Evaluation of Thermoplastic Marking Materials

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16. Abstract

Due to the harsh conditions of airport environments, frequent repainting of existing waterborne pavement markings is required. This painting is expensive and affects life-cycle costs. A thermoplastic marking material has been identified as an alternative to the existing waterborne material. The purpose of this research effort was to determine if this thermoplastic marking material is as effective as the current waterborne material in terms of its retro-reflectivity, chromaticity, friction properties, and its adherence to the airport pavement surface.

Two types of thermoplastic materials were applied on asphalt and concrete surfaces at the Federal Aviation Administration William J. Hughes Technical Center and were evaluated for 1 year starting in June 2006. These materials were also applied on concrete pavement surfaces at the Newark Liberty International Airport and evaluated for 1 year starting in August 2006. One thermoplastic material was 60-mil thick with Type I and III beads and was applied on a heated surface; the other material was 90-mil thick with Type I and IV beads and was applied on cold surface. Retro-reflectivity was measured using a retro-reflectometer; a spectrophotometer was used to measure chromaticity, a Dyna-Meter Pull-Off tester was used to measure adherence strength, and a Saab Surface Friction Tester was used to measure friction properties. Most measurements were taken on a monthly basis.

The results showed that the retro-reflectivity characteristics of thermoplastic marking materials were acceptable. The chromaticity of the thermoplastic was within tolerance for white, red, yellow, and black. The average friction readings recorded on thermoplastic were significantly lower than those taken on bare pavement and about 50% less than waterborne paint. The adherence showed that preparation is necessary for a good bond. The tensile strength of the bond between the thermoplastic marking material and hot-mix asphalt was acceptable. The tensile strength of the bond between the thermoplastic marking material and Portland cement concrete was acceptable when an additional adhesive was applied.

Based on the result of this evaluation, thermoplastic marking material is recommended for taxiways.

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LIST OF SYMBOLS AND ACRONYMS

AC	Advisory Circular
DOT	Department of Transportation
DFW	Dallas Fort Worth International Airport
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
HMA	Hot-mix asphalt
ICAO	International Civil Aviation Organization
IOR	Index of refraction
$mcd/m^2/lx$	Millicandela per meter squared per lux
PCC	Portland cement concrete
psi	Pounds per square inch

EXECUTIVE SUMMARY

Due to the harsh conditions of airport environments, frequent repainting of existing waterborne pavement markings is required. This painting is expensive and affects life-cycle costs. A thermoplastic marking material has been identified as an alternative to the existing waterborne material. The purpose of this research effort was to determine if this thermoplastic marking material is as effective as the current waterborne material in terms of its retro-reflectivity, chromaticity, friction properties, and its adherence to the airport pavement surface.

Two types of thermoplastic materials were applied on asphalt and concrete surfaces at the Federal Aviation Administration William J. Hughes Technical Center and were evaluated for 1 year starting in June 2006. These materials were also applied on concrete pavement surfaces at the Newark Liberty International Airport and evaluated for 1 year starting in August 2006. One thermoplastic material was 60-mil thick with Type I and III beads and was applied on a heated surface; the other material was 90-mil thick with Type I and IV beads and was applied on cold surface. Retro-reflectivity was measured using a retro-reflectometer; a spectrophotometer was used to measure chromaticity, a Dyna-Meter Pull-Off tester was used to measure adherence strength, and a Saab Surface Friction Tester was used to measure friction properties. Most measurements were taken on a monthly basis.

The results showed that the retro-reflectivity characteristics of thermoplastic marking materials were acceptable. The chromaticity of the thermoplastic was within tolerance for white, red, yellow, and black. The average friction readings recorded on thermoplastic were significantly lower than those taken on bare pavement and about 50% less than waterborne paint. The adherence showed that preparation is necessary for a good bond. The tensile strength of the bond between the thermoplastic marking material and hot-mix asphalt was acceptable. The tensile strength of the bond between the thermoplastic marking material and Portland cement concrete was acceptable when an additional adhesive was applied.

Based on the result of this evaluation, thermoplastic marking material is recommended for taxiways.

INTRODUCTION

PURPOSE.

This technical note describes the research evaluation efforts of the Federal Aviation Administration (FAA) Airport Safety Technology Research and Development Section to determine whether thermoplastic marking material can be added as an alternative marking material to the FAA Advisory Circular (AC) 150/5370-10B [1], "Standards for Specifying Construction of Airports," Item P-620, "Runway and Taxiway Painting."

BACKGROUND.

Maintenance of pavement markings is a common problem for airports due to the frequency of repainting and life-cycle cost. As a result, airports need an alternative marking material that will endure the harsh conditions of the airport environment for a longer duration than the standard waterborne paints that are specified in AC 150/5370-10B [1] Item P-620, Runway and Taxiway Painting. One possible candidate is a preformed thermoplastic material, which has been presented to the FAA for consideration. Manufacturers postulate that the durability of the thermoplastic marking material surpasses current waterborne paint marking materials; however, prior to this effort, thermoplastic material has not been formally tested in an airport environment.

Glass beads are used in waterborne paint markings to increase the reflectance of the material, giving the pilot a better visual acquisition of the paint markings during nighttime operations. Glass beads are characterized by their index of refraction (IOR), which is a value used to calculate how much light will bend upon entering and exiting each bead. The characteristics of the IOR vary, depending on the type of glass used, whether it is virgin (never been used) or recycled. Virgin glass beads have a higher IOR than recycled beads, because recycled glass beads retain some color from previous use. Depending on the paint material used, glass beads incorporated within the paint may exhibit less retro-reflectivity when not properly embedded.

With thermoplastic material, glass beads are embedded directly into the material during manufacturing, which keeps the light refraction from diminishing over time. Due to the heat applied during application, the beads embed below the surface of the material. As such, a process known as the double-drop method was used in which beads were added directly to the surface to achieve acceptable initial readings. This double-drop method was used on one thermoplastic marking at Newark Liberty International Airport (EWR). Three types of beads are detailed in the Federal Specification TT-B-1325C: (1) Type I (1.5 IOR) low-index recycled glass bead, (2) Type III (1.9 IOR) high-index virgin glass bead, and (3) Type IV (1.5 IOR) low-index, direct-melt glass bead. Type I beads have less density, roughly 1570 grams per liter, and are commonly referred to as highway beads, and Type III and IV beads have a larger density, roughly 2670 grams per liter, and are referred to as airport beads.

In 2002, Dallas Fort Worth International Airport (DFW) applied thermoplastic marking material using a preformed method of application with Type III glass beads. These thermoplastic markings were applied on nonmovement areas such as hanger aprons and deicing pads. DFW personnel decided that the heat from aircraft engines and tires would melt the thermoplastic material if placed on high-traffic movement areas such as taxiway or runway centerlines. DFW personnel reported that the chemicals used for deicing caused minimal damage to thermoplastic material. One area of concern that DFW personnel noted was thermoplastic degradation. DFW personnel predicted that the thermoplastic material would break off into small hard chips causing a foreign object debris problem. These areas would then have to be thoroughly cleaned to avoid potential damage to aircraft.

SCOPE.

This effort was conducted to determine if preformed thermoplastic marking material is as effective as current paints in retro-reflectivity, chromaticity, friction properties, and adherence to airport pavement surfaces, and if it can be added as an alternative to paint materials to the FAA AC 150/5370-10B [1] regarding standards for runway and taxiway painting. The glass beads evaluated in this study were Type I, III and IV, which were FAA approved for use on airport surfaces. Two manufacturers, hereafter referred to as Manufacturer A and Manufacturer B, provided thermoplastic material and installation oversight for this evaluation. Additional issues, such as cost, construction design, and compliance with environmental requirements, were not addressed during these evaluations.

The preformed thermoplastic materials were applied to hot-mix asphalt (HMA) and aged Portland cement concrete (PCC) surfaces at the FAA William J. Hughes Technical Center at the Atlantic City International Airport for an evaluation period of 1 year starting in June 2006. The thermoplastic marking materials were applied to PCC on taxiway November of EWR for an evaluation period of 1 year starting in August 2006.

OBJECTIVES.

The specific research objectives of this project included:

1. Determine if the chromaticity of the thermoplastic material is equal to the standard waterborne paint used in DOT/FAA/AR-TN03/22, "Development of Methods for Determining Airport Pavement Marking Effectiveness" [2].

2. Determine if the retro-reflectivity of the thermoplastic material is equal to the standard waterborne paint used in DOT/FAA/AR-TN03/22, "Development of Methods for Determining Airport Pavement Marking Effectiveness" [2].

3. Determine if the tensile strength of the bond between the thermoplastic material and HMA or PCC is in accordance with ASTM D 4541 02, "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers" [3].

4. Determine if the friction readings are equal to the standard waterborne paint with beads used in DOT/FAA/AR-02/128, "Paint and Bead Durability Study" [4].

RELATED DOCUMENTATION.

1. DOT/FAA/AR-TN06/33, "Polyester Marking Material Study," August 2006.

2. DOT/FAA/AR-TN96/74, "Polyurea Paint Marking Material Study," October 2006.

3. DOT/FAA/AR-TN06/46, "Follow-On Friction Testing of Retro-Reflective Glass Beads," July 1996.

4. DOT/FAA/CT-94/119, "Evaluation of Alternative Pavement Marking Materials," January 1995.

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

6. FAA AC 150/6320-12C, "Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces," March 18, 1997.

7. FAA AC 150/5340-1J, "Standards for Airport Markings," April 29, 2005.

8. Specification TT-B-1325C, "Beads (Glass Spheres) Retro-Reflective," June 1, 1993.

EVALUATION APPROACH

To perform this evaluation, two distinct phases were undertaken. Phase 1 (June 2006) involved installation of thermoplastic marking material at two locations of the FAA William J. Hughes Technical Center property. These two areas were selected to allow thermoplastic marking material to be applied to PCC and HMA surfaces. For Phase 2 (August 2006), thermoplastic markings were applied at EWR on taxiway November for runway 4R-22L, which is a high-speed turnoff for that runway and is made of PCC. EWR airport operations personnel indicated that this taxiway has approximately 500 aircraft movements over this area per day, and served to demonstrate how thermoplastic marking materials would wear on an actual airport environment.

PHASE 1.

Phase 1 of the evaluation involved applying thermoplastic marking materials to PCC and HMA surfaces at the FAA William J. Hughes Technical Center in June 2006. Manufacturer A used a thermoplastic material at 60-mil thickness with Type I and Type III beads. Manufacturer B used thermoplastic material at 90-mil thickness with Type I and Type IV beads. Tables 1 and 2 list the thermoplastic marking materials applied to various sites on the FAA William J. Hughes Technical Center with the type of marking, surface material, type of beads applied for each manufacturer, and a marking designation.

Table 1. The FAA William J. Hughes Technical Center Thermoplastic Markings for Manufacturer A

Type of Marking	Surface Material	Type of Beads	Marking Designation
Movement/nonmovement line (black)	PCC	I & III	CCMNB-1
Movement/nonmovement line (yellow)	PCC	I & III	CCMNY-1
Aircraft parking designator #6 (red)	PCC	I & III	CCAPD6R-1
Aircraft parking designator #6 (white)	PCC	I & III	CCAPD6W-1
Aircraft parking designator #7 (red)	PCC	I & III	CCAPD7R-1
Aircraft parking designator #7 (white)	PCC	I & III	CCAPD7W-1
3′ red stripe	PCC	I & III	CCRS-1
3′ white stripe	PCC	I & III	CCWS-1
3′ yellow stripe	PCC	I & III	CCYS-1
3′ black stripe	PCC	I & III	CCBS-1
3′ red stripe	PCC	I & III	HMRS-1
3′ white stripe	HMA	I & III	HMWS-1
3′ yellow stripe	HMA	I & III	HMYS-1
3′ black stripe	HMA	I & III	HMBS-1
150′ white stripe	HMA	I & III	HMWSL-1

Table 2. The FAA William J. Hughes Technical Center Thermoplastic Markings for Manufacturer B

Type of Marking	Surface Material	Type of Beads	Marking Designation
Movement/Nonmovement line (black)	PCC	I & IV	CCMNB-2
Movement/Nonmovement line (yellow)	PCC	I & IV	CCMNY-2
Aircraft parking designator #8 (red)	PCC	I & IV	CCAPD8R-2
Aircraft parking designator #8 (white)	PCC	I & IV	CCAPD8W-2
3′ red stripe	PCC	I & IV	CCRS-2
3′ white stripe	PCC	I & IV	CCWS-2
3′ yellow stripe	PCC	I & IV	CCYS-2
3′ black stripe	PCC	I & IV	CCBS-2
3′ red stripe	HMA	I & IV	HMRS-2
3′ white stripe	HMA	I & IV	HMWS-2
3′ yellow stripe	HMA	I & IV	HMYS-2
3′ black stripe	HMA	I & IV	HMBS-2
150′ white stripe	HMA	I & IV	HMWSL-2

Installation of thermoplastic material first occurred on an aged PCC test area using direct open flame wands to heat the material. The movement/nonmovement marking is shown in figure 1.

Figure 1. Movement/Nonmovement Line on PCC at FAA William J. Hughes Technical Center

Three-foot red, yellow, and white stripes are shown in figure 2. Aircraft parking numbers were applied as shown in figures 3, 4, and 5, using both a large area radiant heater and direct open flame wands to heat the material. The thermoplastic material markings were applied afterward on HMA. Three-foot red, white, and yellow stripes were applied, as shown in figure 6, and 150′-long white stripes were applied, as shown in figure 7.

Figure 2. Red, Yellow, and White Stripes on PCC at FAA William J. Hughes Technical Center

Figure 3. Aircraft Parking Location #6 on PCC at FAA William J. Hughes Technical Center

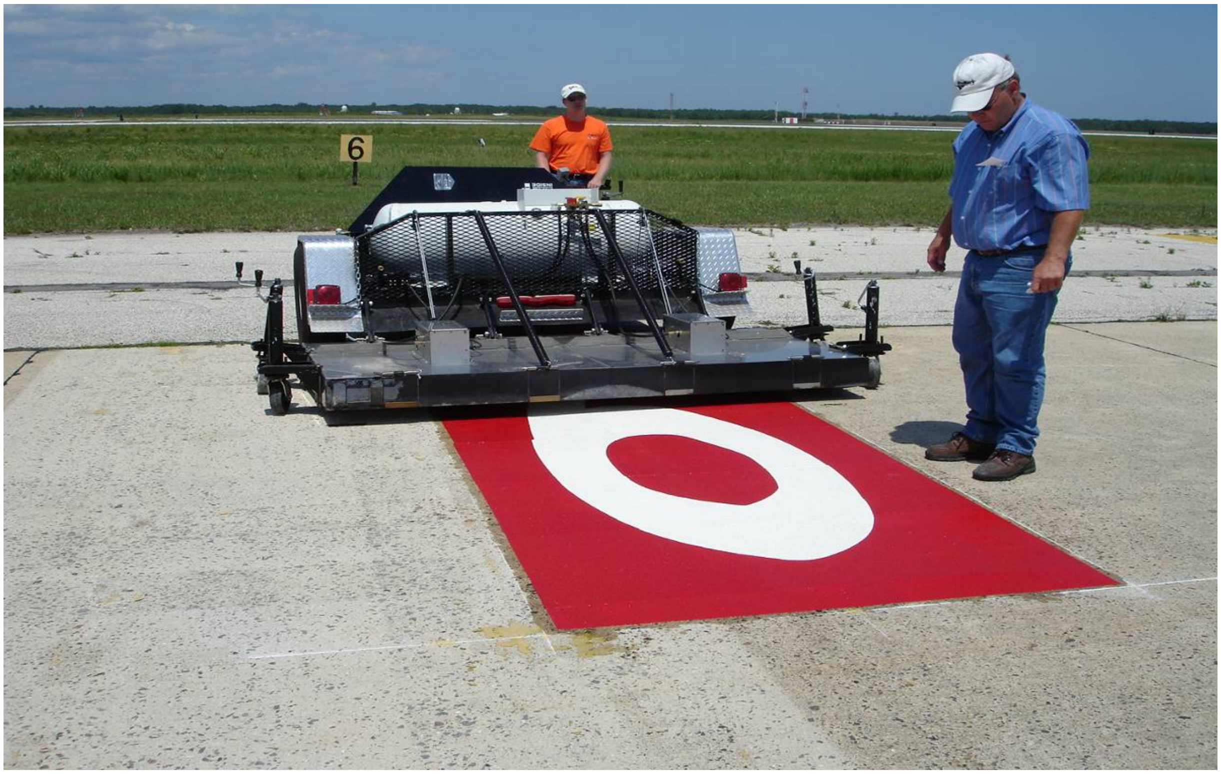


Figure 4. Heating Aircraft Parking Location #6 on PCC at FAA William J. Hughes Technical Center

Figure 5. Aircraft Parking Location #8 on PCC at FAA William J. Hughes Technical Center

Figure 6. White, Yellow, and Red Stripe on HMA at FAA William J. Hughes Technical Center

Figure 7. A 150-Foot White Stripe on HMA at FAA William J. Hughes Technical Center

PHASE 2.

For Phase 2 of the evaluation (August 2006), thermoplastic markings were applied to PCC runways and taxiways at EWR. As indicated in table 3, thermoplastic markings were applied on taxiway November, which is a high-speed turnoff for the primary runway 4R-22L. The identification marking has red and white colors contained within a black border, so they were listed as three separate items. Figure 8 shows the runway identification marking in thermoplastic material applied to PCC at taxiway November on the left side of the taxiway centerline. Standard waterborne paint was applied to the right side of the taxiway centerline. Figure 9 shows the thermoplastic runway identification marking as well as the one solid yellow line of the runway holding position marking.

Table 3. Thermoplastic Markings on PCC at EWR

Type of Marking	Type of Beads	Marking Designation
One solid yellow line of a runway holding position marking	I & III	CCRHPS-YELLOW
One dashed yellow line of a runway holding position marking	I & III	CCRHPD-YELLOW
Runway identification marking—red	I & III	CCRID-RED
Runway identification marking—white	I & III	CCRID-WHITE
Runway identification marking—black	I & III	CCRID-BLACK

Figure 8. Side-by-Side Markings at EWR

Figure 9. Thermoplastic Runway Identification Marking and One Solid Yellow Line of the Runway Holding Position Marking

Figures 10, 11, and 12 show the various thermoplastic markings that were applied to PCC on taxiway November. Figure 11 shows the thermoplastic dashed yellow line marking in which the double-drop method for applying beads was performed.

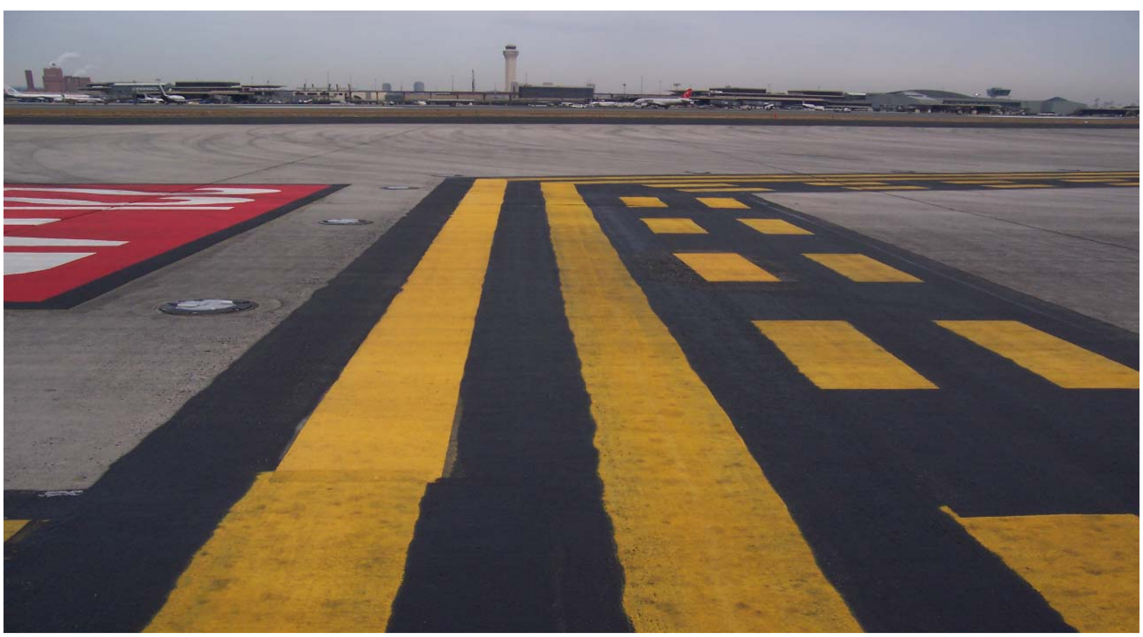


Figure 10. Thermoplastic Solid Yellow Line of Runway Holding Position Marking at EWR

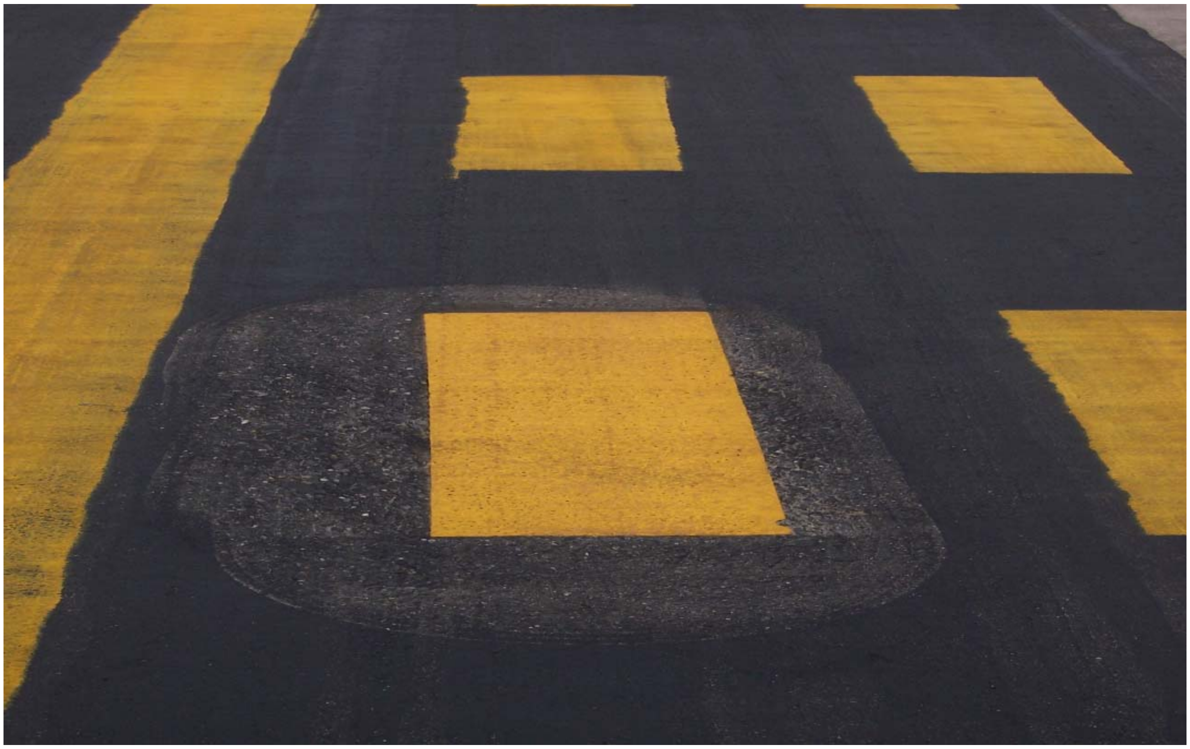


Figure 11. Thermoplastic Dashed Yellow Line of Runway Holding Position Marking at EWR

Figure 12. Thermoplastic Runway Identification Marking at EWR

To assist in Phase 2 of the evaluation, EWR maintenance personnel duplicated the same type of markings as the thermoplastic markings using standard waterborne paint, as shown in figure 13. These markings were painted adjacent to the thermoplastic markings to ensure the same amount of aircraft movements crossed over both the thermoplastic and waterborne paint markings. Table 4 lists the type of markings painted, the type of beads, and the marking designation.

Figure 13. Standard Waterborne Painted Runway Identification Marking at EWR

Table 4. Standard Waterborne Paint Markings on PCC at EWR

Type of Marking	Type of Beads	Marking Designation
Yellow runway holding position marking	I	CCRHP-YELLOW PAINT
Runway identification marking—red	I	CCRID-RED PAINT
Runway identification marking—white	I	CCRID-WHITE PAINT
Runway identification marking—black	I	CCRID-BLACK PAINT

Photographs of the runway identification marking, as shown in figures 14 and 15, represent the deterioration starting on the various markings after only 6 months of testing.

Figure 14. Thermoplastic Marking Material After 6 Months at EWR

Figure 15. Standard Waterborne Paint After 6 Months at EWR

EVALUATION EQUIPMENT.

Figures 16-20 show the evaluation equipment that was used for this project:

- Spectrophotometer, Color-guide 45/0, BYK-Gardner USA, 20mm, 6805-SVC, built by BYK-Gardner of Germany

- Dyna-Meter Z-16 Pull-Off Tester

- Retro-Reflectometer, Flint Trading, Inc., 30-meter geometry, LTL 2000 built by Delta Lights and Optics of Denmark

- Sarsys Saab 9-5 Surface Friction Tester

Figure 16. Spectrophotometer for Measuring Color

Figure 17. Dyna-Meter Z-16 Pull-Off Tester for Measuring Adherence

Figure 18. Retro-Reflectometer, 30-Meter Geometry for Measuring Retro-Reflectivity of the Glass Beads

Figure 19. Sarsys Saab 9-5 Surface Friction Tester

Figure 20. Sarsys Saab 9-5 Surface Friction Tester in Action

BASELINE TEST.

At initial application, baseline measurements of the thermoplastic marking material were taken for each color (red, yellow, and white) on both HMA and PCC. Once the material was applied to the pavement, chromaticity readings were taken using a spectrophotometer. Retro-reflective readings were taken using a retro-reflectometer, pull-off strength testing was accomplished using a Dyna-Meter Pull-Off Tester, and friction test measurements were taken using a Sarsys Saab Surface Friction Tester.

CHROMATICITY TEST.

The chromaticity test was conducted using a spectrophotometer. The readings were taken by placing the instrument on the pavement marking and activating the device. Two color readings per marking were taken after initial application of the thermoplastic marking material and standard waterborne paint markings. Readings were then taken monthly thereafter for 1 year.

RETRO-REFLECTIVITY TEST.

Retro-reflectivity was obtained with the use of a retro-reflectometer. Six readings were taken by placing the instrument on each pavement marking and activating the device. Prior to each use, the instrument was calibrated and had an accuracy of ±5%. Readings were taken after initial application of the thermoplastic marking material and standard waterborne paint markings. Readings were then taken monthly thereafter for 1 year.

PULL-OFF STRENGTH TEST.

The pull-off strength test was used to determine the tensile strength of the bond between the thermoplastic marking material and HMA or PCC. Using a Dyna-Meter Z-16 Pull-Off Tester, a metal disc was glued to the thermoplastic marking material and allowed to cure for 24 hours. The Dyna-Meter Pull-Off Tester was connected to the disc via a draw bolt. The instrument was adjusted to level via adjustable legs. The instrument was then started and the crank was turned, which applied additional pounds per square inch (psi) until the metal disc separated from the pavement. This test was performed in accordance with ASTM D 4541-02 [3].

FRICTION TEST.

Multiple friction test runs were conducted in September 2006 and June 2007 using a Saab Surface Friction Tester. The friction test runs were conducted at a speed of 40 miles per hour (mph), at 31 psi on the ASTM 1551 Smooth Surface test tire with the self-watering system with one millimeter of water applied to the test tire during each run. Twelve test runs were conducted on the bare pavement next to the thermoplastic marking materials: five per manufacturer marking, one baseline, and one posttest run.

DATA COLLECTION

BASELINE TEST.

Color readings were taken and produced three coordinates: Y = depth, x = width, and y = height. These coordinates were used to obtain the base measurement chromaticity of the thermoplastic marking material. In addition, retro-reflectivity readings were taken, which produced millicandela per meter squared per lux ($mcd/m^2/lx$) readings.

CHROMATICITY TEST.

Color readings were taken with a spectrophotometer, which produced Y, x, and y coordinates for its readouts. The readings were then plotted on an International Civil Aviation Organization (ICAO) standard illuminant D65 chromaticity chart, as shown in figure 21. This chart is found in the ICAO Annex 14 Volume I—Aerodrome Design and Operations [5]. This chart was modified to address the aviation yellow used on airports. The FAA boundaries for aviation yellow are not the same as for ICAO yellow. The region for FAA in-service yellow was obtained and is documented in figure A-5 in appendix A of reference 2. The region for white is the same for ICAO and the FAA. A white data point that falls outside of the ICAO white region is considered failed. A yellow data point that falls outside of the FAA in-service aviation yellow region is considered failed.

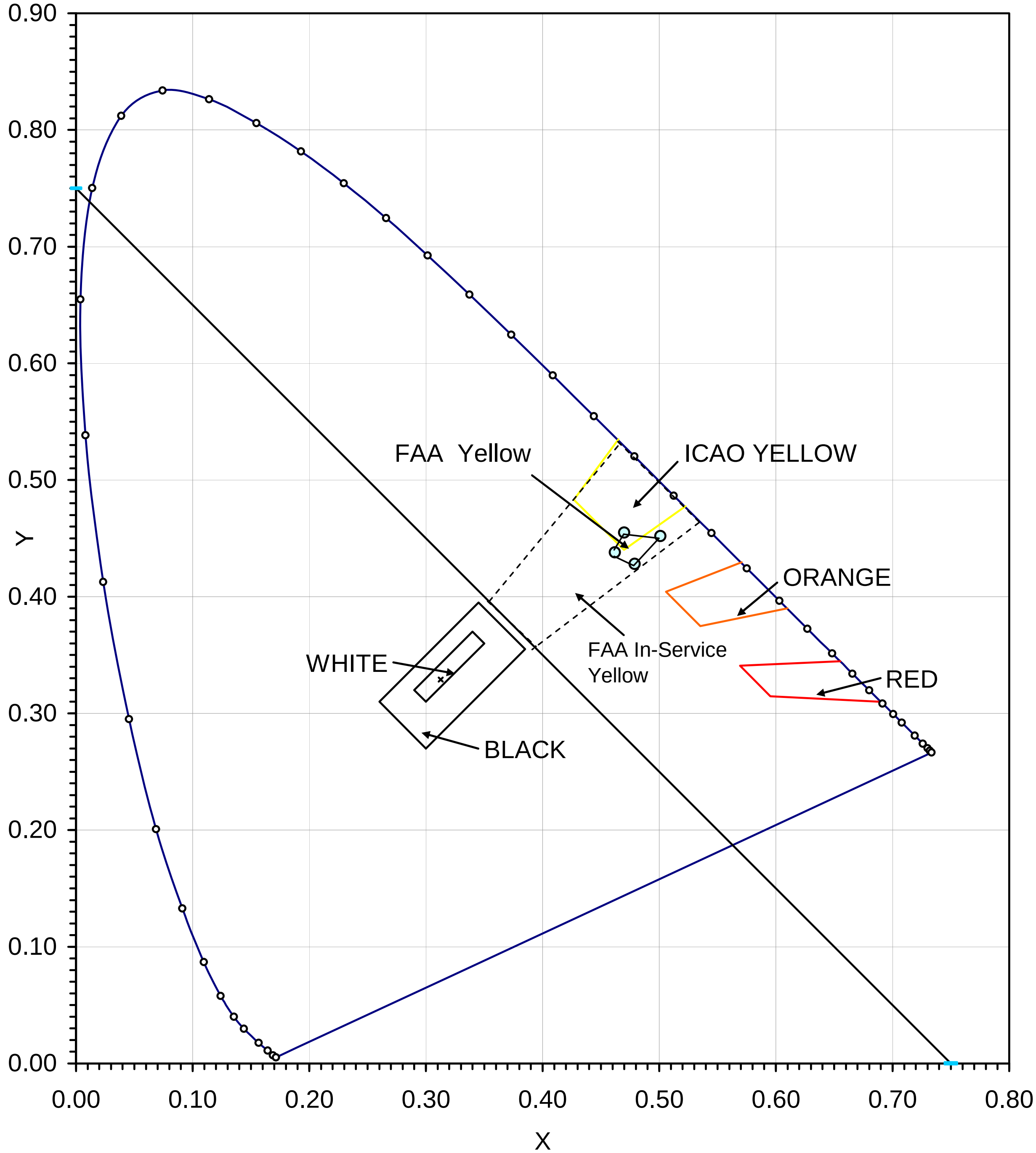


Figure 21. Sample ICAO Standard Illuminant D_{65} Color Chart

RETRO-REFLECTIVITY TEST.

The retro-reflectometer produced millicandela per meter squared per lux readings. Currently, the FAA has no standard for retro-reflectivity limits. A previous paint marking study conducted by the FAA Airport Safety Technology Research and Development Section determined that the recommended minimum was 100 mcd/m^2/lx for white and 70 mcd/m^2/lx for yellow. The color red was not studied as part of this previous effort. Reference 2 elaborates on this test method.

PULL-OFF STRENGTH TEST.

The pull-off strength test determined whether there was an internal failure of the thermoplastic marking material or an external failure of the pavement material (HMA or PCC) based on the type of separation that occurred. Using a Dyna-Meter Z-16 Pull-Off Tester, a metal disc was glued to the thermoplastic marking material and allowed to cure for 24 hours. The Dyna-Meter Pull-Off Tester was connected to the disc via a draw bolt. The instrument was adjusted to level via adjustable legs. The instrument was then started, and the crank was turned, which applied additional psi until the metal disc separated from the pavement. This test was performed in accordance with ASTM D 4541-02 [3]. When the thermoplastic material failed, the tested section separated from the pavement material, resulting in a cohesive failure. When the HMA or PCC failed, the actual pavement material separated with the thermoplastic marking material, resulting in an adhesive failure. The tensile strength readings were measured in psi. The best result should end in a pavement failure (adhesive) rather than a thermoplastic material marking failure (cohesive).

FRICTION TEST.

Multiple friction test runs were conducted using a Sarsys 9-5 Surface Friction Tester, housed in a Saab station wagon. The testing took place at the FAA William J. Hughes Technical Center on HMA where two 150-foot test stripes from Manufacturers A and B were located. The ambient temperature at time of testing was 76°F, humidity was 55%, air pressure was 30.09 inches, and it was cloudy. Figure 22 shows a diagram of the test area layout where the friction test runs were conducted.

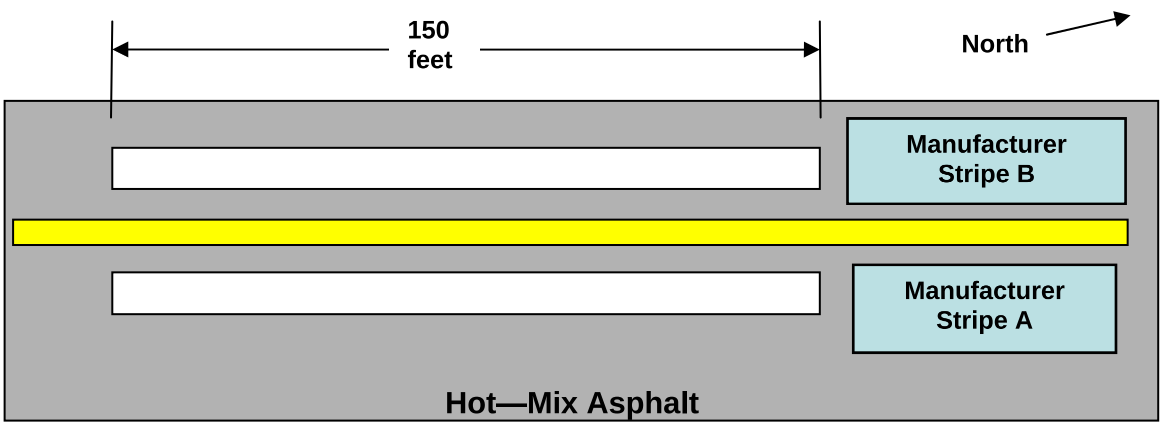


Figure 22. The HMA Friction Test Diagram at FAA William J. Hughes Technical Center

Twelve friction test runs were conducted. A test run was conducted on bare pavement prior to testing to establish a baseline reading. Five runs were conducted on each stripe, alternating runs between Manufacturer Stripe A and Manufacturer Stripe B. A final test run was conducted on the bare pavement as a posttest. The vehicle was operated in a manual mode because the stripes were only 150 feet long, the minimum length for obtaining readings. The operator lowered the test wheel before measuring the test stripes and pressed the start button to begin water flow and friction measurement. The test wheel was then manually lifted at the end of the pass, which ended measurement and turned off the water flow.

RESULTS

BASELINE TEST.

The initial chromaticity readings for red, white, and yellow thermoplastic marking material all fell within their acceptable ranges. (See appendix A for additional data.)

The initial retro-reflectivity readings for Type I and Type III beads were above the recommended minimums of 100 mcd/m^2/lx for white and 70 mcd/m^2/lx for yellow.

CHROMATICITY TEST.

The acceptability range for the white x-coordinate is 0.2895 to 0.3442 and the y-coordinate is 0.3100 to 0.3650. The acceptability range for the yellow x-coordinate is 0.4261 to 0.5266 and the y-coordinate is 0.4300 to 0.5346. As shown in tables 5 through 8, a pass or fail rating was determined for each month of the 12-month evaluation. Two readings per color, per month, were tested along with the marking designation, manufacturer, and color.

Table 5. Pass/Fail Rate for Thermoplastic Chromaticity Test on HMA at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Color	Pass	Fail
HMRS-1	A	Red	24	0
HMWS-1	A	White	4	20
HMYS-1	A	Yellow	24	0
HMBS-1	A	Black	24	0
HMWSL-1	A	White	21	3
HMRS-2	B	White	21	3
HMWS-2	B	Yellow	19	4
HMYS-2	B	Red	5	19
HMBS-2	B	Black	24	0
MWSL-2	B	White	24	0

Table 6. Pass/Fail Rate for Thermoplastic Chromaticity Test on PCC at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Color	Pass	Fail
CCMNB-1	A	Black	22	2
CCMNY-1	A	Yellow	24	0
CCAPD6R-1	A	Red	24	0
CCAPD6W-1	A	White	24	0
CCAPD7R-1	A	Red	24	0
CCAPD7W-1	A	White	24	0

Table 6. Pass/Fail Rate for Thermoplastic Chromaticity Test on PCC at FAA William J. Hughes Technical Center (Continued)

Marking Designation	Manufacturer	Color	Pass	Fail
CCRS-1	A	Red	24	0
CCWS-1	A	White	24	0
CCYS-1	A	Yellow	23	1
CCBS-1	A	Black	24	0
CCMNB-2	B	Black	12	0
CCMNY-2	B	Yellow	12	0
CCAPD8R-2	B	Red	11	1
CCAPD8W-2	B	White	12	0
CCRS-2	B	Red	12	0
CCWS-2	B	White	10	2
CCYS-2	B	Yellow	12	0
CCBS-2	B	Black	12	0

Table 7. Pass/Fail Rate for Thermoplastic Chromaticity Test on PCC at EWR

Marking Designation	Manufacturer	Color	Pass	Fail
CCRHPS-YELLOW	A	Yellow Solid	24	0
CCRHPD-YELLOW	A	Yellow Dash	18	0
CCRID-RED	A	Red	21	3
CCRID-WHITE	A	White	23	1
CCRID-BLACK	A	Black	24	0

Table 8. Pass/Fail Rate for Standard Waterborne Paint Chromaticity Test on PCC at EWR

Marking Designation	Color	Pass	Fail
CCRHP-YELLOW PAINT	Yellow	24	0
CCRID-RED PAINT	Red	24	0
CCRID-WHITE PAINT	White	24	0
CCRID-BLACK PAINT	Black	24	0

RETRO-REFLECTIVITY TEST.

The recommended minimum retro-reflectivity reading is 100 mcd/m^2/lx for white and 70 mcd/m^2/lx for yellow. Table 9 shows the average retro-reflectivity readings for thermoplastic markings on PCC at FAA William J. Hughes Technical Center. After six months of data collection, Manufacturer B's thermoplastic material began to break apart and had to be removed from PCC due to aircraft safety concerns. Table 10 shows the average retro-reflectivity readings for thermoplastic markings on HMA at FAA William J. Hughes Technical Center.

Table 9. Average Retro-Reflectivity Readings of Thermoplastic on PCC at FAA William J. Hughes Technical Center

Marking Designation	July 2006	Aug. 2006	Sep. 2006	Oct. 2006	Nov. 2006	Dec. 2006	Jan. 2007	Feb. 2007	Mar. 2007	Apr. 2007	May 2007	June 2007
CCMNY-1	319	363	392	414	418	394	419	484	334	340	351	278
CCAPD6R-1	54	46	105	98	66	60	146	77	132	66	132	147
CCAPD6W-1	373	468	313	377	314	394	401	640	376	385	322	582
CCAPD7R-1	56	38	74	34	42	40	52	42	44	56	88	54
CCAPD7W-1	274	223	276	219	288	321	254	267	299	372	226	282
CCRS-1	103	112	105	155	161	182	207	230	189	202	214	225
CCWS-1	276	310	298	333	341	361	400	447	361	404	379	380
CCYS-1	301	306	315	386	411	397	428	423	360	434	354	377
CCMNY-2	304	336	343	306	299	296						
CCAPD8R-2	18	47	25	71	48	45						
CCAPD8W-2	340	473	325	332	314	249						
CCRS-2	89	114	145	168	177	182						
CCWS-2	538	543	528	630	614	646						
CCYS-2	200	177	204	231	230	235						

Table 10. Average Retro-Reflectivity Readings of Thermoplastic on HMA at FAA William J. Hughes Technical Center

Marking Designation	July 2006	Aug. 2006	Sep. 2006	Oct. 2006	Nov. 2006	Dec. 2006	Jan. 2007	Feb. 2007	Mar. 2007	Apr. 2007	May 2007	June 2007
HMRS-1	39	45	51	55	41	42	52	56	44	42	38	47
HMWS-1	286	284	303	317	177	167	231	310	123	217	182	194
HMYS-1	412	423	392	344	203	200	261	262	62	186	137	151
HMWSL-1	364	320	309	338	331	280	284	345	260	296	260	218
HMRS-2	58	59	81	87	57	54	69	66	42	41	34	41
HMWS-2	488	408	360	248	160	148	187	183	192	145	132	156
HMYS-2	257	247	213	161	91	85	107	104	169	67	59	72
HMWSL-2	477	512	538	403	368	379	372	264	284	260	285	272

Table 11 shows the average retro-reflectivity readings for thermoplastic markings on PCC at EWR. In December 2006, a thermoplastic dash marking of a holding position was added and evaluated. EWR maintenance personnel applied standard waterborne paint to mirror the thermoplastic markings in the same area for comparison purposes. These standard waterborne paint marking averages for retro-reflectivity are shown in table 12.

Table 11. Average Retro-Reflectivity Readings of Thermoplastic on PCC at EWR

Marking Designation	Sep. 2006	Oct. 2006	Nov. 2006	Dec. 2006	Jan. 2007	Feb. 2007	Mar. 2007	Apr. 2007	May 2007	June 2007	July 2007	Aug. 2007
CCRHPS-YELLOW	34	25	84	113	108	90	97	59	42	138	148	159
CCRHPD-YELLOW				287	231	134	87	40	30	89	80	102
CCRID-RED	15	6	37	32	28	22	22	16	11	33	43	48
CCRID-WHITE	69	83	175	206	209	170	144	135	78	258	278	261

Table 12. Average Retro-Reflectivity Readings of Standard Waterborne Paint on PCC at EWR

Marking Designation	Sep. 2006	Oct. 2006	Nov. 2006	Dec. 2006	Jan. 2007	Feb. 2007	Mar. 2007	Apr. 2007	May 2007	June 2007	July 2007	Aug. 2007
CCRHP-YELLOW PAINT	93	78	125	123	114	56	43	21	13	32	53	153**
CCRID-RED PAINT	46	24	46	38	44	13	11	5	2	6	4	11
CCRID-WHITE PAINT	193	185	226	299	201	107	72	42	22	45	42*	43

*CCRID-White Paint was repainted due to loss of visual identification just prior to July 2007 readings.
**CCRHP-Yellow Paint was repainted due to loss of visual identification just prior to August 2007 readings.

Tables 13, 14, and 15 show the retro-reflective readings of thermoplastic marking material on HMA at the FAA William J. Hughes Technical Center.

Table 13. Red Retro-Reflectivity Readings on HMA at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
HMRS-1	A	I & III	39 mcd/m^2/lx	47 mcd/m^2/lx
HMRS-2	B	I & IV	58 mcd/m^2/lx	41 mcd/m^2/lx

Table 14. Yellow Retro-Reflectivity Readings on HMA at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
HMYS-1	A	I & III	419 mcd/m^2/lx	151 mcd/m^2/lx
HMYS-2	B	I & IV	257 mcd/m^2/lx	72 mcd/m^2/lx

Table 15. White Retro-Reflectivity Readings on HMA at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
HMWS-1	A	I & III	488 $mcd/m^2/lx$	194 $mcd/m^2/lx$
HMWS-2	B	I & IV	340 $mcd/m^2/lx$	156 $mcd/m^2/lx$

Tables 16, 17, and 18 show the retro-reflective readings of thermoplastic marking material on PCC at the FAA William J. Hughes Technical Center. No glue was used by Manufacturer B before the material was placed on PCC. As a result, Manufacturer B's thermoplastic material began to break apart and had to be removed due to aircraft safety concerns. Manufacturer A had specially formulated glue for PCC that performed well.

Table 16. Red Retro-Reflectivity Readings on PCC at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
CCRS-1	A	I & III	103 $mcd/m^2/lx$	225 $mcd/m^2/lx$
CCRS-2	B	I & IV	89 $mcd/m^2/lx$	Removed January 2007

Table 17. Yellow Retro-Reflectivity Readings on PCC at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
CCRY-1	A	I & III	301 $mcd/m^2/lx$	377 $mcd/m^2/lx$
CCRY-2	B	I & IV	200 $mcd/m^2/lx$	Removed January 2007

Table 18. White Retro-Reflectivity Readings on PCC at FAA William J. Hughes Technical Center

Marking Designation	Manufacturer	Bead Type	Start (July 2006)	Finish (June 2007)
CCRW-1	A	I & III	276 $mcd/m^2/lx$	380 $mcd/m^2/lx$
CCRW-2	B	I & IV	538 $mcd/m^2/lx$	Removed January 2007

At EWR, white waterborne paint had to be reapplied after 9 months, and yellow waterborne paint had to be reapplied after 11 months, both due to low retro-reflectivity. Tables 19 and 20 depict the retro-reflectivity readings of yellow thermoplastic markings for Manufacturer A over the course of the 1-year evaluation. All thermoplastic marking materials placed in September had the glass beads directly embedded into the thermoplastic marking material. The yellow dash of a holding position marking had additional glass beads hand spread onto the marking during the heating process.

Table 19. Yellow Line Retro-Reflectivity Readings on PCC at EWR

Marking Designation	Manufacturer	Bead Type	Start (Sep. 2006)	Finish (Aug. 2007)
CCRHPS-YELLOW	A	I & III	34 mcd/m^2/lx	93 mcd/m^2/lx
CCRHP-YELLOW PAINT	Waterborne Paint	I	159 mcd/m^2/lx	53 mcd/m^2/lx

Table 20. Yellow Dash Retro-Reflectivity Readings on PCC at EWR

Marking Designation	Manufacturer	Bead Type	Start (Dec. 2006)	Finish (Aug. 2007)
CCRHPD-YELLOW	A	I & III	287 mcd/m^2/lx	102 mcd/m^2/lx

Table 21 shows that Manufacturer A's thermoplastic material increased in retro-reflectivity as opposed to waterborne paint, which decreased.

Table 21. Red Retro-Reflectivity Readings on PCC at EWR

Marking Designation	Manufacturer	Bead Type	Start (Sep. 2006)	Finish (Aug. 2007)
CCRID-RED	A	I & III	15 mcd/m^2/lx	46 mcd/m^2/lx
CCRID-RED PAINT	Waterborne Paint	I	44 mcd/m^2/lx	11 mcd/m^2/lx

Table 22 shows that Manufacturer A's thermoplastic material increased to a higher level in retro-reflectivity than the suggested 100 mcd/m^2/lx for repaint criteria.

Table 22. White Retro-Reflectivity Readings on PCC at EWR

Marking Designation	Manufacturer	Bead Type	Start (Sep. 2006)	Finish (Aug. 2007)
CCRID-WHITE	A	I & III	69 mcd/m^2/lx	193 mcd/m^2/lx
CCRID-WHITE PAINT	Waterborne Paint	I	261 mcd/m^2/lx	43 mcd/m^2/lx

PULL-OFF STRENGTH TEST.

A comparison of thermoplastic marking material was conducted. Based on a previous study of TT-P-1952D waterborne paint [4], yellow waterborne paint had an average tensile strength of 77 psi, and white waterborne paint had an average tensile strength of 86 psi. White markings were tested on both PCC and HMA, as depicted in table 23.

Table 23. Pull-Off Strength Test of Color White

Surface Material	Manufacturer	psi Rating
HMA	A	57 psi
	B	37 psi
PCC	A	80 psi
	B	47 psi

FRICTION TEST.

The data output of the surface friction test readings was measured in Mu (μ), which is the coefficient of friction between two surfaces. The readings for friction can range from 0 to 1 μ. Readings were taken in September 2006 and in June 2007 of the evaluation period. Table 24 presents the baseline and posttest pavement friction test runs along the bare pavement adjacent to the thermoplastic marking material in September 2006.

Table 24. September 2006 Bare Pavement Friction Test Runs

Test Item	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Baseline Bare Pavement	1	0.74	35
Posttest Bare Pavement	12	0.74	37

Notes: Bare pavement average friction: 0.74 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

Tables 25 and 26 represent the friction test runs of manufacturer stripes 1 and 2 that were taken in September 2006, along with the average friction value below each set of measurements. Table 27 represents the baseline and posttest pavement friction test runs along the bare pavement adjacent to the thermoplastic marking material in June 2007. Tables 28 and 29 represent the friction test runs of manufacturer stripes 1 and 2 along with the average friction value below each set of measurements, as recorded in June 2007.

Table 25. Manufacturer A Friction Test Runs—September 2006

Manufacturer 1	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Stripe 1	2	0.28	36
Stripe 1	4	0.24	38
Stripe 1	6	0.24	37
Stripe 1	8	0.24	37
Stripe 1	10	0.20	40

Notes: Manufacturer A—Stripe 1 average friction: 0.24 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

Table 26. Manufacturer B Friction Test Runs—September 2006

Manufacturer 2	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Stripe 2	3	0.26	40
Stripe 2	5	0.25	38
Stripe 2	7	0.25	37
Stripe 2	9	0.25	35
Stripe 2	11	0.25	37

Notes: Manufacturer B—Stripe 2 average friction: 0.25 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

Table 27. June 2007 Bare Pavement Friction Test Runs

Test Item	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Baseline Bare Pavement	1	0.76	41
Post Test Bare Pavement	8	0.82	40

Notes: Bare pavement average friction: 0.79 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

Table 28. Manufacturer A Friction Test Runs—June 2007

Manufacturer 1	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Stripe 1	2	0.28	40
Stripe 1	4	0.30	41
Stripe 1	6	0.30	41

Notes: Manufacturer A—Stripe 1 average friction: 0.29 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

Table 29. Manufacturer B Friction Test Runs—June 2007

Manufacturer 2	Test Run Number	Average Friction Value in μ	Average Vehicle Speed in MPH
Stripe 2	3	0.31	40
Stripe 2	5	0.31	41
Stripe 2	7	0.29	39

Notes: Manufacturer B—Stripe 2 average friction: 0.30 μ
Waterborne paint with beads on bare pavement average friction: 0.43 μ from reference 4.
Bare pavement average friction: 0.76 μ from reference 4.

CONCLUSIONS

The chromaticity of the thermoplastic marking materials were acceptable when compared with the 1931 CIE standard illumination D_{65} chart and white, red, yellow, and black color chips of the Federal Standard 595B for colors. The D_{65} 10° International Civil Aviation Organization color charts are located in appendix A of this report. None of the colors examined faded out of tolerance.

The retro-reflectivity characteristics of thermoplastic marking material of the white were above 100 $mcd/m^2/lx$ (261 $mdc/m^2/lx$ (number) and the yellow were above 70 $mcd/m^2/lx$ (159 $mcd/m^2/lx$ (stripe) and 102 $mcd/m^2/lx$ (dash)). The color red was acceptable at 46 $mcd/m^2/lx$.

The pull-off strength test showed that preparation on both hot-mix asphalt (HMA) and Portland cement concrete (PCC) is necessary for a good bond. The tensile strength of the bond between the thermoplastic marking material and HMA was acceptable. On HMA, Manufacturer A heated the surface before placing the thermoplastic material, whereas Manufacturer B did not, which resulted in a bond strength 20 psi stronger. The tensile strength of the bond between the thermoplastic marking material and PCC was acceptable when an adhesive was applied. If the adhesive was not applied, the thermoplastic marking material did not meet the tensile strength test. On PCC, glue is needed to obtain a proper bond. Manufacturer A had specially formulated glue for PCC that performed well. Manufacturer B did not use glue to adhere the thermoplastic material to the PCC, which resulted in bond strength 33 psi weaker than Manufacturer A. After 6 months of data collection, Manufacturer B's thermoplastic material began to break apart and had to be removed from the PCC due to aircraft safety concerns.

At the beginning of the test, the average friction readings on bare pavement were 0.74 μ and on thermoplastic were 0.20 μ to 0.28 μ for Manufacturer A and 0.25 μ to 0.26 μ for Manufacturer B. Because of these low friction readings, thermoplastic marking material is not currently suitable for use on runways. However, thermoplastic marking material did prove suitable for use on taxiway and apron markings and, therefore, is recommended for these applications.

REFERENCES

1. "Standards for Specifying Construction of Airports," Item P-620, "Runway and Taxiway Painting," FAA Advisory Circular AC 150/5370-10B, April 25, 2005.

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

3. "Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers," ASTM D 4541-02.

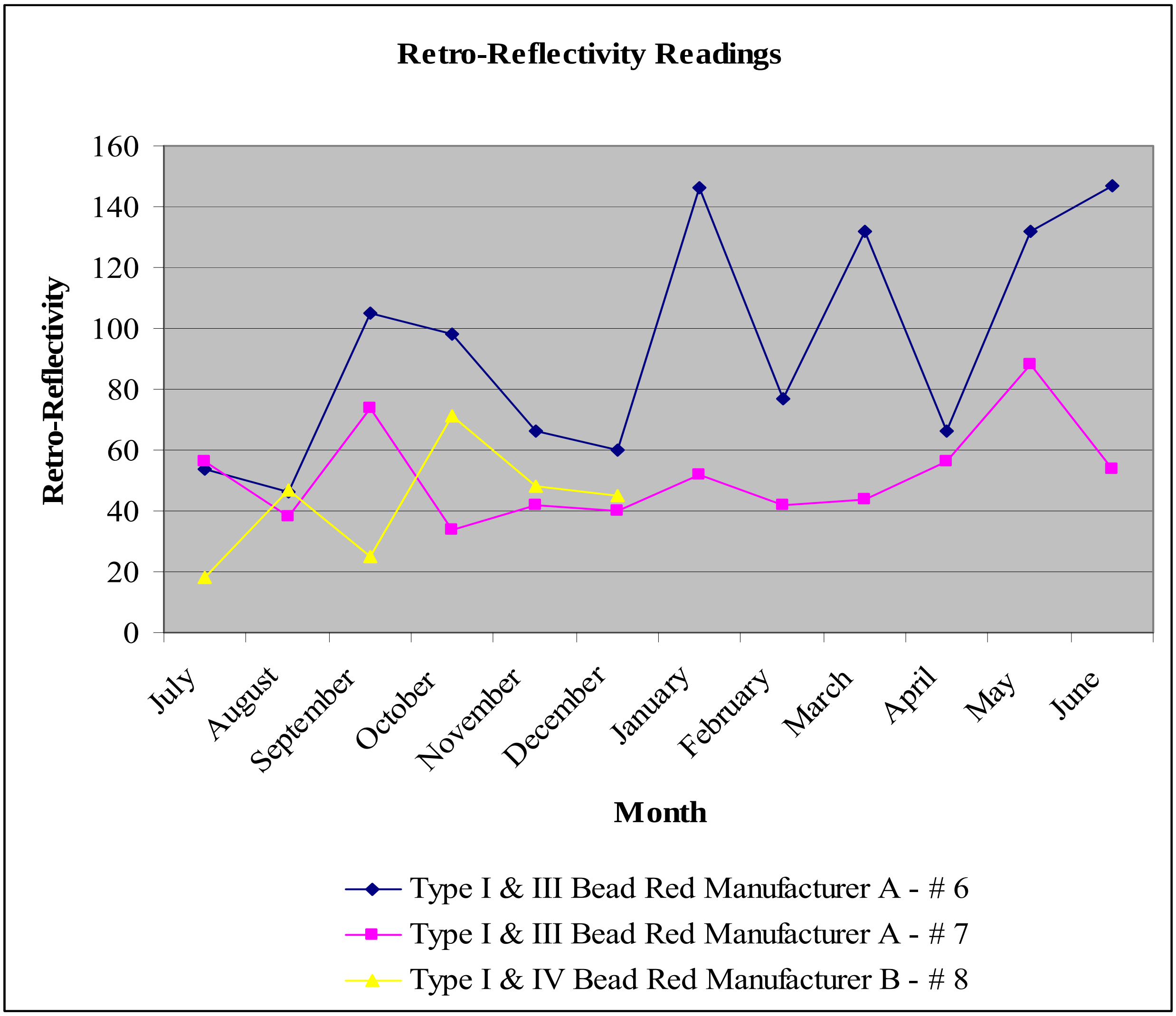
4. Cyrus, H.M., "Paint and Bead Durability Study," FAA report DOT/FAA/AR-02/128, March 2003.

5. "Aerodrome Design and Operation," ICAO Annex 14, Volume I, August 9, 2000.

APPENDIX A—THERMOPLASTIC DATA

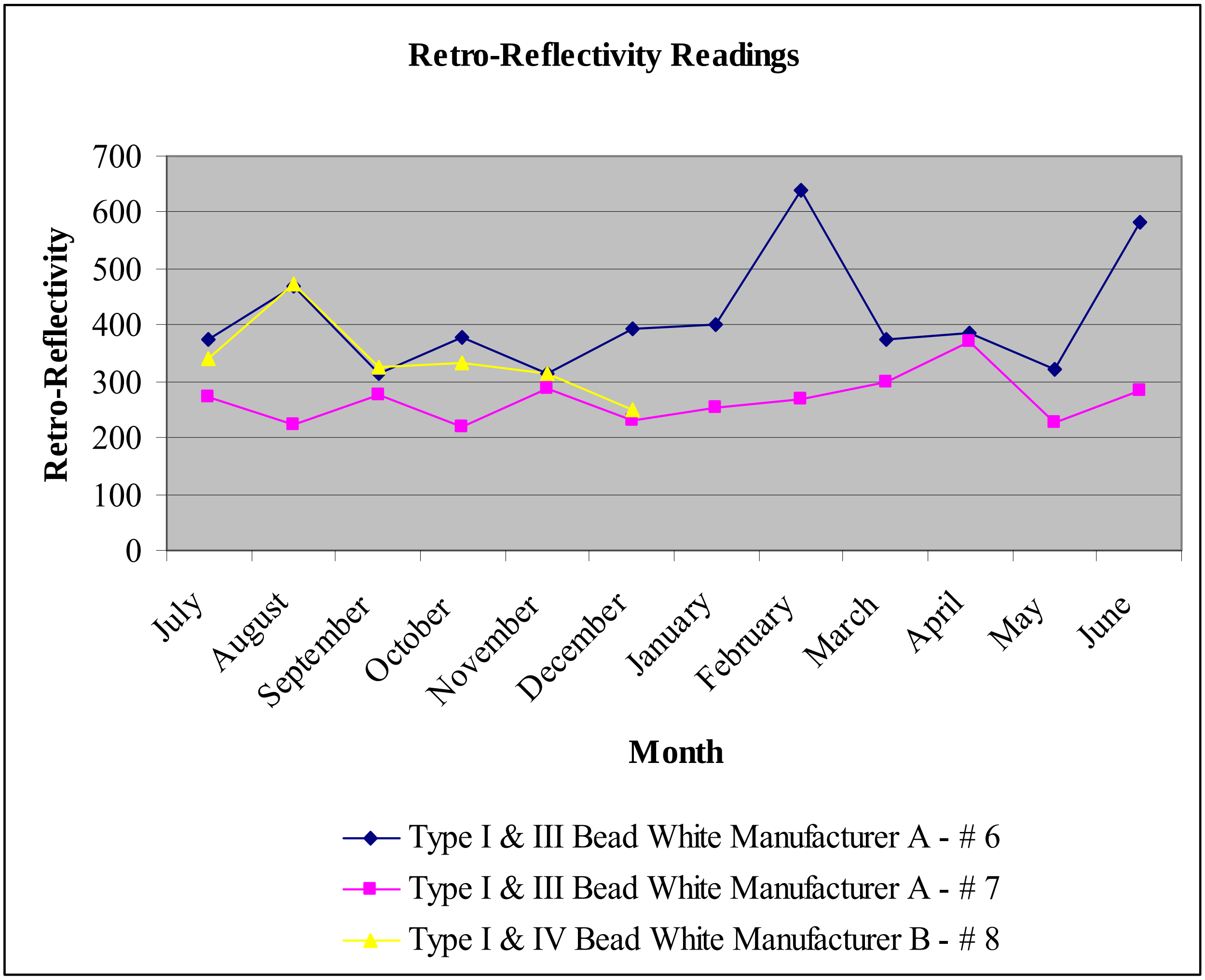
The data in this appendix is retro-reflective and color readings for red, white, and yellow thermoplastic marking material. The following acronyms are used in figures A-1 through A-51.

AC	Advisory Circular
ACY	Atlantic City International Airport
CL	Centerline
DOT	Department of Transportation
DFW	Dallas Fort Worth International Airport
EWR	Newark Liberty International Airport
FAA	Federal Aviation Administration
FOD	Foreign object debris
HMA	Hot-mix asphalt
ICAO	International Civil Aviation Organization
IOR	Index of refraction
lx	Lux
mcd	Millicandela
PCC	Portland cement concrete
psi	Pounds per square inch



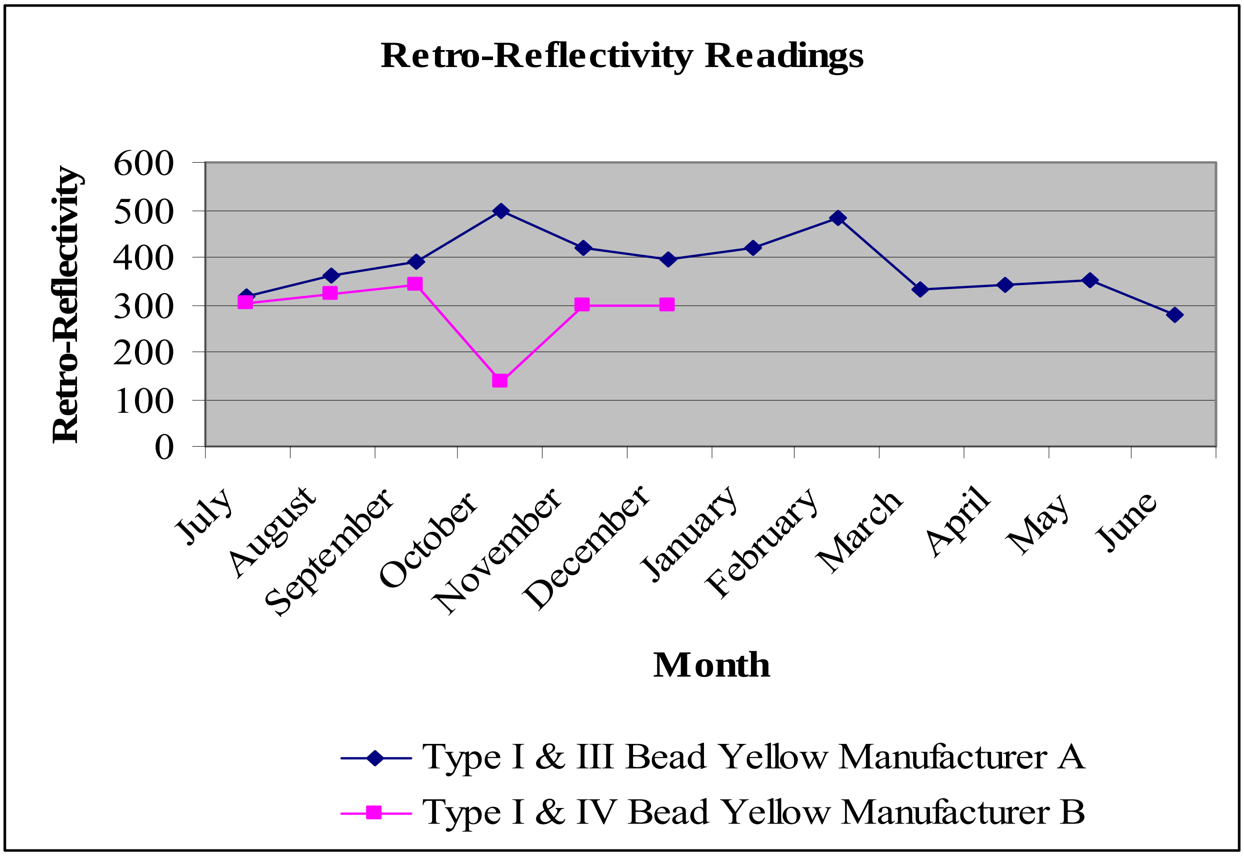
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-1. Graphic Display for Retro-Reflectivity Readings of Beads for Red Thermoplastic Marking Designations CCAPD6R-1, CCAPD7R-1, and CCAPD8R-2 on PCC at FAA William J. Hughes Technical Center



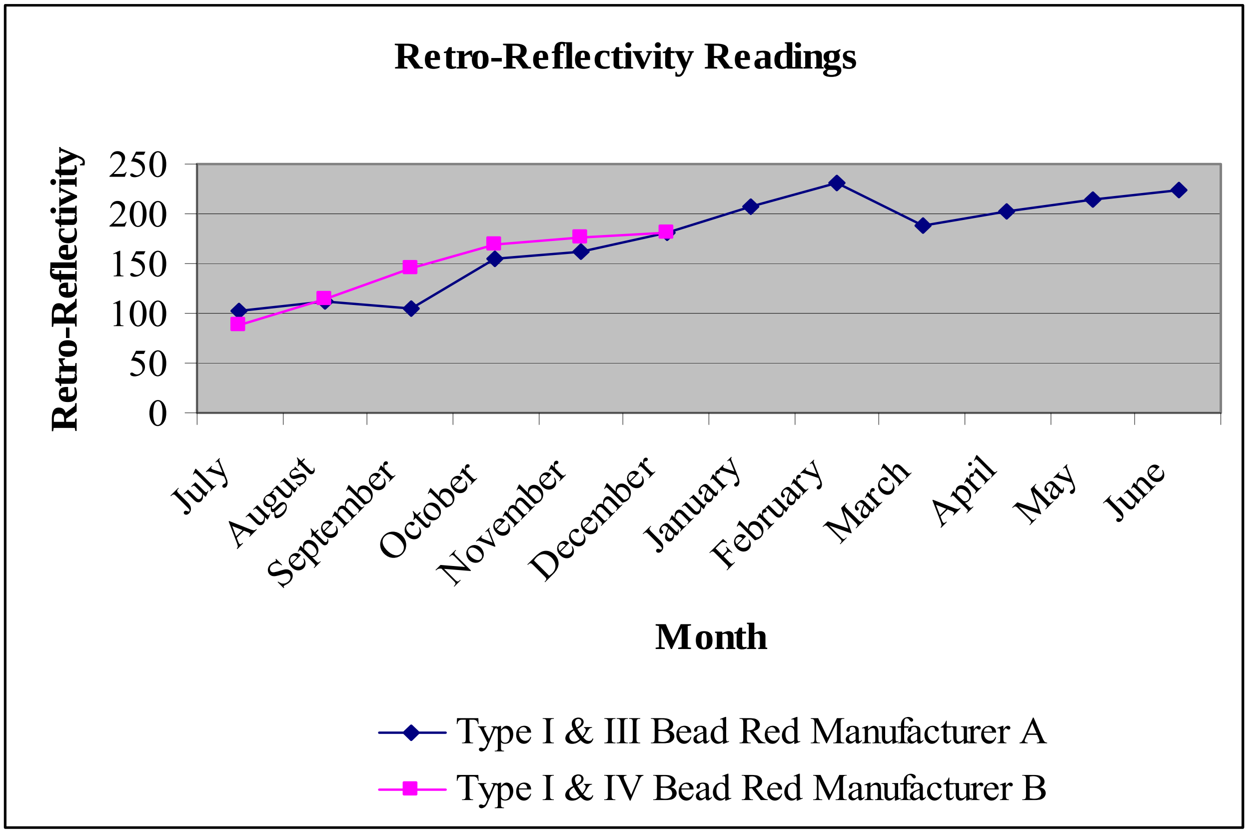
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-2. Graphic Display for Retro-Reflectivity Readings of Beads for White Thermoplastic Marking Designations CCAPD6W-1, CCAPD7W-1, and CCAPD8W-2 on PCC at FAA William J. Hughes Technical Center



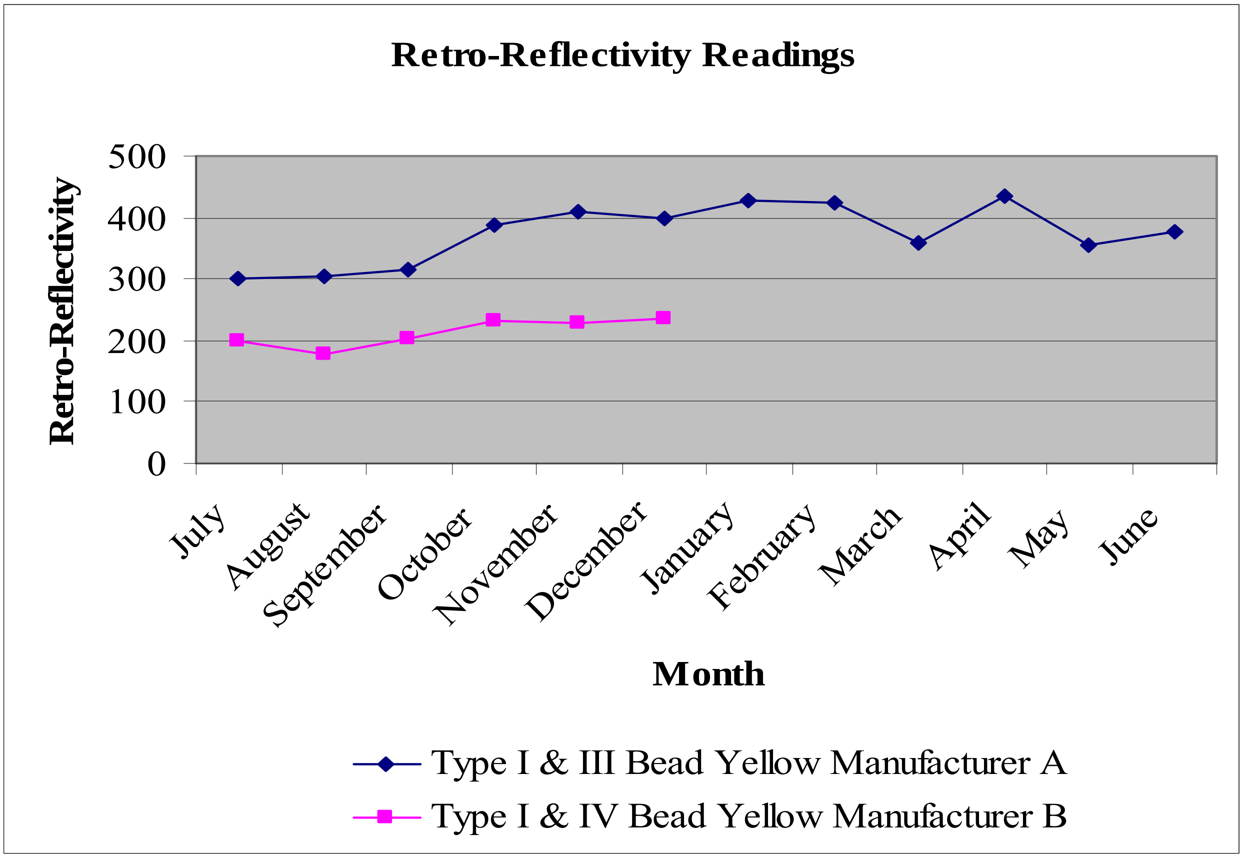
Note: All measurements in millicandela per square meter per lux ($mcd/m^2/lx$).

Figure A-3. Graphic Display for Retro-Reflectivity Readings of Beads for Yellow Thermoplastic Marking Designations CCMNY-1 and CCMNY-2 on PCC at FAA William J. Hughes Technical Center



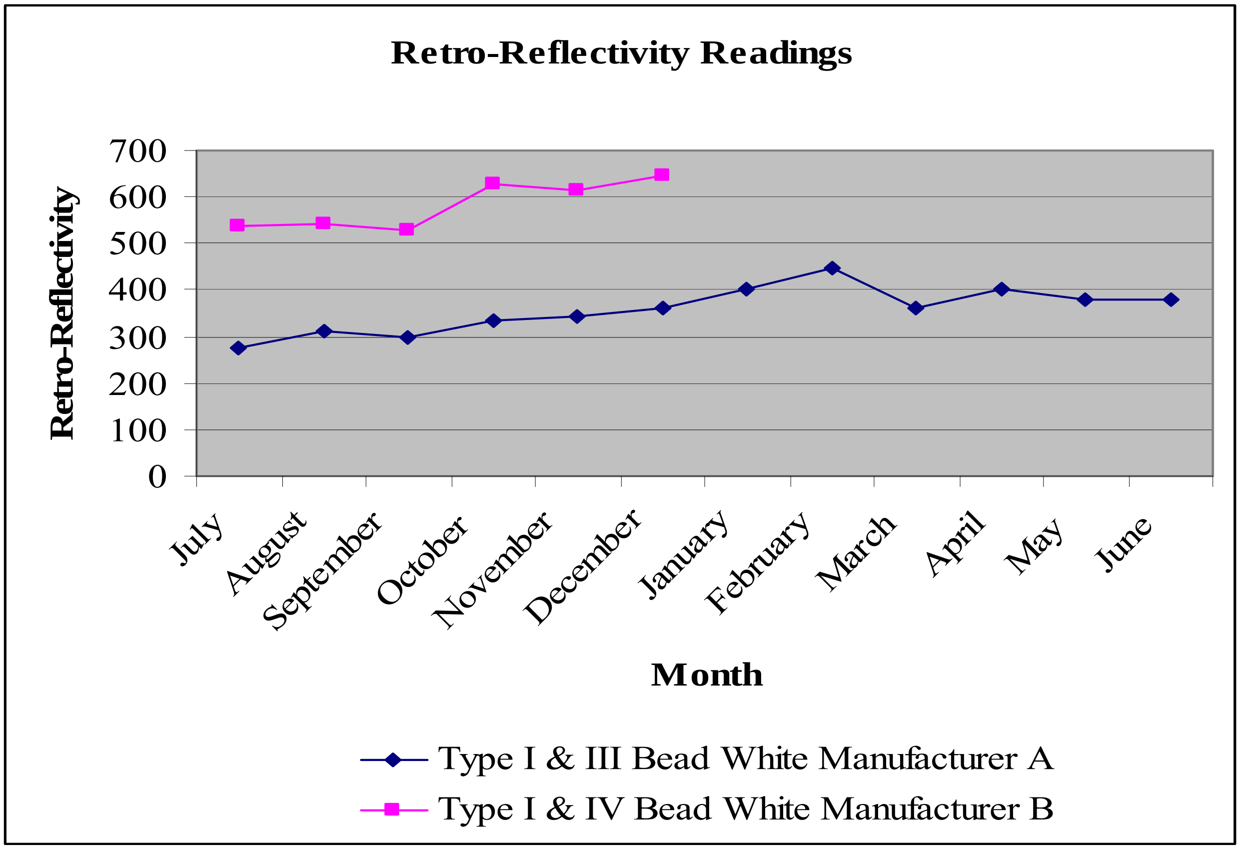
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-4. Graphic Display for Retro-Reflectivity Readings of Beads for Red Thermoplastic Marking Designations CCRS-1 and CCRS-2 on PCC at FAA William J. Hughes Technical Center



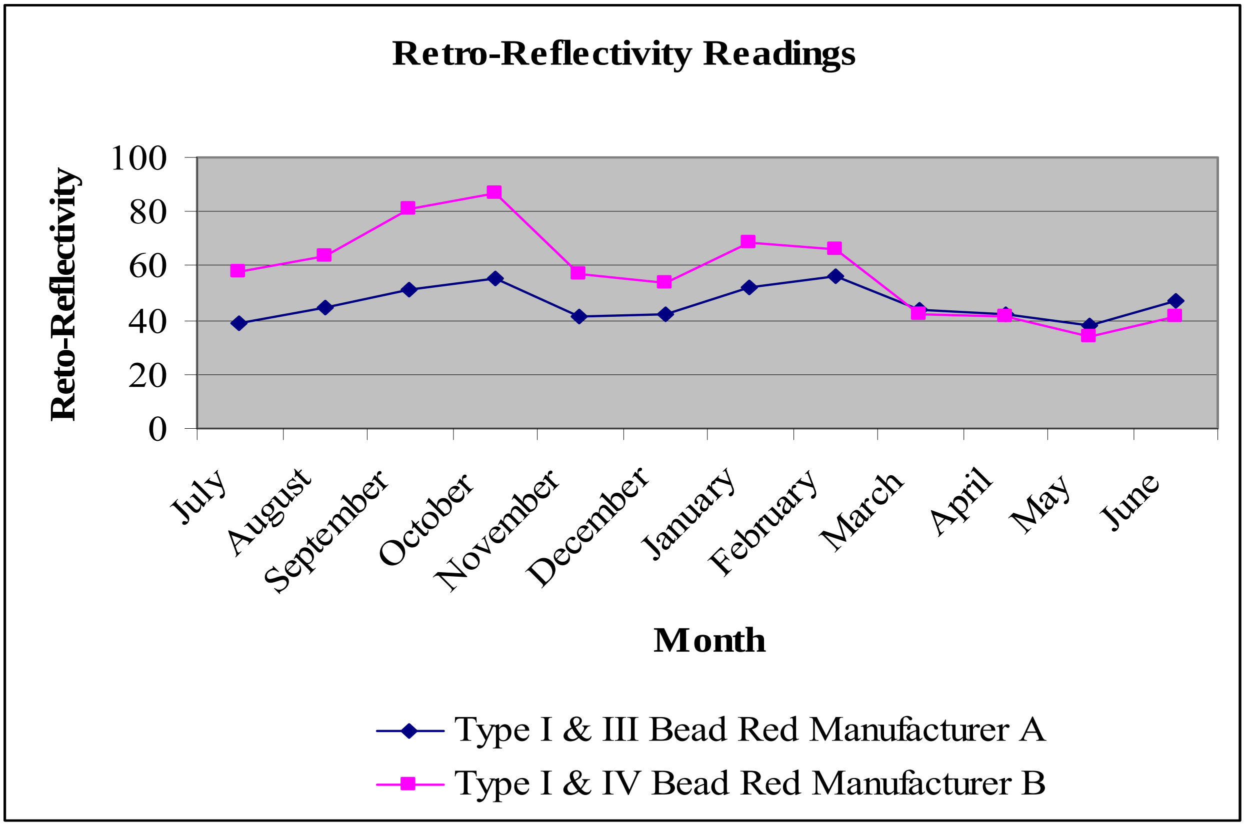
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-5. Graphic Display for Retro-Reflectivity Readings of Beads for Yellow Thermoplastic Marking Designations CCYS-1 and CCYS-2 on PCC AT FAA William J. Hughes Technical Center



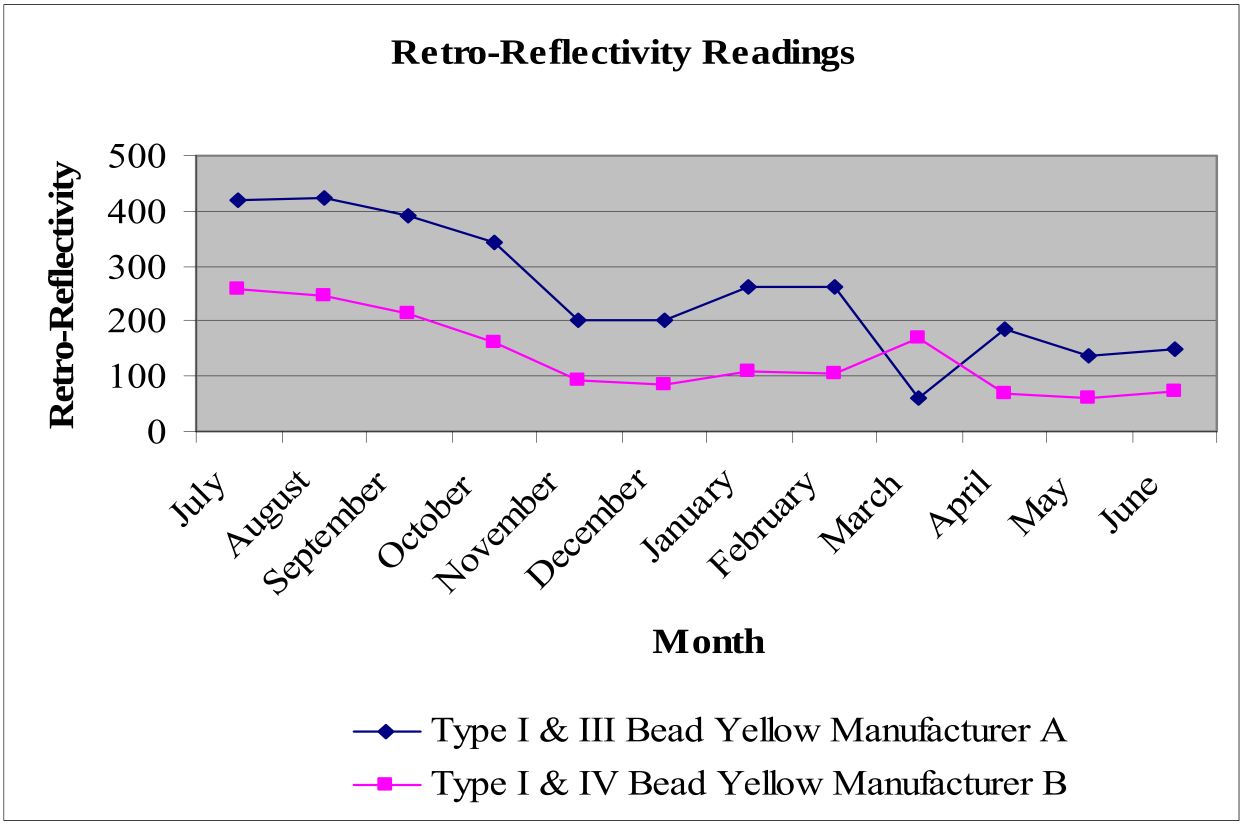
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-6. Graphic Display for Retro-Reflectivity Readings of Beads for White Thermoplastic Marking Designations CCWS-1 and CCWS-2 on PCC at FAA William J. Hughes Technical Center



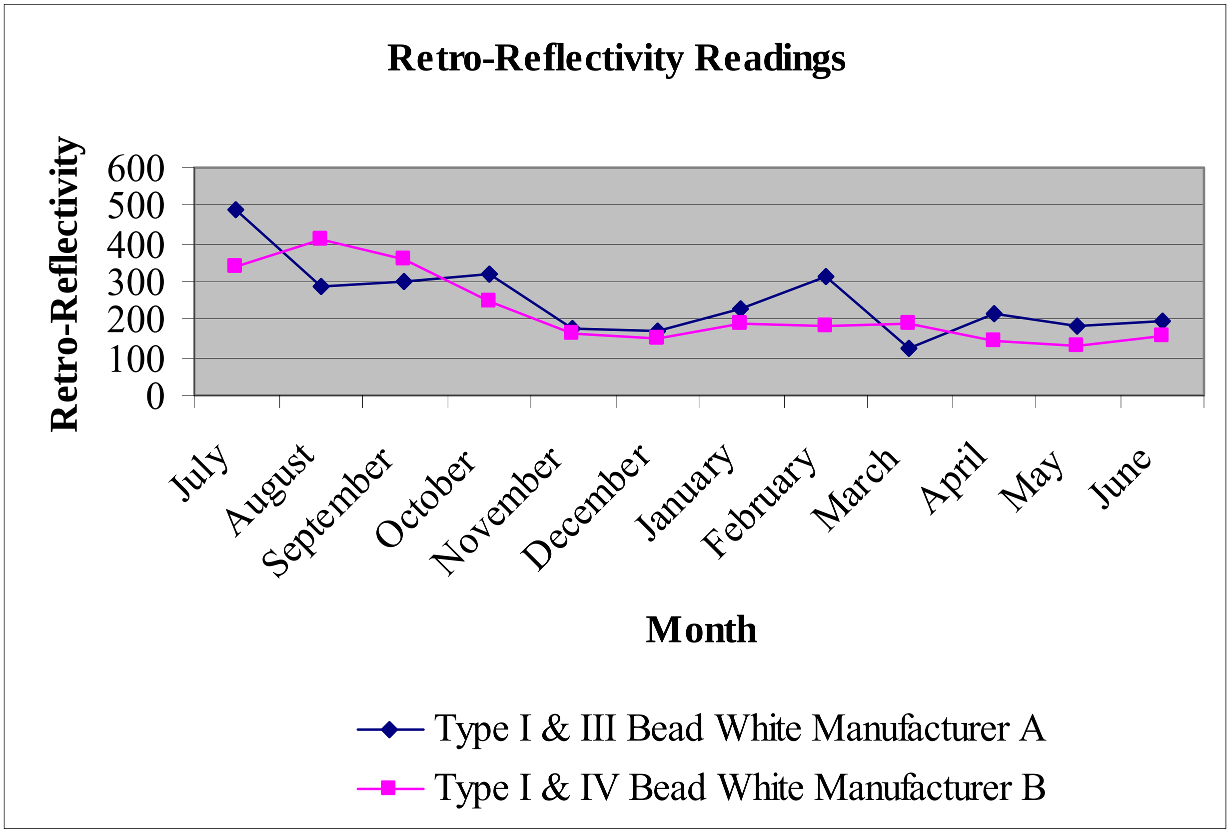
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-7. Graphic Display for Retro-Reflectivity Readings of Beads for Red Thermoplastic Marking Designations HMRS-1 and HMRS-2 on HMA at FAA William J. Hughes Technical Center



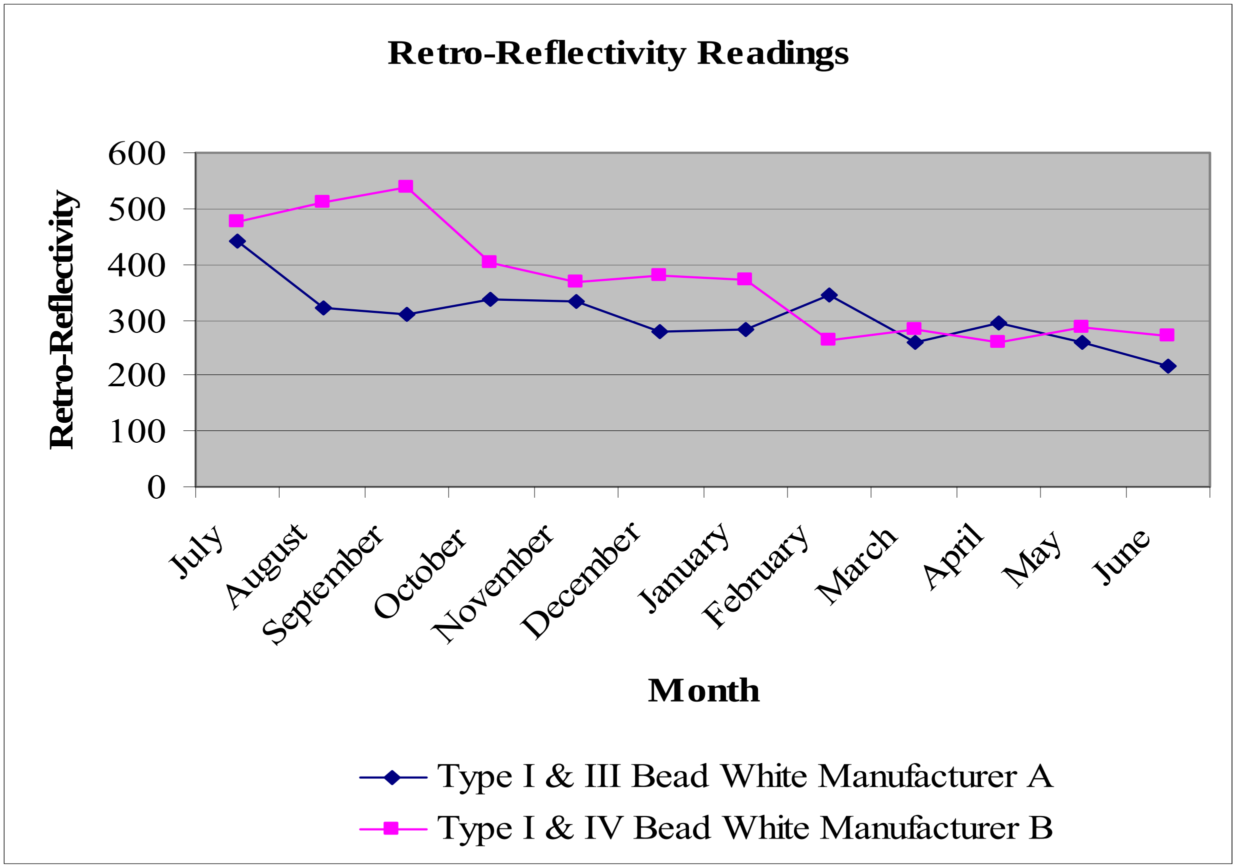
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-8. Graphic Display for Retro-Reflectivity Readings of Beads for Yellow Thermoplastic Marking Designations HMYS-1 and HMYS-2 on HMA at FAA William J. Hughes Technical Center



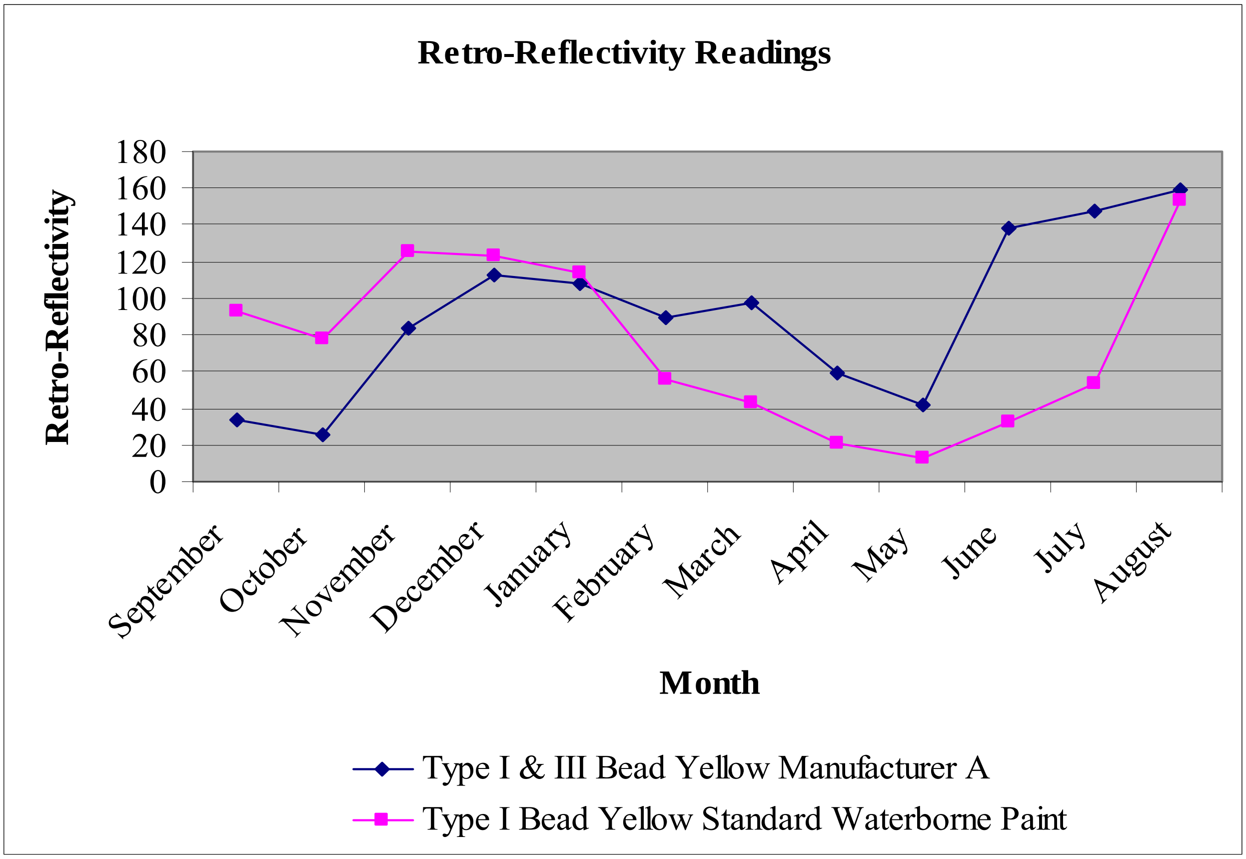
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-9. Graphic Display for Retro-Reflectivity Readings of Beads for White Thermoplastic Marking Designations HMWS-1 and HMWS-2 on HMA at FAA William J. Hughes Technical Center



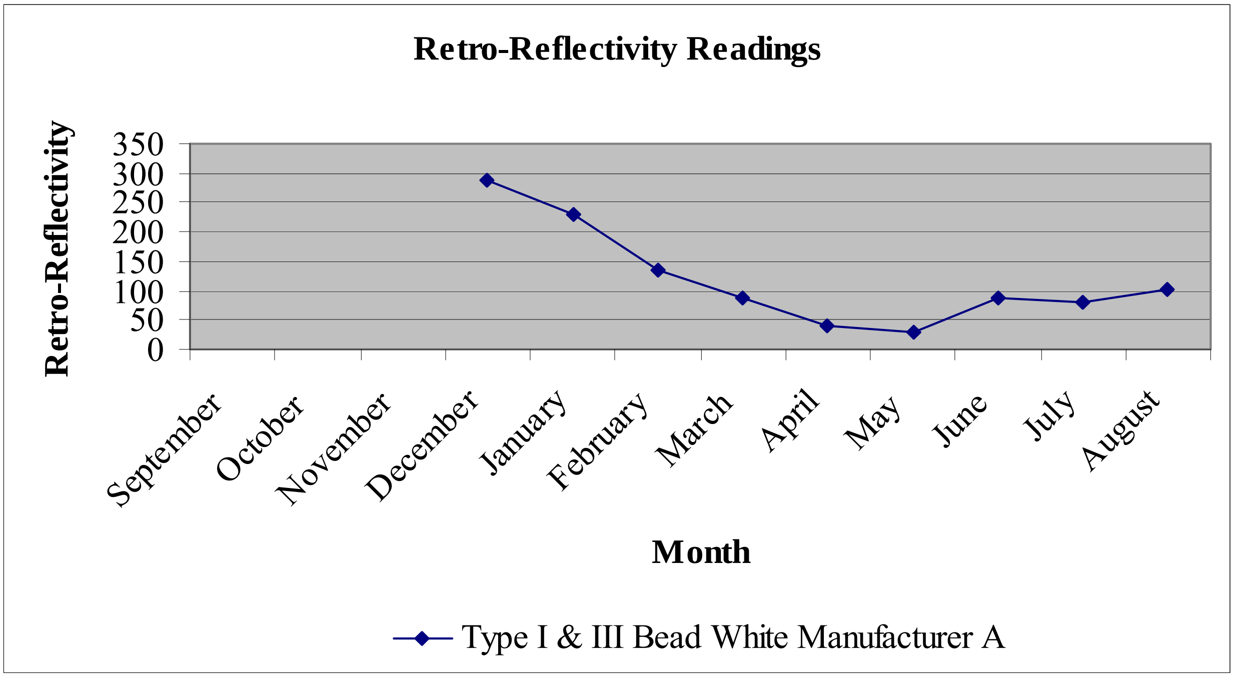
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-10. Graphic Display for Retro-Reflectivity Readings of Beads for White Thermoplastic Marking Designations HMWSL-1 and HMWSL-2 on HMA at FAA William J. Hughes Technical Center



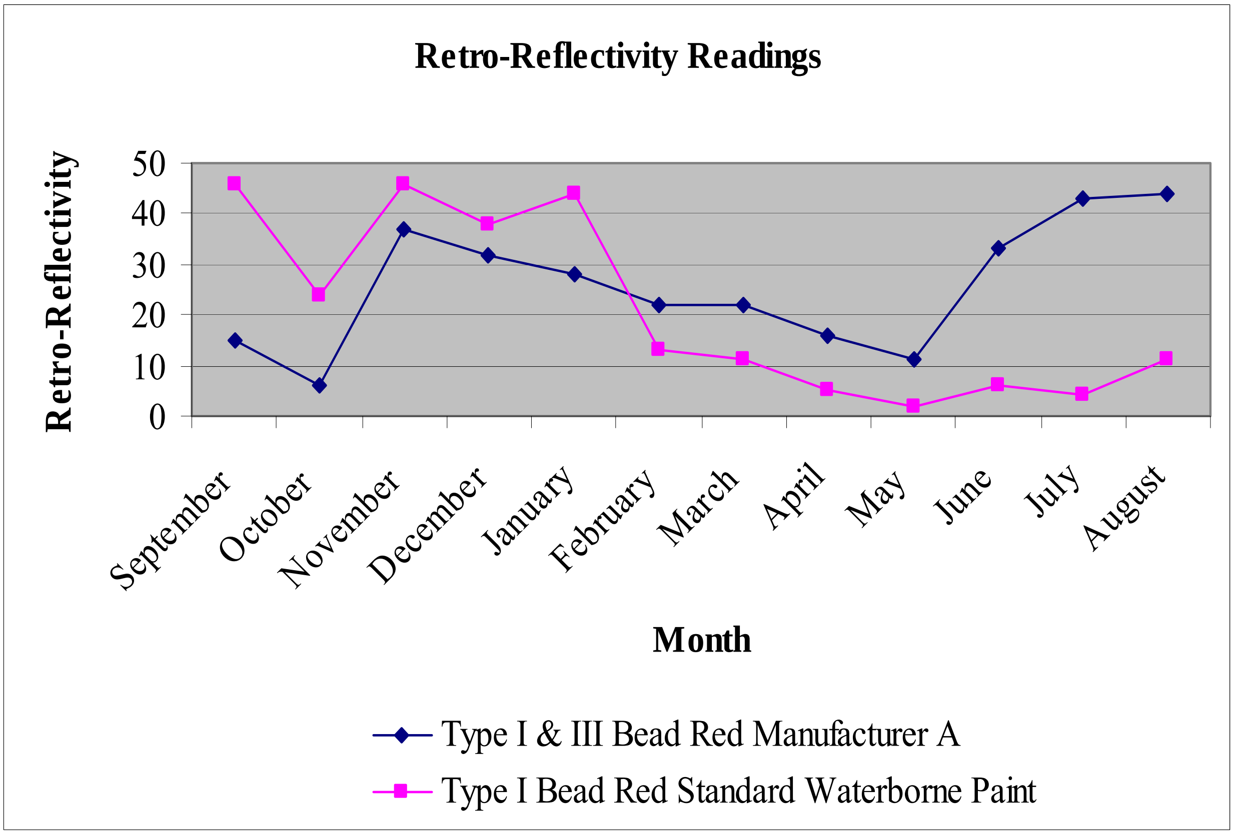
Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-11. Graphic Display for Retro-Reflectivity Readings of Beads for Marking Designation CCRHPS-Yellow and CCRHP-Yellow Paint at EWR



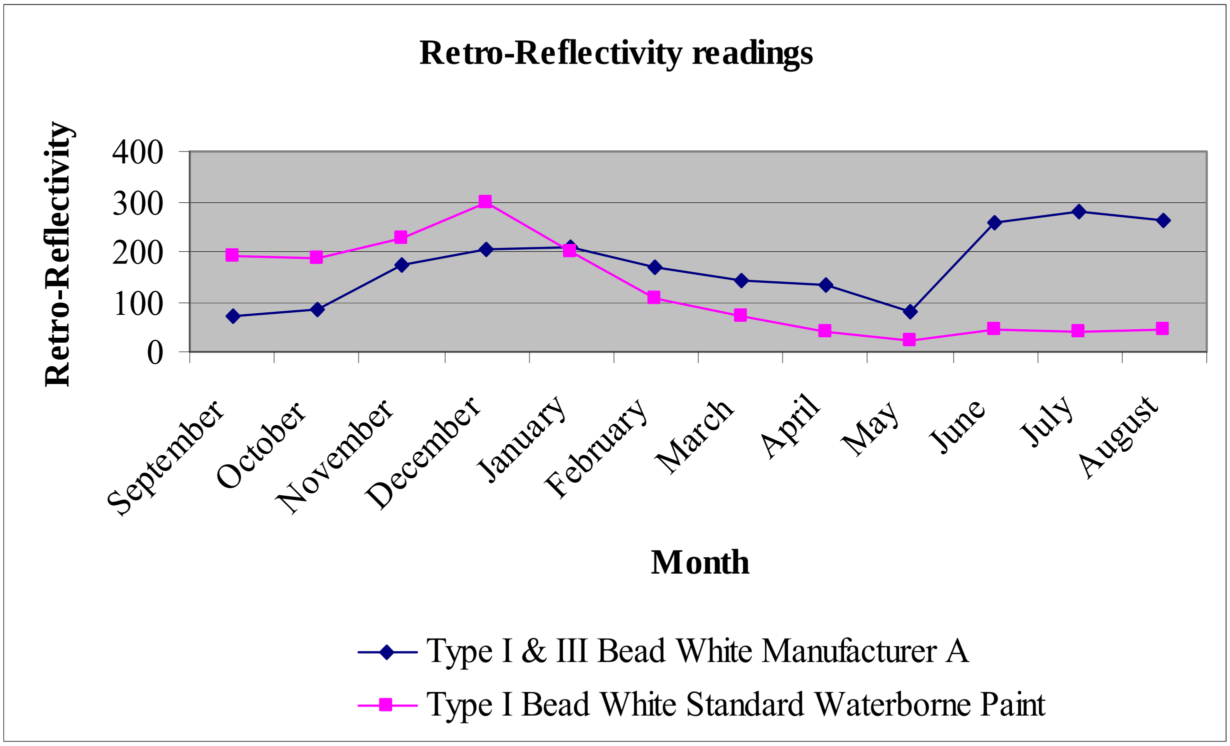
Note: All measurements in millicandela per square meter per lux ($mcd/m^2/lx$).

Figure A-12. Graphic Display for Retro-Reflectivity Readings of Beads for Marking Designation CCRHPD-Yellow at EWR



Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-13. Graphic Display for Retro-Reflectivity Readings of Beads for Marking Designation CCRID-Red and CCRID-Red Paint at EWR



Note: All measurements in millicandela per square meter per lux (mcd/m^2/lx).

Figure A-14. Graphic Display for Retro-Reflectivity Readings of Beads for Marking Designation CCRID-White and CCRID-White Paint at EWR

The x and y coordinates for the chromaticity charts shown in figures A-15 through A-51 have been determined with the following standard conditions:

- the angle of illumination is 45˚,
- the direction of view is perpendicular to the surface, and
- the illuminant is the CIE standard illuminant, D_{65}.

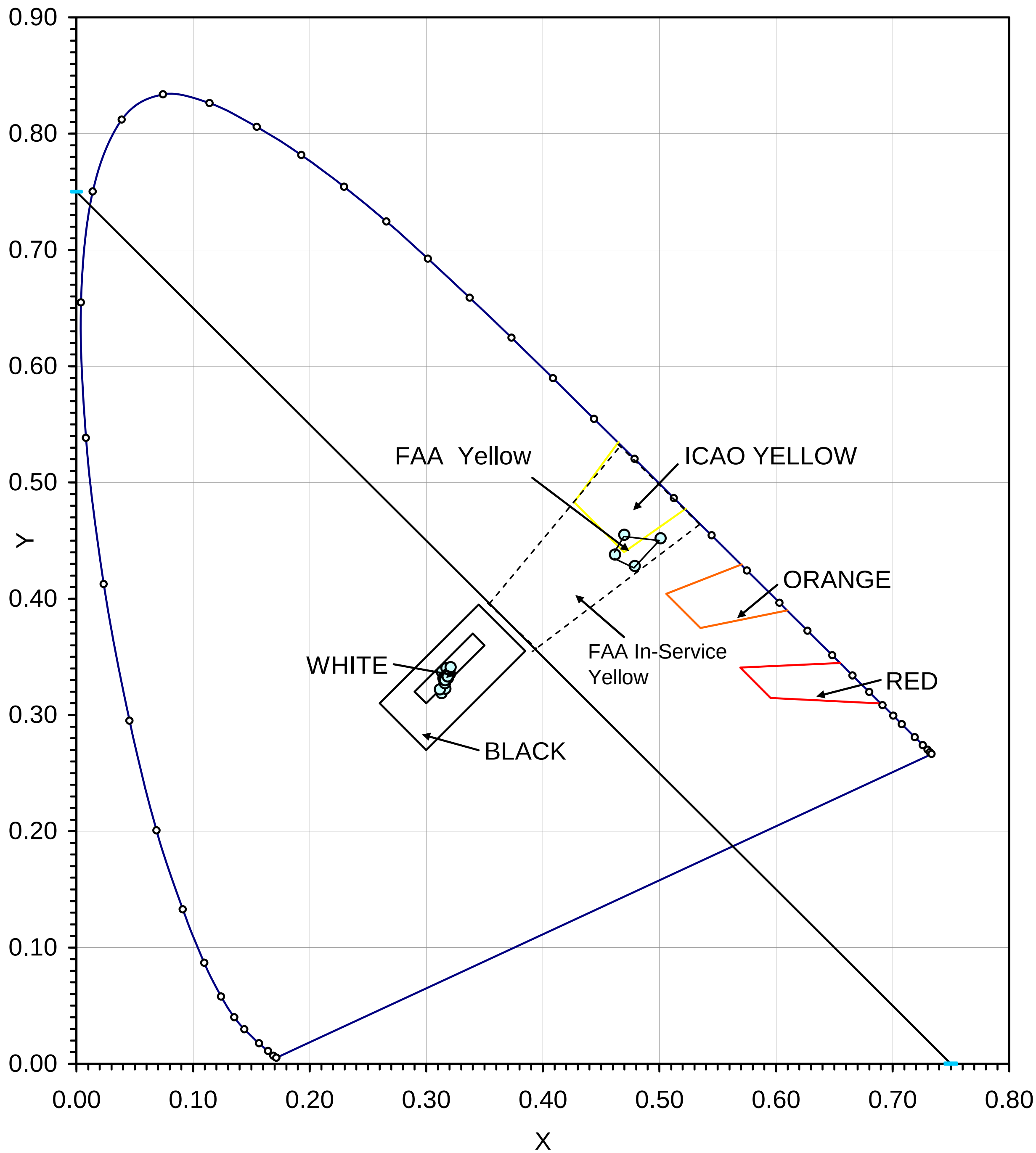


Figure A-15. Chromaticity Readings of CCMNB-1, Movement/Nonmovement Line (Black) at FAA William J. Hughes Technical Center

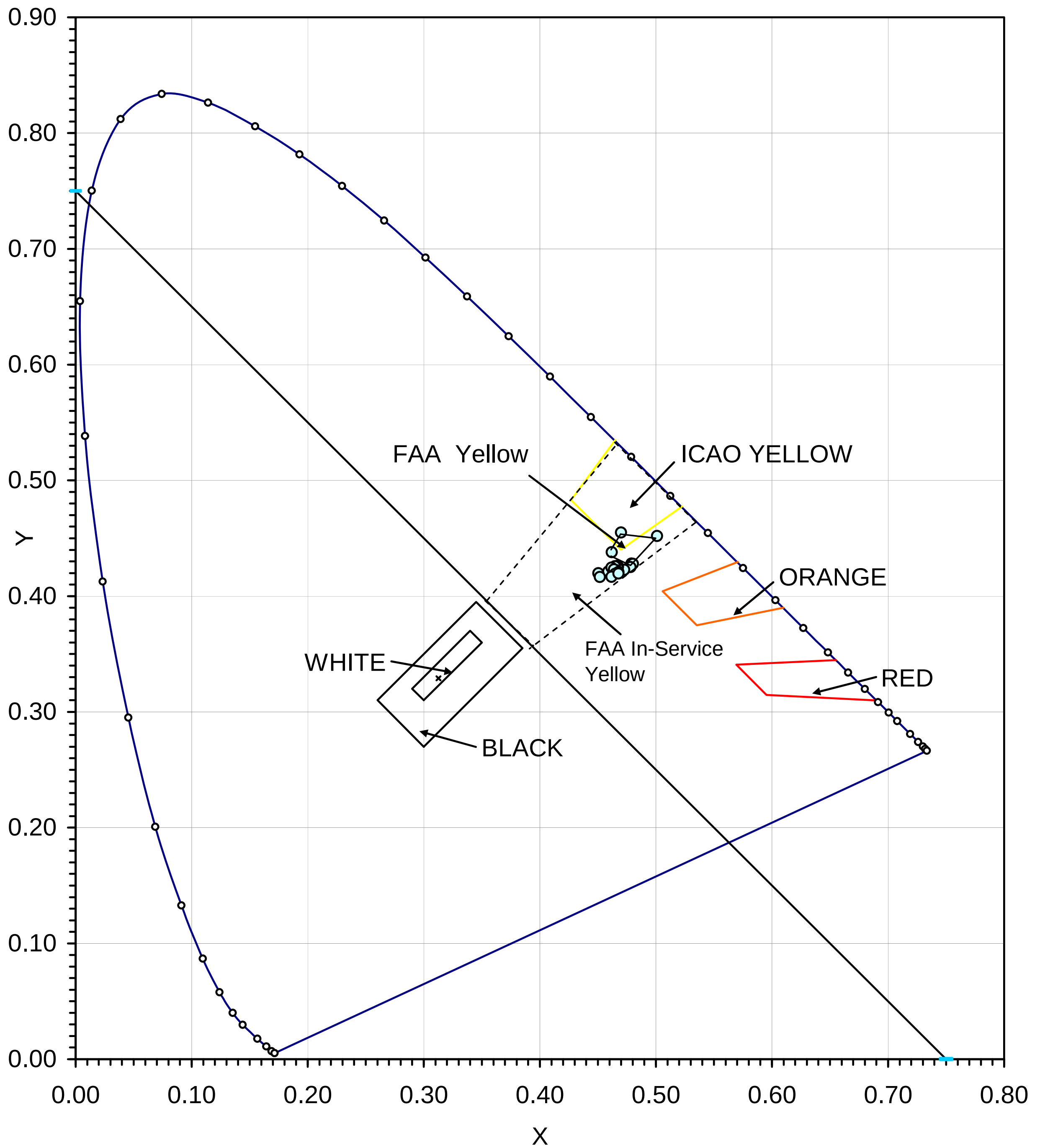


Figure A-16. Chromaticity Readings of CCMNY-1, Movement/Nonmovement Line (Yellow) at FAA William J. Hughes Technical Center

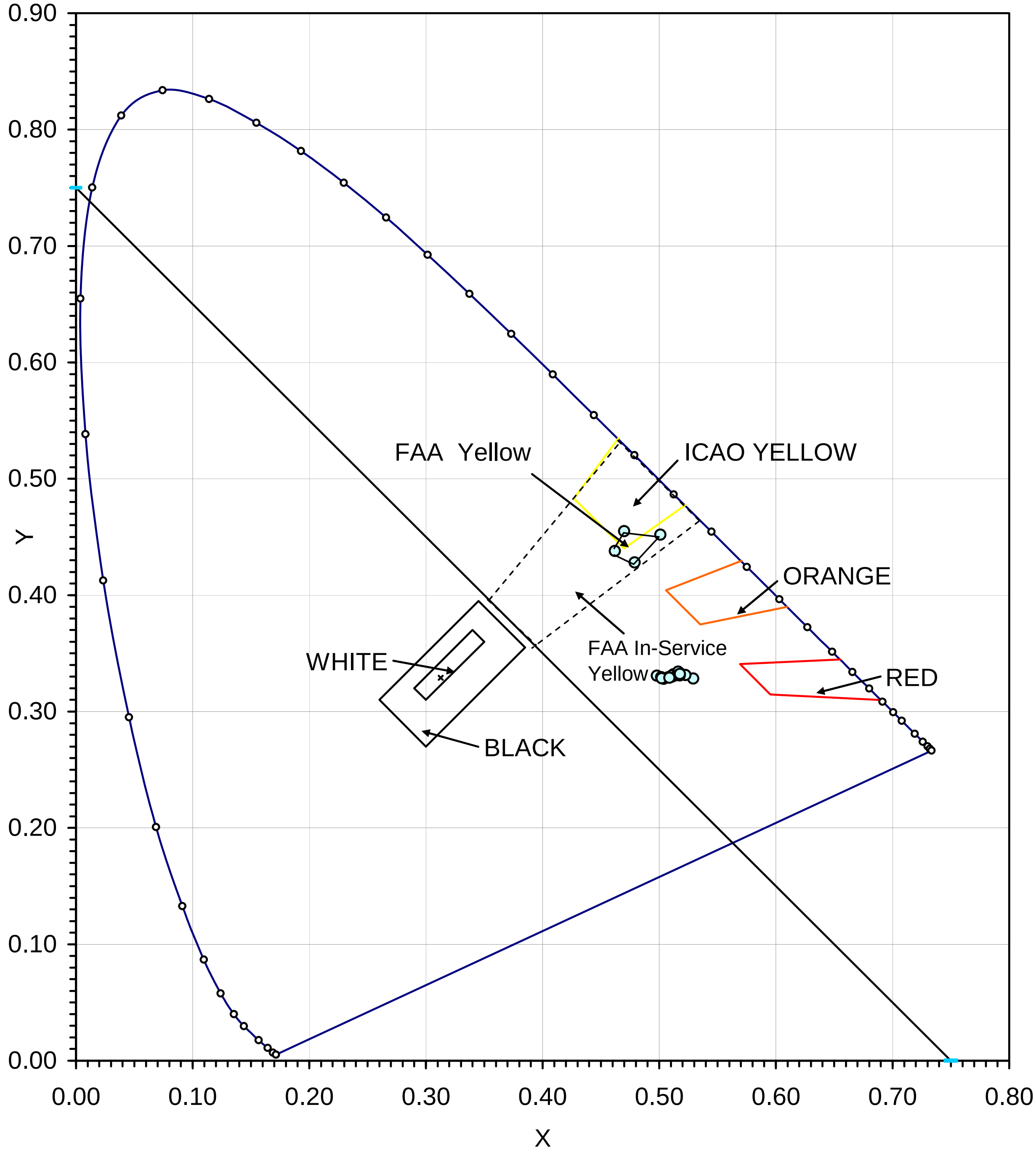


Figure A-17. Chromaticity Readings of CCAPD6R-1, Aircraft Parking Designator #6 (Red) at FAA William J. Hughes Technical Center

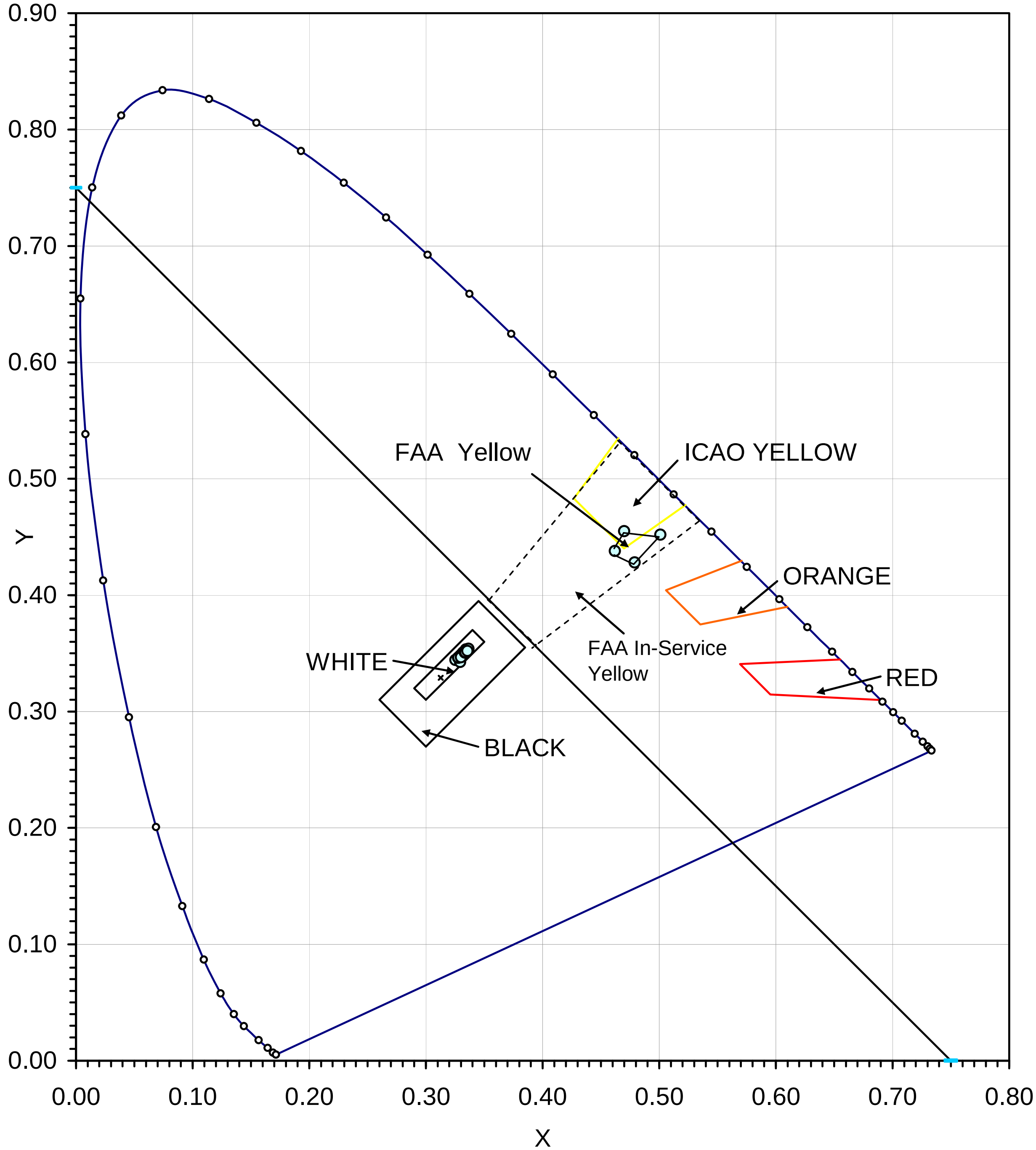


Figure A-18. Chromaticity Readings of CCAPD6W-1, Aircraft Parking Designator #6 (White) at FAA William J. Hughes Technical Center

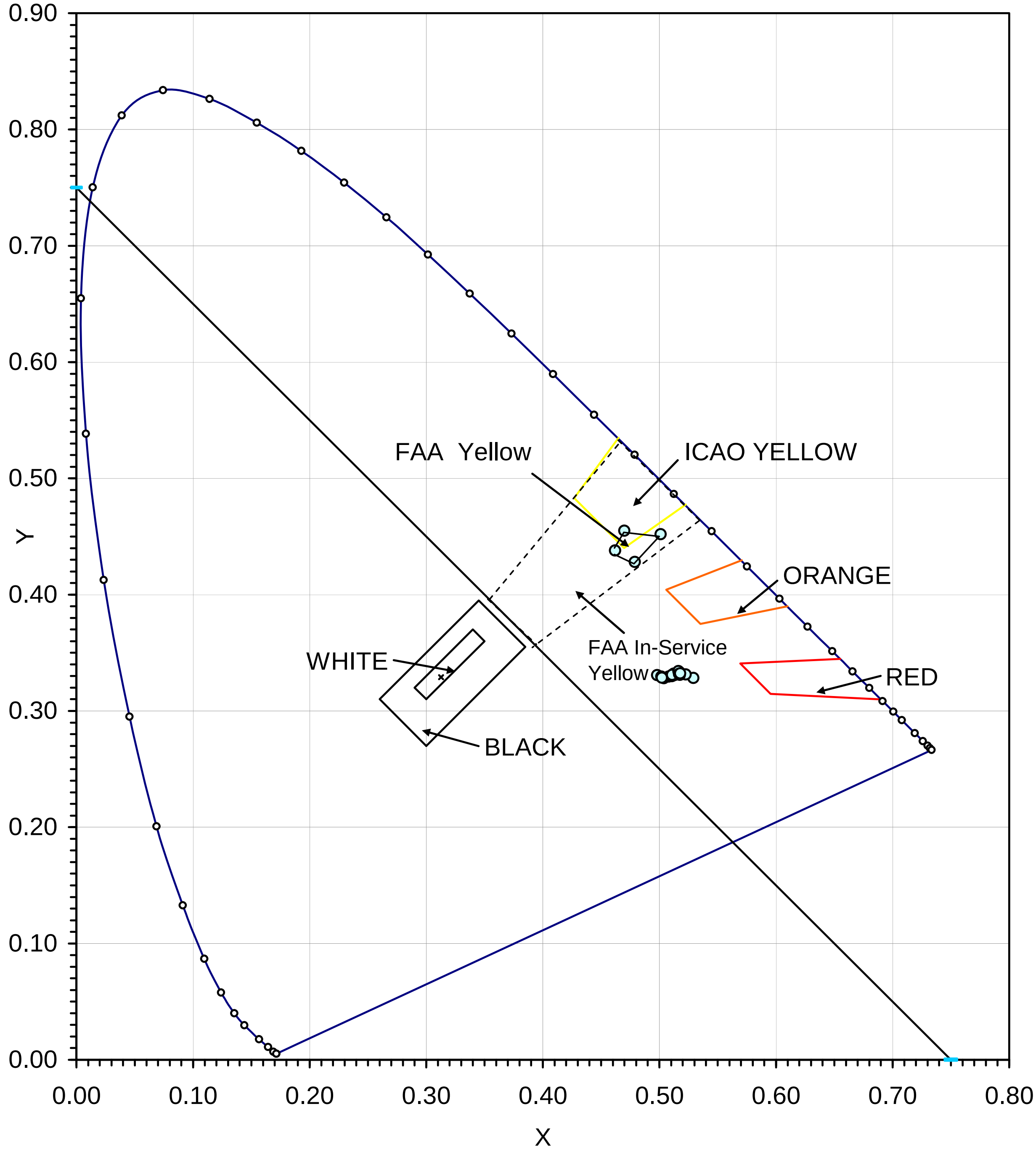


Figure A-19. Chromaticity Readings of CCAPD7R-1, Aircraft Parking Designator #7 (Red) at FAA William J. Hughes Technical Center

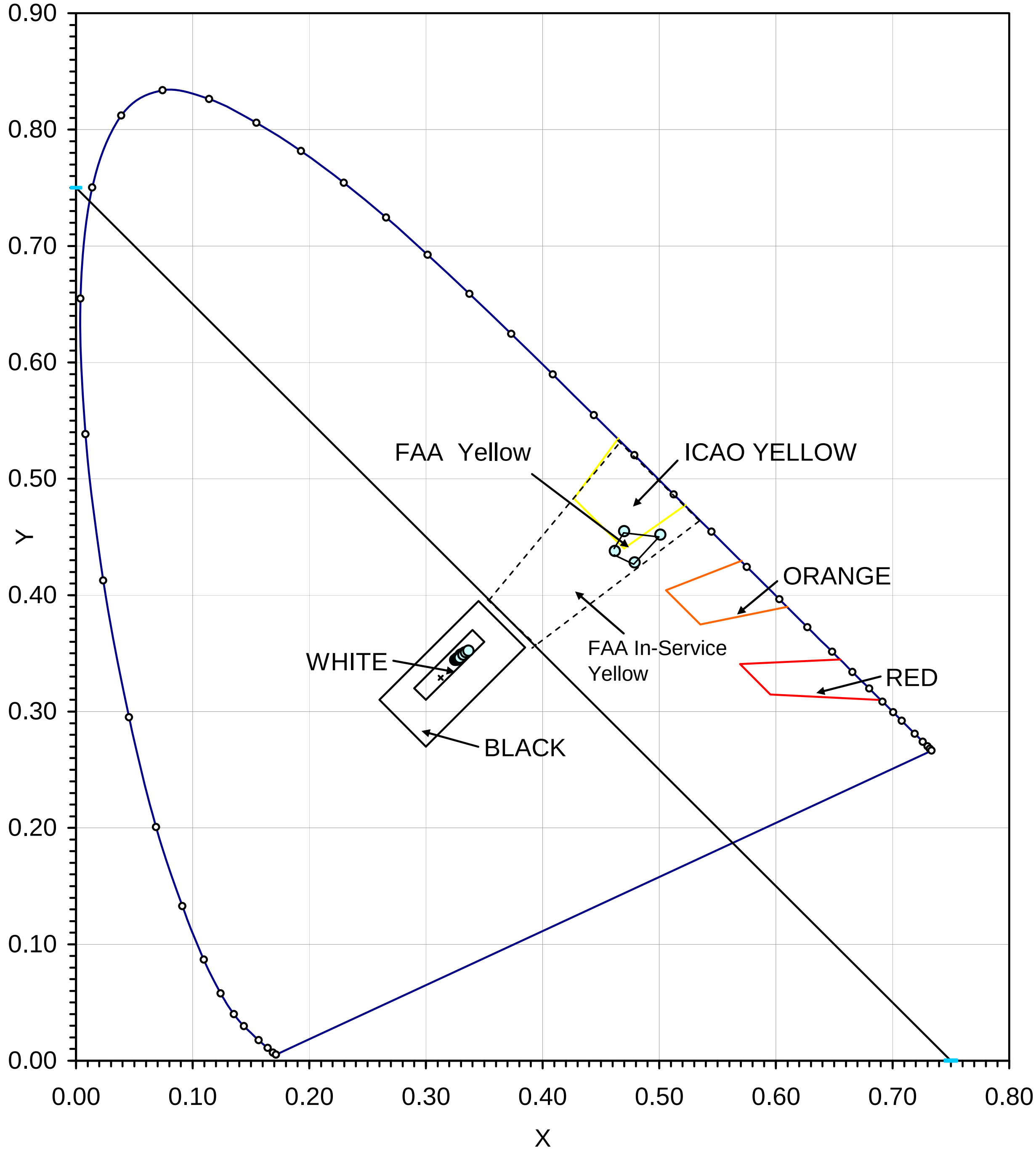


Figure A-20. Chromaticity Readings of CCAPD7W-1, Aircraft Parking Designator #7 (White) at FAA William J. Hughes Technical Center

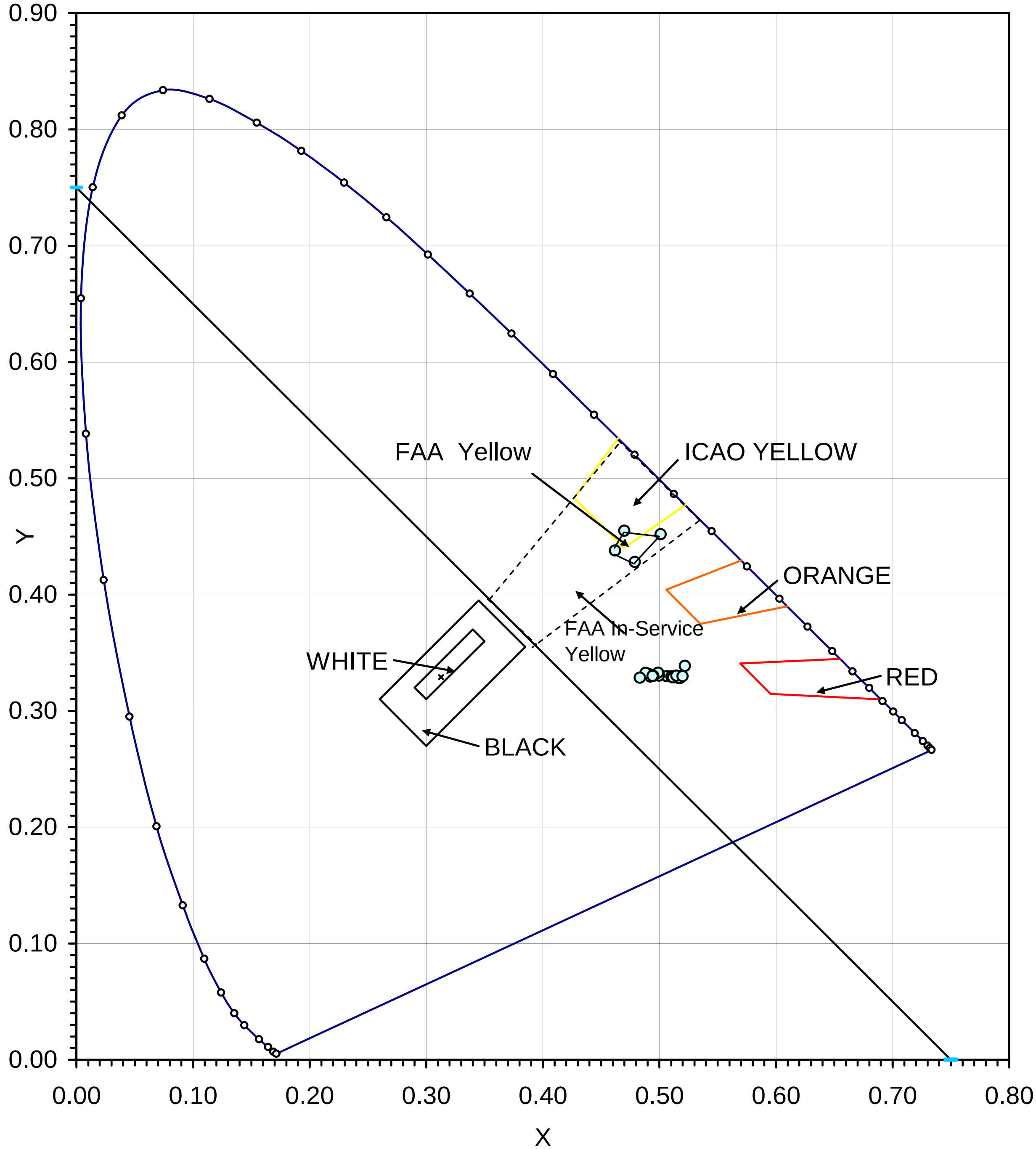


Figure A-21. Chromaticity Readings of CCRS-1, 3-Foot Stripe (Red) at FAA William J. Hughes Technical Center

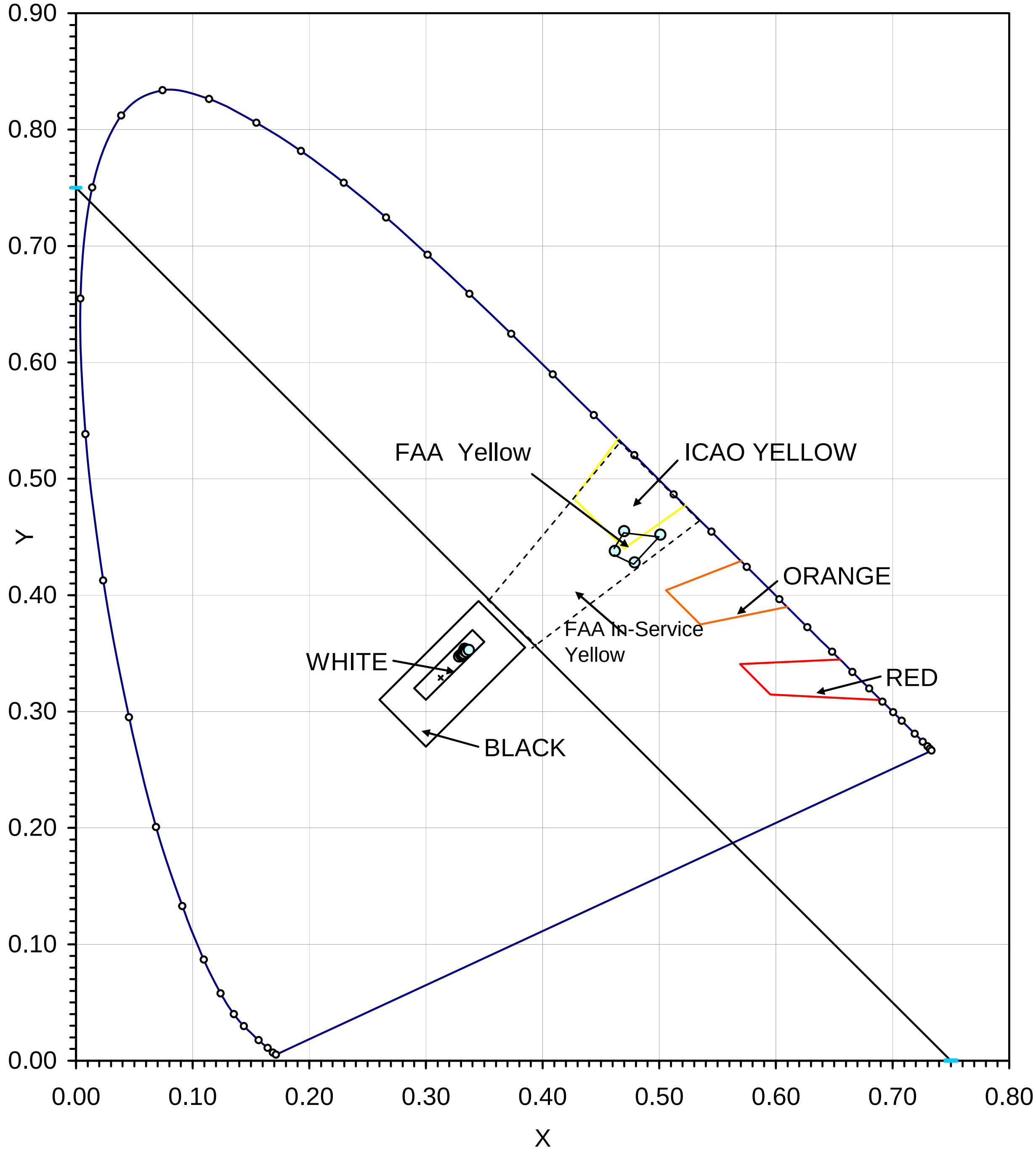


Figure A-22. Chromaticity Readings of CCWS-1, 3-Foot Stripe (White) at FAA William J. Hughes Technical Center

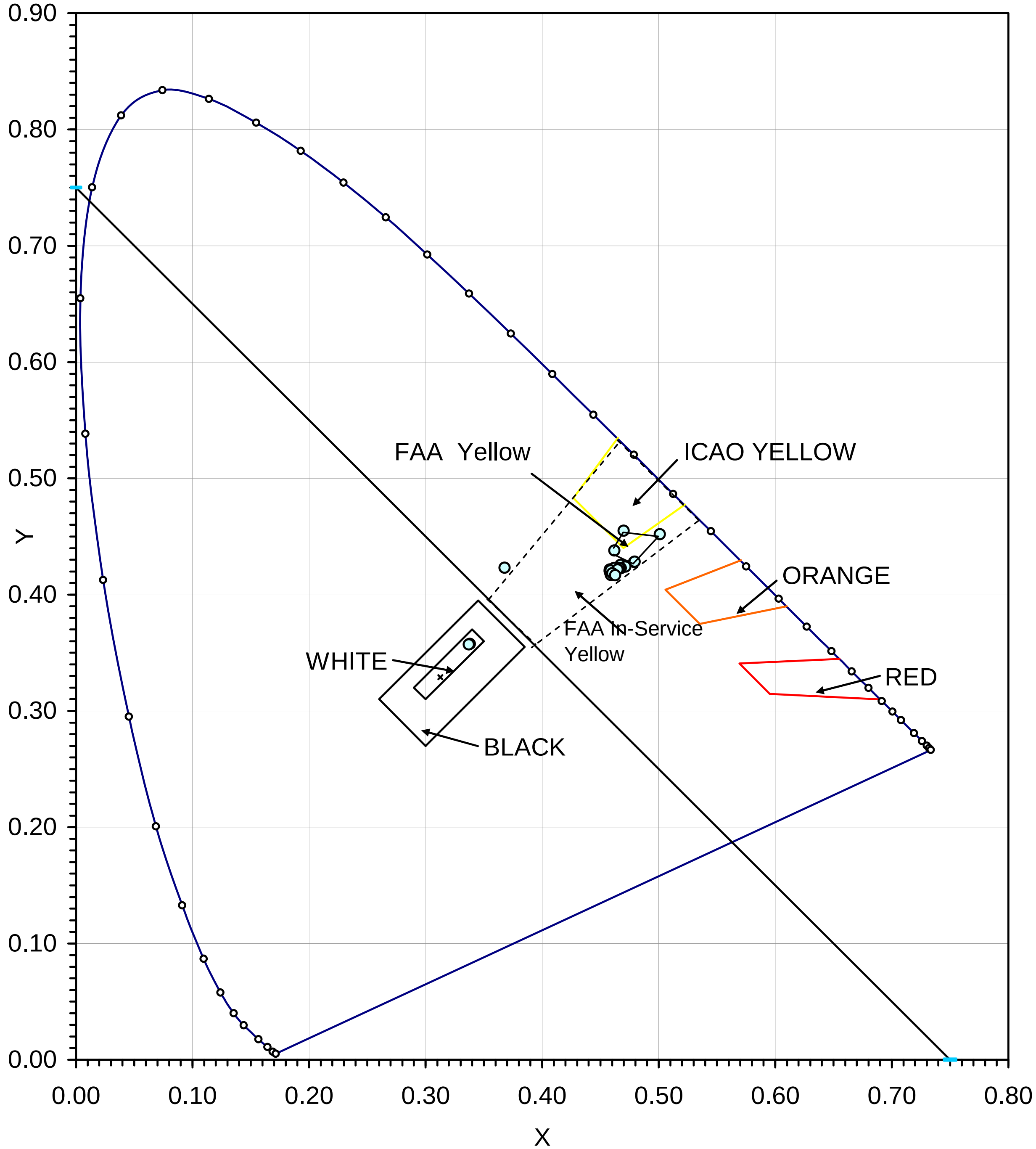


Figure A-23. Chromaticity Readings of CCYS-1, 3-Foot Stripe (Yellow) at FAA William J. Hughes Technical Center

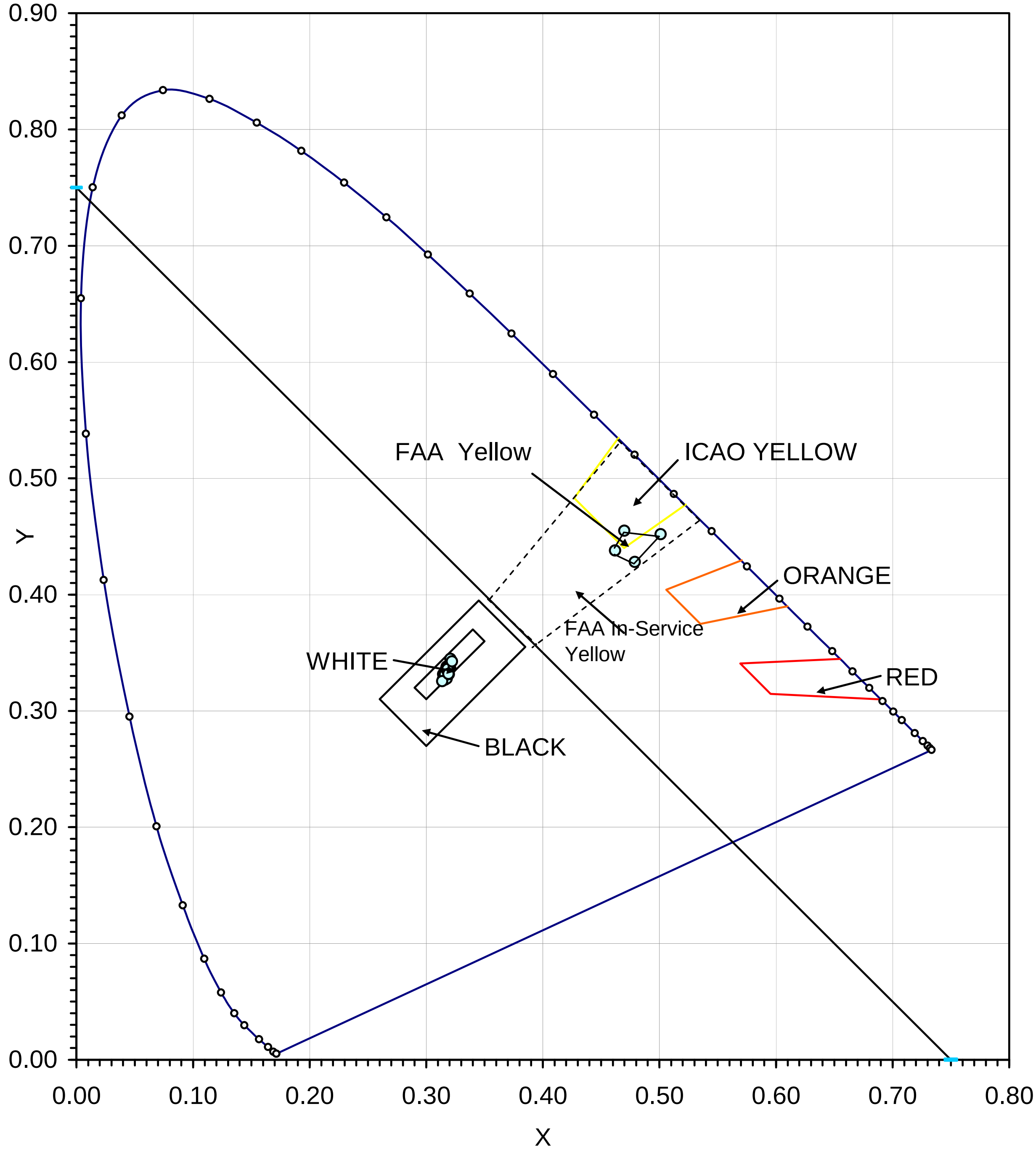


Figure A-24. Chromaticity Readings of CCBS-1, 3-Foot Stripe (Black) at FAA William J. Hughes Technical Center

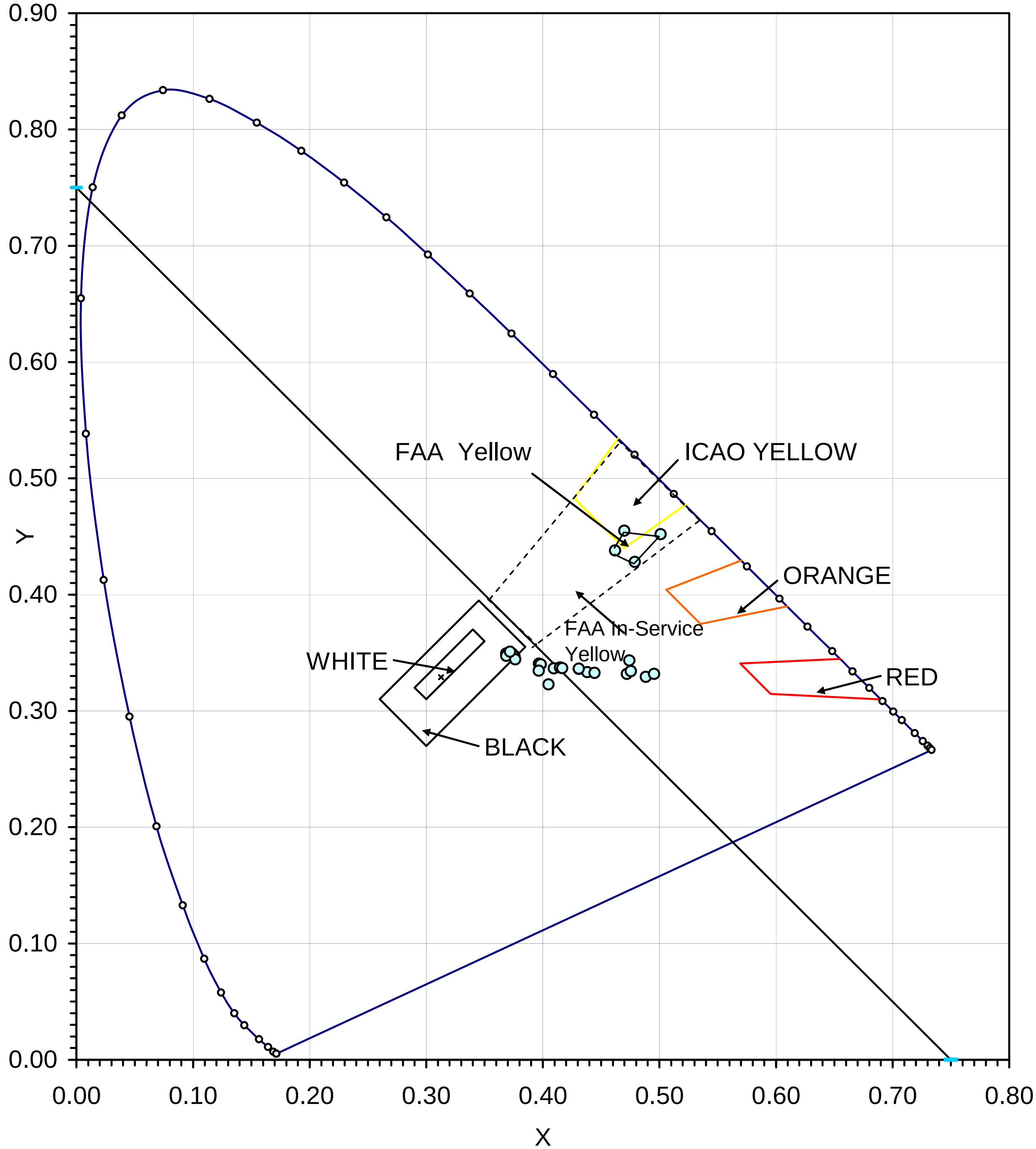


Figure A-25. Chromaticity Readings of HMRS-1, 3-Foot Stripe (Red) at FAA William J. Hughes Technical Center

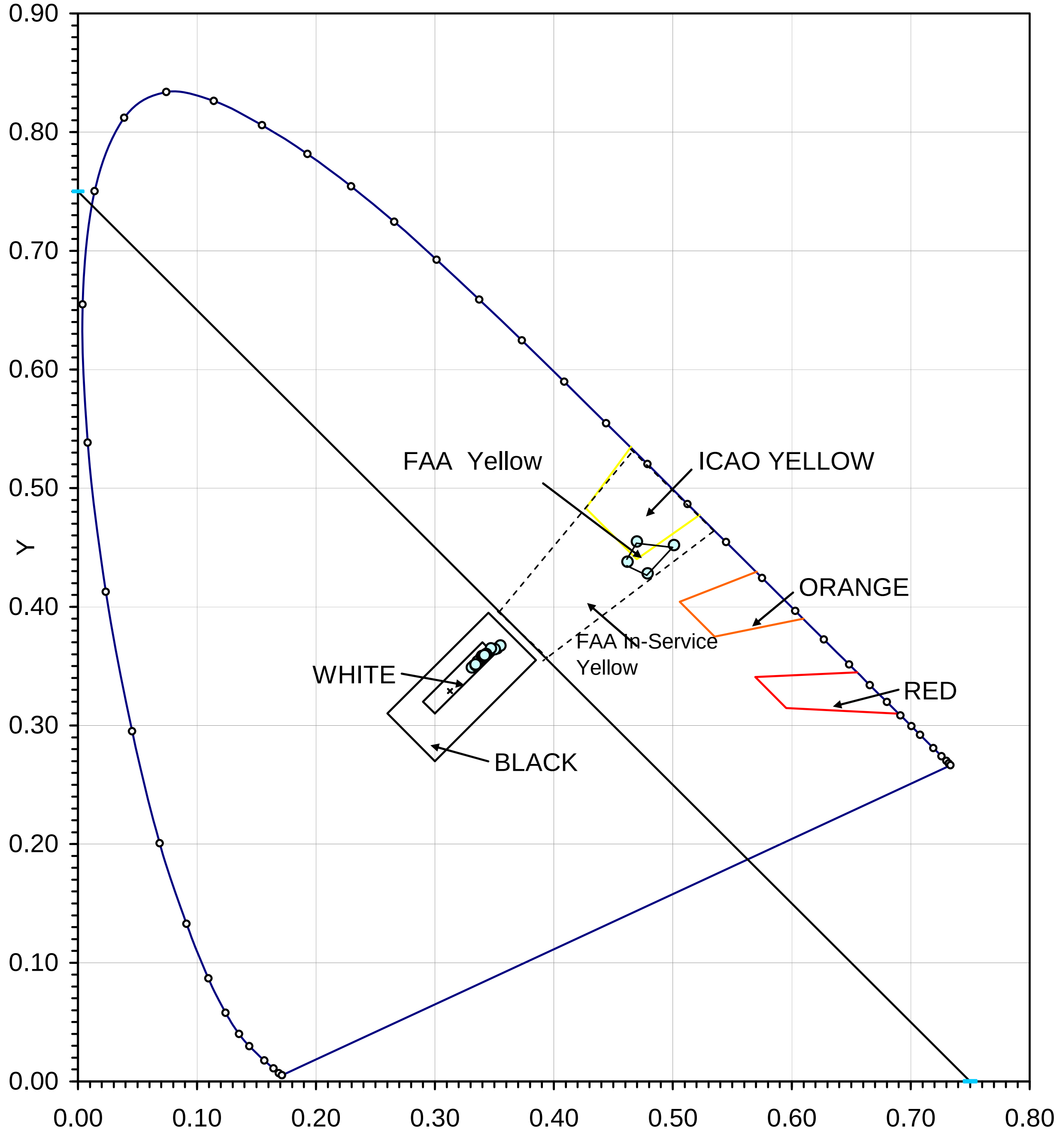


Figure A-26. Chromaticity Readings of HMWS-1, 3-Foot Stripe (White) at FAA William J. Hughes Technical Center

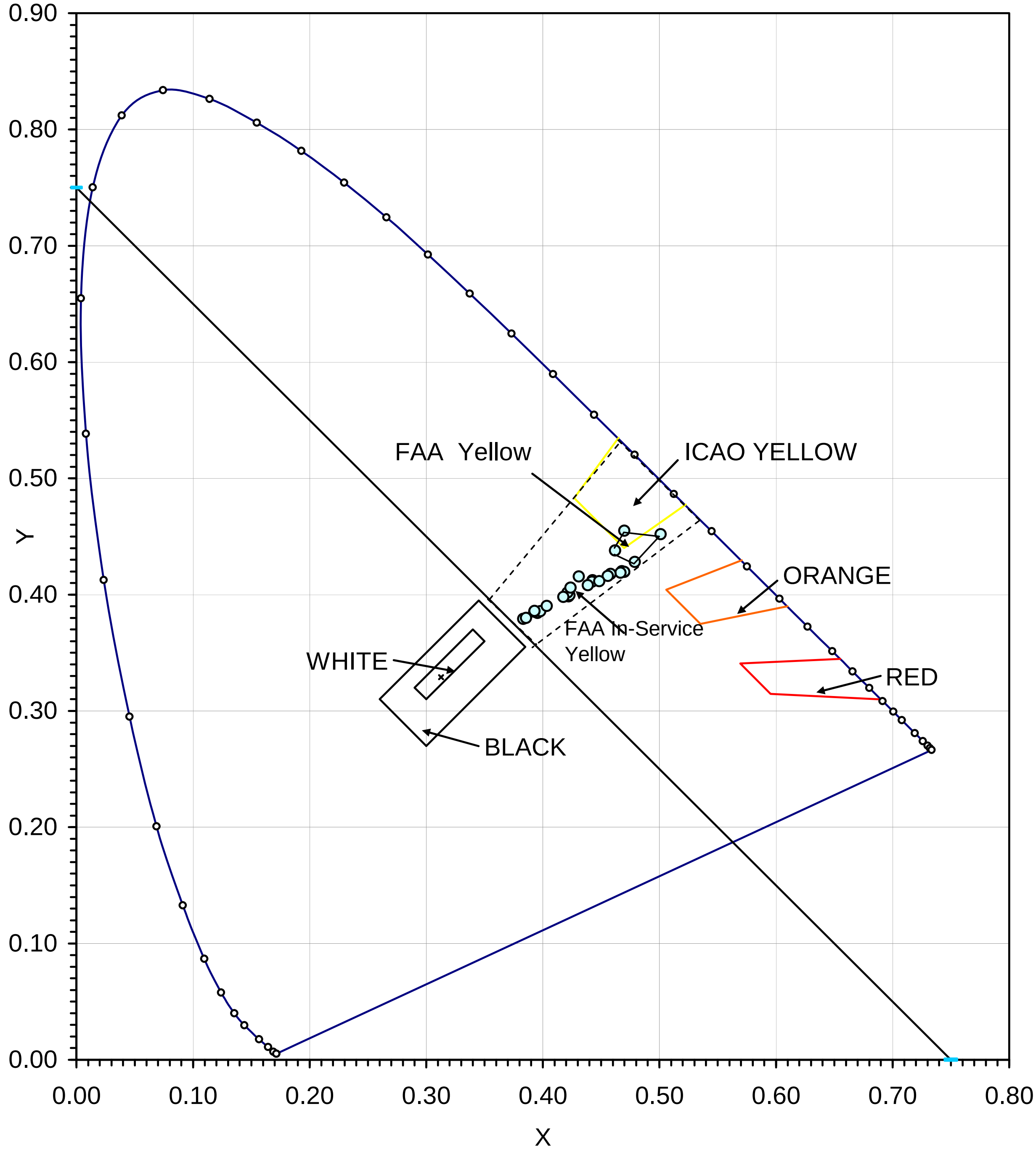


Figure A-27. Chromaticity Readings of HMYS-1, 3-Foot Stripe (Yellow) at FAA William J. Hughes Technical Center

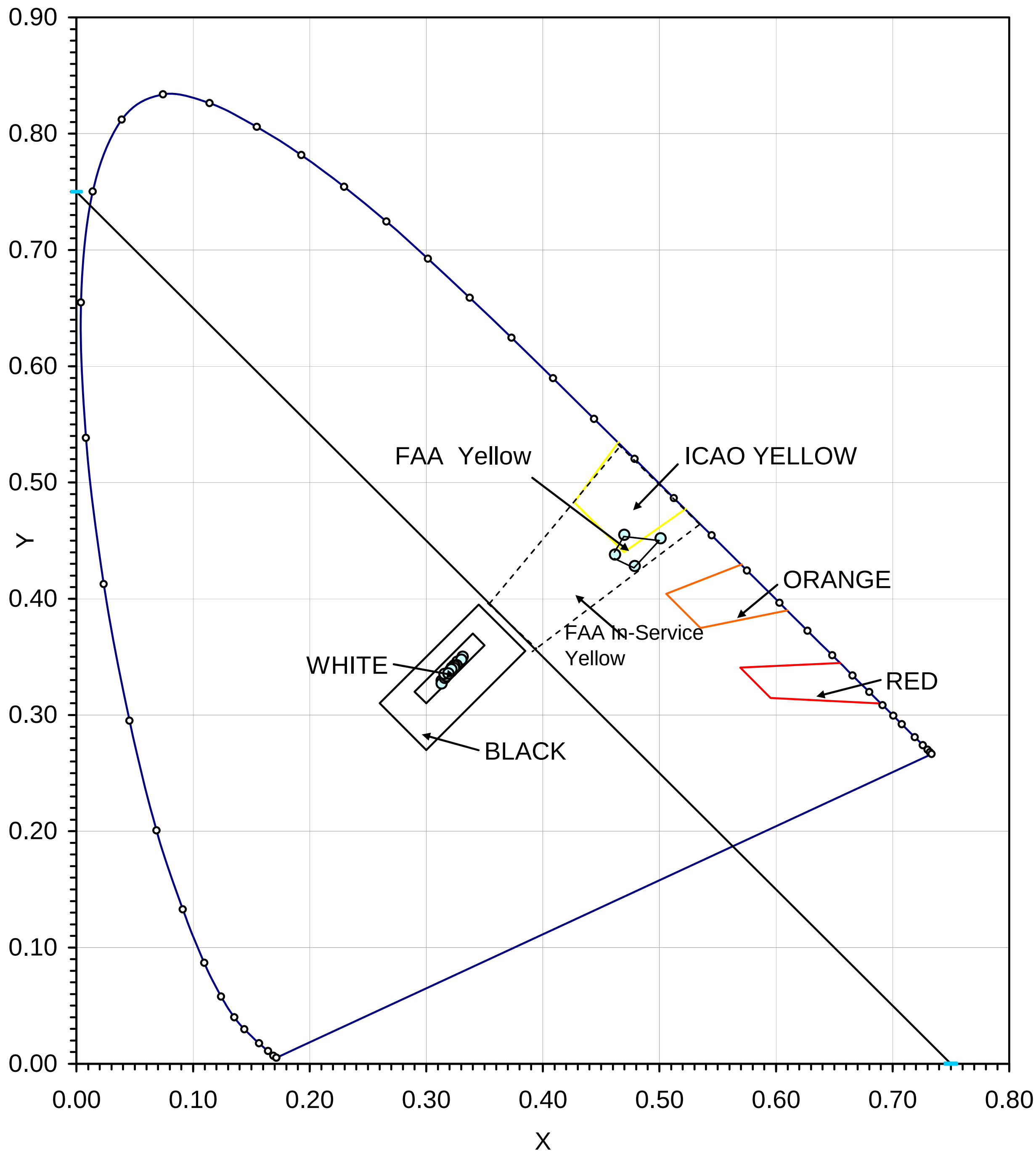


Figure A-28. Chromaticity Readings of HMBS-1, 3-Foot Stripe (Black) at FAA William J. Hughes Technical Center

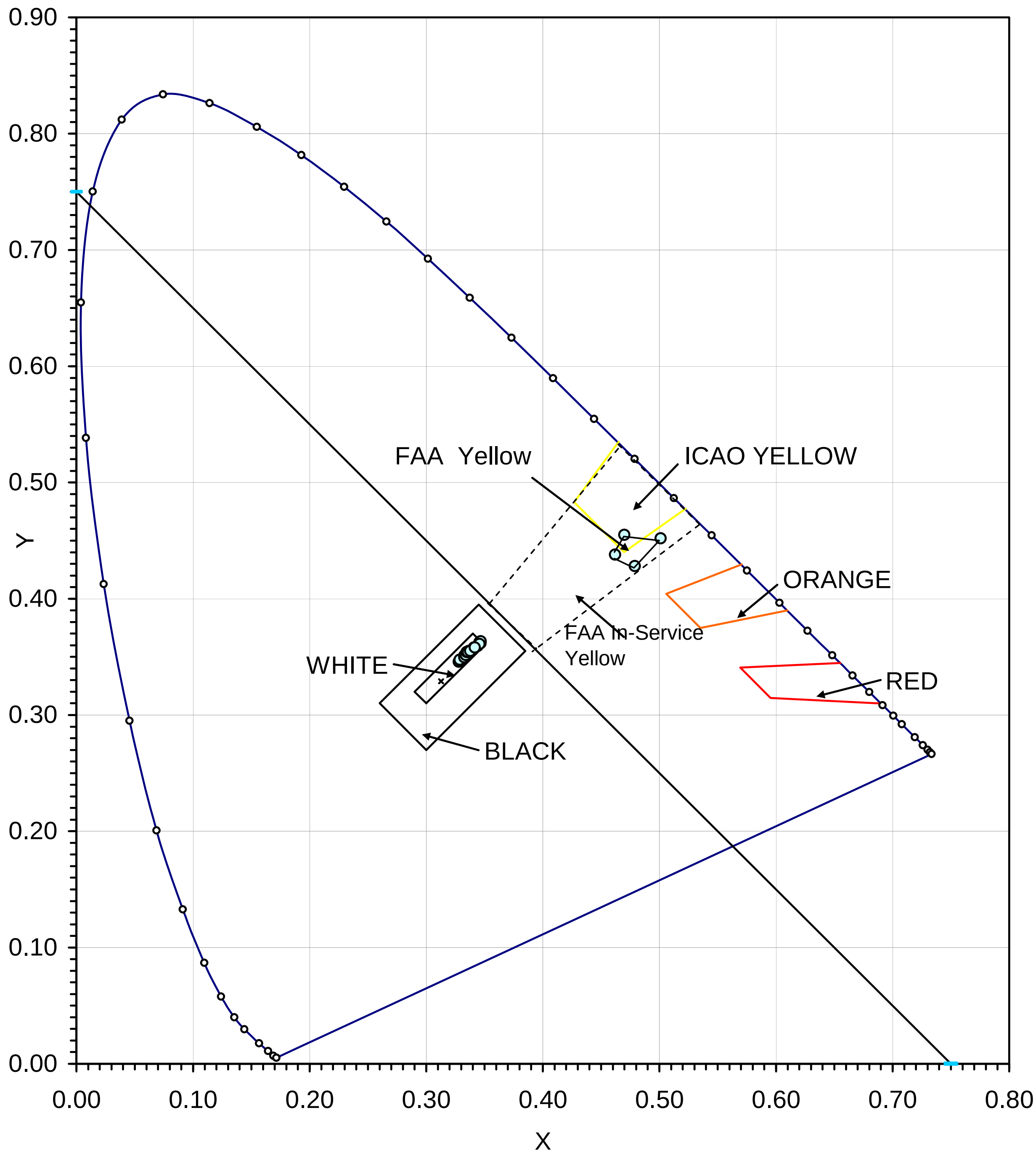


Figure A-29. Chromaticity Readings of HMWSL-1, 150-Foot Stripe (White) at FAA William J. Hughes Technical Center

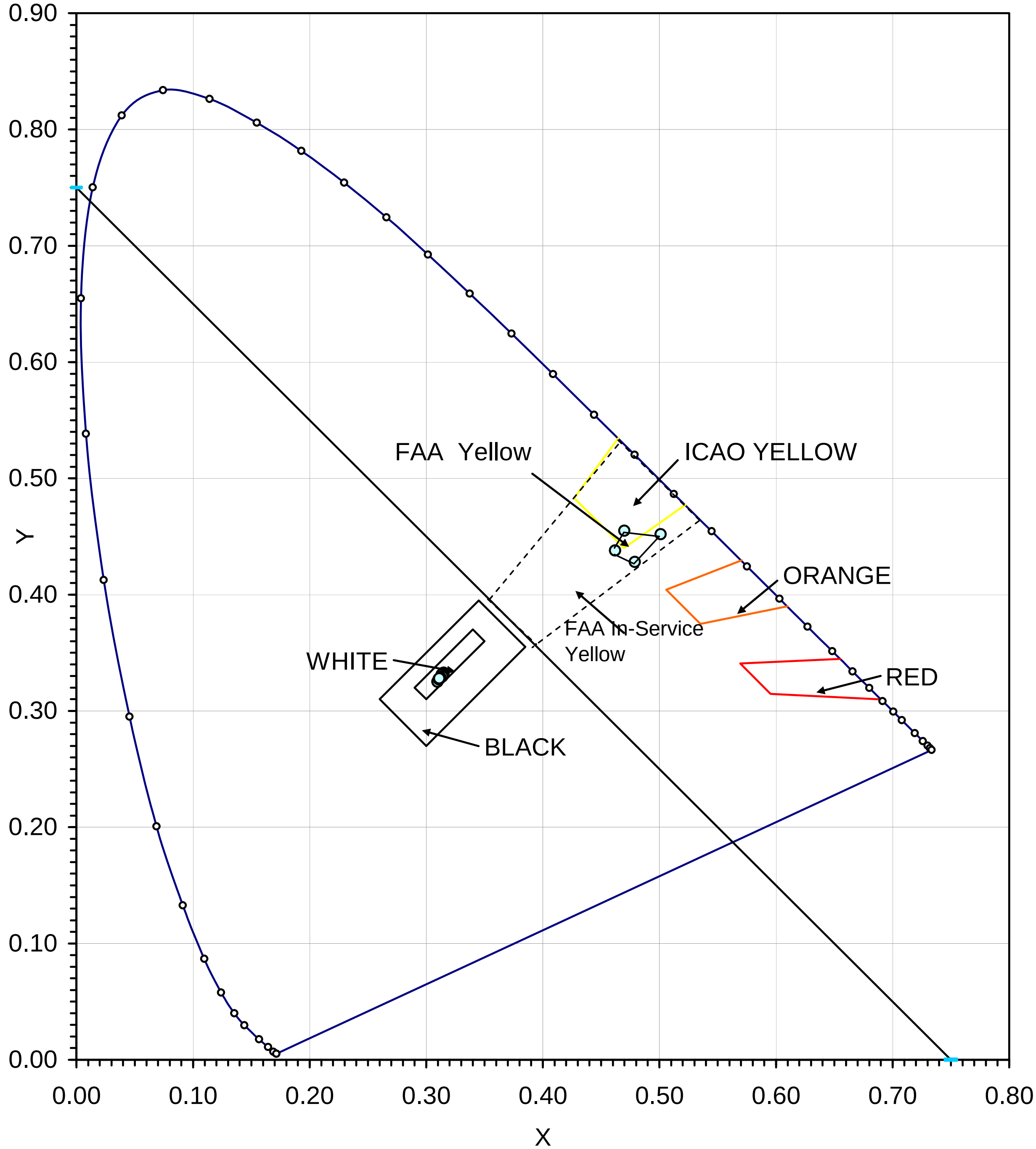


Figure A-30. Chromaticity Readings of CCMNB-2, Movement/Nonmovement Line (Black) at FAA William J. Hughes Technical Center

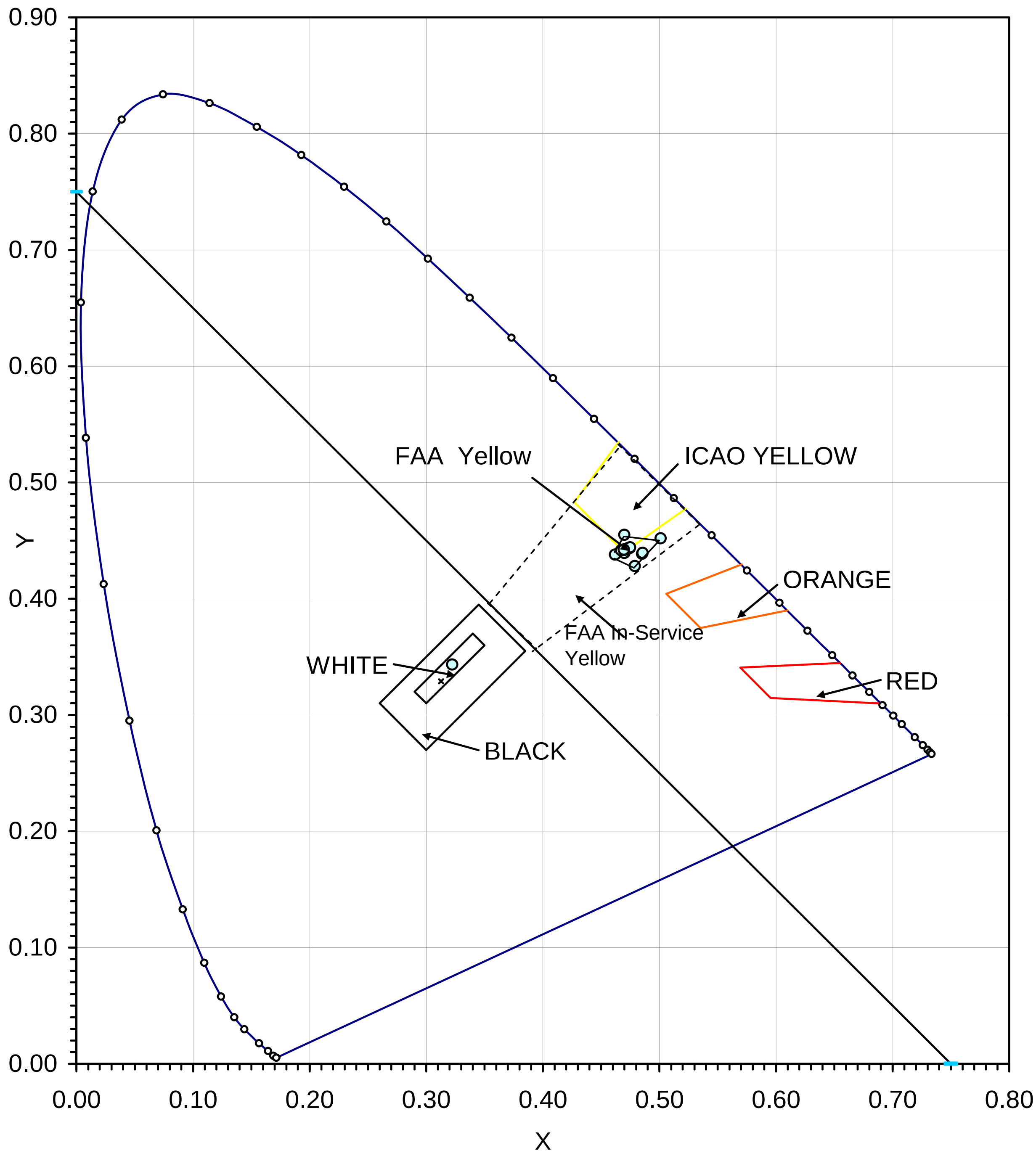


Figure A-31. Chromaticity Readings of CCMNY-2, Movement/Nonmovement Line (Yellow) at FAA William J. Hughes Technical Center

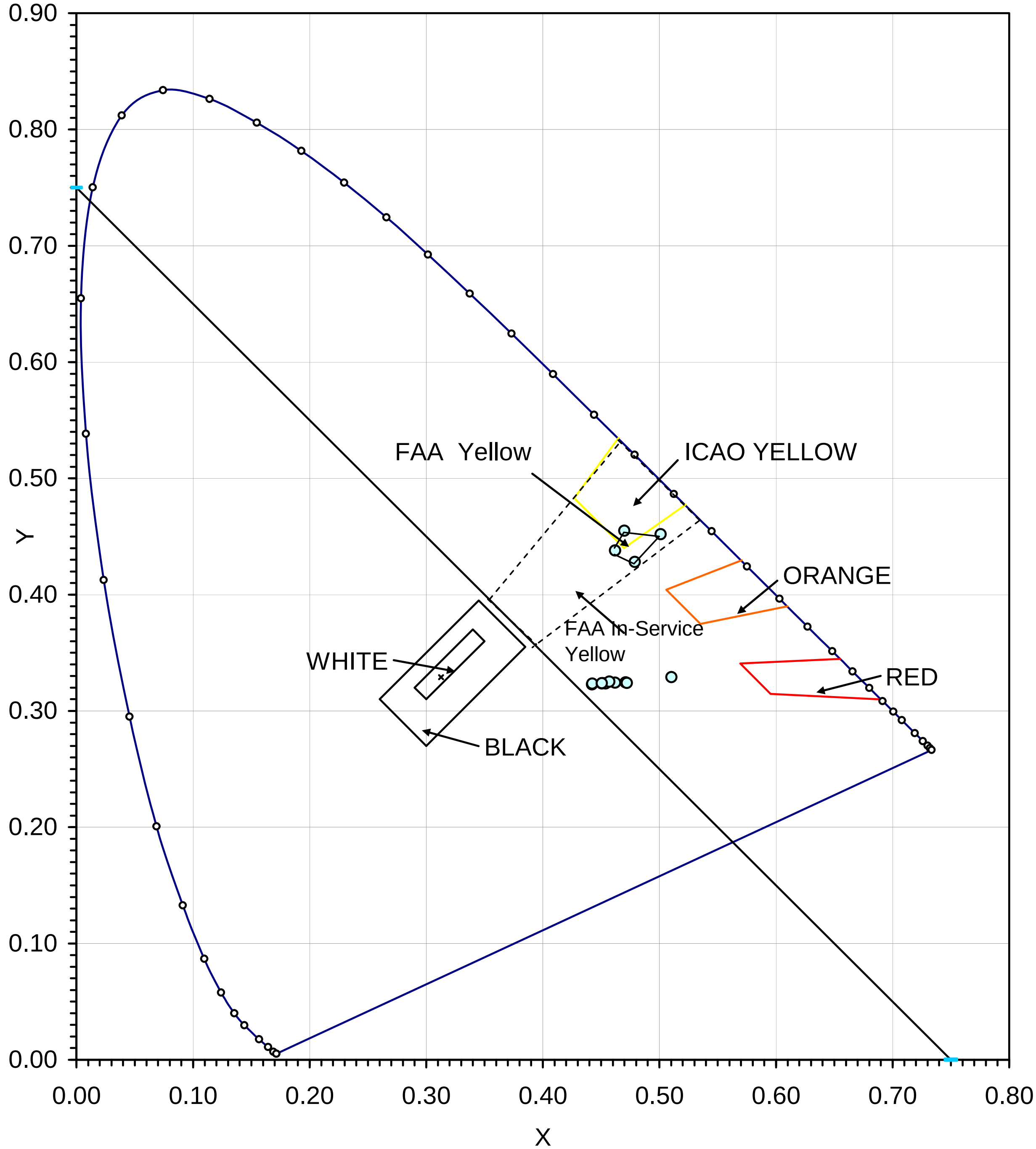


Figure A-32. Chromaticity Readings of CCAPD8R-2, Aircraft Parking Designator #8 (Red) at FAA William J. Hughes Technical Center

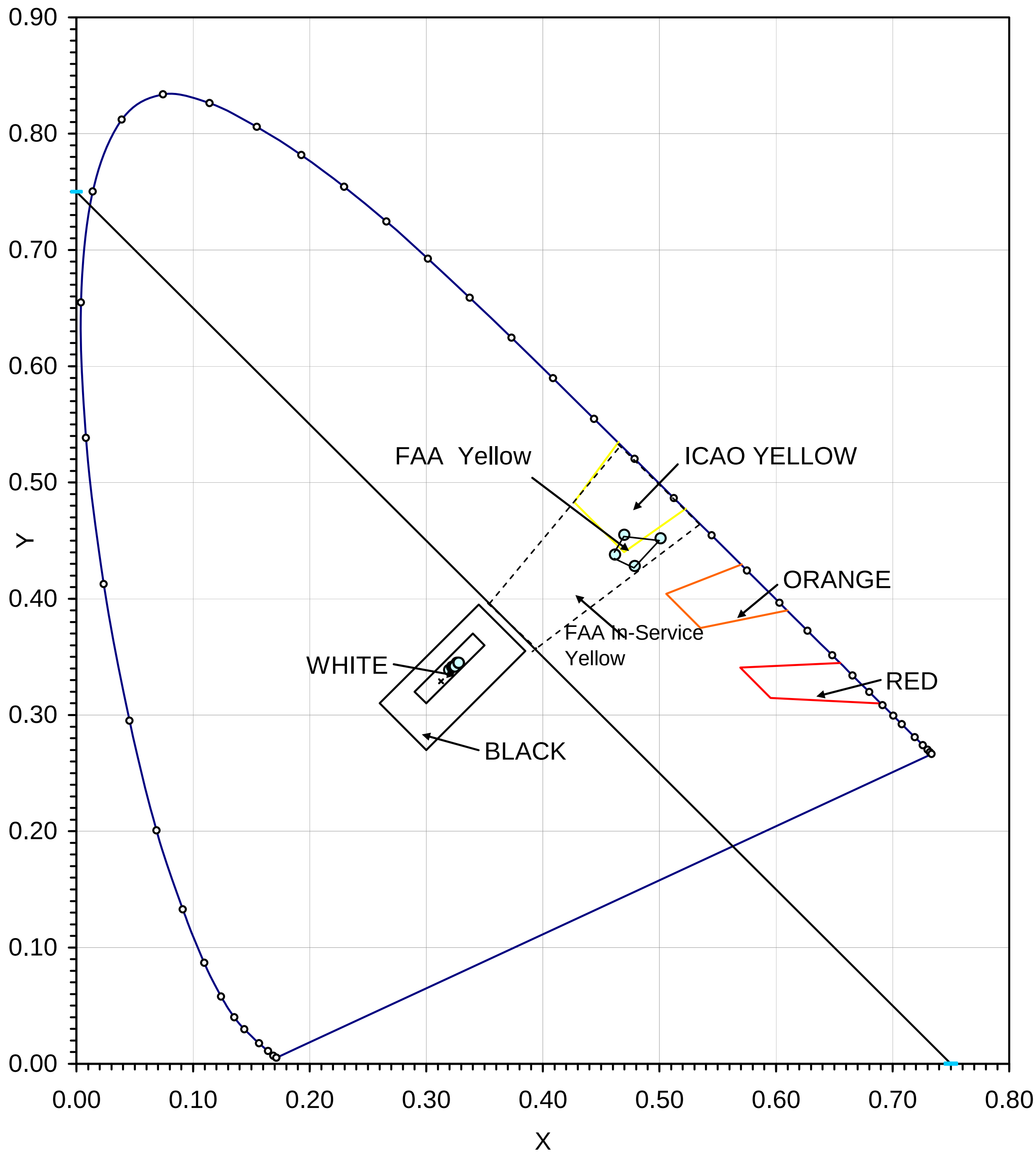


Figure A-33. Chromaticity Readings of CCAPD8W-2, Aircraft Parking Designator #8 (White) at FAA William J. Hughes Technical Center

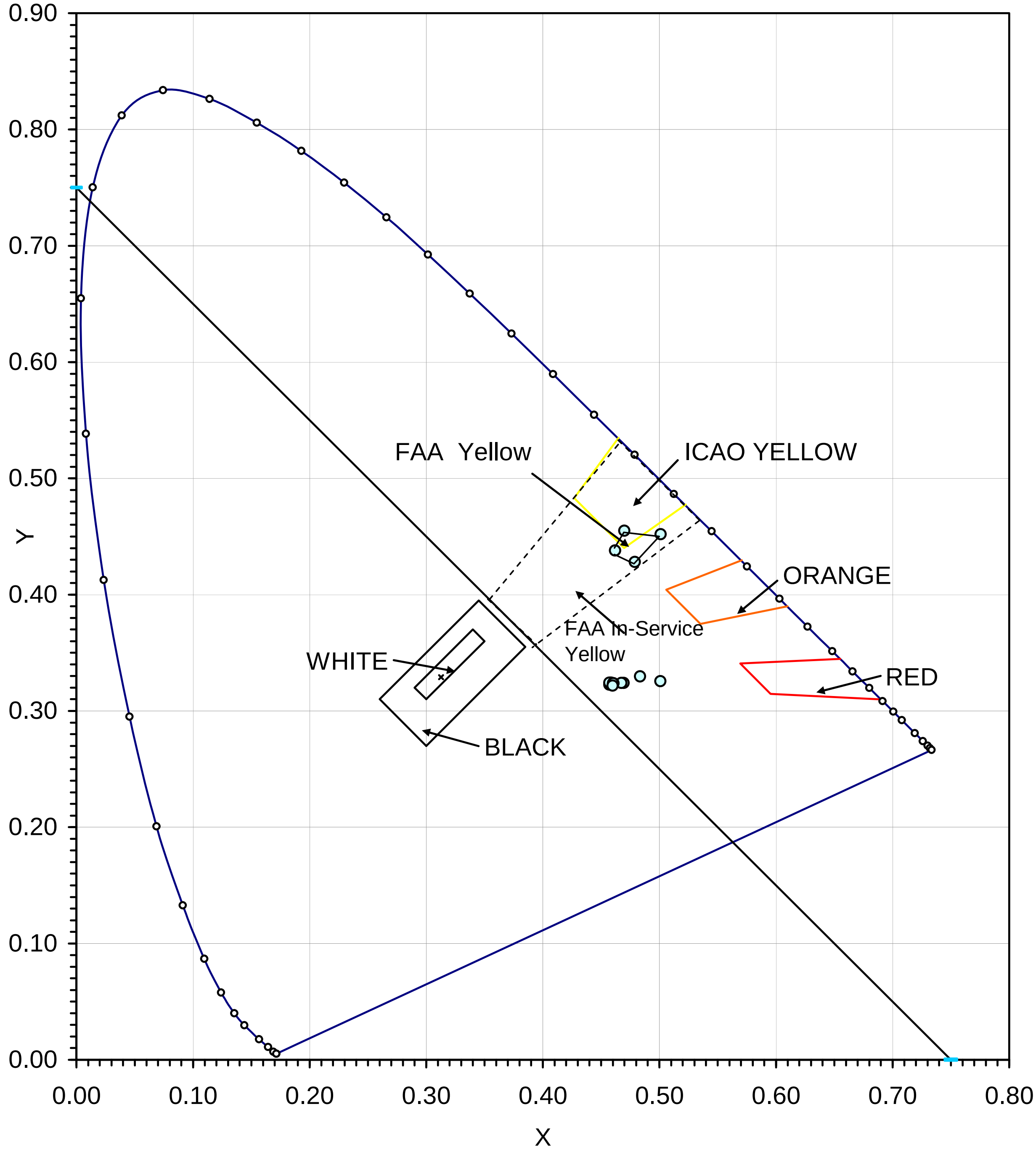


Figure A-34. Chromaticity Readings of CCRS-2, 3-Foot Stripe (Red) at FAA William J. Hughes Technical Center

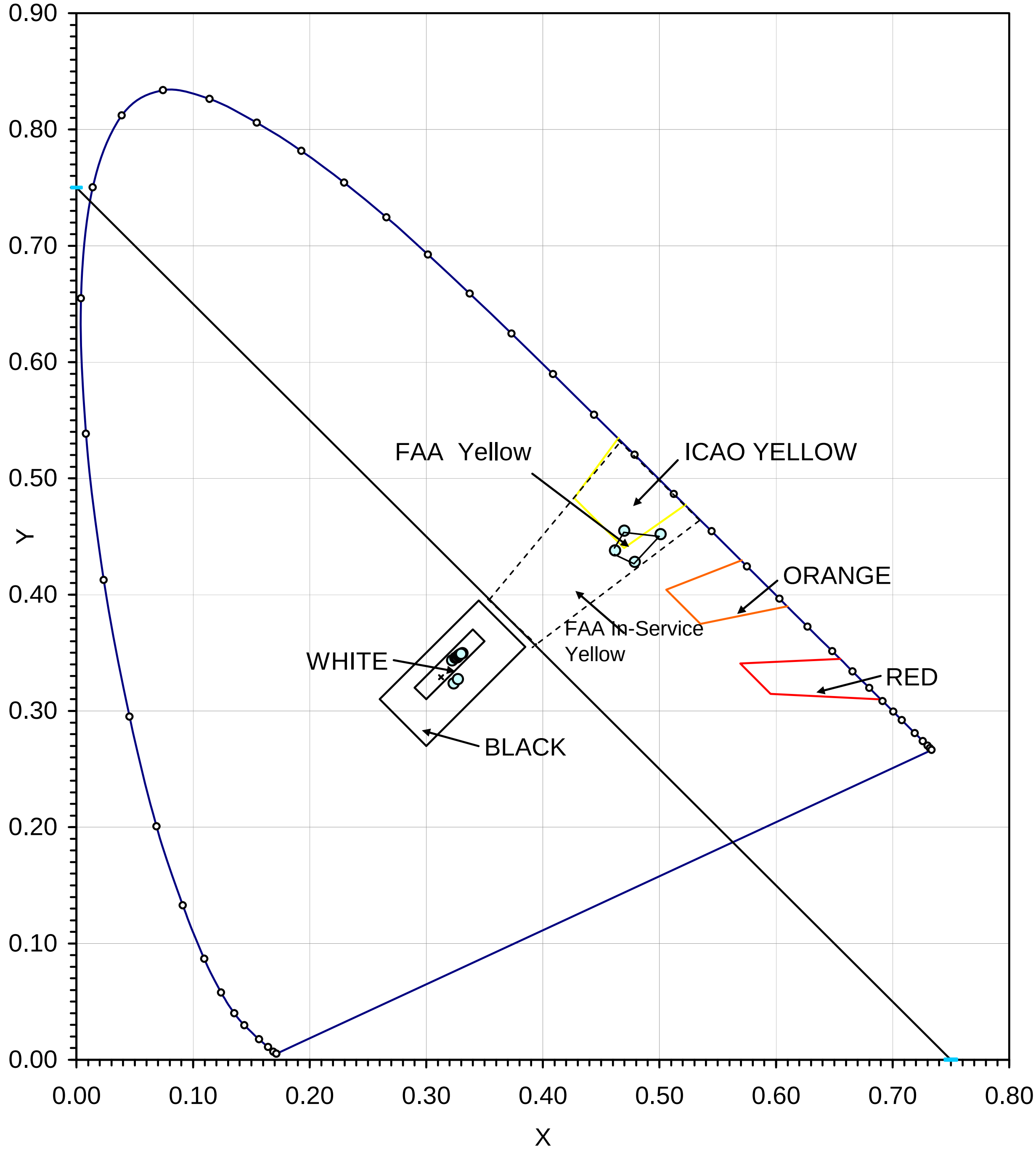


Figure A-35. Chromaticity Readings of CCWS-2, 3-Foot Stripe (White) at FAA William J. Hughes Technical Center

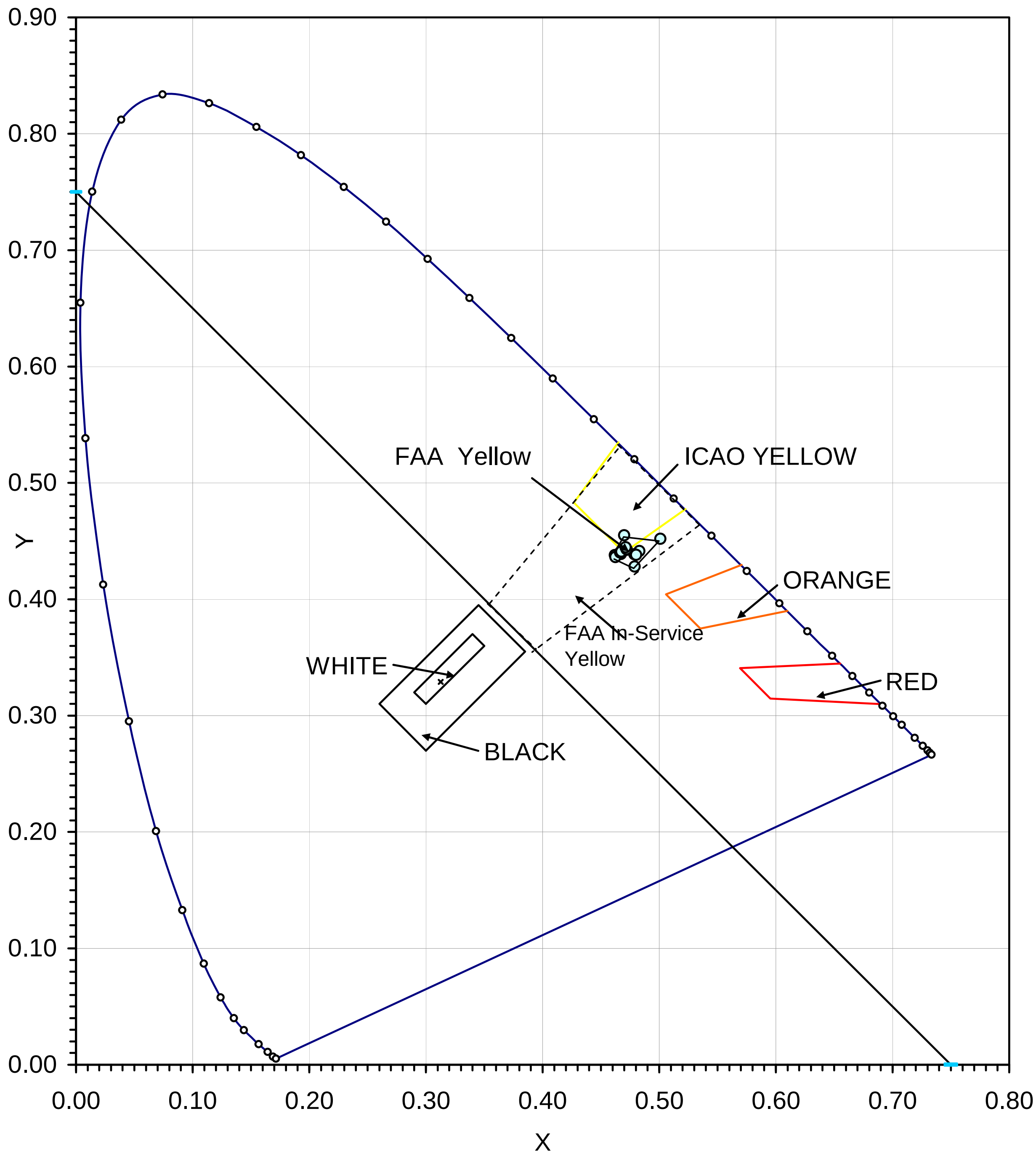


Figure A-36. Chromaticity Readings of CCYS-2, 3-Foot Stripe (Yellow) at FAA William J. Hughes Technical Center

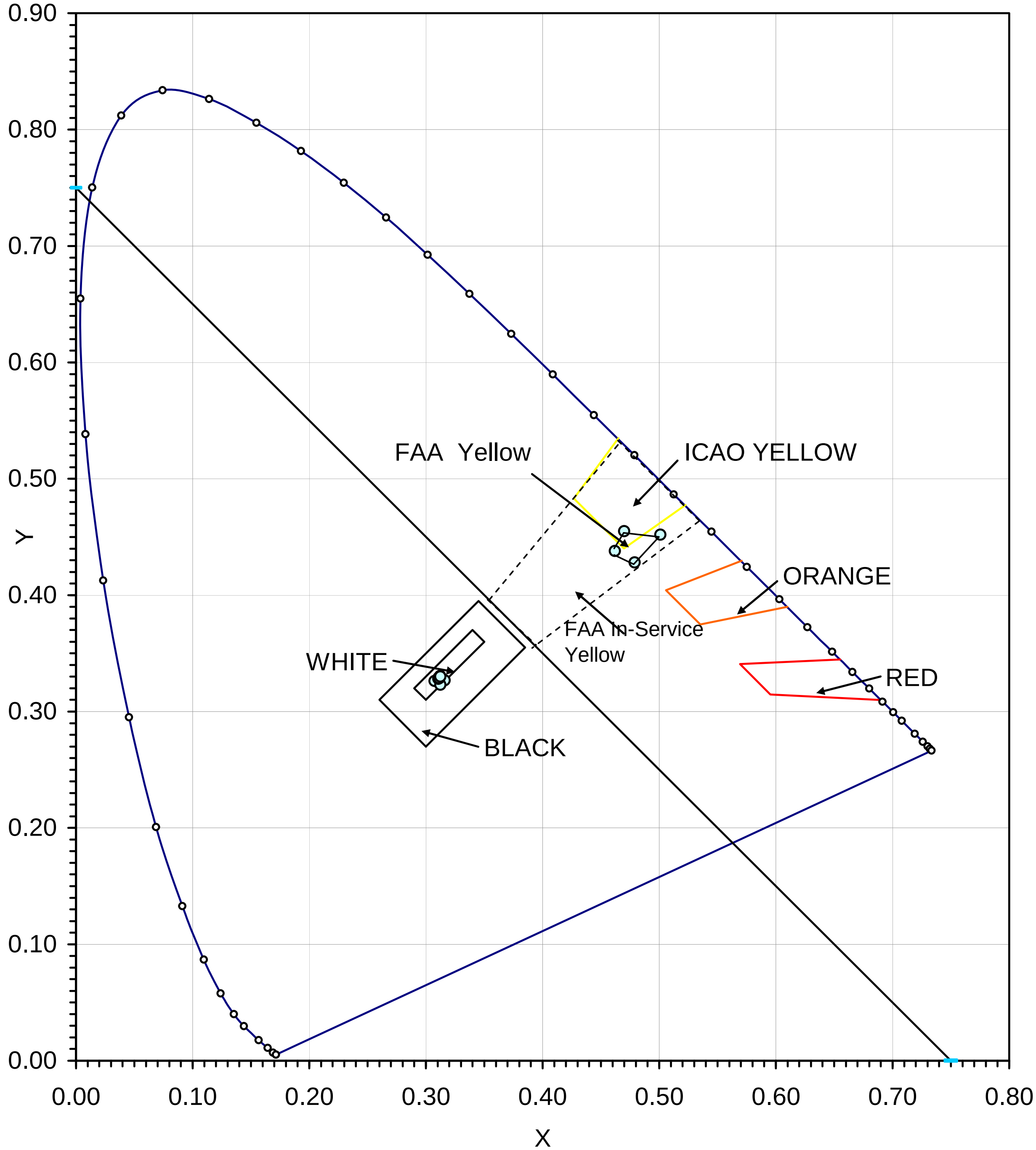


Figure A-37. Chromaticity Readings of CCBS-2, 3-Foot Stripe (Black) at FAA William J. Hughes Technical Center

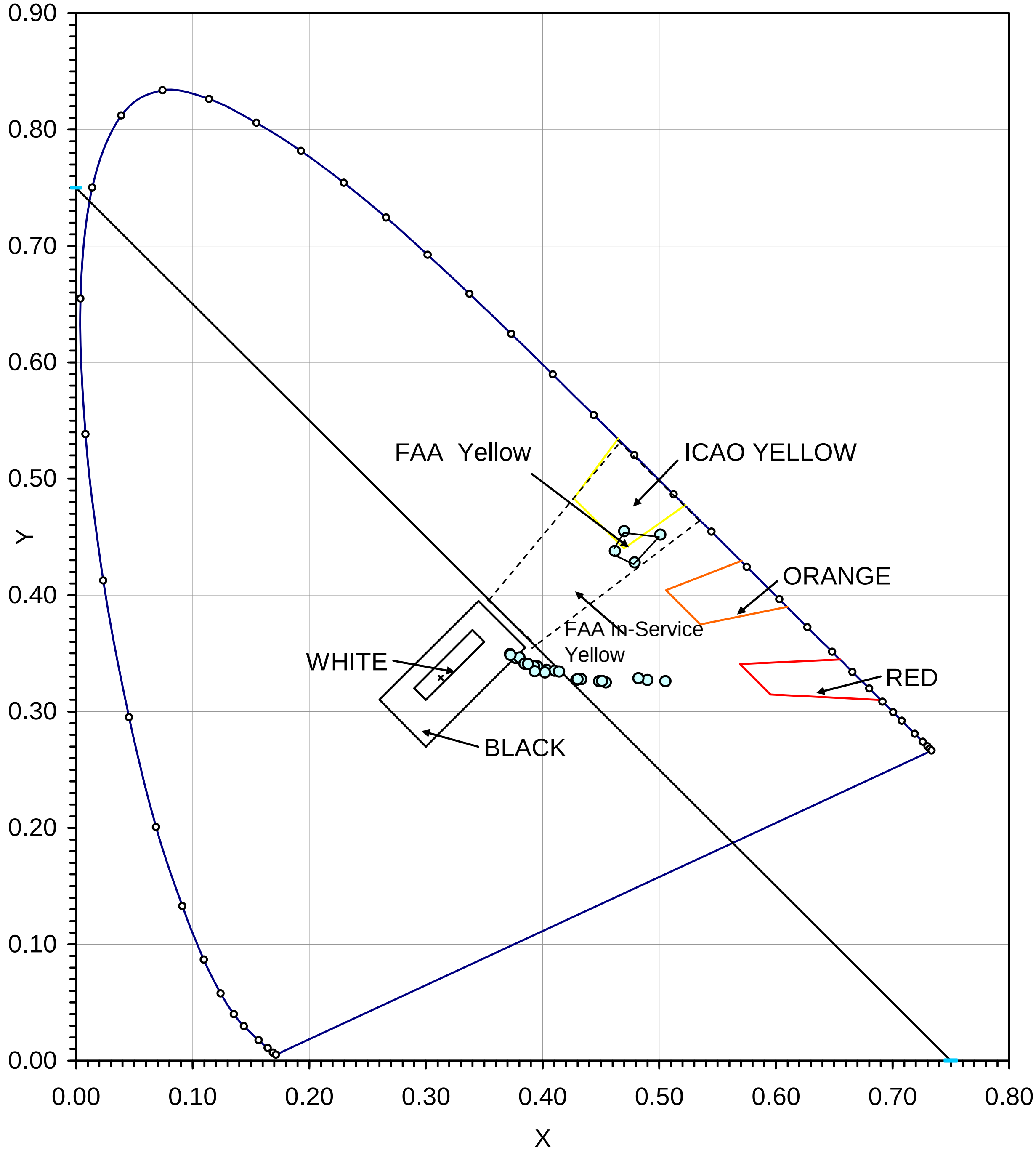


Figure A-38. Chromaticity Readings of HMRS-2, 3-Foot Stripe (Red) at FAA William J. Hughes Technical Center

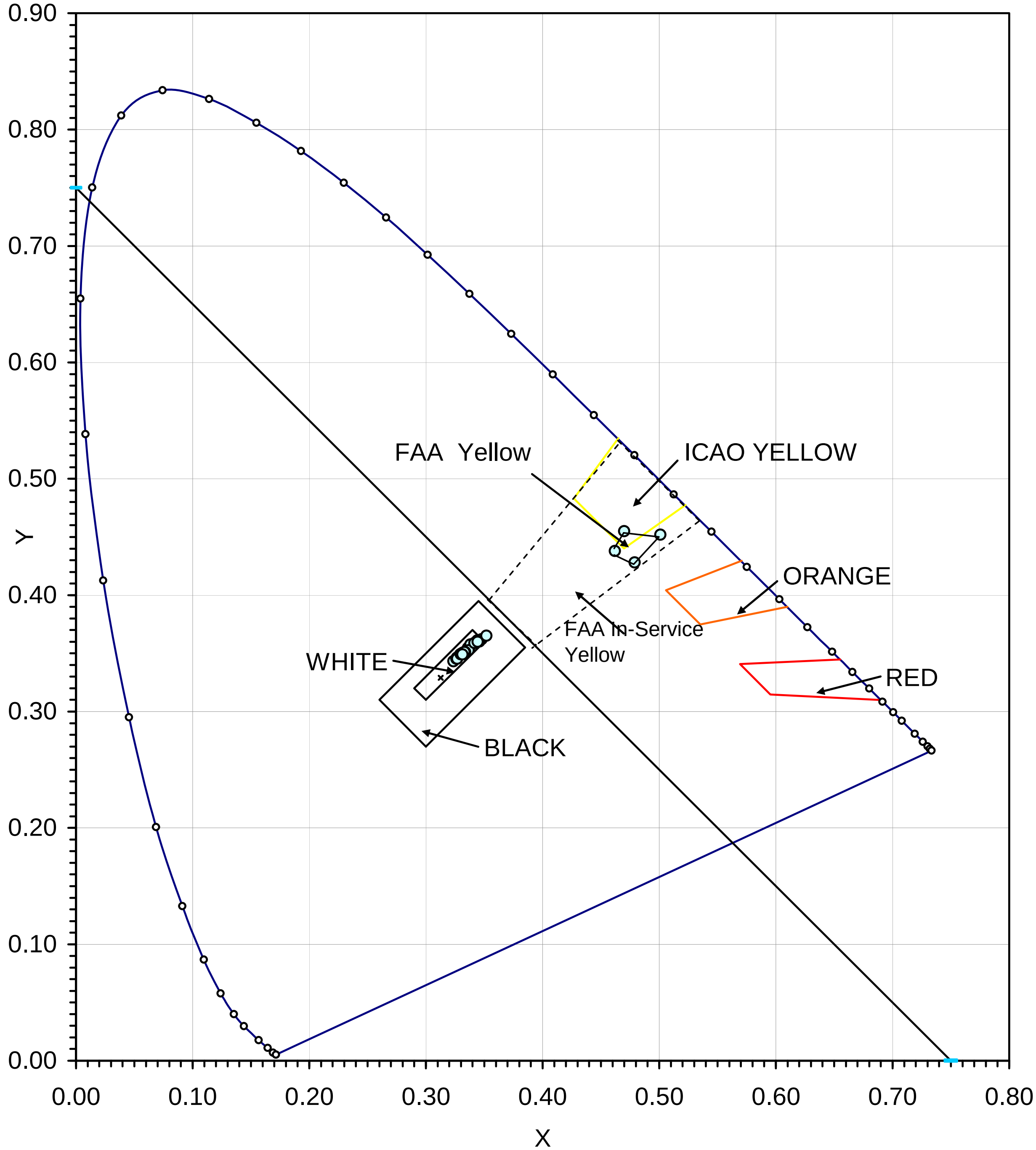


Figure A-39. Chromaticity Readings of HMWS-2, 3-Foot Stripe (White) at FAA William J. Hughes Technical Center

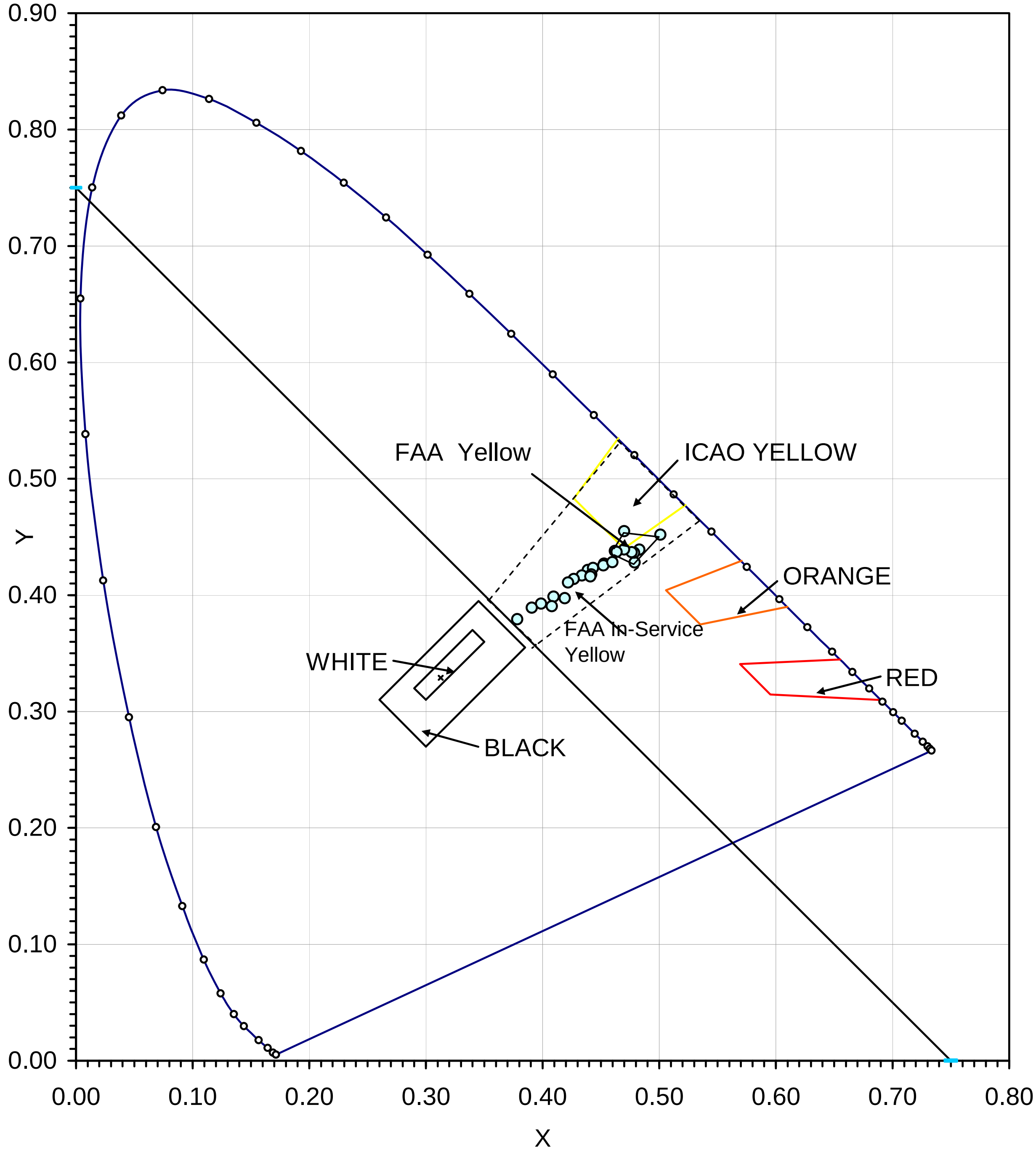


Figure A-40. Chromaticity Readings of HMYS-2, 3-Foot Stripe (Yellow) at FAA William J. Hughes Technical Center

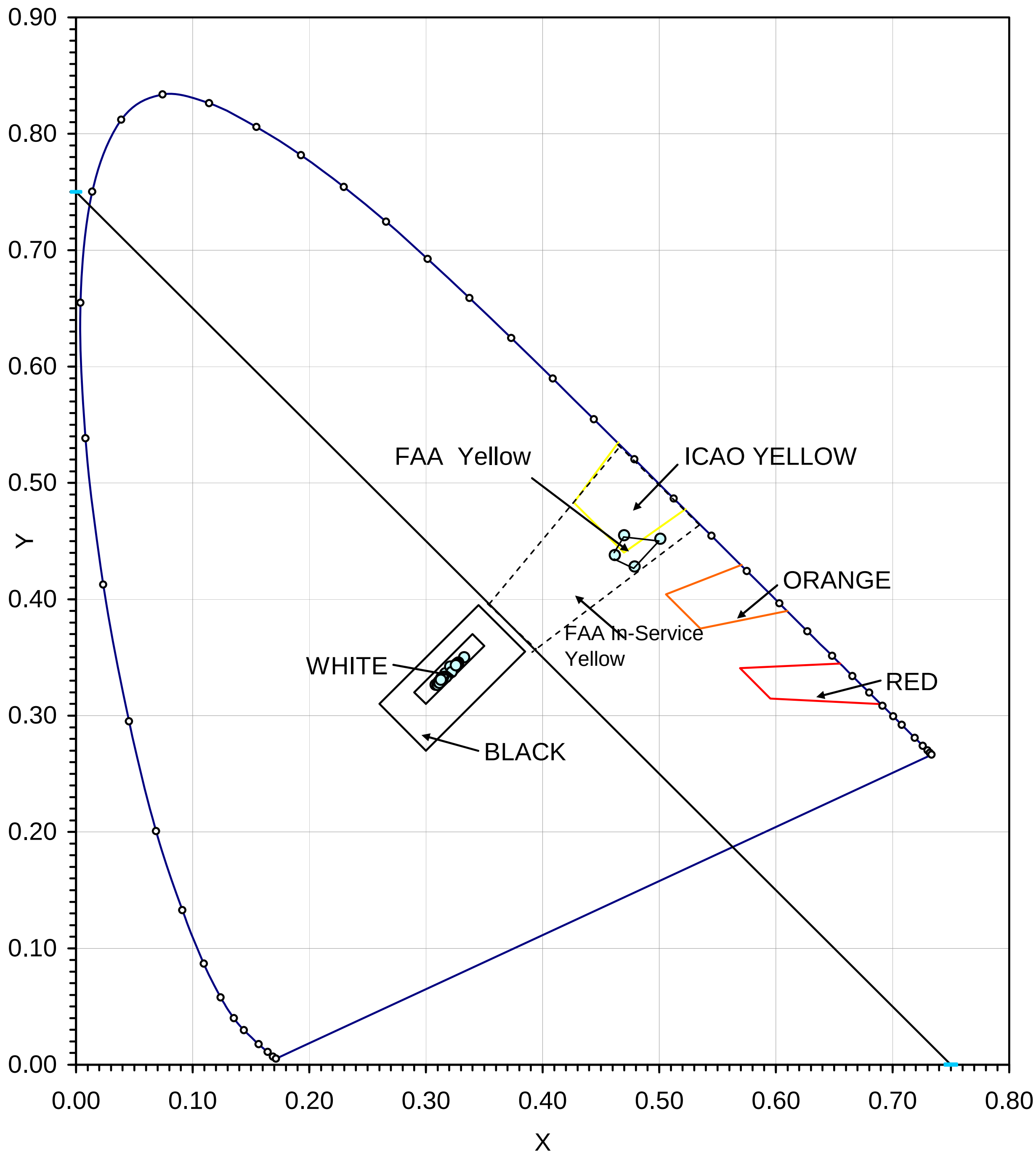


Figure A-41. Chromaticity Readings of HMBS-2, 3-Foot Stripe (Black) at FAA William J. Hughes Technical Center

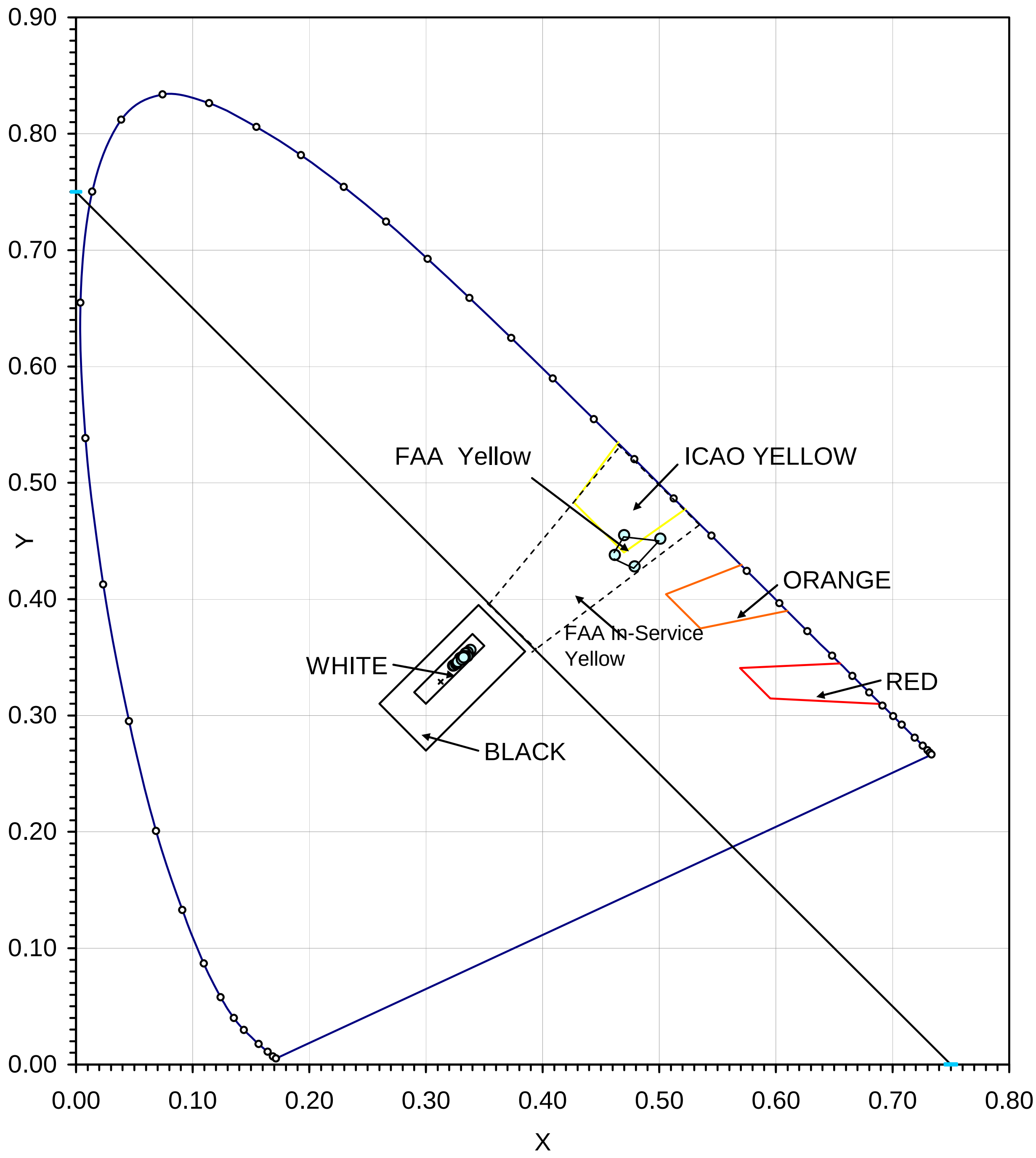


Figure A-42. Chromaticity Readings of HMWSL-2, 150-Foot Stripe (White) at FAA William J. Hughes Technical Center

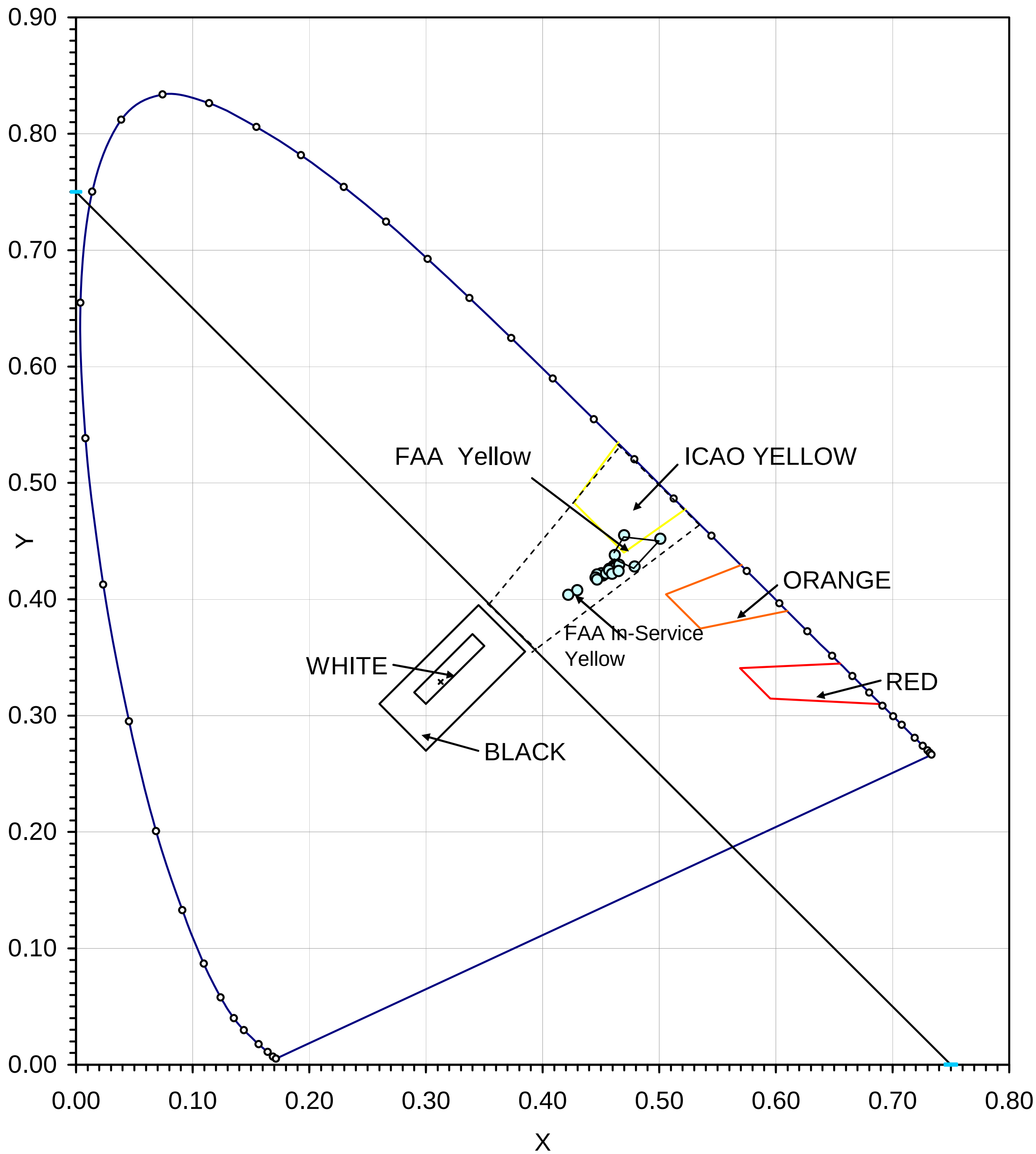


Figure A-43. Chromaticity Readings of CCRHPS, Yellow Thermoplastic Solid Line at EWR

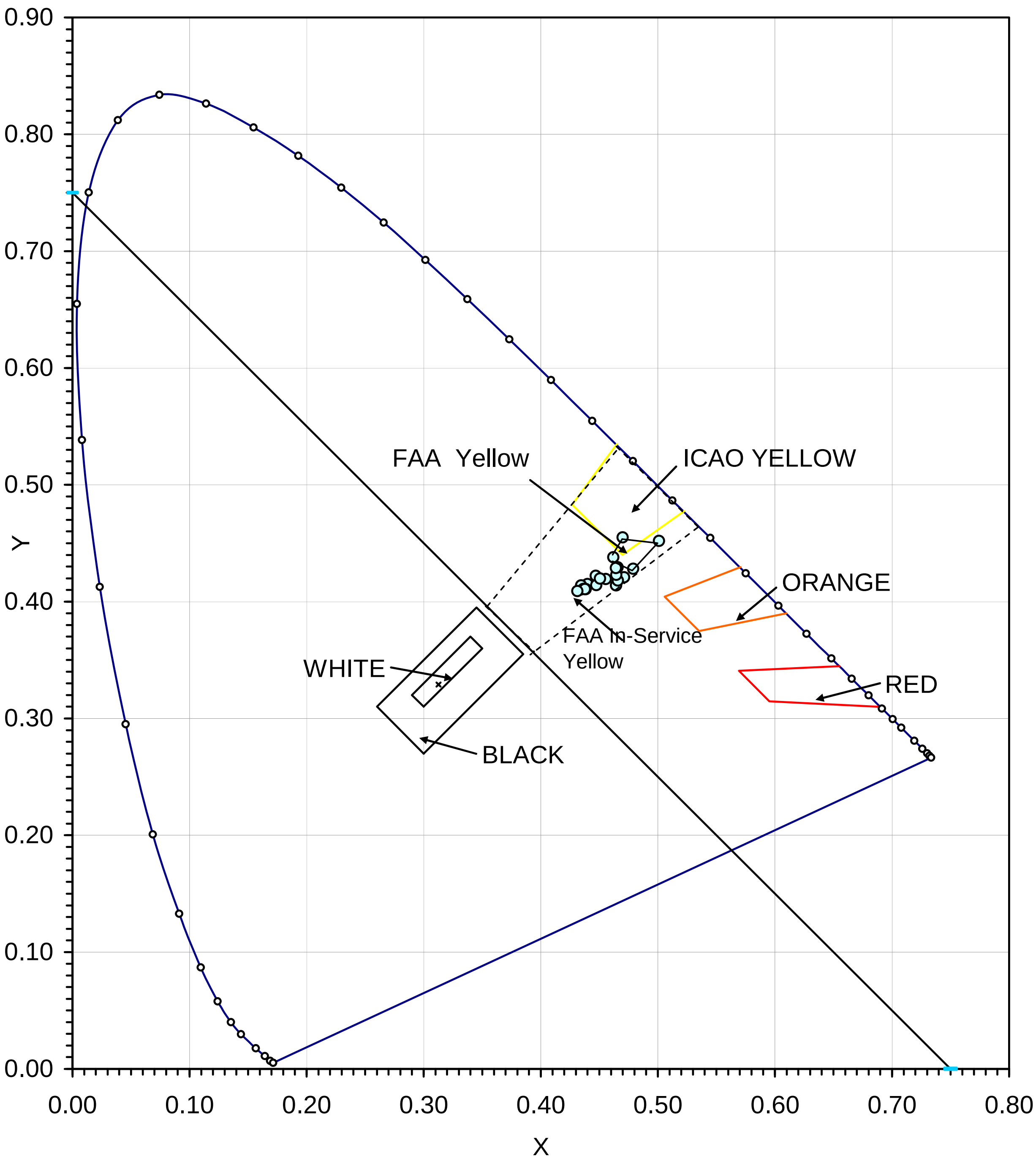


Figure A-44. Chromaticity Readings of CCRHPD, Yellow Thermoplastic Dash Line at EWR

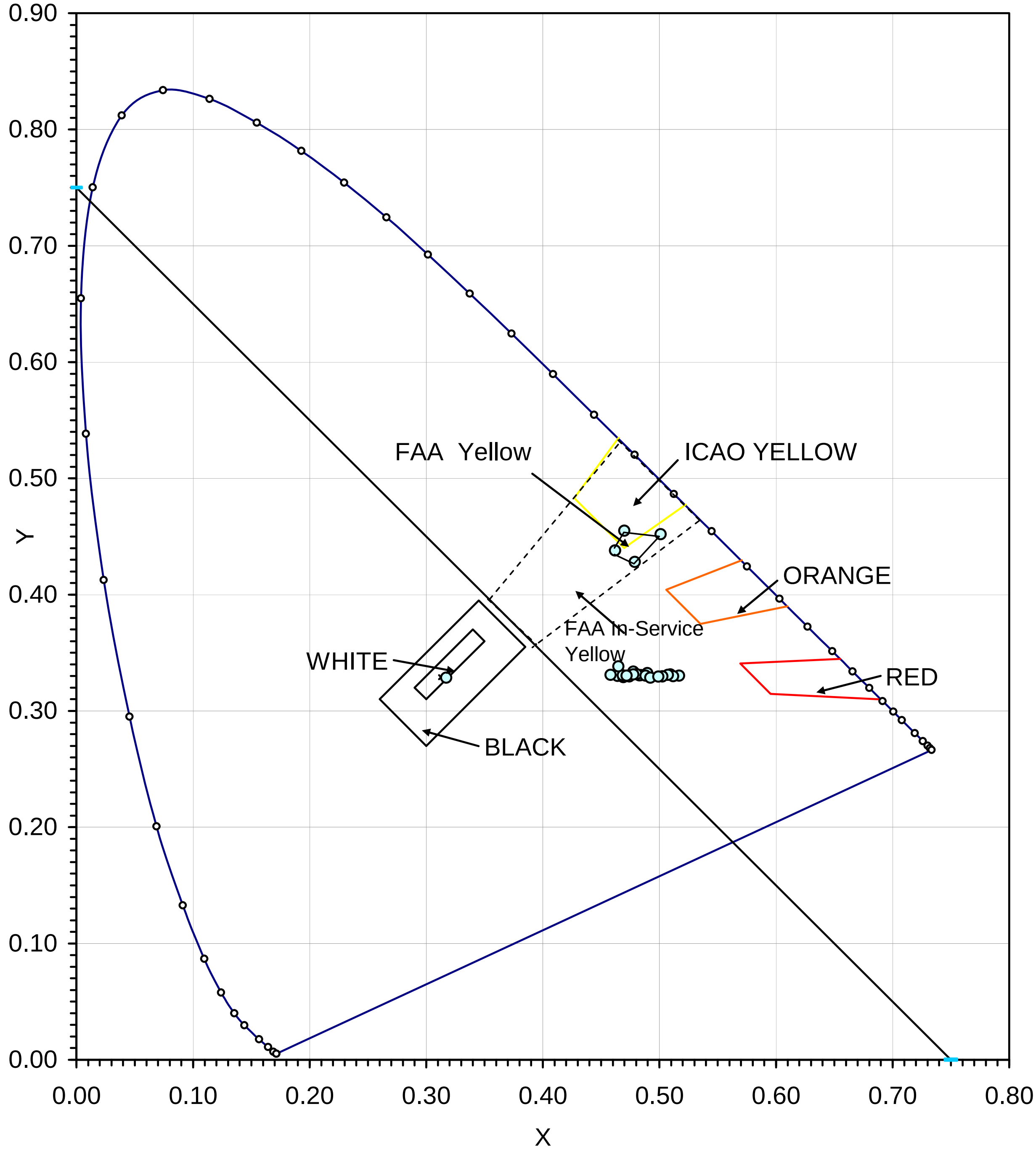


Figure A-45. Chromaticity Readings of CCRID, Red Thermoplastic at EWR

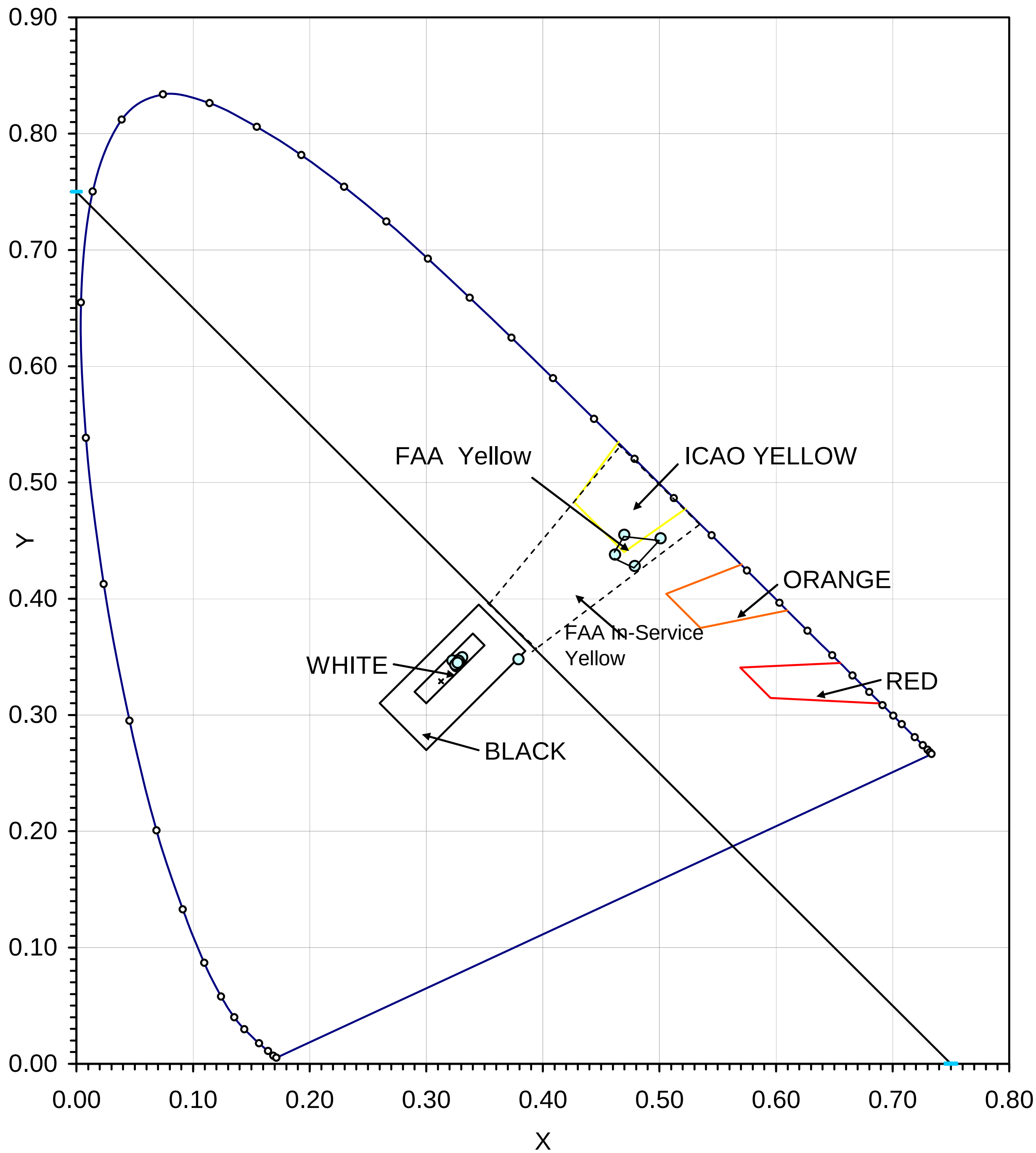


Figure A-46. Chromaticity Readings of CCRID, White Thermoplastic at EWR

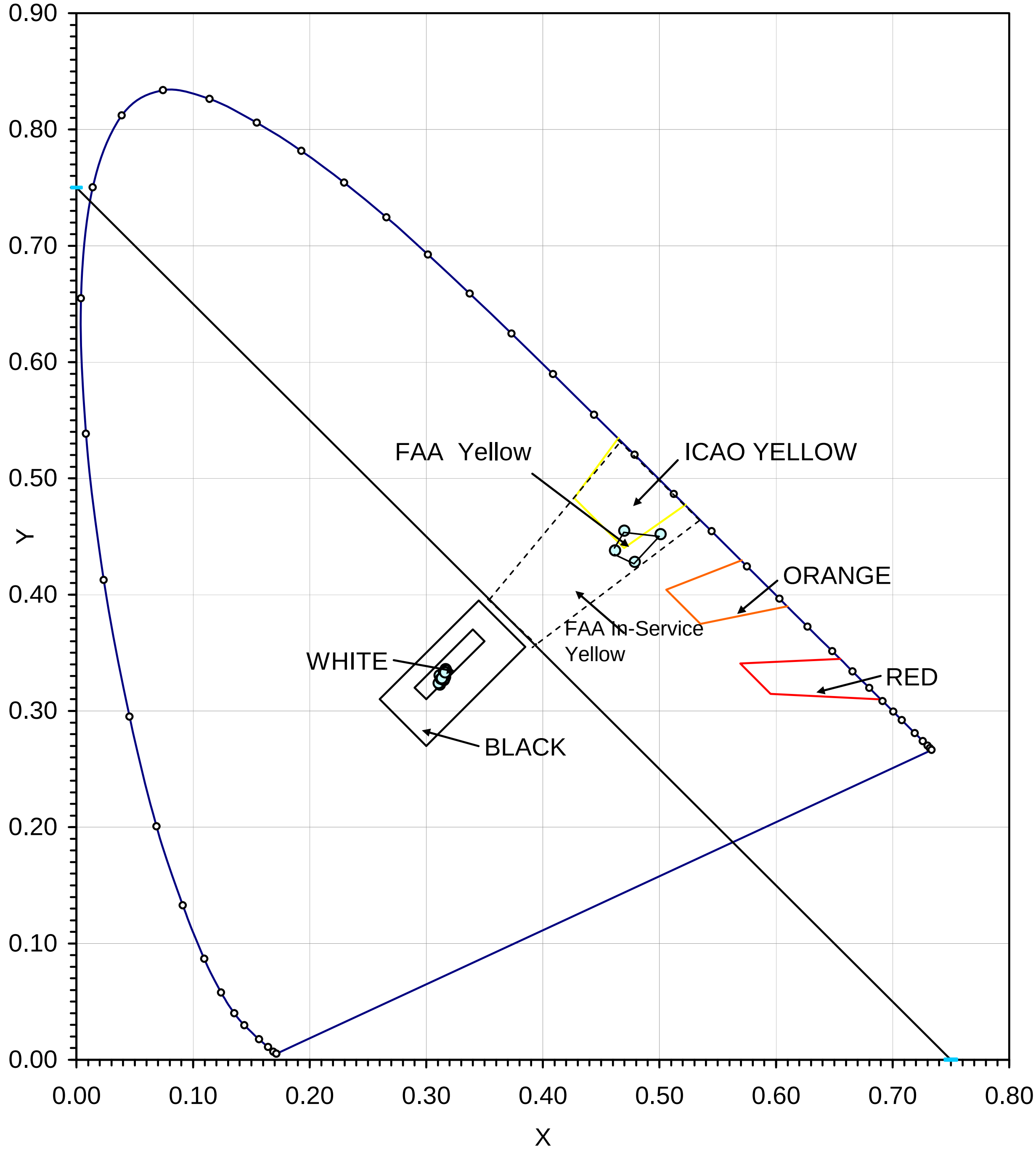


Figure A-47. Chromaticity Readings of CCRID, Black Thermoplastic at EWR

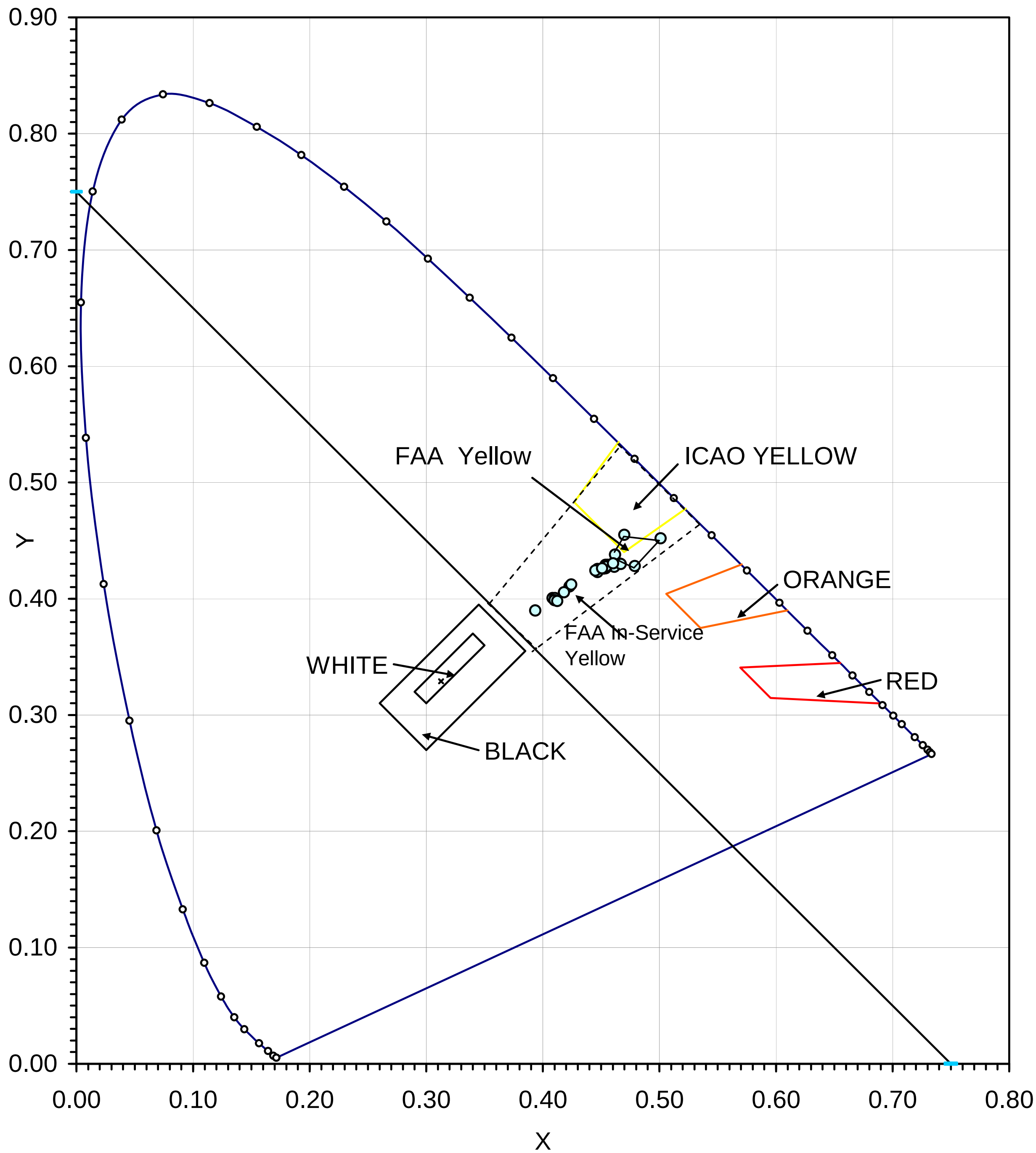


Figure A-48. Chromaticity Readings of CCRHP, Yellow Paint at EWR

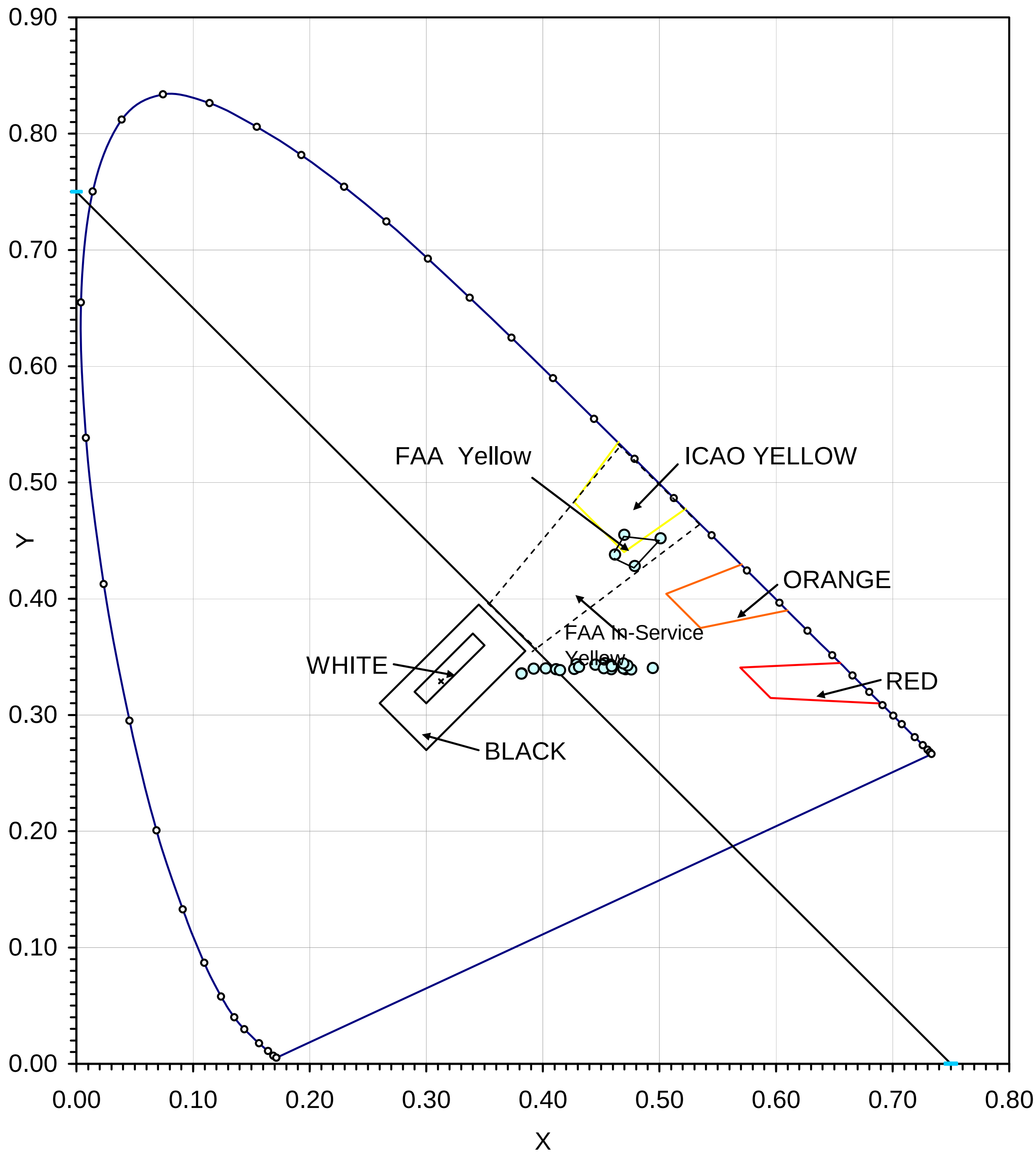


Figure A-49. Chromaticity Readings of CCRID, Red Paint at EWR

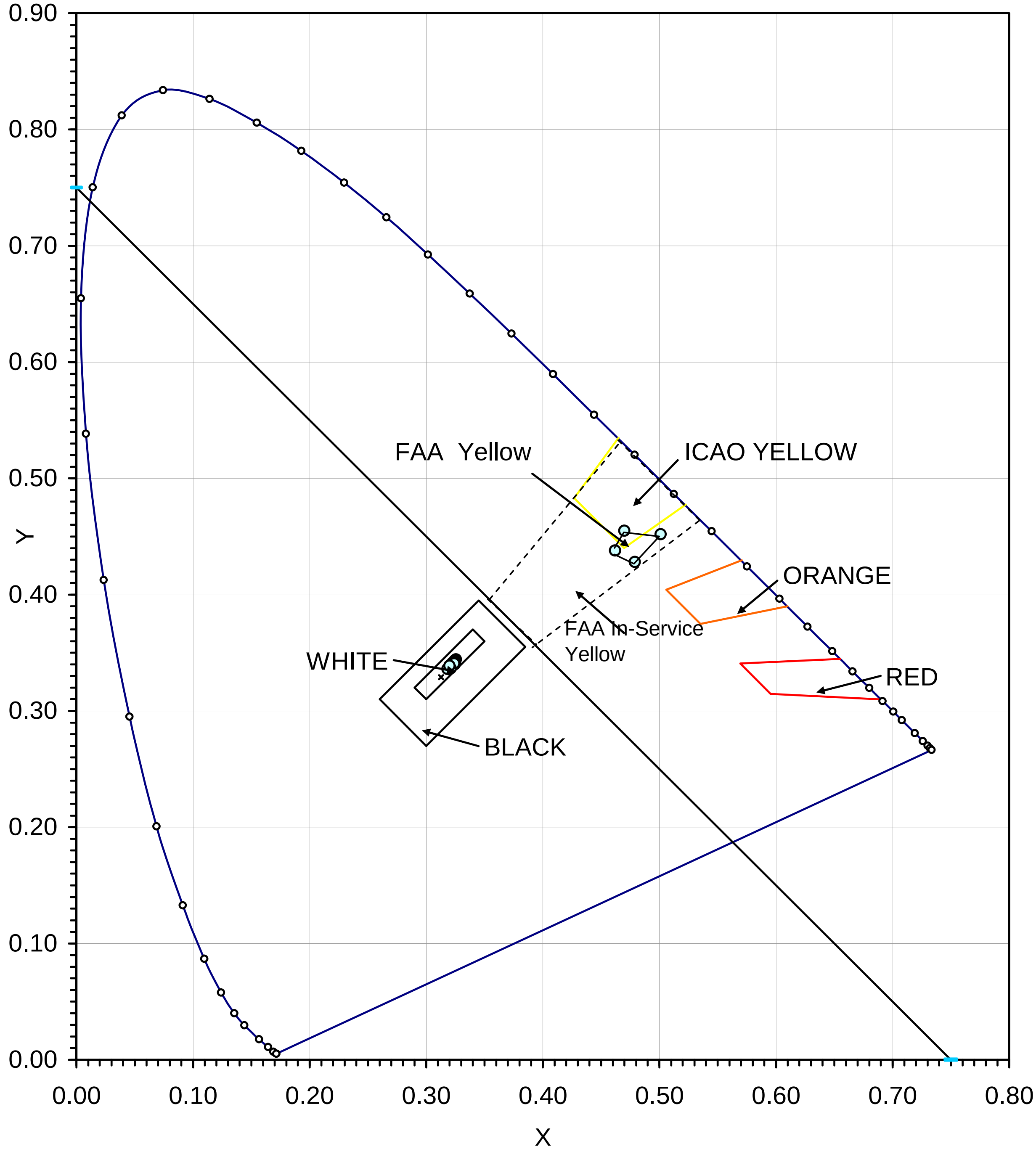


Figure A-50. Chromaticity Readings of CCRID, White Paint at EWR

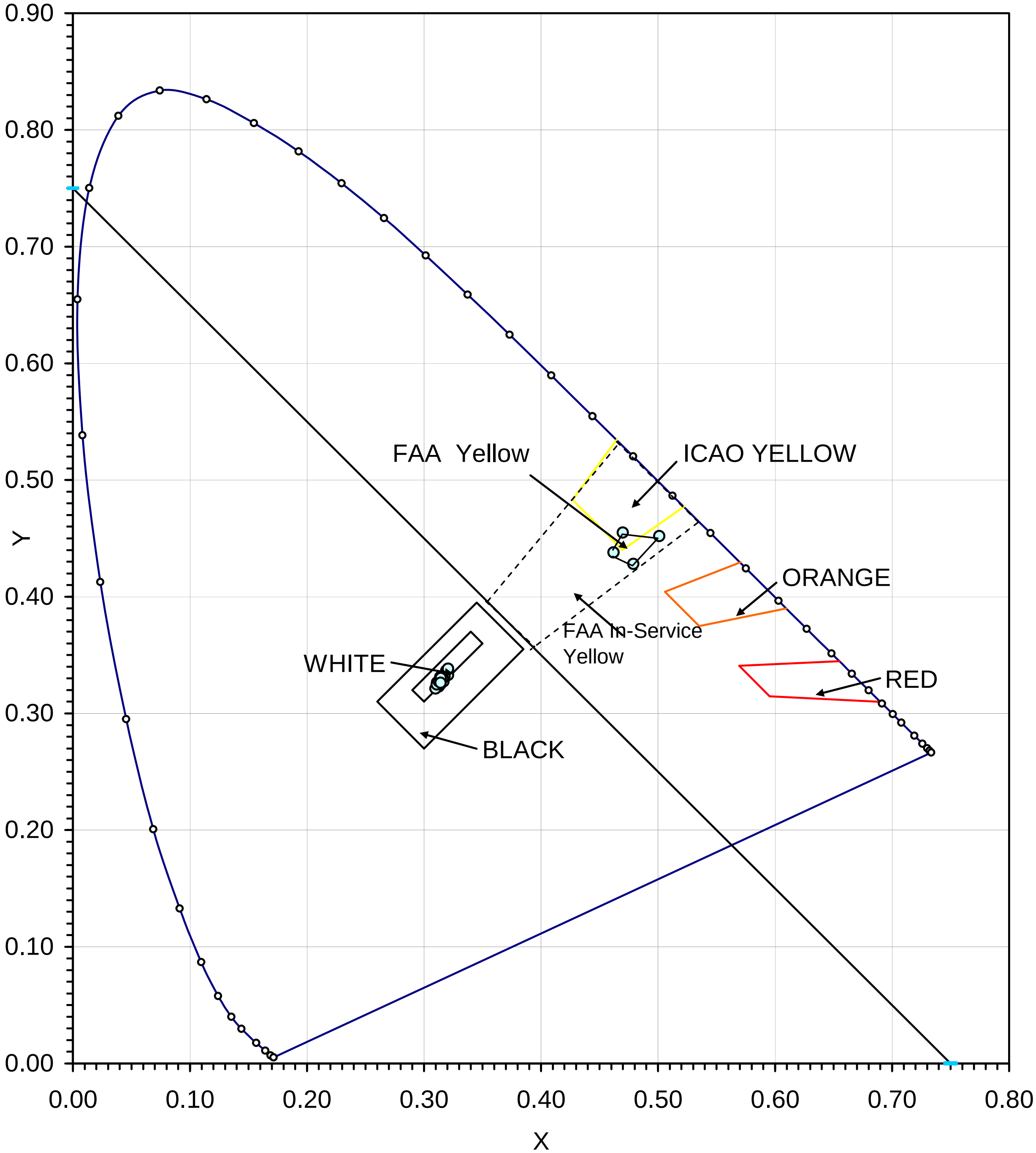


Figure A-51. Chromaticity Readings of CCRID, Black Paint at EWR