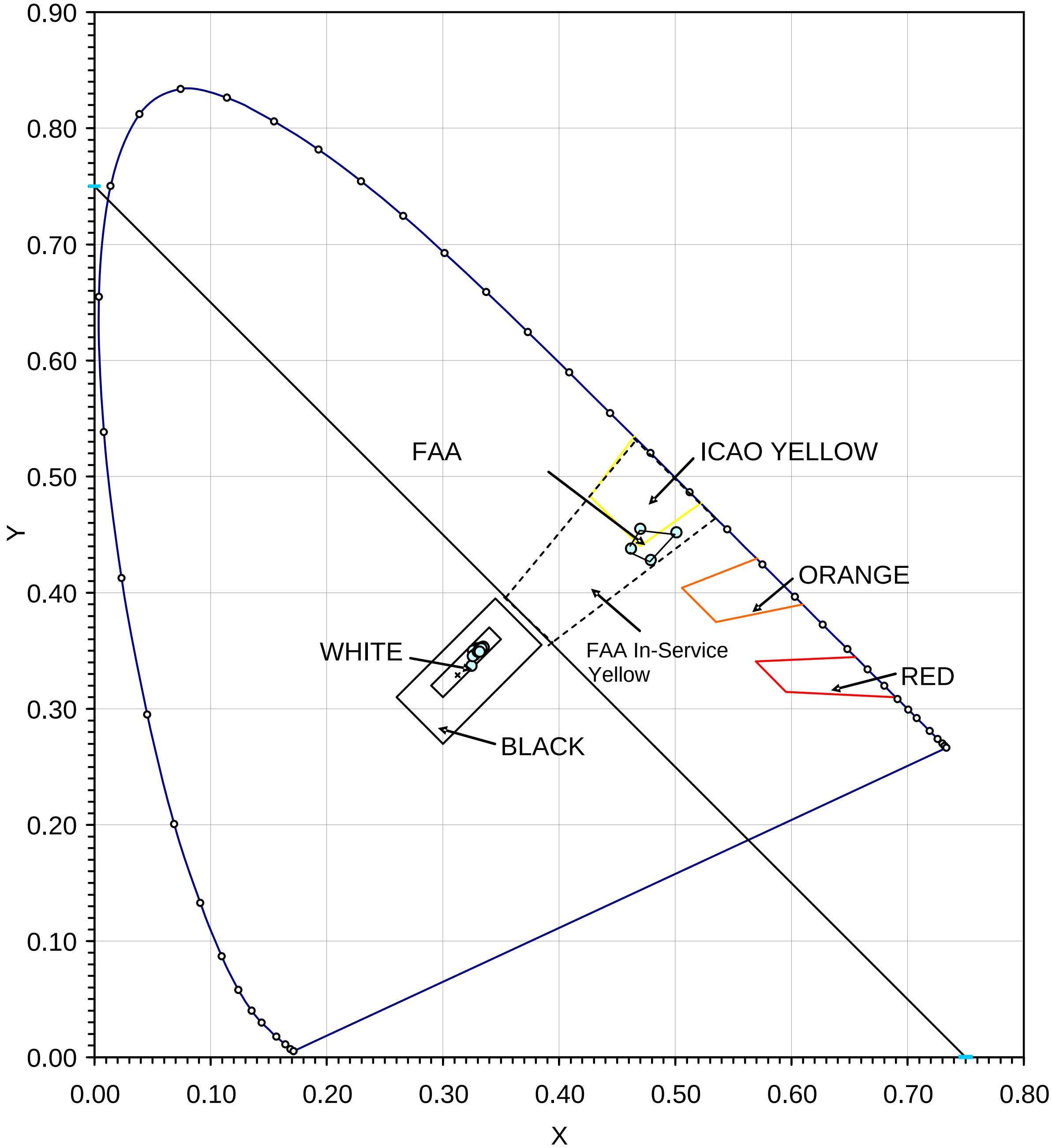

Figure A-14. Chromaticity Readings of Type III Bead on ACY Runway Edge Line

Table A-3. Initial Chromaticity Readings of SAV Type I Beads on Aged Hot-Mix Asphalt

Runway Marking	Y = Depth Coordinate	x = Width Coordinate	y = Height Coordinate
Threshold Bar	67.42	0.3163	0.3378
Threshold Line	73.63	0.3173	0.3366
Designator	73.28	0.3188	0.3393
Centerline	74.91	0.3181	0.3379
Touch Down Zone	77.61	0.3124	0.3357
Aiming Point	79.40	0.3167	0.3360
Edge Line	74.15	0.3173	0.3368

Table A-4. Initial Chromaticity Readings of SAV Type III Beads on Hot-Mix Asphalt

Runway Marking	Y = Depth Coordinate	x = Width Coordinate	y = Height Coordinate
Threshold Bar	71.55	0.3199	0.3393
Threshold Line	77.10	0.3207	0.3390
Designator	76.29	0.3183	0.3369
Centerline	72.88	0.3229	0.3406
Touch Down Zone	73.92	0.3174	0.3381
Aiming Point	79.96	0.3174	0.3359
Edge Line	76.69	0.3173	0.3359

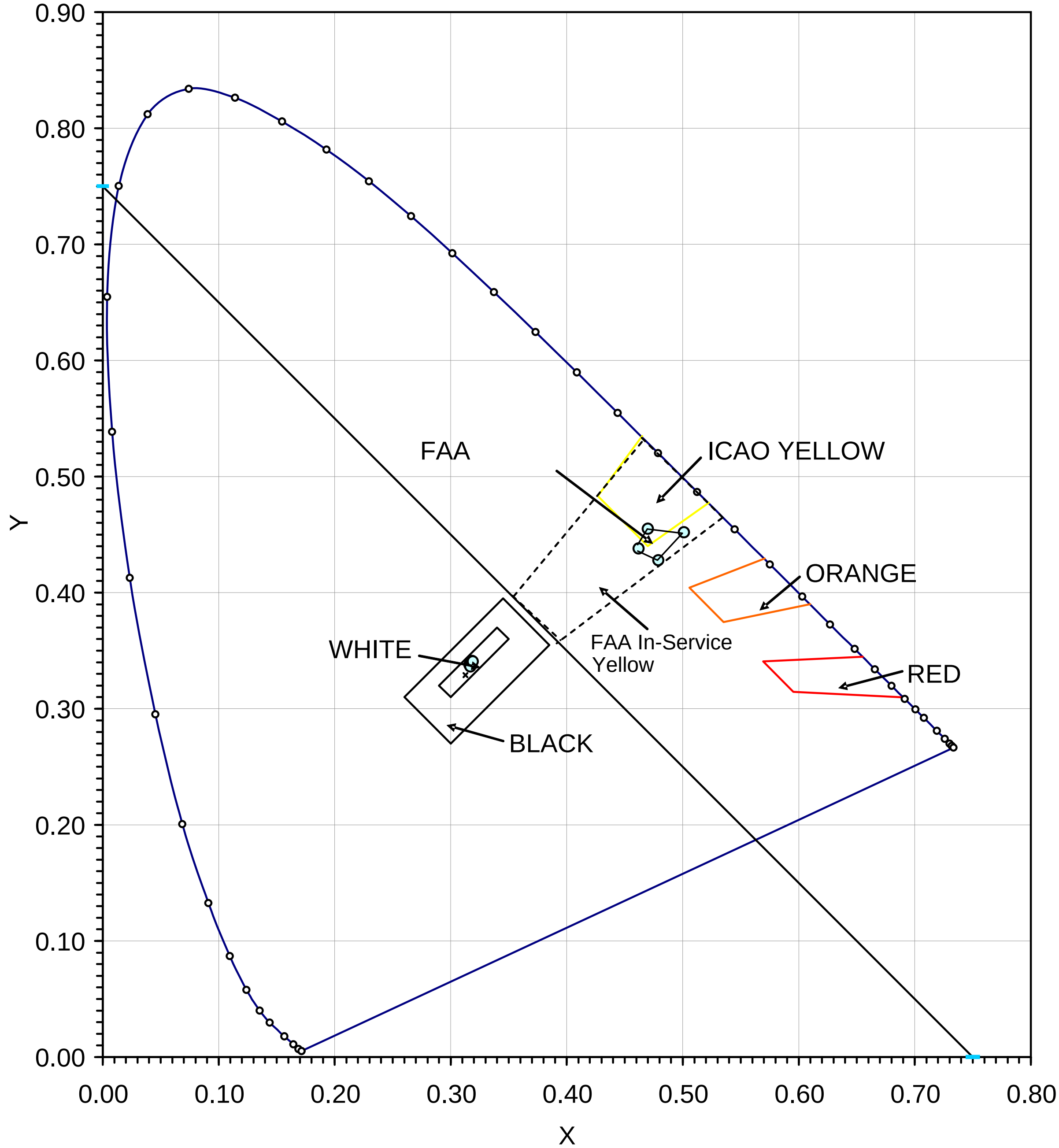

Figure A-15. Chromaticity Readings of Type I Bead on SAV Runway Threshold Bar

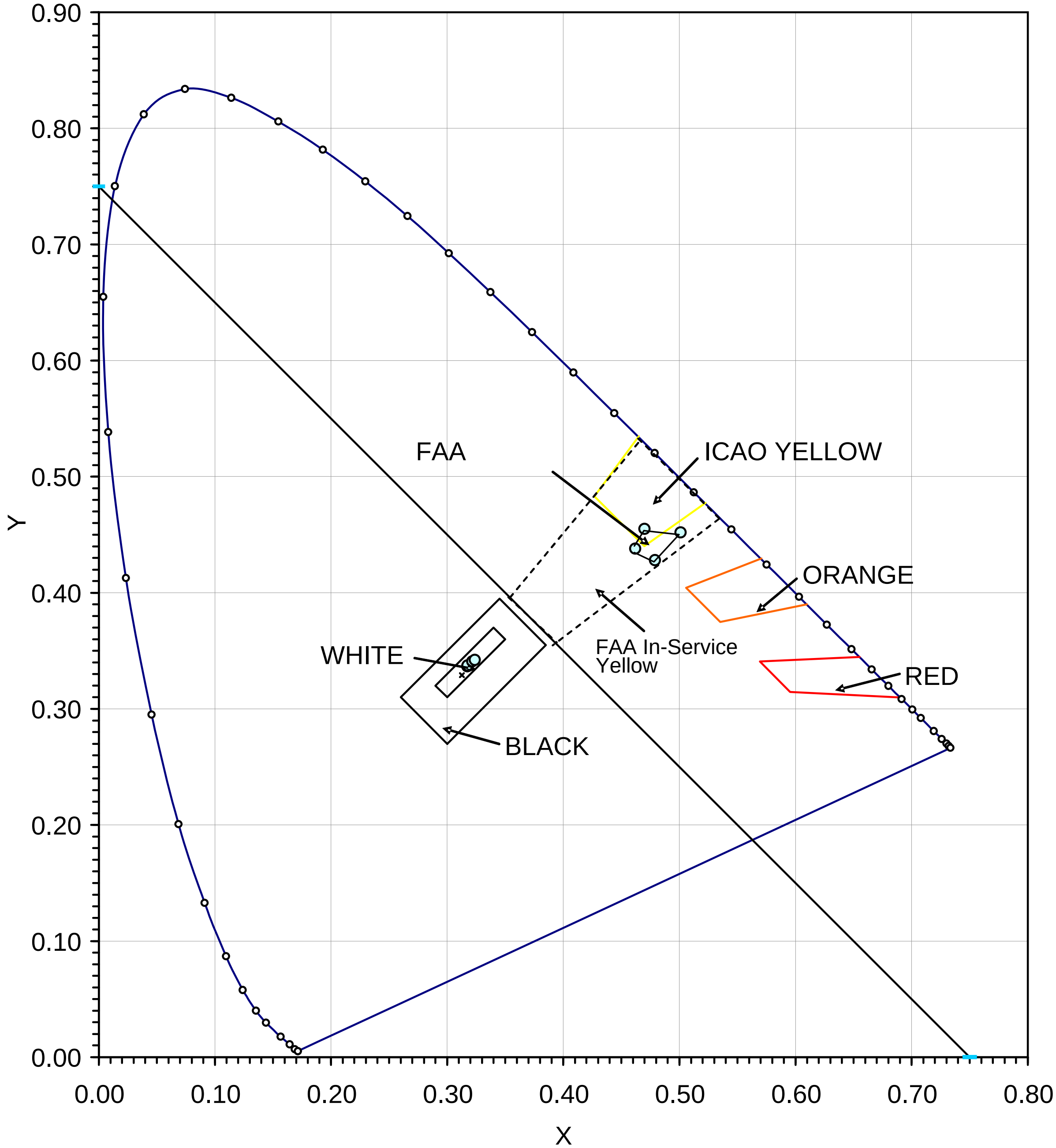

Figure A-16. Chromaticity Readings of Type I Bead on SAV Runway Threshold Line

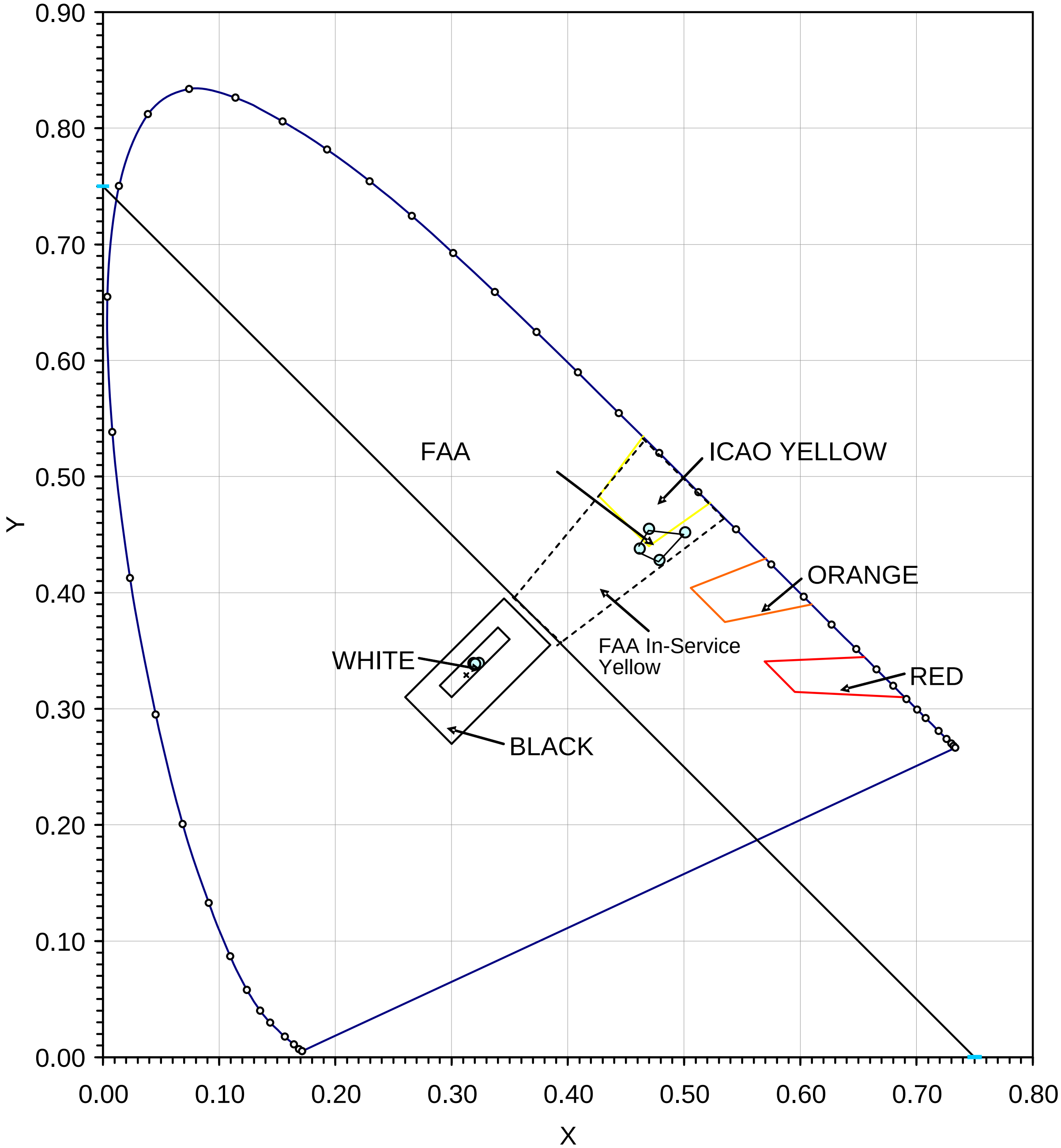

Figure A-17. Chromaticity Readings of Type I Bead on SAV Runway Designator

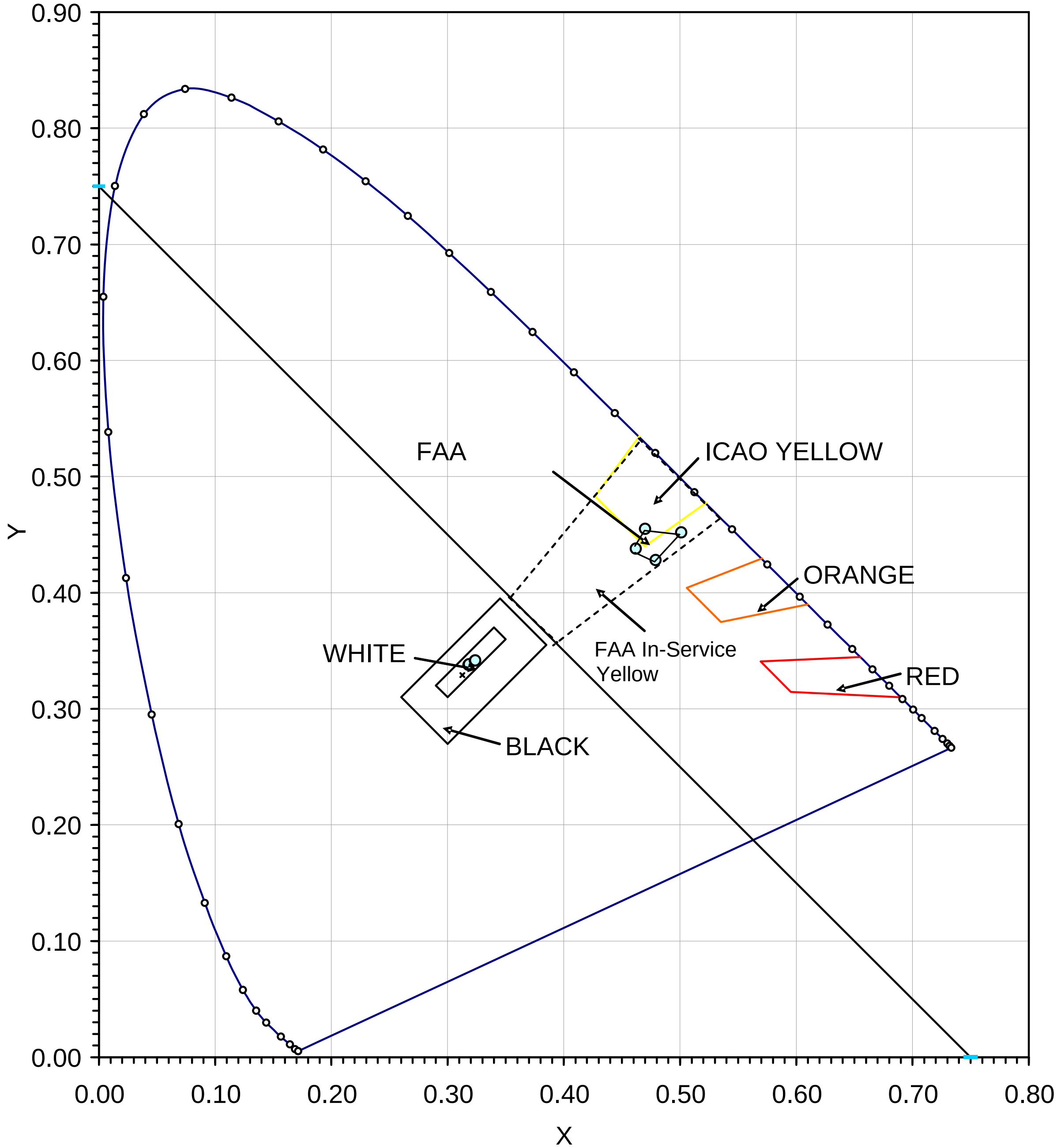

Figure A-18. Chromaticity Readings of Type I Bead on SAV Runway Centerline

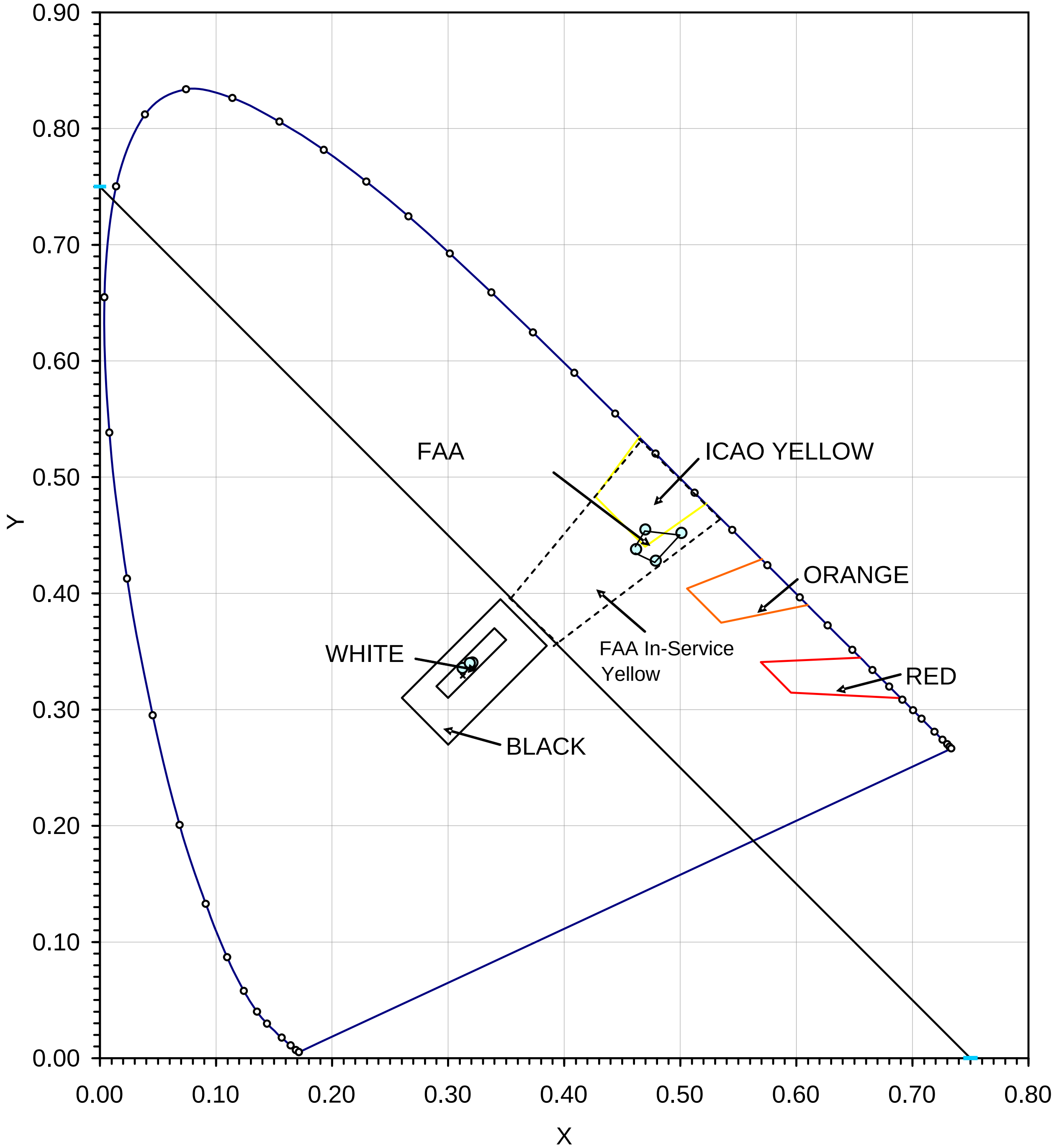

Figure A-19. Chromaticity Readings of Type I Bead on SAV Runway Touch Down Zone

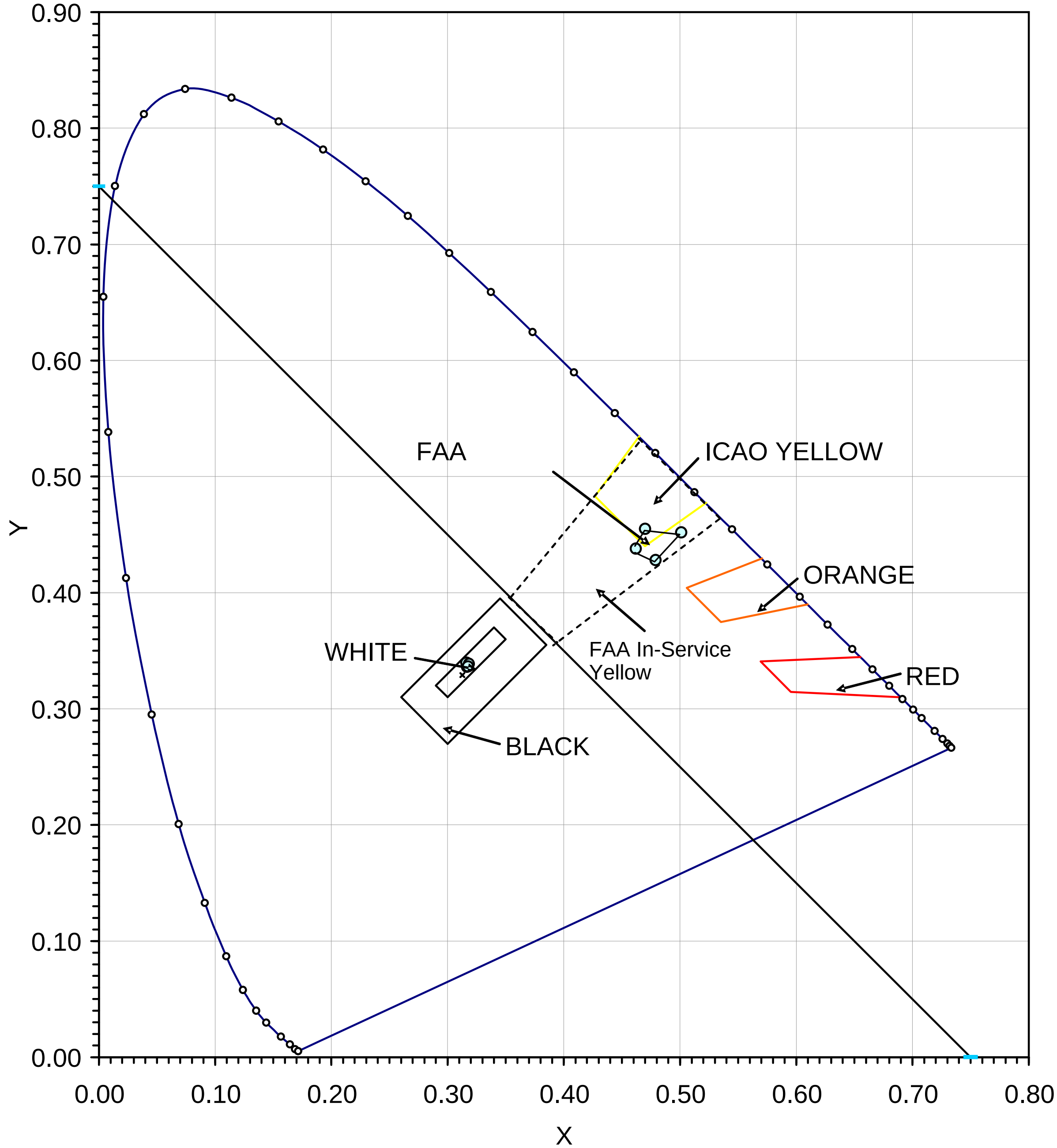

Figure A-20. Chromaticity Readings of Type I Bead on SAV Runway Aiming Point

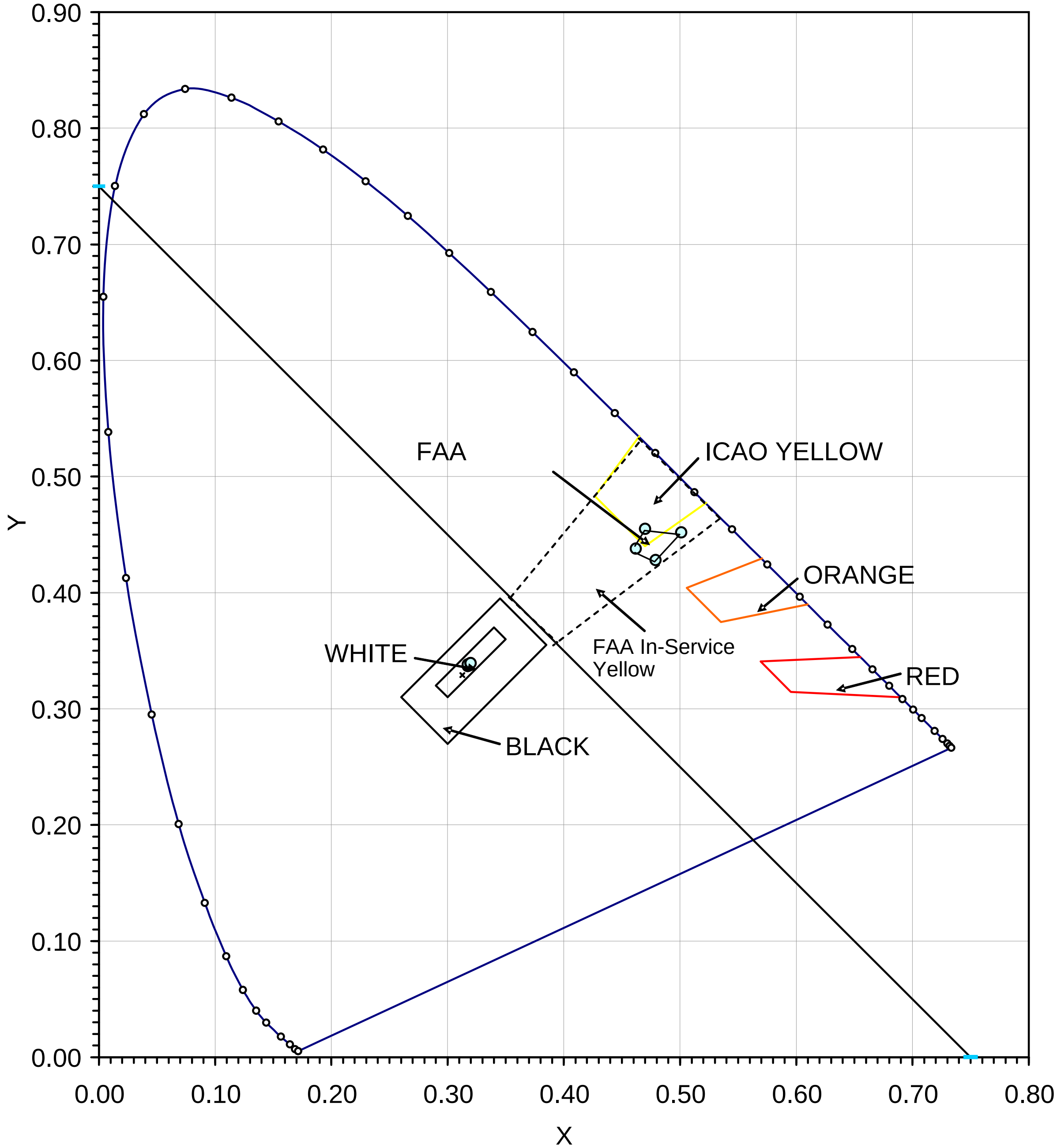

Figure A-21. Chromaticity Readings of Type I Bead on SAV Runway Edge Line

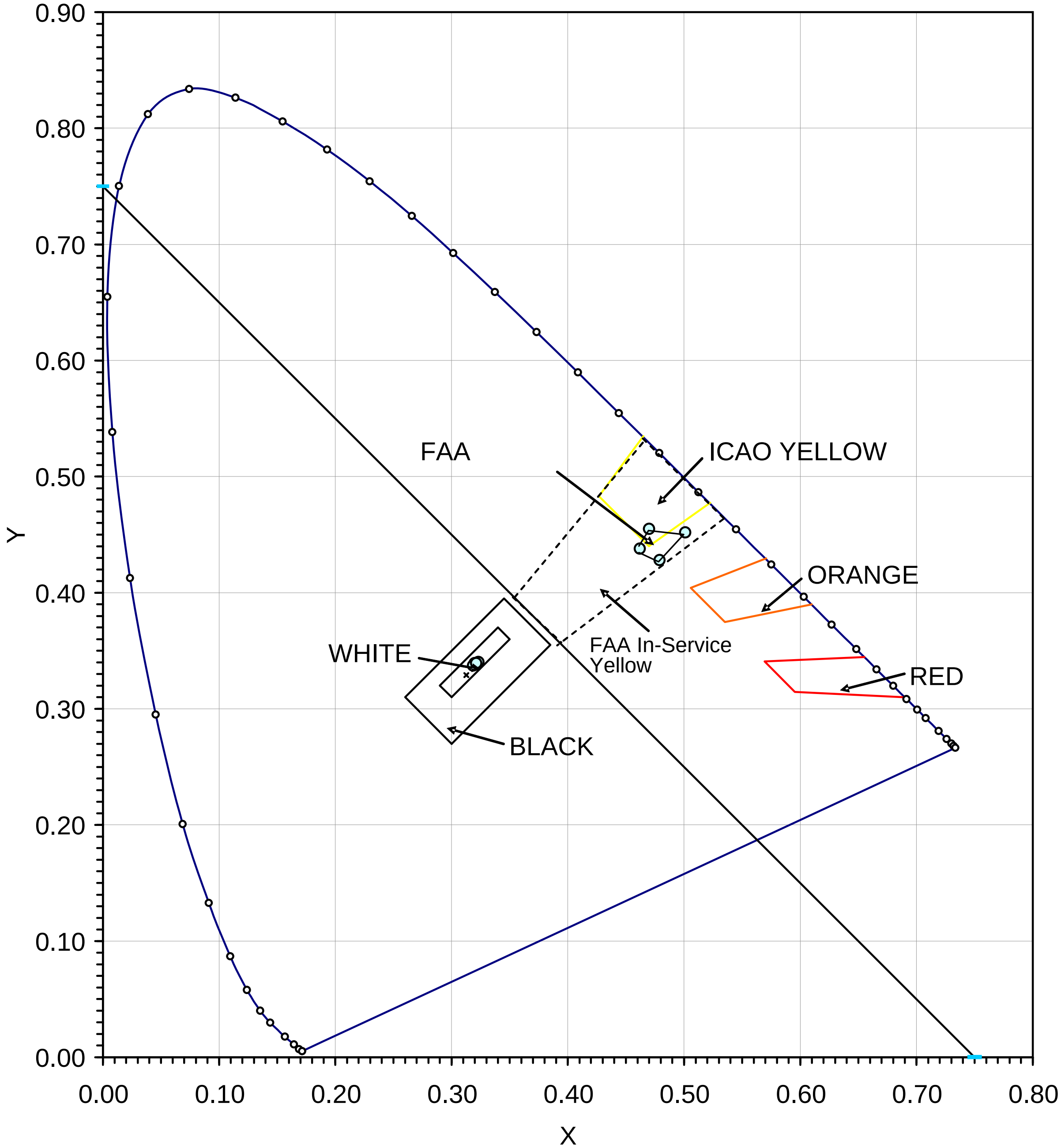

Figure A-22. Chromaticity Readings of Type III Bead on SAV Runway Threshold Bar

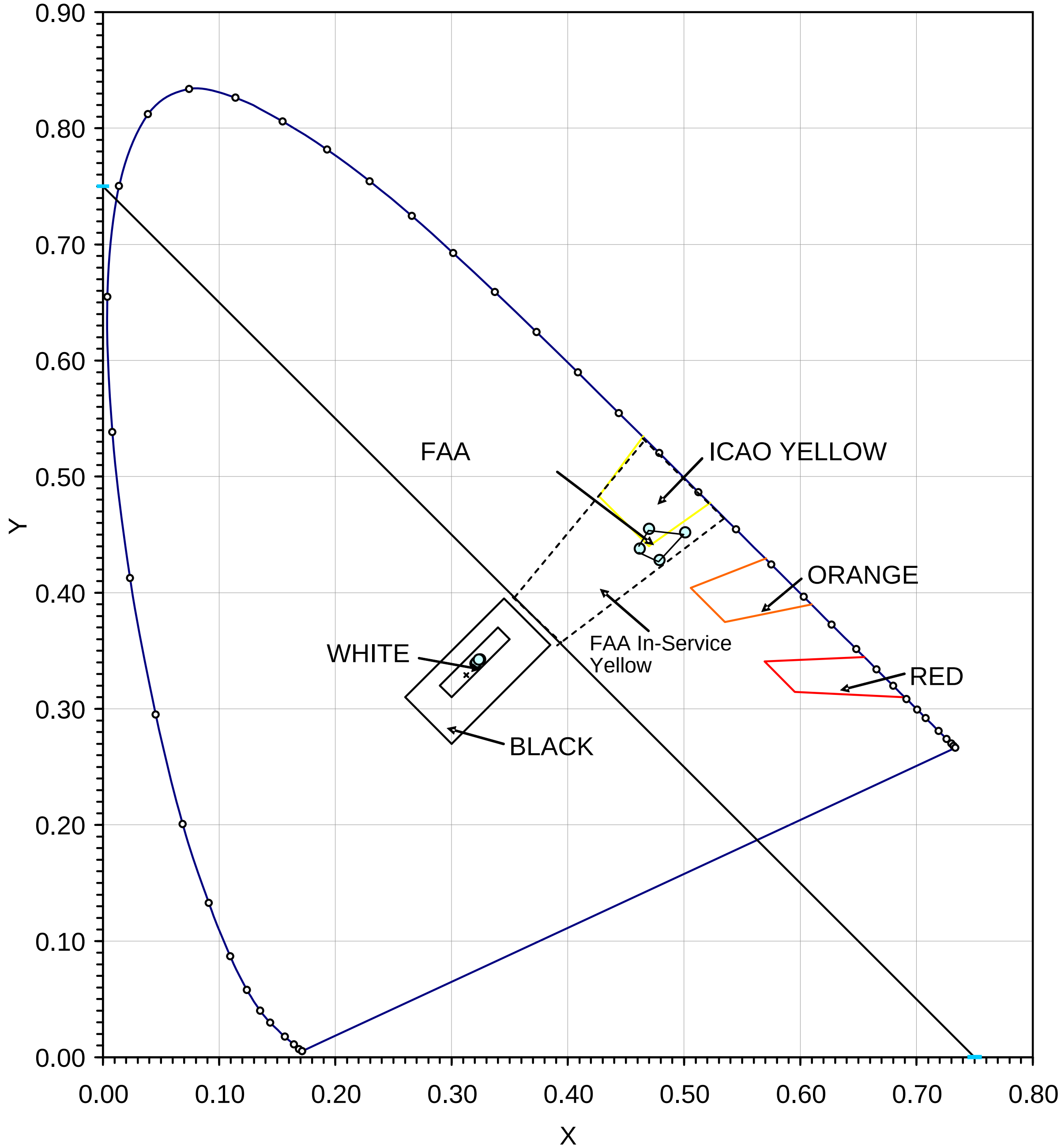

Figure A-23. Chromaticity Readings of Type III Bead SAV on Runway Threshold Line

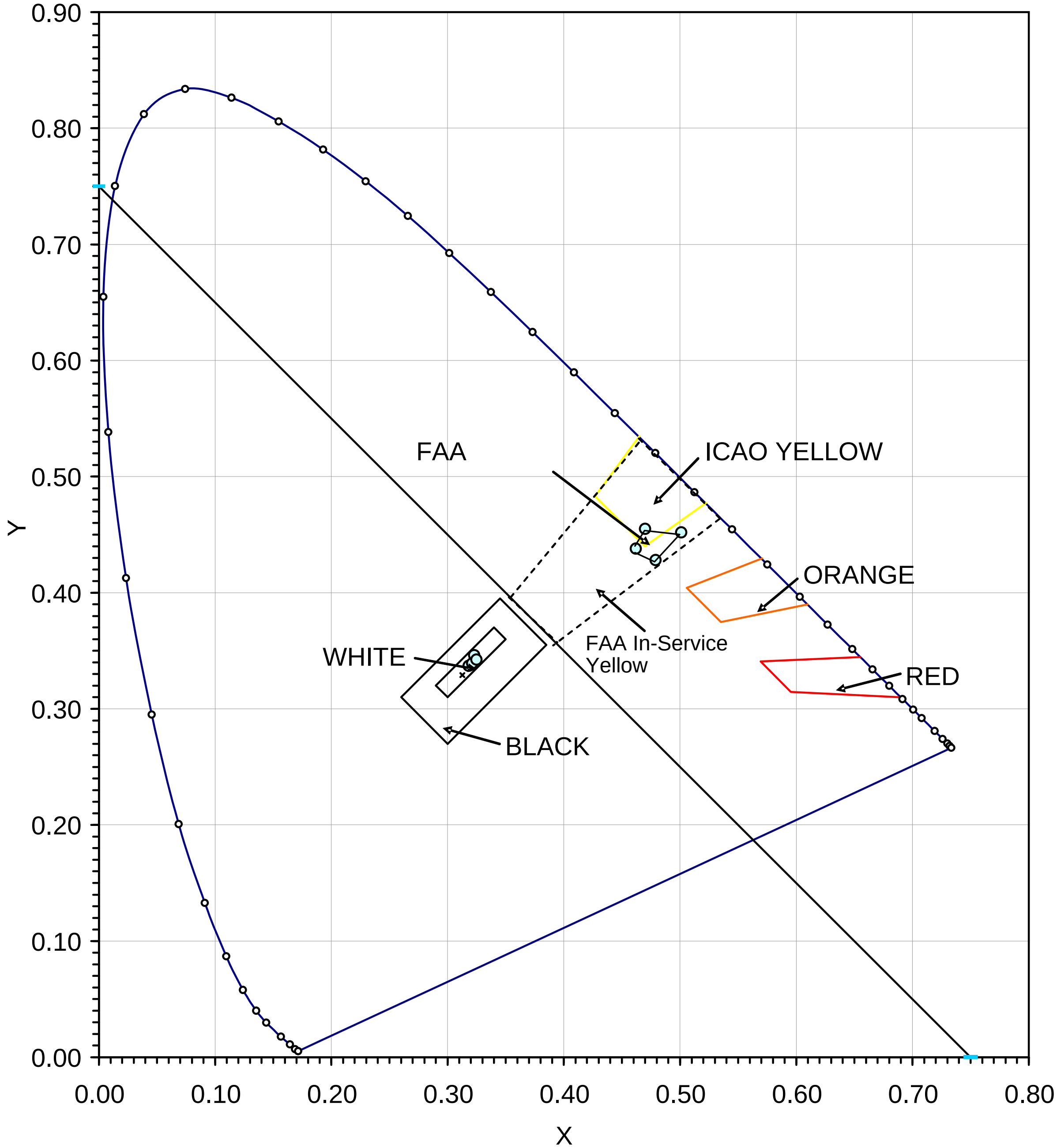

Figure A-24. Chromaticity Readings of Type III Bead on SAV Runway Designator

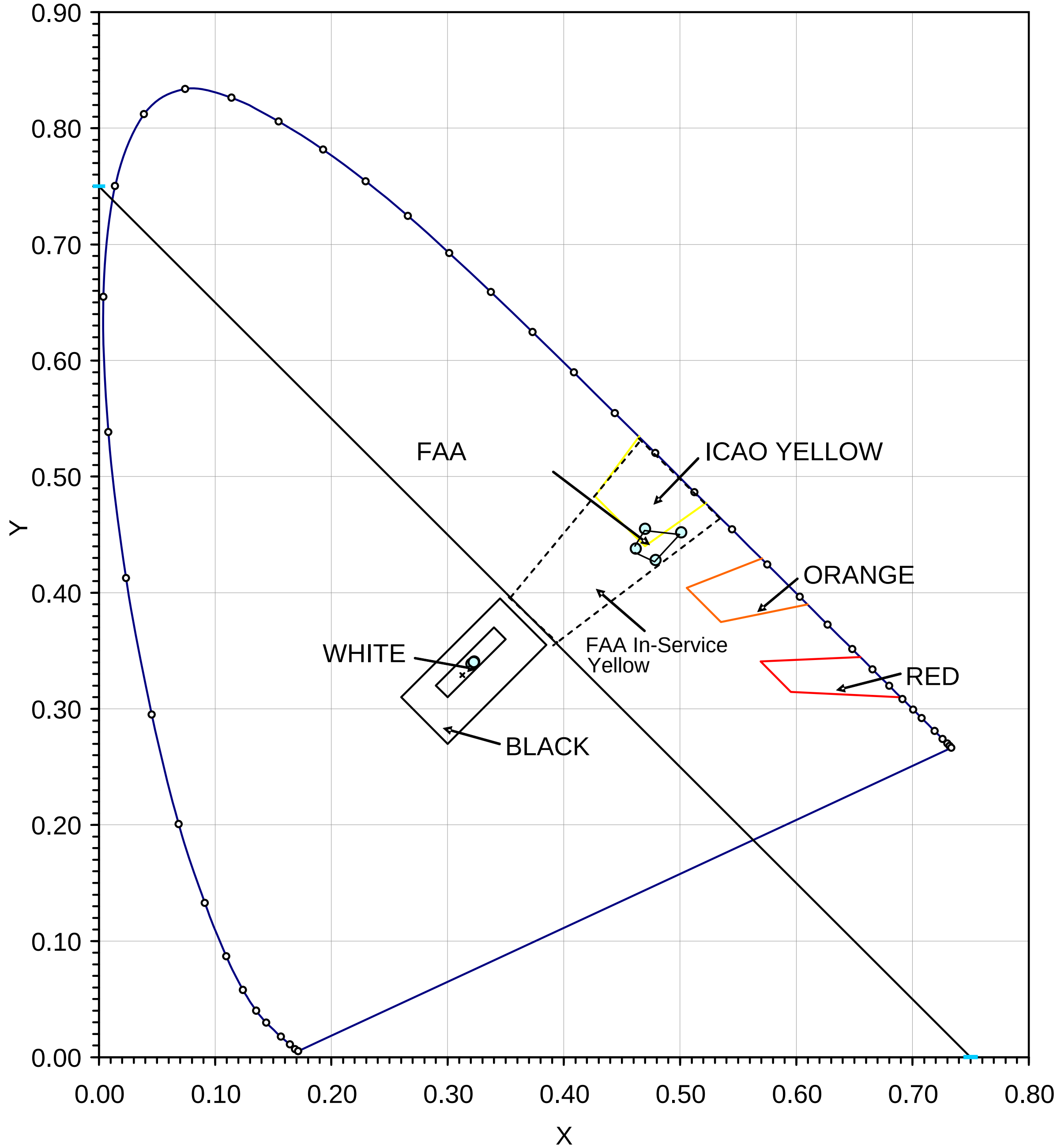

Figure A-25. Chromaticity Readings of Type III Bead on SAV Runway Centerline

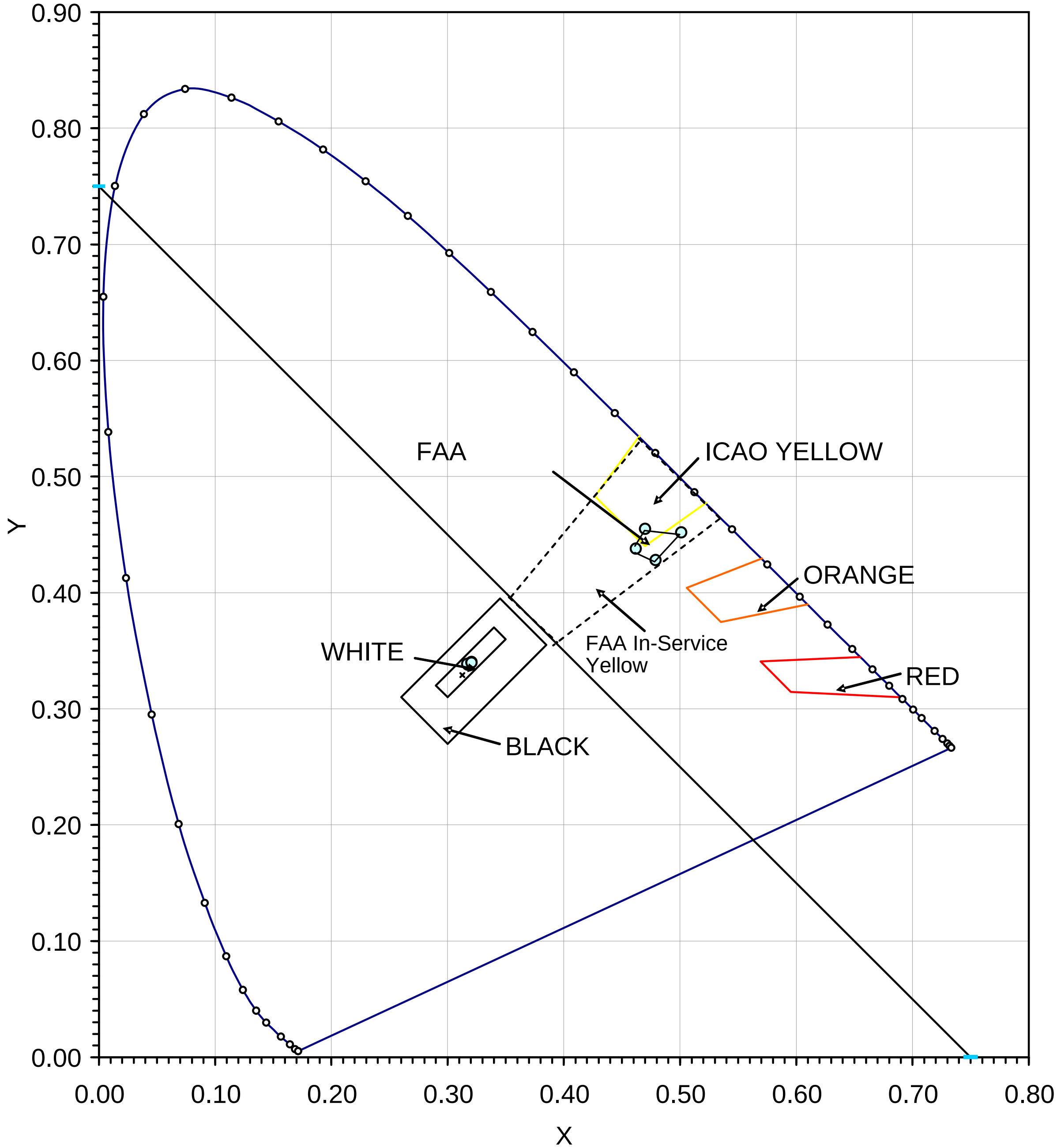

Figure A-26. Chromaticity Readings of Type III Bead on SAV Runway Touch Down Zone

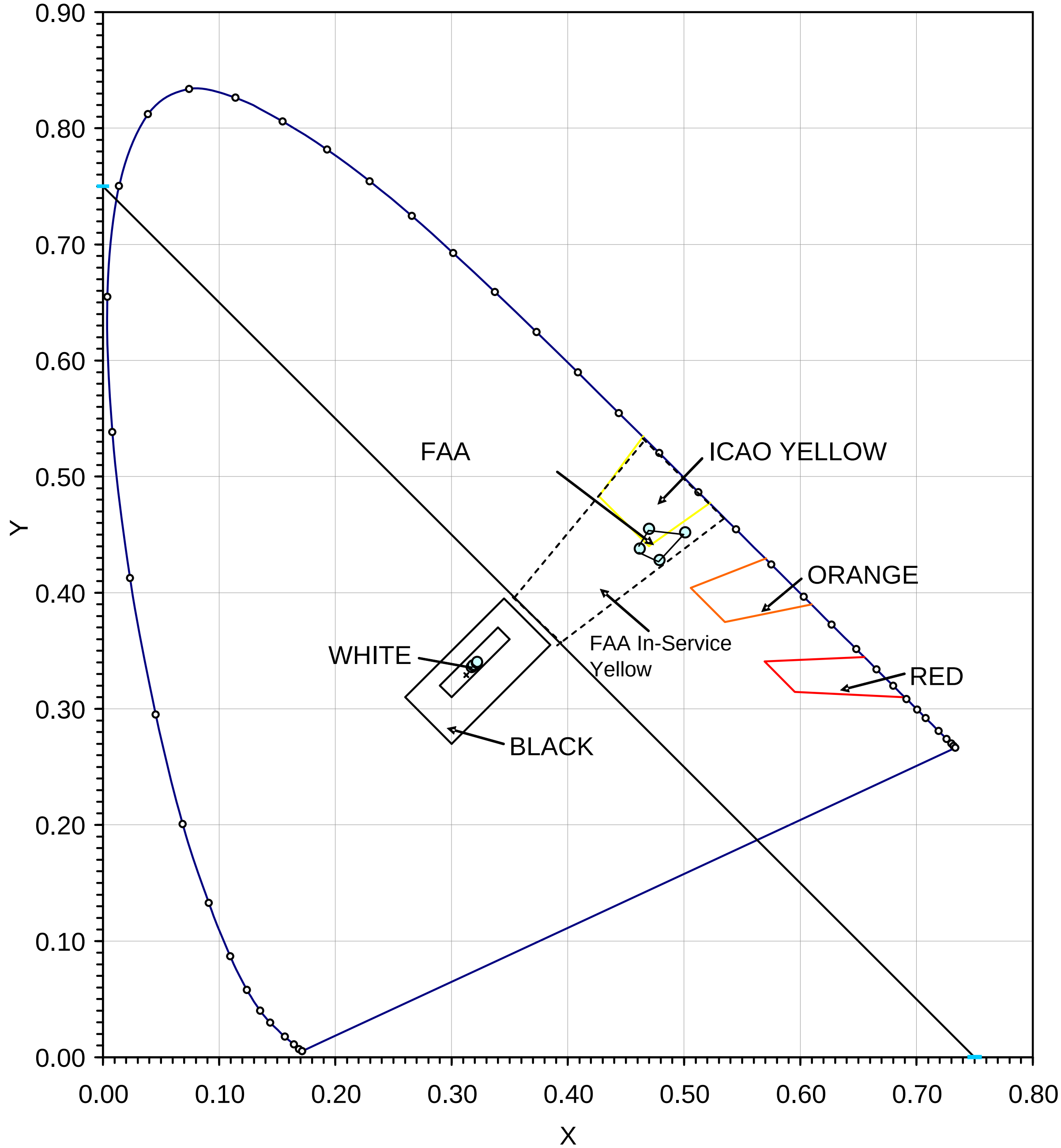

Figure A-27. Chromaticity Readings of Type III Bead on SAV Aiming Point

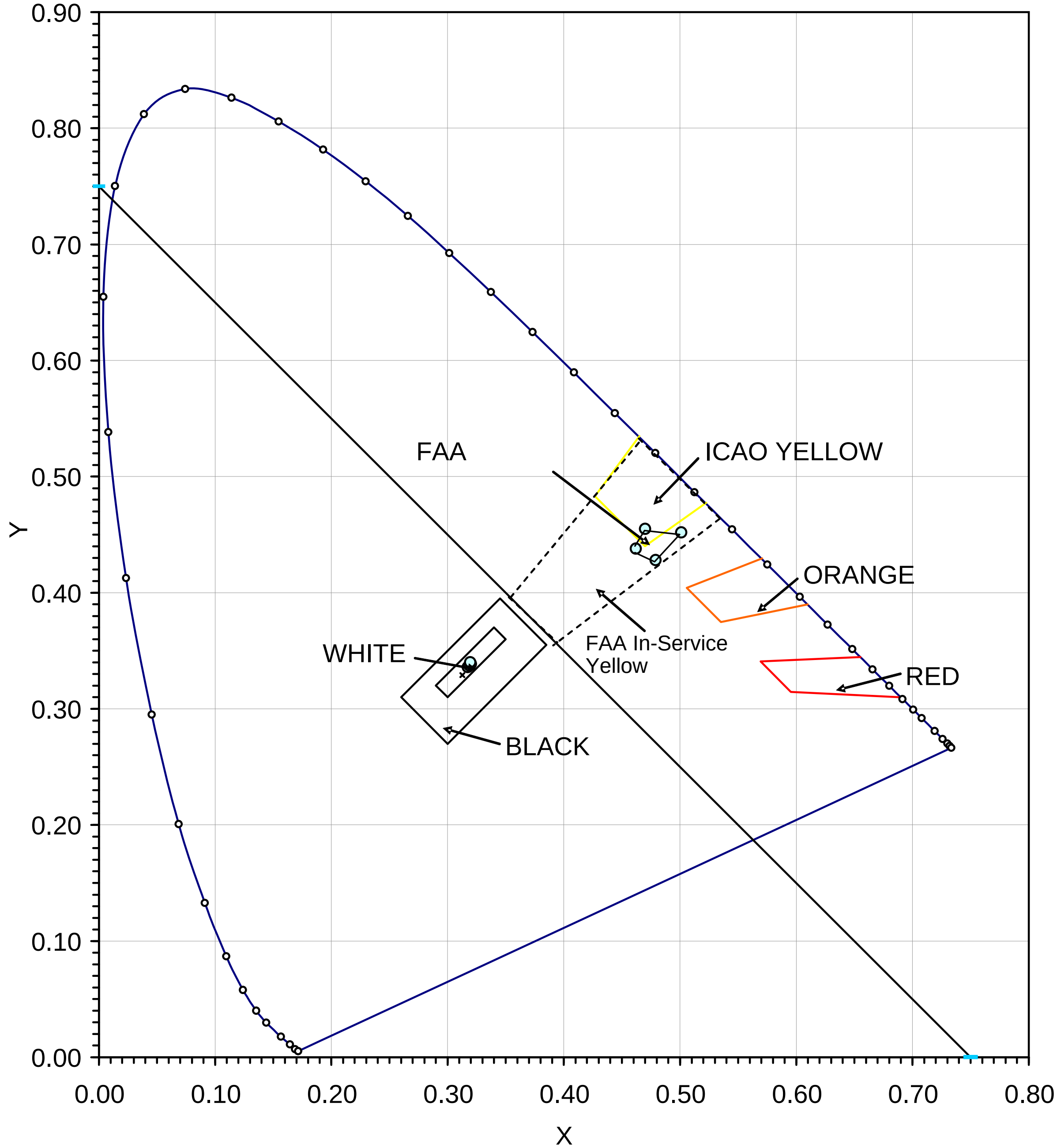

Figure A-28. Chromaticity Readings of Type III Bead on SAV Edge Line

APPENDIX B—RETRO-REFLECTIVITY READINGS

Table B-1. Average Retro-Reflectivity Readings of ACY Type I Beads
(Runway 31 on Aged Hot-Mix Asphalt)

Runway Marking	DEC 2008	JAN 2009	FEB 2009	MAR 2009	APR 2009	MAY 2009	JUN 2009	JUL 2009
Threshold Bar	398	415	524	342	445	472	482	433
Threshold Line	309	499	388	241	220	207	211	251
Runway Designator	448	491	480	320	273	265	302	252
Runway Centerline	448	291	208	82	67	23	120	113
Touch Down Zone	151	462	476	372	504	484	476	465
Aiming Point	238	491	437	299	318	355	427	400
Edge Line	475	508	417	327	430	373	300	276

Readings measured in $mcd/m^2/lx$ per month and year.

Table B-2. Average Retro-Reflectivity Readings of ACY Type III Beads
(Runway 13 on Aged Hot-Mix Asphalt)

Runway Marking	DEC 2008	JAN 2009	FEB 2009	MAR 2009	APR 2009	MAY 2009	JUN 2009	JUL 2009
Threshold Bar	790	618	629	253	780	863	647	752
Threshold Line	1086	967	363	176	154	189	197	142
Runway Designator	1359	1203	729	354	418	336	381	371
Runway Centerline	994	1012	347	212	153	20	5	8
Touch Down Zone	311	852	626	519	569	464	562	519
Aiming Point	599	753	347	353	589	394	543	423
Edge Line	604	645	452	177	247	392	288	246

Readings measured in $mcd/m^2/lx$ per month and year.

Table B-3. Average Retro-Reflectivity Readings of SAV Type I Beads
(Runway 10 on Aged Hot-Mix Asphalt)

Runway Marking	SEP 2009	DEC 2009
Threshold Bar	233	257
Threshold Line	268	274
Runway Designator	280	231
Runway Centerline	293	302
Touch Down Zone	276	273
Aiming Point	293	237
Edge Line	266	252

Readings measured in $mcd/m^2/lx$ per month and year.

Table B-3. Average Retro-Reflectivity Readings of SAV Type III Beads
(Runway 10 on Aged Hot-Mix Asphalt)

Marking Number	SEP 2009	DEC 2009
Threshold Bar	917	631
Threshold Line	220	180
Runway Designator	1134	688
Runway Centerline	647	730
Touch Down Zone	357	673
Aiming Point	706	641
Edge Line	1290	1221

Readings measured in $mcd/m^2/lx$ per month and year.