Real Targets - Unreal Displays
The *twice revived* Slide Show

When I come across a NASA Aviation Safety Reporting System report from 2006, which describe the *same* resident pathogen I had observed two decades prior (see <u>Dejavu</u>), I know that my concerns are still valid.

This is a PDF adaptation of the slide show I had revived back in 2000. That slide show was based upon the *original* slide show I had created in 1991, specifically for my presentation at the Sixth International Symposium on Aviation Psychology.

Blue text is original text from that slide show that was on my (no longer available) http://home.columbus.rr.com/lusch web site.

The complete lack of display of primary radar targets that represented American Airlines Flight 77 (AAL77) on September 11, 2001, after its transponder was turned off, is very much related to the fact that we have voluminous amounts of overlapping radar data, but that much of that surveillance data goes unused. Learn more <u>here</u>.

Thomas G. Lusch <<u>contact</u>>
Aug 6, 2009

Lusch's "RTUD Slide Show"

Welcome to my "slide show" presentation of "Real Targets - Unreal Displays," as adapted for the web from the lecture I gave at the Sixth International Symposium on Aviation Psychology back in April '91. This presentation is a lot less formal than the papers I have written and posted here on my web site, but I think you will find it easy to follow and quite compelling. I might lose you a couple times if you don't have any aviation background because of the jargon. Nevertheless, stick with me...I believe my points will come through loud and clear, and you'll understand a lot more about what's taking place in the ARTCC radar data processing computers, and then you'll understand <u>why this issue is so important to me</u>, *and why it should be so important to everyone else who is involved in the ATC system.* So, sit back, and use your mouse to forward through the slides and follow my story.

This "slide show" consists of 41 "slides" and will probably take an hour to an hour-and-a-half to review. If you don't have time to do it all in one sitting, just make a note of where you stopped, and when you have time, just come back to this page to be able to easily skip forward to where you left off.

This slide show was first adapted for my web site on Feb 6, 2000, and a week later I upgraded it to a version with "frames." Since then I've tweaked it up for display on different browsers and for different resolutions. If your browser supports "frames," *that is the version of the slide show you should try first*, as in the original more simple version the picture moves up out of view as one reads the text. If, when trying out the framed version, you click on the Slide number on the left side of the screen, and an entirely *different* window opens up (that happens to me with my current version of Netscape Navigator), it'd probably be best to view the slide show version *without* frames.

I welcome your feedback and discussion.

Remember, *the main intent and first mission of this web site is to stimulate positive change within the FAA as to how radar data is processed*. Why is that? Well, on with the story...

Tom Lusch
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February 16, 2000

Slide 1 of 41: San Luis Obispo

We'll begin back on August 24, 1984. At that time I was learning how to be a radar controller at Cleveland Center. I was nearly checked out on all the radar sectors in Area C2. Area C2 (later to be known as Area 5) covers much of the Allegheny Mountains to the east of Pittsburgh, from as far south as Cumberland, MD to just south of Bradford, PA.

The news of a midair collision on the west coast got the attention of everyone on the control room floor. We heard that our counterparts in Los Angeles Center were working a commuter aircraft that had just departed an airport, and had just gotten it on radar moments before the collision occurred. In fact, the buzz was that the controllers claimed the other aircraft wasn't on their scope. My first thought was the controller must not have been paying very close attention to have not seen the other aircraft on radar, or maybe the controller wasn't telling the truth, because if you see one aircraft on radar, most certainly the other aircraft that is about to occupy the same chunk of airspace would show up too. *It didn't make sense that the other aircraft wouldn't have been on the radar screen.*

Move on to about a half year later. It was the Spring of '85. I've been a fully certified controller now for just under a half year. I'm working the Clarion sector, which primarily provides sequencing and separation of arrivals into Pittsburgh from the east and northeast, over the GRACE intersection. It wasn't a busy period...I was working maybe 7 aircraft at the time. A Crown Airways Twin Otter departed Dubois, PA and called me for radar traffic advisories. It was such a beautiful day that he didn't need (nor require) ATC separation services, but he did wish to have another set of eyes watching out for him. I radar identified the aircraft, thereby including this commuter's target in my scan, happy to provide such an important service for this pilot and his passengers. Shortly after establishing radar contact with the Twin Otter, this Crown Airways pilot suddenly, and *very emphatically* said, **"Center, DID YOU SEE THAT AIRCRAFT!!!???"** Just after that unnerving transmission did the target symbol of the other aircraft appear...just behind the Twin Otter. I had NOT seen that aircraft in time to warn the Crown Airways pilot, BECAUSE IT WASN'T ON MY RADAR SCOPE till too late. I verified that it wasn't on my radar scope before then by immediately turning my "history" control for a full presentation of the last 5 radar hits (roughly one minute's worth of radar data). It was at that point that I was absolutely positive the other aircraft hadn't been displayed till that very moment. I immediately reported this near midair collision, along with the fact that the other aircraft wasn't on my radar scope, to the supervisor, who then asked if this involved aircraft that were IFR. Since they were both VFR, that was the end of that. Technically, in that airspace, we aren't required to provide separation services to either aircraft. It didn't seem to faze the supervisor that the other aircraft wasn't displayed. I went about my work, but I had this very bad feeling about what just took place...
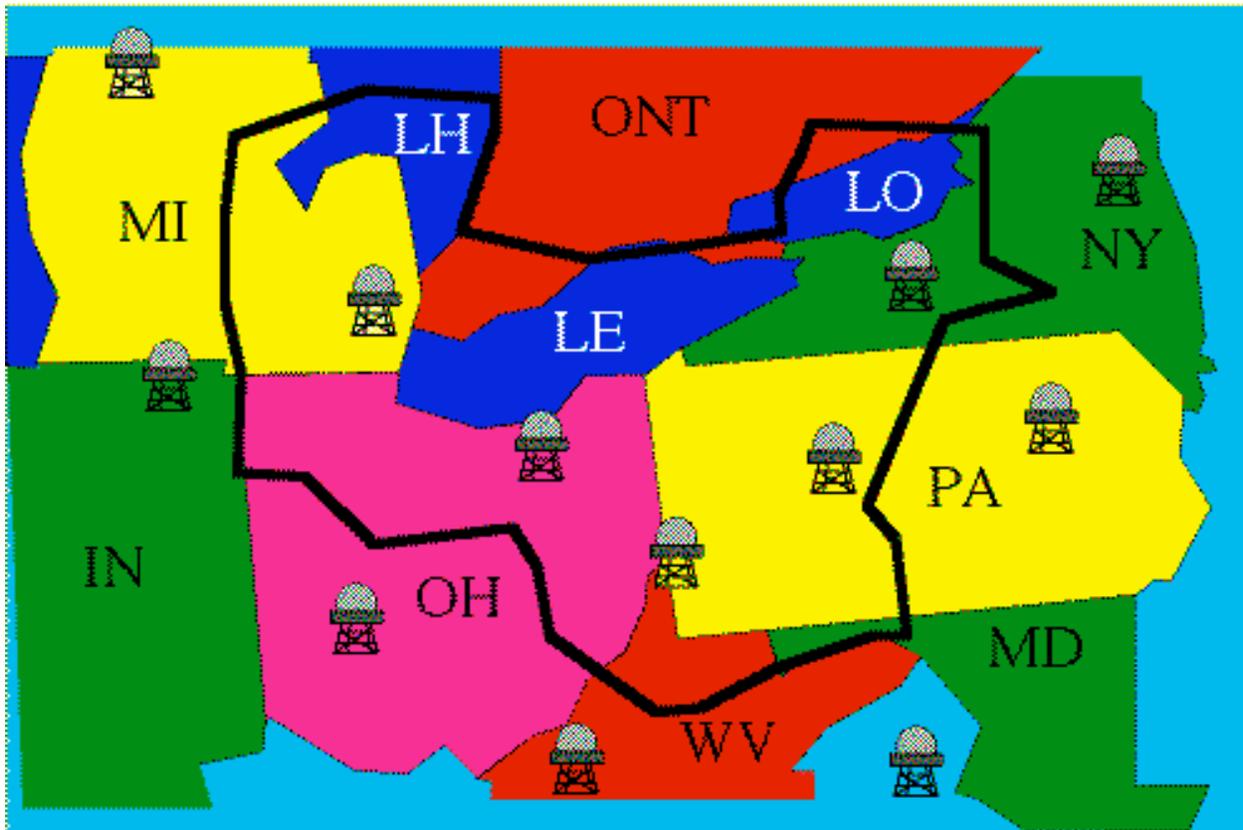
Slide 2 of 41: The long-range radar network

First of all, let me tell you that we have a great network of radar sites in this country. The FAA has done excellent in this aspect, as it is difficult to fly anywhere, especially east of the Mississippi, without being detected by radar. Climb off an airport, and even at low altitudes you're being detected by one or more radar sites. Notice that I used the word "detected." That is a key point in this discussion. As you'll learn, detected by radar, and displayed on a controller's scope, are two different things.

Above is a depiction of the airspace boundary of Cleveland Center. Cleveland Center encompasses approximately 69,000 square miles of airspace. That is small in relation to many other Centers, yet Cleveland Center is the busiest of 'em all. An ARTCC like Cleveland Center utilizes several long-range radar sites (technically termed Air Route Surveillance Radar, or ARSR). These sites are strategically placed to provide the best overall radar coverage. Depicted in this slide are the long-range radar sites located in Empire, MI, LaGrange, IN, Detroit, MI, London, OH, Cleveland, OH, Higby, WV, Pittsburgh, PA, Clearfield, PA, Dansville, NY, Utica, NY, Benton, PA, and The Plains, VA. Missing in this depiction is the ARSR in Coopersville, MI, which lies approximately 120 miles west of the long-range radar in Detroit, or just over 100 miles south of Empire.

The long-range radar near Dubois, which is where the Crown Airways pilot departed, is located high atop a plateau near Clearfield, PA. This radar site served us extremely well. It provided a great depiction of low-altitude aircraft in this area. With it we could even see transponder replies from aircraft *while still on the ground* at Dubois airport, which lies 17 miles west of the radar site! I had a lot of confidence in my radar presentation in this area. It didn't make sense that the Crown Airways aircraft was depicted on my scope, but the VFR that he nearly collided with had not been depicted until too late.

So I began to question how things worked with our radar data processing computer/software. Why would one aircraft show up, and the other not? What follows is an explanation of what I learned...
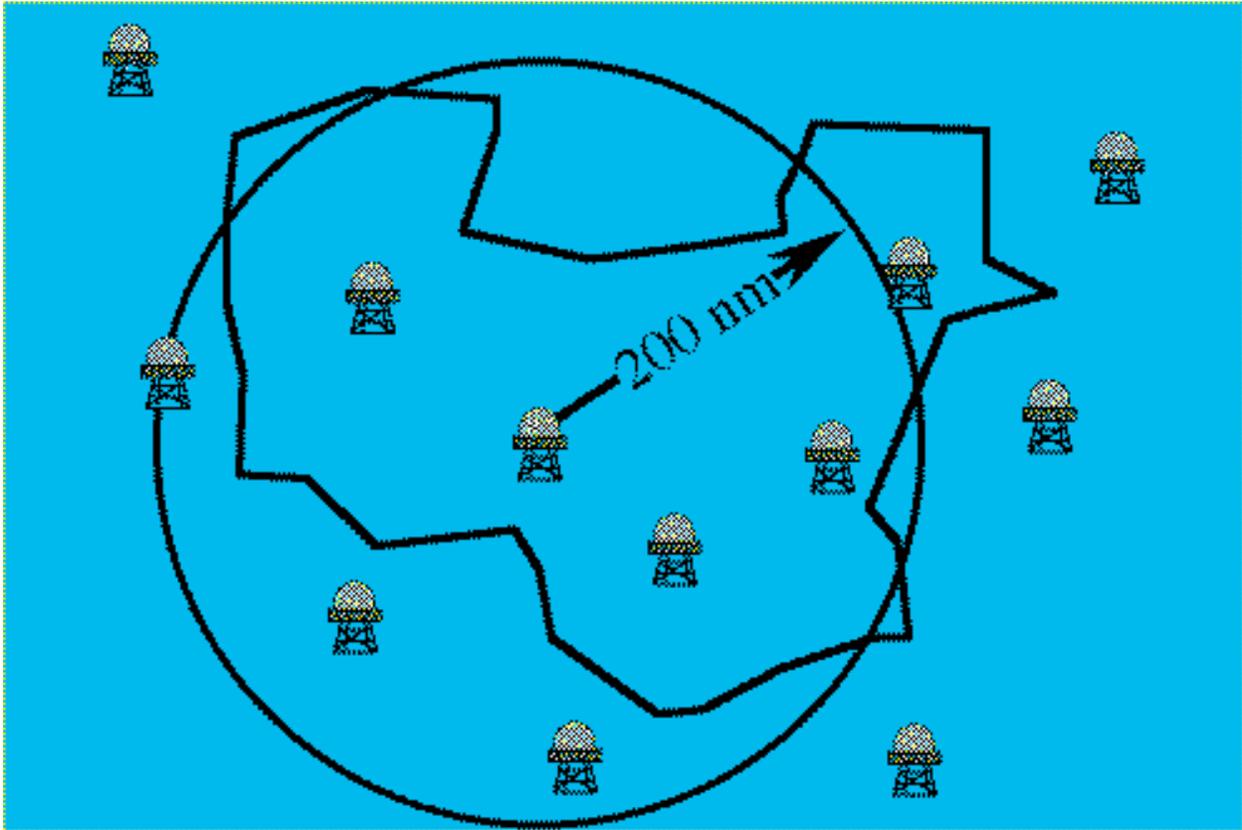
Slide 3 of 41: Overlapping coverage

Did I mention that we have a great amount of overlapping radar coverage out there? A long-range radar can detect aircraft at distances up to approximately 200 nautical miles (if the aircraft is up at a high enough altitude, like 20,000 to 30,000 feet). Notice that 200 miles from the Cleveland (Brecksville) long-range radar overlaps nearly 7 other long-range radar sites. Therefore, an aircraft flying up at Flight Level 310 (roughly 31,000 feet) near Cleveland, Ohio, can be "seen" by probably 8 long-range domestic radar sites at one time. This depiction doesn't show the multitude of Airport Surveillance Radar (ASR) sites located at airports throughout this airspace. Those radar sites have a range of typically 55 miles, and are primary designed for use by controllers serving those airports. None of these smaller terminal radars in the Cleveland Center area are fed to the Cleveland Center computer, and that is typical of other ARTCCs.

There is a lot of radiation out there at the 10 and 23 cm wavelength, along with a lot of interrogation of aircraft transponders taking place on 1030 MHz from these radar sites. Most anywhere east of the Mississippi it is extremely difficult for an airplane to not be detected by one radar site or another.

So, how in the heck does the radar data processing computer handle all that radar data? Just how on earth does it sort it all out?
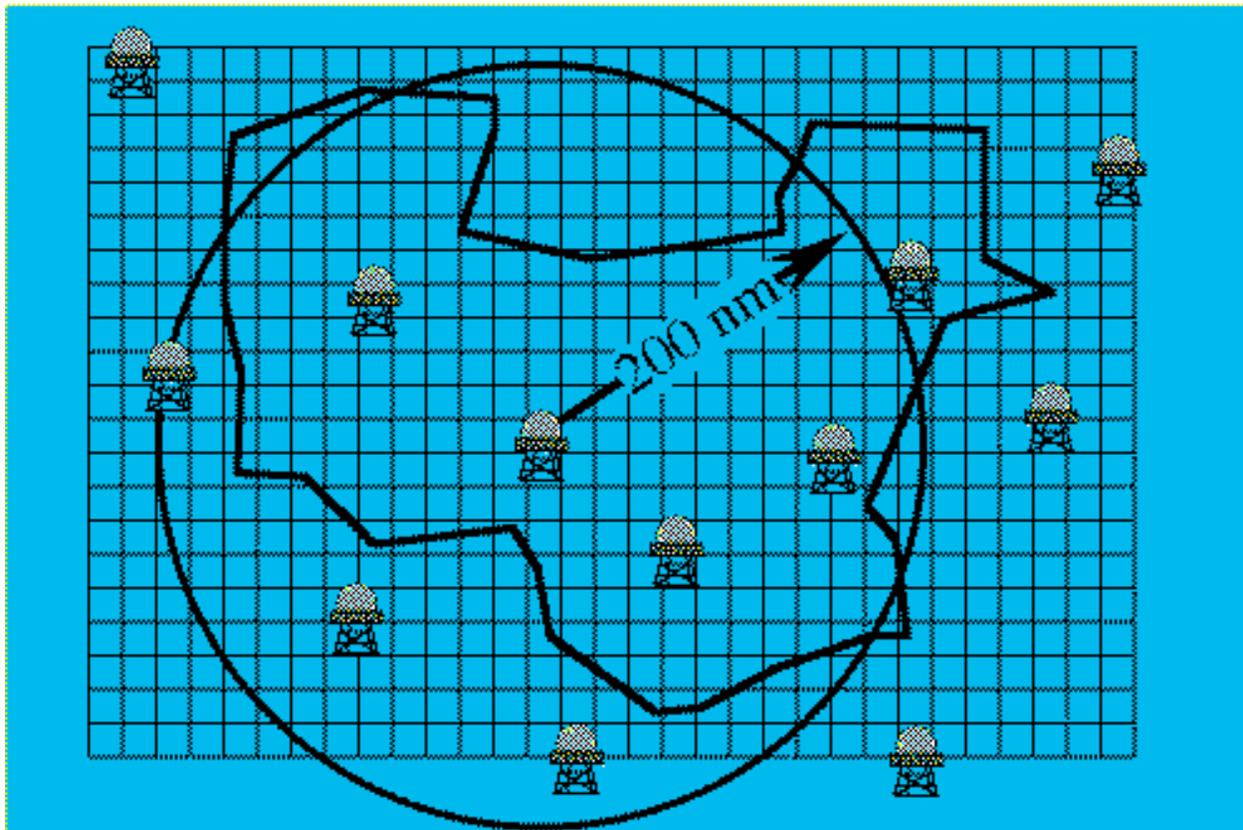
Slide 4 of 41: Bite size chunks

A long time ago a controller would watch a screen that was driven by just one radar site, and it had the typical "sweep." With the advent of computer processing of the radar data, engineers figured out a way to combine all that data from several radar sites, so it could be sent to all plan view displays (another name for radar scopes) in a facility, and the controller didn't necessarily know (or care) which radar site he was using. The displays utilized presumably the "best" data from among the radar sites available.

Apparently crunching all that data was way too much work for the computers, so the engineers had to figure out a way to reduce the data to "bite size chunks." Such was the advent of the "selective rejection" method of handling the data. What the computer program essentially does is divide the airspace into "bite size" boxes. These "bite size" boxes are termed "radar sort boxes." Their size is 16 nautical miles by 16 nautical miles, thereby encompassing 256 square miles each. Each box is assigned up to, but no more than, 4 radar sites. The first radar site is called the preferred radar, the second is the supplemental radar, with the 3rd and 4th radar sites being the backup radar if number 1 or 2 are out of service. If you follow the drift here, you'll be catching on to the fact that *only one radar site's data is used at any given time and any given location*. That's right, one-and-only-one radar's data is used at a time. All the other radar data goes unused, or is dumped into the "bit bucket" as they say in computer programming jargon. That's right...it is thrown out, discarded, abandoned, chucked, unused.

Also, be advised that all of this is taking place inside the bowels of the computer. The air traffic controller has absolutely no control over this internal function. (I know that many people think the air traffic controller can simply "flip a switch" to eliminate VFR radar targets. At the two facilities that I have worked at that is far from the truth...and I never worked beside a colleague who attempted to do such a thing.) By the way, the air traffic controller doesn't see radar sort boxes. These radar sort boxes are strictly an internal thing in the computer program.
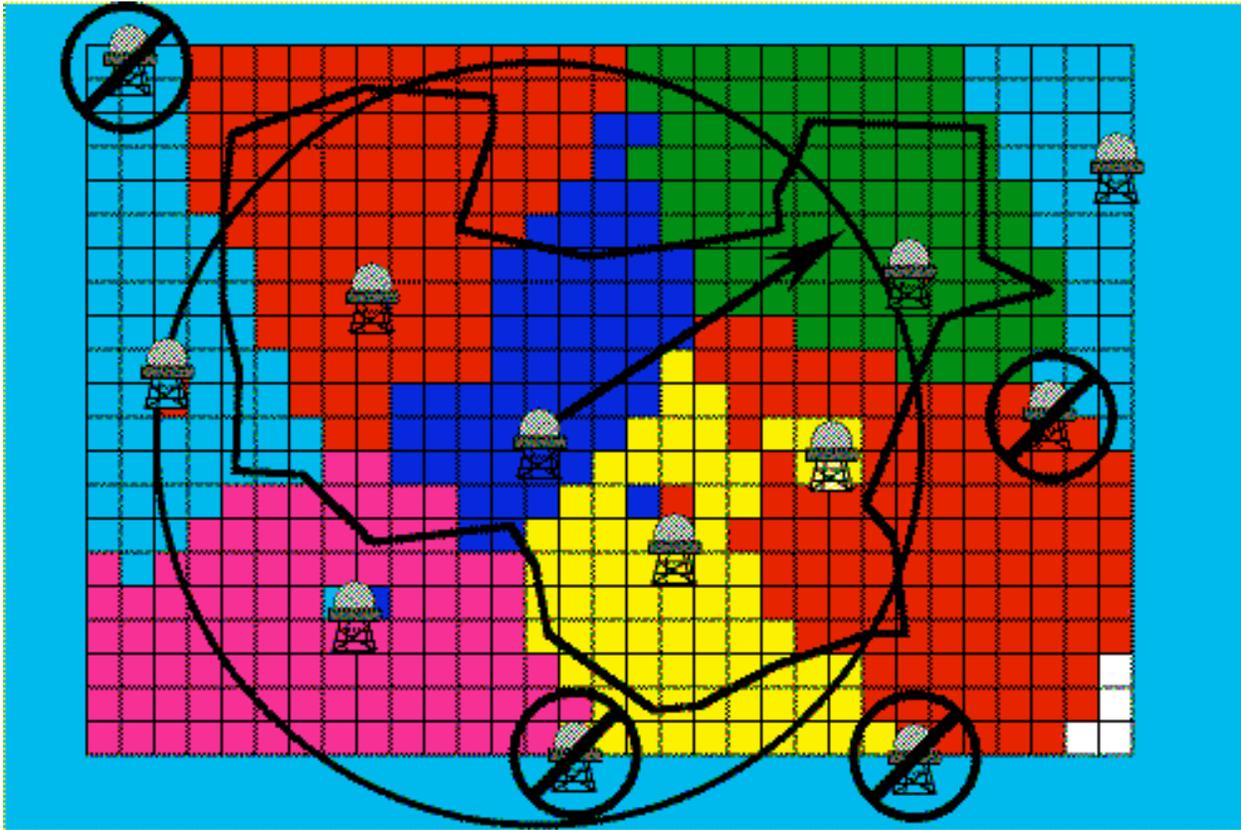
Slide 5 of 41: Much radar data goes unused

Take a look at the Cleveland long-range radar site depicted in the middle of this slide (the one with the 200-mile radius drawn), and notice the squares that are filled with the dark blue color. If you count 'em, you should come up with around 60 sort boxes in which the preferred radar site is Cleveland. If you do a little math, 60 times 256, you come up with 15,360 square miles of airspace. Now, do you recall how to determine the area of a circle? Area is equal to Pi times the square of the radius. Therefore, 200 times 200 equals 40,000, times 3.14 equals 125,600 square miles. The percentage of preferred coverage of this one radar, compared to what the long-range radar actually views, is 15,360 divided by 125,600, or around 12%. ***Yes, that's right, only 12% of the Cleveland long-range radar's data is actually utilized!*** In all fairness, the sort boxes that aren't colored dark blue may utilize Cleveland as the second-in-line radar site, known as the supplemental site, wherein that data is used *if and only if* the preferred radar for that box isn't available, or if the tracking program isn't getting a radar return from a tracked aircraft. More on this later. So, as you can see from this little math exercise, much of the radar data collected by each radar site goes unused!

Note: As a secondary consideration, as it appears that typically 80+% of the transponder replies go unused in the ARTCC environment, consider how much this unused data is contributing to the 1090 MHz transponder reply frequency congestion...
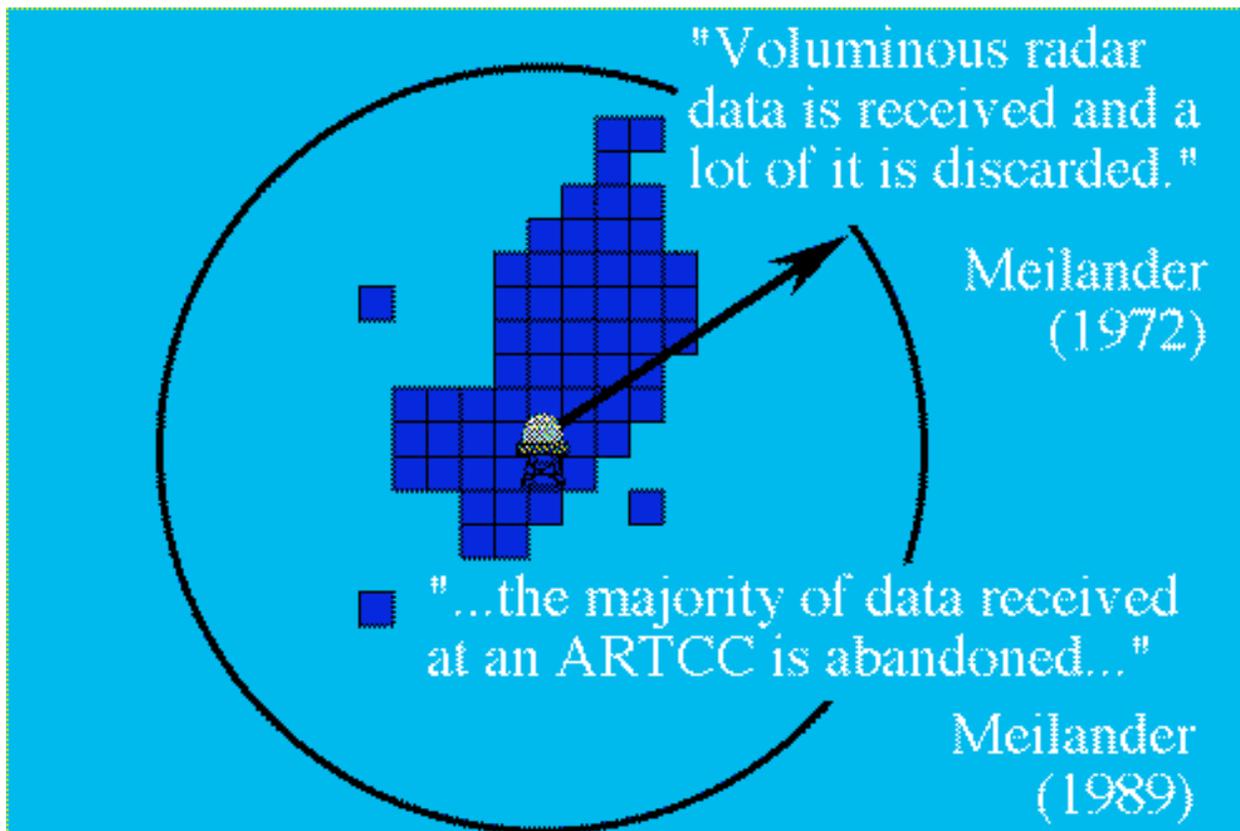
Slide 6 of 41: Willard C. Meilander

The fact that much of the data is thrown out was obvious a long time ago by one of the competitors for the radar data processing contract back in the early 70's. Goodyear Aerospace, one of three companies vying for the contract, had developed a parallel processing computer, termed the Staran. It purportedly utilized all the data, from all the radar sites, all the time, (even the primary radar returns!) and "fused" all the data. Obviously Goodyear Aerospace didn't win the contract, as we utilize serial processors in ATC, not parallel processors. Willard C. Meilander, one of the original designers of the Associative Processor, has written many papers about the importance of utilizing all the data, all the time, from all the radar sites. I made reference to two papers he authored in my "Real Targets - Unreal Displays" paper.

2006-03-23: Read Will Meilander's "Quick Look" note about the state of radar data processing, and his solution.

Update to link [2005-07-29]: Professor Meilander is working towards making his papers available via the web. You can view some of them at http://www.cs.kent.edu/~parallel/papers/
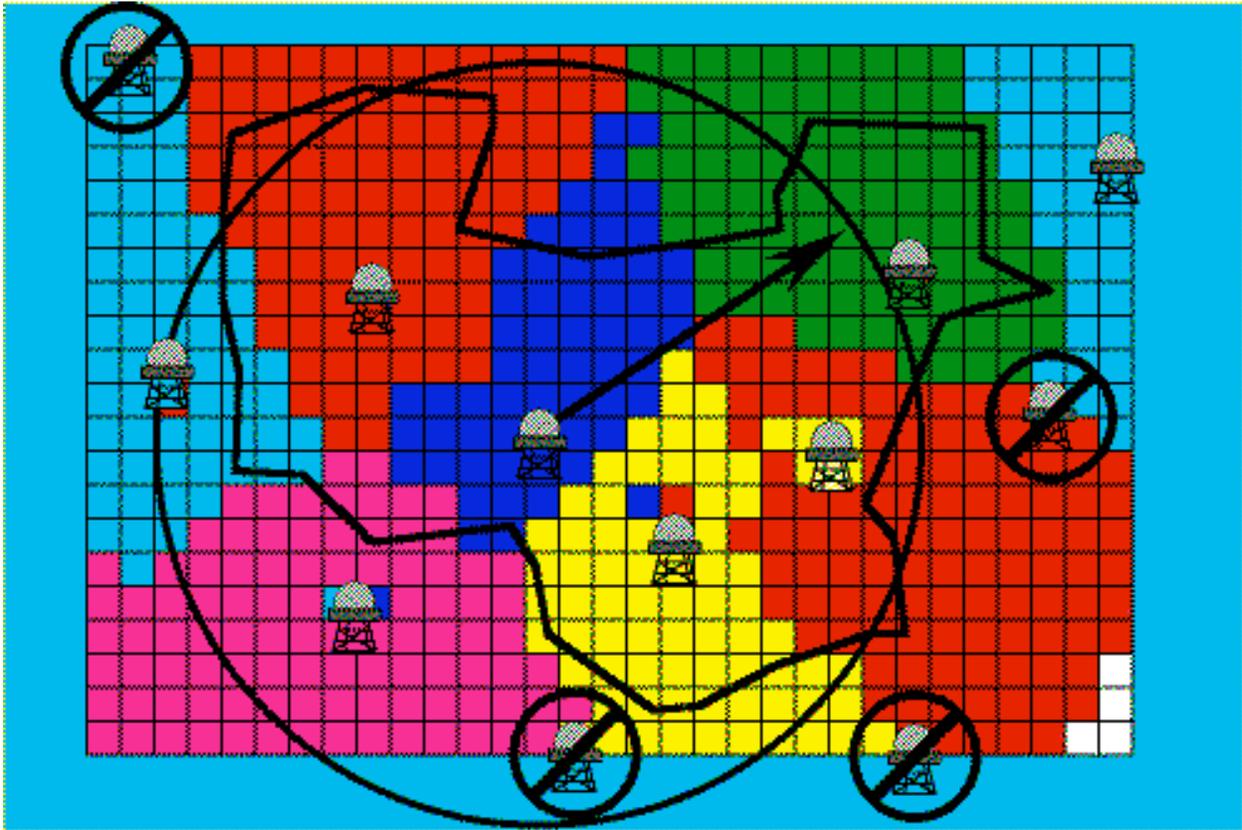
Slide 7 of 41: Not on-line

It's a drag to be "not on-line" these days. You miss out on lots of important information if you're not connected to the internet (important information like this presentation!). In our ARTCC network of radar sites, the problem of being "not on-line" exists, as all radar sites that have coverage into and along the edges of ARTCC airspace are not necessarily feeding that facility. Notice the radar sites that surround Cleveland Center that weren't hooked up when this slide was developed for my talk in '91. Take, for instance, the one at the lower center of this slide. That radar site is located in Higby, WV. A low-altitude aircraft on the southern boundary of Cleveland Center airspace near that radar site, being worked by a controller at Cleveland Center, is not afforded any coverage from that site because it is not even hooked up to Cleveland Center. This situation is very similar to my example given at the introduction page of this web site. In that case, the facility that was providing service to that Piper Arrow on its way in to Frederick was not providing *radar* service because the radar data of the site that could see the aircraft wasn't feeding their facility.

Since I left Cleveland Center in '93, I understand that two more radar sites are now feeding the facility. One of 'em, which I didn't depict, is in Cooperville, MI, and the other is the one in The Plains, VA. Higby ARSR is not yet connected. Nor is the one in Empire, MI. Nor is the one in Benton, PA.
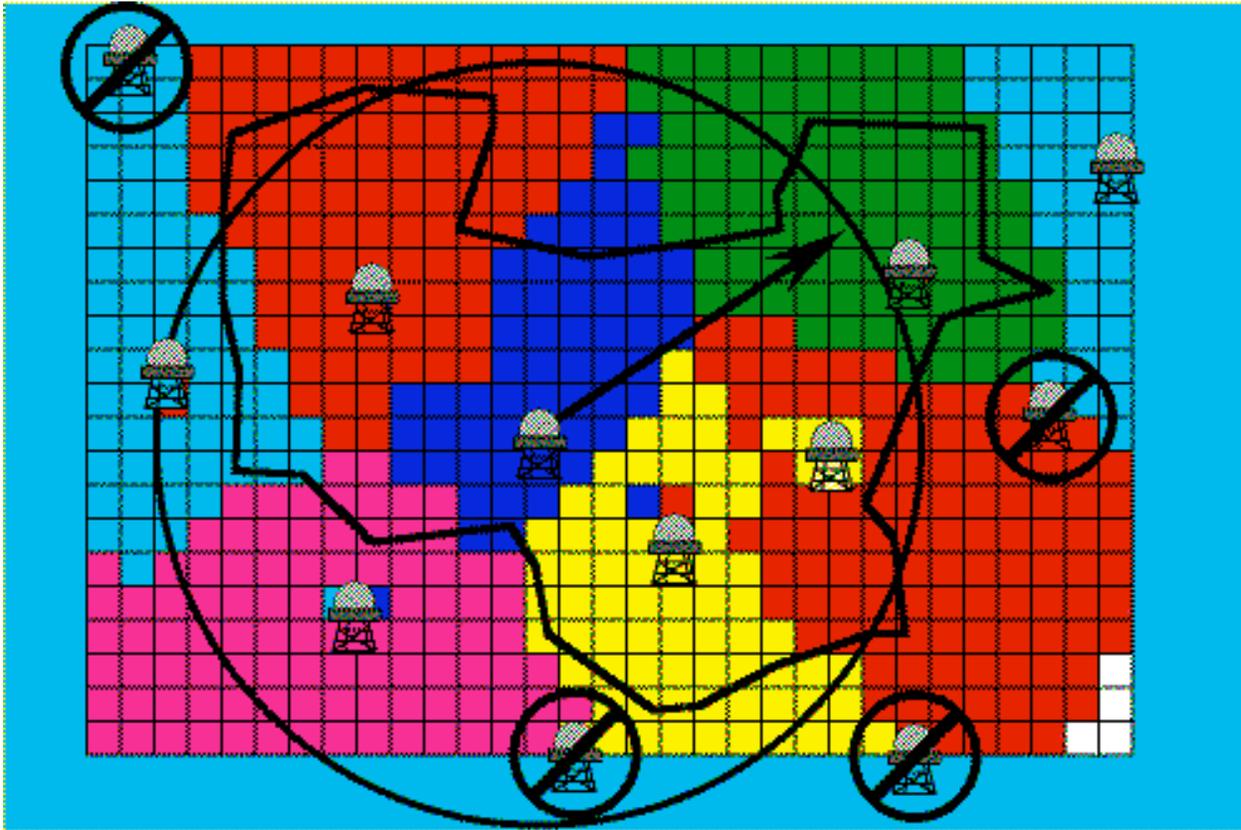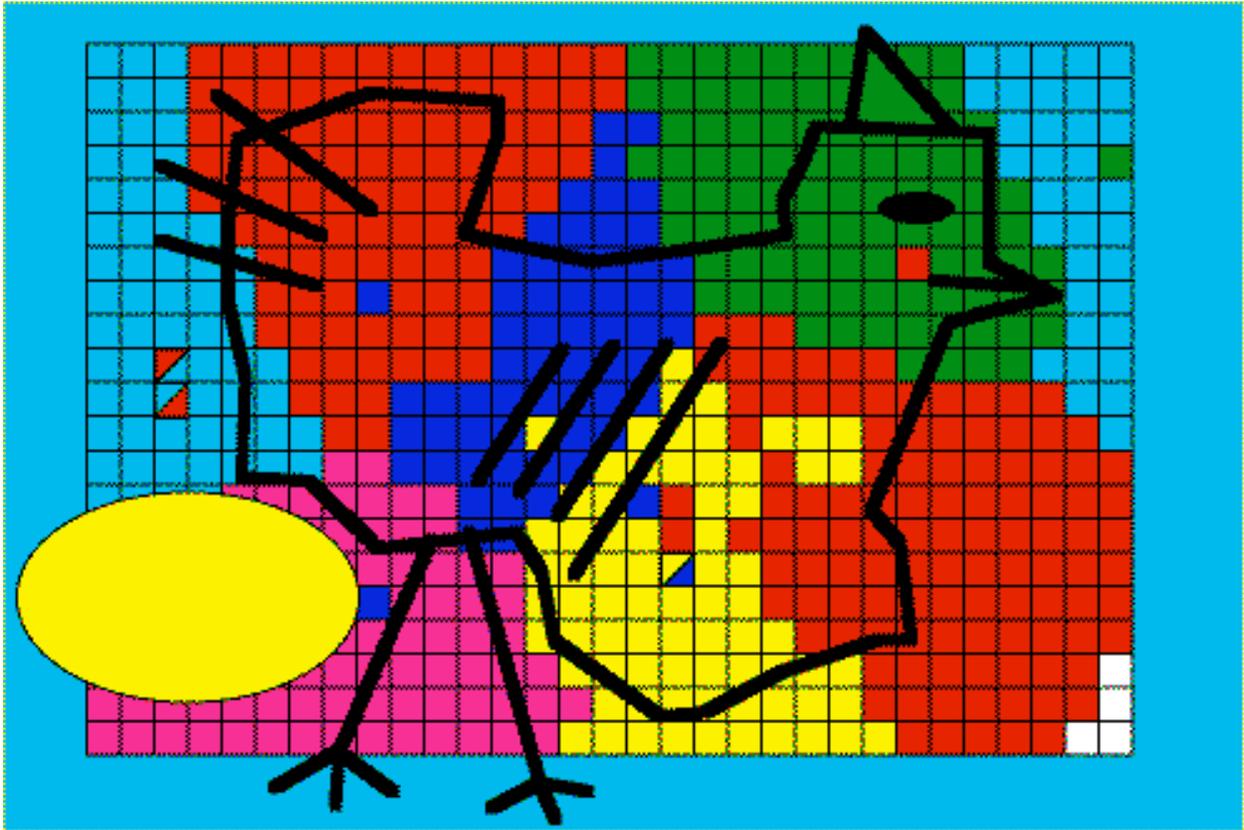
Slide 8 of 41: Rorschach Test

The problems with radar data processing that I discovered and wrote about didn't come up all of the sudden or anything. The near midair collision that occurred in the Spring of '85 was the impetus for my devoting untold hours upon hours upon hours to this topic, in an effort to understand just what was taking place. Then, in April 1988, I observed an operation that made me understand clearly that I wasn't going to get anything addressed by just talking about the problems I saw with radar data processing at Cleveland Center (see section 3.1.1.2 from the paper I reference at the end of this paragraph). I figured I had to learn as much as I could and write something official about it to get things improved. So I started hanging around and talking with the systems maintenance technicians, and asking a lot of questions. Then I dug into their manuals. Mind you, I'm not a computer programmer or electrical engineer, or anything like that. My background had some technical aspects to it. For instance, I got my ham radio license (WA8ZTV) back when I was in 7th or 8th grade, and I built some electronic kits and stuff like that. After high school I went to Ohio Institute of Technology and got an associate degree in Electronics Engineering Technology, then I went out and got a job and worked as an electronic technician. So I have a limited background in electronics and computers, but I'm certainly no whiz at this stuff. However, I stuck with this and learned all I could, then I began to write. What I wrote turned into a paper entitled "Selective Rejection of Low Altitude Radar Data at Air Route Traffic Control Centers: An Unsatisfactory Compromise." I submitted this paper as an Unsatisfactory Condition Report (UCR) on September 26, 1988. The UCR was closed April 4, 1989.

At any rate, one day, out-of-the-blue, I get this letter in the mail. It is a "call for papers" for the Sixth International Symposium on Aviation Psychology (see glossary). I have no idea how I got on this mailing list, but I figure, why not give it a shot, as by that time I had exhausted my avenues in the FAA for addressing this issue. So I submitted an abstract, and much to my surprise I was selected to be one of the speakers! So I then began to formulate another paper, as well as a presentation. The slides you're viewing here originated from that presentation. So, as I'm making up these slides, I'm wondering about what's going to be expected of someone speaking at a symposium on aviation *psychology*. Hmmm...is everyone there going to be psychologists? Let's see, psychologists deal with things like ink blot tests, right? What might be a subject's interpretation of this somewhat abstract graphic design above? What do you see?
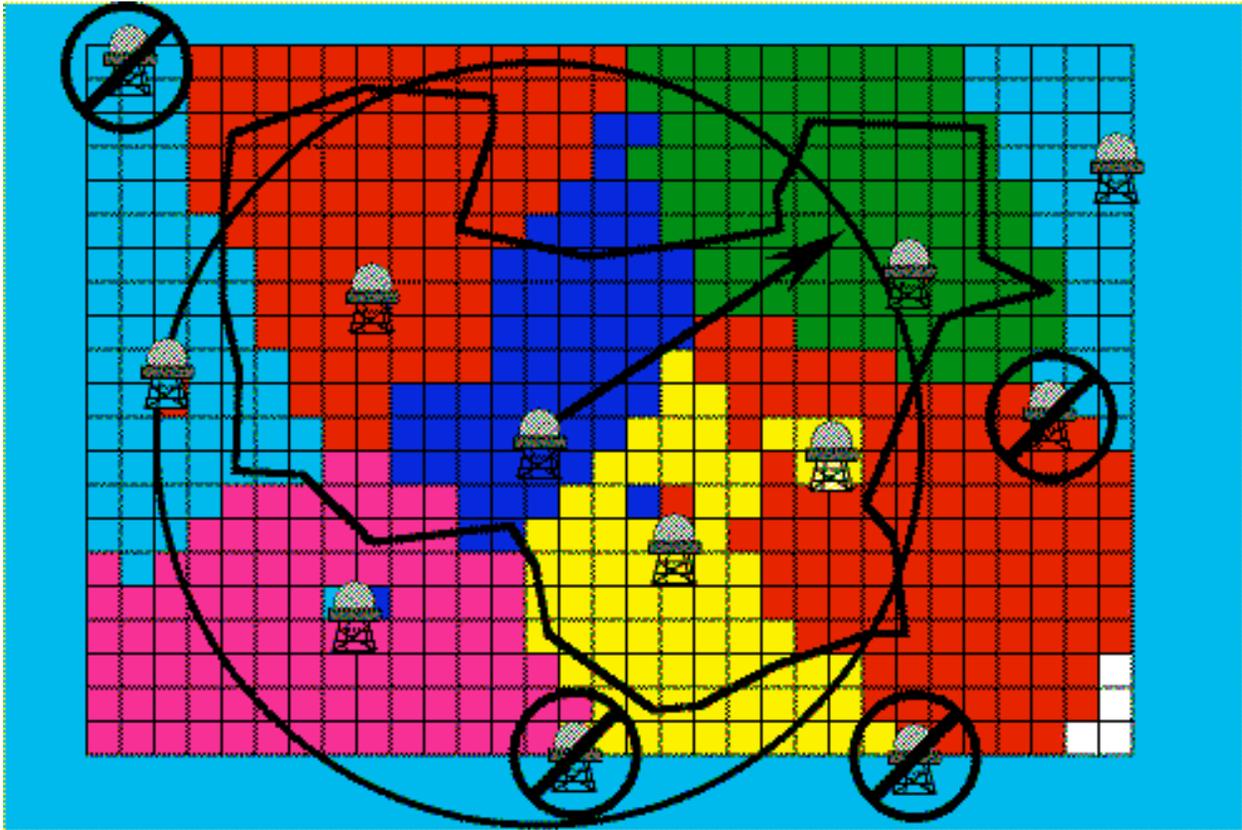
Slide 9 of 41: Rorschach Test results

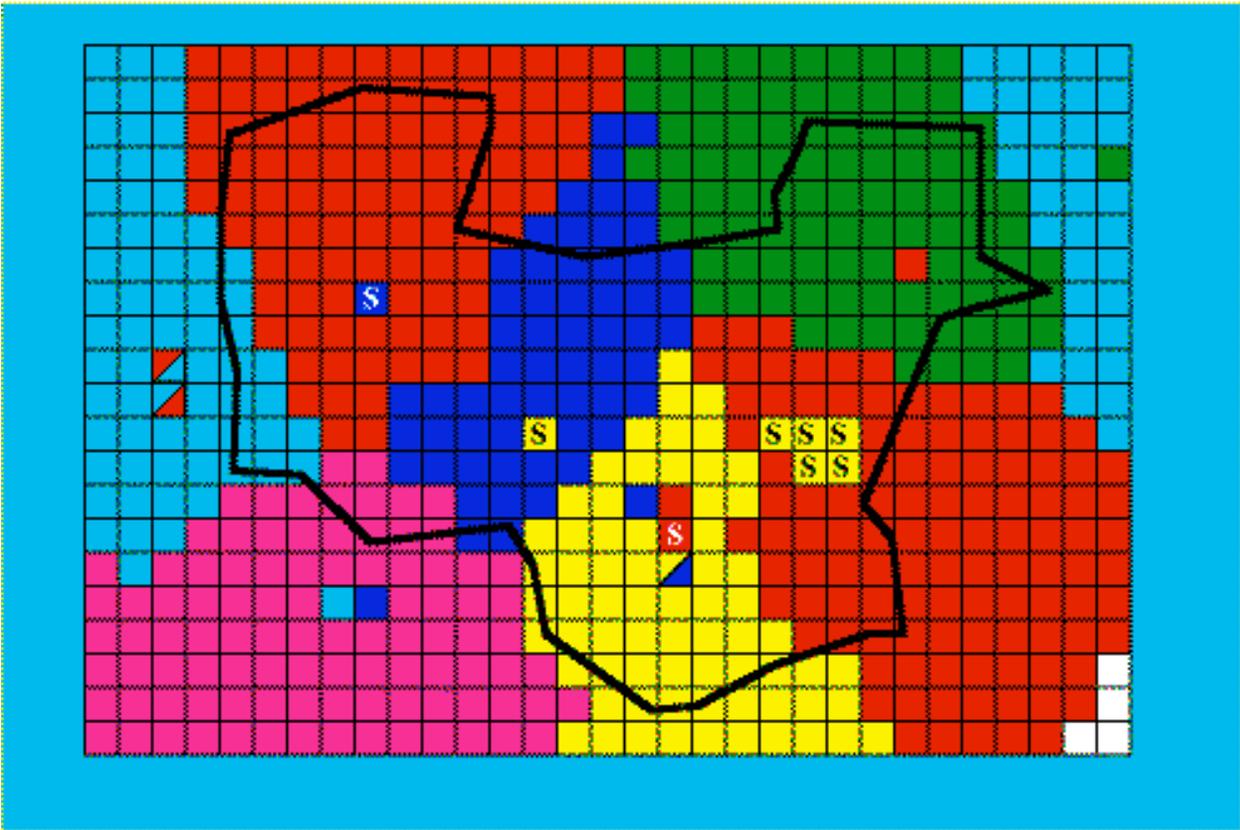Did you see the chicken??? <grin>

Slide 10 of 41: The "eye of the chicken"

Okay, enough with the questionable humor.

As you recall, one problem I've highlighted thus far is the fact that even though an aircraft may be detected by radar, it may not be on the controller's scope because the data simply isn't fed to the facility. That presents a situation very much like what occurred (and still occurs) at Frederick.

The other problem involves the inability of a radar to see directly overhead. Take a look at the "eye" of our chicken. Now, let's remove the radar icons....

Slide 11 of 41: The "cone-of-silence" issue

There. Do you see the red colored sort box, all by itself, in the upper right. It is about where the "eye of the chicken" is located. That "red eye" is the sort box that lies over the Dansville, NY long-range radar site. Why is it red?

Let's zoom in...
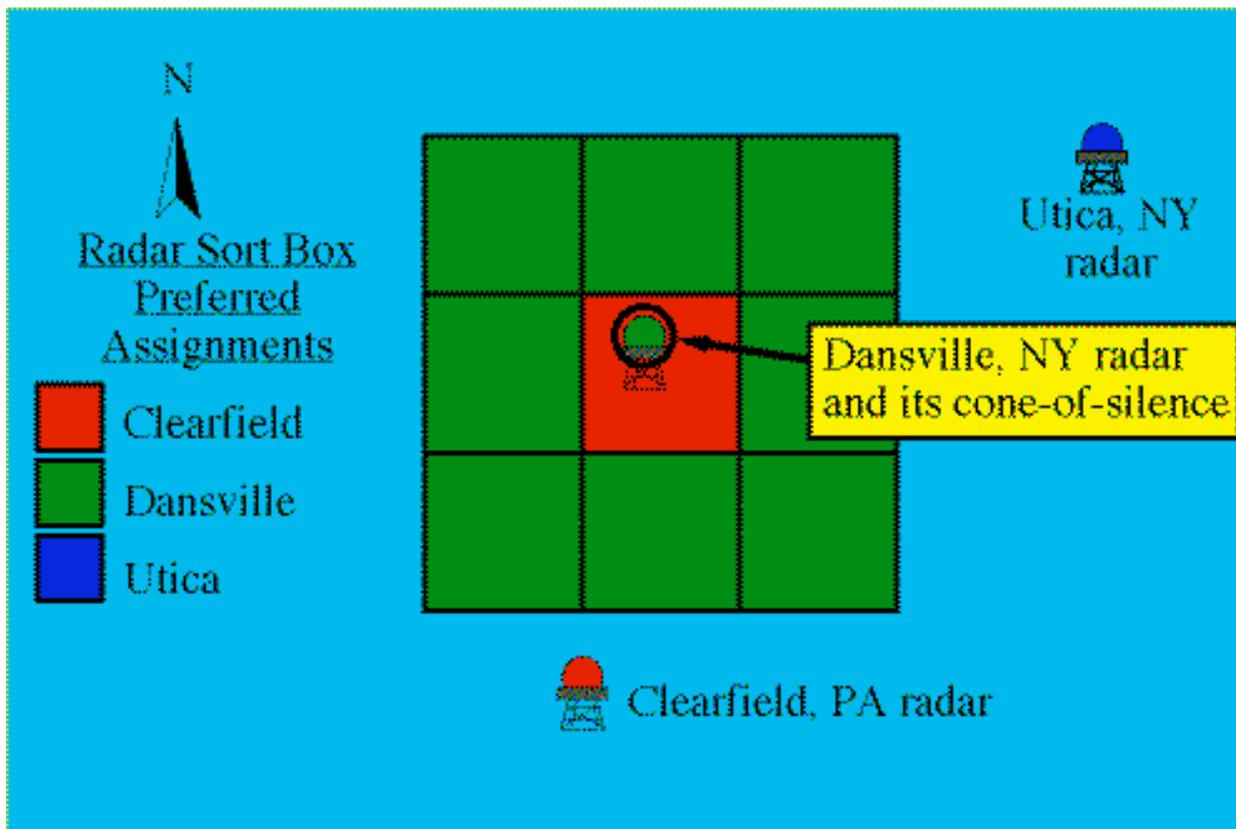
Slide 12 of 41: The "cone-of-silence" adaptation

This slide depicts the programming of preferred assignments in nine sort boxes around the Dansville long-range radar. The Dansville radar itself, which I colored green, is up in the north-northwest part of the middle box. The radar sort boxes which I depicted in green, which match the Dansville radar's icon color, show that the preferred radar for those sort boxes is the "green" Dansville radar. Similarly boxes colored red are utilizing the "red" Clearfield radar as the preferred radar. All boxes colored purple have the "purple" shaded Utica radar as their preferred assignment. Get the idea?

First of all, notice than none of the nine sort boxes are shaded purple. Therefore, even though Utica's coverage extends over this area, it is not used as preferred coverage. The data is tossed into the ole bit bucket. However, the box that overlies the Dansville radar is shaded red, which is the same color I depicted the Clearfield long-range radar. Therefore, any aircraft in this 256 square mile area must been "seen" by Clearfield to be presented for display, because as you recall from our earlier discussion, one-and-only-one radar site is used at any one time. The Clearfield radar site is just over 100 miles south of the Dansville radar site.

Why is it done this way? This is done to make it so an aircraft that flies directly over a radar site, through it's cone-of-silence, will still be displayed, as the radar can't look directly above itself. That was the adaptation (assignments) back till shortly after my "Real Targets - Unreal Displays" paper was published. In the Center enroute environment, it is typical for a site far away to be assigned as the preferred site, so as to compensate for the cone-of-silence. By the way, before we move on, notice my depiction of the difference in size between a cone-of-silence and the 256 square mile radar sort box. A cone-of-silence increases in size the higher one goes. I used a 5 mile diameter for the cone for comparison with the size of a sort box. So, as you can see, we're correcting for a problem in roughly 20 square miles of airspace, but our fix actually covers 256 square miles.

Let's look at this from a different angle...
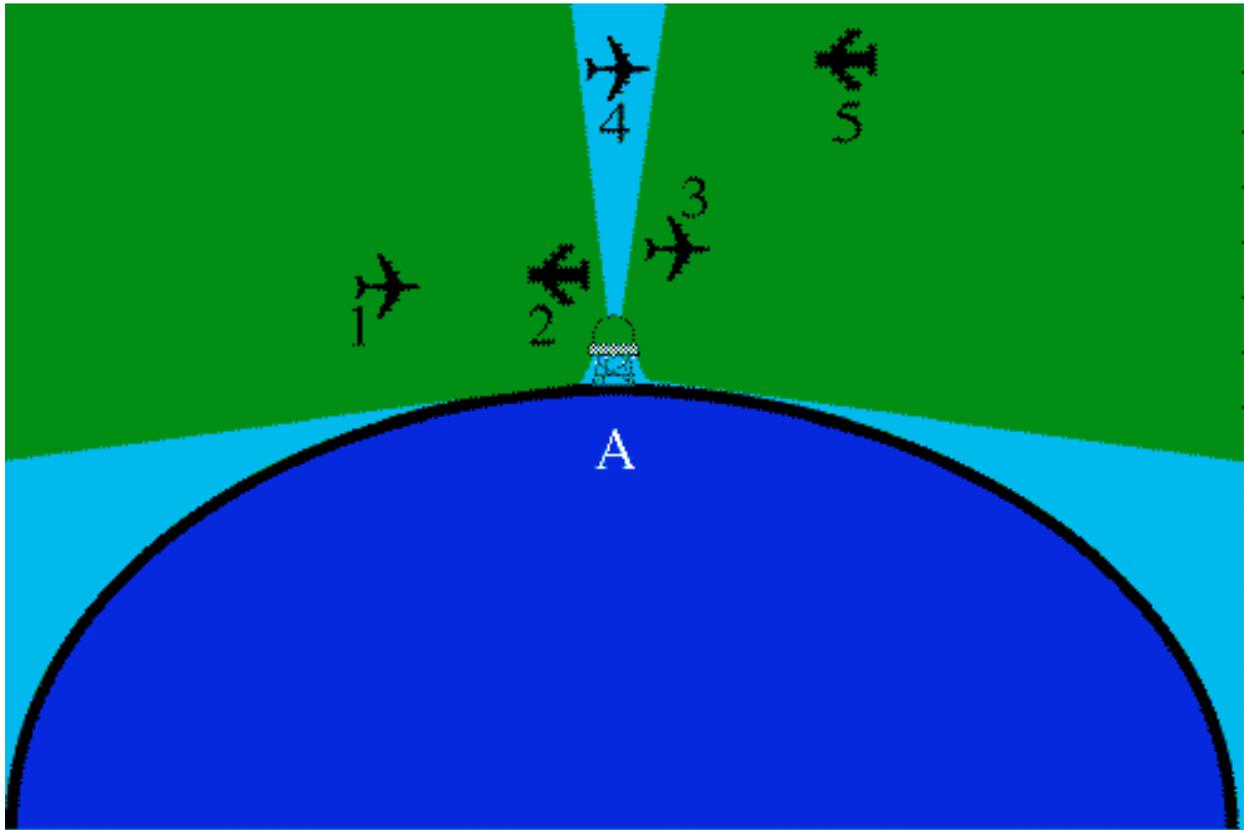
Slide 13 of 41: Cone-of-silence (side view)

As mentioned, ATC radar cannot see directly above itself. It simply isn't designed to be able to do that. In the above example, all but airplane #4 are detected by radar site A. Aircraft 1 and 2 represent low-altitude aircraft, 3 is a slightly higher aircraft, and 4 & 5 are much higher altitude aircraft. Also, before we move on, notice that the cone-of-silence is very small near the radar, and it gets wider the higher we go. That's why they call it a cone.
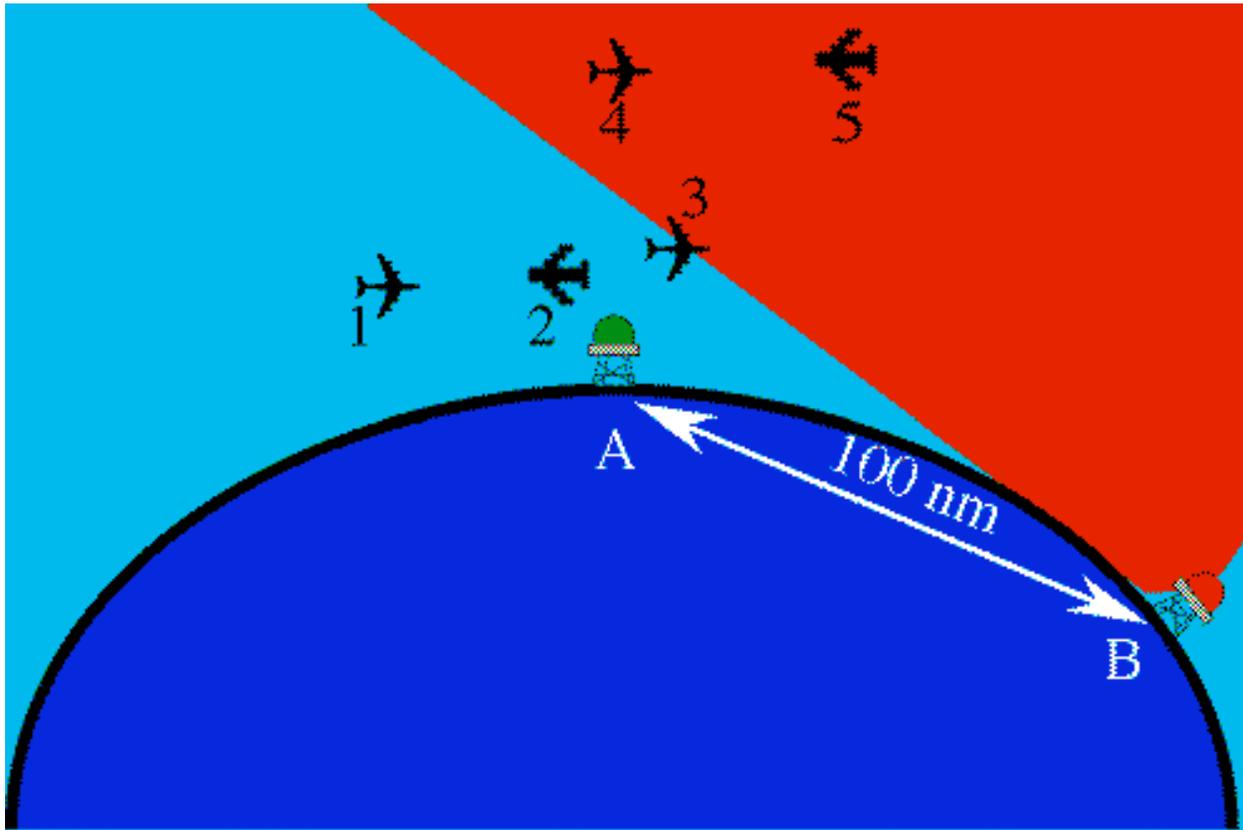
Slide 14 of 41: Coverage over the top of the radar

However, radar sites can see above each other quite easily, and therefore not lose an aircraft as it flies through the other site's "cone-of-silence." In this case, airplane 4 is easily seen by radar B, although airplanes 1 & 2 are below the line-of-sight coverage of radar B due to the curvature of the earth, coupled with their lower altitude. Airplane 3 is just barely detected by site B.

So, remember the "red" chicken's eye? We'll view that from this angle also...
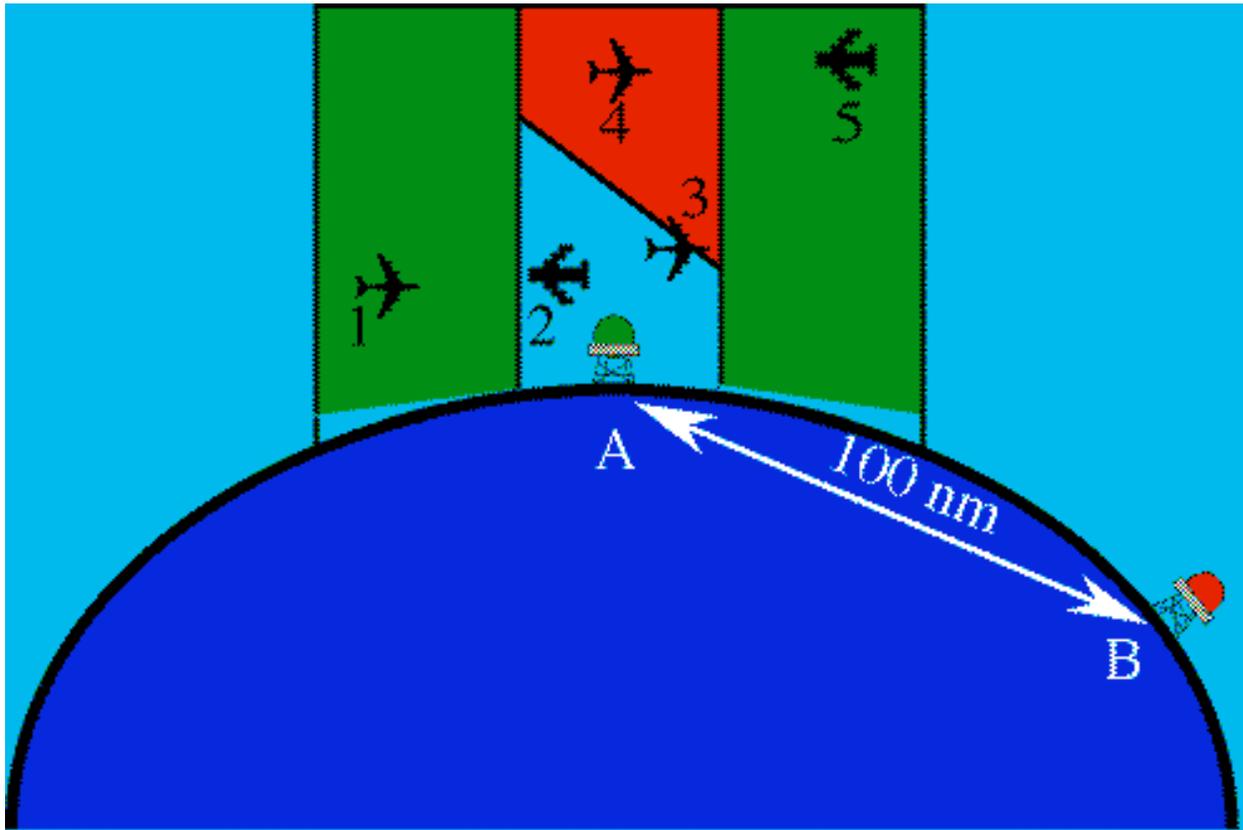
Slide 15 of 41: The "eye of the chicken" (side view)

This is a side view of our red "chicken's eye." The entire 256 square mile area, *from the ground up*, is assigned preferred coverage from radar B (Clearfield in our case), which is nearly 100 miles away. Assigning radar B as preferred over radar A's location takes care of the cone-of-silence problem, as aircraft 4 is detected and processed for display. But look what happens to the low-altitude aircraft. In this example, aircraft 2 & 3 are solidly detected by radar A, but radar A's data is not used. The data made it to the facility, but by the process of selective rejection, this data goes unused, as radar B is assigned preferred. Radar B just barely sees aircraft 3, but it definitely doesn't see aircraft 2.

What can happen when sort boxes are adapted in this manner?
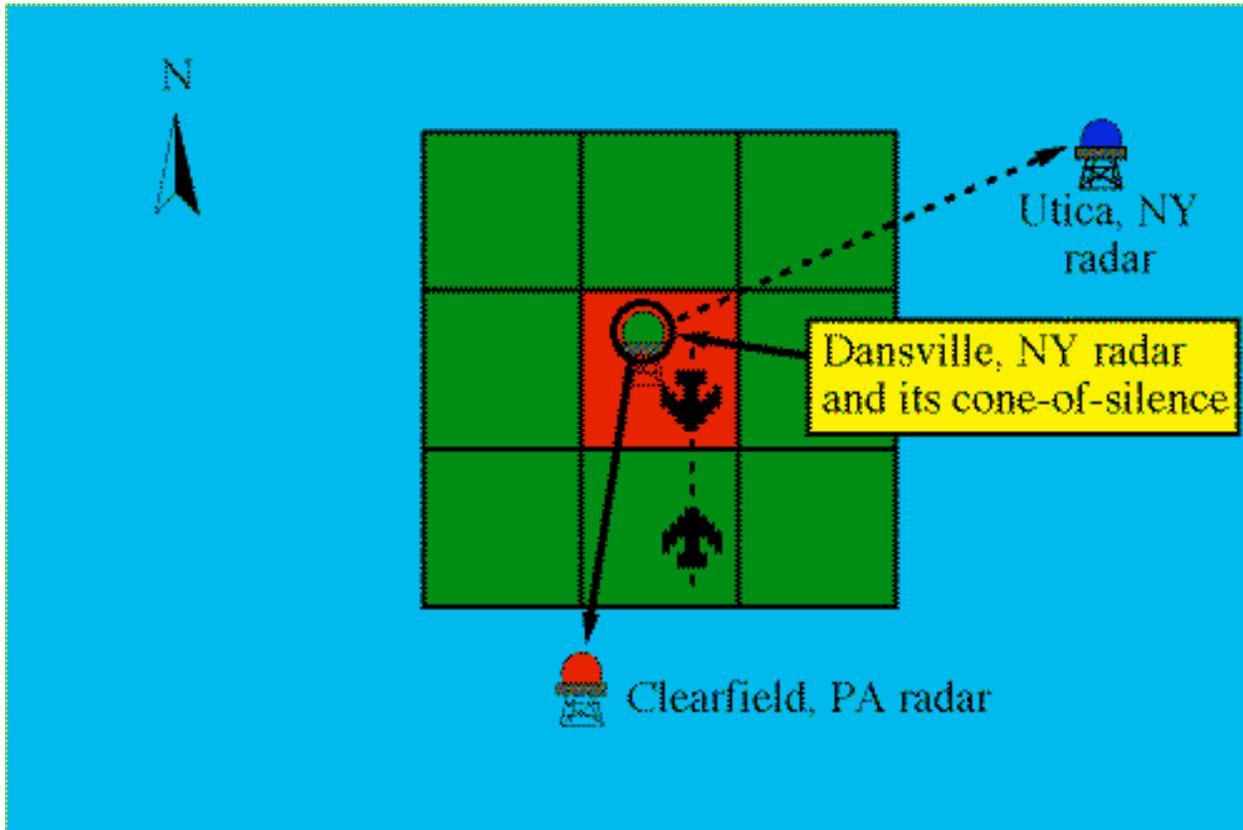
Slide 16 of 41: Head-on traffic not displayed

Here we have a case of a low-altitude north bound aircraft receiving radar service from the controller, whereas the south bound aircraft is flying VFR, not talking to Center (or if the pilot wanted to have radar service from Center, the controller wouldn't be able to identify the aircraft, as it wouldn't be displayed). Both aircraft are detected by one-and-only-one radar site (Dansville). The radar data on both aircraft is sent to the computer at Cleveland Center. However, due to the process of selective rejection and the manner in which these sort boxes are adapted in this example, the south bound aircraft is NOT displayed. Hence, the controller can not issue a traffic advisory or safety alert to the north bound aircraft. The fixing of one problem (cone-of-silence) has contributed to another problem (invisible airplane).

Can this problem be alleviated?
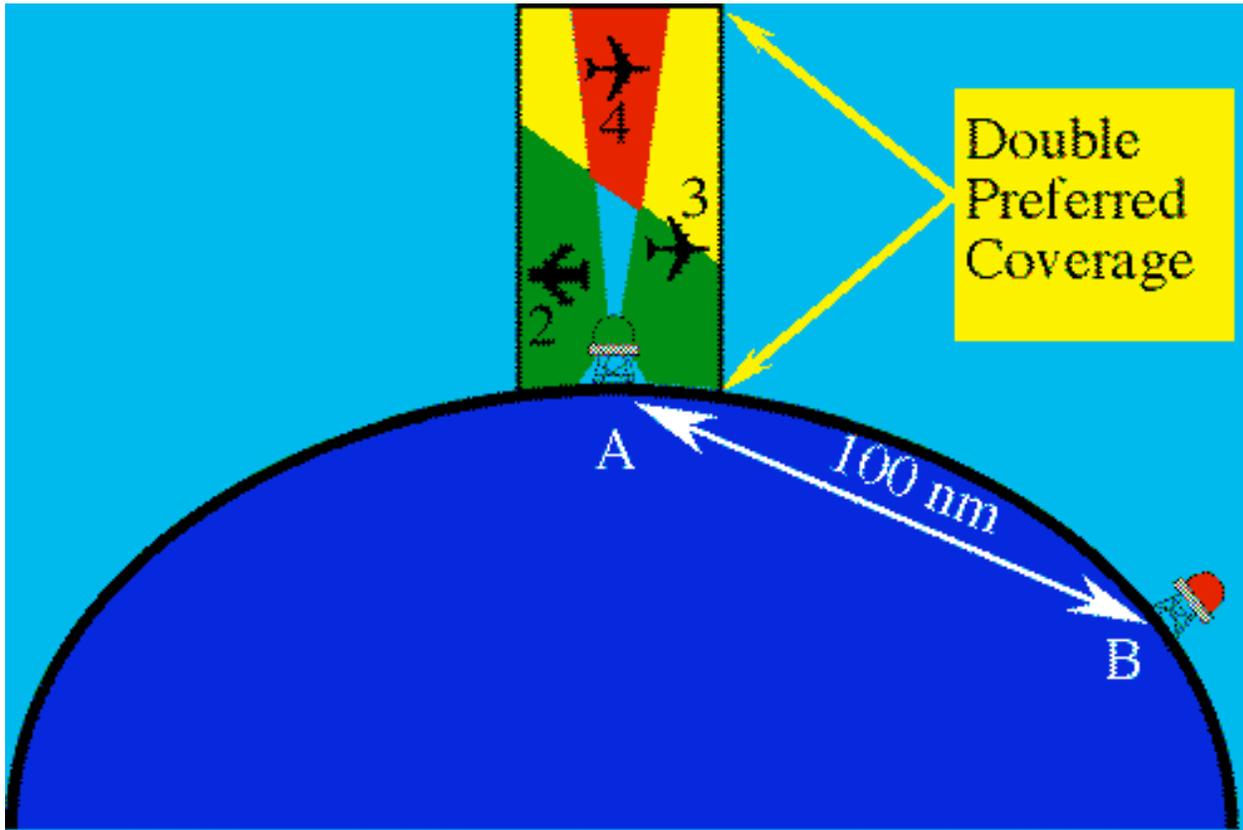
Slide 17 of 41: Double Preferred Coverage

Yes, the problem can be alleviated. Remember how I told you that up to 4 radar sites can be assigned to any one radar sort box? And remember how I told you that the first radar site listed is utilized as preferred, the second as supplemental, and the 3rd and 4th aren't used? Well, this can be adapted somewhat differently in that the second radar site becomes the "alternate preferred." This means that both radar sites in that airspace will be used to display the aircraft. Neither radar site's data will be rejected in a sort box so assigned. This way both aircraft 2 and 4 aren't left out of the picture. However, aircraft 3 is "seen" by both radar sites.
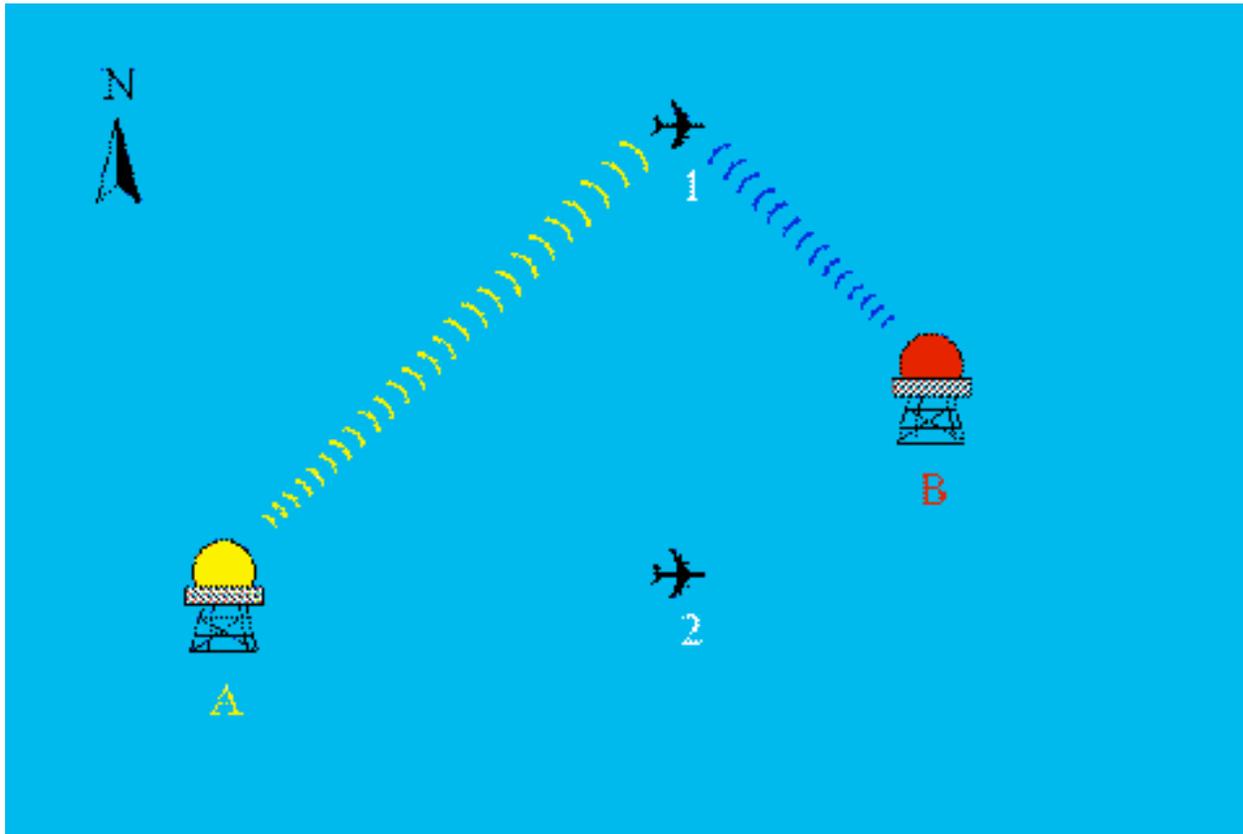
What happens in this case?
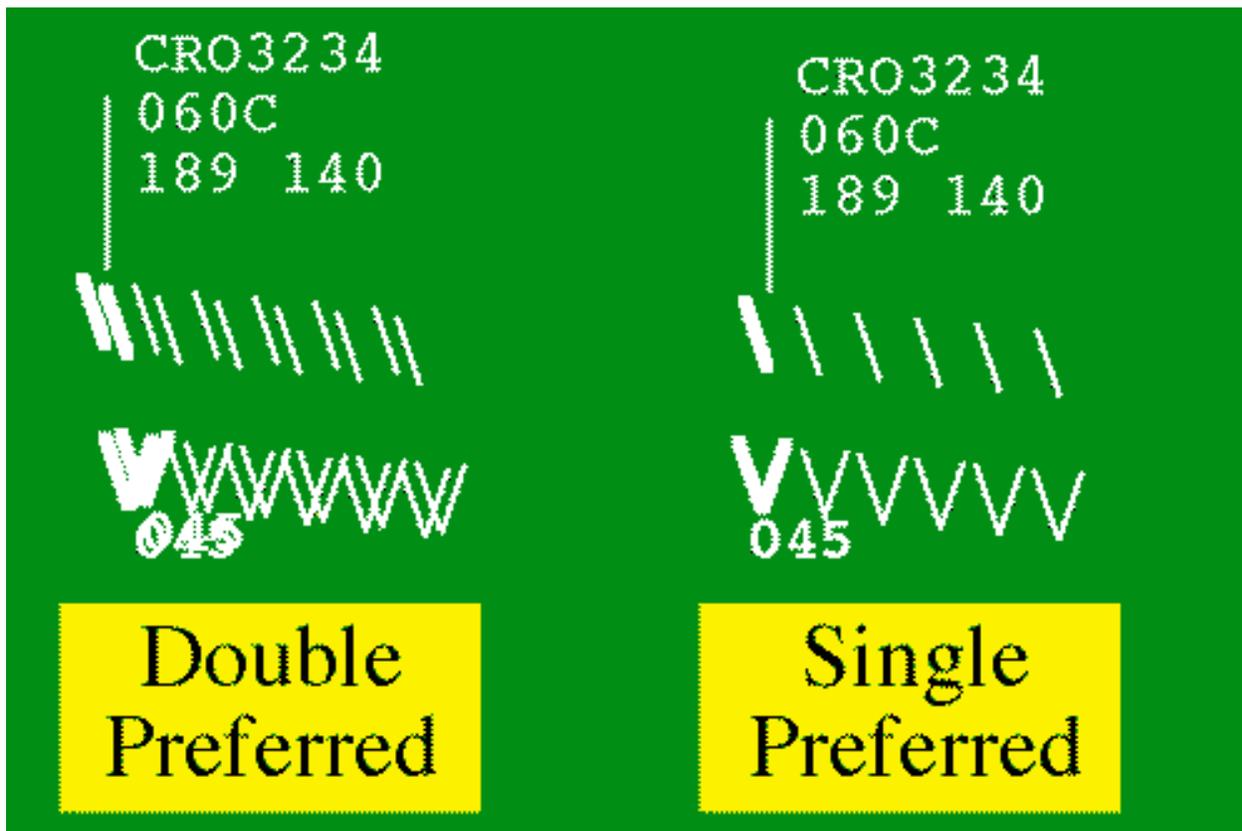
Slide 18 of 41: Display clutter

Here's what occurs on the controller's display when two radar sites are allowed to display the data from the same aircraft at the same time. The slash marks are the targets that represent the airplane. If two radar sites are utilized for display in a given sort box, and the aircraft is detected by both of those sites, two targets will appear, very close to each other. Concentrate on the target symbols (the slash marks and the V symbols). The top left target is what we call a tracked target with a full data block (in this case, the full data block shows that this target is Crown Airways flight 3234). However, with two targets, it looks like two airplanes are in formation flight, westbound. But it is really only that one aircraft, displayed differently by two different radar sites. The bottom target is that of an aircraft flying under VFR, with its transponder set to reply on code 1-2-0-0, and it is reporting an altitude of 4,500 feet. Because the aircraft is detected by both the preferred and the alternate preferred radar sites like the one above it, it also appears that two airplanes are flying in formation, westbound. If the radar sort box only used one radar site for display as is shown on the right side (Single Preferred), the target symbols would appear clean and crisp, showing only one aircraft each (assuming, of course, that the preferred radar actually detected the aircraft). Double Preferred adaptation is specifically kept to an absolute minimum because of this problem of "clutter."

So, why aren't the targets in the exact same location you ask? Are the radar sites that bad at determining an aircraft's point in space, that they don't agree? No, the radar sites are actually pretty darn good, at least from my point of view behind the scope. For example, when I observe an aircraft inbound on an ILS, the center of the target is usually right on the center of the localizer. Also, I can't help but feel that determining an aircraft's position would be much more accurate when two or more radar sites are involved. But it isn't done that way...apparently because the computers can't crunch all that real-time data. Remember, the way it is done to this day, most of the data goes unused...

So, again, why do the targets appear displaced from each other, when in fact they are one in the same airplane?
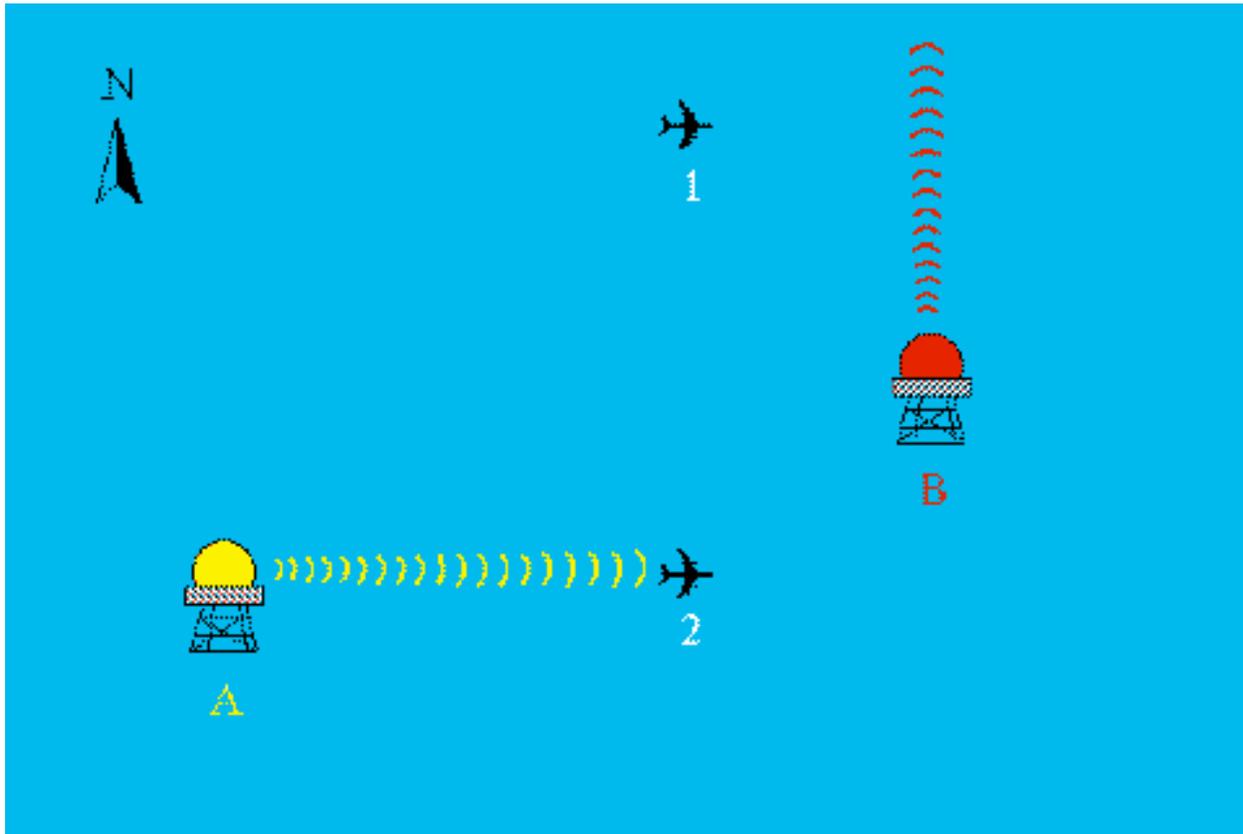
Slide 19 of 41: As the radar turns

In this example, aircraft 1 just happens to be detected by radar sites A & B simultaneously. In this case, the targets would be positioned so close to one another that viewing it at the resolution controllers typically set their scopes to, the two targets would appear virtually as one. However, that was just by chance, and as the radar turns...
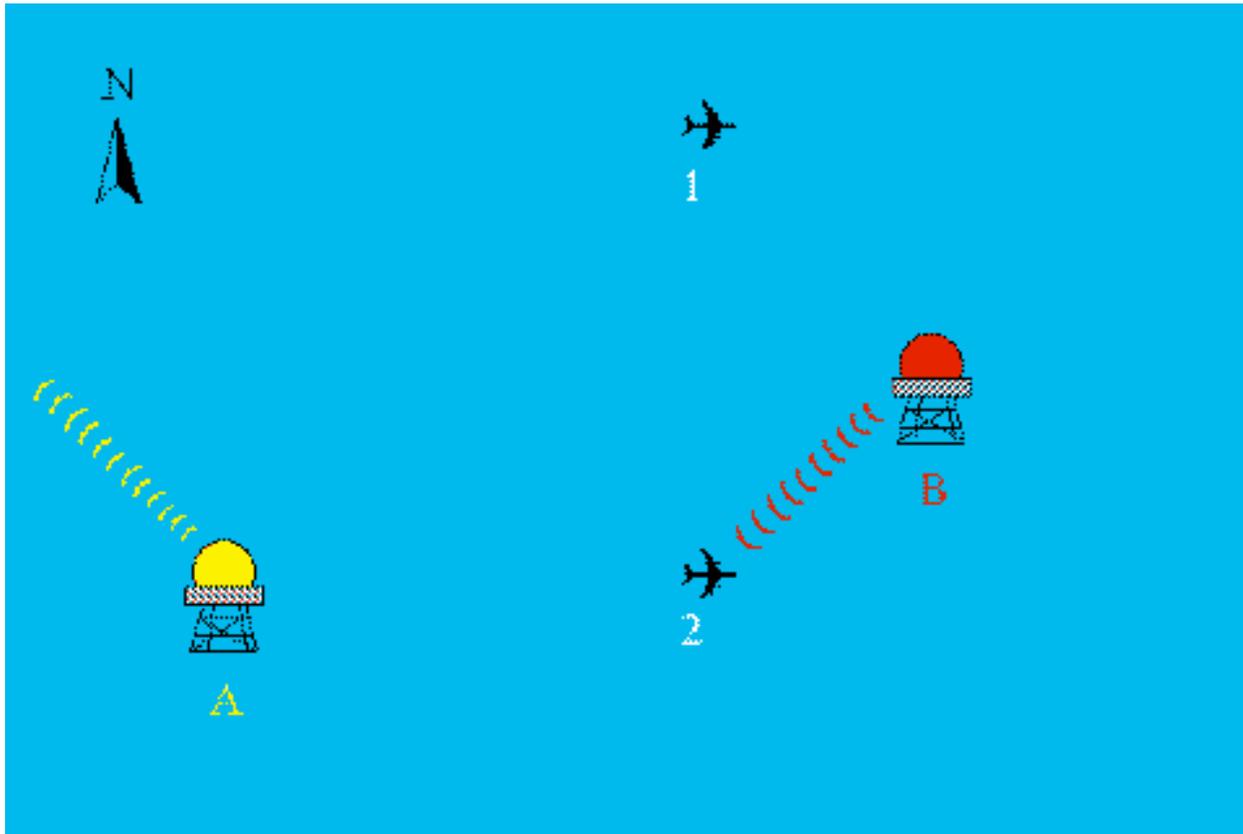
Slide 20 of 41: As the radar keeps turning

Look at airplane 2. When radar A sweeps by airplane 2, radar B is looking up north. Radar B has to sweep 225 degrees before it sees airplane 2.

Slide 21: As the radar continues

Long-range radar sites turn at a rate of 5 rotations per minute. In other words, it takes 12 seconds to make one complete sweep. So, in our example here, to rotate 225 degrees will have taken 7.5 seconds. If the airplane is traveling at 2 miles per minute (120 miles per hour), in 7.5 seconds it will have traveled 1/4 of a mile from the time radar A saw it, till radar B saw it. That is what makes it look like two aircraft flying in formation on the display if double-preferred adaptation is utilized.
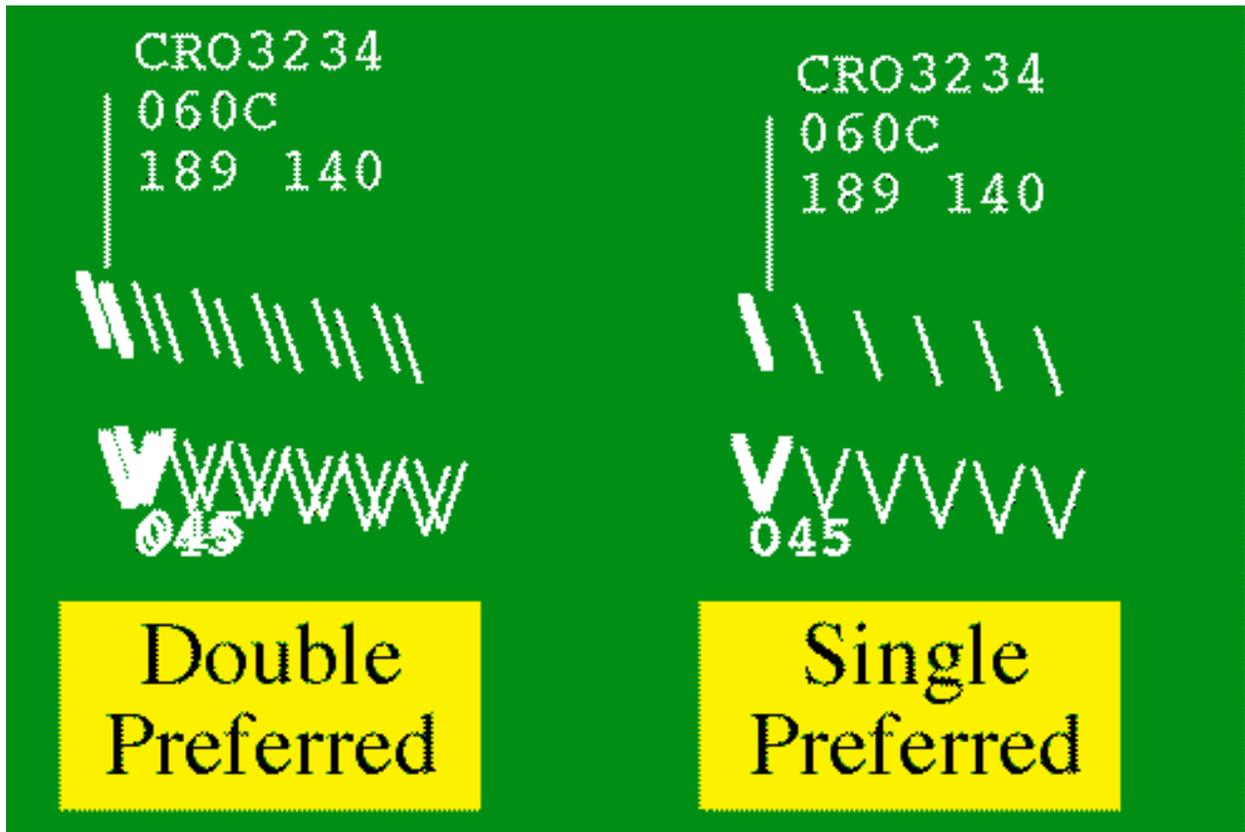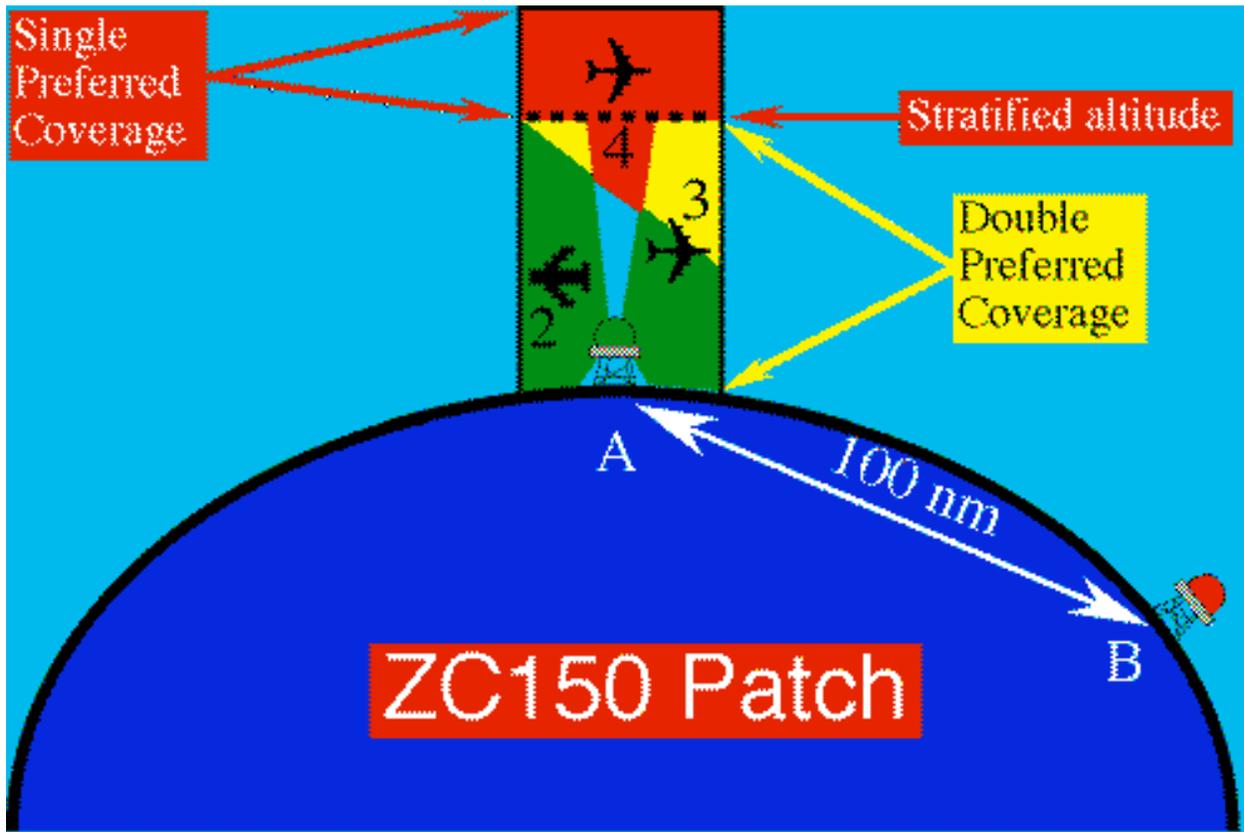
Slide 22 of 41: Double preferred = poor presentation

Hence, with a Double Preferred assignment we're likely to get a poor presentation. Single Preferred will always be crisp. Unfortunately, if the target doesn't happen to be detected by the preferred radar, it will be so crisp that it becomes invisible.

Is there a way we can have the best of both worlds?

Slide 23 of 41: The best of both worlds

Yes, this problem can be "patched." There had existed for years a software patch, called the "ZC150 patch," that made it so the radar sort boxes could be stratified. With stratification, radar B would be assigned as preferred coverage at a set altitude and above for the sort box encompassing radar A, whereas below that altitude there would exist double-preferred coverage in that same sort box. Therefore, in some cases we may have double targets, but not in the majority of cases as would be with double-preferred adaptation without stratification.
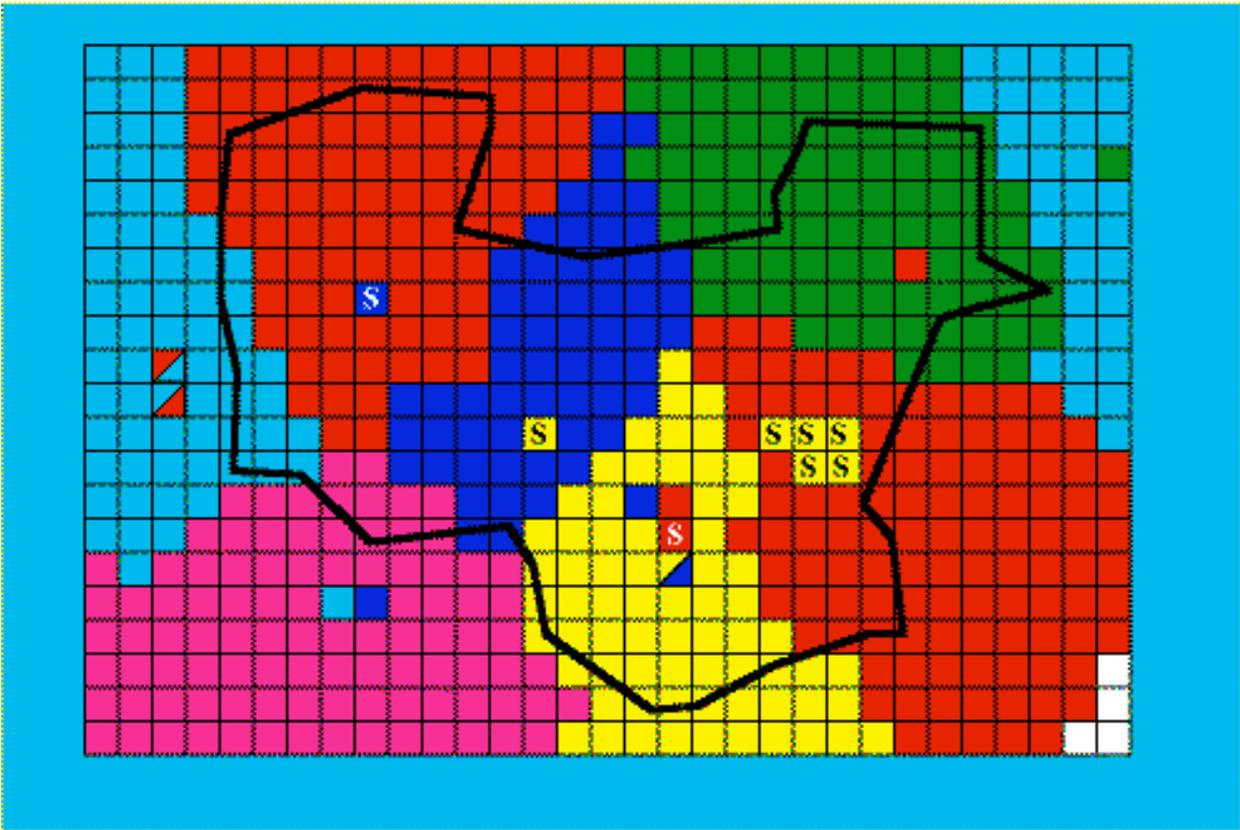
Slide 24 of 41: Stratification finally achieved

My Unsatisfactory Condition Report of Sep '88 addressed this issue and recommended that we implement the use of this software patch. In May '90 this patch was finally implemented for the first time in Cleveland Center. It was used for radar sort boxes over the Detroit, Cleveland, and Pittsburgh long-range radar sites. This was implemented to support CENRAP, wherein center radar data can be supplied to approach controls as an emergency backup should their airport surveillance radar fail. The sort box over Dansville wasn't adapted in this manner until after the Jan-Mar '92 issue of the Journal of Air Traffic Control, which reprinted my paper from the symposium.
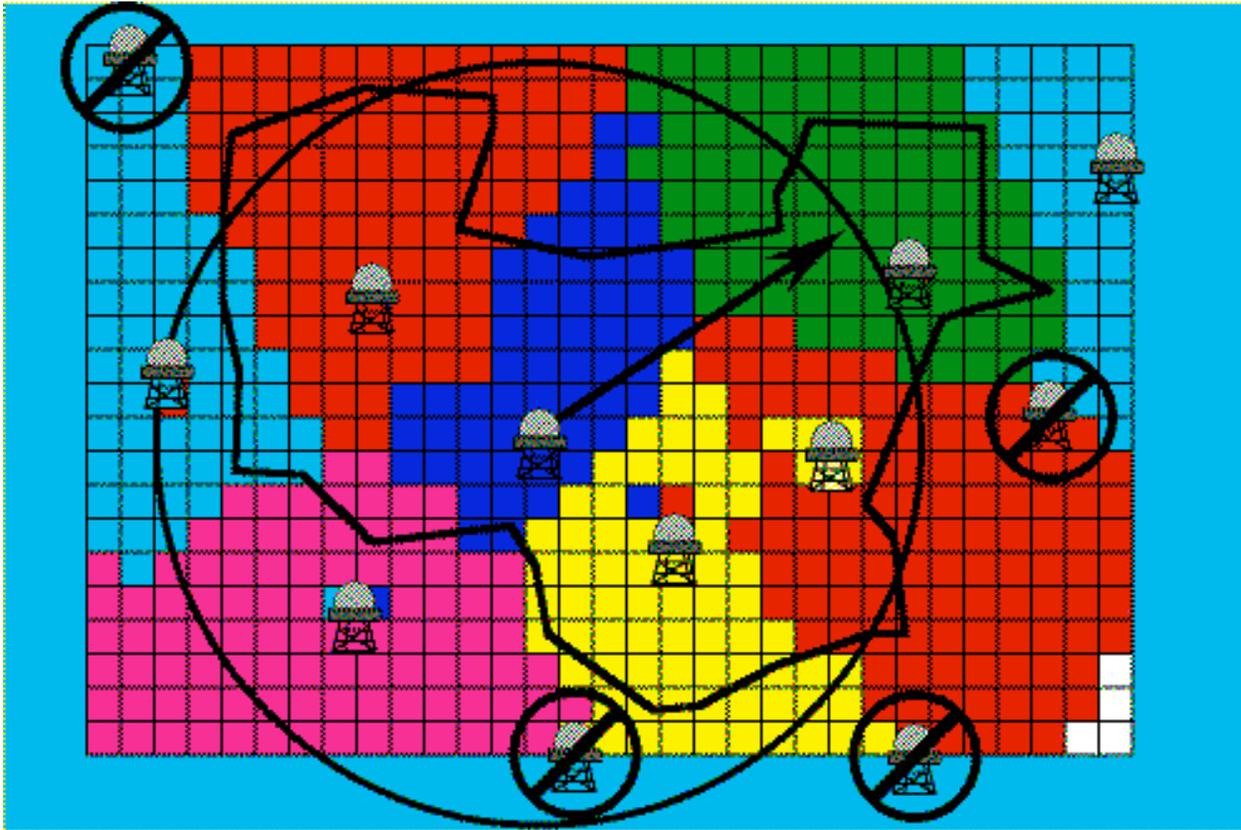
Slide 25 of 41: The midpoint problem

As a review, we have covered two distinct problems in which aircraft, detected by radar, are not displaying on the scope.

The first problem is where radar data is simply not supplied to a neighboring facility. This is like the Frederick "Radar Service Terminated" example. The aircraft may, in fact, be detected by radar, but not displayed on the controller's scope who has responsibility for the aircraft at that time. This problem can only be remedied if the data is supplied to the facility that needs it (and only then it works if that data isn't thrown out by the program!).

The second problem is the "cone-of-silence" problem, wherein the manner of programming to fix one problem (aircraft can't be seen directly above the radar) results in yet another problem (a whole bunch of low-altitude airspace will not show aircraft targets because the radar data is thrown out).

The third problem, however, is much more sinister. It isn't nearly as distinct or easy to recognize. In fact, it will give the controller the impression that an aircraft has a malfunctioning or intermittent transponder.

Take a look at any point midway between any two radar sites that are feeding Cleveland Center. At some point, usually near the midpoint between the radar sites, the preferred coverage changes from one radar to the other. There are no if's, and's, or but's. The aircraft is either displayed by the preferred coverage of one radar, or the preferred coverage of the other...but not both.
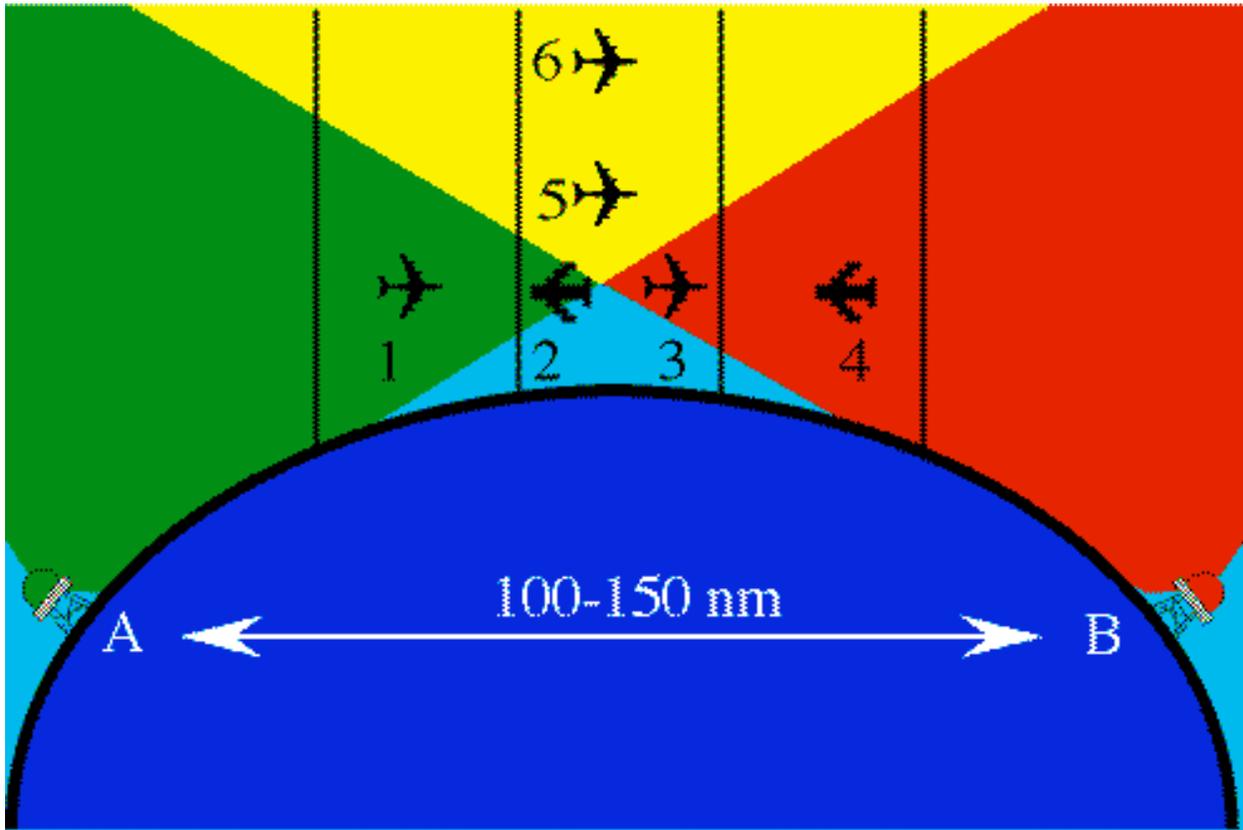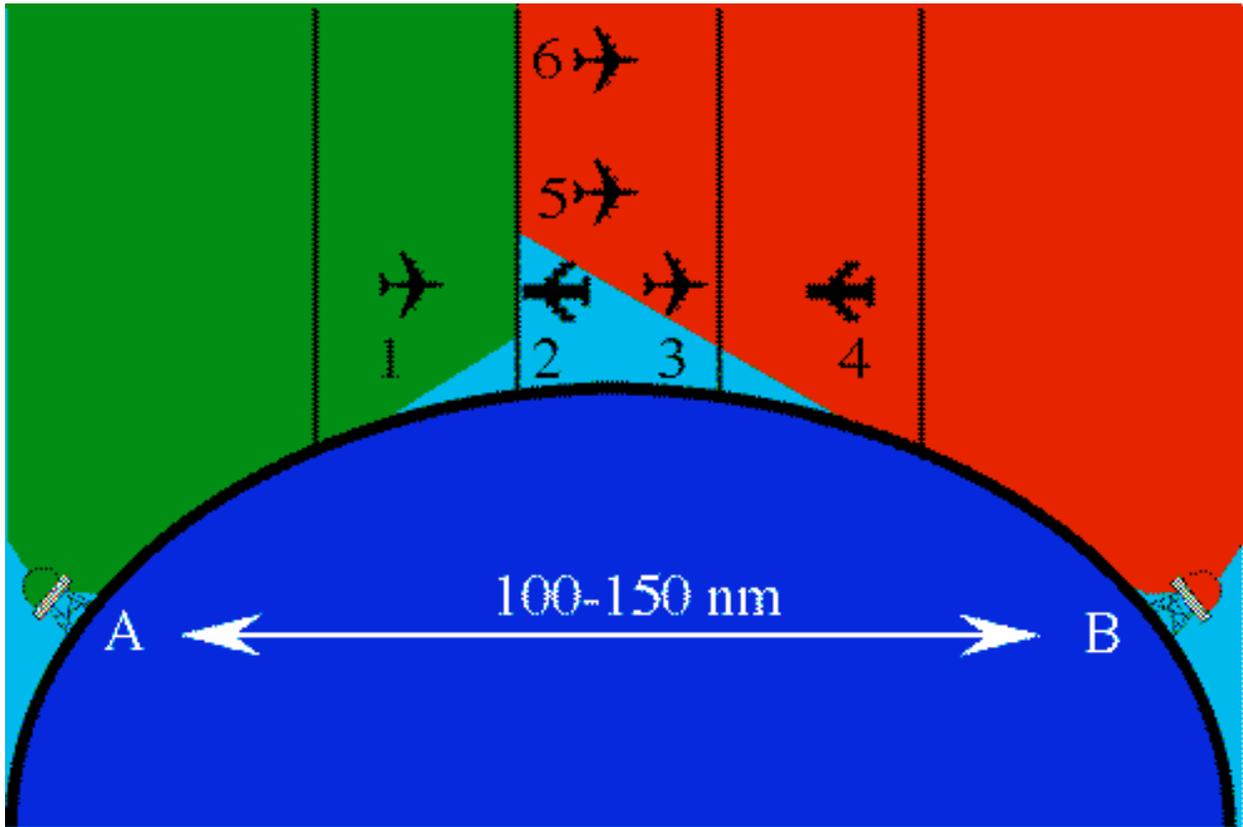
Slide 26 of 41: Midway coverage

Remember what I said about radar coverage in this country? Overall, it is quite complete, especially east of the Mississippi. In this slide you observe that all six aircraft are detected by either the radar on the left, or the radar on the right.

But what happens at some point between the radar sites? Remember, a radar sort box is almost always set to use one-and-only-one radar site's data at any given time or location. So, what if we assign the radar sort box that lies midway between these two radar sites to the radar on the right?
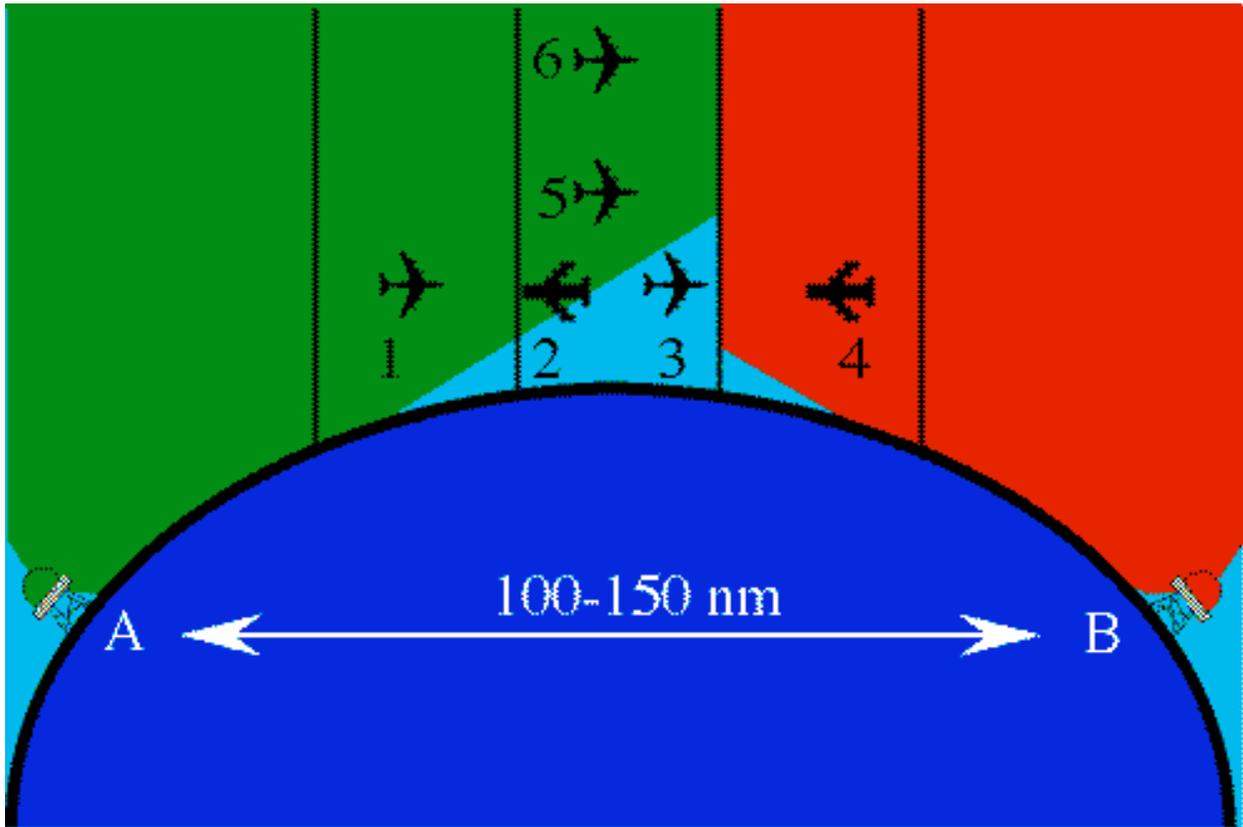
Slide 27 of 41: Midway coverage assigned to one

In this example, we see that low-altitude aircraft 2 will not be processed for display. Every other aircraft in this example will be displayed, but not aircraft 2. It is detected, but not displayed. A controller may very likely assume the problem in displaying aircraft 2 has to do with the aircraft's transponder, as every other aircraft appears just fine.

Of course, we can fix the problem in the displaying of aircraft 2...

Slide 28 of 41: Midway coverage assigned to the other

But like before, when we fix one problem, another problem can crop up. In this case, the controller will once again likely assume that the problem lies with aircraft, or that the radar coverage is simply marginal in this area, as all other targets "seem" to be displayed without any problems. As you see, we changed the preferred coverage of our midway sort box from the radar on the right, to the radar on the left. Now aircraft 2 is displayed just fine. Aircraft 3 is detected, but it is *not* displayed.
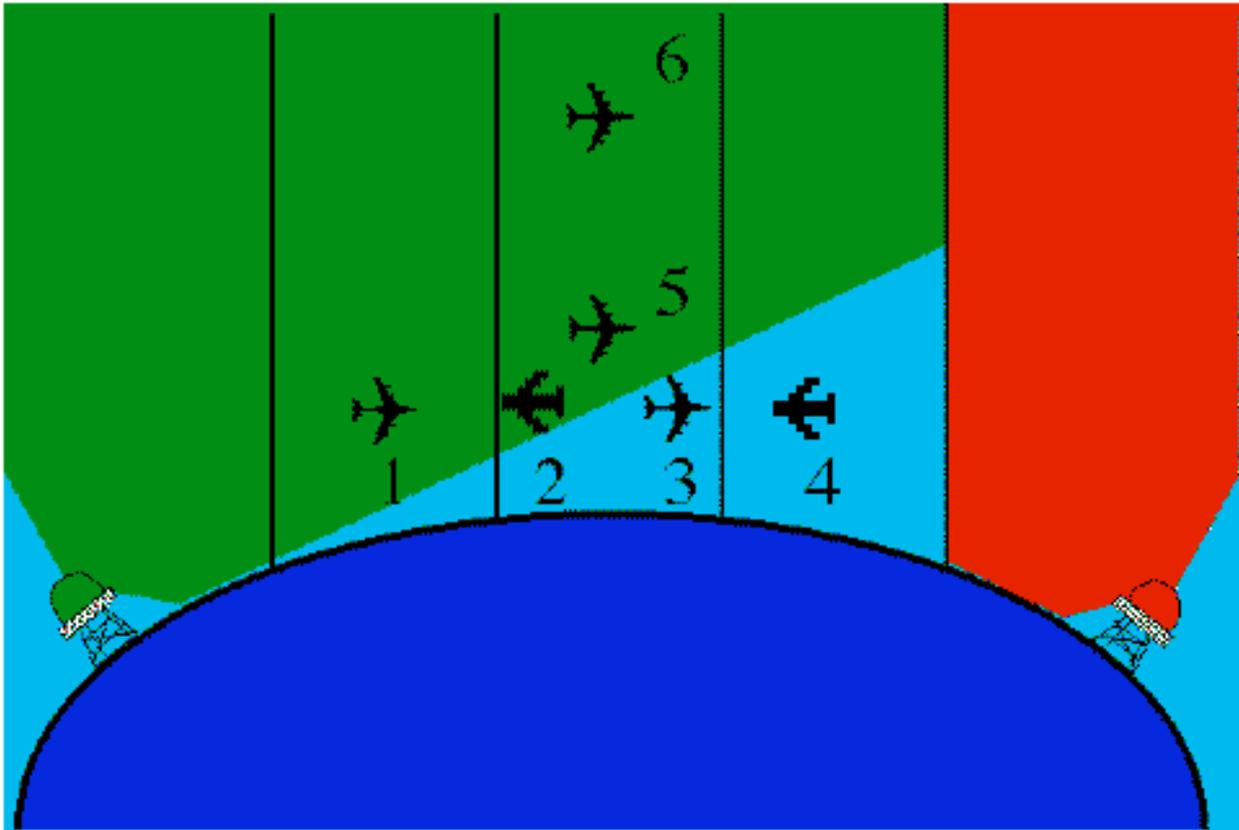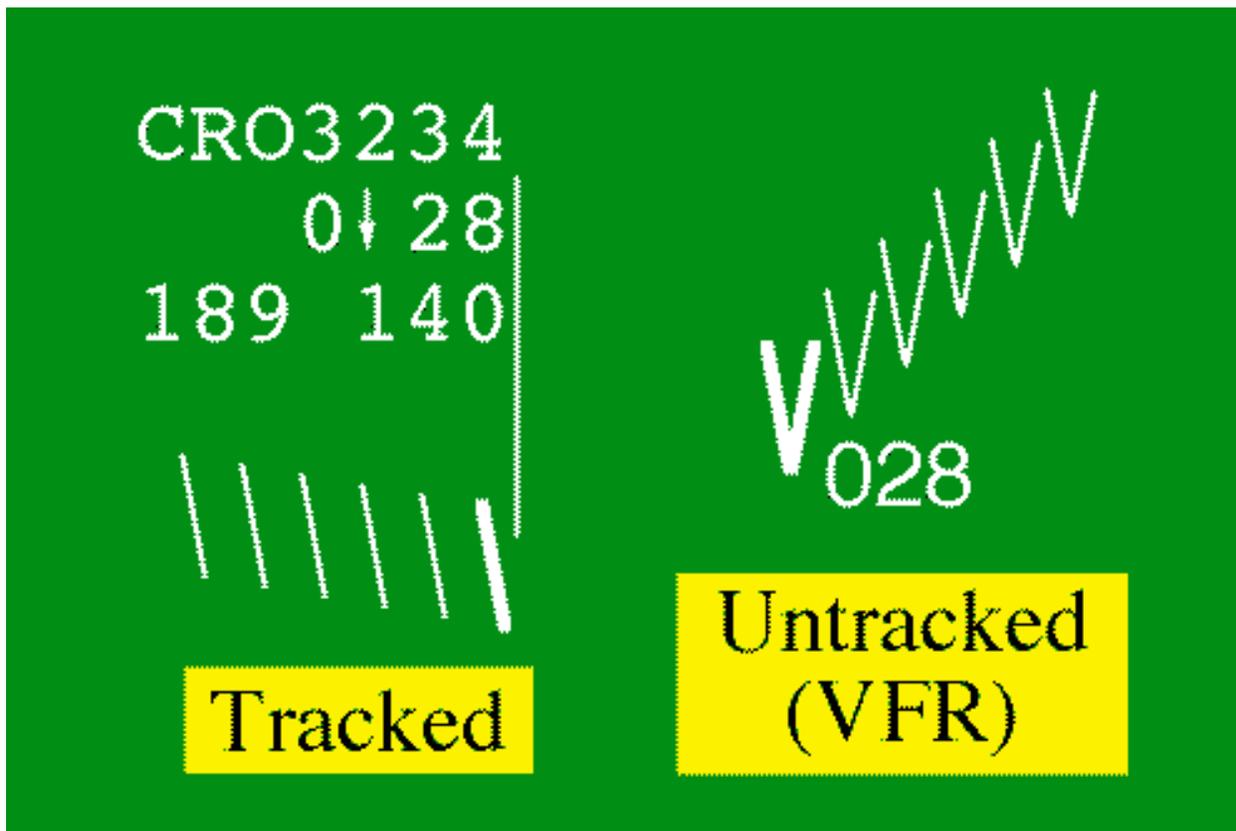
Slide 29 of 41: Sometimes the problem becomes extensive

In some cases, this effect is even more pronounced, increasing the odds that a low-altitude aircraft target won't be processed for display.

Slide 30 of 41: Tracked vs. Untracked

Before we go on to understand how this problem is very sinister and therefore difficult to detect, I'm going to explain the difference between a *tracked* target and an *untracked* target.

A tracked target is associated with an aircraft to whom the controller is providing radar service. In most cases this is an IFR aircraft, but it can also be a VFR aircraft receiving radar traffic advisories. In either case, the tracked target has a Full Data Block.

In the above example, the target on the left has a Full Data Block (FDB). This full data block carries along information like identity, altitudes, speed, etc. In the above FDB, the aircraft is Crown Airways flight 3234. In this example the aircraft is assigned an altitude of zero, which is shorthand a lot of us controllers utilized to show that the aircraft was "cleared for the approach." The mode C altitude data, as received via this aircraft's transponder, reports that the aircraft is at an altitude of 2,800 feet. The 189 is simply a computer identification number, and the 140 represents the ground speed as determined by the radar tracking program. This aircraft is traveling eastbound, and there are five "history" target indications that show where the aircraft has been in the last minute.

An untracked target is typically associated with an aircraft that is flying under Visual Flight Rules (VFR), and has its transponder set to reply with a code 1-2-0-0. Its target is represented by the letter V. It has a Limited Data Block (LDB), so the only thing it shows is the altitude as reported by via the aircraft's transponder. It is reporting at an altitude of 2,800 feet. This aircraft is proceeding southwest bound, as can be ascertained by the five history targets. These aircraft are in close proximity, and if the controller is in communication with the pilot of CRO3234, he'd be saying something like this (with *lots* of inflection)...

"Crown thirty two thirty four, TRAFFIC ALERT! Traffic ten o'clock, one mile, southwest bound, altitude indicates two thousand eight hundred. Suggest you climb IMMEDIATELY!!!"

If the pilot of the Crown Airways aircraft didn't already have the traffic in sight and know that he could safely pass by the aircraft visually, he'd probably follow the controller's advice and execute an immediate climb.

Okay, so other than the full data block versus the limited data block, what's the big deal?
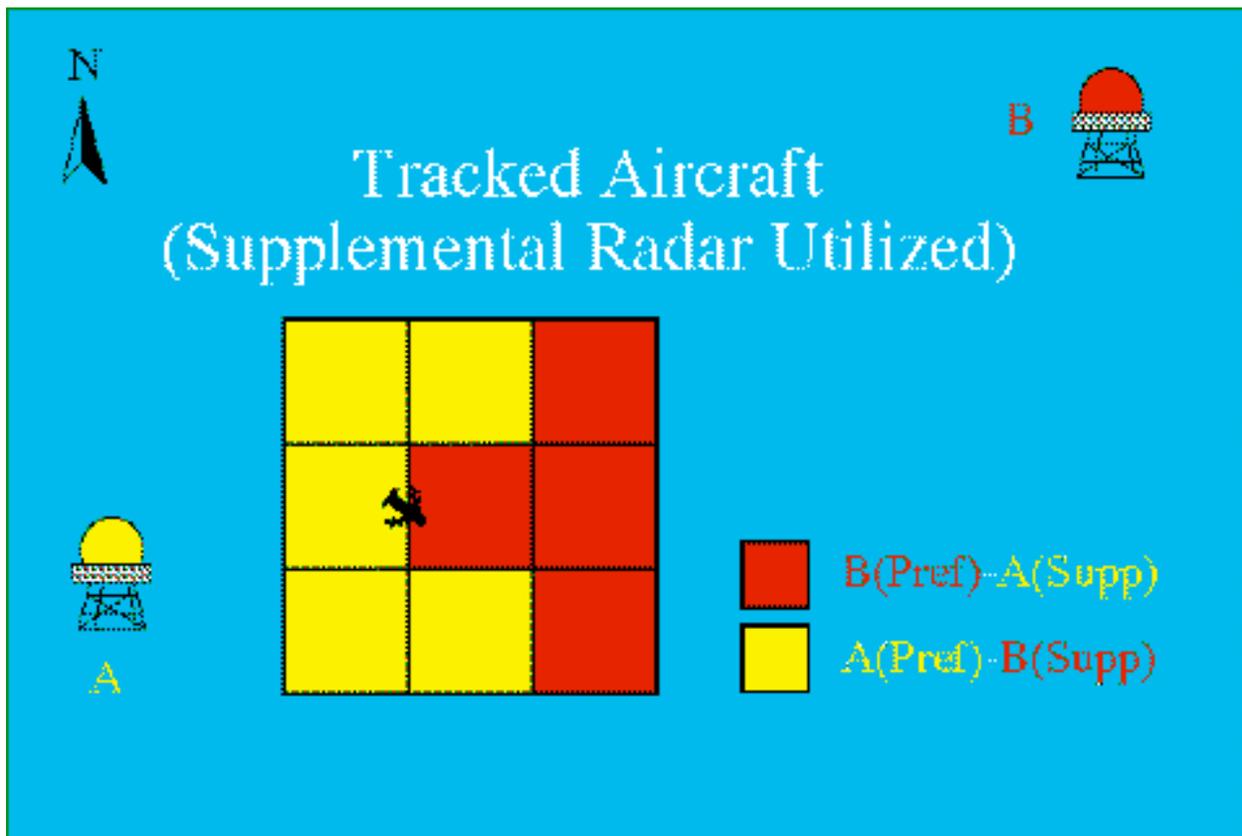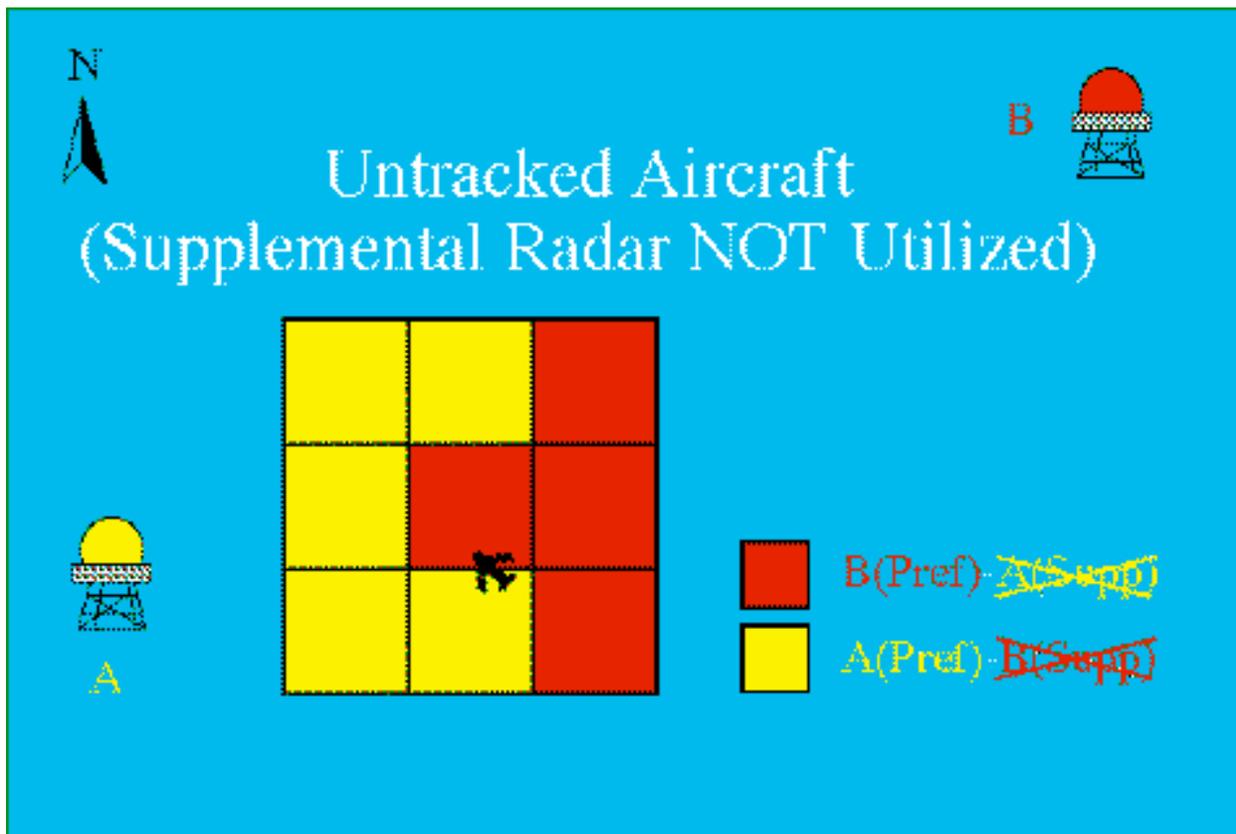
Slide 31 of 41: Tracked uses two radars

Remember when I told you about 4 radar sites being assigned to one sort box? The first in line was termed "preferred," and the second "supplemental," and the 3rd and 4th were there only to cover for the first two if they were off the air.

Well, a radar site assigned to provide supplemental coverage will basically wait in the background and only show its target symbol if the preferred radar loses the target for some reason. Such a reason could be that the aircraft is below the line-of-sight coverage of the radar that is assigned as preferred in that sort box. In the above example, the southeast bound low-altitude aircraft is crossing into a sort box that has its preferred coverage assigned to radar B (shaded red). However, being as this aircraft is a tracked aircraft (full data block), once it gets too low to be seen by radar B, radar A will automatically fill in for B. That's right. In the red shaded box, the yellow shaded radar will fill in. This technique provides automatic and uninterrupted radar service for this tracked aircraft.

Slide 32 of 41: Untracked uses one radar

Here's where things get interesting. The low-altitude northwest bound aircraft represents an untracked target. As discussed before, untracked means there is no full data block (because no center controller is "working" the aircraft). This would be typical of a VFR aircraft, with its transponder set to 1-2-0-0. This aircraft's relatively close proximity to radar A means it is positively detected by that radar. However, being as it is at a low altitude, and a good deal farther from radar B, it falls just below the line-of-slight coverage of B. That doesn't matter while the aircraft is in the yellow shaded sort box, but as soon as it crosses into the red shaded sort box, that's when problems occur. Remember, radar B can't "see" the aircraft. However, radar B is the preferred radar site for that sort box. Here's the important part. **FOR AN UNTRACKED AIRCRAFT, THE RADAR ASSIGNED AS SUPPLEMENTAL IS _NOT_ UTILIZED.** If that aircraft is not detected by radar B, data from radar A will *not* be utilized to put a target symbol on the display, regardless of the fact that its transponder and mode C altitude is dutifully responding to interrogations to radar A. **The VFR aircraft is now invisible on the Center controller's scope!**

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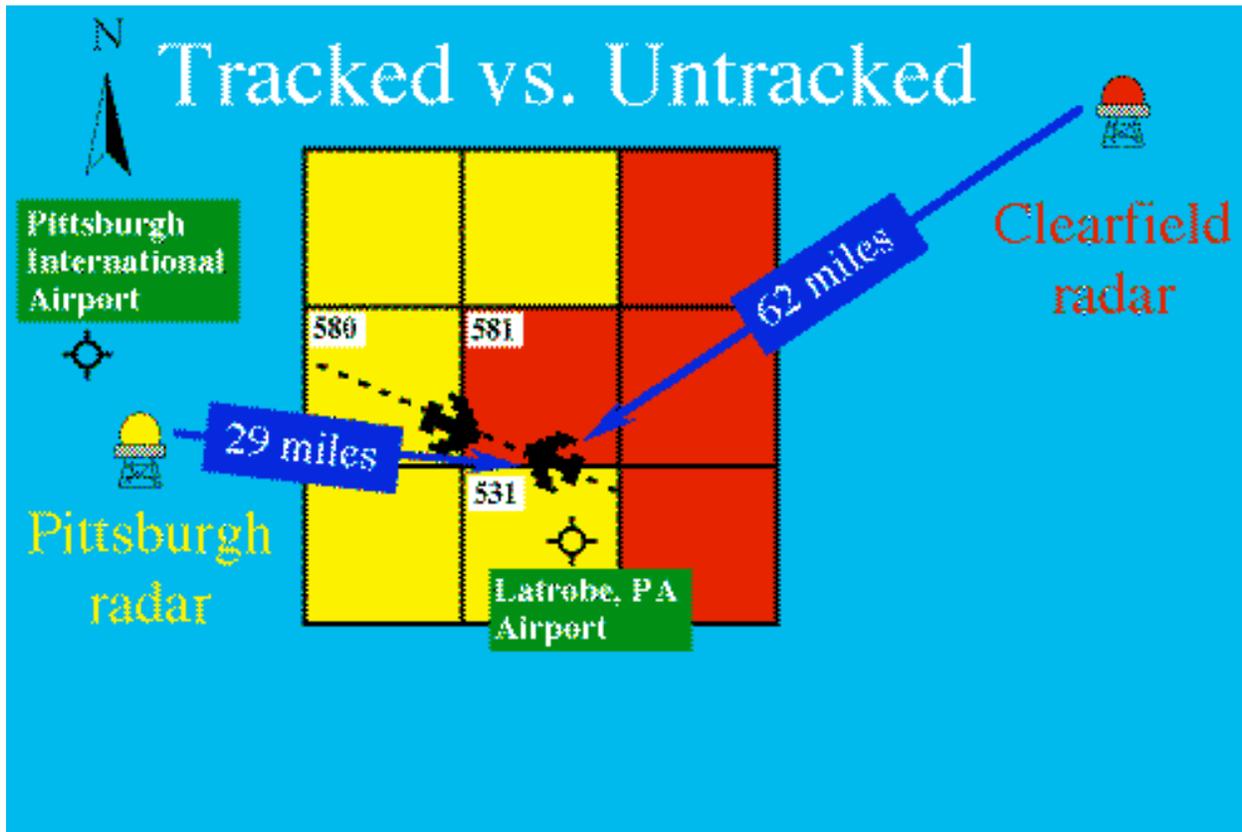
Slide 33 of 41: True life example

This represents a portion of the airspace I worked at Cleveland Center. Sort box 581 had Clearfield as preferred, with Pittsburgh as supplemental. That scenario I just went through on the previous slide was a true life example. On the one hand we (FAA) require aircraft to have a transponder, have it turned on, have it reporting altitude, have it certified every two years, yet on the other hand we take that perfectly good radar data from the transponder and don't necessarily process it for display! (And that assumes the transponder system itself is working reliably. For more on that angle, read my 1999 letter about a transponder stubbornly invisible to just one radar site.)

As I recall, after my paper was published in the Journal of ATC, sort box 581 got reprogrammed with Pittsburgh as preferred, and Clearfield as supplemental. However, does that solve our problems? In that particular scenario, sure. But what about all the other locations that lie midway between long-range radar sites? Which radar site has the absolute best coverage? One radar may see better in one portion of the box, whereas another may see better elsewhere in that box. However, for almost every midpoint situation, one-and-only-one radar is assigned as preferred. This can result in a low-altitude aircraft, that is adequately detected by radar, not being on the controller's display.

I recall when our backup radar display computer, which is named DARC (stands for Direct Access Radar Channel), was upgraded. It used to be that when the computer that drove the main computers would fail, one "switch" was thrown (probably a computer entry) so that all control positions would see the backup display. As I say, DARC was upgraded, and one of the improvements was that we now had individual control at each position for when we wished to switch to DARC. We could switch any time we wished. However, DARC was a lot less capable. For instance, it didn't have radar sort boxes at that time. One-and-only-one radar site could be selected at any one time. Changing the radar site was accomplished by an entry at the position. I distinctly recall my surprise one time when I was working the Clarion sector and I switched to DARC, the "less capable" backup computer. Much to my surprise, just west of the Clarion VOR, I saw two VFR targets flying around at low altitudes. Their transponders were working beautifully, and they were showing altitude. I switched back to our main display computer, the one we used all the time, and these two aircraft were invisible. Nada. Nothing. Zero. Zip. Not a trace of these aircraft existed. I switched back to DARC, and there they were. It was one of those enlightening experiences that drove me this far.
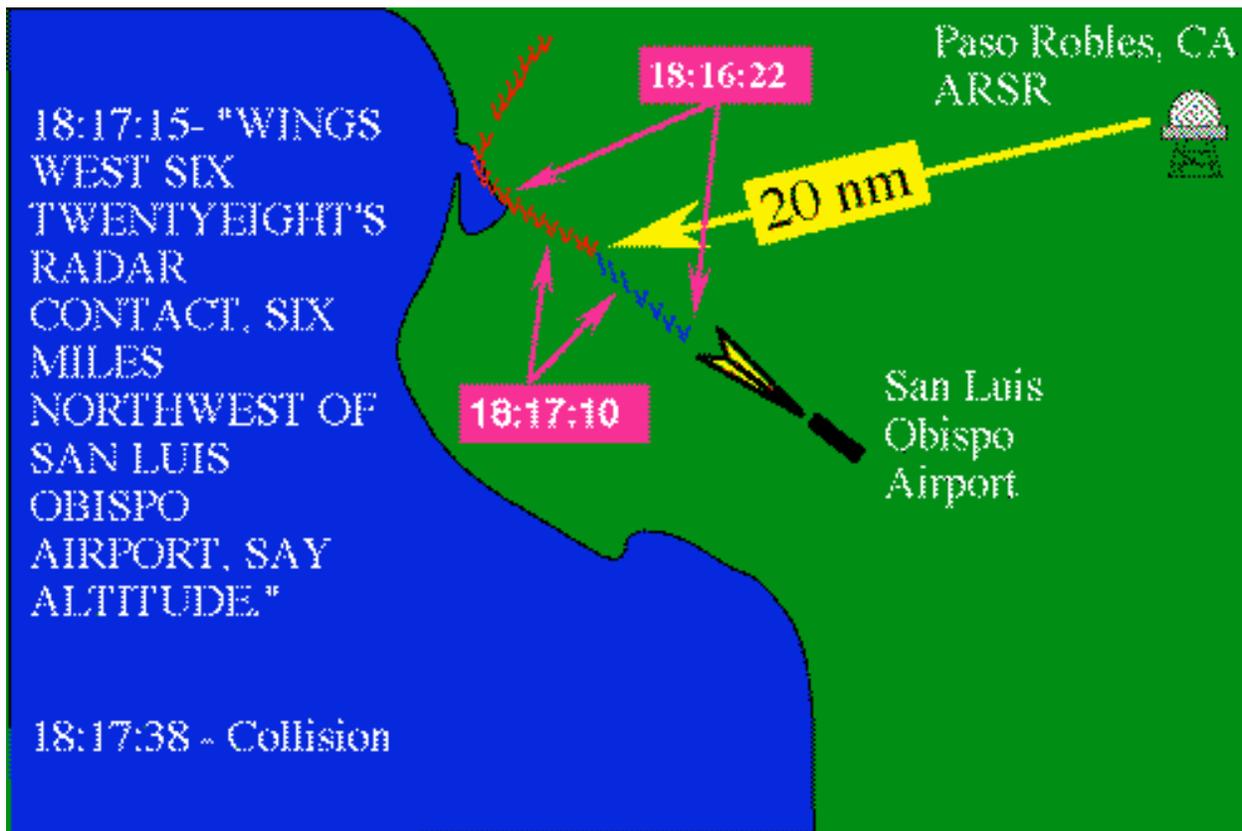
Slide 34 of 41: San Luis Obispo revisited

Okay, let's discuss the midair collision near San Luis Obispo. First of all, the Wings West aircraft departed from San Luis Obispo Airport VFR, and immediately called Los Angeles Center for radar services and to obtain their IFR clearance. This is standard operating practice. Every pilot appreciates the extra set of eyes behind the radar screen helping to point out conflicting traffic. The pilot likes to be in contact with the radar controller as soon as possible because of this valuable assistance we can provide. When the pilot made contact with L A Center, the controller advised the pilot to squawk a discreet transponder code. As soon as the controller noticed the code change from the 1-2-0-0 code (represented by the "V") to the one just assigned, the controller advised the flight that it was in "radar contact," and to "say altitude." This is always done to verify that what the pilot sees on the altimeter in the aircraft agrees with what the controller sees on the radar scope. That makes two times the controller had to be *looking directly at the target*. It was 23 seconds after radar contact was established that the airplanes collided head-on. How could the controller possibly not see the VFR target?

Slide 35 of 41: Only a half of an inch away

When the controller said "radar contact," the conflicting head-on VFR target would only have been 1/2 inch away on the scope. As a controller myself, it is difficult to imagine that a target within that proximity would have been missed. I can understand occasionally neglecting to scan about a target due to one's attention being focused elsewhere on a task, but in this case full attention had to be focused directly on the target of the Wings West aircraft. When a controller says "radar contact," the controller is looking directly at that target symbol. And then when the controller verifies the altitude with the pilot, the controller must once again focus directly at the target. Attention couldn't have been diverted, as the Wings West target was the airplane receiving the full attention of the controller just prior to the collision.

The other item of compelling interest is that this was no ordinary day for the controller working that aircraft. This was a developmental controller who was taking a check ride for sector certification. This is not a time when one slacks off, as one's career progression is on the line. How well one performs during this checkride means everything. And not only was the developmental there, but so was his instructor, right behind him, with full unobstructed view of the scope. And the data position, which is immediately to the right of the scope, was manned by a third experienced controller. And overseeing the certification check ride was a supervisor. None of them noticed any VFR traffic in front of the Wings West aircraft. The two that were ultimately charged with the responsibility of viewing the scope (the developmental and his instructor) testified that the target of the VFR aircraft was NOT displayed.

It was frustrating for me to read the transcript of the NTSB investigation. Many questions were asked, but I could find no mention whatsoever of the software radar data processing method of "selective rejection" discussed, or even brought up. Could this have played a part in this midair collision?
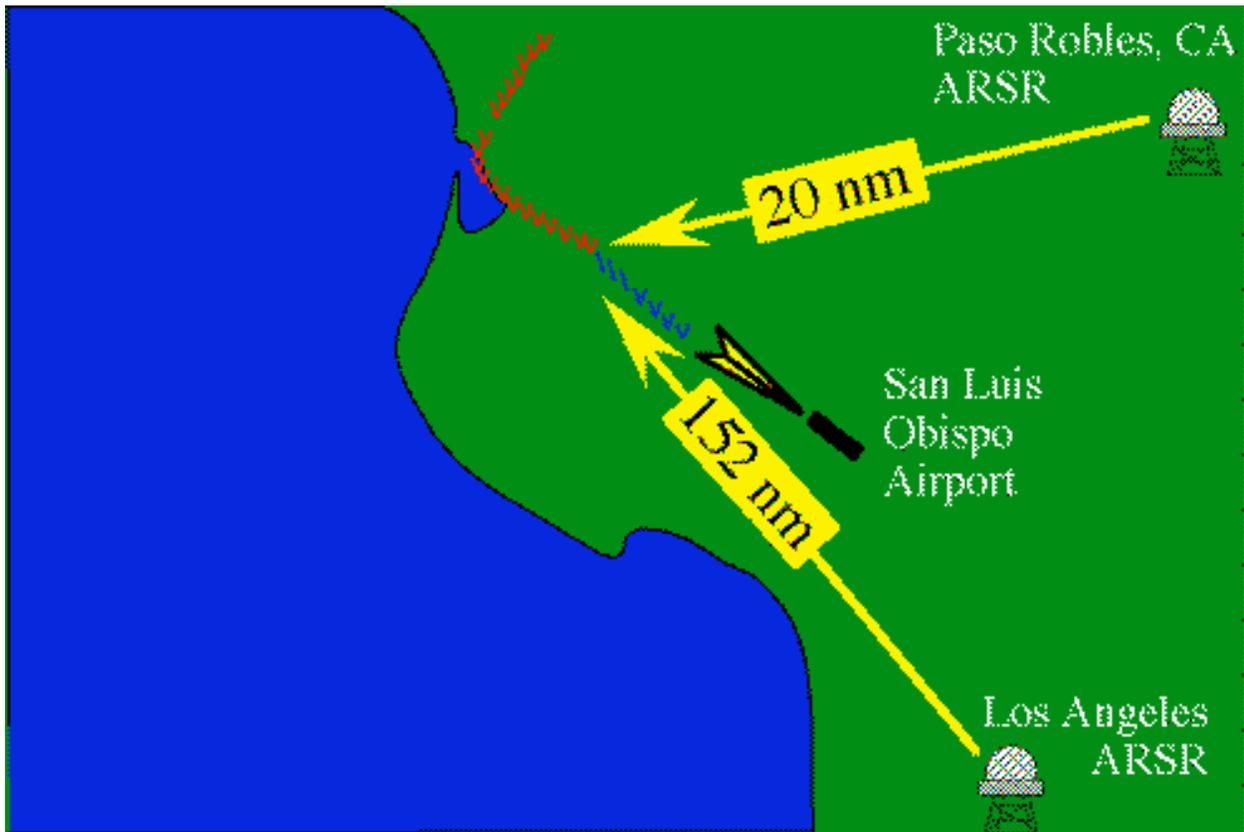
Slide 36 of 41: Distances from the radars

If we look at the distances from the long-range radar sites serving this area, it is obvious, to even the most casual observer, that an aircraft flying at a low-altitude near San Luis Obsipo would not be detected by the long-range radar located in Los Angeles, just over 150 miles away. There was one and only one long-range radar in this scenario that could have possibly detected the aircraft at this low altitude, and that was the radar at nearby Paso Robles. And, in fact, it most certainly did detect both aircraft. The controllers all testified that they observed the Wings West target change from a VFR code 1-2-0-0 "V" target to the controller assigned code target. It made absolutely no sense why the target of the VFR aircraft would not be displayed, especially since there was 7 minutes and 21 seconds of continuously recorded data for that VFR aircraft's transponder reply.

But in looking through the transcripts of the investigation, I never did find where anyone asked about radar sort boxes, and how they were programmed. That made me wonder. From two independent sources I reconstructed how the radar sort boxes fit into this equation...
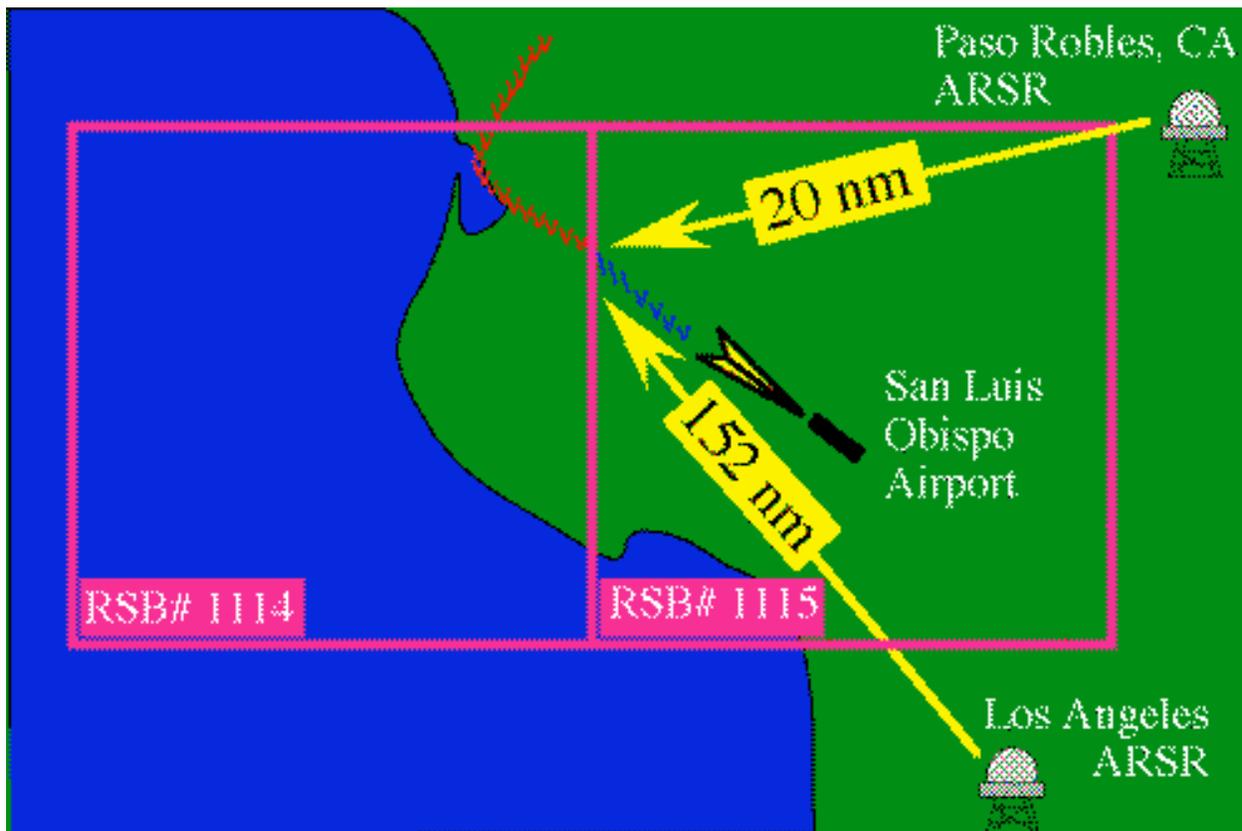
Slide 37 of 41: Reasonable doubt

This was an eye opener! The VFR aircraft, during the entire period that it was established on a straight inbound course to San Luis Obispo airport, was entirely within a separate radar sort box, a completely different sort box than the Wings West aircraft! The aircraft collided nearly directly on the edge of these two sort boxes.

If sort box #1114 had been somehow assigned to provide preferred coverage from the Los Angeles long-range radar, with Paso Robles as supplemental, it would be completely obvious that the radar returns of the VFR aircraft would not have been displayed.

However, there is absolutely no good or logical reason why Los Angeles radar would be assigned as preferred in sort box 1114. It would make absolutely no sense whatsoever to have it this way. (It should be, and when checked for me by others, it was the assigned supplemental radar site for this sort box.) However, if somehow it had been assigned as preferred, by some quirk or oddball chain of events, it certainly would account for the controllers not seeing the radar returns of the VFR aircraft.

Also, if such adaptation had been utilized, it could also account for any reports of transponders appearing unreliable in that area. Remember, a tracked aircraft utilizes supplemental coverage, an untracked does not. So, if a low-altitude "tracked" aircraft would fly from sort box 1115 to 1114, the aircraft's target would still be processed for display. Yet, a low-altitude untracked (typically VFR 1-2-0-0 squawk) aircraft, flying the same exact course, would drop off the display the instant it entered sort box 1114.

However, from what I have been told many times, and as best I can understand from reading the manuals, if a target symbol is not displayed, the radar data for that symbol will not be recorded on the data storage tapes. *[Note: Having radar data go unrecorded carries serious implications for the support of search and rescue operations, especially when attempting to determine the LKP (last known position) of an overdue aircraft.]* My tests at Cleveland Center confirmed for me that VFR targets are not stored if they're not displayed. So I am still left with a feeling of puzzlement about San Luis Obispo. Since the VFR radar returns were stored, according to how I know things work now, it must have been displayed. *I certainly wish the issue of selective rejection and radar sort box programing had been discussed and looked into back then.* (continued next page)

Paso Robles, CA
ARSR

20 nm

San Luis
Obispo
Airport

152 nm

RSB# 1114

RSB# 1115

Los Angeles
ARSR
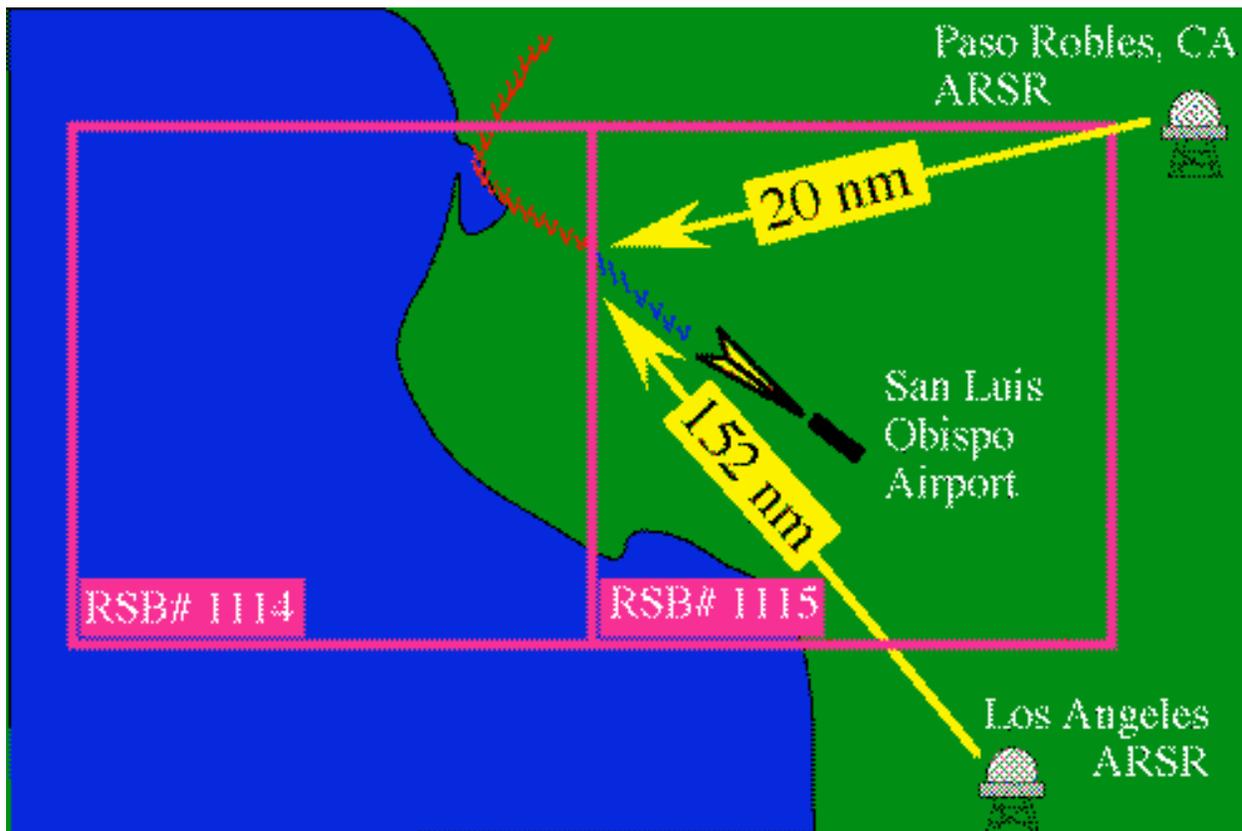
Slide 37 of 41: Reasonable doubt (continued)

However, *without a doubt*, **as I hope you understand from this review, due to the nature of today's radar data processing, THERE ARE DEFINITELY REASONS WHY AN AIRCRAFT THAT IS DETECTED BY RADAR WILL NOT BE DISPLAYED, EVEN IF THAT RADAR SITE FEEDS THE FACILITY**.

Given the above, I have an extremely difficult time accepting the NTSB's analysis in the San Luis Obispo midair collision report that says...

> Since the manager of the FAA En Route Automation Program had testified that, under these conditions, there was no functional reason why the Rockwell Commander's radar return, or any other VFR transponder return, should not have been displayed on the R-15 radar scope, the Safety Board concludes that the Rockwell radar return had been displayed and that the reason the controllers did not observe it cannot be attributed to any failure or malfunction of the Nas Stage A's computers or associated equipment.

Being as the NTSB report made no mention of the software process of selective rejection, and that there was no mention of radar sort box adaptation for that airspace, I feel that there exists reasonable doubt *about that analysis. (For more on this subject, jump to "*Reasonable Doubt*.")*

Regardless of what occurred at San Luis Obispo, the manner in which radar data is processed today must be improved upon. I call upon the industry to correct this problem and improve upon radar data processing methods. As I have suggested in the past, here are my recommendations...

Recommendations
- Make ZC150 mandatory.
- Broaden ZC150. Utilize double-preferred coverage throughout low-altitude environment.

Slide 38 of 41: Recommendations

My Unsatisfactory Condition Report suggested that the software patch that stratifies the sort box over radar sites be *mandatory*, not optional. As mentioned earlier, this patch was implemented at Cleveland Center in 1990 to support CENRAP. However, it wasn't implemented over Dansville at the same time as there is no approach control located near there that required that support. However, shortly after my "Real Targets - Unreal Displays" paper was reprinted in the Jan-Mar '92 issue of the Journal of Air Traffic Control, the sort box over Dansville was stratified. *Remember, use of the patch isn't mandatory.*
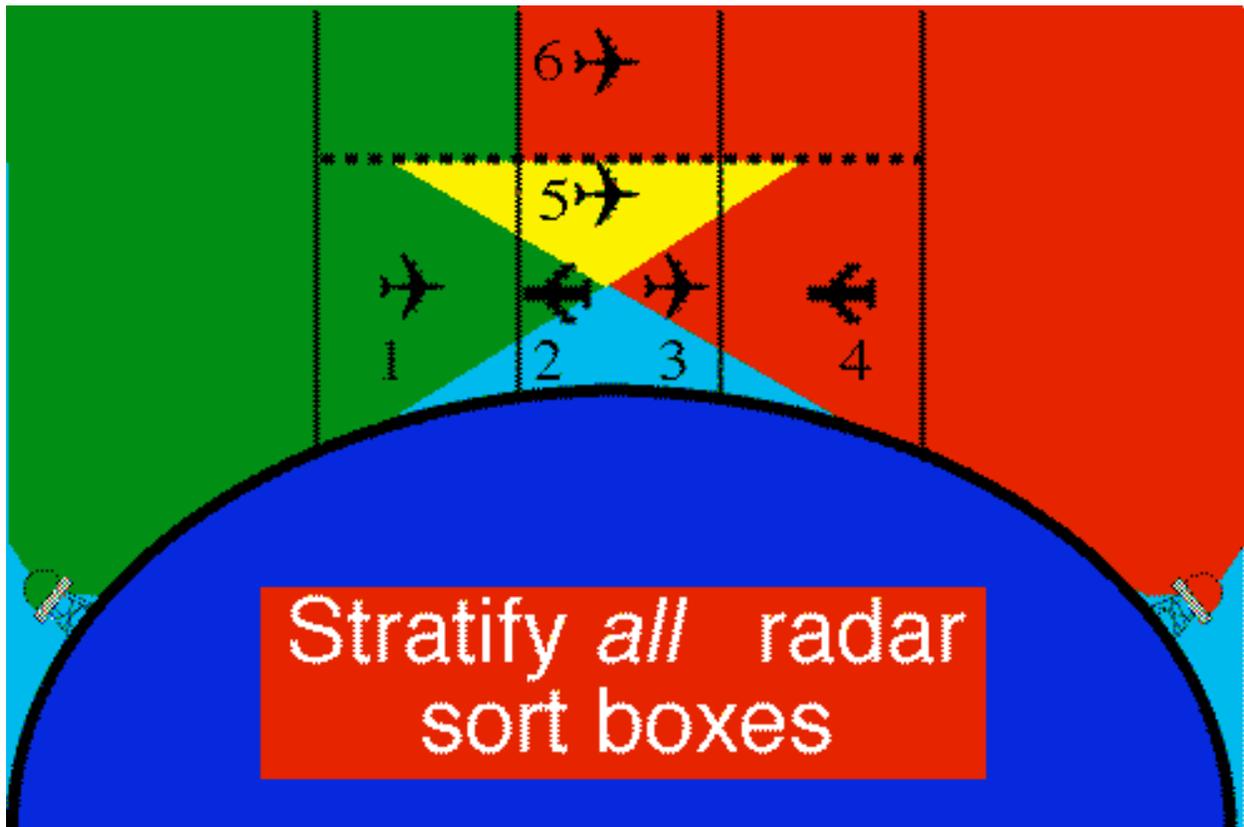
Slide 39 of 41: Stratify many more sort boxes

My second suggestion was then, and still is, that the implementation of this patch be broadened. This would take care of many of those in-between locations where coverage can be unequal. That is, of course, a short term fix, until true fusing of radar data can be accomplished. And it is not a panacea, as there may still be areas where aircraft could be detected but not displayed (where radar site 3 or radar site 4 picks up the target that radar site 1 or radar site 2 missed). It may be objectionable to have the opportunity for double targets to exist, but that sure beats having *invisible* airplanes. And it would only be in the low-altitude strata. I could see it done for virtually all sort boxes in Cleveland Center, say below 10,000 feet as a good safety buffer. This recommendation should apply to every ARTCC.

Slide 40 of 41: Utilize ALL radar data

This was my third suggestion, and still is. Willard Meilander <willcm@mcs.kent.edu> has written many papers over the years, which basically say that current ATC data processing techniques have shown that they cannot satisfy the processing tasks they are called upon to do. He states that "...scheduling complexity theory, an expanding branch of computer technology, shows that dynamically scheduled multiprocessors are not predictable in real-time missions." He says that the FAA has been proving the validity of that statement since the first multiprocessors in 1965. Is anybody listening to this man?

•Seek an understanding (human factors study) to determine why this compromise has existed this long.

Slide 41 of 41: Why?

I think the aviation psychologists need to work on this one. What is it about an agency that shows such resistance toward fixes for such obvious flaws in our radar data processing? Why has this gone on so long? What is the mind set within the FAA that generates replies to my Unsatisfactory Condition Report in which statements like "...described some limitations of our system but *not unsatisfactory conditions*." Huh? Read Lusch's Petition for Reconsideration concerning the San Luis Obispo midair collision.