TOWARDS THE RAPID AND COMPLETE AUTOMATED ALIGNMENT OF MULTI-PROJECTOR DISPLAY SYSTEMS

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Abstract

This paper summarizes the functions and performance of an Automated Alignment (AA) system installed a year ago in four C-130 Hercules flight simulators at Little Rock AFB. This system accurately and completely adjusts geometry, convergence, and the co-alignment of blend zones within two minutes per channel, fast enough that these functions can be completed between training sessions if desired. Additional capabilities include the automatic adjustment of static and dynamic focus, and the adjustment of peak white, white balance, color tracking, and black level across channels. Requiring only five to seven minutes per channel, it is practical to run these functions on a weekly basis if desired. Since the system measures complete gamma functions for each CRT, these data can be passed to the IG on a regular basis for updating gamma correction tables.

Test results show that the spatial errors introduced by the AA system are small as compared with the system level geometry and convergence tolerances for the display system.

At this level of measurement precision, it has become practical to guarantee that automated spatial alignments are at least as good as the best manual alignments. A comparison of the channel-to-channel variation in luminance and color after manual and automated adjustments revealed the residual variance after automated adjustment was one third of the variance after manual adjustments.

For years, flight simulator customers have expressed a strong desire for display system resolution levels that far exceed the capability of currently available (affordable) display technologies. The realization of “eye-limiting” resolution for Level D commercial flight simulators would require some of 30 to 60 M pixels, whereas the typical simulator of today produces only 4 to 8 M pixels. This author suggests that the use of comprehensive, accurate, and reliable AA systems is the logical next step in the evolution of flight simulator display systems design. The past few years have seen a strong trend towards the use of more, smaller, and less expensive image generators for flight simulators. Numerous parties have promoted the use of more, smaller, and less expensive projectors as well.

The use of comprehensive, accurate, and reliable AA systems is essential to the success of this approach.

Introduction

This paper describes an AA system designed for any Barco projection system but first fielded for CRT projectors. Due to space constraints, the description of the use of the AA system for LCD and DLP projection systems will be provided in a future paper. The reader is invited to review the appendix to examine the definitions of key terms so as to avoid potential confusion with other meanings for these same terms. For example, the reader is encouraged to review the difference between blend zone alignment (spatial) and edge blend adjustment (intensity), as well as the difference between unfocus and defocus.

Display System Complexity

The degree of difficulty of the projector adjustment problem can be illustrated by examining the number of measurements and adjustments required. For example, a complete spatial alignment of a five-channel projector system using the specified 11 x 11 pattern for each channel (plus 20 additional alignment marks per blend zone) requires a technician to consider the absolute and relative positions of some 2,055 alignment marks and make adjustments using up to 1,100 separate projector controls. Most of the projector controls affect more than one mark and a few of the controls affect most or all of the marks. Until the recent development of modern graphical user interfaces, such as that used on the Barco Genesis 3 projector or the XRACU interface to Barco multi-projector systems, there was typically no simple one-to-one relationship between the controls and their effects on the positions of specific alignment marks. A “divide and conquer” approach to spatial alignment generally did not work. Technicians must be well trained and acquire significant experience in order to understand the complex relationships between controls and alignment mark positions, as well as the most efficient order in which to make the adjustments.

The preceding paragraph describes only the spatial alignment of the projectors. In addition to the spatial alignment controls, the technician may have to visit several hundred additional controls in order to adjust static and dynamic focus, black level, peak white, shading, and edge blending. The complexity of the adjustment problem is high enough that a well-trained, highly experienced technician requires somewhere between many hours and several shifts to completely align a five-channel flight simulator from scratch.

The high complexity of the alignment problem leads to expense in two distinct ways. First, the training center must keep on staff one or more well-trained and experienced display systems technicians. It is likely that these technicians must be retained full time, even though they spend only a fraction of their time making adjustments. Second, the simulator must be taken out of service for a significant amount of time for routine maintenance tasks such as CRT replacement. In most training centers, the opportunity cost of taking the simulator out of service far exceeds the expense of the technician who must realign the system.

Capabilities and Limitations of Human and Automated Alignment Systems

Relative to machines, few would argue that humans are ill suited for the role of aligning multi-projector systems. Perhaps the most obvious reason is humans have a difficult time sustaining their performance on monotonous tasks for many hours at a time. To date we have not yet encountered a technician who desires the arduous job of making these projector adjustments.

A second argument in favor of automating the adjustment task is that the typical technician is capable of making adjustments to only a single control at a time while considering the positions of only a few alignment marks at a time. Using this strategy,
the technician must traverse a long path through many combinations of projector controls and the alignment mark positions they affect. In sharp contrast with this human-based approach, modern personal computers running multi-dimensional parameter optimization algorithms are capable of calculating the effects of hundreds of controls on the positions of thousands of alignment marks within a matter of seconds.

One noteworthy advantage that humans have over most of the projector alignment systems developed prior to ours is that humans can make very rapid “measurements” of the state of alignment without making any control adjustments. For convergence errors and errors in geometry that can be seen by comparing the projected alignment marks with those produced by the alignment slide projector, technicians require only a few seconds to determine which portions of the total field of view require adjustment. Using this rapid review capability in conjunction with their “mental model” of the projectors, the experienced technician is generally capable of prioritizing and making adjustments to only those controls that have the most direct and largest effects. In other words, the technician typically will adjust only a small fraction of the total set of controls as they will have decided that most of the controls are not needed to correct the particular set of alignment errors present in the display system. For an automated alignment system to exhibit speed comparable with human technicians, it would seem useful to mimic this human-like ability to rapidly assess the state of alignment without the encumbrance of making control movements or other processing steps that require significant time.

Adjustment Objectives

When making corrections to the spatial alignment, the technician will usually try to achieve several distinct objectives for each alignment mark. For example, it is usually desirable to move each alignment mark so that it simultaneously meets a geometry objective (place the marks at their desired positions as measured with a theodolite) as well as a convergence objective (accurately co-align corresponding red, green, and blue marks). (A theodolite is an optical instrument used to measure angles precisely -- less than 0.1 arcmin of error). For alignment marks within a blend region between channels, a third objective must also be pursued, as the corresponding marks from two channels must be co-aligned.

If actual display systems exactly matched the CAD drawings and projectors were perfectly capable of warping the image to any arbitrary shape, and the alignment system measured the positions of alignment marks with absolute accuracy, there would be no need to have separate convergence and blend zone alignment objectives. All three objectives would be achieved if the geometry objective was achieved: if the corresponding red, green, and blue alignment marks in all channels exactly coincided with their geometry targets, then convergence and blend zone alignment would be perfect as well.

In a typical display system, however, several practical realities conspire to make this strategy unusable. First, variations in the performance of the deflection and warping hardware within and between projectors must be expected. The alignment system must be able to account for this variation and must be capable of accurately superimposing images, even if one or more of the warping systems does not have the capability of achieving the desired shape as defined by the geometry targets.

Second, the use of a target or a head up display (HUD) projector in the simulator will generally mean that projectors of two different types (and mounted in two different positions) must be capable of achieving exactly the same shape. Again, the alignment system must be able to align the images to each other more precisely than it aligns either image to the geometry targets.

Perhaps the most common reason it may not be possible to achieve very tight geometry in modern flight simulator display systems are the unavoidable local variations in the shape of
stretched film collimating mirrors, especially along their edges. When these variations affect a portion of the field of view (FOV) that is small relative to the size of a single channel, it may not be possible for the projector to completely compensate for the localized spatial distortion. In this case, it is very important to maintain tight convergence, even if the projector cannot follow the variation in geometry.

Multiple Specifications

For decades, the specifiers of flight simulator display systems have acknowledged that it is generally not possible to achieve perfect geometry as evidenced by the fact that they include separate specifications for geometry, convergence, and blend zone alignment. Typically, the tolerance on convergence is the tightest at a few arcmin. The blend zone tolerance is usually set to about twice that of convergence and the geometry is often set at around 10 times the convergence tolerance.

Zones

It is also generally appreciated that modern display systems are not capable of equal performance everywhere within the total field of view (TFOV, across multiple channels). For this reason, most specifications allow for more stringent tolerances within the primary (central) viewing areas and wider tolerances for those portions of the FOV, which are less used or less important. For example, geometry specifications are often doubled for those portions of the FOV that are across the cockpit or can be seen only by leaning out of the design eye box.

AA System Design Strategy

While display system suppliers are not likely to advertise the fact, a comprehensive AA system must be designed with the explicit assumption that the display system will not be capable of attaining perfect geometry. Given this fact, the Barco AA system was designed with a rich set of controls that allow the setup technician to control the trade offs that must often be made between multiple and sometimes competing alignment objectives. Specifically, the AA system allows the setup technician to specify the relative importance of five or more distinct objectives for spatial alignments: convergence, blend zone, geometry, raster-calligraphic co-alignment, and co-alignment of HUD or target projectors. Additionally, the AA system allows the setup technician to control the relative importance of these error types in different customer-defined zones within the TFOV. Using these “objective level” controls, the setup technician can tune the AA system to nicely emulate many of the complex alignment trade-offs that must be made by human technicians.

Defining System Geometry

Geometry Goals for System

At the level of the display/visual system, the maximum allowable geometry error for multi-channel flight simulators is often specified as +/- 1.0° (about twice the tolerance allowed for the projectors). Within modern multi-channel flight simulators, these geometry errors are measured and controlled with the aid of two distinct “standards: a theodolite and an alignment slide projector with associated slide.

Projector Capability

For more than a decade, electronic projectors designed for multi-channel flight simulators have been specified and designed to provide a wide enough range of image distortion such that geometry targets can be achieved reliably to within +/- 1 percent of the channel height. For a channel that is 45° high, this corresponds with a maximum geometry error of 27 arcmin. To achieve this level of performance, a significant portion of the projector electronics, firmware, and software is dedicated to the generation and precise control of distortion signals that are summed into the deflection system.
Primary Geometry Standard

The theodolite usually serves as the “primary” standard against which the overall display/visual system geometry is measured. Once a simulator has been set up and aligned, the acceptability of the overall system is assessed by mounting a theodolite at the design eye point (DEP) and measuring the relative angles amongst a set of marks that are projected by the electronic projectors. The theodolite serves admirably in the role of primary standard since the maximum error introduced by the theodolite is less than 1/600th of the tolerable error for the system.

Secondary Geometry Standard

While the theodolite can measure the angular positions of alignment marks with great precision, it is far too awkward and time consuming to use a theodolite to check geometry on a regular basis. For this reason, the customers of multi-channel display systems for flight simulators use a “secondary” or “working” standard that can be used to more rapidly and conveniently check geometry. Typically, this secondary standard takes the form of a slide projector with a fixed pattern on a slide that has good geometric stability over time and temperature. Very often the alignment projector and slide are designed so as to project dots or grid intersections at five-degree increments as viewed from the design eye point (DEP).

By using the slide projector as the secondary standard, the alignment of all projectors within the system can be checked visually by turning on both the alignment projector and the electronic projectors at the same time and looking for the mismatch between the locations of the alignment marks produced by each. Using this method, the geometry of a system can be evaluated in a small fraction of the time it would take to measure the alignment marks using a theodolite.

The successful use of a secondary standard depends critically on the accuracy of the secondary standard. It is generally expected that a secondary standard will not be as accurate as the primary standard on which it is based. If it were, the secondary standard would displace the primary standard because it is more convenient. The reduction in accuracy is accepted as an unavoidable tradeoff that must be made for the sake of convenience. It is also generally expected that any standard that will be used to align the system will introduce a negligible amount of error (e.g., less than a few percent) into the system. For the typical flight simulator with a total error budget of +/- 1.0°, one might expect the secondary standard to introduce no more than a few arcmin of error. At this level of error the secondary standard would be allowed to have 10 to 20 times the variance of the primary standard; however, the error is still less than 5% of the total error budget and would not contribute significantly to the overall system error.

Unfortunately, practical experience with alignment projectors and slides indicates that it is difficult to achieve accuracies of a few arcmin. Median geometry errors in the range of 15 to 30 arcmin are likely with maximum errors exceeding 1° being common. The technician who aligns the system geometry to match the alignment slide projector essentially must assume that the slide projector is accurate as they have no other source of geometry information. Any errors introduced due to limitations in the projectors or the skill of the technician is added to those inherent in the alignment slide; therefore, the total error is larger than the error in the slide.

AA System Design Strategy

The use of the Barco AA system as an integral part of the display/visual system makes possible an elegant solution to the problem of excessive errors in the secondary geometry standard.

When the visual system vendor installs the screen/mirror system and associated alignment slide projector, they are required to measure the alignment marks from the DEP using a
theodolite for the purpose of acceptance testing the screen/mirror/DEP geometry. Consequently, for each simulator, a table of measured azimuth and elevation data is acquired for each alignment mark. By taking the difference between the measured and the nominal (desired) positions of the alignment marks, any geometry errors in the alignment slide can be found.

The Barco AA system was designed specifically to use both the nominal and measured locations of the alignment slide marks so that the unavoidable errors in the alignment slide can be determined and accounted for. By employing this strategy of canceling the alignment slide errors, the overall system geometry errors are significantly less than the errors in the secondary geometry standard.

Design Goals

As the previous sections illustrate, multi-projector systems are inherently complex. For this reason, great care was taken with the design of the Barco AA system to keep it simple. This section presents the overall design goals that served as drivers for simplicity.

Alignment, Not Re-alignment

The AA system was designed to “align from scratch”, meaning that a technician does not have to initially prepare a “golden alignment” for the purpose of teaching the system the geometry targets. Rather, geometry is simply specified using a table of azimuth and elevation values indicating the desired locations of the alignment marks. The AA system can start from any arbitrary state of spatial alignment with no need for a technician to pre-align or approximately-align the system.

Pilot Coordinates

The AA system uses the pilot-centric coordinate system (azimuth and elevation, measured from a customer-defined eye point in the cockpit) as the primary coordinate system. The customer, users, and IG programmers do not need to work with any other coordinate system, such as pan and tilt angles, screen dimensions, projector locations, direction vectors, etc.

Single Sensor

The AA system uses a single, camera-gimbal assembly with no other sensors mounted to the projectors or screen. Some competing alignment systems use up to 20 sensors in addition to a camera. The single sensor approach eliminates the need for sensor-to-sensor calibration to achieve uniform measurements across sensors.

User Interface

The inherent simplicity of the AA system is reflected in the user interface that is configured for five-channel simulators at LRAFB. See Figure 1.

Spatial Alignments

The AA system performs two distinct types of spatial alignment: Re-Align and Rough-Align. Both of these functions involve the spatial positioning of the same set of alignment marks but differ in their goals.

The Re-Align function is the “work horse” function intended for use on a regular basis. This function exercises all of the analog geometry and digital convergence controls for the purpose of achieving the geometry, convergence, and blend zone alignment goals. During the process, the system measures the
positions of 161 alignment marks arranged in an 11 x 11 array in the main body of the channel with 20 extra marks occurring in each blend zone.

A prerequisite for running the Re-Align function is that all of the alignment marks be “identified”. By definition, the alignment marks are considered to be identified if all of the marks on a channel are within a radius of less than about 2° of their desired positions as defined by the geometry targets. When the display system is in this state, then all of the marks can be turned on at once and the AA system can reliably identify each mark without confusion. Flight simulators are not expected to drift far enough out of alignment that the marks are not identifiable except on rare occasions such as a motion base failure, a landing which is hard enough to bend the simulator or visual system, a projector failure, or a CRT replacement.

The Rough-Align function was developed to handle the case of unidentifiable alignment marks. Two conditions where the Rough-Align function is expected to be used include the first installation of the display system and periodic replacements of CRTs. The sole purpose of the Rough-Align function is to get the display system into a state where all alignment marks are identified. Once the marks are identified, the Re-Align function is used to achieve the geometry, convergence, and blend zone alignment goals. The Rough-Align function solves the identification problem by iteratively presenting and adjusting a small number of alignment marks at a time. The Rough-Align process is more time consuming than the Re-Align function and has been allocated to a separate function, as it does not need to be performed except in unusual circumstances. The Rough-Align function pursues only the geometry goal and ignores the convergence and blend zone alignment goals. Consequently, the Re-Align function must be invoked after running Rough-Align.

Focus

Within the AA system, the Focus function measures and adjusts the degree of electronic focus of the electron beam of each CRT. Electronic focus adjustments are performed for both the static and dynamic focus systems. For CRT projector systems, optical focus and Scheimpflug adjustments are not considered by the AA system, as we know of no CRT projectors for which these adjustments have been motorized. Electronic focusing is accomplished using a sensitive measurement and control system that finds the point-of-best-focus (PBF) for each portion of each channel. For those cases where the customer may not want the tightest possible focus, such as raster blue dots, the AA system allows each channel to be unfocused (see Appendix A) by a specified amount.

Intensity Functions

The intensity related functions include the measurement and reporting of gamma curves and the adjustment of G2 and contrast for the purpose of controlling the black and peak levels for each color and optimizing color tracking across the primaries.

The peak intensity of each CRT within a multi-projector system will be based on intensity measurements made of the red, green, and blue components of a single color-balanced white field that has been set up using a National Institute of Standards and Technology (NIST) traceable colorimeter. Presumably, once during the initial setup of the AA system, a simulation center technician equipped with a colorimeter will set up the peak luminance and color balance of a single channel based on measurements made from a customer-defined point (e.g., the DEP) from within the aircraft cockpit. Based on the levels obtained in this initial setup, the AA system will learn the intensities for the red, green, and blue CRTs as measured by the AA camera. During subsequent alignments, the AA system will bring the peak intensities of the red, green, and blue CRTs back to these intensities,
stabilizing the light output of the CRTs as they age.

The intensity test pattern consists of a 6 x 6 square array (checkerboard) of small squares, each square set to a different intensity level as commanded by the IG. Using this test pattern, the AA system is capable of measuring the entire gamma curve with a single measurement for an order of magnitude improvement in speed over sequential methods of measuring gamma curves. An example of a gamma curve provided by the AA system is shown in Figure 2. Note, that these gamma curves are normalized to a maximum of 1, as they do not indicate absolute intensity information directly. Rather, a value of 1 in the gamma curve corresponds with the peak luminance for that color that was measured during the set-up procedure.

![Figure 2. AA System Gamma Curve.](image)

**AA System Performance**

The AA system consists of a camera-based measurement system and a projector communications module that operate under the control of an automatic multi-dimensional parameter optimizer. This means two distinct types of specifications are necessary for describing the performance of the AA system: (1) specifications that describe the capability of the measurement system to measure alignment marks and (2) specifications that describe the ability of the projector (or set of projectors) to achieve an alignment given the distortion requirements that result from the design of the optical system (that is, screen, mirror, DEP, and projector placement) for any particular simulator.

Specification of the measurement portion of the AA system is quite straightforward. When making absolute position measurements of alignment marks (as compared with the theodolite), the standard deviation of the errors introduced by the AA system are no greater than 1.5 arcmin. When making relative position measurements, as is done for convergence and blend zone alignment, the standard deviation of the errors introduced by the AA system are no greater than 0.4 arcmin. Note, that these errors are quite small when compared with the overall system specifications of +/- 1° for geometry and +/- 2.5 to 8 arcmin for convergence and blend zone alignment.

Specification of the performance of a set of projectors operating under the control of the AA system is inherently complex because the overall system performance depends primarily on the capabilities of the projectors and the unavoidable anomalies that occur in the design of the display system optics. We know of no way to independently test the performance of the AA system as installed in a flight simulator.

The complexity of verifying the proper operation of the AA system in an operational simulator is greatly reduced if we make the simplifying assumption that the errors introduced by the AA system are such a small fraction of the total error budget that they can be ignored. This “zero error” assumption simplifies the system level Acceptance Test Procedure (ATP) because we can then simply adopt the projector system specifications as the specifications for the combined projector and AA system. Stated differently, we are confident enough in the performance of the AA system that we guarantee that the projectors working under the control of the AA system will work at least as well as the same projectors working under the control of well trained and diligent simulation center technicians who are given sufficient time to keep their display systems well tuned on a
daily to weekly basis. Quite a promise, given that only two years ago we could find few people who believed that an automated system would ever perform as well as technicians.

On the flip side, one must realize that the AA system in no way alters or improves the basic ability of the projectors to warp, converge, or focus images. The best possible alignment that can be achieved by the AA system is no better than the best possible alignment that can be achieved by a skilled technician who takes the time required to make a complete manual alignment.

While in theory the AA system can align no better than a skilled technician, the AA system can achieve an alignment in a small fraction of the time required by a technician. A full manual alignment of a five-channel simulator requires many hours of tedious work; therefore, in practice the typical image quality produced in these systems is lower than the projectors are capable of producing. Using the AA system will allow a technician to maintain image quality within specifications with a significantly reduced workload, as the most time-consuming alignment operations are performed automatically.

**Alignment Times**

The expected alignment times described here are estimates of the time required for the AA system to execute the re-alignment tasks, which include adjustment of geometry, convergence, and blend zone co-alignment using 72 analog parameters and 150 digital parameters for each projector and 161 alignment marks per channel. These estimates are heavily dependent on the particular IG used as a significant portion of the alignment time is spent waiting for IG patterns to load and change.

When the start button is pressed, the AA system first runs through a camera-gimbal initialization process, which takes about two minutes to complete. During the alignment the edge blend must be disabled, so the system needs about 30 seconds to null the edge blend adjustments for five projectors. Once the alignment operations are complete the AA system restores the edge blend adjustments, which requires another 30 sec for five projectors. As a result, the total “overhead” incurred each time the AA system is initiated is about three minutes. If the projectors are started from a null position, as they would be after replacing a CRT, then the Rough-Align function must be used for an additional three minutes per projector.

The time required to re-align geometry, convergence, and blend zones using all projector controls and all alignment marks is approximately two minutes per projector. Totaling the overhead and per-channel times gives 13 minutes to completely re-align a five-projector system fast enough that the realignment can be performed on a daily basis if desired.

**Design Implications for Flight Simulators**

1. Speed and accuracy are high enough that daily adjustments are now practical, keeping the system in the best possible state of alignment.

2. Down time for CRT replacements and other maintenance tasks, which perturb the state of alignment, are significantly reduced.

3. One button, robust operation will lead to a significant reduction in the training requirements for simulation center technicians.

4. Geometry errors in the secondary standard can be removed. There is no longer a need to iterate the design of the alignment slide to obtain sufficient accuracy.

5. IG-based gamma correction tables can be updated on a regular basis, which may allow CRT life to be extended while maintaining acceptable color balance and tracking.

6. The ease of gamma correction may allow new and old CRTs to be mixed within a single simulator.
7. Alignment procedures are simplified, as a single Re-Align function achieves all geometry, convergence, and blend zone alignment goals in a single pass. No need for a more complex “good”, “better”, and “best” approach.

8. Hardware installation time is minimal as a single sensor is used.

9. Alignment slide projector system can be eliminated once customers are confident they no longer need manual alignment as a backup to the AA system.

10. The AA system can assist with maintenance scheduling by indicating when CRTs are approaching their end of life.

11. The AA system can aid projector system diagnostics by providing data indicating the health of key projector subsystems, such as warp engines.

Appendix A – Selected Terms and Concepts

During the process of developing the AA system, it has been shown useful to precisely define terms in order to facilitate discussions among developers, managers, vendors, and customers. This appendix defines selected terms that have caused the greatest confusion, as they are generally terms that may be defined differently by various parties.

**AA System**

Automated Alignment system. Refers to the Barco Model 6100.

**Alignment Slide Projector**

A reference slide-projection system often used to set up the geometric alignment of multiple projector systems. Alignment slide projectors are the most common form of “secondary geometry standard” (see below) used in commercial flight simulators. The alignment projector is separate from the projectors being aligned and can be distinguished as having high-geometric stability over long periods of time. Typically, an alignment slide projector must present an array of hundreds of dots or line intersections that are approximately uniformly distributed over the total field of view of the multi-projector system. Alignment slide projectors are sometimes referred to as *sphere*, *reticule*, or *gradicule* projectors.

**Black Level**

Refers to the adjustment of projector controls such as grid voltage (G2) and contrast with the goal of achieving black levels and uniformity across channels.

**Blend Zone Alignment**

Refers to the *spatial co-alignment* of the green alignment marks from one projector (within the blend zone) relative to the green marks projected by an adjacent projector (within the blend zone). Note the difference between blend zone alignment and edge blending.

**Co-alignment of Images**

The spatial positioning of one image, so that it accurately overlays another. Image co-alignment examples include the alignment of calligraphic images relative to raster, the alignment of a head up display (HUD) or a target projector image within a channel, and the relative alignment of the left and right eye images for stereoscopic display systems.

**Convergence (Analog and Digital)**

Refers to the spatial co-alignment of the red, green, and blue alignment marks within a projector.

**Edge Blending**

Refers to the adjustment of *intensity* across a blend zone with the goal of maximizing brightness and color uniformity. Note the
difference between edge blending and blend zone alignment.

**Focus, Electronic** *(Static and Dynamic)*

Refers to the adjustment of the degree of focus of the electron beam that produces dots at the CRT.

**Gamma Curve**

Refers to the measurement and reporting of the electro-optical response curves for each of the red, green, and blue primaries. Gamma curves are made available to facilitate the generation of IG-based gamma correction curves that are used to maximize color tracking and balance among channels.

**Geometry**

Alignment is defined as the alignment of the spatial positions of green alignment marks projected by each channel with respect to their desired positions. Refer to *Primary and Secondary Geometry Standards* in the Defining System Geometry section for a description of how a customer may specify the desired positions of alignment marks.

**Identification of Marks**

A projected alignment mark is *identified* when that mark (and no other mark) is within a threshold distance of its desired (target) location. Typically, the identification threshold distance is set at 1.5 to 2°, which is just under half of the desired inter-mark distance. When all alignment marks are within this threshold distance then all marks can be turned on at once and the AA system will not confuse one with another. When at least one mark is further than the threshold distance from its desired location, the AA system can potentially misidentify it if all marks are turned on at once. In this case, you would need to run the Rough-Align program, which handles the potential confusion between alignment mark identities by controlling their presentation.

**Intensity**

The AA system measures the relative intensity of test patterns. It does not measure “luminance”, “illuminance”, “chrominance”, “chromaticity coordinates”, or “color” as these terms have specific meanings as defined by the Commission Internationale de l’Eclairage (CIE). The formal measurement of these parameters requires measurements made from the pilot’s position using light measuring instruments that have been calibrated against photometric standards and traceable back to primary standards maintained by a governing body such as the National Institute of Standards and Technology (NIST).

**Peak White**

Refers to the adjustment of projector controls, such as contrast and grid voltage (G2), for the purpose of setting the peak white point of the system.

**Re-Align**

Function involves the adjustment of spatial positions of alignment marks with the goal of achieving the geometry, convergence, blend zone, and multiple image co-alignment objectives.

**Rough-Align**

Function involves the approximate alignment of geometry for the sole purpose of identifying the alignment marks. The rough align function is invoked only for the case of a profound perturbation in geometry such as might occur when the projectors are first installed or CRTs are replaced. The Re-Align function must be invoked after the Rough-Align function has been used.

**TFOV**

Total field of view for a display system, spanning all projectors/channels.
Unfocus

Refers to the intentional, relatively permanent, defocusing of the electron beam for the purpose of reducing phosphor saturation and stabilizing color tracking and uniformity. Users of CRT projectors typically unfocus only the blue CRT; however, the AA system allows all three colors to be unfocused if desired. The term “defocus” is not used here as this term traditionally has been used to describe the temporary, scene-dependent defocusing of the electron beam often used for the purpose of simulating weather effects such as fog and the blurring effect of rain on the aircraft windscreen.

XRACU

Barco’s remote alignment control unit interface for controlling a multiple-projector system. The X in the XRACU acronym denotes the variability of projector types this software can handle. That is, you can have multiple types of Barco projectors – a mix of up to 16 total projectors – in your system. The XRACU software is compatible with a variety of projectors.

Document Location

This document is stored on the following site:

The address is:
http://charleslloyd.us.com/Towards_the_Rapid_and_Complete_Automated_Alignment_of_Multi-Projector_Display_Systems.htm