Cockpit Weather Information *(CWIN)* System

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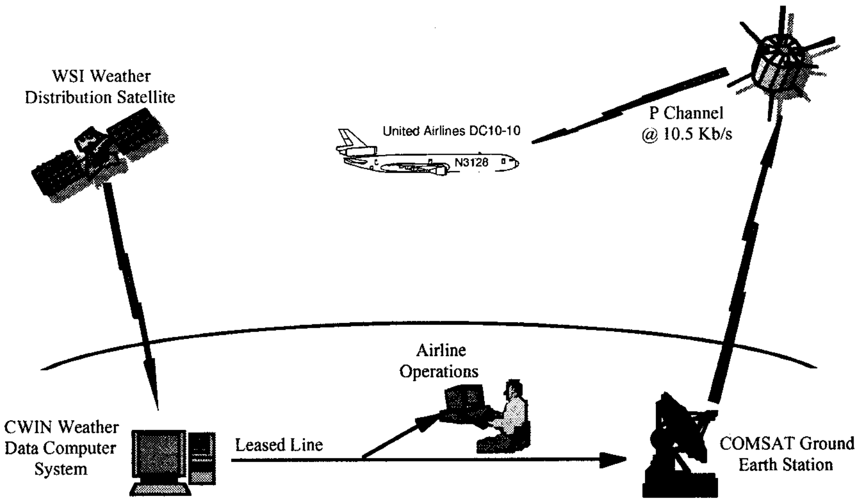

ABSTRACT

The objective of this advanced concept, Cockpit Weather Information System (CWIN), is to develop an aeronautical system that delivers real-time graphical weather information with global-coverage to the flight deck of an aircraft via a satellite communications system (SATCOM)/ global positioning system (GPS).

Pilots today have difficulties obtaining weather information in-flight in a timely manner allowing for accurate trend information and weather avoidance. These problems result in incomplete weather situation awareness, difficulty making strategic re-route decisions, and consequently, close encounters with adverse weather. Furthermore, inadequate dissemination capability of fixed weather stations has always been a concern to the US Air Force and commercial operators. Inadequate and unreliable deployable weather equipment often fails to disseminate information quickly and effectively to pilots. Consequently, mission success probability is affected by this deficiency. The CWIN system offers an opportunity to develop a cockpit graphical weather system for in-flight pilot utilization in meeting the demands of today's operational requirements.

PROBLEM & BENEFIT

Statistical data shows that 40% of all aviation accidents were weather related, and 65% of all delay occurrences were caused by weather. By automating the transmission of graphical weather information to the flight deck, CWIN will reduce flight crew workload, improve safety, and optimize in-flight planning which will reduce fuel burn and life cycle cost of the aircraft. Previous CWIN development and test demonstrated that a 5% fuel saving can be achieved by providing pilots with in-flight real-time and accurate weather information through advanced SATCOM/GPS system. By establishing a pilot graphical workstation that enhances weather situational awareness, provides accurate trend for strategic re-route decisions and weather avoidance, the weather related accidents and delays can also be significantly reduced. CWIN will provide a solution to this weather problem that both

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commercial industry and military are coping with on a daily basis, by retrofitting the aircraft with existing and available technical elements described in the following sections.

IMPLEMENTATION

The objective of this advanced concept is to integrate existing technical elements and conceptual capabilities into an aeronautical CWIN system. These technical elements and attributes include a weather data computer, a ground earth station (GES), a SATCOM, a GPS, graphical weather cockpit avionics, and the installation in an aircraft. These technical attributes and conceptual capabilities are mature and available **now.**

The development of the CWIN system can be divided into three phases, requirement definition & lab installation, detailed design & lab test, and onboard installation & flight test. Past efforts demonstrated that the CWIN concept is practical, feasible, and the CWIN system can be developed from conceptual definition to flight test **within one year**.

ONGOING DEVELOPMENT

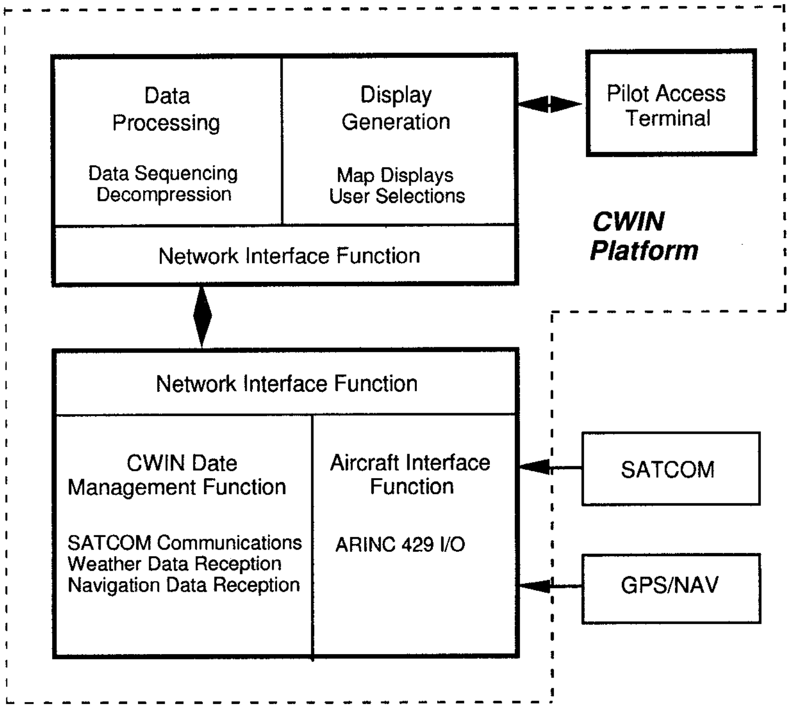
A collaborative consortium is established with NASA LaRC, Boeing, United Airlines (UA), Computing Devices International (CDI), Inmarsat/COMSAT Aeronautical Services, Trimble Navigation, Honeywell Incorporated (HI), Canadian Marconi Corporation (CMC), and WSI Corporation to develop a prototype aeronautical graphical weather system that provides pilots with in-flight real-time weather information.

Existing studies includes the ongoing NASA CWIN program which has afforded a technical foundation for any potential advanced CWIN concept development. This CRAD program has allowed us to define the functional requirement specification from an operational needs standpoint, complete the lab installation for performance evaluation, perform the detailed design and lab test, and install the soft/hardware system onboard a United Airlines DC-10.

From a weather computer in Boston, to a COMSAT ground earth station in Southberry, CT, to the Inmarsat Atlantic West satellite, to the antenna on the roof of our lab, to the flyable processing platform in lab, we have demonstrated that this technology concept is feasible and practical. By using off-the-shelf hardware and software environment, we have demonstrated to airline customers that the CWIN system is useful and economically desirable. With these past experiences as a foundation, we have the ability to develop a near-term product to modernize and enhance the overall mission capability of the military air operations, and competitiveness of commercial airlines operations.

SYSTEM OVERVIEW

The CWIN concept is based upon two basic elements, generic system hardware and functionally specific software. The hardware provides for display/control, processing, mass memory, and aircraft interfaces. Uplinked CWIN weather data is received, stored and processed by the CWIN system for presentation to the flight crew. The processing capabilities of CWIN will construct the graphical displays, move weather displays, color textual displays, and user interface functionality. This information is color



CWIN Functional Overview Diagram

coded distinguish degrees of severity for ground radar summaries, ground lightning strikes, and degrees of category for surface observations and terminal forecasts. The CWIN graphical weather information is presented to the pilot on the Pilot Access Terminal which is a 10.4" color LCD display with touch panel interface for flight crew weather information display and data selection.

With this integrated communication and navigation system, CWIN is capable of providing real-time ground/ onboard weather radar data, ground lightning strike map, surface observations and terminal forecast for domestic and international airports all with a flight plan overlay. Potentially, the CWIN system is capable of displaying windshear, terrain & weather overlay, three dimensional graphics presentation, airport runway taxi map, and other flight operations graphical and textual information.

FUNCTIONAL REQUIREMENT OVERVIEW

The CWIN platform interfaces with existing aircraft/ground communication systems (SATCOM) and navigation systems (GPS NAV) to provide the communications capabilities and navigation data parameters used by the CWIN graphical weather function to generate the desired flight crew display information. The CWIN interfaces with the SATCOM SDU (Satellite Data Unit) to receive graphical weather data uplinked to the aircraft. The SATCOM data link provides the ground to aircraft data communication system to deliver the weather information which is consisted of radar summaries, lightning strike data, surface observations, and terminal forecasts. Periodic weather information updates will be automatically received and stored, giving the flight crew instantaneous access to the latest information. The CWIN weather information is received from the aircraft SATCOM SDU via a GSDB (Ground Earth Station Data Broadcast) digital data interface. The display generation function will accept user data/display selections via the PAT touch panel interface and generate the appropriate display requested. A functional architecture diagram is shown to provide an functional overview and identify the major components of the CWIN system.

The data management capability includes receiving the broadcast information from both the SATCOM SDU and the GPS/NAV unit, and package the data into a pre-arranged form for application specific processing. The arrival patterns of each of the inbound CWIN data types include ground based national radar, air-ground lightning strike, GPS/NAV, surface observations, and terminal forecast information.

The national radar information consists of 8 Km/pixel national radar mosaic which is transmitted to the aircraft every 15 minutes in a compressed file form. The air-to-ground lightning strike information is transmitted to the aircraft every 15 minutes and is consisted of a 5 minute file with the latitude and longitude of each strike. The GPS/NAV information is consisted ARINC 429 parameters such as longitude, latitude, waypoints, heading and etc. The surface observation is consisted of Ceiling and Visibility data for each of the airports listed in the CWIN database. Included in this information is precipitation, flight hazard and excess winds data for each airport. The terminal forecast is consisted of data similar to the surface observations but they are predicted values which is displayed in a color coded textual formatted for a selected airport.

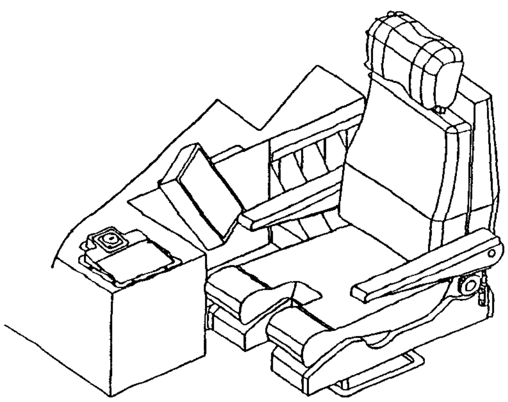
PHYSICAL INSTALLATION

The installation of CWIN into a real-time airborne environment shall be evaluated for its operational effectiveness as related to safety, economy, as well as meteorological validity Our efforts are focused on steering development toward a commercially viable production product. There will be emphasis on defining and testing potential display formats that the final weather information will take. Activities will include looking at the environment and conditions that the actual future product will be used in.

The physical installation of the system, as depicted in CWIN Pilot Interface Diagram, was accomplished after performing human factors analysis on a Computer Aided Design (CAD) system with the geometry of the flight deck environment down-loaded. Installation criteria includes stability of display unit, viewing angle, screen size for graphics, display resolution, and unit mounting.

SUMMARY

The CWIN system leads to a major breakthrough in the flow of weather information to most aircraft in flight. Weather information currently available onboard, including airborne weather radar, voice, and textual information from ACARS, does not provide enough of the overall information to make more efficient enroute routing decisions. By taking the next step of integrating avionics, broadcast satellite transmissions, weather computer networks, etc., into a complete interactive mobile CWIN system, we can develop a customer defined real-time aeronautical graphical weather system that fulfills today's military operational needs.



CWIN Pilot Interface Diagram

EVALUATION OF THE DTED RESAMPLING ALGORITHM USED ON THE COMANCHE PROGRAM

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ABSTRACT

Resampling the raw Digital Terrain Elevation Data to match selected display scales can introduce significant error into the map. This error can be unacceptable when these data are to be used in determining range to specific points within the on-board data base of an aircraft. Bilinear, bicubic and Akima resampling algorithms have been evaluated to illustrate the errors introduced in this resampling process along with their error distributions and the resources required for each of the transformation processes.

DEVELOPMENT

The Comanche weapon system incorporates a feature that automatically detects and classifies targets. In order to accomplish this function, range to the areas of potential targets must be estimated to within 20 % of actual range to meet specified performance requirements. Normally, the system uses a laser ranger to determine range to an imaged pixel within each frame of imagery. The range to other pixels within the image frame are estimated from this pixel using aircraft data and Digital Terrain Elevation Data. The accuracy to which this can be accomplished is well within the 20% range estimation accuracy. These estimations used radar altimeter, Inertial Navigation System (INS) position and DTED to arrive at the range estimate. The more difficult problem arises from a requirement for a silent mode of operation (i.e., without emissions). There are errors in the original data base, errors in the transformation from the original data base to the aircraft data base and errors in the aircraft location. These range error estimates are on a relative basis in-so-far as the DTED is concerned because the aircraft and the potential targets are located within the confines of the aircraft data base, and the absolute errors related to one are exactly related to the other. The display for the map is a 640 x 480 pixel flat panel color display. The Demonstration-Evaluation phase of the program has display scales of :

Display Scale	Distance between pixel centers
- 5 km	- 10.41667m
- 7.5 km	- 15.625 m
- 15 km	- 31.25 m
- 50 km	- 104.1667 m
- 250 km	- 520.8333 m

This requires resampling the DTED base for display compatibility. Associated with resampling is the potential error generation into the data base which just adds to the difficulty in meeting the performance requirements. Estimating range in the passive mode uses the following range estimating equation:

$$R_s = \frac{h_a}{Sin(\phi)} \qquad (1)$$

where **Rs** is the slant range to the point of interest.
ϕ is the elevation angle between horizontal and line-of-sight to point of interest.

ha is the altitude between the aircraft and the point of interest.

The error associated with passive ranging may be found by taking the partial derivative of R_s with respect to h_a and with respect to ϕ

$$\Delta R_s = \left(\left(\frac{\Delta h_a}{Sin(\phi)} \right)^2 + \left(\frac{h_a Cos(\phi)\Delta\phi}{Sin^2(\phi)} \right)^2 \right)^{1/2} \quad (2)$$

where **ΔRs** is the error in slant range.
Δha is the error in between aircraft and the point of interest.
Δϕ is the error in the elevation angle between the aircraft and point of interest.

Contributors to the error in altitude between the aircraft and point of interest include:

- Radar altimeter error.
- DTED source data error.
- Transformation algorithm error.
- INS errors.
  - Latitude
  - Longitude
  - Pitch
  - Roll
  - Heading
- Dynamic Alignment error
  - -Azimuth
  - -Elevation

The range scales selected for the map display necessitates a transformation of the DTED source data to a different scale. The transformation program used by the Map supplier to transform the DTED to map for display uses bilinear interpolation. Although this may be satisfactory for making the displayed map look like a topographical map, it was being used to compute unmasking altitudes to provide line of sight existence to an area to be scanned for imagery, computing flight altitudes to avoid radar threats, passive range estimates for automatic target detection and classification etc. For this reason, it was felt that this was not perhaps the best approach to transforming the original DTED base to a base compatible with the digital displays.

DTED source data representing essentially the world exists at the level I density. These data are constructed at three arcsecond intervals in both latitude and longitude. The height of these sample points represents the surface of the earth at the points. The height of each post is referenced to mean sea level at latitudes and longitudes on a WGS geographic system. Level II DTED are being generated at one second intervals but it is not known when it will provide the necessary coverage of the earths surface. Lacking a source of ground truth to evaluate different resampling algorithms, it was decided to use the only area where we had level II data. A one degree x one degree cell of level II DTED was obtained representing 40-41 degrees North Latitude, 123-122 degrees West Longitude. The vertical accuracy is listed in the header as 14 meters with a point to point vertical accuracy of 6 meters. The horizontal accuracy is listed as 28 meters with a point to point accuracy of 8 meters. previously discussed as truth. A level I data set was created by starting at the North-Western most post as the reference post a_{11} and including every third post in each row (a_{11} a_{14} a_{17} ...) and column $(a_{11}\ a_{41}\ a_{71}...)^T$. A smaller level II data set was then generated using each of the different interpolation algorithms at the same locations of the original level II data set posts. The generated level II post heights were then subtracted from each corresponding post height of the original level II DTED. This data was recorded for each of four interpolation algorithms

Level II DTED
Figure 1

evaluated. The four algorithms evaluated include:

- Bilinear
- Akima
- Improved Akima
- Bicubic

Figure 1 illustrates, in a topographic format, an area of the original level II DTED base from which the evaluation was conducted. The terrain, as can be seen, is not considered rugged.

Bilinear The bilinear algorithm, which is the easiest to implement and is the most timeline efficient is given by:

$y = y_i + m_i(x-x_i)$

where m_i is the slope of the line segment connecting P_i and P_{i+1} and is given by

$m_i = (y_{i+1}-y_i)/(x_{i+1}-x_i)$

Akima The Akima algorithm proved to be significantly less timeline efficient than either the bilinear or bicubic spline algorithms. The results however were better than the bilinear and in some instances better than the bicubic. The interpolation uses a piecewise function composed of a set of third-degree polynomials. The third degree polynomial for the y value in the interval between x_i and x_{i+1} is

$$y = a_o + a_1(x - x_i) + a_2(x - x_i)^2 + a_3(x - x_i)^3$$

The coefficients of the polynomial are determined by the given y values and the estimated y' values at the endpoints of the interval, as

$a_o=y_i$

$a_1=y'_i$

$a_2= -[2(y'_i-m_i)+(y'_{i+1}-m_i)]/(x_{i+1}-x_i)$

$a_3=[(y'_i-m_i)+(y'_{i+1}-m_i)]/[(x_{i+1}-x_i)^2]$

where m_i is the slope of the line segment connecting P_i and P_{i+1} and is given by

$m_i = (y_{i+1}-y_i)/(x_{i+1}-x_i)$

The first derivative at P_i is estimated with a set of five data points, P_{i-2}, P_{i-1}, P_i, P_{i+1}, and P_{i+2}. Two line-segment slopes, m_{i-1} and m_i, are used as the primary estimates of the first derivative, and the final estimate is calculated as the weighted mean of the primary estimates.

Improved Akima The Improved Akima algorithm did not provide measurable improvement in accuracy with the data set available for evaluation. It was also less timeline efficient and thus was dropped from further analysis.

Bicubic Spline The bicubic spline algorithm is less timeline efficient than the bilinear algorithm but had provided excellent results in a B-52 terrain following radar simulation program several years ago. The equations for implementation and a FORTRAN listing of the program CUBSPL may be found in reference 4, pages 53 through 59.

Results

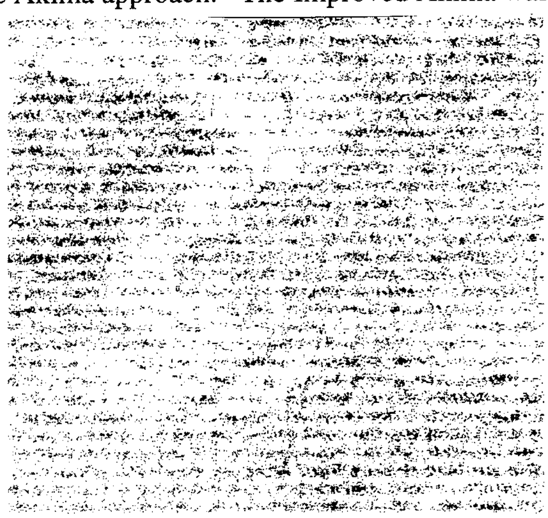
The difference between the original data post height and the height estimated from the interpolation algorithms at points of the original post locations was generated by subtracting the interpolated height from the original height. These were then provided in a topographical format to show where the errors existed. The residual error introduced during the generation of the Level II DTED from the Level I DTED using bilinear interpolation is illustrated in

Bi-linear map error topographical Comparison
Figure 2

The bicubic spline interpolation algorithms shows an improvement over the bilinear case as can be seen in figure 3. This was the case for all display scales used in the evaluation. The Akima showed an improvement over the bicubic for the 7.5 km range scale however it was just a slight improvement and does not justify the much longer run time that the Akima method requires.

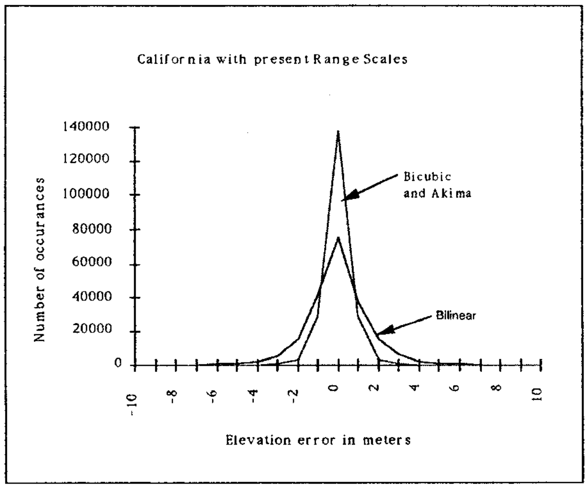
Bi-cubic map error topographical Comparison
Figure 3

The Akima interpolation results from this type of comparison does not appear to show any improvement over the bicubic spline approach. Figure 4 illustrates the topographical distribution of the Akima approach. The Improved Akima was run



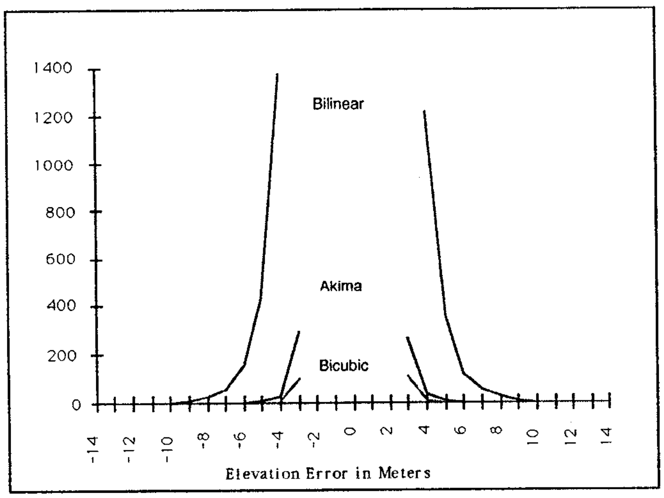
Topographical Distribution of Residual error from the Akima Interpolation
Figure 4

over the same area but did not show any improvement over the Akima. Histograms of the residual error from each of the methods evaluated were gathered to provide a quantitative ranking of the resampling algorithms. These are shown in figures 5 and 6. Figure 6 is an amplified portion of figure 5 to show the tails of the histogram distributions.



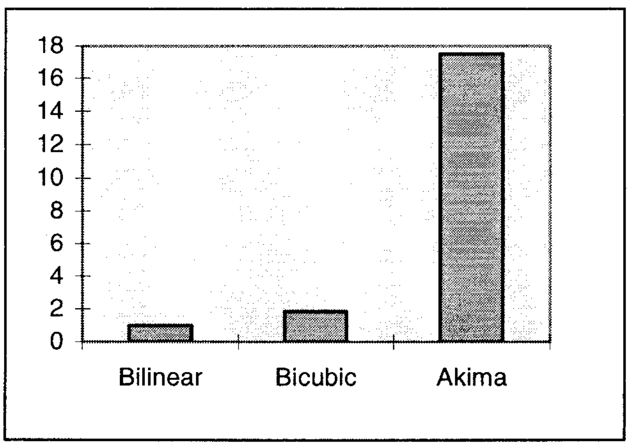
Histogram of Errors
Figure 5

Figure 5 shows that both bicubic and Akima algorithms are superior to bilinear to reproduce the original DTED, but shows no perceptible difference between the Bi-cubic and Akima. Figure 6 shows that the bicubic is slightly better than the Akima for this particular terrain and scale factor. The maximum induced errors for each of the algorithms



Magnified base of Figure 5
Figure 6

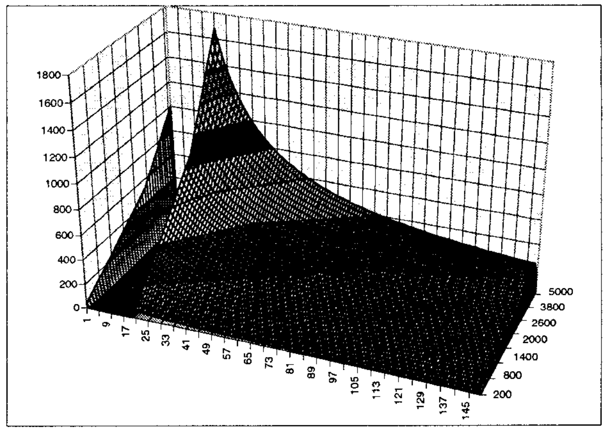
were 14 meters for the bilinear, 6 meters for the bicubic and the Akima. On the other hand, resampling the DTED for use on the aircraft data base takes time. The different algorithms were evaluated for run time. The bilinear has the fastest run time and is used herein as the bench mark. As illustrated in figure 7, the bicubic algorithm takes approximately twice the time that the bilinear algorithm takes. The Akima algorithm takes between 15 and 20 times that which the bilinear takes. Discussions with the army led to dropping the Akima algorithms based on run time. The transformation of the DTED data to a data base compatable with the display scale selection is planned to be performed on the AMPS ground workstation. Although the transformation time may not be as critical on the ground as in the air, the Akima method took far too much time even for the ground planning station. All algorithms introduced error into the resampled data base. In some areas the Akima proved superior to the bicubic and in other areas, it was inferior. Over the entire data base however, the Akima and bicubic were comparable with the bicubic being somewhat superior as shown in figure 6.



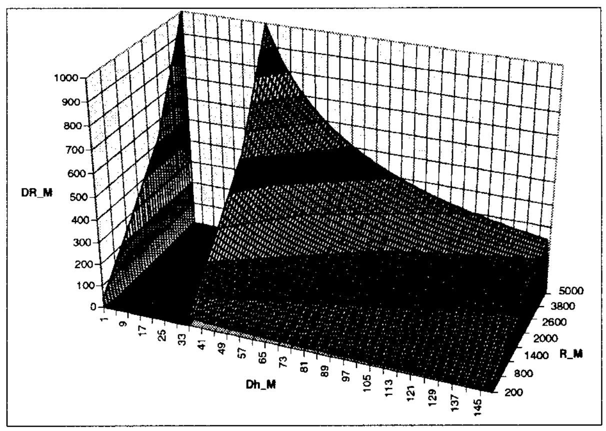
Algorithm Run Time Comparison
Figure 7

The problem with passive ranging for ATD/C was evaluated using all error sources identified above with results illustrated in figures 8 and 9. These data show that we can expect to meet requirements if we are at an altitude of greater than 21 meters above the points of interest given the data base uses bicubic interpolation. On the other hand, if we continue with the bilinear interpolation, we have to climb to an altitude of 37 meters above the points of interest.

During the course of this investigation, it appeared that the display scales selected for a weapon system that includes the digital map should take into account more than just human factor considerations. It must consider the operational performance of



Region of Specification compliance
Figure 8



Region of Specification compliance
Figure 9

every function that the map supports. We believe that the following considerations should be taken into account in the selection of the digital map range scales:

a. Level I data posts are 3 arcseconds apart.
b. Level II data posts are 1 arcsecond apart.
c. Scales should be integer multiples of both a and b.
d. Scales should be powers of 2 of each other.

e. Scales should be integer multiples of 480.
f. Scales should be compatible with ADRG and CADRG.
g. Scales should be compatible with WGS-84 earth model.
h. Scales should be compatible with human factors.
i. Scales should be compatible with sensor range performance.

SUMMARY

Resampling the DTED base is a major source of error in the aircraft data base when the data base is being used for passive ranging. If resampling is required, it should be accomplished with an algorithm that minimizes the error introduced into the system. The Akima provided best results in some areas and bicubic provided better results in other areas. Both however, were superior to the bilinear interpolation. The drawback with the Akima interpolation is run time. This was the only level II data available to us for the evaluation.
The terrain profile was evaluated along both rows and columns to determine decorrelation distances for this data and for some level I data representing an area in New York state. This data had a correlation distance of from 6 to 9 km. The New York data had a correlation distance of 1.2 to 1.7 km. An evaluation of the interpolation algorithms in the New York area or some more rugged terrain would probably result in even greater error than what we encountered here.

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