Construction Proposal, 3rd Level Review 10/22/15

1. Executive Summary

Objection with Comments

The proposal has a physical and/or electromagnetic radiation effect upon the LAX north and LAX south ASR-9/Mode S radar facilities. The proposal affects the quality and/or availability of LAX's radar signals to the Southern California TRACON (SCT). Effects: 1) An increase in false beacon targets and target jumps and splits directly from the proposal due to multipath reflections. False targets would be caused by aircraft movement west of Hawthorne and Compton and placed on or near runway approaches 24L, 24R, 25L, and 25R. Target splits and jumps will occur with aircraft on each of the four westward approaches. 2) Although there are features in the Mode-S and STARS automation designed to prevent these types of reflections from displaying, breakthrough is expected as a result of the unusual configuration of the proposed structure and its placement. Other AT Facilities Affected: ZLA ARTCC

Effects to radar coverage include:

a) False beacon targets on or near all four westbound approaches into LAX
b) Beacon splits and jumps for aircraft on all four westbound approaches into LAX
c) Garbling of beacon downlink data from RW 24L and 24R approaches that will cause aircraft transponder and altitude codes to change briefly

The above assessment was made with the understanding that the location of the LAX airport approaches, radar detection equipment, and the proposed stadium create a geometry that will place false beacon targets and target jumps on or near the critical approach paths if post-detection processing in the radar equipment and the STARS automation cannot detect and remove them. The proximity of ATCRBS traffic from nearby Hawthorne Municipal Airport in class D airspace operating in radar shadows produced by nearby building is expected to provide opportunities for false beacon targets that cannot be mitigated.

Analysis of the measure of reflectance of the stadium in this study has been performed using classic radar cross section models normally encountered for rectangular and cylindrical buildings. This method provides a conservative estimate for the radar cross section. If it is desired to pursue a more exact estimate or an analysis of a change in structure or material, then it should be done using more detailed surface rendering and modeling techniques.

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Possible design changes for mitigation include:

1) Relocate stadium
2) Lower the above-ground profile
3) Reshape the face of the structure in a way to reduce the radar cross section
4) Replace reflective surface material with a non-reflective material
5) Consider radar absorbing material as a coating over reflective surfaces

Contents

2. Risk Elements

2.1. Affected Facility

LAX – Los Angeles International Airport and Southern California TRACON (SCT)
ZLA – Los Angeles ARTCC

2.2. Affected Equipment

a. LAX north (LAXN) ASR-9 Radar w/Mode-S
b. LAX south (LAXS) ASR-9 Radar w/Mode-S
c. STARS Automation and Display System

2.3. Airport Operations Affected

Each of the four westbound approaches into LAX (24L-R and 25L-R)

2.4. Possible Effects Investigated

a. Radar line of sight
b. Primary radar false targets
c. False beacon targets situated on or near westbound approaches.
d. Beacon reply garbling, track drops and jumps along westbound approaches.

2.5. Hazards Associated with Proposal

LAX is the largest and most heavily utilized airport in the southwestern United States, ranked 5th in the world for passenger throughput[1]. Trade winds from the west and efforts to control noise levels over the heavily populated urban areas east of LAX favor a westerly approach pattern into the four parallel runways. The proposed structure identified in this paper is placed below and between the parallel approaches approximately 2.5 to 3.1 nmi from the runway thresholds. This is a critical area requiring precision monitoring of all aircraft activity. Hazards identified in this paper include the occurrence of false beacon targets and intermittent loss of beacon and/or altitude data for tracked targets along these approaches. Additionally, aircraft on the approach may jump laterally from reflections off the stadium surface, triggering a conflict alert.

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[1] Katia Hetter, CNN, 8/31/15

3. Configuration

The proposal being considered places a stadium structure near the center of the approach corridor into LAX. **Figure 1** provides a general idea of the configuration.

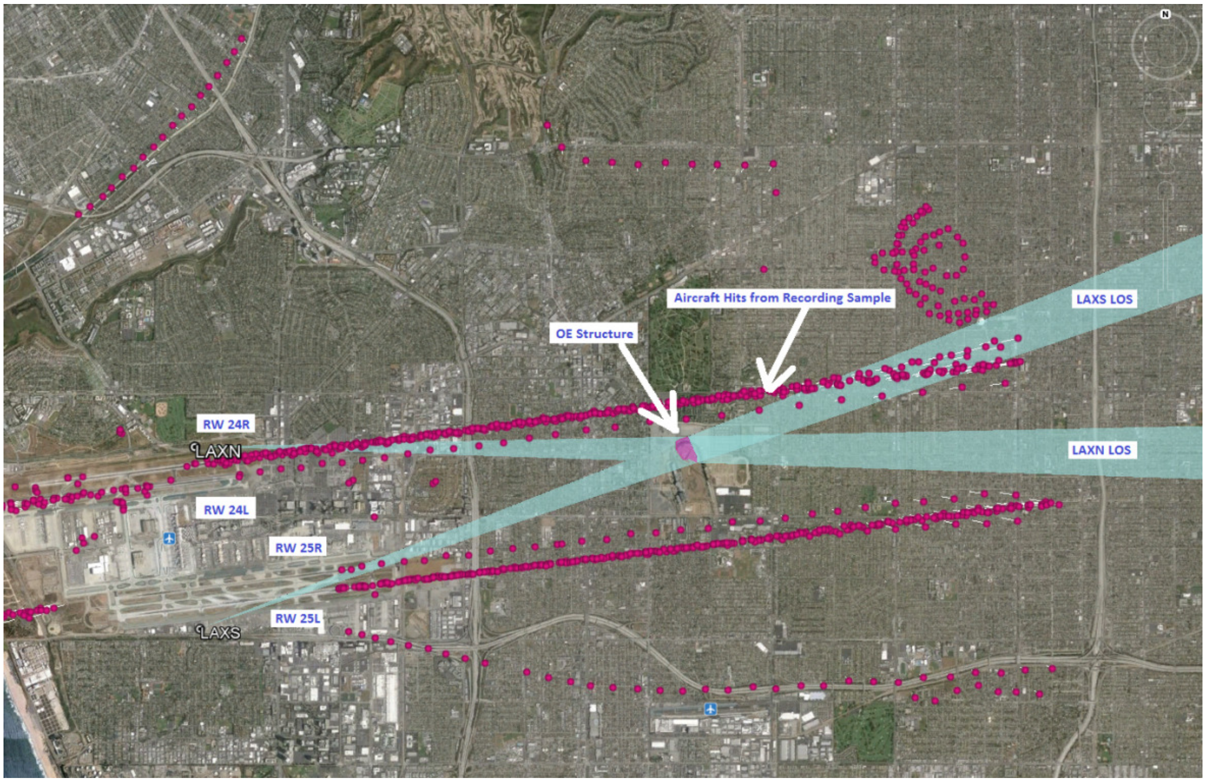

Figure 1 – General Configuration with Sample Recording

The pink polygon in the middle of **Figure 1** shows the outline of the proposed stadium structure and its orientation with respect to the runway approaches. LAX has two pairs of parallel approach runways: RW24L and R and RW25L and R. The red dots are a truncated view of aircraft 'hits' recorded over about 100 scans on an average day when the airport is running in west-flow conditions. The light blue wedges identify the line-of-sight (LOS) areas of concern between the radars and proposed structure. The extended wedges beyond the structure (to the right) indicate where false targets may be present if the structure is capable of a successful reflection and where reply code garbling or intermittent loss may occur if a multipath geometry develops.

Figure 2 shows one of several architectural renditions of the proposed structure and its orientation with respect to each of the two radars. The overall cross sectional dimensions as viewed from the two LAX radars are about 1,700' wide by 870' deep. The height of the structure varies over a series of complex curves. Elevation values included in each of the 7460 submissions were not found in any of the drawings received from the proponent, which is a small subset of the whole design. For this study 290' MSL was used as the highest point of the structure as indicated in 2015-AWP-6465-OE however reflective surfaces that may generate a hazard do not rise above 250' MSL. Those drawings received from the proponent showed elevations as architectural reference values. The MSL value is 70' lower than the architectural value in each case. For example, the floor of the stadium is at 100' as indicated in drawing X6-01, or 30' MSL. This elevation is about 95' below the ground level of 125' MSL.

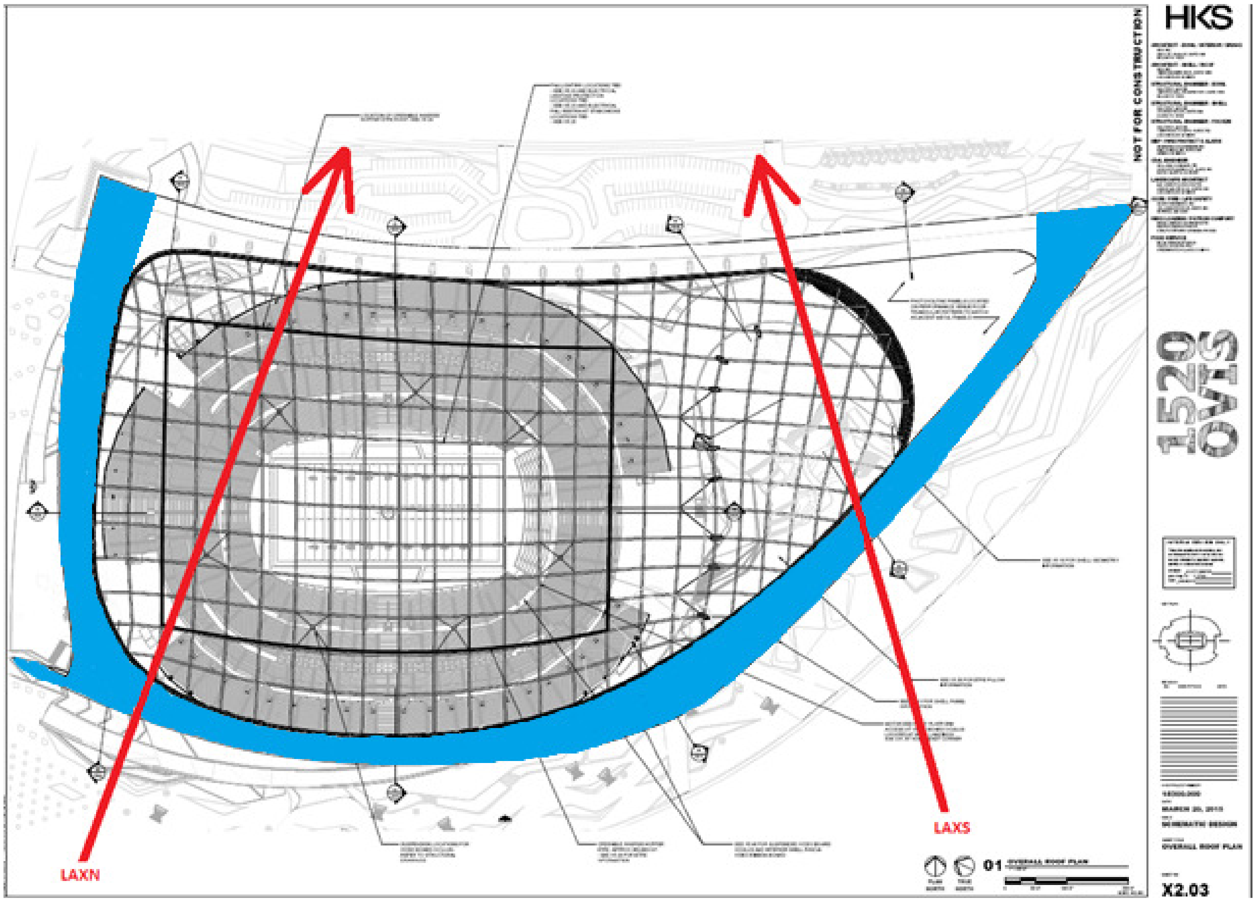

Figure 2 – Plan View of Structure

The drawing in **Figure 2** shows how the structure is encased in a metallic shell composed of triangular sheets approximately 5' on a side. This shell is composed of an aluminum skin similar to an aircraft fuselage except with holes in it. Its surface geometry is composed of continually varying curves, complicating attempts to characterize its reflective response to radar stimulus. **Figures 3 and 4** further illustrate this complex design. The blue shading has been added to highlight surfaces of significant interest to this study.

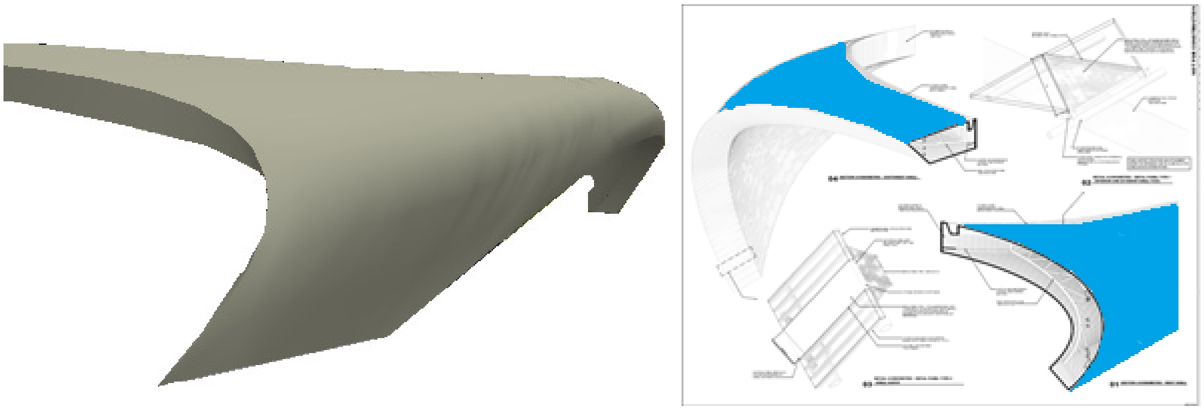

Figure 3 – Front Nacelle Edge Facing Radars

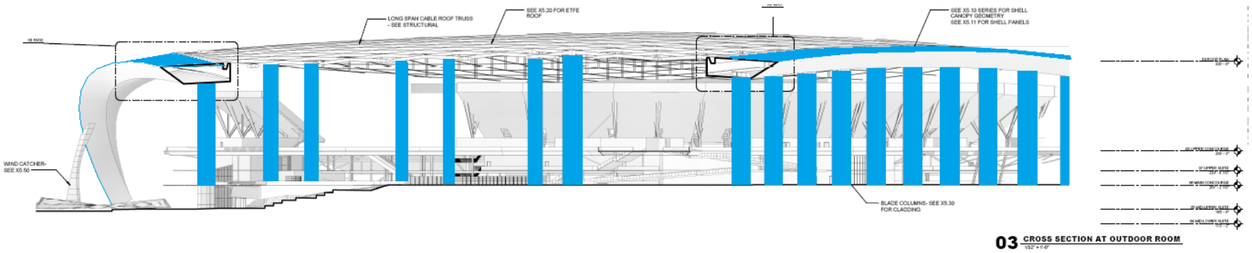

Figure 4 – Cutaway Elevation View from Drawings

The central roof, as shown in **Figure 5** is covered in a translucent fabric-like material stretched over cables in a pillow arrangement with a matrix of 5” diameter pipes and 1 ½” cables anchored to 24” support tubes. Each panel is about 15’ square and 4’ deep. Many, though not all, of these panels will hinge down to allow ventilation.

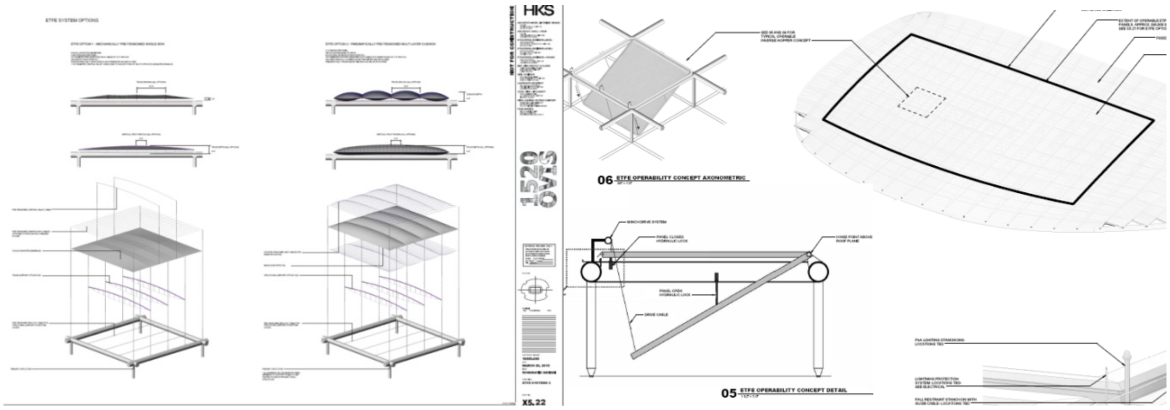

Figure 5 – Roof Structure

Analysis

The proposed structure is being evaluated mainly for the following impacts to FAA radar systems used for approach control into the LAX airport.

1) Radar line of sight obstruction
2) Primary radar false targets
3) Secondary beacon radar false targets
4) Radar and beacon multipath (fading)
5) Beacon reply code garbling geometries

3.1. Radar Line of Sight Obstructions

Shadowing results when an opaque object, (opaque to a signal of interest), is placed between the signal source (radar) and target (aircraft). At microwave frequencies an optical shadow does not necessarily mean a microwave shadow will be present as sharp, metallic (electrically conductive) corners, such as those on building edge flashing, can provide a path for microwave energy to wrap around into the optical shadow to a limited extent[2]. This effect, called edge diffraction, is well documented for ideal conditions but difficult to predict in real-world situations. Different edge radii and materials will affect the efficiency of the diffraction geometry. For this paper, edge diffraction is ignored and so the shadowing discussed will be optical, for worst case.

The following elevations used for the LOS study have been determined from examination of the supplied documents, 7460 submissions, and line-of-sight (LOS) analysis from each of the two radars:

1) Stadium site ground elevation	˜120’ to 130’	MSL
2) Peak of stadium roof	290’	MSL
3) LAX North Primary Radar	146’	MSL
4) LAX South Primary Radar	165’	MSL
5) LAX North Beacon Radar	152’	MSL
6) LAX South Beacon Radar	171’	MSL

The proposed structure has a maximum height of 290’ MSL at approximately 170’ above ground level (AGL) on the west side towards the radars. A model was built for radar simulation software[3] using 290’ MSL across the width of the structure for simplicity and worse case. The green area outlined in the top of **Figure 6** shows the shadowing expected from all ground obstructions projected on a 1,000’ MSL plane. The light green area indicated with the information bubble is the difference with the stadium added. An elevation profile of this geometry is shown in the lower half of the figure with the 1,000’ elevation shown as an orange line. Note that ranges indicated in the elevation profiles are in statute miles as a Google default.

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[2] “Theory of Edge Diffraction in Electromagnetics”, Ufimtsev, revised edition

[3] Software used for shadow analysis is the Radar Support System, or RSS, created and maintained by Technology Services Corporation.

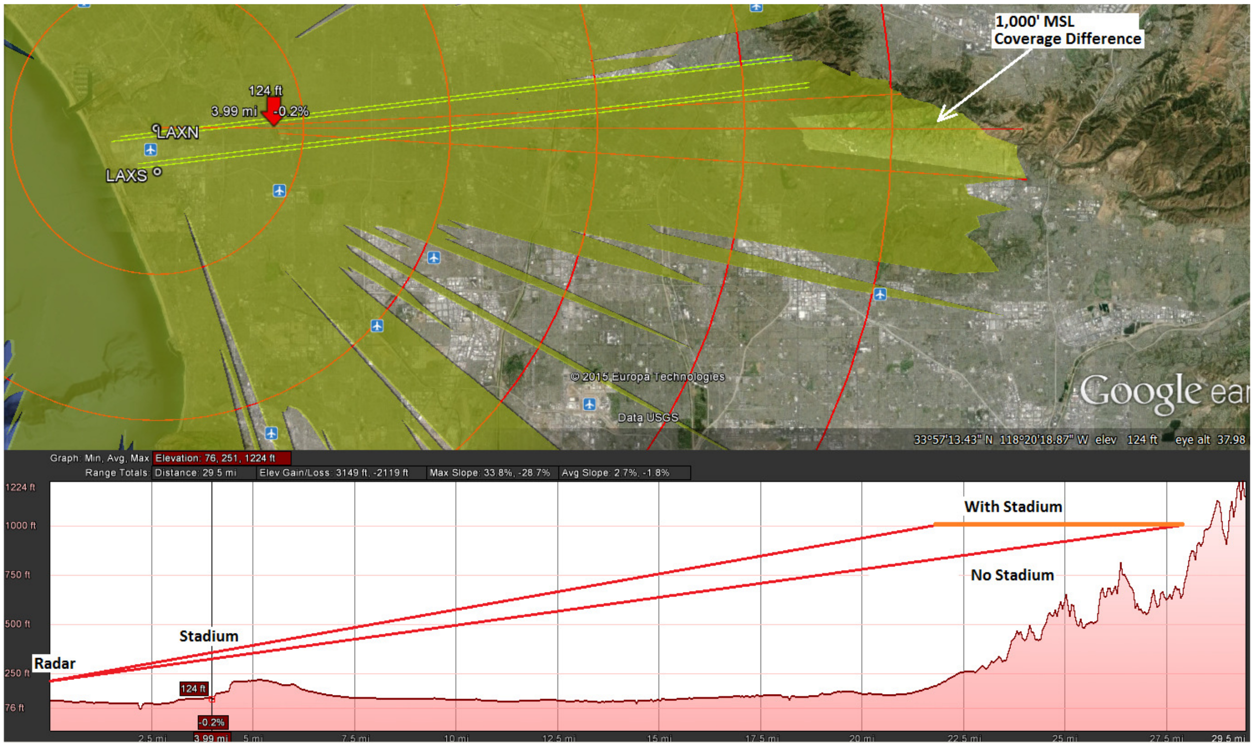

Figure 6 – Line of Sight Shadow for LAXN from Stadium to 1,000' MSL

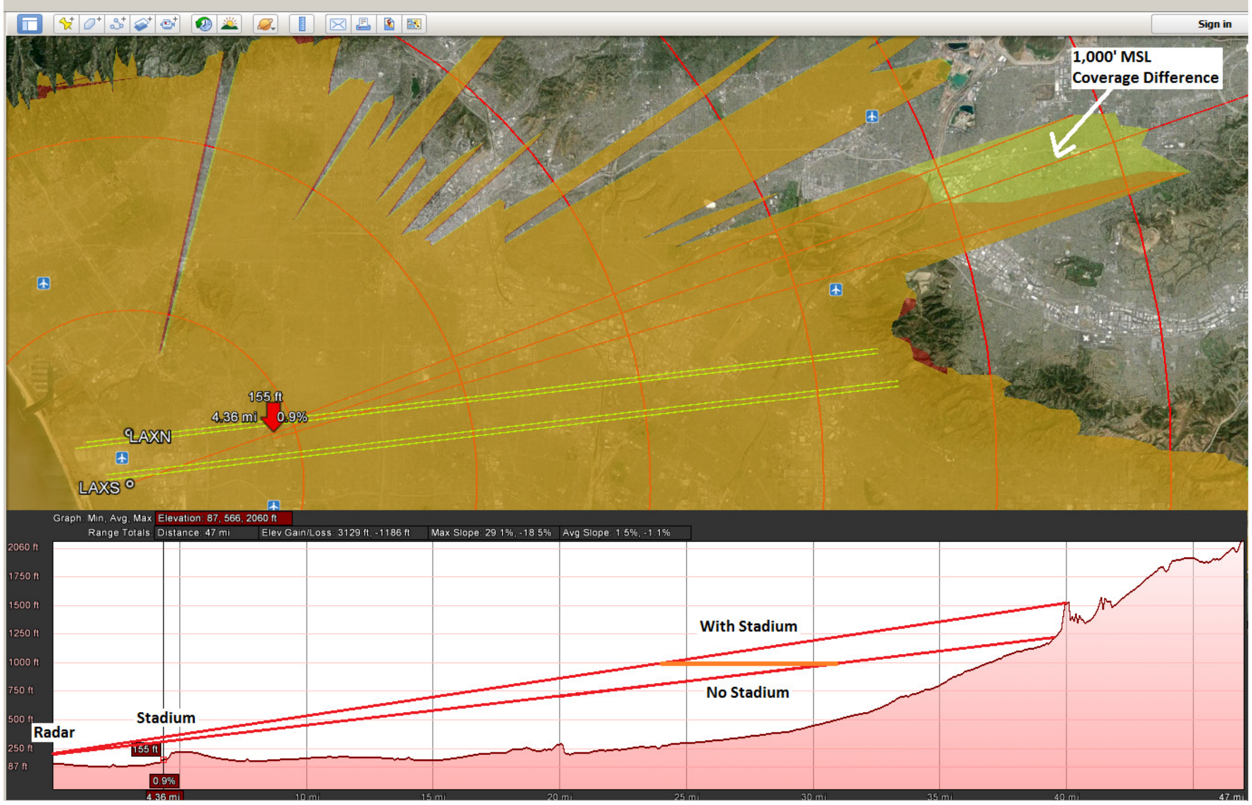

Figure 7 – Line of Sight Shadow for LAXS from Stadium to 1,000' MSL

Shadowing of LAXS radar from the stadium is similarly shown in **Figure 7** with the terrain rising into the lower edge of the coverage beam. This change in altitude coverage is not expected to affect coverage of aircraft intersecting the westbound LAX approaches or of any other airport approach, departure, jet route, or victor airway within 35nmi of the LAX airport.

3.2. Primary Radar False Targets

False primary returns resulting from reflection geometries are rare due to the high signal losses incurred at each reflecting surface. Although the stadium radar cross section is very large, its surface is covered with panels that have randomly placed holes that are ¼" to 1 ¼" in diameter. The hole sizes, some larger than ¼ wavelength[4], and placement are expected to disturb the reflected signal, reducing its ability to transfer a phase-stable signal to the radar receiver. Neither of the LAX primary radars are expected to suffer negative interference effects resulting from stadium construction.

3.3. Beacon Radar False Targets

Beacon false targets can arise in several forms and are almost always present in the raw data delivered from the target detection equipment to the post-processing equipment. This section will concentrate on predicted reflection geometries and how failures to remove false targets will impact the ability to monitor and control air traffic along the most critical sections of the LAX approach paths.

3.3.1. Geometry

Figure 8 shows the orientation geometry of the stadium with respect to the two LAX radars and the approach paths into the airport. If unintended transponder interrogations occur as a result of reflections off the stadium surface, a corresponding false image will occur in one of the two colored wedges shown below

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[4] $\lambda = 0.107$ meters = 4.21"

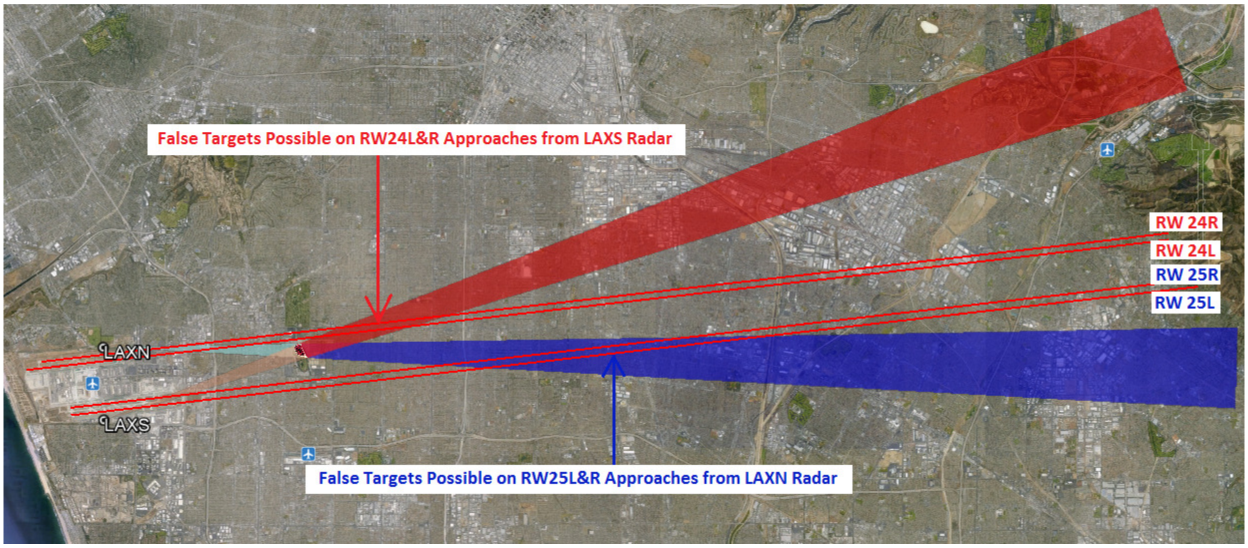

Figure 8 – Predicted Beacon False Target Geometries

Figure 9 looks closer at the geometry of the reflecting surfaces with respect to each radar. The west surface is curved not only north to south but presents a horizontal cylindrical nose to the radars as well, as depicted in **Figures 3 and 4**. These complex shapes determine the swept area and effective range that a reflected signal might successfully interrogate an aircraft transponder through the reflected path.

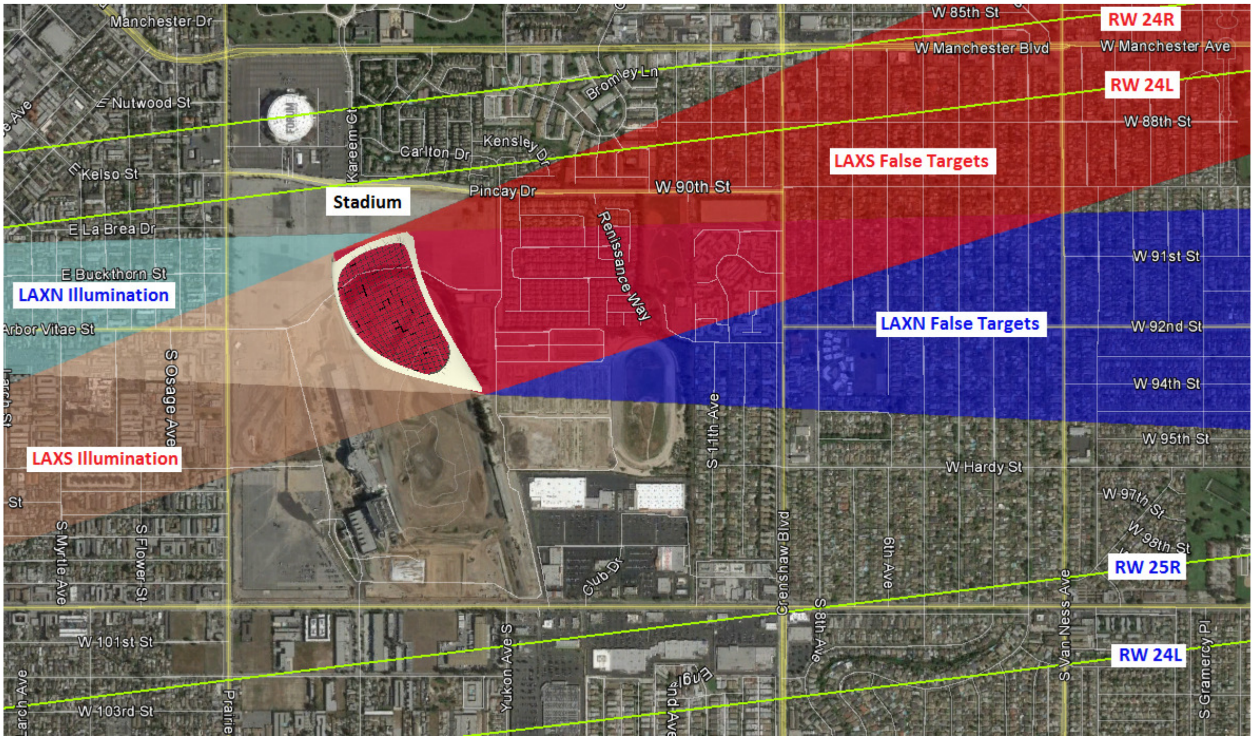

Figure 9 – Reflecting Surfaces

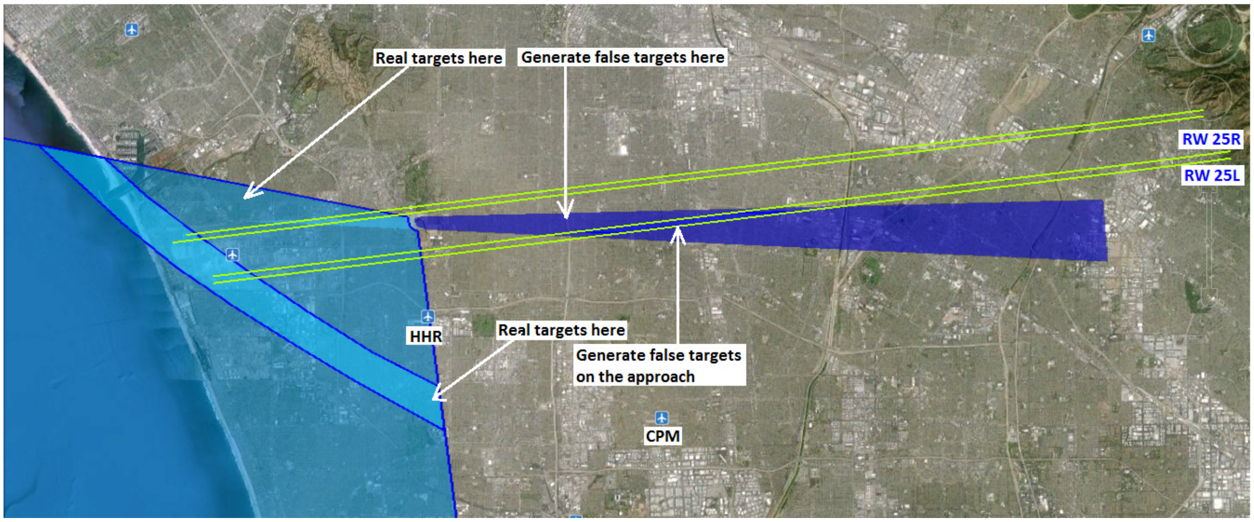

Figure 10 – LAXN False Target Geometry

Figure 10 shows areas in light blue indicating where real targets reflecting off the west stadium shell can generate corresponding false targets in the dark blue region. Of particular interest is the area within and boundaries surrounding the narrow light blue wedge marked “Real targets here”. If a false interrogation occurs within the edges of the narrow light blue wedge, it will show up between RW 25L and 25R approaches. And, if the aircraft is near the inner or outer edges of the narrow light blue wedge, the false image will show up directly on the approach.

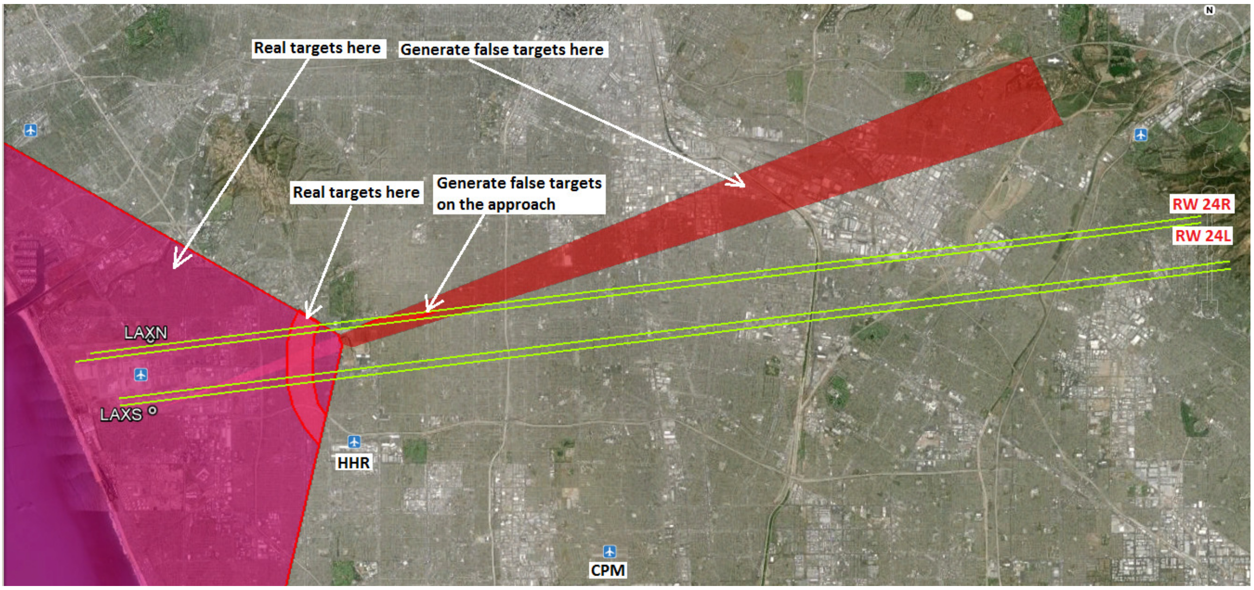

Figure 11 – LAXS False Target Geometry

Figure 11 shows a similar geometry for the south LAX radar with a large capture area for real targets and a much smaller area for the false targets. This concentration configuration results from the convex curvature of the west stadium fascia as seen in **Figure 2**.

3.3.2. Reflective Surfaces

The surfaces shown in **Figures 12** through **14** have been highlighted in blue to show what parts of the stadium are expected to interact with the radar signals. In addition to the outer skin surface, columns within the skin are metal-clad and may also provide a limited interrogation range of their own. Both LAXN and LAXS are presented with a frontal view of the west face of the stadium and a glancing view of the south face. Only the west surfaces are expected to generate significant levels of reflected interrogation energy to cause false targets.

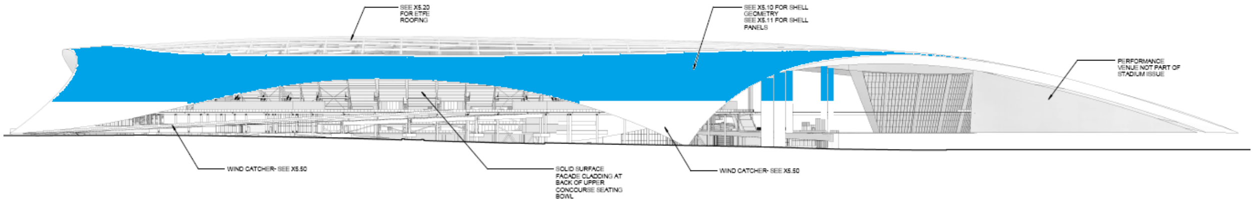

Figure 12 – West Elevation Looking East

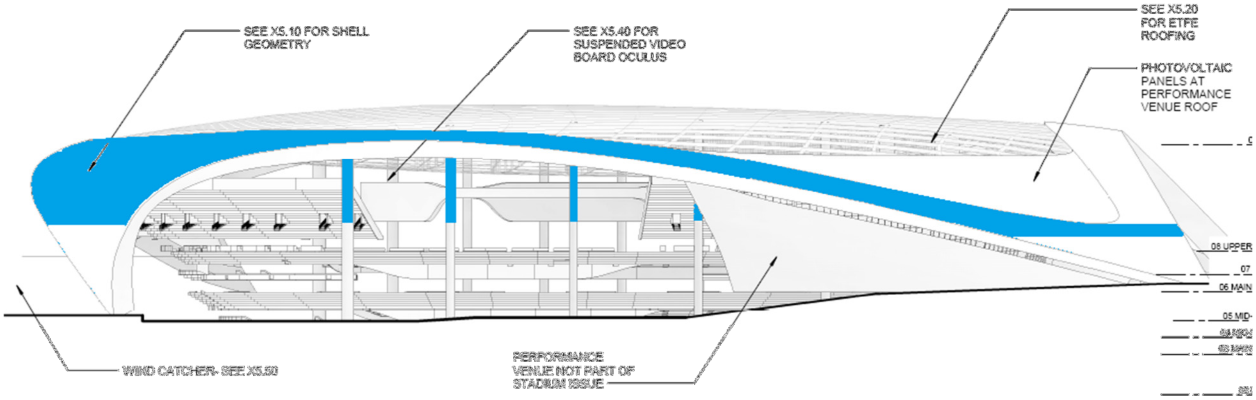

Figure 13 – South Elevation Looking North

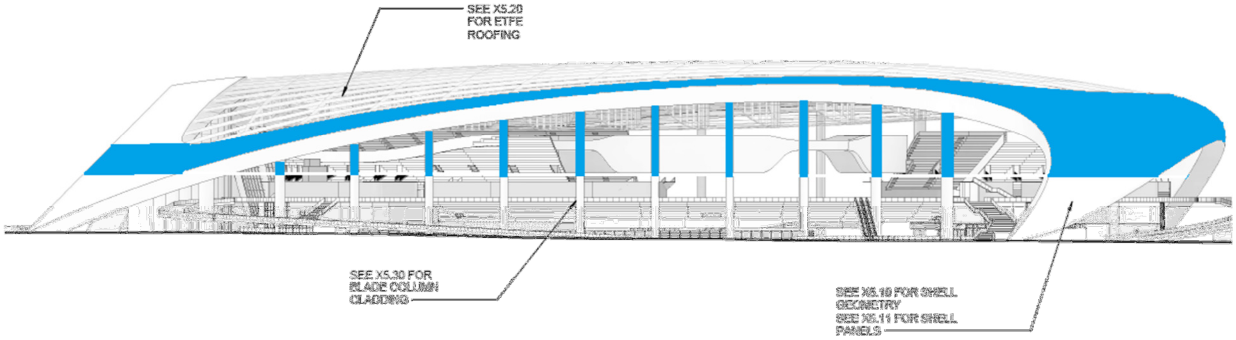

Figure 14 – North Elevation Looking South

3.3.3. Interrogation Range Lobes

Previous sections have described the geometry of the reflecting elements. This section will determine a distance from the stadium surface where an aircraft transponder may be interrogated through the reflected path. Although the stadium has many surfaces expected to reflect radar energy, only the west upper nose is expected to provide enough energy to trigger a transponder in the narrow critical areas identified in **Figures 10 and 11**. Classic mathematical RCS (radar cross section) models for a flat plate and a horizontal cylinder were used to approximate the stadium's west nacelle[5]. Neither of these is an exact model for this application however they are standard tools used to approximate RCS.

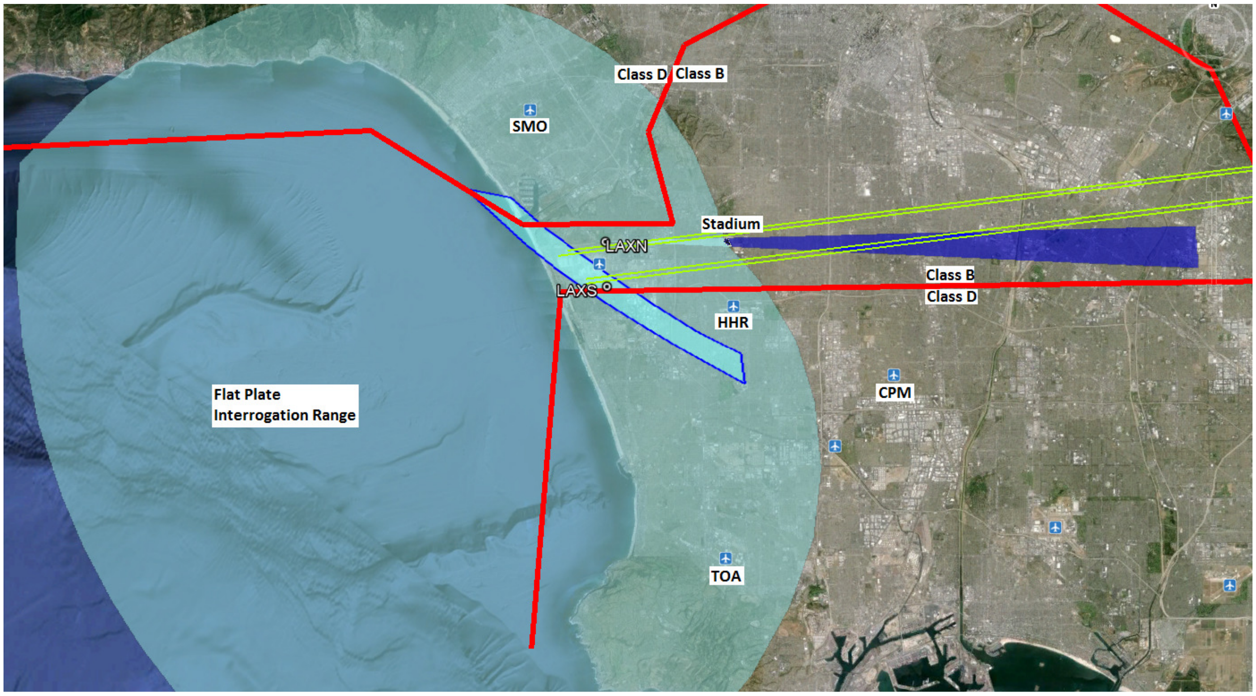

Figure 15 – LAXN Reflected Interrogation Range Limits for Flat Plate Model

The large blue bulge to the left (west) in **Figure 15** shows the extent of reflected beacon directional power capable of triggering an aircraft transponder and generating a false target for a flat plate model applied to transmissions from the LAXN radar. This represents a worse-case analysis for the dimensions of this stadium but does not properly represent what might be expected from the curved nacelle.

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[5] See Appendix for range lobe calculations

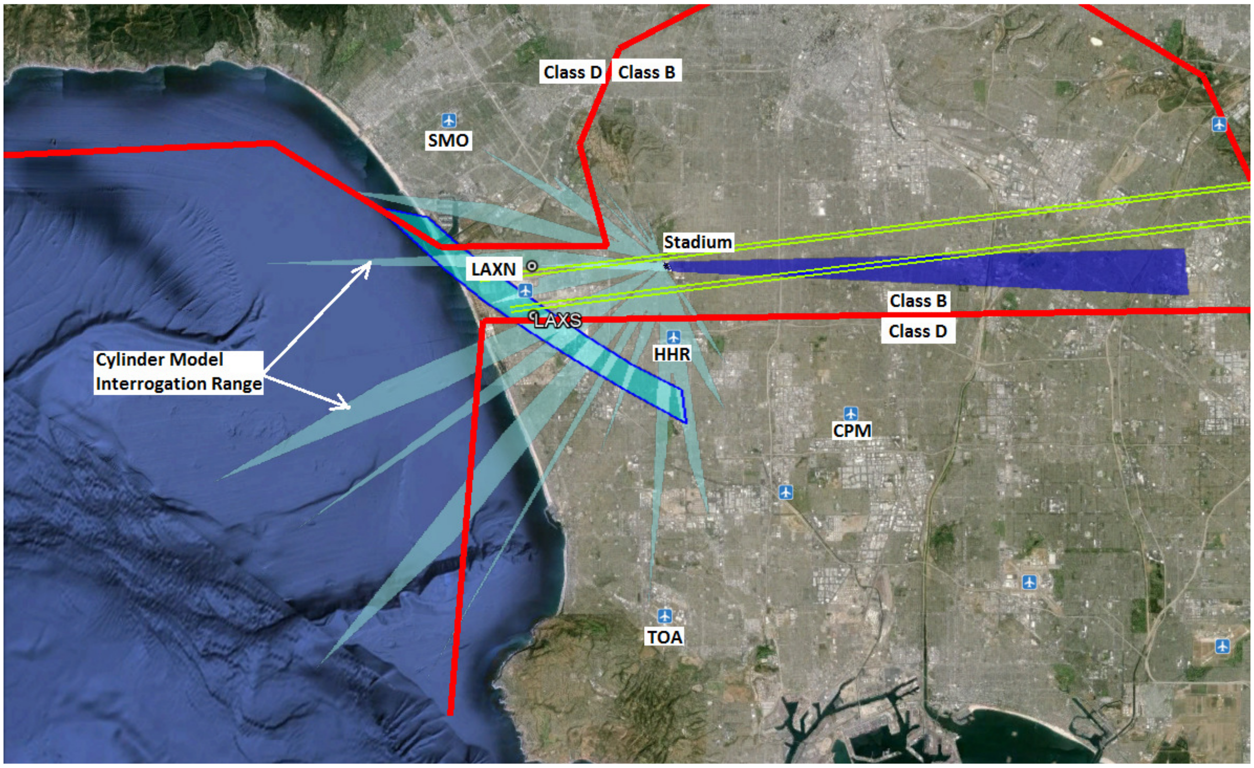

Figure 16 – LAXN Reflected Interrogation Range Limits for Cylinder Model

Replacing the flat plate with a horizontal cylinder in the model produces the much more complicated range lobe shown in **Figure 16**. The narrow fingers are a result of the sinx/x nature of the off-axis cylindrical RCS equation[6]. The odd non-symmetrical shapes are the result of a limited sample space.

Figures 17 and 18 include a line of sight (LOS) shadow map of coverage from LAXN at 500' MSL. Areas within the salmon-colored overlay indicate target visibility to the radar at 500' MSL and above. Areas where the salmon coloring does not reach indicate a shadow to the radar below 500' MSL. The purple dots represent aircraft positions recorded on each scan of the radar. One 24 hour recording was analyzed to generate this map[7]. Note that there are aircraft positions located in the radar shadow area. Under optical shadowing conditions this should not occur, however with all the buildings and sharp edges between the radar and the aircraft, it is common for some edge diffraction to bend the beam down behind an obstruction to illuminate shadowed targets. This behavior is complex and unpredictable however and cannot be modeled for this study. It must be noted that the aircraft positions in the figures are on a single elevation plane at 500' MSL. Aircraft ascending and descending through this region will show a truncated track in the images. In addition, there may be missing hits because of the shadowing that aren't obvious in these images. Individual track analysis would be required to determine track consistency in the shadowed area.

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[6] See Appendix for range lobe calculations
[7] Wednesday August 5, 2015

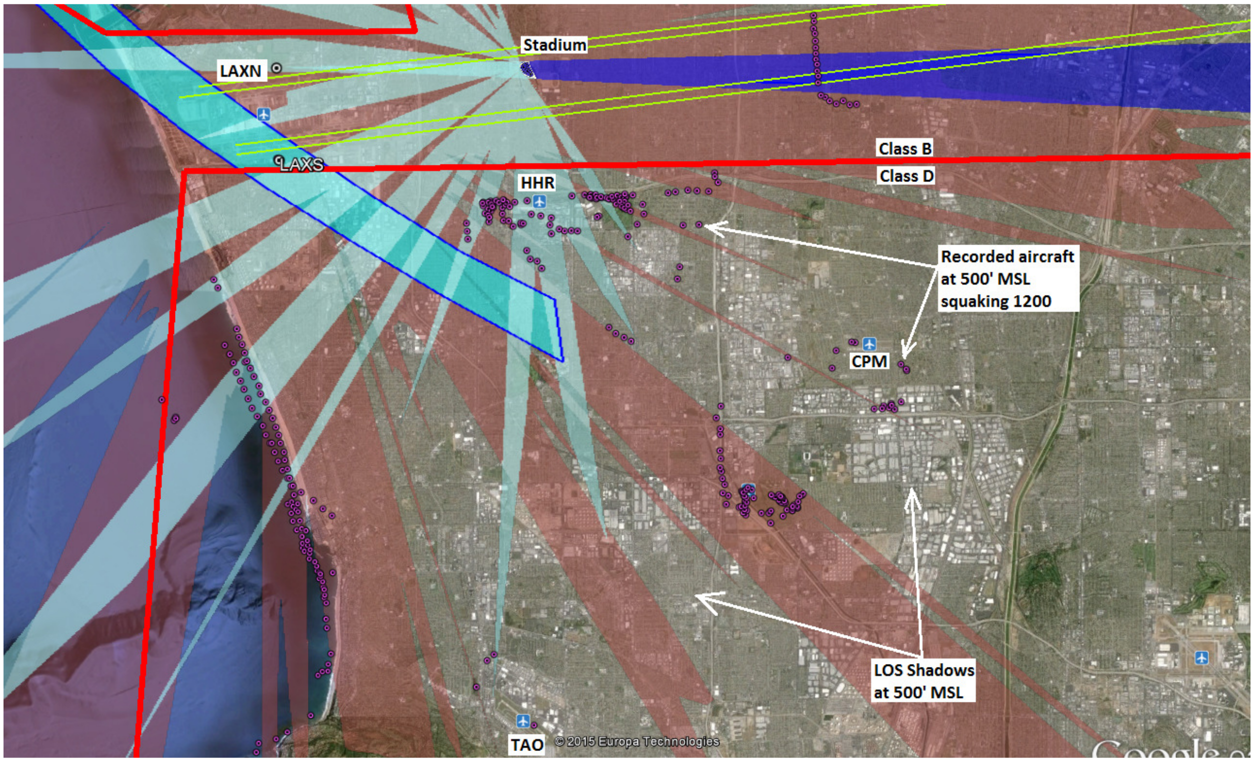


Figure 17 – LAXN Interrogation Lobes with 500’ LOS Shadows and 1200 Code A/C

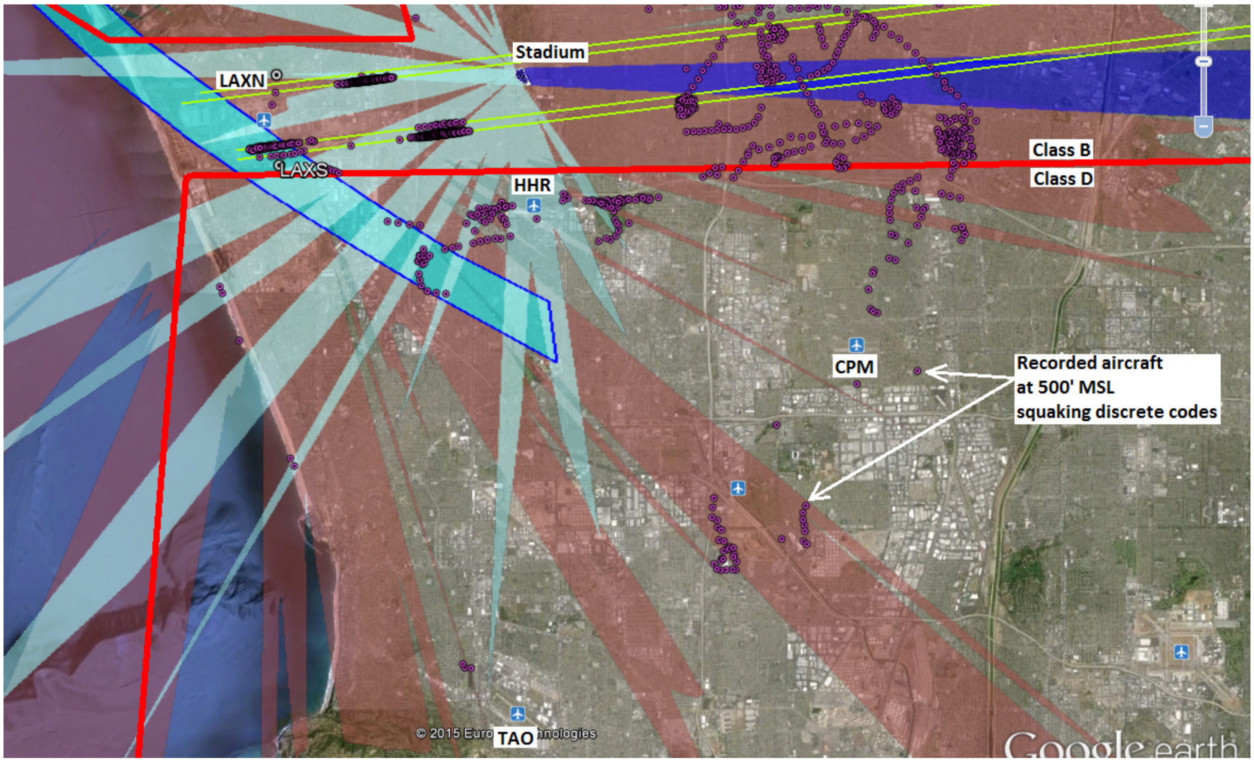
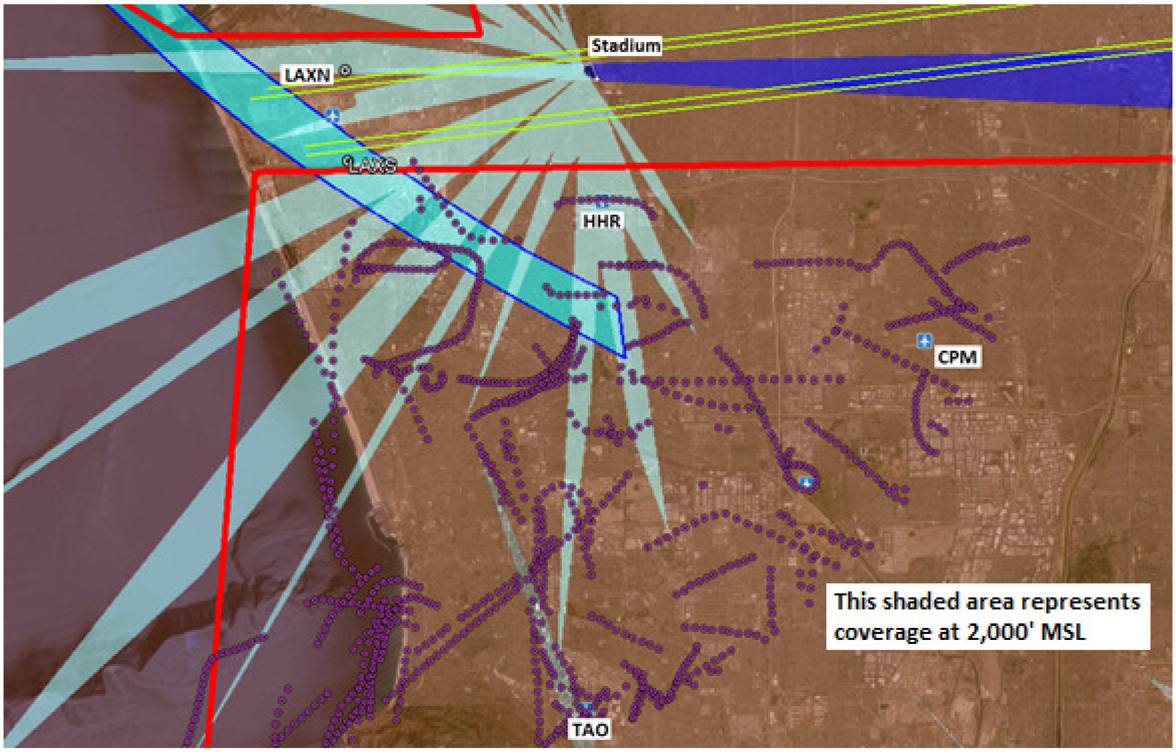


Figure 18 – LAXN Interrogation Lobes with 500’ LOS Shadows and Discrete Code A/C

Of great importance to consider when reviewing these images is that there are aircraft flying at low altitudes in areas with compromised radar coverage. These same aircraft are expected to be subjected to reflected energy from the stadium with enough power to trigger the transponder and produce a viable target reply for radar and STARS processing. With no previous track or direct interrogation of these aircraft, there is no way for post-detection equipment to know that the aircraft was falsely interrogated, thus producing a valid target that will be presented to the controller, possibly on or adjacent to the westbound approaches.

One common false target detect algorithm utilizes the aircraft identification code, or mode 3/A code. Aircraft assigned a unique, or discrete, code are not expected to be displayed in more than one location unless that number has been manually entered into a database specifically allowing such an event (e.g., emergency aircraft). Duplicates indicate a false interrogation and reply has occurred or the pilot has incorrectly set his transponder code. Post-detection algorithms can usually extract the real target by reviewing a track history and calculations of probable reflections off known reflectors. In the case of aircraft squawking a non-discrete 1200 code, it cannot be used as a filter against other 1200 codes for valid positioning. For this particular LAXN configuration, general aviation, or GA, aircraft climbing from HHR in the shadow of buildings are expected to encounter interrogations from reflections off the stadium before they become visible to LAXN through a valid direct interrogation. This may last long enough to build a track history in the dark blue region of **Figure 17**, complicating efforts to suppress the false track once the real one becomes available and especially in a dense traffic environment.



This shaded area represents coverage at 2,000' MSL

Figure 19 – LAXN Interrogation Lobes and 1200 Code Aircraft at 2,000' MSL

Assuming the false target has a valid altitude, low altitude aircraft such as those shown in **Figures 17 and 18** that show up near the critical LAX approaches would likely be below the normal glide slope of the approach, allowing some measure of filtering to occur either through automation algorithms or controller discretion. A much more serious situation can occur if a false target is placed on the approach with a valid approach altitude. **Figure 19** shows 1200 code aircraft at 2,000' MSL. The shaded area at 2,000' MSL shows almost complete direct coverage from LAXN except for a narrow wedge over TAO. Aircraft with discrete codes at this altitude are expected to have good direct LOS to the radar so any false interrogations and replies should be filtered out automatically. Those squawking 1200 will present additional challenges to the automation filtering algorithms.

The LAXS configuration relative to the stadium is much the same as LAXN. **Figure 20** shows a flat plate model of the false interrogation range, which is almost identical to **Figure 15** except rotated slightly. Similarly, **Figure 21** shows the expected false interrogation lobes from a cylinder model.

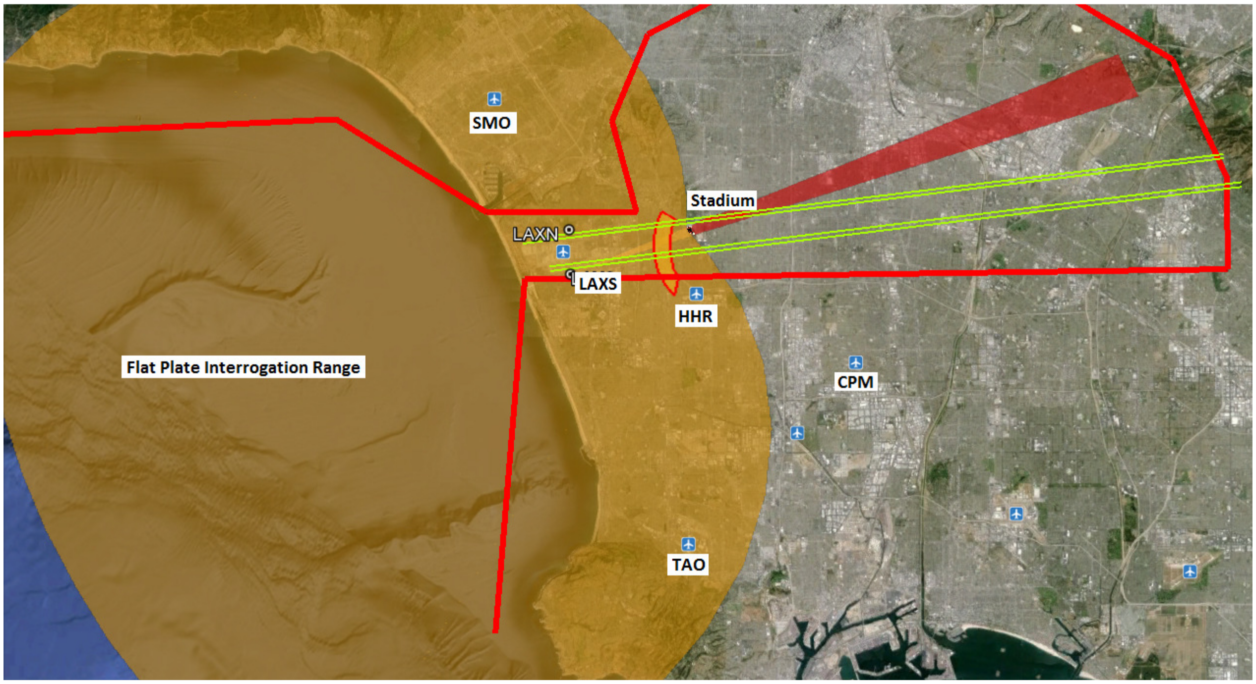


Figure 20 – LAXS Reflected Interrogation Range with Flat Plate Model

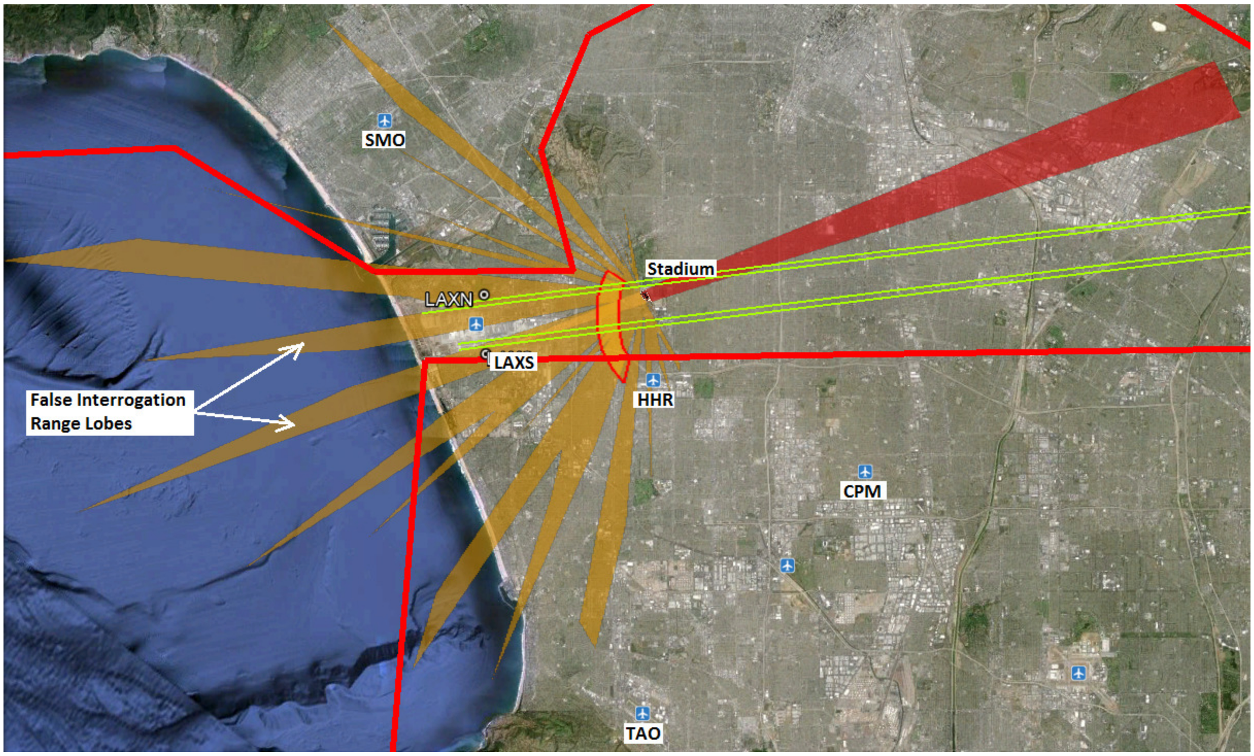


Figure 21 – False Target Geometry from LAXS Radar

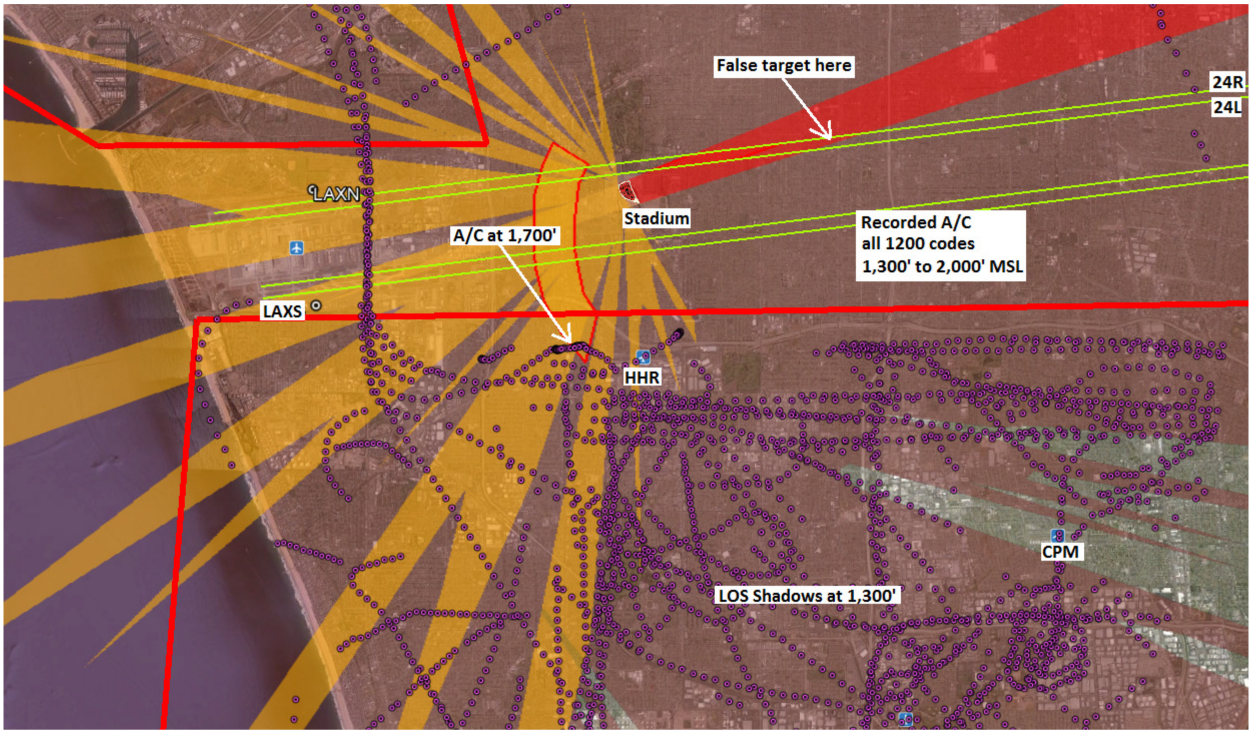


Figure 22 – LAXS Predicted False Target Example at 1,700’

Figure 22 includes 1200 code A/C flying between 1,300' and 2,000' MSL, which correspond to aircraft on final approach into RW 24L and 24R. All 1200 code aircraft flying within the yellow reflected interrogation lobe are subject to generating a false target behind the stadium. **Figure 22** captures an aircraft flying about 1,600 feet as it transitions through the critical capture area. When the aircraft enters the critical wedge its false target will occur between runways 24L and 24R. When it crosses the left edge of the wedge, its false image will occur directly on RW 24R approach at 1,600', which is within the normal approach altitude.

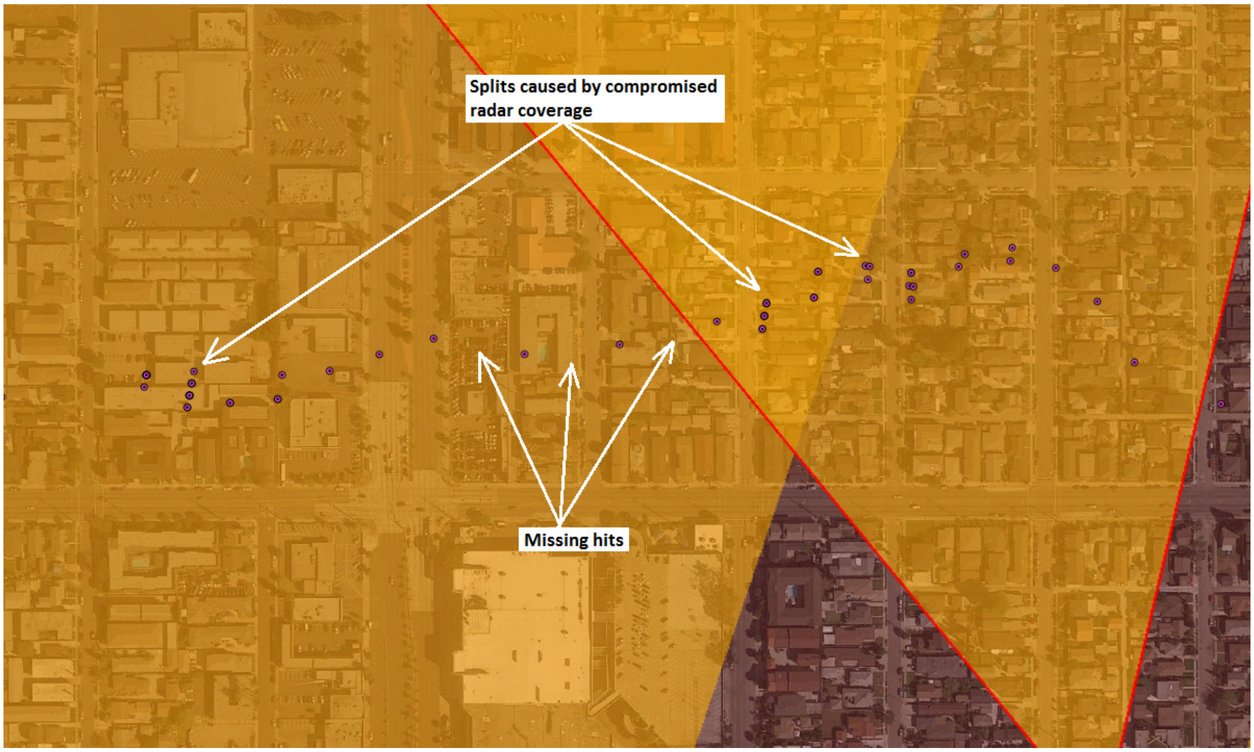


Figure 23 – Splits Indicating Compromised Radar Coverage

Looking further into the track of this aircraft in **Figure 23**, evidence of target misses and splits is found. This is most likely caused by either multipath interference, shadowing from buildings between the radar and the target, or interference caused by cranes or narrow towers. Such interference can provide opportunities for false targets to be created.

The post-processing path for data detected by each of the LAX radars includes the Mode-S dynamic false target processor (when in Mode-S mode), the ASR-9 9-PAC dynamic false target processor (when in IBI mode), and STARS display automation. A Mode-S secondary radar is collocated with each LAX ASR-9 radar. When operating in monopulse mode (also called Mode-S mode), target processing is done in the Mode-S. The Mode-S utilizes a high-resolution monopulse configuration which allows more precise target tracking and a longer data stream word length allowing interrogations of individual aircraft which greatly reduces the number of interrogation transmissions. The Mode-S monopulse mode utilizes amplitude and phase techniques to centroid the target. When the monopulse equipment is not available, the beacon radar reverts to Interim Beacon Interrogator (IBI) mode which centroids the targets with a much larger number of interrogations to increase the statistical accuracy of the centroid since only a binary thresholding detection technique is available. The higher number of interrogations in a dense traffic environment and loss of monopulse precision will greatly increase the probability of false interrogations.

Although Mode-S mode is typically available 99% of the time, the increase in false targets while in IBI mode is expected to be disruptive to event-free approach control.

In summary, beacon false targets are to be expected as a result of reflections off the stadium surface. A dense collection of aircraft flying in an already compromised radar environment are expected to generate numerous and complex reply scenarios to the post-detection processors. Most of the false replies will be detected and removed with existing automation algorithms, however variations are expected that will require intensive, and time consuming, manual analysis, not all of which will be successful. The rate of false targets observed is expected to be high at first, especially during construction when the structure and crane configuration is constantly changing. Eventually the rate should diminish as technicians figure out ways to mitigate each of the false target configurations through logical filtering. These filters quite often involve trade-offs such as areas where no new tracks are allowed to start. A valid new target then becomes invisible until it leaves the filter area.

The greatest hazard however is the location of false targets directly on an active approach path with seemingly valid ID and altitude codes similar to the real traffic. The use of fusion with multiple radars feeding STARS is expected to exacerbate the situation as target detection is the main focus. Any radar that determines a target is valid will have its product displayed until it can be determined as false and removed.

3.4. Multipath Geometries

Applying standard multipath geometric analysis used to determine path fading[8], it was determined that reflecting surfaces on the structure are not large enough, given the range from the radar transmitter, to sustain a significant null formation that could interfere with detection of air traffic, either at the ASR frequencies or the beacon frequencies.

Horizontal beam splitting however is of considerable concern with glancing reflections off vertical and near-vertical surfaces on the north and south sides of the stadium. This can cause targets east of the stadium to jump laterally. An example of this is currently being investigated from a wall on the Hollywood Park Casino adjacent to the proposed stadium. An aircraft arriving on RW25L was observed darting to the right, towards another aircraft on the parallel RW25R. This movement was large enough to cause a CA, or Conflict Alert. The proposed stadium will produce several similar reflection configurations on a much larger scale. Currently there is no known fix for this problem.

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[8] FAA Order 6310.6 1982, "*Primary/Secondary Terminal Radar Siting Handbook*", Section 2b "Vertical Lobing" and "Propagation of Short Radio Waves", MIT Radiation Laboratory Series 1964, Section 5.4 on "Surface Roughness"

3.5. Beacon Reply Code Garbling Geometries

The stadium was analyzed with respect to both radars for geometries conducive to beacon reply code garbling. Garbling can occur when the reply code from an aircraft transponder finds a reflected path as well as the intended direct path. The difference in path length can cause pulse stretching for short distance differences, or duplicate pulses where the path length differences are large. Mode-S mode de-garbling is much more robust than IBI mode.

Figure 24 shows a horizontal section of the north nacelle which was analyzed for this study. Although the nacelle elevation is above the radar antenna, the broad, extended curvature of the structure was found to provide enough reflective surface to sustain a viable signal to the radar receiver. Path differences to both runway approach paths were found to be problematic with a 0.133µs delay found for an aircraft on RW 24R and 0.278µs for RW 24L. Any delay above 0.10µs[9] for the 0.80µs wide pulses will interfere with the ability of the equipment to parse the code for usable information.

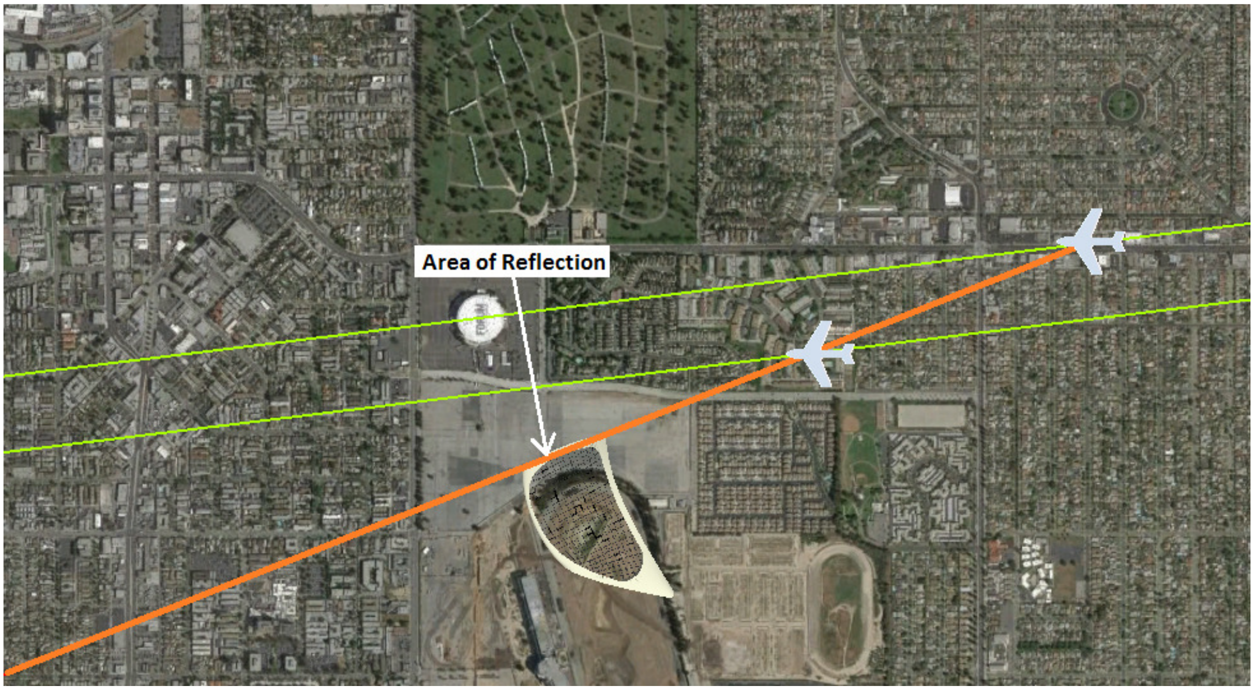

Figure 24 – Selected Beacon Code Garbling Path

The Mode-S has the ability to perform an amplitude envelope test that will indicate the presence of stretched pulses and multiple interleaved pulse trains. Calculation of the reflected pulse amplitude versus the direct pulse amplitude indicate that there will be a 26.1dB difference for the RW 24R configuration and a 22.7dB difference for the RW 24L configuration. This difference is large enough that the Mode-S is expected to separate out the pulses without error.

A similar interference configuration exists for LAXN radar aircraft on RW 25L and 25R however the stretch is limited just 0.05µs and 0.04µs, acceptably shy of the 0.1µs threshold to cause interference.

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[9] "Secondary Surveillance Radar", Stevens 1988, sect 7.2

The above analysis assumes the radar will be in Mode-S mode where the Mode-S detection circuitry performs an analog amplitude measurement. However, when operating in IBI mode, the ASR-9 will perform a two-point detection procedure where a pulse is either detected or not detected by comparison to a constant threshold. Thus the ASR-9 BTD (Beacon Target Detector) must use other algorithms to extract a useful reply pulse train. Therefore, when operating in IBI mode there is a low probability that mode 3/A or C errors will occur as approaching aircraft cross this narrow section. These errors cannot last more than one scan however as the plane is traveling too fast. In this case the severity is moderate but the probability of occurrence is extremely low due to the narrowness of the reflection surface geometry.

4. Possible Mitigation

The following discussion is intended to provide suggestions which may help alleviate the issues described in this paper. It is not to be used as a prescription for action that will lead to a successful acceptance of the stadium design. Any changes determined by the proponent must be resubmitted for review through the obstruction evaluation process. Changes to the stadium design to accommodate the following observations are expected to enhance future submissions for acceptance.

1) Relocate stadium
2) Lower the above-ground profile
3) Reshape the face of the structure in a way to reduce the radar cross section
4) Replace reflective surface material with a non-reflective material
5) Consider radar absorbing material as a coating over reflective surfaces

4.1. Relocate Stadium

The configuration of the stadium between the two runways coupled with the uncertainty of its reflective properties is the root cause of the objection to this proposal. Any breakthrough of the false target rejection processing will allow false beacon targets to appear near or on the critical approach corridors to LAX. In its current location, the evaluating analyst must be absolutely convinced that there can rarely[10] be a false target on any of the approaches resulting from its construction. The complexity of the stadium's current design precludes such a decision. Were the stadium relocated away from the runway approach paths, chances for successful passage would greatly improve.

4.2. Lower Above-ground Profile

The current stadium design makes excellent use of the low profile principle with the stadium floor some 70 feet below grade. It should be noted that about the first 50 feet or so of the stadium above grade is shadowed from each of the two radars by buildings already constructed. Lowering the reflecting surfaces below this shadow would allow construction at its current location since it would no longer interact with the radar signals.

4.3. Reshape Face

Several features of the existing stadium design reduce its ability to reflect radar signals significantly but can have secondary affects. These include:

a) Vertical surfaces that slope downward, projecting the reflected signal into the ground. Normally this works well with few side effects if the ground surface features are rough.

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[10] FAA Order 7400.2, para 6-3

Smooth wet concrete however can create dihedral or even trihedral configurations that are enormously reflective.[11]

b) Rounded surfaces that act to disperse the reflected radar signal. Unfortunately these also spread out the detection lobe of the reflection. A proper proportion can generate just the right dispersion and reduced reflected interrogation range lobe.

c) Long, deep illuminated flat or slightly curved surfaces can generate multipath and/or garbling paths. Utilizing a flat roof that drops away from the face nearest the radar would mitigate this.

4.4. Non-Reflective Surface Finish

The non-metallic roof material currently in the design of the center of the stadium roof is an excellent example of ways to reduce its radar reflective properties. The aluminum skin of the nacelle however is problematic in that it is an excellent reflector. Use of textured concrete is recommended wherever possible.

4.5. Radar Absorbing Materials

The strategic placement of radar absorbing materials can greatly reduce reflectivity of the stadium. These materials have been used before to correct radar reflection problems. Material costs range from $40 to $80 per square foot and may require periodic maintenance or replacement.

4.6. Mitigations Involving FAA Systems

Relocate one or both radar systems – A typical ASR site relocation costs from $6M to $8M plus land acquisition. A typical site selection process including iterative engineering studies usually takes from 1 to 3 years with some difficult sites taking much longer[12]. Site acquisition in a densely packed urban environment can take from 1 to 4 years. This paper concluded that both radars at LAX would be affected by the stadium so both radars would require relocation.

Coordinate stadium construction with ADS-B implementation – The Automatic Dependent Surveillance Broadcast network is currently being deployed nationally. With multiple receivers and transmitters communicating with aircraft directly and with air to air communications between aircraft possible, false beacon targets would no longer be an issue for air traffic control. The intention is to replace the Mode-S and other ground-based beacon radar systems with ADS-B by 2020, however technical issues and a lack of ADSB-equipped aircraft may challenge this goal. Until ADS-B can be fully implemented and the Mode-S systems decommissioned, false targets, jumps, and splits caused by the stadium will remain a troublesome affect. Construction coordination with ADS-B implementation would require full operation without the requirement of Mode-S data before any ground work could begin on the stadium.

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[11] "SEA RAM Results", FAA WSA OESG, Steve Walsh, 5/3/2012

[12] Seatac ASR-9/Mode-S relocation, site selection 1996 to 2002, construction 2002 to 2005

Supplement Mode-S radars with a WAM system – The Wide Area Multilateration system uses technology similar to ADS-B but without the need for additional equipment on the aircraft. Multiple remote sensor locations are required with high speed communications between each station and a central processor. Implementing this system will require multiple lease arrangements and/or land acquisitions. WAM used to supplement terminal radar equipment is currently in development by the FAA for use at Charlotte Douglas International Airport (CLT). Assuming successful system integration with STARS Fusion, completion should be expected sometime next year. Possible implementation of this system at LAX would likely take 2 to 4 years after successful completion of CLT. A WAM system solution at LAX would have to be fully operational before any ground work could begin on the stadium.

Appendix Example of Range Lobe Calculations

Frequency	**f**	1030	MHz
Wavelength	**λ**	2.91E-01	meters
Velocity of Light	**γ**	3.00E+08	m/s
Power Out	P_t	50	Watts
Power Out	P_t	47	dBm
Mode-S Gain Antenna	G_i	24	dB
Transponder Antenna Gain	G_t	2	dB
Structure Ht (nose radius)	**a**	6.1	meters
Structure Length	**L**	319.0	meters
Beamwidth	**β**	2.35	degrees
Length, Beamwidth	**L**	272.0	meters
Effective Length	L_e	272.00	meters
RCS	σ_{sm}		dBsm
Transmit-Receive Angle	$Ø_i$	90.40	degrees
Sensitivity Transponder	S_{min}	(74)	dBm
Sensitivity Transponder	S_{min}	0.04	µW
Range, Radar to Stadium	R_2	3.6	nmi
Range, Radar to Stadium	R_2	6,628.0	meters
System Losses	L_s	5.50	dB
Range, Stadium to Aircraft	R_2		meters
Range, Stadium to Aircraft	R_2		nmi
Oblate Spheroid Radius =	r_s	405.8	meters
Cylinder Axis =	**β**	160.0	degrees

General Range Equation

$$R1 = \sqrt{\frac{P_t G_i G_t \sigma_{sm}}{(4\pi R_2)^2 S_{min} L_s}}$$

RCS for Flat Plate

$$\sigma_{sm} = \frac{2\pi a {L_e}^2}{\lambda}$$

RCS for Cylinder

$$\sigma_{sm} = \frac{2\pi a L^2}{\lambda} \left| \cos\left(\frac{Ø}{2}\right) \frac{\sin\left(kl \sin\left(\frac{Ø}{2}\right)\right)}{kl \sin\left(\frac{Ø}{2}\right)} \right|$$

See "Radar Cross Section Lectures", 1988 Fuhs
and "Radar Cross Section", Knott, 2nd edition 2004, sect 5.3