An Aircraft Collision Avoidance Algorithm

1090 MHz 56 bit single packet mode S random squitter

single downlink format packet containing position and velocity

Loran-C sensor for best accuracy

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http://www.monarch-air.com/sponder/index.htm

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The United States Federal Aviation Administration (FAA) has always admitted that it is unable to provide collision avoidance between all equipped aircraft through the Air Traffic Control (ATC) system of Secondary Surveillance Radar (SSR) operating on 1030/1090 MHz utilizing Air Traffic Control Remote Beacon System (ATCRBS) {pronounced "at-crabs"} transponders. The FAA operators of the ATC system have long confirmed problems ("Real Targets-Unreal Displays - The Inadvertent Suppression Of Critical Radar Data" by Thomas G. Lusch, FAA Air Traffic Control Specialist, Journal of ATC, January-March 1992, pp29-33; Proceedings of the Sixth International Symposium on Aviation Psychology, Ohio State University, pages 460-465), accompanying as the first companion paper. Also the FAA technical center has confirmed technical problems (http://www.monarch-air.com/sponder/tn97_7.pdf). Additional more recent problems have led to the FAA endorsement and support of a radical new "replacement" system from II Morrow {pronounced "tomorrow"} named Automatic Dependent Surveillance-Broadcast (ADS-B) (http://www.ads-b.com/Content/index.htm). However, the FAA seems to have admitted serious deficiencies in the GPS navigation system upon which ADS-B is dependent (http://www.aerotraining.com/html_gif/gpsdead.htm).

The problems with ATCRBS, the only existing aviation collision avoidance system, are composed of two factors. 1). Equipment design that was never intended for the aircraft density (responder) and radar density (interrogator) of today's aviation environment. 2). Procedures that only guarantee separation of IFR from IFR aircraft (participating positive control). The three other collision permutations involving VFR aircraft (IFR from VFR, VFR from IFR, VFR from VFR) are not provided, except on an "as time permits" basis (and time never permits sufficiently), and then only to a subset of aircraft, and then further only when all are flying above the radar floor.

The old FAA "fix" was to insist that many aircraft carry ATCRBS transponder interrogators. This Traffic Collision Avoidance System (TCAS) is advertised as equipment that will allow the pilot of the aircraft to see and avoid all other aircraft. That was an augmentation system, utilizing the ATCRBS transponder. Unfortunately, there were problems.

The new FAA "fix" is a "replacement" system - requiring all new equipment in each aircraft. ADS-B is presently about $300,000 per aircraft, although the FAA and II Morrow have stated that they intend to attempt to reduce that to $12,000 per aircraft. Unfortunately, the system requires a large installation of ground equipment to be backwards compatible to see ATCRBS only equipped aircraft. There is no discussion of the cost of the Traffic Information System (TIS) ground equipment, which may require an additional investment of billions of dollars. Yet, and this is perhaps the most serious shortcoming of ADS-B, there is a hard limitation on capacity. ADS-B can handle only about 300 aircraft within hearing range, at that level causing a catastrophic failure of the ATCRBS data link. To solve other ADS-B design deficiencies, it is proposed to increase ADS-B transmission power levels, which would further decrease the capacity. A catastrophic failure of the ATCRBS data link would mean that the entire present and future collision avoidance systems (ATCRBS, TCAS, ADS-B) would fail, and that number is at about 0.015 aircraft per square nautical mile for the equipment shown at AirVenture99 (http://www.airventure.org/), less with the proposed fix.

Fortunately, there is an alternative proposal, which will support an "average density" of traffic at about 1.5 aircraft per square nautical mile, for a total cost per aircraft of approximately $500 (wjbarton@teleport.com). Automatic Independent Surveillance Positioning (AIS-P) is an "augmentation" system - present equipment in the aircraft is upgraded, instead of being replaced, no aircraft modifications. At that price, there is no need for an additional TIS ground system. And, while we were at it, this augmentation to the ATCRBS transponder also fixes the ATCRBS P4 problem (http://www.monarch-air.com/sponder/P4Problem.htm), created by the FAA, in order to allow TCAS technology.

The AIS-P system can utilize many types of external positioning sensor apparatus. Though a custom integrated circuit was built for GPS and altimeter interface; this paper also explains a Loran-C interface, for greater positional accuracy, utilizing a NMEA data stream converter. GPS requires dynamic real time correction (dGPS, LAAS, WAAS), Loran-C requires semi-static occasional correction (ASF), to yield satisfactory absolute positional accuracy. For collision avoidance purposes, these errors are common mode, and are unimportant.

The replacement ADS-B system additionally poses significant risks to aviation security (http://www.monarch-air.com/gaviation/ads-b_2.htm). The AIS-P augmentation to the present ATCRBS system does not have that significant design deficiency.

Classically, in the Los Angeles basin, the transponder density and interrogator installation density have each always been too great for the ATCRBS system design to have ever operated correctly, since about the 1960s. TCAS airborne interrogator equipment now also extends this interrogator density problem to the northeast triangle (Boston - New York - D.C.), and all major airports during the busiest times of the day. Of necessity, the "radar" display was further augmented with the post radar computer algorithm named "coast mode", which assumes zero acceleration target motion. The targets coast along, when radar discontinues to see them, even when the controllers order a change to the flight path. The interrogator density problem is that there is not enough link capacity to get all information through. The only solution is to limit the need for interrogators in system operation. The FAA elected to increase the number of interrogators as the solution to that problem.

When mode S (mode Selective) transponders were added as an augmentation to this system design (necessary to allow TCAS technology to work at all), some ATCRBS radars were replaced by mode S radars. These (TCAS and mode S radar) interrogators issue a different interrogation, with an added P4 pulse. Changing the interrogation without changing the ATCRBS transponder detection digital logic exacerbated the problem of aircraft not announcing their appearance. This problem was created by unintentionally causing ATCRBS transponders to suppress reply to thought still valid SSR interrogations (which contained the new P4 pulse two microseconds aft of the P3 pulse in the main beam of the radar). When airborne TCAS, and the new mode S radar, interrogators were added as an augmentation to fix the interrogation density problem, "not appearing on the radar display" got worse. The interrogations from TCAS and mode S interrogators unintentionally contained this extra side lobe suppression instruction to many ATCRBS transponders (depending on logic design), and those did that unintended command.

The December 1976 manual for the Narco AT-150 transponder, the design certified by the FAA, does not contain transistor Q415, nor its driving resistor R508. This circuitry, that had to be added to the transponders (as they came in for service problems or alignment), is employed so that the U403 output can short out Q413 (the presence of the P4 pulse from the receiver is shorted out before it can set the side lobe suppression latch, in order to prevent the received P4 pulse causing unintended suppression of the reply). The AT-150 of today must have these components because ATCRBS transponders that do not contain these components will behave in an unintended fashion when there is a P4 pulse present in the interrogation - they do not reply to the interrogation for TCAS and mode S radar. How many, of the total manufactured, have been modified? And, also, it was discovered, the multivibrator tuning is critical. How many are properly tuned? How many have been over two years since last they were checked (VFR aircraft owners generally believe that a transponder bi-annual is not required by the FAA)? Why is it necessary to have "bi-annuals" to "tune" "digital" circuitry? Why does not the FAA require avionics repair shops to have transponder test equipment which includes the P4 pulse in the test interrogation? These are the P4 problem.

Additionally, every transponder has another circuit that says "if interrogated and reply" or "if interrogated and suppress", do not respond to further interrogations for a while. It is easy to visualize how the additional TCAS interrogators will cause a diminution of responses to interrogations, which would, then, include those from the ground. Diminution of responses to interrogations that happen not only at the same time, but that also happen within this "out of service" "window". This is the "5 o'clock slam dunk" problem, brought by airborne TCAS interrogators to every busy hub airport.

Unfortunately, these problems are not linearly additive, but seem to be multiplicatively related. The cumulative problem magnitude can be characterized as somewhere between N**2 and N**3, where N is the number of interrogators.

Fortunately, few aircraft have these TCAS systems, because of their extreme cost. That "low population" will increase with the advent of the B. F. Goodrich "SkyWatch" TCAS, which reduces the cost from the original ~ $225,000 to ~$25,000 for general aviation (http://www.bfgavionics.com/docs/skywatch.html). Even the Ryan TCAD, classically a non-interrogating collision avoidance device, now offers active interrogation (http://www.ryan-tcad.com/) to increase the problem. Also the FAA requirement for TCAS has changed from "big airliners" to "all airliners", and FAA is proposing "all freight carriers" to be added to that mix. Fortunately, few ATCRBS radars have been replaced with the new mode S radars, because of their extreme cost, but that number is increasing. As these three populations of interrogators grow, the precarious SSR based collision avoidance system we have now will fail worse than it fails now. Regardless, at the present time, "working" is defined, by number of passengers, 90% of the "populated" aircraft, cannot know about, by number of aircraft, 90% of the aluminum in the sky. This problem is further enhanced because of an FAA equipment design requirement that "VFR" traffic which is "non-participatory" shall, when seen by the radar, be culled by the "1200 filter" before display. Most of the aircraft seen by ground radar are removed from the ground radar display used by the controllers. ATC does, additionally to the above mentioned problems, not even try to display most of the traffic, in which it has "no interest", even though that traffic is seen by the radar, and can collide with and bring down the aircraft "of interest". This is the "not want to look" problem.

The ATCRBS system is the only aircraft collision avoidance system we have. It is so poor in quality and accuracy of operation, that the FAA is seeking a total replacement of all ground and airborne equipment. The ADS-B initiative is the surviving contender favored by the FAA for this entirely new and radical departure from the present air traffic control system.

There are several significant problems with this new and radical system design, which will render it ineffective to the standards of even the present ATC system design, which is itself insufficient.

One issue is the extremely high cost, due to the extreme complexity, of the ADS-B equipment; which is necessary for every aircraft to possess in order to be seen by any other. Therefore, limited employment amongst only a small minority of aircraft is the likely result - a subset system covering exposure to only those that have the equipment (which is what TCAS is now, except that TCAS in the aircraft can also occasionally see some of the other ATCRBS transponders). From the perspective of the system users, different technology, more insufficient result.

Another issue is that, since only partial information is provided in each mode S "packet" transmission by the ADS-B transmitter, multiple "packet" transmissions are necessary to convey the "message" (minimum required information of a single report). This results in far diminished system capacity - the other packet "times" could have been used, otherwise, by more aircraft, if full information were transmitted in one packet. From the perspective of the system users, ADS-B is different technology, with even less total system capacity. Mitre estimates that ~300 aircraft within an 80 NMi radius will collapse the ATCRBS data link with the mode S standard compliance. With that collapse would be the loss of all ADS-B, TCAS, TCAD, and ATCRBS "radar" information, resulting in all "ground radar" targets in coast mode, and airplanes blind to traffic. If the transmitter power output is increased, as is proposed by the ADS-B engineers, any engineer can calculate (for the same 1/(R*R)) how this range radius will increase (allowable aircraft density will decrease).

With 300 aircraft allowable within a "hearing range" of 80 nautical miles, a first hand approximation would be that 300 aircraft are allowable within 20,106.2 square nautical miles. Dividing by that 300 yields an "average density" of traffic of one aircraft per every 67 square nautical miles. Taking the reciprocal, 0.015 aircraft per square nautical mile. If power were then increased to cover the desired design goal of a 250 nautical mile effective range, that same 300 aircraft limit would be allowable in, now, 196,349.5 square nautical miles. Dividing by that 300 yields an "average density" of traffic of one aircraft per every 655 square nautical miles. Taking the reciprocal, 0.0015 aircraft per square nautical mile. AIS-P will allow increase of that capacity to 1.5 aircraft per square nautical mile.

Yet another issue is diminished security with ADS-B. To connect these different packets which form a single message containing all necessary information from one aircraft, a means is necessary to tie the different packets together to form the complete message. The mechanism chosen is to add a number field, which further diminishes, therefore, the amount of message data capacity for the packet. In this field is a number algorithmically derived from the tail number of the aircraft. The algorithm is published in the international mode S standard. This is a common problem shared with the mode S transponder equipment. However, mode S equipment must be interrogated, and tells only who he is. ADS-B equipment need not be interrogated, and tells who and where and which way and how fast.

The problem of "I am Airforce One, and I am at latitude longitude altitude speed direction (the missile should come there to meet me, missile need not carry big battery for interrogator transmitter, directional antenna, or the transmitter)" is addressed in the second companion paper (http://www.monarch-air.com/gaviation/ads-b_2.htm). The reader is encouraged to contact Litton Guidance and Control Systems of Northridge, CA (818-678-7666) and ask for the color sales brochure of the AN/PPX-3B and TPI-10 interrogator sets, inquire as to the intended purpose, and query the missiles now proven to work with this system.

There is a way to save the present ATCRBS transponder system, currently in place, with a simple technical upgrade. This solves the "P4 in the new interrogation" problem, but also provides the ADS-B collision avoidance goals, while all objections to the ADS-B system design are removed, these together solving the entire above listed set of problems. This is available as a modification to the common ATCRBS transponder (by disabling or removing many old integrated circuits, eliminating potentiometer adjustments, adding a small 49x53 millimeter circuit board containing a clock IC, an Actel 42MX09 FPGA IC (http://www.actel.com/products/antifuse/) also (http://www.actel.com/products/antifuse/mx.html), a hysteresis IC (74LC14), one diode, one resistor, and six capacitors). The interface to the old transponder is an eight wire cable. This is a field upgrade, inside the old transponder, which can be accomplished by any avionics shop, utilizing the Monarch-Air modification kit. Another version of this same design is provided for new transponder designs, available to the transponder manufacturer, from keith.peshak@gtwn.net. This contains all of the transponder digital circuitry, and eliminates all need for any adjustments. A transponder that requires no bi-annual, because there is nothing to adjust. Both solve the P4 problem and both provide the AIS-P augmentation described.

The new circuitry knows to ignore the P4 pulse, just as if the FAA had not required its addition to the transmission by TCAS and Mode S radar interrogators. This option is sufficiently economical, so that all presently equipped aircraft can continue to participate in the ATC system with their installed equipments, and also provide AIS-P compliance. New transponders, become much less expensive to manufacture, because this Actel IC replaces many components. No alterations are necessary to any aircraft to allow it to be seen by software modified ADS-B/TCAS/TCAD equipments or by the new AIS-P proximity warning equipments.

There is additional regulatory agency effort required to allow fielding of the AIS-P capability. The packet utilized is a mode S downlink data format, but not one contained in the present international mode S standard. In that standard is a five bit field in the mode S downlink data packet format which specifies a binary data format number (DF# or DFN). This is the identification of one of thirty-two possible different downlink message allowable format types. There are several downlink format numbers not being used. Adding the AIS-P data message format to the mode S specification is as simple as requesting John Mark Loscos at ICAO (514-954-6713) to assign to the AIS-P specification (http://www.gtwn.net/~keith.peshak/Keith_ais.htm) one of the unused and available downlink format numbers. This will be used for a mode S squitter packet. This would create and add to the mode S system one available packet type which would contain all of position and velocity data, and would not contain ID (tail number) data. We wish for one of the undesignated downlink format numbers to be assigned to the format specification to allow system compatibility with all existing mode S and TCAS equipments.

There would be no need to change or update those equipments. ATCRBS equipments would already just ignore this "noise" {else TCAS and mode S transponders would have already failed within the ATCRBS system}. There would be no need to change any transponder or ground "radar" equipments. Those ADS-B/TCAS/TCAD equipments that would desire to "see" the AIS-P equipped aircraft would require only simple software update. Those aircraft that would desire to "hear" the AIS-P equipped aircraft ("Warning, 9 o'clock, four miles, three hundred, high, thirteen seconds (to impact)") could purchase the $2500 panel mount "transponder sized" Proximity Detector box shown at AirVenture99 (contact narco@netreach.net to request). Those aircraft that would desire to "see" the AIS-P equipped aircraft could purchase the EFIS display from Sierra Flight Systems shown at AirVenture99 (contact ncalvin@sierraflightsystems.com to request). An audio tape is available from EAA (http://www.eaa.org/) for the "TCAS almost free" seminar in Sporty's Pavilion on Saturday night of AirVenture99 - a technical presentation explaining the details and discussing the working equipments. The FAA has been "highly resistive" to the AIS-P concept, as competition to ADS-B, and also highly resistive to the concept of a repair for the P4 problem. This is quizzical, in view of the drastic airline flight delays, occurring as a result of necessary extreme spacing, implemented as a countermeasure to accommodate the failure of transponders. Contact jane.garvey@faa.gov to request an explanation, and come to AirVenture00 at Oshkosh, the "Meet The Boss" seminar in the FAA building on Sunday morning, to ask her for an extemporaneous explanation.

We now address the optimal position and velocity sensor to employ for any collision avoidance technique. Loran-C is more repeatably accurate for positioning (http://www.gtwn.net/~keith.peshak/loranpos.gif) than is GPS (http://www.gtwn.net/~keith.peshak/gpspos.gif). The offset from true position (the center) is corrected by the input of extremely recent (last second) dGPS information for that exact location, or the last ATIS broadcast of Additional Secondary Factor (ASF) observation information for that region of the country. Glonass would be a second choice for most repeatably accurate (http://www.gtwn.net/~keith.peshak/glonasspos.gif), if more satellites were to be put back in orbit to replenish the constellation (http://www.gtwn.net/~keith.peshak/visibility.gif). That would remove the red, and congeal the blue and green. GPS is, clearly, the poorer third choice in absolute accuracy!

Satellite position accuracy can be increased by utilizing all satellite navigation constellations, with such as the Ashtech GG-24 receiver (http://www.gtwn.net/~keith.peshak/bothpos.gif), to help solve the problem of the low number of Glonass satellites available. But the ideal solution would favor Glonass only, once that satellite constellation is again filled, and it will, then, be on a par with Loran-C with ASF for the last weather observation, for the area, entered into the sensor. The ASF can be obtained from an ATIS broadcast over the NavCom, then dialed into the Loran-C sensor by the pilot (no data link needed and no equipment alteration required of the aircraft), or that process could be automated if a data link were put in place and an equipment added to the ground and aircraft.

Loran-C, certainly, could be the most accurate instrument landing and navigation system available, both in repeatability, and absolute accuracy. If no ASF correction, then there will be a relatively constant offset error to Loran-C absolute position, but that error will be common mode to all aircraft (important for instrument landing, unimportant for collision avoidance). Even without ASF correction, Loran-C is a more accurate sensor for the application of collision avoidance.

There are other deficiencies, and solutions, to reliable use Loran-C technology in aviation.

The first issue is that precipitation static renders the technology potentially impotent. This only happens in rain or snow, more the latter than the former. Use of airframe grounding techniques and static wicks reduces the problem, and is a well known solution for the same problem observed by the Airborne Direction Finder (ADF) equipment operating on the 200-400 KHz band. Unfortunately, this "static" equipment is poorly maintained on the average aircraft, rendering it a poor solution. Use of an H field antenna (coil) to replace the E field antenna (long wire) eliminates that deficiency. Static electricity discharges are typically extremely high voltage, but extremely low current.

The second issue is that the sudden loss of one of the three Loran chain stations being used to determine a position causes loss of position. This only happens rarely, and the new updated Loran-C technology of "automated blink" allows the receiver to be made immediately aware of the loss of a station. Like the little red "NAV" flag on the VOR or localizer or glideslope, the pilot can be made aware of the fault, and can change the selected chain or chain stations. The use of a masterless algorithm, like that pioneered on the Ray Jefferson PL-99 handheld Loran-C, of the late 1980s, now used in many experimental class and part 103 class aircraft, minimizes that deficiency by utilizing all stations in the selected chain for position determination. An "all in this chain" position solution convergence algorithm, sometimes called by the name "masterless navigation".

The third issue is multi-chain reliability. GPS requires at least four intersecting "range" spheres to resolve a position. In the early years, GPS used a three channel receiver, opting for a fourth pseudorange from earth centric, by employment of a blind atmospheric pressure altitude sensor. An economic design trade-off. We have since learned the value of the twelve channel "all in the sky" solution convergence algorithm, enabled by 12 channel hardware correlator receivers. Use all chains, each with masterless navigation, and use of geometry weighted position contribution to the final solution, presents an elimination of the minimized deficiency. Locus Incorporated, of Madison Wisconsin, is one company that has introduced an all-chain Loran-C sensor (http://www.locusinc.com/loran-news.htm).

We now detail how the goal of the appropriate AIS-P sentence, containing the positional and motion data gathered from the Loran-C sensor, can be generated for the Actel ATCRBS transponder chip AIS-P input. We here consider the common Ray Jefferson PL-99 Loran-C sensor.

A low cost microcomputer, based on such as the PIC chip, (http://www.radioshack.com/sw/swb/projects/bstampidx.htm) can be placed between the transponder chip and the Loran-C sensor. We must interface to the Actel transponder chip, which was designed to require a specific GPS sentence, from the loran-C position sensor, which speaks a different series of sentences, the combined having the necessary information. The PL-99 does not produce a single output sentence with all of the necessary data, but does provide the necessary information. The PL-99 is not FAA certified equipment, so the interface containing the PIC chip can also remain outside the purview of FAA certification (for experimental class and part 103 class aircraft). This saves monumental DO-178 certification costs (http://www.rtca.org/).

The AIS-P specified packet data input format used by the Actel chip is the standard NMEA-0183 $GPRMC GPS sensor sentence. This micro will produce that, assembled from fragments of the Loran-C NMEA sentences produced by the PL-99 sensor:

$LCGLL,3032.61,N,09754.45,W
    Latitude and Longitude we will use
        deg-min.xx, N/S, deg-min.xx, E/W
$LCGTD,16339.3,31349.9,41960.2,54801.3,.
    Loran time differences
        LOP Td for each slave, 5th missing in this example
$LCSTD,2,2,2,2,2,
    Td status (A first quality indicator)
        0=good
        1=low SNR
        2=cycle error
        4=blink (station not usable)
        8=searching
$LCSIU,0,,,,4,5
    Stations in use
        0=master
        4=Y
        5=Z
$LCSGR,9610
    GRI of chain in use
        10s of microseconds
$LCSNT,0,A,9610,V,0,,,3,4,
    Status of fix (a quality indicator, rec GRI, rec stations)
        position fix quality
            0=no fix
            1-9 increasing quality (second quality indicator)
        recommended new GRI alarm
        GRI in 10s of microseconds
        recommended new stations alarm
        recommended stations in increasing order
            not recommended is null
            0=master
$LCBWC,,3041.01,N,09740.84,W,010,T,010,M,014.4,N,099
- Bearing and distance to selected waypoint (PL-99 internal navigation)
        UTC (null)

Latitude
N/S of waypoint
Longitude
E/W of waypoint   another source
Bearing, true
Bearing, magnetic
Distance, nautical
Waypoint number

$LCAPA,A,V,1.20,R,N,V,V,059,M,099

Autopilot (Crosstrack, bearing to destination)

ORed blink and SNR
Cycle lock
Cross track error distance
Cross rack error L/R sense
distance in nautical miles
Arrival circle
Arrival perpendicular
Bearing dest waypoint from origin waypoint
True or Magnetic
Waypoint number

$LCWNC,002.3,N,099

Distance from start to destination

distance
nautical miles
waypoint number

$LCZTG,,005827,099

Time to go to waypoint

UTC (null)
Estimated time enroute
Waypoint number

$LCVTG,,,299,M,14.6,N,,

Track and Ground Speed

Track degrees (null)
True (null)
Track degrees we will use
Magnetic we will use
Speed we will use
Knots we will use
Speed in kilometers (null)

#LCSNR,03,04,04,03,05

A third quality indicator

The programming required to operate an input serial port, intake these Loran-C NMEA sentences from the Loran-C sensor, glean and assemble the proper data for the sentence needed by the Actel chip, and operate an output serial port, is standard engineering practice. In the prototype PIC interface, we chose the $LCGLL for 2D horizontal positioning, $LCVTG for track and ground speed, and combine the $LCSIU and $LCSTD for the detection of "little red NAV flag". We prefer a minimum of 5 or better SNR with at least three secondaries with a master (or four secondaries), to produce an acceptable confirmed position solution. This flag to other aircraft was accomplished by setting the Loran data in the AIS-P output packet to all 0 if there is Loran position sensor unhappiness, and enforcing incorrect parity. There is very little likelihood that there would be a stationary target at exactly zero latitude and zero longitude, but this is shown to be false by the incorrect parity. The altitude data, of course, continues to be sourced by the blind pressure encoder on the aircraft, which already connects to the transponder (so we still have altitude separation capability {which is how the FAA is now utilizing the ATCRBS system because of the coast mode problem} if there is Loran sensor failure).

The goal was to build a cockpit based, all-aircraft, fully functional collision avoidance system, that does not need specific aircraft tail number; and, but also, to provide announcement of collision potential for all aircraft for free inside an augmentation to the ATCRBS existing transponder that was necessary to correct for the FAA created P4 induced unintentional suppression problem. The chip we made to fix the "FAA new P4 pulse in the interrogation makes many ATCRBS transponders fail" problem can contain all that is necessary to produce the requirements to be seen for collision avoidance of ADS-B, without the deficiencies and without the cost of the new airborne and ground equipments, not to mention the costs of installation. The transponder needs a new brain anyway, it is not complicated, there is room left over in the Actel chip to implement, so add this AIS-P packet to the output modulator control of the transmitter. No changes to the government practices or equipment. No charges to the aircraft owner (he has already spent way too much money on his expensive new microwave landing system that didn't work, his expensive new mode S transponder that didn't work, and his expensive new GPS sole use navigation system that FAA announced won't work). Keep the ATCRBS collision avoidance system ground and airborne equipment that we have, add the necessary repair to fix the transponders so that they will again show up on the ground radar scope and the aircraft TCAS scope, and add the ADS-B desired capability in there without the ID security deficiency, and without the exorbitant costs, utilizing AIS-P, so that each aircraft may be seen by every other aircraft that so desires, without any need for new equipment or aircraft alteration. Might as well use the most accurate position sensor available - Loran-C. It is a wonder that the FAA refuses cooperation (has received, refuses to test, has returned equipment).

With AIS-P (not an option with FAA's ADS-B), buy a separate receiver, if you want to see other airplanes, or don't. You do not need to participate, other than to give the other guy a chance to see you and stay alive, which costs you nothing, while we fix your transponder so that it will work again. It works everywhere on the planet where there is positional information coverage, Loran-C seems to be best, at least until Glonass or a European satellite system constellation can be completed, provides at least minimal necessary collision avoidance to all aircraft from all aircraft, is free, and requires no additional ground or airborne equipments. Where needed most on the planet, the AIS-P option provides TCAS or better performance. More accurate than anything else is a good capability for that additional cost level. However, without the needed DF# to be assigned by ICAO (John Mark Loscos at 514-954-6713) for the AIS-P packet for a mode S all-call squitter, this capability is presently disallowed by international law.

Memorandum

U.S. Department of Transportation
Federal Aviation Administration

Rx'D [redacted]-91

[redacted] ARTC Center

Subject: INFORMATION: Outside Lecturing

Date: [redacted] 1991

From: Area Manager, [redacted]

Reply to Attn. of:

13

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To: ATCS [redacted]

In response to your notification that you will be lecturing at the [redacted], I would direct you to
103 49 CFR 99.735-11(c). That regulation states in part:

> Although employees are encouraged to engage in teaching, lecturing and writing,...an employee shall not engage in such activities under circumstances:
>
> (2) Which depend on information or official data obtained as a result of government employment, except when the information has been made available to the general public or when an appropriately designated official gives written authorization for use of non-public information following a determination that the basis for the use is in the public interest.

I have read your paper, [redacted], upon which
1408
11370
your upcoming presentation is based. As a result of my review, as well as discussions with the [redacted] Center Air Traffic Manager, Assistant Manager for Automation and Airways Facilities System Engineers, it would seem that much of the information upon which your presentation is based is "non-public information" and as such is prohibited by 49 CFR 99.735-11(c). I would also direct you to Executive Order 11222. Under that order Federal employees are to avoid any action which might result in adversely affecting the confidence of the public in the integrity of the Government. Once again, it seems that a presentation based on your aforementioned paper may have a prohibited result.

It is not my intention to question your motives, however, the situation described herein seems to raise some questions regarding ethical conduct and prohibited off-duty activities. At a minimum, I believe the text of your presentation would require written approval of an appropriate official prior to its public presentation.

I will be happy to discuss this matter further if you have any questions.

[redacted]

Attachment (1)

Real Targets— Unreal Displays

The inadvertent suppression of critical radar data

by Thomas G. Lusch
FAA Air Traffic Control Specialist
Oberlin, Ohio

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Abstract

In today's Air Route Traffic Control Center (ARTCC) environment, some very important low-altitude radar data is suppressed. This radar data is not suppressed by the controllers themselves. Rather, it is a result of a compromise in the radar data processing software, and the manner in which the software is adapted by automation personnel. This suppressed radar data has led to air traffic controllers being unable to provide accurate and timely advisories about aircraft which pose a collision threat. An existing software technique to correct a portion of this problem has existed for years, but it is optional and is not adapted system-wide. There must be a concerted effort to address this inadvertent suppression of low-altitude radar data, as well as an examination into the human factors aspect of why it is allowed to continue.

Background

On August 24, 1984, Wings West Airlines Flight 628 departed the San Luis Obispo, CA airport en route to San Francisco. Twenty two seconds after the controller advised Flight 628 that radar contact was established, the Wings West aircraft collided head-on with a single-engine Rockwell Commander aircraft at an altitude of approximately 3,400 ft. No safety advisory was issued by the controller to the crew of Flight 628. When Flight 628 was advised of radar contact, the Rockwell Commander, flying under Visual Flight Rules (VFR), was a mere 2½ nautical miles (nm) away. Seventeen people lost their lives. The Los Angeles Center controllers testified that the radar return of the VFR aircraft was not displayed. The National Transportation Safety Board (1985) concluded that it had to have been displayed.

In early 1985, while I was providing radar service to a commuter flight, a similar tragedy nearly took place. I was paying close attention to the radar scope. During the commuter's climb to cruising altitude, I was surprised when the pilot radioed, "Center, did you SEE THAT AIRCRAFT?!" Just after this unnerving query, a VFR code 1-2-0-0 beacon target appeared directly behind the commuter aircraft's target. I immediately verified that it was indeed the first time this VFR aircraft was displayed within the previous minute.

In 1988, I wrote a paper addressing this compromise of suppressed targets. It was submitted as Unsatisfactory Condition Report (UCR) #330069 to Cleveland ARTCC (Lusch, 1989). The UCR was closed in April, 1989. No action was taken.

Discussion

The primary purpose of the air traffic control system is to prevent a collision between aircraft. The controller's highest priority duty is described in the ATC procedures manual 7110.65F, para. 2-2. That duty is to separate Instrument Flight Rules (IFR) aircraft and to issue a safety alert to the pilot if the controller is aware of any aircraft which may be on a collision course. Monan (1989) writes of several near-midair collisions where controllers claimed that aircraft were not displayed on their scopes.

An aircraft, detected by radar, may be suppressed from the controller's display by the software process of selective rejection. The ARTCC controller has absolutely no control over this radar data filtering process.

In the following discussions, all references to radar refer strictly to radar data processed by computers at Air Route Traffic Control Centers. Also, all examples are based on Cleveland Center. It should be emphasized that Cleveland Center is likely doing a better job than most other ARTCCs in the processing of low-altitude radar data. Due to the nature of this problem, however, the inadvertent suppression of low-altitude radar data still occurs.

Attachment (2)

Mosaicing

Mosaicing is the method employed to deal with the enormous amount of radar data from overlapping radar sites. Mosaicing is a method of sorting the data from several radars of an ARTCC into hundreds of small boxes, known as radar sort boxes (RSBs). The dimensions of a radar sort box is 16 nm by 16 nm. Mosaicing makes it possible for the computer to utilize data from one and only one radar site at a time, at any given point in space. Within a sort box, data from overlapping radar sites is prioritized into preferred data, and supplemental data. Data from a preferred radar site will be utilized first, and if unavailable, the data from the supplemental radar site may be utilized. Where a radar site is neither assigned as preferred nor as supplemental within a sort box, its radar data is completely rejected by the computer within that 256 square nautical mile (sq nm) area.

Due to past computer software and hardware processing limitations, the enormous amount of radar data from multiple radar sites simply had to be reduced. Otherwise the computers were overloaded. Today's software and hardware processing limitations still require mosaicing to reduce computer processor demands, as the majority of radar data received at an ARTCC is still abandoned (Meilander, 1989). Unfortunately, mosaicing contributes to some important low-altitude radar data not being utilized. This results in some aircraft not being displayed on the controller's scope, even though these low-altitude aircraft are, in fact, adequately detected by radar.

Compromise #1. ATC radar is not designed to detect aircraft directly above the radar antenna. This area is known as the cone-of-silence. Aircraft flying in a radar's cone-of-silence may, however, be detected by another, or several other radar sites a hundred or so miles away due to their overlapping coverage. Figure 1 depicts a 5 nm diameter cone-of-silence area above the Dansville radar. Aircraft at all altitudes within this cone-of-silence area are not detected by the Dansville radar. If these aircraft are high enough, however, they will be detected by the Clearfield, PA, and Utica, NY, radars, which are between 100 to 115 nm away. To solve a cone-of-silence problem, it is common practice to assign the coverage, within a sort box which overlies the radar, to a distant radar site. As shown in Figure 1, the preferred coverage within RSB#986 is assigned to Clearfield radar. Such software adaptation easily eliminates the problem of a cone-of-silence. Unfortunately, it also eliminates many low-altitude radar targets near the radar site from being processed for display.

Dansville radar data is not utilized within RSB#986. It is neither assigned as preferred nor supplemental. Low-altitude aircraft, below 5,000 to 6,000 ft in this vicinity, will not be detected by either the Clearfield or Utica radars. This is due to the fact that the radar signals are strictly line-of-sight, and are therefore blocked by the earth due to its curvature.

As shown in Figure 1, a northbound aircraft is about to collide with a southbound aircraft. The northbound aircraft is within RSB#936 and is being provided radar service by Cleveland Center. Due to its low altitude, it is detected by only the Dansville radar. The southbound aircraft is within RSB#986 and has a properly functioning transponder set to the VFR code of 1-2-0-0. Since this low-altitude aircraft is not within Dansville radar's cone-of-silence it is detected by Dansville, and its position is sent to the ARTCC computer, along with the position of the northbound aircraft. Like the northbound aircraft, due to its low altitude, this southbound aircraft is not detected by either the Clearfield or Utica radars, which are assigned as preferred and supplemental within RSB#986. Unfortunately, the controller will be unable to issue a warning to the pilot of the northbound aircraft prior to the collision with the southbound aircraft at position A. This is because the Dansville radar data on this southbound aircraft is discarded by the program.

As one can see, the steps taken to correct the problem of a loss of data in a radar's cone-of-silence leads to the loss of important low-altitude radar data. Note the difference in size between the depicted 20 sq nm cone-of-silence area, as compared to the much greater 256 sq nm area within the sort box. Unfortunately, the manner in which the

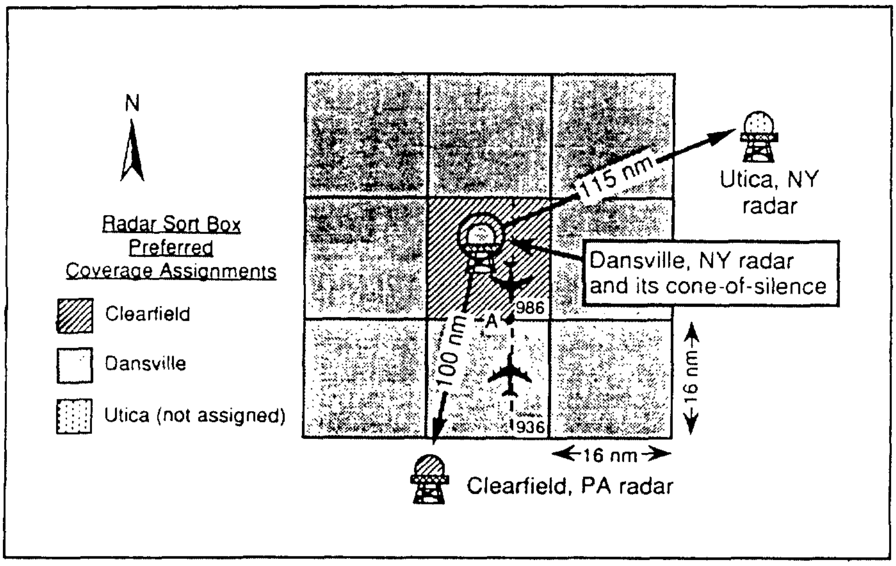

Figure 1. Two aircraft detected by only the Dansville radar. The southbound aircraft is not displayed since Dansville radar data is suppressed within RSB#986. (Distances are in nautical miles [nm].)

radar data is processed results in 236 sq nm of low-altitude radar data not being displayed.

These inherent shortcomings do not need to be accepted. One method of addressing this problem is to utilize data from more than one radar at the same time. Instead of assigning one and only one radar as the preferred radar, a sort box may be adapted with one radar as preferred and another as alternate preferred. When two radars are designated in this manner, a sort box is said to have double-preferred coverage. This solution results in a less than pleasing display, as there will be two targets per aircraft when the aircraft are detected by both radars. Software documentation discourages the adaptation of sort boxes as double-preferred.

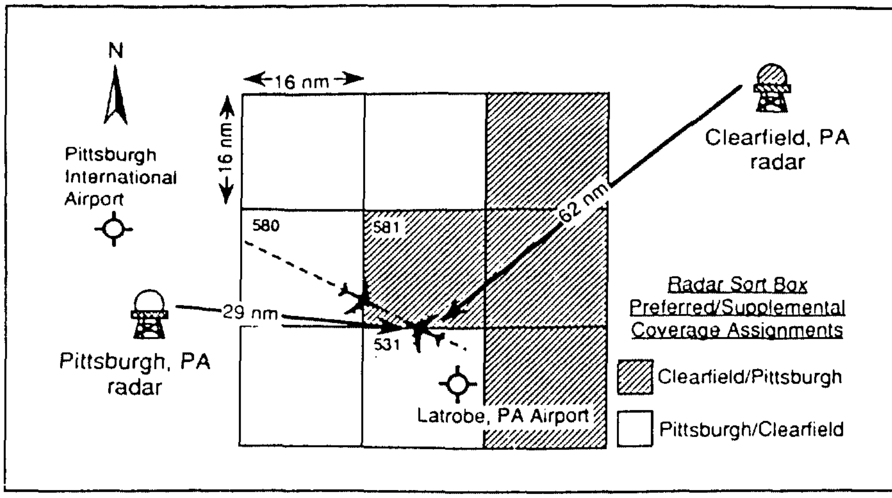

Figure 2. Two aircraft detected by only the Pittsburgh radar. The southeast-bound aircraft is tracked and displayed within RSB#581. The northwest-bound aircraft is untracked, and therefore is not displayed within RSB#581. (Distances are in nautical miles [nm].)

There is a similar, but much better way to deal with this problem. It is to utilize the optional software routine called the ZC150 patch. This patch stratifies a sort box. High-altitude aircraft are still depicted by a distant radar site, which solves the cone-of-silence problem, but low-altitude aircraft which are detected by the radar site within the sort box are not suppressed. A sort box with this patch adapted utilizes single-preferred coverage at or above the stratified altitude, whereas double-preferred coverage exists below the stratified altitude. The ZC150 patch has been in use at Cleveland Center since May 23, 1990. It has been adapted for all radar sort boxes overlying radar sites within Cleveland Center, except for RSB#986.

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Compromise #2. Another compromise inherent with mosaicing occurs when the adapted preferred coverage changes from one radar to another. This often takes place midway between two radar sites. If the coverage from both radars is equal, suppression of targets may be minimal, but it can still occur. Sometimes the changeover point is much closer to one radar than the other. When sort boxes are adapted in this manner the results can be somewhat mystifying, in that one aircraft will be displayed, but another, within the same sort box, will not be displayed! See Figure 2.

One may find it unsettling that two aircraft, both within the same radar sort box, both at the same altitude, both with transponders faithfully responding to radar interrogations from the same radar, and both about to collide, can result in one aircraft being displayed, and the other totally invisible to the controller. The difference that causes this phenomenon is that one aircraft is tracked, and the other untracked. An aircraft that is tracked by the software is one that is being provided radar service by an ARTCC. Besides having a target symbol, it will include a full datablock, which displays information such as identification, assigned altitude, etc. An untracked target is typically a VFR aircraft, whose pilot is operating under the see-and-be-seen rules, and has the aircraft's transponder set to the VFR code 1-2-0-0. A low-altitude VFR aircraft on the code 1-2-0-0 will be represented by the target symbol V, and the only other data that will be associated with it will be its altitude data, assuming the aircraft is equipped with altitude reporting. There is a significant difference between the display of a tracked and an untracked aircraft. This is that a tracked aircraft, when no longer detected by the preferred radar yet still detected by the supplemental radar, will display a target symbol and full datablock. However, an untracked aircraft, when not detected by the preferred radar yet still detected by the supplemental radar, will not display a target symbol nor any other data for that matter. It is invisible to the controller.

Figure 2 shows the path of a typical commuter flight from Pittsburgh International Airport to the Latrobe, PA Airport. Cleveland Center provides radar service to an aircraft on this route of flight from approximately 15 nm east of Pittsburgh until the aircraft is instructed to contact the Latrobe air traffic control tower. As the commuter aircraft enters RSB#581 the preferred radar coverage changes from Pittsburgh to Clearfield. As this aircraft descends through 2,900 ft, the Clearfield radar will no longer detect it. The computer software will then automatically utilize the supplemental radar data from the much nearer Pittsburgh radar to continue to display this tracked aircraft within RSB#581. Simultaneously, a northwest-bound VFR aircraft which is 62 nm away from the Clearfield radar yet only 29 nm away from Pittsburgh radar, is on a collision course with the commuter. This VFR aircraft will soon be within 30 nm of Pittsburgh International Airport, and as required by Federal Aviation Regulation 291.215, it is equipped with an operable transponder with automatic altitude reporting. This VFR aircraft's altitude is steady at 2,800 ft. As this untracked VFR aircraft enters RSB#581 it disappears from the controller's display. This is due to the fact that it is detected by only the Pittsburgh radar, and it is not tracked by the computer software. While this VFR aircraft was in RSB#531, it was displayed because Pittsburgh radar is designated as preferred within that sort box. As the aircraft enters RSB#581, where Pittsburgh radar is no longer assigned as preferred, yet it is the only radar that detects this VFR aircraft, the target vanishes from the controller's display. The pilot of the commuter aircraft will not be warned about this VFR aircraft. The Pittsburgh radar detects both aircraft and sends this data to the ARTCC computer, but only the tracked aircraft receiving radar service by Cleveland Center is displayed. The VFR aircraft is detected by radar but not displayed!

Conclusion

Did the controllers at Los Angeles Center simply not see the VFR aircraft as it was about to collide with the Wings West commuter aircraft? When the controller established radar contact on the commuter aircraft, the VFR aircraft would have been a mere ½ inch (1.27 cm) away on the screen. Could the VFR aircraft have been inadvertently suppressed from their display due to selective rejection? Upon my review of the radar data from that accident, I could not help but notice that both aircraft were in separate radar sort boxes until the collision took place. Regardless of whether the controller just didn't see the VFR aircraft, or whether selective rejection made that VFR aircraft invisible to the controller, it is important to realize that in today's ARTCC environment, the ongoing inadvertent suppression of low-altitude radar data could result in a similar tragic scenario being replayed.

Shortly after I became a full performance level radar controller, that near-midair collision occurred in which I was unable to issue a safety advisory because a VFR aircraft was not displayed. I then began to question our radar data processing methods. Nearly everywhere I turned, I was assured that the new computer hardware and software would most certainly enhance the display of traffic, and that this new equipment was "coming soon." That was 1985. Six years later, and over three years after the replacement of the ARTCC mainframe computers with the upgraded HOST[1] computer, the suppression of low-altitude radar data still exists. New hardware and software are "coming soon," but can we be assured that the display of low-altitude aircraft will be enhanced? When a partial remedy has existed for years, such as the ZC150 patch, it is difficult to understand why it has not been fully implemented. It is truly a shame to have excellent radar coverage, yet not have done our utmost to be certain that the radar data of low-altitude aircraft are displayed for the controller. This problem begs for immediate attention. Should a midair

[1]The HOST computer systems, installed in all 20 ARTCCs, replaced the 20 year old IBM 9020 computers. Cleveland's HOST was inaugurated on Jan. 29, 1988

collision occur tomorrow, and it was found that no safety advisory is issued because of target suppression due to selective rejection, this problem would certainly be addressed and corrected nearly immediately. This subject should be addressed as if tomorrow's midair has already occurred.

Recommendations

To correct the problems as related in Compromise #1, the first step should be to make the ZC150 patch mandatory instead of optional. Such immediate action costs little, as the software and hardware already exists. The only thing necessary is a directive that it be accomplished. The second step should be to correct the suppression of low-altitude aircraft targets as described in Compromise #2. There is no software patch currently designed to address this specific problem. Resources should be directed to remedy this situation. Possibly the most expeditious way to handle this task is to stratify all sort boxes and utilize *double-preferred coverage* throughout the low-altitude environment. The methods in the ZC150 patch could likely be broadened to include all sort boxes to achieve this goal. The third step, which is a long range goal, should be to seriously consider the advantages of simultaneously utilizing all data from all radars, in an effort to track all aircraft. Potter and Meilander (1989) discuss the advantages of utilizing an array processor supercomputer to achieve the performance requirements necessary to process the great amount of radar data that goes unused today.

It would also be wise to initiate a human factors study to determine why, when a problem of such importance is brought to the attention of the Federal Aviation Administration (Lusch, 1989), that no action is taken.

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Automatic Dependent Surveillance - Broadcast
ADS-B - Terrorist's Dream, Aviation's Nightmare
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These five stories are set slightly in the future, but only slightly. Perhaps five years from now. They illustrate how ADS-B aids the terrorist, the extortionist, and the vengeful employee. The scenarios also show how ADS-B harms corporate aviation and how it forms the infrastructure for user fees. The technology described is an accurate portrayal of ATC systems of today, or in the case of ADS-B, an accurate portrayal of systems that are test flying today. The individuals are fictional of course.

Scenario One .... Terrorism

A lone mideast terrorist comes to the United States and purchases (or rents or steals) a light aircraft such as a Cessna 172 or Beech Bonanza or Piper Arrow. While selecting his plane, he is looking for just one item, ADS-B collision avoidance equipment. He knows that ADS-B, installed on all airliners and some business and pleasure aircraft, automatically reports the precise position of the aircraft and also the identity of the aircraft, twice per second.

He has no particular target, his only desire is to cause as much fear and destruction and death to The Great Satan as possible. Having waited for a day of poor visibility, he completes his prayers. Then he flies at low altitude and slow speed above the interstate highway toward a major airport. He knows that Air Traffic Control radar will not see him because he has disabled his transponder output, thereby assuring that there will be no secondary returns nor any ADS-B transmissions. His aircraft is smaller than the semitrucks on the highway below, and the ATC primary radar has been programmed to eliminate highway clutter from the display. He will not be seen.

The terrorist also knows that the interval when a large aircraft is most vulnerable is on final approach. It is moving slowly at low altitude, flaps and slats and gear are extended

Attachment (3)

and engines spooled down, this is the point in the flight when the plane is least maneuverable. Using the ADS-B readout to spot his target, he flies up the glideslope and directly toward the doomed airliner.

Until the last moment he cannot see the oncoming plane but he knows it is there. The display on his ADS-B is showing its altitude and position with an accuracy of a few meters. The airline crew, monitoring their instruments and complying with pre-landing checklists, never sees him at all. At the last instant he shouts "Allah Akbar" as he flies through the windshield of the larger aircraft, taking hundreds of people to their death including many in the city below.

Scenario Two .... Extortion

I'll call him Joe. He is not mentally disturbed, at least not any more disturbed than the average guy in this hurried-up society. His intelligence is above par, it's just that he doesn't have any ethical constraints. Joe might have become a successful bank robber or con artist, but he is a loner and has long understood that the cops can't infiltrate a group of one. Plus, he'd rather have 100% of the take than to split it with guys who might get drunk and tell the whole story to some hooker. Joe is sharp on computers and enjoys playing with model airplanes, and would rather be tinkering with technology than shooting pool at the neighborhood bar. In the vernacular, Joe is a geek.

One day Joe reads an article about ADS-B. It tells how the planes are precisely reporting their 3D position, in the clear on 1090 MHz, twice per second. And here's the best part: the identification of the specific aircraft is included along with the position. Suddenly he envisions the whole plan. Extortion! A million dollar bank job would be impossible for one man, but to the airlines a million dollars is pocket change. He flips a coin and decides that UAL is his target.

The question is, should he ask for the money first and only destroy an airliner if his demands are refused? Or should he begin by dropping one flight unannounced? The former requires credibility, he will have to reveal how he is going to carry out the threat if his demands are not met. This means he will have to disclose some of his ideas and maybe provide a photograph of his weapon. Worse yet, it requires more than one exchange of information with the airline. After the first letter, the FBI and everyone else will be scurrying to find him. Best to keep the exchanges to a minimum.

The latter choice, destroying one plane first to demonstrate his capability, seems more foolproof. He can do that before anyone knows what is going on. Then, if the airline balks on payment, he can threaten to publicize the reason the plane went down and drive their customers away overnight. United might fear the publicity as much as they would fear another crash.

Joe goes to work. He builds a model plane, a large one. He has already attended model meets where 1/4 scale planes were flown, he knows that some models weigh nearly as much as a real airplane. Joe's plane will only have one flight, it need not be pretty nor fast nor powerful, its sole purpose is to precisely meet an airliner on final approach while carrying a gallon of gasoline to explode inside the airliner cockpit when the planes collide head on.

He doesn't have access to ADS-B equipment, but that doesn't matter. It's a simple task to put a $100 GPS receiver from WalMart in the model plane, coupled to a readily available wireless LAN card. With a similar card in his laptop, he can monitor precisely where his aircraft is. Joe doesn't have a lot of test equipment either, and it might be time consuming to build a 1090 MHz ADS-B receiver from scratch. Instead, he simply takes the receiver from a DBS satellite system he purchased at the discount store for $199 cash. That receiver, half the size of a deck of cards, tunes from 950 to 1450 MHz which is precisely what he requires. All Joe needs to do is write a little software, and voila, he can monitor the exact position and identification of every airliner within 20 or 30 miles.

At this point, Joe has been able to do the entire job single-handedly with information and materials that are readily available and 100% legal. While finishing construction of the plane, he spends a few days listening to the tower and watching the ADS-B data on his computer. Soon he has a good list of United Airlines ADS-B ID tags. He is ready to go, and no other person on earth has any idea what is about to happen.

Scenario Three .... Revenge

Thomas Whitten, Ph.D., is a brilliant scientist. He served honorably in the Army during Vietnam, finished his education soon after, and has been working for a major pharmaceutical firm ever since. His career reached its peak when he developed the latest miracle drug which will ease suffering and save untold lives worldwide.

"I was a loyal employee" Tom said. "Many of my colleagues jumped from one firm to another, always at an increase in pay. I didn't. I stayed here year after year, decade fading into decade, because I truly believed in what I was doing. For the past 17 years I have been working on a single project, trying to unravel the relationship between DNA and this particular disease. It was rewarding when we made progress, it was discouraging when we didn't, and altogether too much time was wasted cajoling management to fund our work. Several times the project was almost canceled, and each time I managed to convince the executives that we should continue.

"And look at the company now. We were the stars of the latest mega-merger, the largest ever in the pharmaceutical arena. Our stockholders made billions, literally billions, because of my work. The CEO himself received a $14 Million bonus, other top management guys received millions more.

"And me? What do they give me? A nice little write-up in the company newsletter, that's what I got. I'm making $94k a year, and when I retire next year I'll drop to 60% of that. Don't those bastards understand who produced the drug that created all the wealth? Yes, I think they understand. I think they just don't give a damn."

That was all Dr. Whitten said aloud. But the longer he thought, the angrier he got.

It ate and ate at him, eventually reaching the point where he couldn't take it any longer. He contemplated rigging a virus release in the laboratory, but that didn't make sense. His fellow workers weren't the problem, he wouldn't do anything to harm them. Management was the problem and they didn't work in the laboratory, they divided their time between the head office in New York and company facilities scattered across the globe. They spent their time flitting from place to place on one of the company jets rather than working...........wait a minute - that's it. The company aircraft! Planes carry top executives. And planes crash.

He established several guidelines. First, his plan must not put him in physical danger. Second, to the greatest extent possible it must not put innocent parties in danger. Third, it must be repeatable because it may take several crashes to achieve the objective. That ruled out trying to plant a bomb on a company aircraft. He might get by with it once - or he might get caught or be blown up in the attempt - and in any event he couldn't manage it repeatedly. Bombs were out, he had to find another way.

If there was one thing Tom Whitten knew how to do, it was research. He had no aviation knowledge beyond a lot of coach class business trips and a handful of trips in company jets, plus the little he remembered from his military days. He had no specific knowledge of how to cause a plane to crash but he had faith it could be done.

So he went to work. He combed aviation journals at the university. He combed the Internet. He kept meticulous notes. Under an assumed name he called various aircraft and avionics manufacturers and interviewed engineers about system specifics. He talked with FAA maintenance personnel too. All the information was there, in the open. It wasn't classified, it wasn't trade secret, it wasn't even company confidential. He asked how a plane was navigated, how it interfaced with Air Traffic Control. He learned what the crew did and what systems they depended on for guidance. He learned what portion of the flight was most hazardous and vulnerable. He studied the localizer and glide slope and marker beacons and DME and GPS and all the rest. He bought a Radio Shack airband radio and became familiar with communications jargon.

Eventually Tom found the RTCA documents that contain the standards each navigation system must meet. Every tiny detail was openly available.

And he learned about ADS-B. When Dr. Whitten located RTCA DO-242 he knew he had found the mother lode. This was the key to the whole plan. He wanted to destroy specific aircraft while causing no harm to others. ADS-B reports the precise location of the aircraft, in 3D coordinates, and simultaneously reports the identity of the aircraft. That was exactly what his plan had been missing, the means to target a specific plane, and ADS-B provided it.

Outsiders imagine that lab researchers spend their days stirring test tubes and peering into microscopes. Once upon a time that was an accurate picture, but electronics is the dominant force today. Tom was skilled in designing instrumentation to solve fresh problems. Now he turned this talent to his new field of interest.

In ADS-B, every plane has a unique 24 bit identifier which remains with the aircraft. In fact, there is an algorithm to convert tail number to ADS-B identification number. It was a simple matter, with binoculars, to get the "N" number of the company jets when they came to town. Dr. Whitten then hand-processed the algorithm and learned the 24 bit ID code of each plane. Now he could receive the 1090 MHz frequency and know which plane was which.

His plan was simple. On an instrument landing the plane is following electronic signals. The localizer gives left/right guidance, the glide slope provides up/down information. The former is on VHF, the latter UHF, with the frequencies listed on aircraft approach charts and other documents. The signals are not encrypted, they aren't even digital. The ILS signal, like most of aviation technology, was established near the end of World War II and long before the invention of the transistor or integrated circuit. Some systems (such as the ancient amplitude modulation used for voice communications) date back far earlier. Aviation is unlike other fields of endeavor because the people who develop the technology are not the people who use the technology. And a third group who are neither skilled in the technology - nor skilled in the use thereof - are the ones who make the decisions. Through the years a lot of wacky decisions have been made. In the case of ILS, the radio carrier is amplitude modulated by two tones, 90 and 150 Hz, which are equal amplitude if the plane is centered on the beam. If a particular aircraft receives a false signal it will follow a false path.

Traditionally the marker beacons, all on 75 MHz, give the pilot an indication when he is nearing the airport but don't allow any sort of readout to the touchdown point, so Tom could ignore them. Often the pilot monitors his Distance Measuring Equipment, DME, to determine his distance to touchdown. Tom reasoned that it would be easiest to simply jam the DME frequency for the critical few seconds. Likewise with GPS, once he had identified his particular aircraft he would jam the very weak Global Positioning Satellite signals on 1575.42 MHz.

None of this was particularly difficult for an experienced researcher such as Dr. Whitten. Indeed, a kid with an interest in ham radio could do as much. But Tom had access to decades of obsolete instrumentation from which he could scrounge the necessary bits and pieces. The ultimate irony, he could use company material to accomplish the objective.

It was easy to phase lock the ILS spoofing transmitters to the real ILS signal, from a van parked a mile or so from the airport and under the final approach. He used directional antennas that beamed his signals upwards to the particular flight while anyone else on the àpproach would receive the proper ILS signal. Phase locking his signals to the actual ILS would assure that there would be no flag or indication when the target aircraft transitioned from the correct signal to the spoof. Sure, it took some effort, but the specifications were all available so it was far easier than other projects he had accomplished.

The weather was miserable the night of the first crash. Most flights were landing successfully, but missed approaches weren't uncommon. Some planes were experiencing airframe ice, winds were gusty and unpredictable, the rain was heavy at times, and ATC had traffic backed up halfway to Cleveland. The company Gulfstream IV was making what appeared to be a normal approach when it began to drift to the right. It descended prematurely about a half mile from the end of the runway, struck an embankment at the outer perimeter road, bounced over two maintenance buildings and a communications shack, hit the ground with its left wing, cartwheeled, and burned. All aboard were killed.

The NTSB accident investigation concentrated on the navigational aids, aircraft systems, ATC actions, and crewmember performance. The ILS checked out perfectly and no other plane had experienced any ILS problems. The aircraft systems checked out OK, at least the parts that could be reconstructed. ATC had made no blunder and there was nothing on the communications or radar recordings to indicate a problem. Predictably, the crash was blamed on pilot error.

But Thomas Whitten, Ph.D., wasn't finished. Several months later, at a different airport, the same pharmaceutical company mysteriously lost another flight.

Scenario Four .... Data Mining

One hot new field in the information age is data mining, finding and extracting the nuggets of valuable information from the immense field of electronic data that exists all around us. Some data mining is legal, some is illegal, but most is too new and expanding too fast for any legal or ethical framework to develop. The old fashioned concepts of privacy and ownership are being questioned in ways that were unimaginable 20 years ago.

Meet DataMiners, LLC. For a small fee, DataMiners makes it easy for a company to track its fleet of aircraft. Or the fleet of the competitor. For an additional fee, DataMiners will reduce and analyze the information. For instance, the news that the competitor's bizjet traveled to a specific plant is not particularly useful. But when travel patterns are analyzed and combined with data from other sources, a message emerges that the competitor is having quality problems, or vendor problems, or management problems. Or perhaps the competitor is secretly developing a new product or negotiating a merger. Information like this is quite valuable in the marketplace.

Wouldn't a stock trader have liked to know that the Chrysler and Daimler Benz aircraft were visiting the same destination - on the same days - in the months leading up to their merger? Our securities laws protect the market from insider information, but DataMiners LLC is an outsider and whatever they discover is available to the highest bidder.

Whether it's a mid sized company or a multinational corporation, conducting business in privacy (and thus traveling anonymously) is essential to survival and maintaining the competitive advantage. In an ADS-B world, the company aircraft will be a liability rather than an asset.

NBAA has already learned this lesson and has done a complete turnaround from their earlier support of Aircraft Situational Display to Industry (ASDI). At least with ASDI, the data is filtered and slightly delayed before release by the FAA, and VFR data isn't included at all. Unlike ASDI, ADS-B comes directly from the aircraft and is freely available to anyone with a 1090 MHz receiver, without passing through any agency for filtering or control. For more on this from NBAA's perspective, see http://www.nbaa.org/digest/1998/11/opsnotes2.htm and http://www.nbaa.org/pr/1998/98-18.htm

ADS-B and efficient use of the corporate fleet are incompatible. If we are promoting aviation for business purposes, we must oppose ADS-B.

Scenario Five .... User Fees

Harvey Patton started his company for the best of reasons. His city was about to close the airport and turn the land into an industrial park. The various factions had fought over this issue for years and Harvey realized that if the airport users were seen to be paying their own way, and perhaps a bit extra, then the city could be convinced to keep the airport open.

In that light, local airport user fees didn't look so bad. If the fees were structured according to the weight of each aircraft, the bulk of the expense would be borne by the companies that could afford it while the pleasure pilots would only pay a token sum. It sure beat losing the airfield.

So Harvey went to the city with this proposal: He would supply and maintain the equipment at no cost to the city, all the city had to supply was a place to house a PC and antenna. The equipment would receive and log the ADS-B signals and routinely modem the data to Harvey's business where billing and collecting would be done. The city would receive 85% of the monthly billings without lifting a finger to do any work. All aircraft activity would be monitored 24 hours a day, 7 days a week whether the tower or FBO were on duty or not.

The city accepted, and the idea worked. Every month the city received a substantial check which went into the airport fund and provided a surplus. Everyone was happy. Well, the users weren't totally happy but they realized it was better than closing the airport altogether. And many users, the smaller aircraft, were escaping user fees by not installing ADS-B. True, not having the collision avoidance equipment meant a higher risk, but many pilots were more concerned with high costs than improved margins of safety.

Harvey realized that we are losing an airport a day in the United States and some of those are important GA facilities similar to his airport. He went to those cities and sold the same deal, it was easy to do the collections from his base location. He was getting 15% of the take from a number of fields and the revenue began to roll in. Next step was to approach the Westchesters and Addisons all over the country with the same arrangement, every airport needs additional funding and this deal was too good for them to resist. Business increased by leaps and bounds (or takeoffs and landings) and Patton Aviation Revenue was a resounding success.

Within a few years Patton equipment was working all over the country. It was installed, it was functioning, it was a proven source of aviation funding. Of course the users were unhappy, particularly at the fields where the fees were set to limit traffic or limit noise or for some other artificial reason. But the corporate users, those who were required to use ADS-B, had no alternative but to pay.

Then the new Congress instituted federal user fees for General Aviation. This hadn't happened previously because there was no billing and collecting infrastructure, but Harvey Patton had changed all that. Or more accurately, ADS-B had changed all that.

The feds contracted with Patton Aviation Revenue in the same way they contract with Jeppesen or Flight Safety or others who provide a service. Patton did the billing and kept a percentage of the take. Suddenly every takeoff, every flight mile, every landing was computer monitored. VFR or IFR, the airspace bill arrived at the end of the month.

The users screamed, they cursed Harvey Patton, but it was no use. If they were going to fly with ADS-B they were going to be billed. Yet the pilots with foresight, those who had never installed ADS-B, weren't paying a cent. Until a court action was filed, that is.

The US Federal Court for the Ninth District ruled that all airspace users must be treated equally. The court left it up to the FAA to determine what "equally" consisted of but the edict was firm, equality in user fees had to be maintained.

What happened then? There are many possible endings to this story. Maybe the non-ADS-B aircraft received an "average" bill every month whether they flew or not. Maybe every plane was forced to install ADS-B and the resulting frequency overload created the same situation we've had at Oshkosh for many years: "turn your transponder to standby when 30 miles out". Then the planes, with their ADS-B turned off, were prohibited from flying in controlled airspace. Or maybe the aircraft owners simply gave up and sold the birds for whatever they could get and pleasure flying died, taking FBOs and manufacturers with it.

Today it is not possible to saddle General Aviation with user fees for one simple reason - there is no infrastructure to collect those fees. The test for ADS-B or any similar technology is simple: Are there any words that Congress could say that will hurt us? If the answer to that question is yes, then aviation must reject the technology.

Proponents of ADS-B tell us that there will be an "anonymous" mode that the user can select. But that will be true only as long as the rules permit it. Once upon a time we could turn off the transponder if we wanted to, but as the years passed that choice was eliminated. The same will inevitably be true of an anonymous setting, it can only be used until it is prohibited. First prohibited at flight levels and at major hubs, then prohibited in IFR, then prohibited, period.

Proponents of ADS-B also tell us that we can be tracked today. That is somewhat true, but recent experience in the well publicized JFK Jr. accident is instructive. His plane went down around 9 PM Friday, was reported to the FSS (but not acted on) at 10 PM, was reported again (and acted on) at 3 AM, and the search and rescue efforts began at 6 AM Saturday. Those efforts continued, under intense press scrutiny, through all of Saturday, all of Sunday, and all of Monday. Around midday Tuesday the FAA finally decoded their radar tapes and determined the location where the plane went into the water. After the spot was pointed out, the remains of the aircraft were promptly found.

It took FAA more than 72 hours to find one aircraft, an aircraft that the President of the United States and the world press corps were actively interested in finding. Given the number of flights daily, it is clear that the FAA does not begin to have the resources to track and bill every flight. Tracking every IFR flight would be somewhat easier, but many of those will switch to VFR if there is a substantial money saving.

And if it comes to that, safety will suffer. Isn't safety what ADS-B was for in the first place? Don't you detect something wrong here?

This is Who I Am
This is Where I Am

Automatic Dependent Surveillance - Broadcast, ADS-B, links "This is Who I Am" with "This is Where I Am". Never before in aviation have we put those two pieces of information together, with great precision, and broadcast them in the open for anyone to receive and use as they see fit. We should not do so now.

Decades of ATC experience have proven that identification of traffic is not something the pilot needs. He or she needs to know where the traffic is, which way it is moving, perhaps its size or its speed, but never its identification number. ADS-B flies in the face of this experience.

ADS-B has not been widely deployed yet. There is still time to stop it. Most airlines have not invested any money in it yet, nor have the government entities nor the general aviation community. I suggest that it is not in the best interest of aviation to deploy ADS-

B in its present form. Like AAS, MLS, and other recent systems, its gestation has exceeded its usefulness. ADS-B made a great deal of sense when it was first proposed. But data processing capability is not the same today as it was twenty years ago. We live in a different technological world now, just as we live in a different political environment.

The ADS-B community will laugh off my scenarios. They will explain that identification is necessary in order for aircraft to autonomously interchange information and automatically negotiate evasive techniques. That was true 20 years ago, it is not true today because of the great strides made in computer and DSP technologies. "Not Invented Here" is alive and well in the ADS-B community, these people have devoted major parts of their careers to ADS-B and it's understandable that they are unwilling to see their system rejected. Nevertheless, aviation deserves a collision avoidance and traffic management tool that achieves the positive objectives without the serious negatives I have described.

For those who would discount my message, I offer copies of Litton datasheets on their AN/PPX-3B and TPI-10 IFF interrogator sets. This equipment is apparently unclassified and readily available. I picked up these sheets at the Farnborough airshow, Sept 1998. These units have one function, using the transponder as an aid in destroying the plane. The equipment exists today, and presumably works well with shoulder-launched missiles that have their own target tracking capability. ADS-B would allow this sort of technology to be greatly expanded. I would assume Litton (and others) will develop or have developed ADS-B versions. Since no interrogation is needed with ADS-B, and specific aircraft can be targeted, the potential threat is immense.

My purpose in writing these scenarios is to illustrate the problems that I perceive. I am not delivering a threat, rather I am delivering the message that ADS-B is a threat. ADS-B is a terrorist's dream and security's worst nightmare. I have previously talked with various people within the FAA, with no success. It seems to be a matter of compartmentalization or jurisdiction. I have talked with those charged with "aviation security", they see their job as one of gates and fences and bomb-sniffing machines. They are not concerned with anything that happens after the wheels leave the runway. I have talked with ATC and ADS-B systems people, they have no interest beyond air traffic control and airspace utilization. In essence, the security problem introduced by ADS-B falls in an FAA department that hasn't been created yet. In addition, there is a great deal of buck-passing between FAA and ICAO and RTCA and the EU and other participants. No one wants to reject "progress", and ADS-B inches closer to reality.

My background in this topic comes from a decade of producing and marketing general aviation equipment that receives the 1090 MHz frequency, and as a pilot and aircraft owner with more than 30 years experience. I have learned how easy it is to receive the data, and how much diverse data is available on that frequency. I understand that any data can be used for good or it can be used for evil. And I believe that the systems of tomorrow must be designed with both in mind.

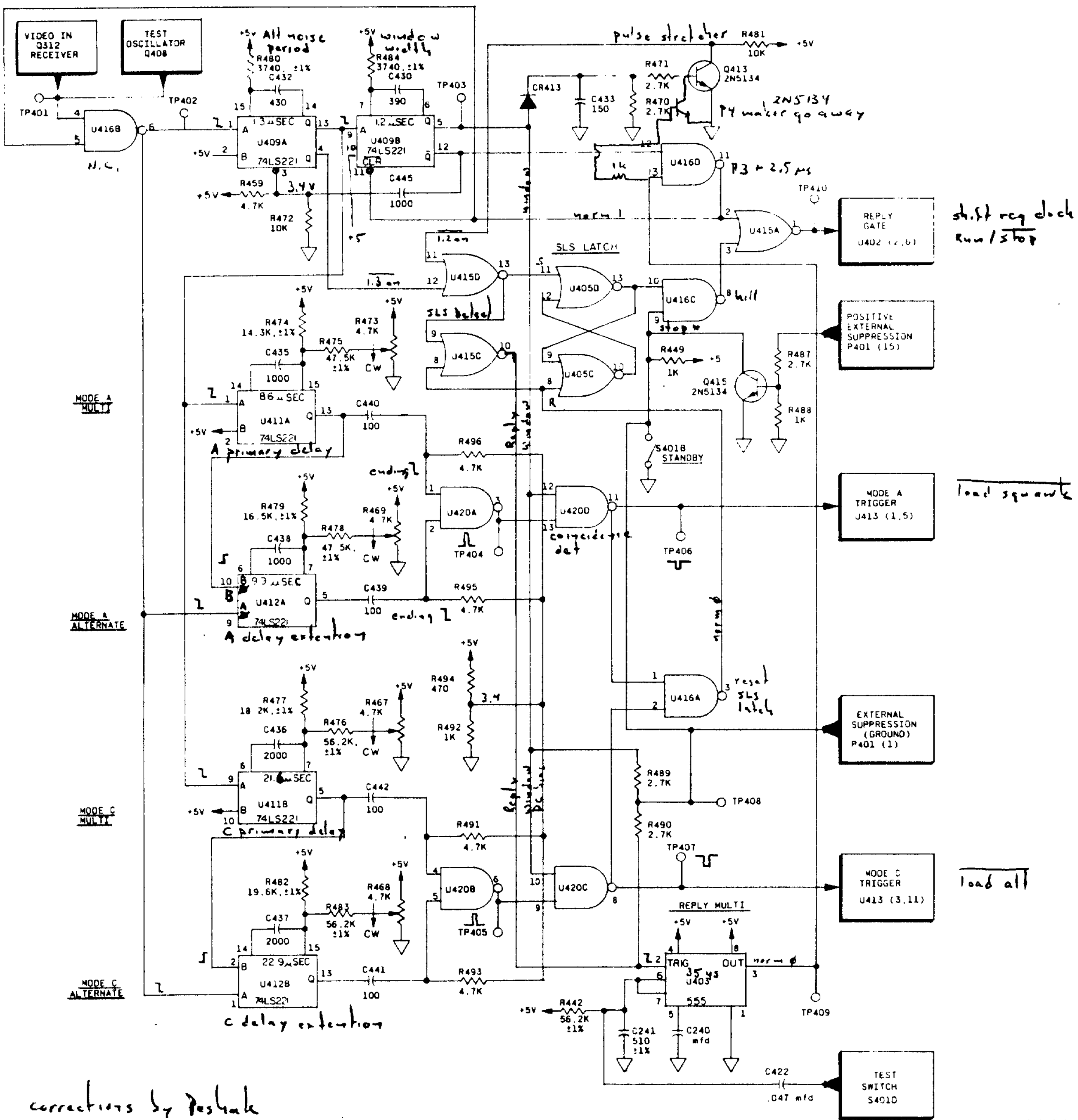
Finally, it should be noted that we can't beat something with nothing. The ad hoc TailLite group has evolved a system over the past several years, currently dubbed AIS-P, that provides the benefits of ADS-B without the problems. The hardware exists, it is compatible with today's ATC and tomorrow's free flight, and it is cost effective for all of aviation. It is the "Plan B" that should be developed now. In that way, it can be ready if and when the ADS-B nightmares occur.

End paper

Additional comment by B. Keith Peshak:

All that is needed to make the AIS-P information packet (http://www.gtwn.net/~keith.peshak/Keith_ais.htm) compatible with the mode S standard (and all equipments that have been manufactured or envisioned) is to assign one of the available DFNs (Downlink Format Number, of which several are available and have no use identified). This assignment authority is presently in the hands of John Mark Loscos of ICAO (514-954-6713).

End of comment



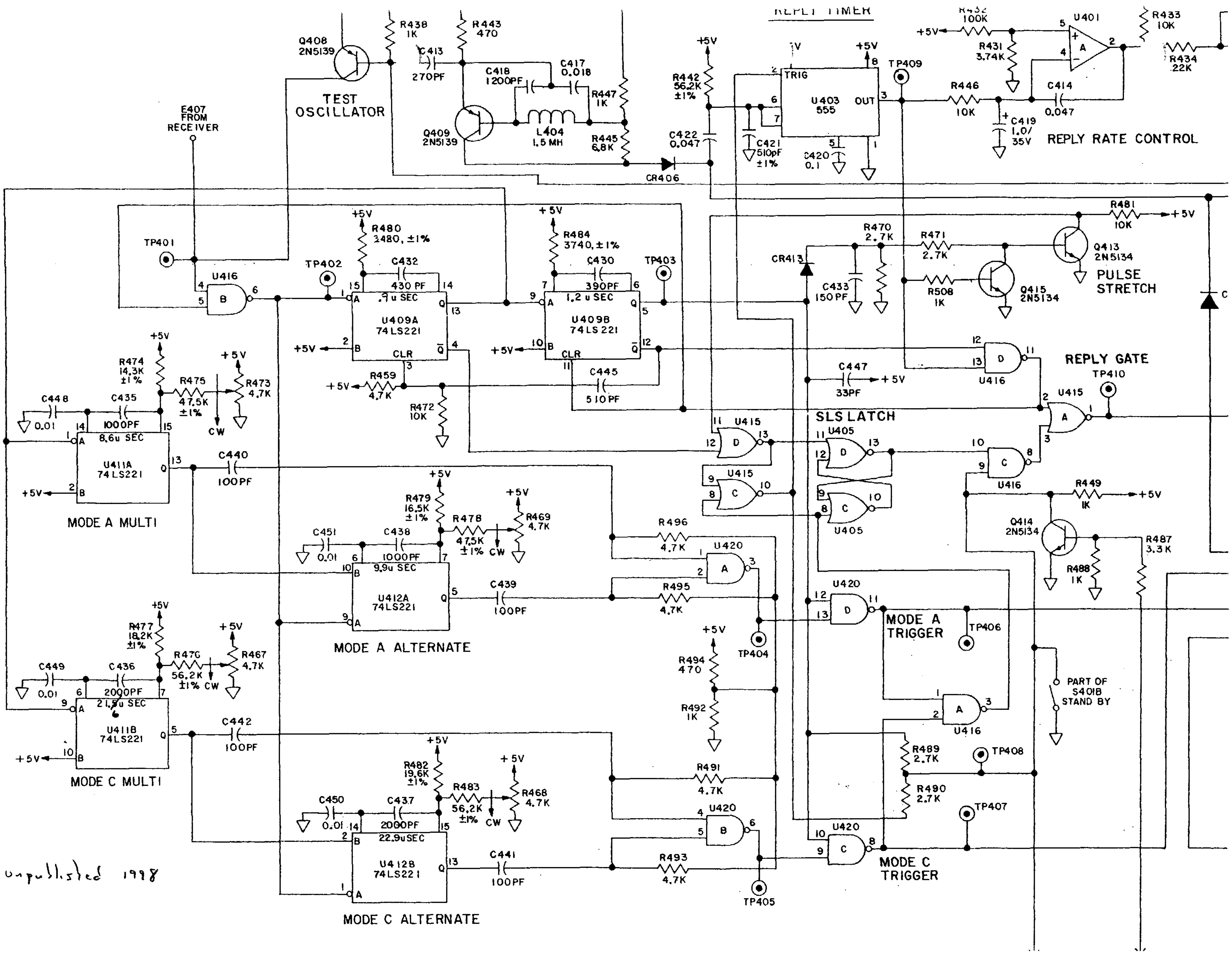
corrections by Peshak
because you should know how it really works
9/25/98

D-02487-A
Sheet 1 of 3

FIGURE 6-1. DECODER SCHEMATIC

published December 1976

AT-150

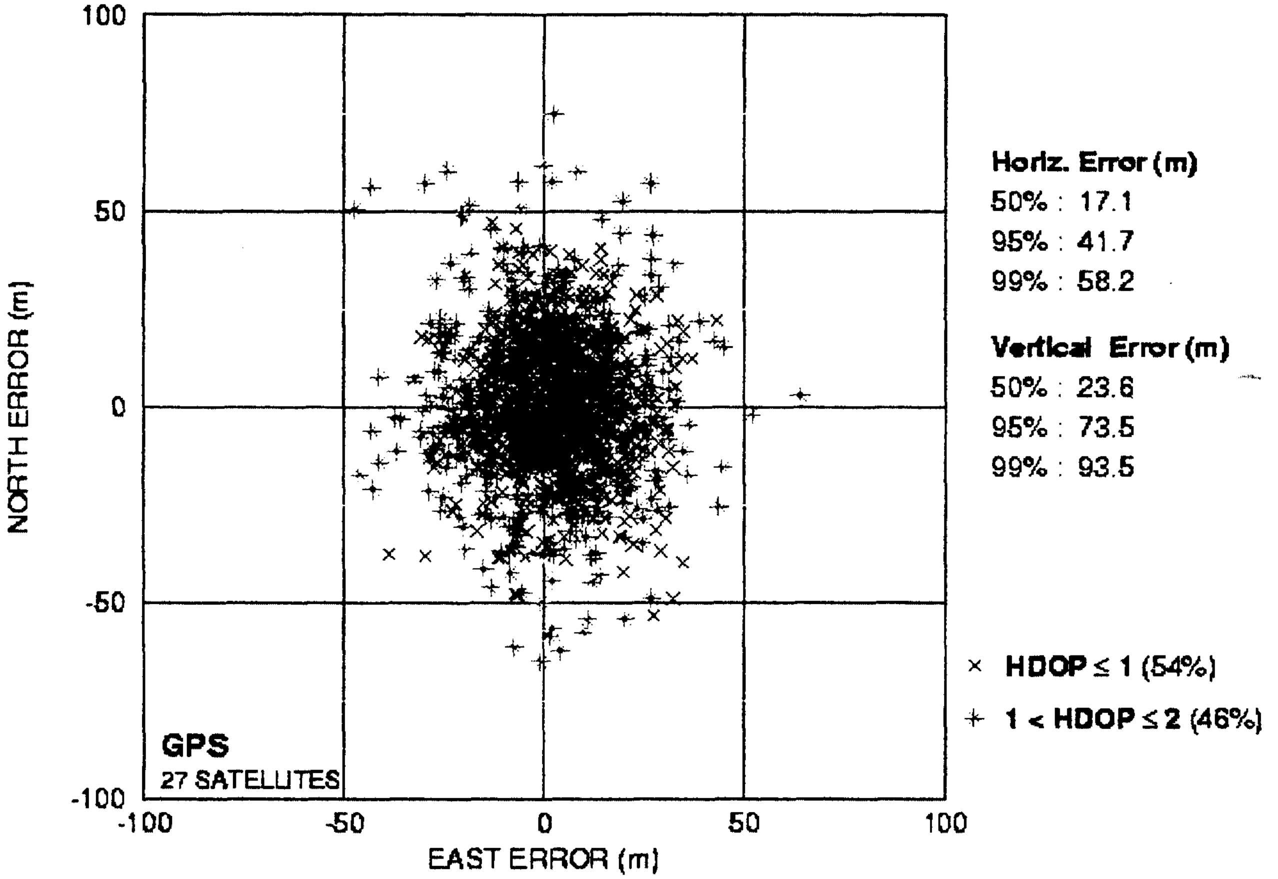


unpublished 1998

http://www.gtwn.net/~keith.peshak/gpspos.gif

GPS POSITION ESTIMATES *

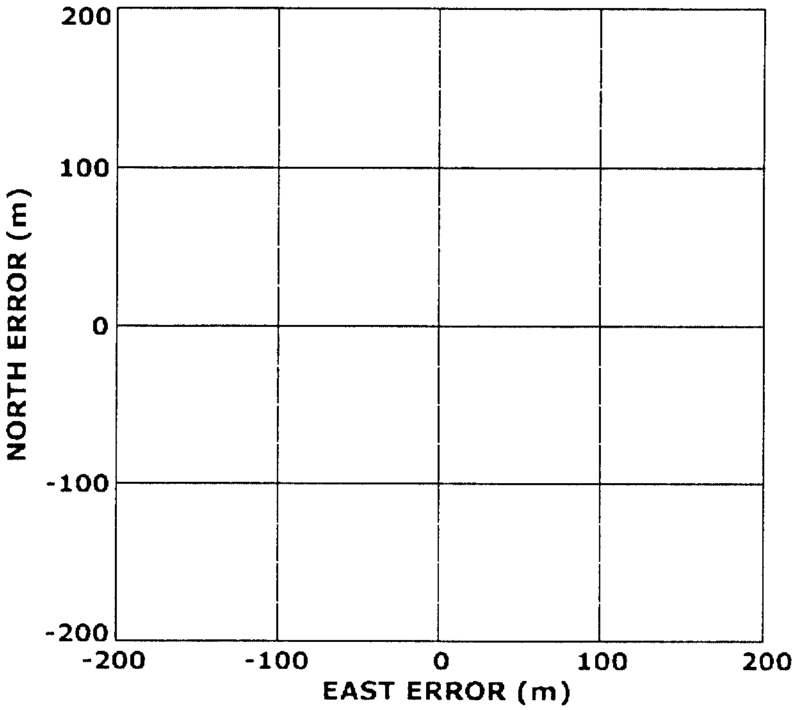
1-MINUTE SAMPLES, 26 MARCH 1999



* At N42:27:34 W71:15:54
RECEIVER: Ashtech GG24

MIT Lincoln Laborat—y
Satellite Navigation G.ou

LORAN POSITION ESTIMATES *



* At N42:27:34 W71:15:54, Using chain 9960, no ASF corrections
Receiver: Locus LRS-II

◂ Day ▸
◂ Week ▸
Today

MIT Lincoln Laboratory
Satellite Navigation Group

Brian Burke
Last modified: Thu Feb 4 18:51:17 EST 1999

http://www.gtwn.net/~keith.peshak/loranpos.gif